Section 10
Materials Handling

by

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10.1 MATERIAL HOLDING, FEEDING, AND METERING

by Vincent M. Altamuro

FACTORS AND CONSIDERATIONS

The movement of material from the place where it is to the place where it is needed can be time consuming, expensive, and troublesome. The material can be damaged or lost in transit. It is important, therefore, that it be done smoothly, directly, with the proper equipment and so that it is under control at all times. The several factors that must be known when a material handling system is designed include:

1. Form of material at point of origin, e.g., liquid, granular, sheets, etc.
2. Characteristics of the material, e.g., fragile, radioactive, oily, etc.
3. Original position of the material, e.g., under the earth, in cartons, etc.
4. Flow demands, e.g., amount needed, continuous or intermittent, timing, etc.
5. Final position, where material is needed, e.g., distance, elevation differences, etc.
6. In-transit conditions, e.g., transocean, jungle, city traffic, in-plant, etc., and any hazards, perils, special events or situations that could occur during transit
7. Handling equipment available, e.g., devices, prices, reliability, maintenance needs, etc.
8. Form and position needed at destination
9. Integration with other equipment and systems
10. Degree of control required

Other factors to be considered include:

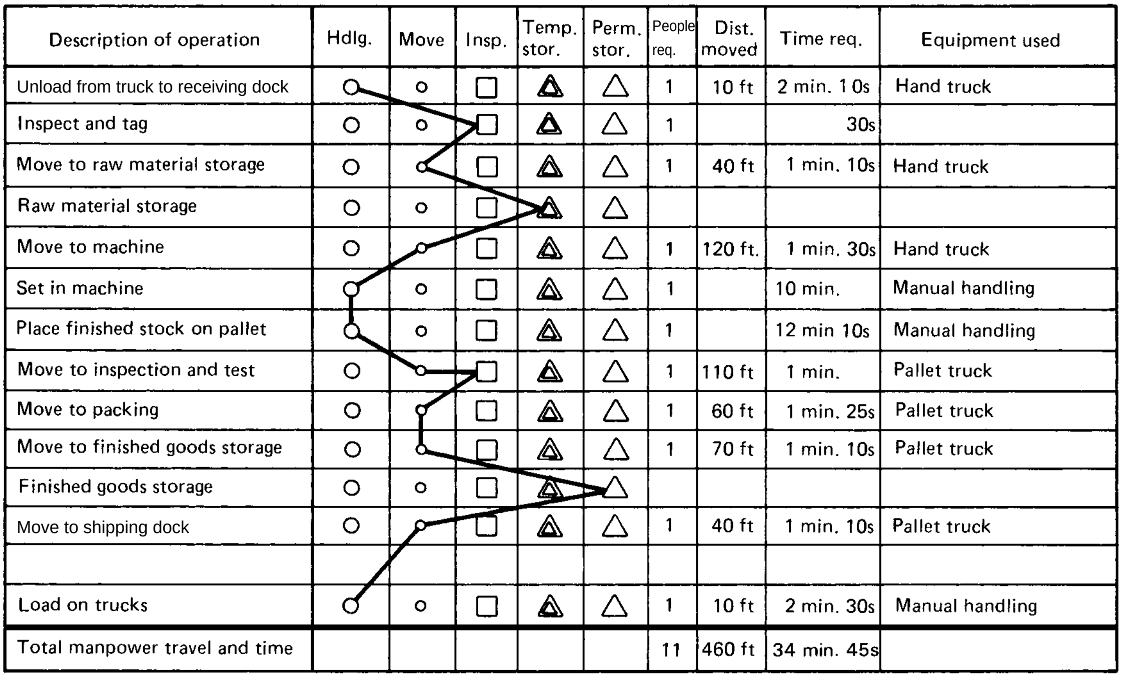
1. Labor skills available
2. Degree of mechanization desired
3. Capital available
4. Return on investment
5. Expected life of installation

Since material handling adds expense, but not value, it should be reduced as much as possible with respect to time, distance, frequency, and overall cost. A straight steady flow of material is usually most efficient. The use of mechanical equipment rather than humans is usually, but not always, desirable—depending upon the duration of the job, frequency of trips, load factors, and characteristics of the material. When equipment is used, maximizing its utilization, using the correct equipment, proper maintenance, and safety are important considerations.

The proper material handling equipment can be selected by analyzing the material, the route it must take from point of origin to destination, and knowing what equipment is available.

FLOW ANALYSIS

The path materials take through a plant or process can be shown on a flowchart and floor plan. See. Figs. 10.1.1 and 10.1.2. These show not only distances and destinations, but also time required, loads, and other information to suggest which type of handling equipment will be needed.



Description of operation	Hdlg.	Move	Insp.	Temp. stor.	Perm. stor.	People req.	Dist. moved	Time req.	Equipment used
Unload from truck to receiving dock	○	○	☐	△	△	1	10 ft	2 min. 10s	Hand truck
Inspect and tag	○	○	☐	△	△	1		30s	
Move to raw material storage	○	○	☐	△	△	1	40 ft	1 min. 10s	Hand truck
Raw material storage	○	○	☐	△	△				
Move to machine	○	○	☐	△	△	1	120 ft.	1 min. 30s	Hand truck
Set in machine	○	○	☐	△	△	1		10 min.	Manual handling
Place finished stock on pallet	○	○	☐	△	△	1		12 min 10s	Manual handling
Move to inspection and test	○	○	☐	△	△	1	110 ft	1 min.	Pallet truck
Move to packing	○	○	☐	△	△	1	60 ft	1 min. 25s	Pallet truck
Move to finished goods storage	○	○	☐	△	△	1	70 ft	1 min. 10s	Pallet truck
Finished goods storage	○	○	☐	△	△				
Move to shipping dock	○	○	☐	△	△	1	40 ft	1 min. 10s	Pallet truck
Load on trucks	○	○	☐	△	△	1	10 ft	2 min. 30s	Manual handling
Total manpower travel and time						11	460 ft	34 min. 45s	

Fig. 10.1.1 Material flowchart.

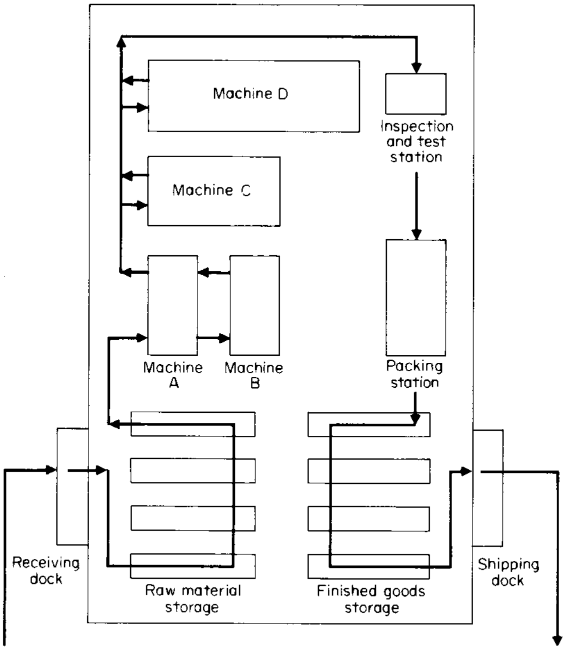


Fig. 10.1.2 Material flow floor plan.

CLASSIFICATIONS

Material handling may be divided into classifications or actions related to the stage of the process. For some materials the first stage is its existence in its natural state in nature, e.g., in the earth or ocean. In other cases the first stage would be its receipt at the factory's receiving dock. Subsequent material handling actions might be:

1. Holding, feeding, metering
2. Transferring, positioning
3. Lifting, hoisting, elevating
4. Dragging, pulling, pushing
5. Loading, carrying, excavating
6. Conveyor moving and handling
7. Automatic guided vehicle transporting
8. Robot manipulating
9. Identifying, sorting, controlling
10. Storing, warehousing
11. Order picking, packing
12. Loading, shipping

FORMS OF MATERIAL

Material may be in solid, liquid, or gaseous form. Solid material may be in end-product shapes or in intermediate forms of slabs, sheets, bars, wire, etc., which may be rigid, soft, or amorphous. Further, each item may be unique or all may be the same, allowing for indiscriminate selection and handling. Items may be segregated according to some characteristic or all may be commingled in a mixed container. They might have to be handled as discrete items, or portions of a bulk supply may be handled. If bulk, as coal or powder, their size, size distribution, flowability, angle of repose, abrasiveness, contaminants, weight, etc., must be known. In short, before any material can be held, fed, sorted, and transported, all important characteristics of its form must be known.

HOLDING DEVICES

Devices used to hold material should be selected on the basis of the form of the material, what is to be done to it while being held (e.g., heated, mixed, macerated, dyed, etc.), and how it is to be fed out of the device. Some such devices are tanks, bins, hoppers, reels, spools, bobbins, trays, racks, magazines, tubes, and totes. Such devices may be stationary—either with or without moving parts—or moving, e.g., vibrating, rotating, oscillating, or jogging.

The material holding system is the first stage of a material handling system. Efforts should be made to assure that the holding devices never become empty, lest the entire system's flow stops. They can be refilled manually or automatically and have signals to call for refills at carefully calculated trigger points.

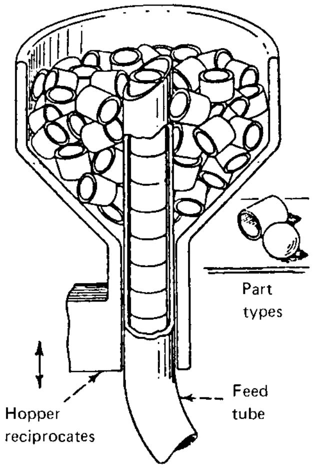


Fig. 10.1.3 Reciprocating feeder. Either hopper or tube reciprocates to obtain, orient, and feed items.

MATERIAL FEEDING AND METERING MODES

Material can be fed from its holding devices to processing areas in several modes:

1. Randomly or by selection of individual items
2. Pretested or untested
3. Linked together or separated
4. Oriented or in any orientation
5. Continuous flow or interruptible flow
6. Specified feed rate or any rate of flow
7. Live (powered) or unpowered action
8. With specific spaces between items or not

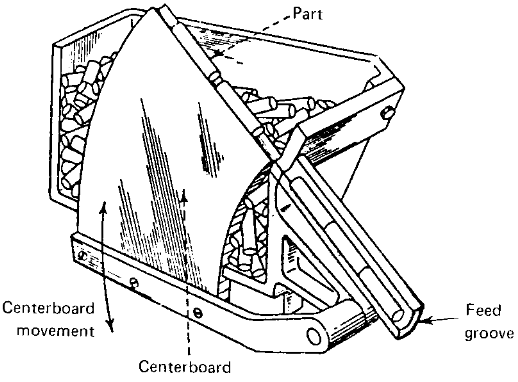


Fig. 10.1.4 Centerboard feeder. Board, with edge shaped to match part, dips and then rises through parts to select part, which then slides into feed groove.

FEEDING AND METERING DEVICES

The feeding and metering devices selected depend on the above factors and the properties of the material. Some, but not all, possible devices include:

1. Pumps, dispensers, applicators
2. Feedscrews, reciprocating rams, pistons
3. Oscillating blades, sweeps, arms
4. Belts, chains, rotaries, turntables
5. Vibratory bowl feeders, shakers
6. Escapements, mechanisms, pick-and-place devices

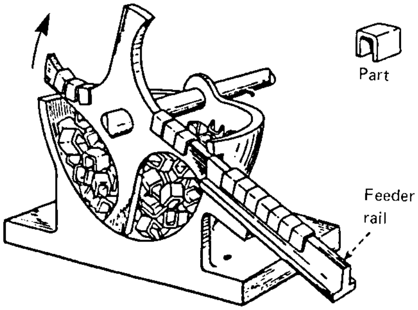


Fig. 10.1.5 Rotary centerboard feeder. Blade, with edge shaped to match part, rotates through parts, catching those oriented correctly. Parts slide on contour of blade to exit onto feeder rail.

Figures 10.1.3 to 10.1.8 illustrate some possible feeding and metering devices.

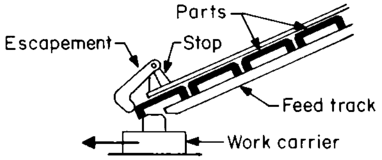


Fig. 10.1.6 Escapement feeder. One of several variations. Escapement is weighted or spring-loaded to stop part from leaving track until it is snared by the work carrier. Slope of track feeds next part into position.

TRANSFERRING AND POSITIONING

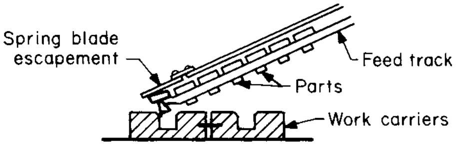


Fig. 10.1.7 Spring blade escapement. Advancing work carrier strips off one part. Remainder of parts slide down feed track. Work carrier may be another part of the product being assembled, resulting in an automated assembly.

There is frequently a need to transfer material from one machine to another, to reposition it within a machine, or to move it a short distance. This can be accomplished through the use of ceiling-, wall-, column-, or floor-mounted hoists, mechanical-advantage linkages, powered manipulators, robots, airflow units, or special devices. Also turrets, dials, indexers, carousels, or conveyors can be used; their motion and action can be:

1. In-line (straight line)
   a. Plain (without pallets or platens)
   b. Pallet or platen equipped
2. Rotary (dial, turret, or table)
   a. Horizontal
   b. Vertical
3. Shuttle table
4. Trunnion
5. Indexing or continuous motion
6. Synchronous or nonsynchronous movement
7. Single- or multistation

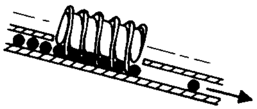


Fig. 10.1.8 Lead screw feeder. Parts stack up behind the screw. Rotation of screw feeds parts with desired separation and timing.

10.2 LIFTING, HOISTING, AND ELEVATING

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CHAIN

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Chain, because of its energy absorption properties, flexibility, and ability to follow contours, is a versatile medium for lifting, towing, pulling, and securing. The American Society for Testing and Materials (ASTM) and National Association of Chain Manufacturers (NACM) have divided chain into two main groups: welded and weldless. Welded chain is further categorized into grades by strength and used for many high-strength industrial applications, while weldless chain is used for light-duty low-strength industrial and commercial applications. The grade designations recognized by ASTM and NACM for welded steel chain are 30, 43, 70, and 80. These grade numbers relate the mean stress in newtons per square millimeter (N/mm^2) at the minimum breaking load. As an example, the mean stress of Grade 30 chain at its minimum breaking load is 300 N/mm^2 while those for Grades 80, 70, and 43 are 800, 700, and 430 N/mm^2 respectively.

Graded welded steel chain is further divided by material and use. Grades 30, 43, and 70 are welded carbon-steel chains intended for a variety of uses in the trucking, construction, agricultural, and lumber industries, while Grade 80 is welded alloy-steel chain used primarily for overhead lifting (sling) applications.

As a matter of convenience when discussing graded steel chains, chain designers have developed an expression which contains a constant for each given grade of chain regardless of the material size. This expression is $M = N \times (\text{dia.})^2 \times 2000$ where M is the chain minimum ultimate strength in pounds; N is a constant: 91 for Grade 80, 80 for Grade 70, 49 for Grade 43, and 34 for Grade 30. Note that N has units of lb/in^2 and dia. is the actual material stock diameter in inches.

Table 10.2.1 Grade 80 Alloy Chain Mechanical and Dimensional Requirements

Nominal chain size		Material diameter		Working load limit, max		Proof test,* min		Minimum breaking force*		Inside length, max		Inside width, min to max	
in	mm	in	mm	lb	kg	lb	kN	lb	kN	in	mm	in	mm
7/32	5.5	0.217	5.5	2,100	970	4,300	19.0	8,500	38.0	0.693	17.6	0.270 to 0.325	6.87 to 8.25
9/32	7.0	0.276	7.0	3,500	1,570	7,000	30.8	13,800	61.6	0.900	22.9	0.344 to 0.430	8.75 to 10.92
⅜	10.0	0.394	10.0	7,100	3,200	14,200	63.0	28,300	126.0	1.260	32.0	0.492 to 0.591	12.50 to 15.00
½	13.0	0.512	13.0	12,000	5,400	23,900	107.0	47,700	214.0	1.640	41.6	0.640 to 0.768	16.25 to 19.50
⅝	16.0	0.630	16.0	18,100	8,200	36,200	161.0	72,300	322.0	2.020	51.2	0.787 to 0.945	20.00 to 24.00
¾	20.0	0.787	20.0	28,300	12,800	56,500	252.0	113,000	504.0	2.520	64.0	0.984 to 1.180	25.00 to 30.00
⅞	22.0	0.866	22.0	34,200	15,500	68,400	305.0	136,700	610.0	2.770	70.4	1.080 to 1.300	27.50 to 33.00
1	26.0	1.024	26.0	47,700	21,600	95,400	425.0	191,000	850.0	3.280	83.2	1.280 to 1.540	32.50 to 39.00
1¼	32.0	1.260	32.0	72,300	32,800	144,600	644.0	289,300	1288.0	4.030	102.4	1.580 to 1.890	40.00 to 48.00

* The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes.

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Note that the foregoing expression can also be stated as chain ultimate strength $= N \times (\text{dia.})^2 \times$ (short tons) where short tons = 2,000. Therefore, knowing the value of the constant N and the stock diameter of the chain, the minimum ultimate strength can be determined.

As an example, the ultimate strength of ½-in Grade 80 chain can be verified as follows by using the information contained in Table 10.2.1:

$$M = (91\ \text{lb/in}^2)\ (0.512\ \text{in})^2 \times 2{,}000 = 47{,}700\ \text{lb}\ (214\ \text{kN})$$

While graded steel chains are not classified as calibrated chain, since links are manufactured to accepted commercial tolerances, they are sometimes used for power transmission in pocket wheel applications. In most such applications, however, power transmission chain is special in that link dimensions are held to very close tolerances and the chain is processed to achieve special wear and strength properties. More in-depth discussions of chain, chain fittings, power transmission, and special chain follow in this section.

Grade 80 Welded Alloy-Steel Chain (Sling Chains)

The ASTM and NACM specifications for alloy-steel chain (sling chain) has evolved over a period of many years dating back to the mid-1950s. The load and strength requirements for slings and sling chain have unified and are currently specified at Grade 80 levels in the ASME standard for slings and the NACM and ASTM specifications for alloy steel chain. Table 10.2.1 relates the ASTM and NACM Grade 80 specifications. As noted, the working load limit or maximum load to be applied during use is approximately 25 percent of the minimum breaking force. Because the endurance limit is about 18 percent of the breaking strength, applications which call for a high number of load cycles near the rated load should be reconsidered to maintain the load within endurance limits. As an alternative, a larger-size chain with a higher working load limit could be applied.

Alloy steel chain manufactured to the Grade 80 specification varies in hardness among producers from about 360 to 430 Brinell. This range has narrowed, on average, in recent years from a prior range of 250 to 450 Brinell which was common in the 1960s. The current values equate to a material tensile strength range of 175,000 to 215,000 lb/in^2 or an average chain tensile strength of 116,000 lb/in^2 (800 N/mm^2) to 145,000 lb/in^2 (1000 N/mm^2). Thus the tensile strengths expressed for Grade 80 chain provide a breaking strength range of $91 \times (\text{diam})^2$ to $114 \times (\text{diam})^2$ short tons. The approximate conversion is $1.0 \times (\text{diam})^2$ short tons = 8.78 N/mm^2. Thus, Grade 80 chain has a minimum breaking strength of $91 \times (\text{diam})^2$ short tons.

As is the case with chain strength, chain dimensions have become standardized in the interest of interchangeability of chain and chain fittings. Thus, the dimensions presented in Table 10.2.1 are intended to assure interchangeability of products between manufacturers.

Present ASTM and NACM chain specifications call for a minimum elongation of 15 percent at rupture. This figure was established in 1924 as an attempt to guarantee against brittle fracture and to give visible warning of overloading. For low-hardness carbon-steel chains (under 200 Brinell) in use prior to the advent of hardened alloy steel, the requirement for sling chains to have 15 percent minimum elongation at rupture provided some usefulness as an overload warning signal. However, since high-quality Grade 80 alloy steel chain of 360 Brinell or higher has replaced carbon-steel chain in high-strength applications, elongation as an indicator of overload is not so apparent. Grade 80 chain achieves about 50 percent of its total elongation during the final 10 percent of loading just prior to rupture. For this reason, only about 50 percent of the total elongation is useful as a visual indicator of overloading. Thus, it is increasingly important that sling chain and slings of optimum strength, toughness, and durability be properly selected, applied, and maintained as advised in applicable standards.

Total deformation (plastic plus elastic) at failure is important as one of the determinants of energy-absorption capability and therefore of impact resistance. However, its companion determinant—breaking strength—is equally important. The only practical way to measure their composite effect is by actual impact tests on actual chain samples—not by tests on Charpy or other prepared specimens of material. Special impact testers equipped with high-speed measuring and integrating devices have been developed for this purpose.

General-Purpose Welded Carbon-Steel Chains

Grade 30 (proof coil) chain is made from low-carbon steel containing about 0.08 percent carbon. It has a minimum breaking strength of approximately $34 \times (\text{diam})^2$ short tons at 125 Brinell, while its working load limit is 25 percent of its minimum breaking force. Applications include load securement, guard rail chain, and boat mooring. It is not for use in critical or lifting applications. Table 10.2.2 gives pertinent ASTM-NACM size and load data.

Grade 43 (high test) chain is made from medium carbon steel having a carbon content of 0.15 to 0.22 percent. It is typically heat-treated to a minimum breaking strength of $49 \times (\text{diam})^2$ short tons at a hardness of 200 Brinell. Table 10.2.3 presents the ASTM-NACM specifications for Grade 43 chain. As shown, the working load limit is approximately 35 percent of the minimum breaking force. The major use of this chain grade is load securement, although it also finds use for towing and dragging in the logging industry.

Grade 70 (transport) chain was previously designated *binding chain* by NACM. This is a high-strength chain which finds use as a load securement medium on log and cargo transport trucks. It may be made from carbon or low-alloy steel with boron or manganese added in some cases to provide a uniformly hardened cross section. Carbon content is in the range of 0.22 to 0.30 percent. The chain is heat-treated to a minimum breaking force of $80 \times (\text{diam})^2$ short tons with the working load limit at 25 percent of the minimum breaking force. Although this chain approaches the strength of Grade 80, it is not recommended for overhead lifting because of the greater energy absorption capability and toughness demanded of sling chain. Table 10.2.4 presents the ASTM-NACM specifications for Grade 70 chain.

Table 10.2.2 Grade 30 Proof Coil Chain
Note: Not to be used in overhead lifting applications.

Nominal chain size		Material diameter		Working load limit, max		Proof test,* min		Minimum breaking force*		Inside length, max		Inside width, min	
in	mm	in	mm	lb	kg	lb	kN	lb	kN	in	mm	in	mm
⅛	4.0	0.156	4.0	375	170	800	3.6	1,600	7.1	0.94	23.9	0.25	6.4
3⁄16	5.5	0.217	5.5	800	365	1,600	7.2	3,200	14.3	0.98	24.8	0.30	7.7
¼	7.0	0.276	7.0	1,300	580	2,600	11.6	5,200	23.1	1.24	31.5	0.38	9.8
5⁄16	8.0	0.315	8.0	1,900	860	3,400	15.1	6,800	30.2	1.29	32.8	0.44	11.2
⅜	10.0	0.394	10.0	2,650	1200	5,300	23.6	10,600	47.1	1.38	35.0	0.55	14.0
½	13.0	0.512	13.0	4,500	2030	8,950	39.8	17,900	79.6	1.79	45.5	0.72	18.2
⅝	16.0	0.630	16.0	6,900	3130	13,600	60.3	27,200	120.6	2.20	56.0	0.79	20.0
¾	20.0	0.787	20.0	10,600	4800	21,200	94.3	42,400	188.5	2.76	70.0	0.98	25.0
⅞	22.0	0.866	22.0	12,800	5810	25,600	114.1	51,200	228.1	3.03	77.0	1.08	27.5

* The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes.
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Table 10.2.3 Grade 43 High Test Chain
Note: Not to be used in overhead lifting applications.

Nominal chain size		Material diameter		Working load limit, max		Proof test,* min		Minimum breaking force*		Inside length, max		Inside width, min	
in	mm	in	mm	lb	kg	lb	kN	lb	kN	in	mm	in	mm
¼	7.0	0.276	7.0	2,600	1,180	3,750	16.6	7,500	33.1	1.24	31.5	0.38	9.8
5⁄16	8.0	0.315	8.0	3,900	1,770	4,900	21.6	9,700	43.2	1.29	32.8	0.44	11.2
⅜	10.0	0.394	10.0	5,400	2,450	7,600	33.8	15,200	67.6	1.38	35.0	0.55	14.0
½	13.0	0.512	13.0	9,200	4,170	12,900	57.1	25,700	114.2	1.79	45.5	0.72	18.2
⅝	16.0	0.630	16.0	11,500	5,220	19,500	86.5	38,900	172.9	2.20	56.0	0.79	20.0
¾	20.0	0.787	20.0	16,200	7,350	30,400	130.1	60,700	270.2	2.76	70.0	0.98	25.0

* The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes.
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Table 10.2.4 Grade 70 Transport Chain
Note: Not to be used in overhead lifting applications.

Nominal chain size		Material diameter		Working load limit, max		Proof test,* min		Minimum breaking force*		Inside length, max		Inside width, min	
in	mm	in	mm	lb	kg	lb	kN	lb	kN	in	mm	in	mm
¼	7.0	0.276	7.0	3,150	1,430	6,100	27.0	12,100	53.9	1.24	31.5	0.38	9.8
5⁄16	8.7	0.343	8.7	4,700	2,130	9,400	41.8	18,800	83.5	1.32	33.5	0.48	12.2
⅜	10.0	0.394	10.0	6,600	2,990	12,400	55.0	24,700	110.0	1.38	35.0	0.55	14.0
7⁄16	11.9	0.468	11.9	8,750	3,970	17,500	77.7	35,000	155.4	1.64	41.6	0.65	16.6
½	13.0	0.512	13.0	11,300	5,130	20,900	92.9	41,800	185.8	1.79	45.5	0.72	18.2
⅝	16.0	0.630	16.0	15,800	7,170	31,700	140.8	63,300	281.5	2.20	56.0	0.79	20.0
¾	20.0	0.787	20.0	24,700	11,200	49,500	219.9	98,900	439.8	2.76	70.0	0.98	25.0

* The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes.
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Chain Strength

Welded chain links are complex, statically indeterminate structures subjected to combinations of bending, shear, and tension under normal axial load. When a link is loaded, the maximum tensile stress normal to the section occurs in the outside fiber at the end of the link [see Fig. 10.2.1], which shows the stress distribution in a ⅜-in (10-mm) Grade 80 chain link with rated load, determined by finite element analysis (FEA). In Fig. 10.2.1, stress distribution is obtained from FEA by assuming that peak stress is below the elastic limit of the material. If the material is ductile and the peak stress from linear static FEA exceeds the elastic limit, plastic deformation will occur, resulting in a distribution of stresses over a larger area and a reduction of peak stress.

It is interesting to note that the highest stress in the chain link is compressive and occurs at the point of loading on the inside end of the link. Conversely, traveling around the curved portion of the link, the compressive and tensile stresses reverse and the outside of the link barrels are in compression. Since the outside of the barrels of the link, unlike the link ends, are unprotected, they are vulnerable to damage such as wear from abrasion, nicks, and gouges. Fortunately, since the damage occurs in an area of compressive stress, their potentially harmful effects are reduced.

Maximum shear stress, as indicated in Fig. 10.2.1, occurs on a plane approximately 45° to the x axis of the link where the bending moment is zero. Chains such as Grade 80 with low to medium hardness (BHN 400 or less) normally break when overloaded in this region. As hardness increases, there is a tendency for the fracture mode to shift from one of shear as described above to one of tension bending through the end of the link where the maximum tensile stress occurs. A member made of ductile material and subjected to uniaxial stress fails only after extensive plastic deformation of the material. The yielding results in deformation, causing a reduction in the link's cross section until final failure occurs in shear.

Combined stresses referred to initially in this section result in higher stresses than those computed by considering the load applied uniformly in simple tension across both barrels. For example, a ⅜-in (10-mm) Grade 80 alloy chain with a BHN of 360 has a material strength of

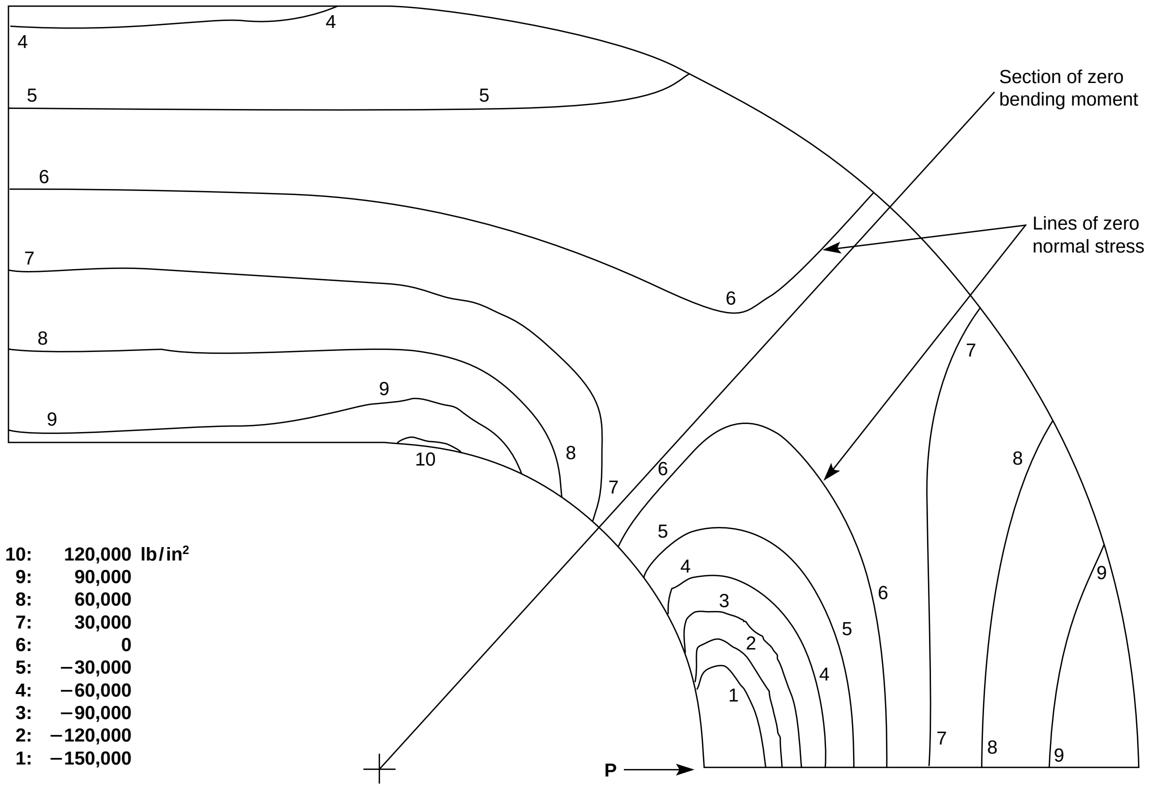


Fig. 10.2.1 Stress distribution in a ⅜-in (10-mm) Grade 80 chain link at rated load.

180,000 lb/in^2 (1240.9 MN/m^2). Based on a specified ultimate strength of the chain of 91 × (diam)^2 tons, which is 28,300 lb (12,800 kg), the average stress in each barrel of the chain would be 116,000 lb/in^2 (799.7 MN/m^2). The actual breaking strength, however, because of the effects of the combined stresses, is magnified by a factor of 180,000/116,000 = 1.5 over the average stress in each barrel.

Most chain manufacturers now manufacture a through-hardened commercial alloy sling chain, discussed in this section. Although designed primarily for sling service, it is used in many original equipment applications. Typical strength of this Grade 80 chain is 91 × (diam)^2 tons with a BHN of 360 and a minimum elongation of 15 percent. This combination of strength, wear resistance, and energy absorption characteristics makes it ideal for applications where the utmost dependability is required under rugged conditions. Typical inside width and pitch dimensions are 1.25 × diam and 3.20 × diam.

Chain End Fittings

Most industrial chains must be equipped with some type of end fittings. These usually consist of oblong links, pear-shaped links, or rings (called masters) on one end to fit over a crane hook and some variety of hook or enlarged link at the other end to engage the load. The hooks are normally drop-forged from carbon or alloy steel and subsequently heat-treated. They are designed (using curve-beam theories) to be compatible in strength with the chain for which they are recommended. Master links or rings must fit over the rather large section thicknesses of crane hooks, and they therefore must have large inside dimensions. For this reason they are subjected to higher bending moments, requiring larger section diameters than those on links with a narrower configuration.

CM Chain Division of Columbus McKinnon recommends that oblong master links be designed with an inside width of 3.5 × diam and an inside length of 7.0 × diam, where diam is the section diameter in inches. Using a material with a yield strength of 100,000 lb/in^2, the diameter can be calculated from the relationship diam = (WLL)/20,000$^{1/2}$, where WLL is the working load limit in pounds.

Rings require a somewhat greater section diameter than oblong links to withstand the same load without deforming because of the higher bending moment. **Master rings** with an inside diameter of 4 × diam can be sized from the relationship diam = (WLL)/15,000$^{1/2}$ in. Rings require a 15 percent larger section diameter and a 33 percent greater inside width than oblong links for the same load-carrying capacity, and the use of the less bulky oblong links is therefore preferred.

Pear-shaped master links are not nearly as widely in demand as oblong master links. Some users, however, prefer them for special applications. They are less versatile than oblong links and can be inadvertently reversed, leading to undesirable bending stresses in the narrow end due to jamming around the thick saddle of the crane hook.

Hooks and **end links** are attached to sling chains by means of coupling links, either welded or mechanical. Welded couplers require special equipment and skill to produce quality and reliability compatible with the other components of a sling and, consequently, must be installed by sling chain manufacturers in their plants. The advent of reliable mechanical couplers such as **Hammerloks** (CM Chain Division), made from high-strength alloy forgings, have enabled users to repair and alter the sling in the field. With such attachments, customized slings can be assembled by users from component parts carried in local distributor stocks.

Welded-Link Wheel Chains

These differ from sling chains and general-purpose chains in two principal aspects: (1) they are precisely calibrated to function with pocket or sprocket wheels and (2) they are usually provided with considerably higher surface hardness to provide adequate wear life.

The most widely used variety is hoist load wheel chain, a short link style used as the lifting chain in hand, electric, and air-powered hoists. Some roller chain is still used for this purpose, but its use is steadily declining because of the higher strength per weight ratio and three-dimensional flexibility of welded link chain. Wire rope is also sometimes used in hoist applications. However, it is much less flexible than either welded link or roller chain and consequently requires a drum of 20 to 50 times the rope diameter to maintain bending stresses within safe limits. Welded link chain is used most frequently in hoists with three- or four-pocket wheels; however, it is also used in hoists with multipocket wheels. Pocket wheels, as opposed to cable drums, permit the use of much smaller gear reductions and thus reduce the hoist weight, bulk, and cost.

Welded load wheel chain also has 3 times as much impact absorption capability as a wire rope of equal static tensile strength. As a result, wire rope of equal impact strength costs much more than load wheel chain. Since average wire rope life in a hoist is only about 5 percent of the life of chain, overall economics are greatly in favor of chain for hoisting purposes.

To achieve maximum flexibility, hoist load wheel chain is made with link inside dimensions of pitch = 3 × diam and width = 1.25 × diam. Breaking strength is 90 × $(\text{diam})^2$ tons, and endurance limit is about 18 × $(\text{diam})^2$ tons. In hand-operated hoists, it can be used safely at working loads up to one-fourth the ultimate strength (a design factor of 4). In powered hoists, the higher operating speeds and expectancy of more lifts during the life of the hoist require a somewhat higher design factor of safety. CM Chain Division recommends a factor of 7 for such units where starting, stopping, and resonance effects do not cause the dynamic load to exceed the static chain load by more than 25 percent. For this condition, chain fatigue life will exceed 500,000 lifts, the normal maximum requirement for a powered hoist. Standard hoist load wheel chains, now produced in sizes from 0.125-in (3-mm) through 0.562-in (14-mm) diameter, meet requirements for working load limits up to approximately 5 or 6 short tons (5 long tons) for hand-operated hoists and 3 short tons (2.5 long tons) for power-operated hoists. More complete technical information on this special chain product and on chain-hoist design considerations is available from CM Chain Division.

Another widespread use of welded link chain is in conveyor applications where high loads and moderate speeds are encountered. As contrasted to link-wheel chain used in hoists, conveyor chain requires a longer pitch. For example, the pitch of hoist chain is approximately 3.0 × diam and conveyor chain is 3.5 × diam. The longer-pitch chain, in addition to being more economical, accommodates the use of shackle connectors between sections of the chain to which flight bars are attached.

CM Corporation, for example, manufactures conveyor chains in four metric sizes and in two different thermal treatments (Table 10.2.5). These chains are precisely calibrated to operate in pocket wheels. They may have a high surface hardness (500 Brinell) to provide adequate wear life for ash conveyors in power generating plants and to provide high strength and good wear properties for drive chain applications. Also, the long-pitch chain is used extensively in longwall mining operations to move coal in the mines.

Table 10.2.5 Conveyor Chain Specifications

Chain size, mm	Link pitch, mm	Minimum breaking force, 1000 lb (454 kg)	
		Case-hardened	Through-hardened
14	50	36.5	50.0
18	64	65.0	92.2
22	86	75.0	121.5
26	92	90.0	169.8

SOURCE: Columbus McKinnon Corporation.

Power Transmission

Power transmission, in the sense used to describe the transfer of power in machines from one shaft to another one close by, is a relatively new field of application for welded-link chain. Roller chain and other pin-link chains have been widely used for this purpose for many years. However, recent studies have shown that welded-link chain can be operated at speeds to 3,000 ft/min. Its three-dimensional flexibility, which can sometimes eliminate the need for direction-change components, and its high strength-weight ratio suggest the possibility for significant cost savings in some power-transmission applications.

Miscellaneous Special Chains

Special requirements calling for corrosion or heat resistance, nonmagnetic properties, noncontamination of dyes and foodstuffs, and spark resistance have resulted in the development of many special chains. They have been produced from beryllium copper, bronze, monel, Inconel, Hadfield's manganese, and aluminum and from a wide variety of AISI analyses of stainless and nonstainless alloys. However, the need for such special chains, other than those of stainless steel, is so infrequent that they are seldom carried as stock items.

WIRE ROPE

Load Suspension and Haulage

Wire rope used for suspending loads is usually required to be as flexible as possible to minimize the diameters of the drums or sheaves involved. Thus, a rope having six strands of 19 wires each on a hemp core is used. Extra pliable ropes made with six strands of 37 wires each or eight strands of 19 wires each on a hemp core are also available but are much less durable because of the finer individual wires used. Hoisting ropes are constructed with the relative twist of the wires in the strands the reverse of the twist of the strands about the core (Fig. 10.2.2).

Based upon the service to be expected, special attention should be given to the ratio of drum and sheave diameters to cable diameter. For example, hoists having moderate duty cycle may have a ratio of diameters as low as 20 : 1, but for extensive duty or where there is need for great safety, such as in elevators, this should be at least 45 : 1 or larger. Often the need for storing enough cable to obtain sufficient lift length may require a larger drum diameter than would otherwise be needed.

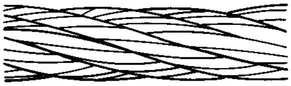


Fig. 10.2.2 Haulage rope.

Haulage ropes are of the same construction as **suspension ropes** or are of the **lang-lay** type shown in Fig. 10.2.3, with the twist of the wire and strand in the same direction. This lang-lay construction increases the wear resistance of the rope, but it tends to untwist and should not be used where the load is in free suspension. Lang-lay rope is difficult to splice. By preforming individual wires and strands before laying up, secondary stresses due to bending are reduced and longer life is obtained. Preformed ropes have less tendency to kink and are easier to handle.

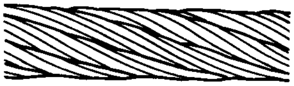


Fig. 10.2.3 Lang-lay rope.

Hoisting and haulage ropes should be frequently **greased** to minimize wear and to prevent corrosion; either a special commercial lubricant or boiled linseed oil may be used on ropes subjected to atmospheric action, and a tacky petroleum and graphite on hoisting ropes in wet places. Crude oil or other lubricants having an acid or basic characteristic should not be used because of corrosive action on both wire and sisal core. To ensure penetration, lubricant can be applied hot, or a volatile solvent can be used. Ropes should be inspected frequently for broken wires and excessive wear.

Track Cables

Cables used as **tracks to support loads suspended on trolleys** are either the locked-coil type for longest life (Fig. 10.2.4) or round-wire track strand.

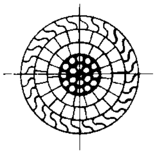


Fig. 10.2.4 Locked-coil track strand wire rope. *(United States Steel.)*

The strength of the locked-coil type is given in Table 10.2.6. This type of wire minimizes the impact loads on the outer wires which result from the rolling of the trolley.

Fittings

Fittings for ropes are attached at the ends by (1) passing the rope around a minimum-radius thimble and then *(a)* attaching the rope to itself with rope clips (approximately 80 percent efficient), *(b)* splicing the rope to itself (80 to 95 percent efficient), *(c)* attaching the rope to itself by a metal ring which is swaged or crimped on (90 to 95 percent efficient), (2) using a fitting part of which is a steel tube which is pressed or swaged over the rope (90 to 100 percent efficient), (3) using zinc to embed the end of the rope in a fitting having a socket to receive it (100 percent efficient).

Drums

Drums are made with smooth surfaces on hand-powered hoists and on power hoists subject to light-duty operation. Medium-and heavy-duty drums are normally grooved. Drums can be welded or cast, depending upon the quantity to be manufactured, since cast drums are economical when mass-produced. Large drums frequently have separate shells welded to the spider or end plate. Drum shells may be made from steel plates which are bent to a cylindrical shape and welded to the end plates with welded hubs before they are grooved for the rope. Steel-plate shells are stronger than cast shells, better balanced, and free from hidden initial defects. The thickness can be less, thus reducing the inertia of the rotating drum and the resulting acceleration-peak loads. Conical and cylindroconical drums are frequently used on large mine hoists. Faces of drums for medium and heavy duty are made wide enough to hold the rope in one layer plus two to four holding turns. The hole for attachment of the rope should be as shown in Fig. 10.2.5 to prevent excessive bending; this method of anchoring is normally done on cast drums which have a limited face width. Figure 10.2.6 shows an alternate, preferred method of anchoring the rope on welded and cast drums when space is not a problem. The pitch diameter of the drum should be at least 20 times the rope diameter in order to obtain reasonable life for both drum and rope. Long life requires 45 to 60 times the rope diameter.

Table 10.2.6 Locked-Coil Track Strand Wire Rope

Diameter		Special grade		Standard grade		Weight	
in	mm	Short ton	tonne	Short ton	tonne	lb/ft	kg/m
¾	19.1	31.5	28.6	25	22.7	1.41	2.10
⅞	22.2	41.5	37.6	32	29.0	1.92	2.86
1	25.4	52.5	47.6	42	38.1	2.50	3.72
1⅛	28.6	66.0	59.9	54	49.0	3.16	4.70
1¼	31.8	81.0	73.5	65	59.0	3.91	5.82
1⅜	34.9	100.0	90.7	78	70.8	4.73	7.04
1½	38.1	120.5	109.3	93	84.4	5.63	8.38
1⅝	41.3	140.0	127.0	108	98.0	6.60	9.82
1¾	44.5	165.0	150	125	113.4	7.66	11.4
1⅞	47.6	187.5	170	138	125.2	8.79	13.1
2	50.8	215	195	158	143	10.00	14.9
2¼	57.2	280	254			12.50	18.6
2½	63.5	345	313			15.2	22.6
2¾	69.9	420	381			18.3	27.2
3	76.2	500	454			22.2	33.0
3¼	82.6	580	526			25.6	38.1
3½	88.9	690	626			29.9	44.5
3¾	95.3	785	712			33.9	50.4
4	101.6	880	798			38.4	57.1

SOURCE: United States Steel Corp.

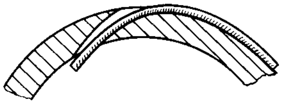


Fig. 10.2.5 Hole for anchoring rope on drums.

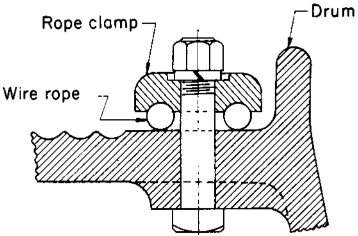


Fig. 10.2.6 Rope-anchoring attachment. *(McDowell Wellman.)*

Where there is side draft on the rope, movable **idlers** are provided to align the rope and groove. The idlers may be moved parallel to the face of the drum by the side pressure of the rope or may be driven positively sideways, thus eliminating friction and increasing the life of rope. In Fig. 10.2.7, idler sheave *c* revolves between fixed collars on shaft *a*, which is connected to the drum shaft by sprocket and chain. The shaft is prevented from rotating by a feather key. On sprocket *b*, a nut is held

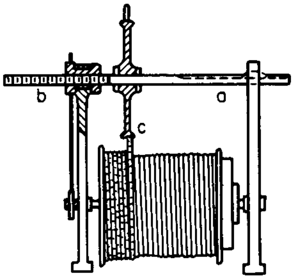


Fig. 10.2.7 Hoisting drum.

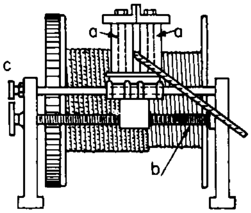


Fig. 10.2.8 Hoisting drum.

from moving sideways by flanges; the shaft *a* with sheave *c* moves in the direction of its axis. In an alternative construction, the idler shaft is threaded but held stationary, and the sheave hub is a nut. The sheave is turned by the friction of the rope, which causes it to travel back and forth. Figure 10.2.8 shows a construction used when the side draft is excessive. The upright rollers *a* are moved sideways by screw *b*, which is driven by sprocket and chain *c* from the drum shaft. For winding the rope on the drum in several layers, a clutch is provided which reverses the direction at the end of travel.

Sheaves

Sheaves should be grooved to fit the rope as closely as possible in order to prevent the rope from assuming an oval or elliptical shape under heavy load. They should be balanced and properly aligned to prevent swaying of the rope and abrasion against the sheave flanges. Sheaves and drums should be as large as possible to obtain maximum rope life, but factors such as weight of machinery for easy transport, minimizing headroom, and high-speed operation call for small sheaves. Hence rope life is sometimes sacrificed for overall economy. Undue wear on sheaves is avoided by flame-hardening them and by properly aligning them with the drum. The fleet angle of the rope should not exceed 1½°, but sometimes with grooved drums up to 2° is acceptable. Sheaves of any diameter can be welded or cast; most manufacturers make cast sheaves since they are economical. To avoid rope damage, worn sheaves should be replaced or the grooves turned before the sheaves are used with a new rope. In some cases, especially in mines, the grooves are lined with renewable, well-seasoned hardwood blocks.

Tackle blocks consist of one or two blocks, each carrying one or more sheaves. A single-sheave block (generally used to change the direction of a lead line and frequently arranged for easy removal of the loop of rope) is called a **snatch block**. Blocks are made for both manila and wire rope. Those for manila rope are usually made with wooden cheeks to prevent chafing of the rope and have sheaves of smaller diameter than wire-rope blocks for the same size of rope. Heavy hoisting is almost universally done with wire-rope blocks. Tests by the American Bridge Co. found the following approximate efficiencies for well-designed and properly maintained ¾-in (19.1-mm) wire-rope tackle.

	Number of ropes supporting load											
	1	2	3	4	5	6	7	8	9	10	11	12
Efficiency, %	86	96	91	87	82	78	74	71	68	65	62	59

Each snatch block between the hoisting blocks and the hoist or winch will have an efficiency of about 86 percent.

Brakes

Small hoists are provided with hand-operated band brakes or electrically operated disk brakes; larger hoists have mechanically operated post brakes. On electric hoists, it is usual to apply the brake with a weight or spring and to remove it by a solenoid. Where controlled rate of application of a brake is desirable, a **thrustor** is frequently used. This is a self-contained unit consisting of a vertical motor, a centrifugal pump in a piston, and a cylinder filled with oil. Starting the motor raises the piston and connected counterweight. Stopping the motor permits the weight to fall. An adjustable range of several seconds in falling sets the brake slowly. Thrustors are built with considerably greater load capacities and stroke lengths than solenoids. Should the current fail, the brakes are automatically applied. On steam hoists, the brake is taken off by a steam piston and cylinder instead of by a solenoid. On overhead cranes, load brakes are used to sustain the load automatically at any point and occasionally to regulate the speed when lowering.

In one type of **load brake** (Fig. 10.2.9), the motor *A* drives drum *B* through the load brake on intermediate shaft *D*. A spider *C* is keyed to shaft *D*, its inner end supporting one end of a coiled bronze spring of square section *E*. The opposite end of the spring is fixed in flange *F*, which is loosely fitted to shaft *D* and directly attached to pinion *G*. Any relative angular motion of flange *F* and spider *C* alters the closeness of the coiling of spring *E*, consequently altering its outside diameter (considered as a drum). This outer surface is one of the friction surfaces of the brake, the other being provided by the internal face of drum *H*, which revolves loosely on shaft *D* at one end and on flange *F* at the other. Drum *H* is restrained from moving in one direction by ratchet *I* and pawls *J*. The exterior of drum *H* is grooved for heat dissipation.

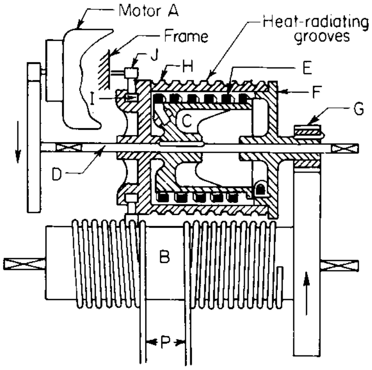


Fig. 10.2.9 Load brake.

The action of the **load brake** in Fig. 10.2.9 is as follows: When hoisting, the brake revolves as shown by the arrow. Pawls *J* permit drum *H* to revolve; consequently, the whole mechanism is locked and revolves as one piece. When stopping the load, the downward pull of the load reacts to drive drum *H* against pawl *J*. Flange *F* therefore moves slightly in an angular direction relative to spider *C*, and spring *E* consequently untwists until it grips the interior of drum *H*, thus locking the load. The action is such that the grip is slightly more than necessary to hold the load. Reversing the motor for lowering the load drives the interior of the brake surface against drum *H* so that the power consumed is the amount necessary to overcome the excess holding power of the brake over the load reaction.

Load brakes of the **disk** and **cone** types are also used and embody the same principle of pawl locks and differential action. The choice of brake type should be based on considerations of smoothness of working and lack of chatter, as well as on the power requirements for lowering at different values of load within the range of the crane.

In **regenerative braking,** the motor, when overhauled, acts as a generator to pump current back into the line.

HOLDING MECHANISMS

Lifting Tongs

Figure 10.2.10 shows the type of tongs used for lifting plates. The cams *a* grip the plate when the chains tighten, preventing slipping. Self-

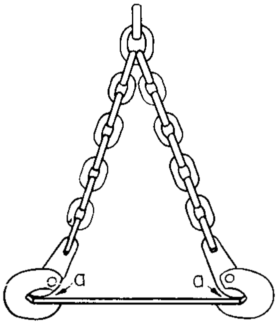


Fig. 10.2.10 Lifting tongs.

closing tongs (Fig. 10.2.11) are used for handling logs, manure, straw, etc. The rope *a* is attached to and makes several turns around drum *b*; chains *c* are attached to the bucket head *e* and to drum *b*. When power is applied to rope *a*, drum *b* is revolved, winding itself upon chains *c* and closing the tongs. To open, slack off on rope *a*, holding tongs on rope *d*, attached to head *e*.

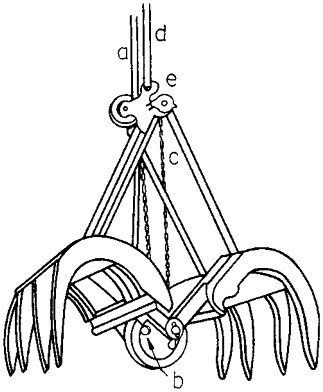


Fig. 10.2.11 Lifting tongs.

Lifting Magnets

Lifting magnets are materials-handling devices used for handling pig iron, scalp iron, castings, billets, tubes, rails, plates, skull-cracker balls, and other magnetic material.

At temperatures above dull-red heat, ordinary magnetic materials lose their magnetic properties, while certain stainless and high-manganese steels are nonmagnetic even at normal temperatures. Such materials cannot be handled by lifting magnets.

Most lifting magnets are not designed for continuous operation but for operation with the normal off times generally associated with materials-handling applications. In addition, attention should be given to operation of magnets on high-temperature loads so as to keep the magnet-coil temperature within the design limits of the insulation. Lifting magnets can be used for underwater operation when they are supplied with watertight cases and specially designed lead connections.

To obtain optimum magnet performance, a suitable **magnetic controller** should be used. It is necessary in most cases to provide means to reverse the current in the magnet in order to release the materials efficiently from the magnet. The controller should also have protective features to absorb the stored energy of the magnet during its discharge, especially when the dc power requirements for a magnet are supplied from a **rectifier-type** power supply.

Lifting magnets can be classified as follows:

1. **Circular Magnets.** This configuration makes the most efficient use of materials, is extremely rugged, and is best suited for general lifting applications. Recently this category of magnets has been subdivided into two distinct types: a relatively large diameter magnet, which is especially efficient on low-permeability material such as scrap; and a magnet which, for equal weight, has a smaller diameter but a much deeper magnetic field, making it more suitable for high-permeability loads typically found in steel mills. Dings Elektrolift series of 8, 13, and 18 in diameters (203, 330, and 457 mm) is designed for machine-shop usage from 2,500 to 13,500 lb (1,130 to 6,120 kg).

2. **Rectangular Magnets.** Many types of materials such as rails, beams, and plates can be handled more efficiently with a rectangular magnet. The tendency of these materials to pull away from the face of the magnet because of deflection rather than total weight is a limiting factor when these magnets are applied. Two or more small rectangular magnets mounted on a spreader beam usually give a better lifting performance than a single large magnet of equal weight. This is especially true in the case of thin plates.

3. **Specialty Magnets.** Loads such as coiled steel present unique problems when lifted by a magnet. Special magnets are available for loads of this type, but the scope of this text does not permit detailed discussion.

Construction features of a typical **circular magnet** are shown in Fig. 10.2.12. A winding of either strap aluminum or copper is located inside the cast-steel case. Strap material with insulating tape between turns, rather than insulated wire, is used for windings since it permits a greater number of turns in the same space. Recent advances in the processing of anodized aluminum have permitted the elimination of the turn-to-turn insulation, thereby allowing an increase in the number of turns, which results in increasing lifting capacity. A nonmagnetic manganese-steel bottom plate is welded to the case to make the coil cavity watertight. The center and outer pole shoes are made so that they can be replaced, since they will wear in severe service.

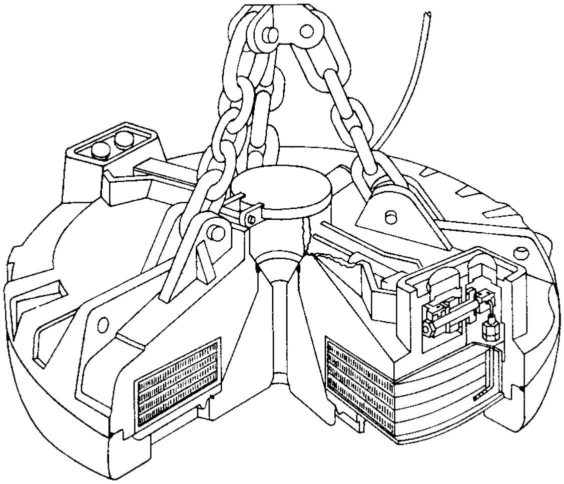


Fig. 10.2.12 Circular lifting magnet. *(Dings.)*

Rectangular-magnet construction features are shown in Fig. 10.2.13, which illustrates a typical plate-handling magnet. Coils for this type of magnet are generally wound with wire and formed to fit over the center pole. A manganese bottom plate is used to hold the coils in place and seal the coil cavity. The external flux path is from the center pole to each of the outer poles.

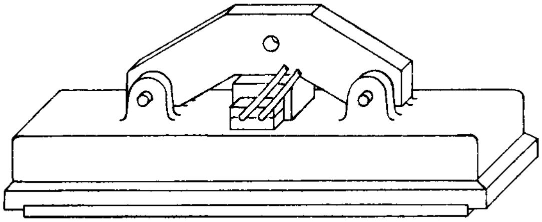


Fig. 10.2.13 Rectangular lifting magnet. *(Dings.)*

Buckets and Scrapers

One type of **Williams self-filling dragline bucket** (Fig. 10.2.14) consists of a bowl with the top and digging end open. The shackles at *c* are so attached that the cutting edge will penetrate the material. When filled, the bucket is raised by keeping the line *a* taut and lifting on the fall line *d*. In this position, the bucket is carried to the dumping position, where by slacking off on line *a*, it is dumped. Line *b* holds up line *a* and the bridle chains while dumping. Such buckets are built in sizes from ¾ yd^3 to as large as 85 yd^3 (0.6 to 65 m^3), weighing 188,000 lb (85,000 kg).

Figure 10.2.15 shows an **open-bottom-type scraper**. Inhauling on cable *a* causes the sloping bottom plate to dig and load until upward pressure of the material against the top prevents further loading. The scraper continues its forward haul to the dumping point. Pulling on cable *b* deposits the load and returns the scraper to the excavation point. Scrapers are made in sizes from ⅓ to 20 yd^3 capacity (0.25 to 15 m^3).

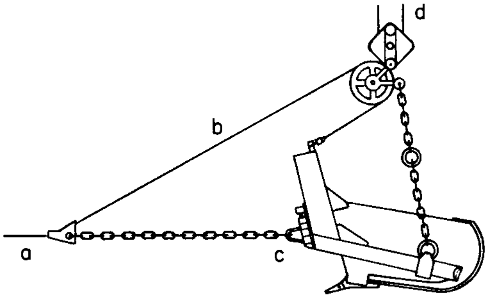


Fig. 10.2.14 Self-filling dragline bucket.

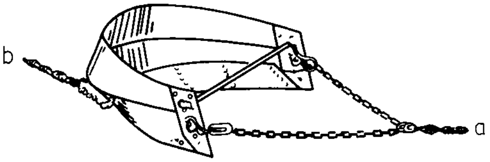


Fig. 10.2.15 Scraper bucket. *(Sauerman.)*

The **Hayward clamshell** type (Fig. 10.2.16) is used for handling coal, sand, gravel, etc., and for other flowable materials. The holding rope *a* is made fast to the head of the bucket. The closing rope *b* makes several wraps around and is made fast to drum *d*, mounted on the shaft to which the scoops are pivoted. The chains *c* are made fast to the head of the bucket and to the smaller diameter of drum *d*. When power is applied to rope *b*, it causes the drum to wind itself up on chain *c*, raising the drum and closing the bucket. To dump, hold rope *a* and slack off rope *b*. The digging power of the bucket is determined by its weight and by the ratio of the diameters of the large and small parts of the drum. Hayward also has an **orange-peel** bucket that operates like the clamshell type (Fig. 10.2.16) but has four blades pivoted to close.

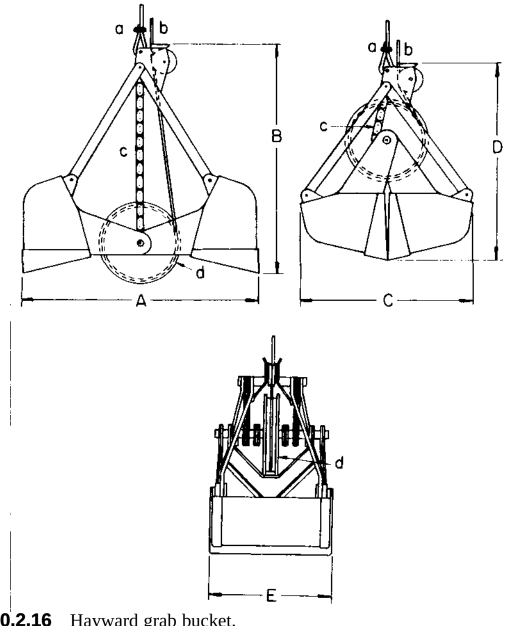


Fig. 10.2.16 Hayward grab bucket.

The **Hayward electrohydraulic** single-rope type (Fig. 10.2.17) is used not only for handling ore and sand but also where it is desirable to hook the bucket on a derrick or crane hook. The bucket requires only to be hung from the crane or derrick hook by the eye and an electric line plugged in. No ropes are fed into the bucket and no time-consuming shifting of lines is required—thus facilitating changing from magnet to bucket. The bowls are suspended from the head, which contains a complete electrohydraulic power unit consisting of an ac or dc motor, hydraulic pump, directional valve, sump, filters, and cylinders. When current is turned on, the motor drives the pump which provides system pressure. Energizing the solenoids in the directional valve directs the fluid flow to either end of the cylinders, which are attached to the blade arms, thus opening or closing the bucket. The system uses a pressure-compensated variable-displacement pump which enters a no-delivery mode when system pressure is reached during the closing or opening action, thus avoiding any heat generation and reducing the load on the motor while maintaining system pressure. The 1 yd^3 (0.76 m^3) bucket is provided with a 15-hp (11.2-kW) motor and 15 gal/min (0.95 l/s) pump. The 2 and 3 yd^3 (1.5 to 2.3 m^3) buckets have motors of 20 to 25 hp (15 to 19 kW), according to duty.

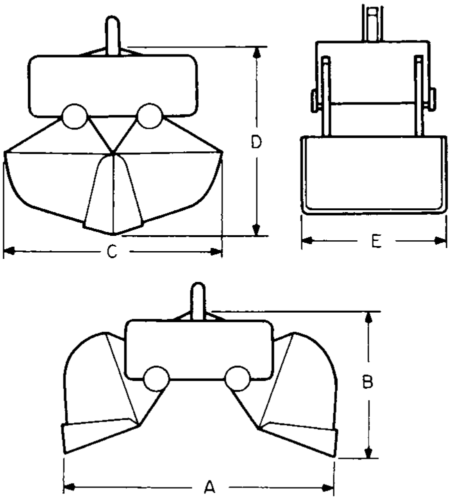


Fig. 10.2.17 Hayward electrohydraulic single-rope-type grab bucket.

HOISTS

Hand-Chain Hoists

Hand chain hoists are portable lifting devices suspended from a hook and operated by pulling on a hand chain. There are two types currently in common use, the high-speed, high-efficiency hand hoist (Fig. 10.2.18) and the economy hand hoist. The economy hand hoist is similar in appearance to the high-efficiency hand hoist except the handwheel diameter is smaller. This smaller diameter accounts for a smaller headroom dimension for the economy hoist. High-speed hoists have mechanical efficiency as high as 80 percent, employ Weston self-energizing brakes for load control, and can incorporate load-limiting devices which prevent the lifting of excessive overloads. They require less hand chain pull and less chain overhaul for movement of a given load at the expense of the larger head size when compared to economy hoists. As noted, this larger head size also creates a minimum headroom dimension somewhat greater than that for the economy hoists. High-speed hoists find application in production operations where low operating effort and long life are important. Economy hoists find application in construction and shop use where more compact size and lower unit cost compensate for the higher operating effort and lower efficiency.

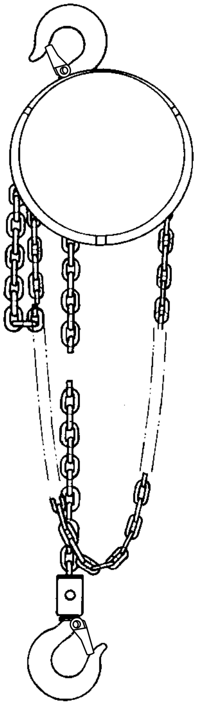


Fig. 10.2.18 High-speed hand hoist. *(CM Hoist Division, Columbus McKinnon.)*

Both hoist types function in a similar manner. The hand chain operates over a handwheel which is connected via the brake mechanism and gear train to a pocket wheel over which the load chain travels. The brake is disengaged during hoisting by a one-way ratchet mechanism. In lowering, the hand chain is pulled continuously in a reverse direction to overcome brake torque, thus allowing the load to descend.

Although a majority of hand chain hoist applications are fixed hook-suspended applications, sometimes a hand hoist is mounted to a trolley to permit horizontal movement of the load, as in a forklift battery-changing operation. This is accomplished by directly attaching the hoist hook to the trolley load bar, or by using an integrated trolley hoist which combines a high-speed hoist with a trolley to save headroom (Fig. 10.2.19).

Hand chain hoists are available in capacities to 50 tons (45 tonnes). Tables 10.2.7 and 10.2.8 provide data for high-speed and economy hoists in readily available capacities to 10 tons (9 tonnes), respectively.

Pullers or Come-Alongs

Pullers, or come-alongs, are lever-operated chain or wire rope hoists (Fig. 10.2.20). Because they are smaller in size and lower in weight than equivalent capacity hand chain hoists, they find use in applications where the travel (take-up) distance is short and the lever is within easy reach of the operator. They may be used for lifting or pulling at any angle as long as the load is applied in a straight line between hooks. There are two types of lever-operated chain or wire rope hoists currently in use: long handle and short handle. The long-handle variety, because of direct drive or numerically lower gear ratios, allows a greater load chain take-up per handle stroke than the short-handle version. Conversely, the short-

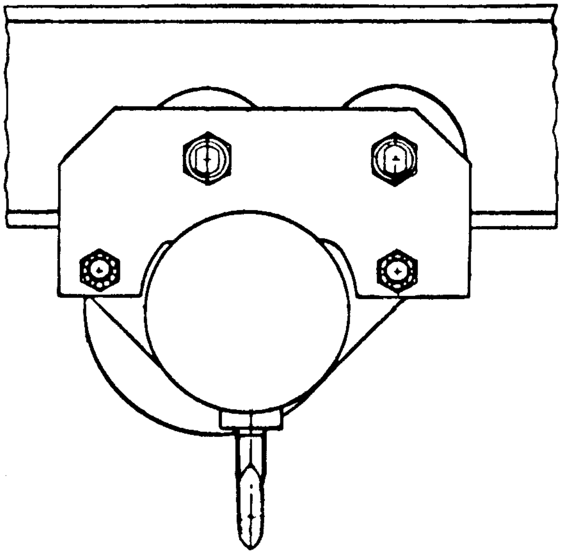


Fig. 10.2.19 Trolley hoist, shown with hand chain removed for clarity. *(CM Hoist Division, Columbus McKinnon.)*

Table 10.2.7 Typical Data for High-Speed Hand Chain Hoists with 8-ft Chain Lift

Capacity		Hand chain pull to lift rated capacity load		Retracted distance between hooks (headroom)		Net weight		Hand chain overhaul to lift load 1 ft	
short tons	tonnes	lb	kg	in	mm	lb	kg	ft	m
¼	0.23	23	10.4	13	330.2	33	15.0	22.5	6.9
½	0.45	46	20.9	13	330.2	33	15.0	22.5	6.9
1	0.91	69	31.3	14	355.6	36	16.3	30	9.1
1½	1.36	80	36.3	17.5	444.5	59	26.8	40.5	12.3
2	1.81	83	37.6	17.5	444.5	60	27.2	52	15.8
3	2.7	85	38.6	21.5	546.1	84	38.1	81	24.7
4	3.6	88	39.9	21.5	546.1	91	41.3	104	31.7
5	4.5	75	34.0	24.5	622.3	122	55.3	156	47.5
6	5.4	90	40.8	25.5	647.7	127	57.6	156	47.5
8	7.3	89	40.3	35.5	901.7	207	93.9	208	63.4
10	9.1	95	43.1	35.5	901.7	219	99.3	260	79.2

SOURCE: CM Hoist Division, Columbus McKinnon.

Table 10.2.8 Typical Data for Economy Hand Chain Hoist with 8-ft Chain Lift

Capacity		Hand chain pull to lift rated capacity load		Retracted distance between hooks (headroom)		Net weight		Hand chain overhaul to lift load 1 ft	
short tons	tonnes	lb	kg	in	mm	lb	kg	ft	m
½	0.45	45	20	10	254	15	7	32	9.8
1	0.91	74	34	12	305	22	10	39	11.9
2	1.81	70	32	17	432	53	24	77	23.5
3	2.7	54	25	22	559	69	31	154	46.9
5	4.5	88	40	24	610	74	34	154	46.9
10	9.1	90	41	32	813	139	63	308	93.9

SOURCE: CM Hoist Division, Columbus McKinnon.

Table 10.2.9 Typical Data for Short- and Long-Handle Lever-Operated Chain Hoists

Capacity		Retracted distance between hooks (headroom)		Handle pull to lift rated capacity				Net weight*			
				Short		Long		Short		Long	
short tons	tonnes	in	mm	lb	kg	lb	kg	lb	kg	lb	kg
¾	0.68	11	279	35	15.8	58	26.3	18	8.2	14	6.4
1½	1.4	14	356	40	18.1	83	37.6	27	12.2	24	10.9
3	2.7	18	457	73	33.1	95	43.1	45	20.4	44	20.0
6	5.4	23	584	77	35.0	96	43.5	66	30.0	65	29.5

* With chain to allow 52 in (1322 mm) of hook travel.
SOURCE: CM Hoist Division, Columbus McKinnon.

handle variety requires less handle force at the expense of chain take-up distance because of numerically higher gear ratios. Both types find use in construction, electrical utilities and industrial maintenance for wire tensioning, machinery skidding, and lifting applications.

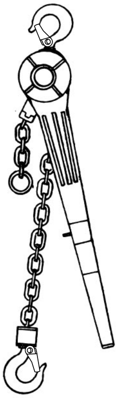


Fig. 10.2.20 Puller or come-along hoist. *(CM Hoist Division, Columbus McKinnon.)*

A reversible ratchet mechanism in the lever permits operation for both tensioning and relaxing. The load is held in place by a Weston-type brake or a releasable ratchet. Lever tools incorporating load-limiting devices via slip clutch, spring deflection, or handle-collapsing means are also available. Table 10.2.9 provides data for lever operated chain hoists.

Electric Hoists

Electric hoists are used for repetitive or high-speed lifting. Two types are available: chain (see Fig. 10.2.21) (both link and roller), in capacities to 15 tons (13.6 tonnes); wire rope (see Fig. 10.2.22), in ratings to 25 tons (22.7 tonnes). The typical hoist has a drum or sprocket centered in the frame, with the motor and gearing at opposite ends, the motor shaft passing through or alongside the drum or sprocket. Many have an integral load-limiting device to prevent the lifting of gross overloads.

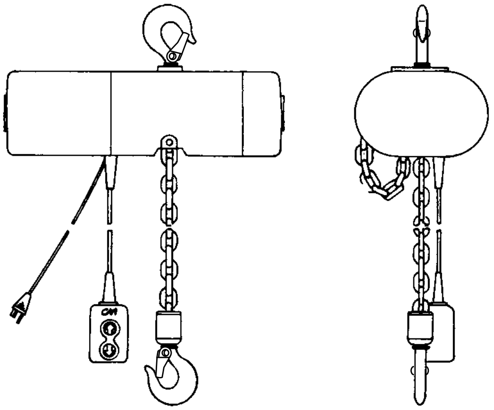


Fig. 10.2.21 Electric chain hoist. *(CM Hoist Division, Columbus McKinnon.)*

Electric hoists are equipped with at least two independent braking means. An electrically released brake causes spring-loaded disk brake plates to engage when current is off. When the hoist motor is activated, a solenoid overcomes the springs to release the brake. In the lowering direction, the motor acts as a generator, putting current back into the line and controlling the lowering speed. Some electric hoists use the same type of Weston brake as is used in hand hoists, but with this type, the motor must drive the load downward so as to try to release the brake. This type of brake generates considerable heat that must be dissipated—usually through an oil bath. The heat generated may also lower the useful-duty cycle of the hoist. If the Weston brake is used, an additional auxiliary hand-released or electrically released friction brake must be provided since the Weston brake will not act in the raising direction. All electric hoists have upper-limit devices; lower-limit devices are standard on chain hoists, optional on wire-rope hoists. Control is usually by push button: pendant ropes from the controller are obsolescent. Control is ''deadman'' type, the hoist stopping instantly upon release. Modern multiple-speed and variable-speed ac controls have made dc hoists obsolete. Single-phase ac hoists are available to 1 hp, polyphase in all sizes.

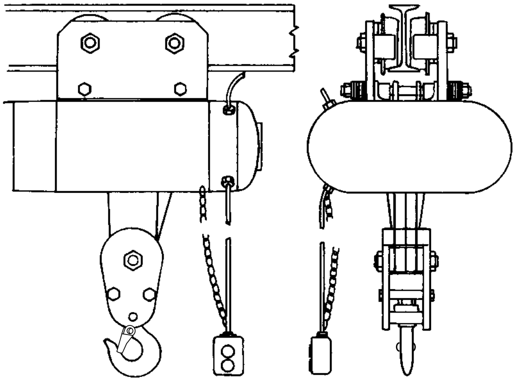


Fig. 10.2.22 Electric wire-rope hoist. *(CM Hoist Division, Columbus McKinnon.)*

The hoist may be suspended by an integral hook or bolt-type lug or may be attached to a trolley rolling on an I beam or monorail. The trolley may be plain (push type), geared (operated by a hand chain), or motor-driven; the latter types are essential for heavier loads. Table 10.2.10 gives data for electric **chain hoists,** and Table 10.2.11 for **wire-rope hoists**.

Air Hoists

Air hoists are similar to electric hoists except that air motors are used. Hoists with roller chain are available to 1 ton capacity, with link chain to 3 short tons (2.7 tonnes) and with wire rope to 15 short tons (13.6 tonnes) capacity. The motor may be of the rotary-vane or piston type. The piston motor is more costly but provides the best starting and low-speed performance and is preferred for larger-capacity hoists. A brake, interlocked with the controls, automatically holds the load in neutral; control movement releases the brake, either mechanically or by air

Table 10.2.10 Typical Data for Electric Chain Hoists*

Capacity		Lifting speed		Retracted distance between hooks (headroom)		Net weight		Motor	
short tons	tonnes	ft/min	m/min	in	mm	lb	kg	hp	kW
⅛	0.11	32	10	15	381	62	28	¼	0.19
⅛	0.11	60	18	15	381	68	31	½	0.37
¼	0.23	16	5	15	381	62	28	¼	0.19
¼	0.23	32	10	15	381	68	31	½	0.37
½	0.45	8	2.5	18	457	73	33	¼	0.19
½	0.45	16	5	15	381	68	31	½	0.37
½	0.45	32	10	16	406	114	52	1	0.75
½	0.45	64	20	16	406	121	55	2	1.49
1	.91	8	2.5	18	457	79	36	½	0.37
1	.91	16	5	16	406	114	52	1	0.75
1	.91	32	10	16	406	121	55	2	1.49
2	1.81	8	2.5	23	584	139	63	1	0.75
2	1.81	16	5	23	584	146	66	2	1.49
3	2.7	5.5	1.5	25	635	163	74	1	0.75
3	2.7	11	3.3	25	635	170	77	2	1.49
5	4.5	10	3	37	940	668	303	5	3.73
5	4.5	24	7	37	940	684	310	7½	5.59
7½	6.8	7	2	40	1016	929	421	5	3.73
7½	6.8	16	5	40	1016	957	434	7½	5.59
10	9.1	7	2	42	1067	945	429	5	3.73
10	9.1	13	4	42	1067	961	436	7½	5.59
15	13.6	4	1.2	48	1219	1155	524	5	3.73
15	13.6	8	2.5	48	1219	1167	529	7½	5.59

* Up to and including 3-ton hook suspended with 10-ft lift. 5- through 15-ton plain trolley suspended with 20-ft lift. Headroom distance is beam to high hook.
SOURCE: CM Hoist Division, Columbus McKinnon Corporation.

Table 10.2.11 Typical Data for Electric Wire Rope Hoists*

Capacity		Lifting speed		Beam to high hook distance		Net weight		Motor	
short tons	tonnes	ft/min	m/min	in	mm	lb	kg	hp	kW
½	0.45	60	18	27	686	430	195	4.5	3.36
¾	0.68	37	11	27	686	430	195	4.5	3.36
1	0.91	30	9	25	635	465	211	4.5	3.36
1	0.91	37	11	27	686	435	197	4.5	3.36
1	0.91	60	18	27	686	445	202	4.5	3.36
1½	1.36	18	5.5	25	635	465	211	4.5	3.36
1½	1.36	30	9	25	635	465	211	4.5	3.36
1½	1.36	37	11	27	686	445	202	4.5	3.36
2	1.81	18	5.5	25	635	465	211	4.5	3.36
2	1.81	30	9	25	635	480	218	4.5	3.36
3	2.7	18	5.5	25	635	560	254	4.5	3.36
5	4.5	13	4	30	762	710	322	4.5	3.36
7½	6.8	15	4.6	36	914	1100	499	7.5	5.59
10	9.1	13.5	4.1	40	1016	1785	810	10	7.46
15	13.6	13	4	49	1245	2510	1139	15	11.19

* Up to and including 5-ton with plain trolley. 7½- to 15-ton with motor-driven trolley.
SOURCE: CM Hoist Division, Columbus McKinnon.

pressure. Some air hoists also include a Weston-type load brake. The hoist may be suspended by a hook, lug, or trolley; the latter may be plain, geared, or air-motor-driven. Horizontal movement is limited to about 25 ft (7.6 m) because of the air hose, although a runway system is available with a series of normally closed ports that are opened by a special trolley to supply air to the hoist.

Air hoists provide **infinitely variable speed,** according to the movement of the control valve. Very high speeds are possible with light loads. When severely overloaded, the air motor stalls without damage. Air hoists are smaller and lighter than electric hoists of equal capacity and can be operated in explosive atmospheres. They are more expensive than electric hoists, require mufflers for reasonably quiet operation, and normally are fitted with automatic lubricators in the air supply.

Jacks

Jacks are portable, hand-operated devices for moving heavy loads through short distances. There are three types in common use: screw jacks, rack-and-lever jacks, and hydraulic jacks. Bell-bottom **screw jacks** (Fig. 10.2.23) are available in capacities to 24 tons and lifting ranges to 14 in. The screw is rotated by a bar inserted in holes in the screw head or by a ratchet lever fitted to the head. Geared bridge jacks will lift up to 50 short tons (45 tonnes). A lever ratchet mechanism turns a bevel pinion; an internal thread in the gear raises the nonrotating screw. **Rack-and-lever jacks** (Fig. 10.2.24) consist of a cast-steel or malleable-iron housing in which the lever pivots. The rack toothed bar passes through the hollow housing; the load may be lifted either on the top or on a toe extending from the bottom of the bar. The lever pawl may be biased either to raise or to lower the bar, the housing pawl holding the load on the return lever stroke. Rack-and-lever jacks to 20 short tons (18 tonnes) are direct-acting. Lever-operated geared jacks range up to 35 short tons (32 tonnes). Lifting heights to 18 in (0.46 m) are provided. **Track jacks** are rack-and-lever jacks which may be tripped to release the load. They are used for railroad-track work but not for industrial service where the tripping features might be hazardous. **Hydraulic jacks** (Fig. 10.2.25) consist of a cylinder, a piston, and a lever-operated pump. Capacities to 100 short tons (91 tonnes) and lifting heights to 22 in (0.56 m) are available. Jacks 25 short tons (22.7 tonnes) and larger may be provided with two pumps, the second pump being a high-speed unit for rapid travel at partial load.

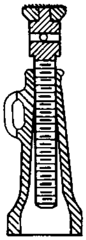


Fig. 10.2.23 Bell-bottom screw jack.

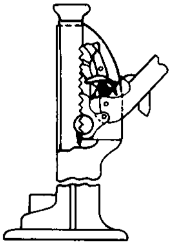


Fig. 10.2.24 Rack-and-lever jack.

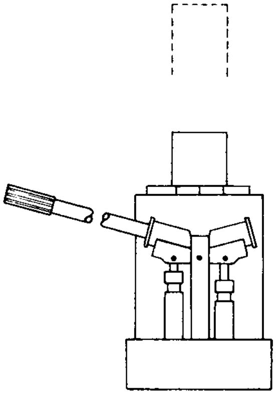


Fig. 10.2.25 Hydraulic jack.

MINE HOISTS AND SKIPS
by Burt Garofab

Pittston Corporation

There are two types of hoists, the drum hoist and the friction hoist. On a **drum hoist,** the rope is attached to the drum and is wound around and stored on the drum. A drum hoist may be single-drum or double-drum. There are also several different configurations of both the single-drum and the double-drum hoist. A drum hoist may be further divided as either unbalanced, partially balanced, or fully balanced.

On a **friction hoist,** which is often referred to as a **Koepe hoist,** the rope is not wound around the drum, but rather passes over the drum. A friction hoist may utilize a single rope or multiple ropes.

The operation of hoists may be controlled manually, automatically, or semiautomatically. There are also arrangements that use combinations of the different control types.

There are currently three types of grooving being used on new drums for drum hoists. They are helical grooving, counterbalance (Lebus) grooving, and antisynchronous grooving. Helical grooving is used primarily for applications where only a single layer of rope is wound around the drum. Counterbalance and antisynchronous grooving are used for applications where multiple layers of rope are wound around the drum.

Mine hoists are generally divided into (1) **Metal-mine hoists** (e.g., iron, copper, zinc, salt, gypsum, silver, gold, ores) and (2) **coal-mine hoists**. These classes subdivide into main hoists (for handling ores or coal) and hoists for men, timbers, and supplies. They are designed for operating (1) mine shafts, vertical and inclined, balanced and unbalanced; and (2) slopes, balanced and unbalanced. When an empty cage or platform descends while the loaded cage or platform ascends, as when both cables are wound on a single drum, the machine is referred to as a **balanced hoist.** Most medium- and large-sized hoists normally operate in balance, as the tonnage obtained for a given load and rope speed is about double that for an unbalanced hoist and the power consumption per ton hoisted is lower. Balanced operation can also be obtained by a counterweight. The counterweight (approximately equal to all the dead loads plus one-half the live load) is usually installed in guides within a single shaft compartment. The average depth of ore mines is about 2,000 ft (610 m), and that of coal mines is close to 500 ft (152 m). Most ore-mine hoists are of the double-drum type, normally hosting in balance, each drum being provided with a friction clutch for changing the relative positions of the two skips when operating from various levels.

Hoists for coal mines are principally of the keyed-drum type, for operating in balance from one level. For high rope speeds in shallow shafts, it is generally advantageous to use **combined cylindrical and conical drums**. The cylindroconical drum places the maximum rope pull (weight of rope and loaded skip) on the small diameter so that during the acceleration period of the cycle, the weight of the opposing skip is offering the greatest counterbalance torque, reducing motor peak loads and slightly reducing the power consumption. The peak reduction obtained becomes greater when shafts are shallower and hoisting speeds are higher, provided that the proportion between the smaller and the large diameters is increased as these conditions increase. By varying the ratio of diameters and the distribution of rope on the drum profiles with respect to the periods of acceleration, retardation, and constant speed, static and dynamic torques can be modified to produce the most economical power consumption and the minimum size of motor. The conical drum is not applicable for multiple-level operation, and except in very special cases, only a single layer of rope can be used.

Skip hoists for industrial purposes such as power-plant fuel handling and blast-furnace charging are similar to shallow-lift slow-speed coal-mine hoists in that they operate from a single level. Speeds of 100 to 400 ft/min (0.5 to 2 m/s) are usual. For blast-furnace charging with combined bucket and load weights up to 31,000 lb (14,000 kg) and a speed of 500 ft/min (2.5 m/s), modern plants consist of straight-drum geared engines, frequently with Ward Leonard control.

Industrial skip hoists may be specified where the lift is too high for a bucket elevator, where the lumps are too large for elevator buckets, or where the material is pulverized and extremely abrasive or actively corrosive. For high lifts having a vertical or nearly vertical path, the skip with supporting structure usually costs less than a bucket elevator or an inclined-belt conveyor with bridge. Typical paths are shown in Fig. 10.2.26, paths *C* and *D* being suitable when the load is received through a track hopper.

The skip may be **manually loaded** direct from a dump car or **automatically loaded** by a pivoted chute, which is actuated by the bucket and which, when upturned, serves as a cutoff gate (Fig. 10.2.27).

For small capacities, the skip can be manually loaded with semiautomatic control. When the bucket has been filled, the operator pushes the start button and the bucket ascends, dumps, and returns to loading position. With automatic loading and larger capacity, the skip may have full automatic control. For economy, the bucket is counterbalanced by a weight, usually equaling the weight of the empty bucket plus half the load. For large capacity, a balanced skip in which one bucket rises as the other descends may be used. High-speed skips usually have automatic slowdown (two-speed motor) as the bucket nears the loading and discharge points.

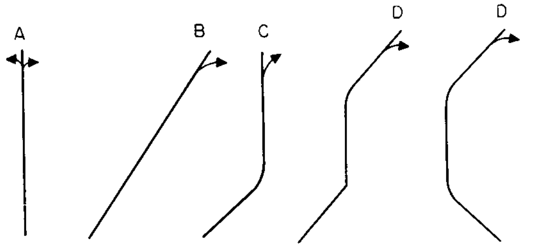


Fig. 10.2.26 Typical paths for skip hoists. (*a*) Vertical with discharge to either side; (*b*) straight inclined run; (*c*) incline and vertical; (*d*) incline, vertical, incline.

There are various types of wire ropes used in hoisting. Hoist ropes can be categorized into three main types, round strand, flattened strand, and locked coil. **Round strand rope** is used on drum hoists in applications when a single layer of rope is wound on the drum. **Flattened strand rope** is used on drum hoists when multiple layers of rope are wound on the drum. Flattened strand rope can also be used on friction hoists. **Locked coil rope** is used on friction hoists.

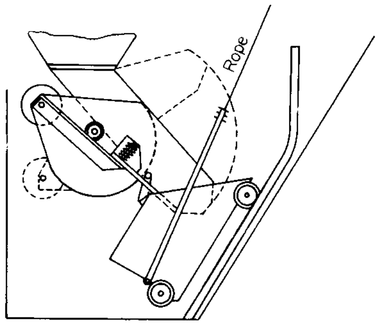


Fig. 10.2.27 Automatic loader (in loading position).

Plow steel and improved plow steel are the most commonly used grades; the latter is used where the service is severe. Some state mining regulations require higher factors of safety than the usual hoisting requirements. The working capacity of new ropes is usually computed by using the minimum breaking strength given in the manufacturer's tables and the following factors of safety: rope lengths of 500 ft (152 m) or less, minimum factor 8; 500 to 1,000 ft (152 to 305 m), 7; 1,000 to 2,000 ft (305 to 610 m), 6; 2,000 to 3,000 ft (610 to 914 m), 5; 3,000 ft (914 m) or over, 4½. These are gross factors between the rated minimum breaking strength of the rope and the maximum static pull due to suspended load plus rope weight. The net factor, which should be used in dealing with large capacities and great depth, must take into consideration stresses due to acceleration and bending around the drum, together with suitable allowances for shock. With 6-by-19 wire construction, the pitch diameter of the drums is generally not less than sixty times the diameter of the rope. Drums are made of either cast iron or cast steel machine-grooved to suit the size of rope (see above). In large hoists, a lifting device is installed at the free rope end of the drum to assist the rope in doubling back over the first layer.

Brakes There are three main types of brakes used on hoists: the jaw brake, the parallel motion brake, and disk brakes. Brake control is accomplished through air or hydraulics. Brake shoes are steel with attached friction material surfaces.

Hoist Motors Determining the proper size of motor for driving a hoist calls for setting up a definite cycle of duty based upon the required daily or hourly tonnage.

The **permissible hoisting speed** for mine hoists largely depends upon the depth of the shaft; the greater the depth, the higher the allowable speed. Conservative maximum hoisting speeds, as recommended by *Bu. Mines Bull.* 75, are as follows:

Depth of shaft		Hoisting speed	
ft	m	ft/min	m/s
500 or less	150 or less	1,200	6
500–1,000	150–300	1,600	8
1,000–2,000	300–600	2,000	10
2,000–3,000	600–900	3,000	15

High hoisting speeds call for rapid **acceleration** and **retardation**. For small hoists, the rate of acceleration may be made as low as 0.5 ft/s^2 (0.15 m/s^2). An average value of 3 ft/s^2 is adopted for large hoists with fairly high speeds. Exceptional cases may require up to 6 ft/s^2 (1.9 m/s^2). The speed should also be considered with regard to the weight of the material to be hoisted per trip. The question of whether the load should be increased and the speed reduced or vice versa is controlled by local conditions, mining laws, and practical experience. The rest period assigned to the duty cycle, i.e., the requisite time for loading at the bottom and unloading at the top, is dependent upon the equipment employed. With skips loaded from underground ore-storage hoppers, 5 to 6 s is the minimum that can be assumed. Unless special or automatic provision is made, the loading time should be taken as 8 to 10 s minimum. When the (1) hoisting speed, (2) weight of skip or cage, (3) weight of load, (4) periods of acceleration, (5) retardation, and (6) time for loading have been decided upon, the next step is to ascertain the ''root-mean-square'' equivalent continuous load-heating effect on the motor, taking into account rope and load weights, acceleration and deceleration of all hanging and rotating masses, and friction of sheaves, machines, etc. The friction load is usually taken as constant throughout the running period of the cycle. The overall efficiency of the mechanical parts of a single-reduction-geared hoist averages 80 percent; that of a first-motion hoist is closer to 85 percent. The motor selected must have sufficient starting torque to meet the temporary peaks of any cycle, including, in the case of balanced hoists, the requirements of trips out of balance.

Electrical equipment for driving mine hoists is of four classes:

1. *Direct-current motors* with resistance control for small hoists, usually series-wound but occasionally compound-wound in conjunction with dynamic braking control.

2. *Alternating-current slip-ring-type motor* with secondary resistance.

3. *Ward Leonard system of control* for higher efficiency, particularly on short lifts at high rope speeds, where the rheostatic losses during acceleration and retardation represent a large proportion of the net work done during the cycle; for accuracy of speeds, with high-speed hoists; and for equalization of power demands. Complete control of the speed from standstill to maximum is obtained for all values of load from maximum positive to maximum negative. The lowering of unbalanced loads without the use of brakes is as readily accomplished as hoisting.

4. The *Ilgner Ward Leonard system* consists of a flywheel directly connected to a Ward Leonard motor-generator set and a device for automatically varying the speed through the secondary rheostatic control of the slip-ring induction motor driving the set. This form of equipment is used under conditions that prohibit the carrying of heavy loads or where power is purchased under heavy reservation charges for peak loads. It limits the power taken from the supply circuit to a certain predetermined value; whatever is required in excess of this value is produced by the energy given up by the flywheel as its speed is reduced.

ELEVATORS, DUMBWAITERS, ESCALATORS

by Louis Bialy

Otis Elevator Corporation

The advent of the safety elevator changed the concept of the city by making high-rise buildings possible. Elevators are widely used to transport passengers and freight vertically or at an incline in buildings and structures. Elevators are broadly classified as low-rise, medium-rise, and high-rise units. Low-rise elevators typically serve buildings with between 2 and 7 floors, medium-rise elevators serve buildings with between 5 and 20 floors, while high-rise elevators serve buildings with more than 15 floors. The speed of the elevator is indexed to the rise of the building so that the overall flight time from bottom to top, or vice versa, is approximately the same. A typical **flight time** is about one minute. Typical speeds for low-rise elevators are up to 200 ft/min (1.0 m/s). Typical speeds for medium rise elevators are up to 400 ft/min (2.0 m/s). High rise elevators typically travel at speeds of up to 1,800 ft/min (9.0 m/s).

Low rise elevators are usually oil-power hydraulic devices. The simplest version consists of a hydraulic jack buried in the ground beneath the elevator car. The jack is approximately centrally located beneath the car and the ram or plunger is connected to the platform or structure which supports the car. The car is guided by guiderails which cover the full rise of the elevator hoistway. Guideshoes or guiderollers typically guide the elevator as it ascends and descends the hoistway. The hydraulic cylinder is equipped with a cylinder head which houses the seals and bearing rings which locate the ram. The ram typically runs clear of the inner cylinder wall. Buried cylinders are typically protected against corrosion.

Hydraulic power is usually supplied by a screw-type positive-displacement pump driven by an induction motor. It is common for the motor and pump to be coaxially mounted and submersed in the hydraulic reservoir. Operating pressures are typically 300 to 600 lb/in^2 (2 to 4 MPa). A hydraulic control valve controls the flow of oil to the hydraulic jack and hence the speed of the elevator. In the down direction, the pump is not powered, and the elevator speed is controlled by bleeding fluid through the control valve.

Another manifestation of the **hydraulic elevator** is called the *holeless hydraulic* elevator. These typically have one or more hydraulic jacks mounted vertically alongside the elevator car, the plunger being either directly attached to the car or connected to the car by steel wire cables (also known as *wire ropes*). Elevators of the latter type are known as *roped hydraulic elevators.* These elevators are often roped 1 : 2 so that the elevator moves at twice the speed of the hydraulic ram. The rise of the elevator is also twice the stroke of the ram. Holeless hydraulic elevators with the ram directly connected to the elevator car may have single-stage jacks or multistage telescopic jacks, depending on the required rise.

Medium- and high-rise elevators are typically traction-driven units; i.e., the rotary motion of the drive sheave is transmitted to the steel wire cables or ropes via friction. The elevators are typically counterweighted so that the motor and drive only need overcome the unbalanced load. The **counterweight** mass is typically the car mass plus approximately half the duty load (load of passengers or freight). With high-rise elevators, the weight of the rope is neutralized by compensating chains hung from the underside of the counterweight and looped to the bottom of the car. If the compensation weight matches the suspension rope weight, then irrespective of the position of the car, there will be no imbalance due to rope weight. The drive sheave is usually grooved to guide the rope and enhance the traction. Roping ratios may be 1 : 1 or 2 : 1. With 1 : 1 ratios the car speed is the same as the rope speed. With 2 : 1 ratios the elevator speed is half of the rope speed.

Medium-rise elevators are typically driven by geared machines which transmit the motor power to the drive sheave. Gear reduction ratios are typically in the range from 12 : 1 to 30 : 1.

Right-angle worm reduction gear sets are most common; however, helical gears are becoming more acceptable because of their higher operating efficiency and low wear characteristics.

High-rise elevators are typically driven by gearless machines, which provide the smoothest and most precise performance of all elevators (see Fig. 10.2.28).

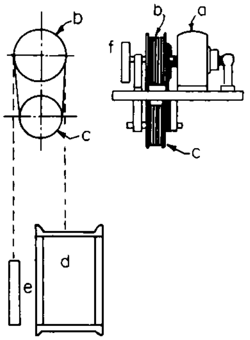


Fig. 10.2.28 Electric traction elevator.

Motors Both dc and ac motors are used to power the driving sheave. Direct current motors have the advantages of good starting torque and ease of speed control. Elevator motors are obliged to develop double rated torque at 125 percent rated current and have frequent starts, stops, reversals, and runs at constant speed. With sparkless commutation under all conditions, commercial motors cannot as a rule meet these requirements. For constant voltage, cumulative-compound motors with heavy series fields are used. The series fields are gradually short-circuited as the motor comes up to speed, after which the motor operates shunt. The shunt field is excited permanently, the current being reduced to a low value with increased resistance instead of the circuit opening when the motor is not in operation.

Drive Control for DC Motors Two types of drives are used for dc motors: Ward Leonard (voltage control) systems using motor-generator sets, and thyristor [silicon controlled rectifier (SCR)] drives. With voltage control, an individual dc generator is used for each elevator. The generator may be driven by either a dc or an ac motor (see Ward Leonard and Ilgner systems, above). The generator voltage is controlled through its field current which gives the highest rates of acceleration and retardation. This system is equally efficient with either dc or ac supply.

AC Motor and Control Squirrel-cage induction motors are becoming more prevalent for elevator use because of their ruggedness and simplicity. The absence of brushes is considered a distinct advantage. The motors are typically three-phase machines driven by variable-voltage, variable frequency (VVVF) drives. The VVVF current is provided by an inverter. High-current-capacity power transistors modulate the power to the motor. Motion of the rotor or the elevator is often monitored by devices such as optional encoders which provide a feedback to the control system for closed loop control.

Elevators installed in the United States are usually required to comply with the ANSI/ASME A17.1 Safety Code or other applicable local codes. The A17.1 code imposes specific safety requirements pertaining to the mechanical, structural, and electrical integrity of the elevator. Examples of **code requirements** include: factors of safety for mechanical and structural elements; the number and type of wire ropes to be used; the means of determining the load capacity of the elevator; the requirements for speed governors and independent safety devices to arrest the car should the car descend at excessive speeds; the requirements for brakes to hold the stationary car with loads of up to 125 percent of rated load; the requirements for buffers at the bottom of the elevator shaft to decelerate the elevator or counterweight should they descend beyond the lowest landing; the type and motion of elevator and hoistway doors; the requirement that doors not open if the elevator is not at a landing; the requirement that door motion cease or reverse if a passenger or obstruction is in their path and that the kinetic energy of the door motion be limited so as to minimize the impact with a passenger or obstruction should they fail to stop in time. The code also requires electrical protective devices which stop the car should it transcend either upper or lower terminal landings, remove power to the motor, and cause the brake to apply should the speed exceed governor settings, etc. The A17.1 code also provides special requirements for elevators located in high seismic risk zones.

Loads Table 10.2.12 shows the rated load of passenger elevators.

Table 10.2.12 Rated Load of Passenger Elevators

Rated Capacity,	lb	2,500	3,500	4,500	6,000	9,000	12,000
	kg	1,135	1,590	2,045	2,725	4,085	5,450
Net inside area,	ft^2	29.1	38.0	46.2	57.7	80.5	103.0
Platform area,	m^2	2.7	3.5	4.3	5.4	7.5	9.6

Efficiencies and Energy Dissipation per Car Mile The overall efficiency and hence the energy dissipation varies greatly from elevator to elevator, depending on the design, hoistway conditions, loading conditions, acceleration and deceleration profiles, number of stops, etc.

For a load of 2,500 lb (1,130 kg) for **geared traction elevators** driven at 350 ft/min (1.75 m/s) by SCR-controlled dc motor or VVVF-controlled ac motor, typical values are as follows: efficiency 60 percent, energy dissipation 4.5 kWh (16 MJ).

Under same conditions for **gearless traction elevators** traveling at 700 ft/min (3.5 m/s), the efficiency may be 70 percent and the energy dissipation 4 kWh (14.5 MJ).

Note that efficiencies are based on net load, i.e., full load minus overbalance.

Car Mileage and Stops (per elevator, 8-h day)

Office buildings, local elevators: intensive service, 12 to 20 car miles (19 to 32 car kilometers), making about 150 regular stops per mile

Express elevators: 20 to 40 car miles (32 to 64 car kilometers), making about 75 to 100 regular stops per mile

Department store elevators: 4 to 8 car miles (6 to 13 car kilometers), making about 350 regular stops per mile.

Operational Control of Elevators Most modern passenger elevators are on fully automatic group collective control. Each group of elevators is controlled by a dispatching system which assigns specific elevators to answer specific hall calls. Modern dispatch systems are microprocessor-based or have some equivalent means of processing information so that each call registered for an elevator is answered in a timely manner. The determination as to which elevator is assigned to answer a specific call is a complex process which in the case of microprocessor-controlled dispatch systems requires the use of sophisticated algorithms which emulate the building dynamics. Some dispatch systems use advanced decision-making processes based on *artificial intelligence* such as *expert systems* and *fuzzy logic* to optimize group collective service in buildings. With better dispatching systems it is possible to achieve excellent elevator service in buildings with the minimum number of elevators, or the efficient service of taller buildings without devoting more space to elevators.

The operational control systems also provide signals for door opening and closing.

Dumbwaiters follow the general design philosophy of elevators except that code requirements are somewhat more relaxed. For example, roller-link chain can be used for support instead of wire rope. Moreover, a single steel wire rope can be used instead of the mandatory minimum of three for traction-type elevators and two for drum-type elevators. Dumbwaiters are not intended for the transportation of people.

Escalators have the advantages of continuity of motion, great capacity, and small amounts of space occupied and current consumed for each passenger carried. Escalators are built with step widths of 24, 32, and 40 in (610, 810, and 1015 mm). The angle of incline is 30° from the horizontal, and the speed is 90 to 120 ft/min (0.45 to 0.6 m/s).

Approximate average handling capacities for escalators traveling at 90 ft/min are 2,000, 2,300, and 4,000 passengers per hour for 24-in, 32-in, and 40-in (610-, 810-, and 1015-mm) escalator step sizes respectively. Higher-speed escalators have proportionally higher passenger-carrying capacity.

Escalators are equipped with a handrail on each side, mounted on the balustrade. The handrail moves at the same speed as the escalator. Escalator steps are so arranged that as they approach the upper and lower landings they recede so that they are substantially level with the floor for safe embarkation and disembarkation of the escalator.

10.3 DRAGGING, PULLING, AND PUSHING

by Harold V. Hawkins
revised by Ernst K. H. Marburg and Associates

HOISTS, PULLERS, AND WINCHES

Many of the fundamental portable lifting mechanisms such as hoists or pullers (see above) can also be used forcefully to drag or pull materials. In addition, nonmobile versions, called **winches,** utilizing hoisting drums can also be used.

LOCOMOTIVE HAULAGE, COAL MINES

by Burt Garofab

Pittston Corporation

The haulage system of an underground mine is used to transport personnel and material between the face and the portal. It can be subdivided into face haulage and main haulage. The main haulage system extends from the end of the face haulage system to the outside.

Rubber-tired haulage at the coal face was introduced in 1935 and received further impetus with the introduction of the rubber-tired shuttle car in 1938. Crawler-mounted loaders and rubber-tired universal coal cutters completed the equipment needed for complete off-track mining. This off-track mining caused a revolution in face haulage, since it eliminated the expense of laying track in the rooms and advancing the track as the face of the coal advanced. It also made gathering locomotives of the cable-reel, crab-reel, and battery types obsolete. Practically all the gathering duty is now performed by rubber-tired shuttle cars, chain conveyors, extensible belt conveyors, and other methods involving off-track equipment. Some mines eliminated track completely by having belt conveyors carry the coal to the outside.

Most coal mines today utilize a combination of haulage systems. Personnel and supplies are transported by either rail or rubber-tired haulage. Coal is transported by belt or rail, predominantly belt.

Locomotives used in rail haulage may be trolley wire powered, battery powered, or diesel powered. Battery and diesel powered locomotives are commonly used to transport supplies in mines which utilize belt as the main coal haulage system. Trolley-wire-powered locomotives are used when rail is the main coal haulage system. The sleek, streamlined, fast, and easy-riding **Jeffrey** eight-wheel four-motor locomotives are available in 27-, 37-, and 50-short ton (24-, 34-, and 45-tonne) sizes. This type of locomotive has two four-wheel trucks, each having two motors. The trucks, having Pullman or longitudinal-type equalizers with snubbers, will go around a 50 ft (15 m) radius curve, have short overhang, and provide a very easy ride. This construction is easy on the track, with consequent low track-maintenance cost. Speed at full load ranges from 10 to 12.5 mi/h (4.5 to 5.6 m/s), and the maximum safe speed is approximately 30 mi/h (13.4 m/s).

The **eight-wheel locomotive** usually has a box frame; series-wound motors with single-reduction spur gearing; 10 steps of straight parallel, full electropneumatic contactor control; dynamic braking; 32-V battery-operated control and headlights, with the battery charged automatically from the trolley; straight air brakes; air-operated sanders; air horn; automatic couplers; one trolley pole; two headlights at each end; and blowers to ventilate the traction motors. The equipment is located so that it is easily accessible for repair and maintenance.

The eight-wheel type of locomotive has, to a great extent, superseded the tandem type, consisting of two four-wheel two-motor locomotives coupled together and controlled from the cab of one of the units of the tandem.

The older Jeffrey **four-wheel-type locomotive** is available in 11-, 15-, 20-, and 27-short ton (10-, 13.6-, 18-, 24.5-tonne) nominal weights. The 20- and 27-short ton (18- and 24.5-tonne) sizes have electrical equipment very much like that of the eight-wheel-type locomotive. Speeds are also comparable. The 15-short ton (13.6-tonne) locomotive usually has semielectropneumatic contactor control, rather than full electropneumatic control, and dynamic braking but usually does not have the 32-V battery-operated control. The 11-short ton (10-tonne) locomotive has manual control, with manual brakes and sanders, although contactor control, air brakes, blowers, etc., are optional.

Locomotive motors have a horsepower rating on the basis of 1 h at 75°C above an ambient temperature of 40°C. Sizes range from a total of 100 hp (75 kW) for the 11-ton (10-tonne) to a total of 720 hp for the 50-ton.

The following formulas are recommended by the Jeffrey Mining Machinery Co. to **determine the weight of a locomotive** required to haul a load. Table 10.3.1 gives haulage capacities of various weights of locomotives on grades up to 5 percent. The tabulation of haulage capacities shows how drastically the tons of trailing load decrease as the grade increases. For example, a 50-ton locomotive can haul 1,250 tons trailing load on the level but only 167 tons up a 5 percent grade.

The following formulas are based on the use of steel-tired or rolled-steel wheels on clean, dry rail.

Weight of locomotive required on level track:

$$W = L(R + A)/(0.3 \times 2{,}000 - A)$$

Weight of locomotive required to haul train up the grade:

$$W = L(R + G)/(0.25 \times 2{,}000 - G)$$

Weight of locomotive necessary to start train on the grade:

$$W = L(R + G + A)/(0.30 \times 2{,}000 - G - A)$$

where W is the weight in tons of locomotive required; R is the frictional resistance of the cars in pounds per ton and is taken as 20 lb for cars with antifriction bearings and 30 lb for plain-bearing cars; L is the weight of the load in tons; A is the acceleration resistance [this is 100 for 1 mi/(h · s) and is usually taken at 20 for less than 10 mi/h or at 30 from 10 to 12 mi/h, corresponding to an acceleration of 0.2 or 0.3 mi/(h · s)]; G is the grade resistance in pounds per ton or 20 lb/ton for each percent of grade (25 percent is the running adhesion of the locomotive, 30 percent is the starting adhesion using sand); 2,000 is the factor to give adhesion in pounds per ton.

Where the grade is in favor of the load:

$$W = L(G - R)/(0.20 \times 2{,}000 - G)$$

To brake the train to a stop on grade:

$$W = L(G + B - R)/(0.20 \times 2{,}000 - G - B)$$

where B is the braking (or decelerating) effort in pounds per ton and equals 100 lb/ton for a braking rate of 1 mi/(h · s) or 20 lb/ton for a braking rate of 0.2 mi/(h · s) or 30 lb for a braking rate of 0.3 mi/(h · s). The adhesion is taken from a safety standpoint as 20 percent. It is not advisable to rely on using sand to increase the adhesion, since the sandboxes may be empty when sand is needed.

Time in seconds to brake the train to stop:

$$\text{s} = \frac{\text{mi/h (start)} - \text{mi/h (finish)}}{\text{deceleration in mi/(h}\cdot\text{s)}}$$

Distance in feet to brake the train to a stop:

$$\text{ft} = [\text{mi/h (start)} - \text{mi/h (finish)}] \times \text{s} \times 1.46/2$$

Storage-battery locomotives are used for hauling muck cars in tunnel construction where it is inconvenient to install trolley wires and bond the track as the tunnel advances. They are also used to some extent in metal mines and in mines of countries where trolley locomotives are not permitted. They are often used in coal mines in the United States for hauling supplies. Their first cost is frequently less than that for a trolley installation. They also possess many of the advantages of the trolley locomotive and eliminate the danger and obstruction of the trolley wire. Storage-battery locomotives are limited by the energy that is stored in the battery and should not be used on steep grades or where large, continuous overloads are required. Best results are obtained where light

Table 10.3.1 Haulage Capacities of Locomotives with Steel-Tired or Rolled-Steel Wheels*

		Weight of locomotive, tons†					
Grade		11	15	20	27	37	50
Level	Drawbar pull, lb	5,500	7,500	10,000	13,500	18,500	25,000
	Haulage capacity, gross tons	275	375	500	675	925	1,250
1%	Drawbar pull, lb	5,280	7,200	9,600	12,960	17,760	24,000
	Haulage capacity, gross tons	132	180	240	324	444	600
2%	Drawbar pull, lb	5,260	6,900	9,200	12,420	17,020	23,000
	Haulage capacity, gross tons	88	115	153	207	284	384
3%	Drawbar pull, lb	4,840	6,600	8,800	11,880	16,280	22,000
	Haulage capacity, gross tons	67	82	110	149	204	275
4%	Drawbar pull, lb	4,620	6,300	8,400	11,340	15,540	21,000
	Haulage capacity, gross tons	46	63	84	113	155	210
5%	Drawbar pull, lb	4,400	6,000	8,000	10,800	14,800	20,000
	Haulage capacity, gross tons	31	50	67	90	123	167

* Jeffrey Mining Machinery Co.

† Haulage capacities are based on 20 lb/ton rolling friction, which is conservative for roller-bearing cars. Multiply lb by 0.45 to get kg and tons by 0.91 to get tonnes.

and medium loads are to be handled intermittently over short distances with a grade of not over 3 percent against the load.

The general construction and mechanical features are similar to those of the four-wheel trolley type, with battery boxes located either on top of the locomotive or between the side frames, according to the height available. The motors are rugged, with high efficiency. Storage-battery locomotives for coal mines are generally of the explosion-tested type approved by the Bureau of Mines for use in gaseous mines.

The **battery** usually has sufficient capacity to last a single shift. For two- or three-shift operation, an extra battery box with battery is required so that one battery can be charging while the other is working on the locomotive. Motor-generator sets or rectifiers are used for charging the batteries. The overall efficiency of the battery, motor, and gearing is approximately 63 percent. The speed varies from 3 to 7 mi/h, the average being 3½ to 4½ mi/h. Battery locomotives are available in sizes from 2 to 50 tons. They are usually manufactured to suit individual requirements, since the sizes of motors and battery are determined by the amount of work that the locomotive has to do in an 8-h shift.

INDUSTRIAL CARS

Various types of narrow-gage industrial cars are used for handling bulk and package materials inside and outside of buildings. Those used for bulk material are usually of the dumping type, the form of the car being determined by the duty. They are either pushed by workers or drawn by mules, locomotives, or cable. The **rocker side-dump car** (Fig. 10.3.1) consists of a truck on which is mounted a V-shaped steel body supported on rockers so that it can be tipped to either side, discharging material. This type is mainly used on construction work. Capacities vary from ⅔ to 5 tons for track gages of 18, 20, 24, 30, 36, and 56½ in. In the **gable-bottom car** (Fig. 10.3.2), the side doors *a* are hinged at the top and controlled by levers *b* and *c*, which lock the doors when closed. Since this type of car discharges material close to the ground on both sides of the track simultaneously, it is used mainly on trestles. Capacities vary from 29 to 270 ft^3 for track gages of 24, 36, 40, and 50 in. The **scoop dumping car** (Fig. 10.3.3) consists of a scoop-shaped steel body pivoted at *a* on turntable *b*, which is carried by the truck. The latch *c* holds the body in a horizontal position, being released by chain *d* attached to handle *e*. Since the body is mounted on a turntable, the car is used for service where it is desirable to discharge material at any point in the circle. This car is made with capacities from 12 to 27 ft^3 to suit local requirements. The **hopper-bottom car** (Fig. 10.3.4) consists of a hopper on wheels, the bottom opening being controlled by door *a*, which is operated by chain *b* winding on shaft *c*. The shaft is provided with handwheel and ratchet and pawl. The type of door or gate controlling the bottom opening varies with different materials.

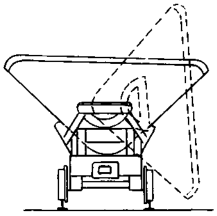


Fig. 10.3.1 Rocker side-dump car.

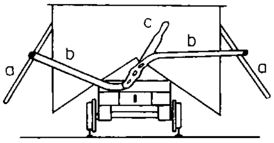


Fig. 10.3.2 Gable-bottom car.

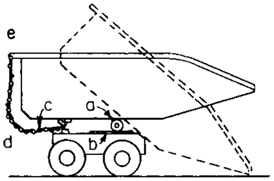


Fig. 10.3.3 Scoop dumping car.

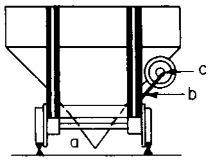


Fig. 10.3.4 Hopper-bottom car.

The **box-body dump car** (Fig. 10.3.5) consists of a rectangular body pivoted on the trucks at *a* and held in horizontal position by chains *b*. The side doors of the car are attached to levers so that the door is automatically raised when the body of the car is tilted to its dumping position. The cars can be dumped to either side. On the large sizes, where rapid dumping is required, dumping is accomplished by compressed air. This type of car is primarily used in excavation and quarry work, being loaded by power shovels. The greater load is placed on the side on which the car will dump, so that dumping is automatic when the operator releases the chain or latch. The car bodies may be steel or steel-lined wood. **Mine cars** are usually of the four-wheel type, with low bodies, the doors being at one end, and pivoted at the top with latch at the bottom. Industrial **tracks** are made with rails from 12 to 45 lb/yd (6.0 to 22 kg/m) and gages from 24 in to 4 ft 8½ in (0.6 to 1.44 m). Either steel or wooden ties are used. Owing to its lighter weight, the steel tie is preferred where tracks are frequently moved, the track being made up in sections. Industrial cars are frequently built with one wheel attached to the axle and the other wheel loose to enable the car to turn on short-radius tracks. Capacities vary from 4 to 50 yd^3 (3.1 to 38 m^3) for track gages of 36 to 56½ in (0.9 to 1.44 m), with cars having weights from 6,900 to 80,300 lb (3,100 to 36,000 kg). The frictional resistance per ton (2,000 lb) (8,900 N) for different types of mine-car bearings are given in Table 10.3.2.

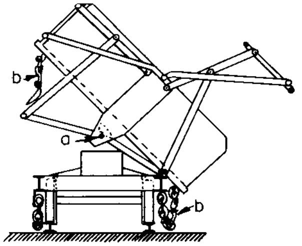


Fig. 10.3.5 Box-body dump car.

Table 10.3.2 Frictional Resistance of Mine Car Bearings

	Drawbar pull					
	Level track		2% grade		4% grade	
Types of bearings	lb/short ton	N/tonne	lb/short ton	N/tonne	lb/short ton	N/tonne
Spiral roller	13	58	15	67	46	205
Solid roller	14	62	18	80	53	236
Self-oiling	22	98	31	138		
Babbitted, old style	24	107	40	178		

DOZERS, DRAGLINES

The dual capability of some equipment, such as **dozers** and **draglines,** suggests that it should be mentioned as prime machinery in the area of materials handling by dragging, pulling, or pushing. Dozers are described in the discussion on earthmoving equipment since their basic frames are also used for power shovels and backhoes. In addition, dozers perform the auxiliary function of pushing carryall earthmovers to assist them in scraping up their load. Dragline equipment is discussed with below-surface handling or excavation. The same type of equipment that would drag or scrape may also have a lifting function.

MOVING SIDEWALKS

Moving horizontal belts with synchronized balustrading have been introduced to expedite the movement of passengers to or from railroad trains in depots or planes at airports (see belt conveyors). A necessary feature is the need to prevent the clothing of anyone (e.g., a child) sitting on the moving walk from being caught in the mechanism at the end of the walk. Use of a comblike stationary end fence protruding down into longitudinal slots in the belt is an effective preventive.

CAR-UNLOADING MACHINERY

Four types of devices are in common use for unloading material from all types of open-top cars: crossover and horn dumps, used to unload mine cars with swinging end doors; rotary car dumps, for mine cars without doors; and tipping car dumps, for unloading standard-gage cars where large unloading capacity is required.

Crossover Dump Figure 10.3.6 shows a car in the act of dumping. Figure 10.3.7 shows a loaded car pushing an empty car off the dump. A section of track is carried by a platform supported on rockers *a*. An extension bar *b* carries the weight *c* and the brake friction bar *d*. A hand lever controls the brake, acting on the friction bar and placing the dumping under the control of the operator. A section of track *e* in front of the dump is pivoted on a parallel motion and counterbalanced so that it is normally raised. The loaded car depresses the rails *e* and, through levers, pivots the horns *f* around the shafts *g*, releasing the empty car. The loaded car strikes the empty car, starting it down the inclined track. After the loaded car has passed the rails *e*, the springs return the horns *f* so that they stop the loaded car in the position to dump. Buffer springs on the shaft *g* absorb the shock of stopping the car. Since the center of gravity of the loaded car is forward of the rockers, the car will dump automatically under control of the brake. No power is required for this dump, and one operator can dump three or four cars per minute.

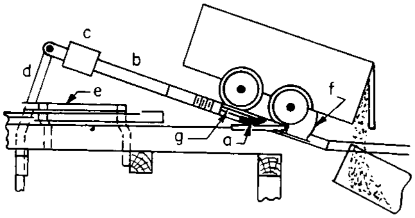


Fig. 10.3.6 Crossover dump: car unloading.

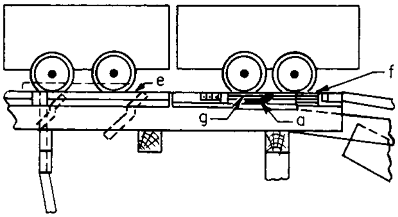


Fig. 10.3.7 Crossover dump: empty car being pushed away.

der supported by a shaft *a*, its three compartments carrying three tracks. The loaded car *b* is to one side of the center and causes the cylinder to rotate, the material rolling to the chute beneath. The band brake *c*, with counterweight *d*, is operated by lever *e*, putting the dumping under control of the operator. No power is required; one operator can dump two or three cars per minute.

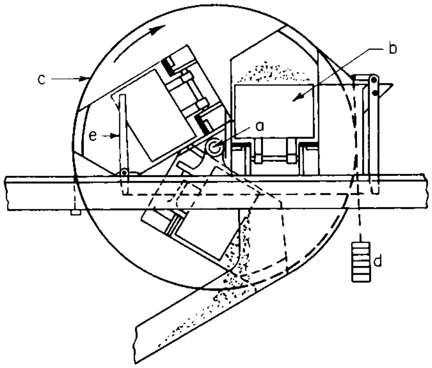


Fig. 10.3.8 Rotary gravity dump.

Rotary-power dumpers are also built to take any size of open-top railroad car and are frequently used in power plants, coke plants, ports, and ore mines to dump coal, coke, ore, bauxite, and other bulk material. They are mainly of two types: (1) single barrel, and (2) tandem.

The McDowell-Wellman Engineering Co. dumper consists of a revolving cradle supporting a platen (with rails in line with the approach and runoff car tracks in the upright position), which carries the car to be dumped. A blocking on the dumping side supports the side of the car as the cradle starts rotating. Normally, the platen is movable and the blocking is fixed, but in some cases the platen is fixed and the blocking movable. Where there is no variation in the car size, the platen and blocking are both fixed. The cradle is supported on two end rings, which are bound with a rail and a gear rack. The rail makes contact with rollers mounted in sills resting on the foundation. Power through the motor rotates the cradle by means of two pinions meshing with the gear racks. The angle of rotation for a complete dump is 155° for a normal operation, but occasionally, a dumper is designed for 180° rotation. The clamps, supported by the cradle, start moving down as the dumper starts to rotate. These clamps are lowered, locked, released, and raised either by a gravity-powered mechanism or by hydraulic cylinders.

With the advent of the **unit-train system,** the investment and operating costs for a dumper have been reduced considerably. The design of dumpers for unit train has improved and results in fewer maintenance problems. The use of rotary couplers on unit train eliminates uncoupling of cars while dumping because the center of the rotary coupler is in line with the center of rotation of the dumper.

Car Shakers As alternatives to rotating or tilting the car, several types of car shakers are used to hasten the discharge of the load. Usually the shaker is a heavy yoke equipped with an unbalanced pulley rotated at 2,000 r/min by a 20-hp (15-kW) motor. The yoke rests upon the car top sides, and the load is actively vibrated and rapidly discharged. While a car shaker provides a discharge rate about half that of a rotary dumper, the smaller investment is advantageous.

Car Positioner As the popularity of unit-train systems consisting of rail cars connected by rotary couplers has increased, more rotary dumping stations have been equipped with an automatic train positioner developed by McDowell-Wellman Engineering Company. This device consists of a carriage moving parallel to the railroad track actuated by either hydraulic cylinders or wire rope driven by a winch, which carries an arm that rotates in a vertical plane to engage the coupling between the cars. The machines are available in many sizes, the largest of which are capable of indexing 200-car trains in one- or two-car increments through the rotary dumper. These machines or similar ones are also available from FMC/Materials Handling System Division, Heyl and

10.4 LOADING, CARRYING, AND EXCAVATING

by Ernst K. H. Marburg

CONTAINERIZATION

The proper packaging of material to assist in handling can significantly minimize the handling cost and can also have a marked influence on the type of handling equipment employed. For example, partial carload lots of liquid or granular material may be shipped in rigid or nonrigid containers equipped with proper lugs to facilitate in-transit handling. Heavy-duty rubberized containers that are inert to most cargo are available for repeated use in shipping partial carloads. The nonrigid container reduces return shipping costs, since it can be collapsed to reduce space. Disposable light-weight corrugated-cardboard shipping containers for small and medium-sized packages both protect the cargo and permit stacking to economize on space requirements. The type of container to be used should be planned or considered when the handling mechanism is selected.

SURFACE HANDLING

by Colin K. Larsen

Blue Giant Equipment Co.

Lift Trucks and Palletized Loads

The basis of all efficient handling, storage, and movement of unitized goods is the cube concept. Building a cube enables a large quantity of unit goods to be handled and stored at one time. This provides greater efficiency by increasing the volume of goods movement for a given amount of work. Examples of cube-facilitating devices include pallets, skids, slip sheets, bins, drums, and crates.

The most widely applied cube device is the pallet. A **pallet** is a low platform, usually constructed of wood, incorporating openings for the forks of a lift truck to enter. Such openings are designed to enable a lift truck to pick up and transport the pallet containing the cubed goods.

Lift truck is a loose term for a family of pallet handling/transporting machines. Such machines range from manually propelled low-lift devices (Fig. 10.4.1) to internal combustion and electric powered ride-on high-lift devices (Fig. 10.4.2). While some machines are substitutes in terms of function, each serves its own niche when viewed in terms of individual budgets and applications.

Pallet trucks are low-lift machines designed to raise loaded pallets sufficiently off the ground to enable the truck to transport the pallet horizontally. Pallet trucks are available as manually operated and propelled models that incorporate a hydraulic pump and handle assembly (Fig. 10.4.1). This pump and handle assembly enables the operator to raise the truck forks, and push/pull the load. Standard manual pallet trucks are available in lifting capacities from 4,500 to 5,500 lb (2,045 to 2,500 kg), with customer manufactured models to 8,000 lb (3,636 kg). While available in a variety of fork sizes, by far the most common is 27 in wide × 48 in long (686 mm × 1,219 mm). This size accommodates the most common pallet sizes of 40 in × 48 in (1,016 mm × 1,219 mm) and 48 in × 48 in (1,219 mm × 1,219 mm). Pallet trucks are also available in motorized versions, equipped with dc electric motors to electrically raise and transport. The power supply for these trucks is an on-board lead-acid traction battery that is rechargeable when the truck is not in use. Control of these trucks is through a set of lift, lower, speed, and direction controls fitted into the steering handle assembly. Powered pallet trucks are available in walk and ride models. Capacities range from 4,000 to 10,000 lb (1,818 to 4,545 kg), with forks up to 96 in (2,438 mm) long. The longer fork models are designed to allow the truck to transport two pallets, lined up end to end.

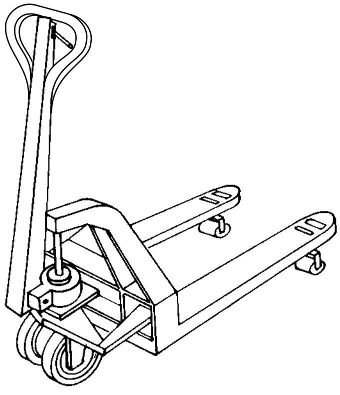


Fig. 10.4.1 Manually operated and propelled pallet truck.

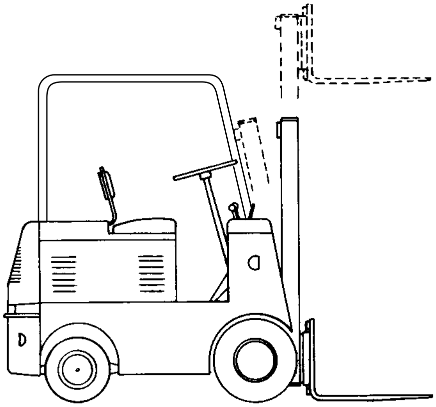


Fig. 10.4.2 Lift truck powered by an internal-combustion engine.

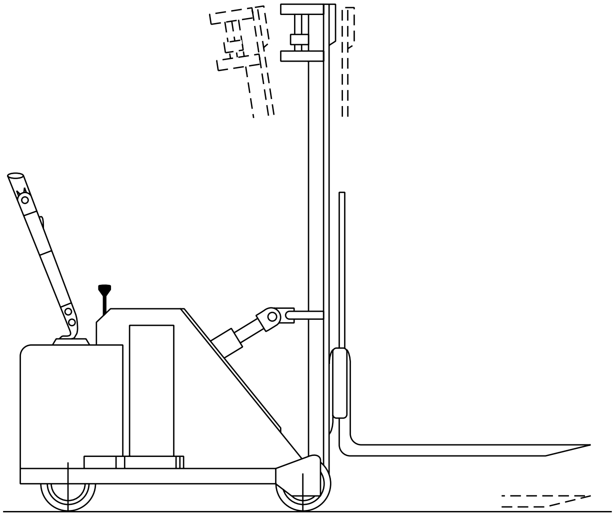


Fig. 10.4.3 Counterbalanced electric-battery-powered pallet truck. *(Blue Giant.)*

Stackers, as the name implies, are high lift machines designed to raise and stack loaded pallets in addition to providing horizontal transportation. Stackers are separated into two classes: straddle and counterbalanced. **Straddle stackers** are equipped with legs which straddle the pallet and provide load and truck stability. The use of the straddle leg system results in a very compact chassis which requires minimal aisle space for turning. This design, however, does have its trade-offs insomuch as the straddles limit the truck's usage to smooth level floors. The limited leg underclearance inherent in these machines prohibits their use on dock levelers for loading/unloading transport trucks. Straddle stackers are available from 1,000 to 4,000 lb (455 to 1,818 kg) capacity with lift heights to 16 ft (4,877 mm). **Counterbalanced stackers** utilize a counterweight system in lieu of straddle legs for load and vehicle stability (Fig. 10.4.3). The absence of straddle legs results in a chassis with increased underclearance which can be used on ramps, including dock levelers. The counterbalanced chassis, however, is longer than its straddle counterpart, and this requires greater aisle space for maneuvering. For materials handling operations that require one machine to perform a multitude of tasks, and are flexible in floor layout of storage areas, the counterbalanced stacker is the recommended machine.

Off-Highway Vehicles and Earthmoving Equipment

by Darrold E. Roen, John Deere and Co.

The movement of large quantities of bulk materials, earth, gravel, and broken rock in road building, mining, construction, quarrying, and land clearing may be handled by **off-highway vehicles**. Such vehicles are mounted on large pneumatic tires or on crawler tracks if heavy pulling and pushing are required on poor or steep terrain. Width and weight of the rubber-tired equipment often exceed highway legal limits, and use of grouser tracks on highways is prohibited. A wide range of working tool attachments, which can be added (and removed) without modification to the basic machine, are available to enhance the efficiency and versatility of the equipment.

Proper selection of size and type of equipment depends on the amount, kind, and density of the material to be moved in a specified time and on the distances, direction, and steepness of grades, footing for traction, and altitude above sea level. Time cycles and pay loads for production per hour can then be estimated from manufacturers' performance data and job experience. This production per hour, together with the corresponding owning, operating, and labor costs per hour, enables selection by favorable cost per cubic yard, ton, or other pay unit.

Current rapid progress in the development of off-highway equipment will soon make any description of size, power, and productivity obsolete. However, the following brief description of major off-highway vehicles will serve as a guide to their applications.

Crawler Tractors These are track-type prime movers for use with mounted bulldozers, rippers, winches, cranes, cable layers, and side booms rated by net engine horsepower in sizes from 40 to over 500 hp; maximum traveling speeds, 5 to 7 mi/h (8 to 11 km/h). Crawler tractors develop drawbar pulls up to 90 percent or more of their weight with mounted equipment.

Wheel Tractors Sizes range from rubber-tired industrial tractors for small scoops, loaders, and backhoes to large, diesel-powered, two- and four-wheel drive pneumatic-tired prime movers for propelling scrapers and wagons. Large, four-wheel-drive, articulated-steering types also power bulldozers.

Bulldozer—Crawler Type (Fig. 10.4.4) This is a crawler tractor with a front-mounted blade, which is lifted by hydraulic or cable power control. There are four basic types of moldboards: straight, semi-U and U (named by top-view shape), and angling. The angling type, often called **bullgrader** or **angledozer,** can be set for side casting 25° to the right or left of perpendicular to the tractor centerline, while the other blades can be tipped forward or back through about 10° for different digging conditions. All blades can be tilted for ditching, with hydraulic-power tilt available for all blades.

APPLICATION. This is the best machine for pioneering access roads, for boulder and tree removal, and for short-haul earthmoving in rough terrain. It push-loads self-propelled scrapers and is often used with a rear-mounted ripper to loosen firm or hard materials, including rock, for scraper loading. U blades drift 15 to 20 percent more loose material than straight blades but have poor digging ability. Angling blades expedite sidehill benching and backfilling of trenches. Loose-material capacity of straight blades varies approximately as the blade height squared, multiplied by length. Average capacity of digging blades is about 1 yd^3 loose measure per 30 *net* hp rating of the crawler tractor. Payload is 60 to 90 percent of loose measure, depending on material swell variations.

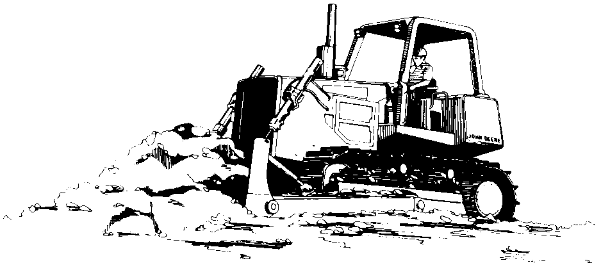


Fig. 10.4.4 Crawler tractor with dozer blade. *(John Deere.)*

Bulldozer—Wheel Type This is a four-wheel-drive, rubber-tired tractor, generally of the hydraulic articulated-steering type, with front-mounted blade that can be hydraulically raised, lowered, tipped, and tilted. Its operating weights range to 150,000 lb, with up to 700 hp, and its traveling speeds range from stall to about 20 mi/h for pushing and mobility.

APPLICATION. It is excellent for push-loading self-propelled scrapers, for grading the cut, spreading and compacting the fill, and for drifting loose materials on firm or sandy ground for distances up to 500 ft. Useful tractive effort on firm earth surfaces is limited to about 60 percent of weight, as compared with 90 percent for crawler dozers.

Loader—Crawler Type (Fig. 10.4.5) This is a track-type prime mover with front-mounted bucket that can be raised, dumped, lowered, and tipped by power control. Capacities range from 0.7 to 5.0 yd^3 (0.5 to 3.8 m^3), SAE rated. It is also available with grapples for pulpwood, logs, and lumber.

Fig. 10.4.5 Crawler tractor with loader bucket. *(John Deere.)*

APPLICATION. It is used for digging basements, pools, ponds, and ditches; for loading trucks and hoppers; for placing, spreading, and compacting earth over garbage in sanitary fills; for stripping sod; for removing steel-mill slag; and for carrying and loading pulpwood and logs.

Loader—Wheel Type (Fig. 10.4.6) This is a four-wheel, rubber-tired, articulated-steer machine equipped with a front-mounted, hydraulic-powered bucket and loader linkage that loads material into the bucket through forward motion of the machine and which lifts, transports, and discharges the material. The machine is commonly referred to as a *four-wheel-drive loader tractor.* Bucket sizes range from ½ yd^3 (0.4 m^3) to more than 20 yd^3 (15 m^3), SAE rated capacity. The addition of a quick coupler to the loader linkage permits convenient interchange of buckets and other working tool attachments, adding versatility to the loader. Rigid-frame machines with variations and combinations of front/rear/skid steer, front/rear drive, and front/rear engine are also used in various applications.

Fig. 10.4.6 Four-wheel-drive loader. *(John Deere.)*

Application. Four-wheel-drive loaders are used primarily in construction, aggregate, and utility industries. Typical operations include truck loading, filling hoppers, trenching and backfilling, land clearing, and snow removal.

Backhoe Loader (Fig. 10.4.7) This is a self-propelled, highly mobile machine with a main frame to support and accommodate both the rear-mounted backhoe and front-mounted loader. The machine was designed with the intention that the backhoe will normally remain in place when the machine is being used as a loader and vice versa. The backhoe digs, lifts, swings, and discharges material while the machine is stationary. When used in the loader mode, the machine loads material into the bucket through forward motion of the machine and lifts, transports, and discharges the material. Backhoe loaders are categorized according to digging depth of the backhoe. Backhoe loader types include variations of front/rear/articulated and all-wheel steer and rear/four-wheel drive.

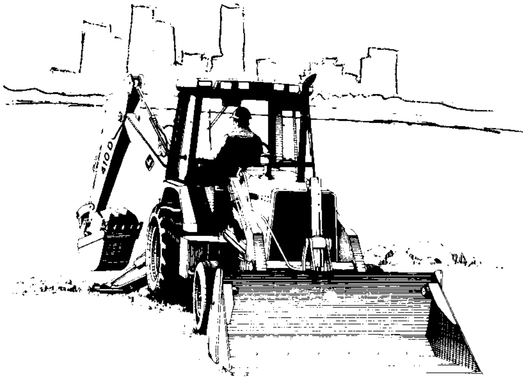


Fig. 10.4.7 Backhoe loader. *(John Deere.)*

Application. Backhoe loaders are used primarily for trenching and backfilling operations in the construction and utility industries. Quick couplers for the loader and backhoe are available which quickly interchange the working tool attachments, thus expanding machine capabilities. Backhoe loader mobility allows the unit to be driven to nearby job sites, thus minimizing the need to load and haul the machine.

Scrapers (Fig. 10.4.8) This is a self-propelled machine, having a cutting edge positioned between the front and rear axles which loads, transports, discharges, and spreads material. Tractor scrapers include open-bowl and self-loading types, with multiple steer and drive axle variations. Scraper rear wheels may also be driven by a separate rear-mounted engine which minimizes the need for a push tractor. Scraper ratings are provided in cubic yard struck/heaped capacities. Payload capacities depend on loadability and swell of materials but approximate the struck capacity. Crawler tractor-drawn, four-wheel rubber-tired scrapers have traditionally been used in a similar manner—normally in situations with shorter haul distances or under tractive and terrain conditions that are unsuitable for faster, self-propelled scrapers.

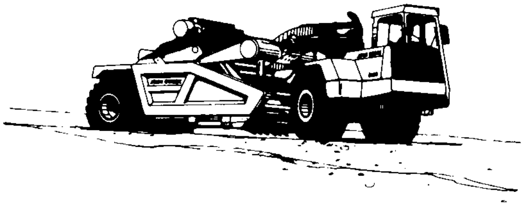


Fig. 10.4.8 Two-axle articulated self-propelled elevating scraper. *(John Deere.)*

Application. Scrapers are used for high-speed earth moving, primarily in road building and other construction work where there is a need to move larger volumes of material relatively short distances. The convenient control of the cutting edge height allows for accurate control of the grade in either a cut or fill mode. The loaded weight of the scraper can contribute to compaction of fill material. All-wheel-drive units can also load each other through a push-pull type of attachment. Two-axle, four-wheel types have the best maneuverability; however, the three-axle type is sometimes preferred for operator comfort on longer, higher-speed hauls.

Motor Grader (Fig. 10.4.9) This is a six-wheel, articulated-frame self-propelled machine characterized by a long wheelbase and mid-mounted blade. The blade can be hydraulically positioned by rotation about a vertical axis—pitching fore/aft, shifting laterally, and independently raising each end—in the work process of cutting, moving, and spreading material, to rough- or finish-grade requirements. Motor graders range in size to 60,000 lb (27,000 kg) and 275 hp (205 kW) with typical transport speeds in the 25-mi/h (40-km/h) range. Rigid-frame machines with various combinations of four/six wheels, two/four-wheel drive, front/rear-wheel steer are used as dictated by the operating requirements.

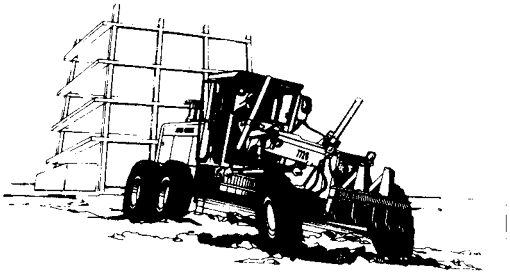


Fig. 10.4.9 Six-wheel articulated-frame motor grader. *(John Deere.)*

Application. Motor graders are the machine of choice for building paved and unpaved roads. The long wheelbase in conjunction with the midmounted blade and precise hydraulic controls allows the unit to finish-grade road beds within 0.25 in (6 mm) prior to paving. The weight, power, and blade maneuverability enable the unit to perform all the necessary work, including creating the initial road shape, cutting the ditches, finishing the bank slopes, and spreading the gravel. The motor grader is also a cost-effective and vital part of any road maintenance fleet.

Table 10.4.1 Typical Monorail Trolley Dimensions

Capacity, short tons	I-beam range (depth), in	Wheel-tread diam, in	Net weight, lb	*B*,* in	*C*, in	*H*, in	*M*, in	*N*, in	Min beam radius,* in
½	5–10	3½	32	3¼	4⅛	9⅞	2⅜	6¼	21
1	5–10	3½	32	3¼	4⅛	9⅞	2⅜	6¼	21
1½	6–10	4	52	3⅞	4⅝	11⅜	$2\frac{15}{16}$	$7\frac{7}{16}$	30
2	6–10	4	52	3⅞	4⅝	11⅜	$2\frac{15}{16}$	$7\frac{7}{16}$	30
3	8–15	5	88	$4\frac{7}{16}$	5⅜	13½	$2\frac{13}{16}$	$7\frac{15}{16}$	42
4	8–15	5	88	$4\frac{7}{16}$	5⅜	13½	$2\frac{13}{16}$	$7\frac{15}{16}$	42
5	10–18	6	137	$5\frac{3}{16}$	$6\frac{3}{16}$	15⅜	$3\frac{5}{16}$	10⅛	48
6	10–18	6	137	$5\frac{3}{16}$	$6\frac{3}{16}$	15⅜	$3\frac{5}{16}$	10⅛	48
8	12–24	8	279	5½	$7\frac{7}{16}$	21⅜	$4\frac{3}{16}$	13¾	60
10	12–24	8	279	5½	$7\frac{7}{16}$	21⅜	$4\frac{3}{16}$	13¾	60

Metric values, multiply tons by 907 for kg, inches by 25.4 for mm, and lb by 0.45 for kg.
* These dimensions are given for minimum beam.
SOURCE: CM Hoist Division, Columbus McKinnon.

Excavator (Fig. 10.4.10) This is a mobile machine which is propelled by either crawler track or rubber-tired undercarriage, with the unique feature being an upper structure that is capable of continuous rotation and a wide working range. The unit digs, elevates, swings, and dumps material by action of the boom, arm, or telescoping boom and bucket. Excavators include the hoe type (digging tool cuts toward the machine and generally downward) and the shovel type (digging tool cuts away from the machine and generally upward). Weight of the machines ranges from 17,600 lb (8 tonnes) to 1,378,000 lb (626 tonnes) with power ratings from 65 to 3644 hp (48.5 to 2719 kW).

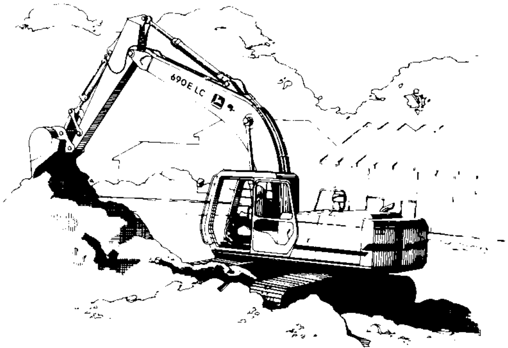


Fig. 10.4.10 Excavator with tracked undercarriage. *(John Deere.)*

APPLICATION. The typical attachment for the unit is the bucket, which is used for trenching in the placement of pipe and other underground utilities, digging basements or water retention ponds, maintaining slopes, and mass excavation. Other specialized attachments include hydraulic hammers and compactors, thumbs, clamshells, grapples, and long-reach front ends which expand the capabilities of the excavator.

Dumpers A dumper is a self-propelled machine, having an open cargo body, which is designed to transport and dump or spread material. Loading is accomplished by means external to the dumper. Types are generally categorized into rear, side, or bottom dump with multiple variations of front/articulated steer, two to five axles, and front/rear/center/multiaxle drive.

APPLICATION. Dumpers are used for hauling and dumping blasted rock, ore, earth, sand, gravel, coal, and other hard and abrasive materials in road and dam construction and in quarries and mines. The units are capable of 30 to 40 mi/h (50 to 65 km/h) when loaded (depending on terrain/slopes), which makes the dumper an excellent choice for longer haul distances.

Owning and Operating Costs These include depreciation; interest, insurance, taxes; parts, labor, repairs, and tires; fuel, lubricant, filters, hydraulic-system oil, and other operating supplies. This is reduced to cost per hour over a service life of 4 to 6 years of 2,000 h each—average 5 years, 10,000 h. Owning and operating costs of diesel-powered bulldozers and scrapers, excluding operator's wages, average 3 to 4 times the delivered price in 10,000 h.

ABOVE-SURFACE HANDLING

Monorails

Materials can be carried on light, rigid trackage, as described for overhead conveyors (see below). Trolleys are supported by structural I beams, H beams, or I-beam-like rails with special flat flanges to improve rolling characteristics of the wheels. Size of wheels and smoothness of tread are important in reducing rolling resistance. Figure 10.4.11 shows a typical rigid trolley for traversing short-radius track curves. Typical dimensions for both types are given in Table 10.4.1. These trolleys may be plain, with geared handwheel and hand chain, or motor-drive. For very low headroom, the trolley can be built into the hoist; this is known as a **trolley hoist**.

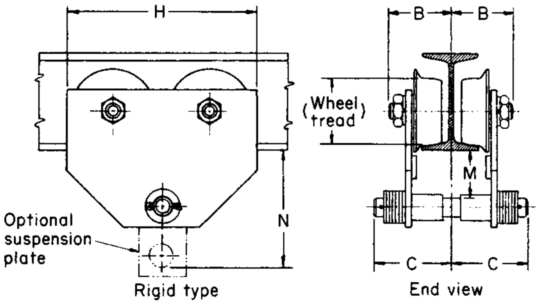


Fig. 10.4.11 Monorail trolley. *(CM Hoist Division, Columbus McKinnon.)*

Overhead Traveling Cranes

by Alger Anderson, Lift-Tech International, Inc.

An **overhead traveling crane** is a vehicle for lifting, transporting, and lowering loads. It consists of a bridge supporting a hoisting unit and is equipped with wheels for operating on an elevated runway or track. The hoisting unit may be fixed relative to the bridge but is usually supported on wheels, permitting it to traverse the length of the bridge.

The motions of the crane—hoisting, trolley traversing, and bridging — may be powered by hand, electricity, air, hydraulics, or a combination of these. Hand-powered cranes are generally built in capacities under 50 tons (45 tonnes) and are used for infrequent service where slow speeds are acceptable. Pneumatic cranes are used where electricity would be hazardous or where advantage can be taken of existing air supply. Electric cranes are the most common overhead type and can be built to capacities of 500 tons (454 tonnes) or more and to spans of 150 ft (46 m) and over.

Single-Girder Cranes (Fig. 10.4.12) In its simplest form, this consists of an I beam *a* supported by four wheels *b*. The trolley *c* traveling on the lower flanges carries the chain hoist, forming the lifting unit. The crane is moved by hand chain *d* turning sprocket wheel *e*, which is keyed to shaft *f*. The pinions on shaft *f* mesh with gears *g*, keyed to the axles of two wheels. An underslung construction may also be used, with pairs of wheels at each corner which ride on the lower flange of I-beam rails. Single-girder cranes may be hand-powered by pendant hand chains or electric-powered as controlled by a pendant push-button station.

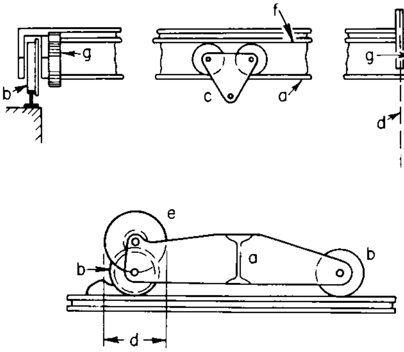


Fig. 10.4.12 Hand-powered crane.

Electric Traveling Crane, Double-Girder Type (Fig. 10.4.13) This consists of two bridge girders *a*, on the top of which are rails on which travels the self-contained hoisting unit *b*, called the trolley. The girders are supported at the ends by trucks with two or four wheels, according to the size of the crane. The crane is moved along the track by motor *c*, through shaft *d* and gearing to the truck wheels. Suspended from the girders on one side is the operator's cab *e*, containing the controller, or master switches, master hydraulic brake cylinder, warning device, etc. The bridge girders for small cranes are of the I-beam type, but on the longer spans, box girders are used to give torsional and lateral stiffness. The girders are rigidly attached to the truck end framing, which carries the double-flanged wheels for supporting the bridge. The end frames project over the rails so that in case of a broken wheel or axle, the frame will rest on the rail, preventing the crane from dropping. One wheel axle on each truck is fitted with gears for driving the crane or is coupled directly to the shaft which transmits power from the gear reducer. On a cab-operated bridge, a brake, usually hydraulic, is applied to the motor shaft to stop the crane. Floor-operated cranes generally utilize spring engaged, electrically released brakes.

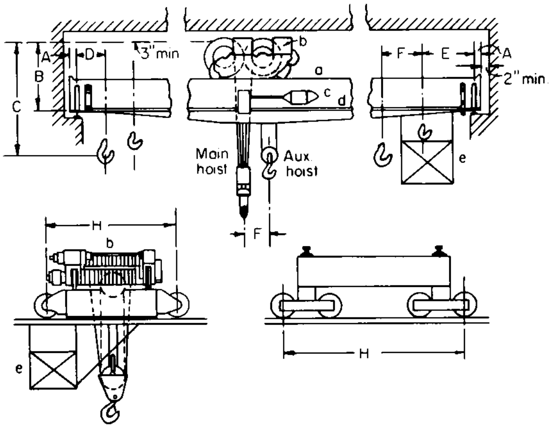


Fig. 10.4.13 Electric traveling crane.

The trolley consists of a frame which carries the hoisting machinery and is supported on wheels for movement along the bridge rails. The wheels are coupled to the trolley traverse motor through suitable gear reduction. Trolleys are frequently equipped with a second set of hoisting machinery to provide dual lifting means or an auxiliary of smaller capacity. The hoisting machinery consists of motor, motor brake, load brake, gear reduction, and rope drum. Wire rope winding in helical grooves on the drum is reeved over sheaves in the upper block and lower hook block for additional mechanical advantage. Limit switches are provided to stop the motors when limits of travel are reached. Current is brought to the crane by sliding or rolling collectors in contact with conductors attached to or parallel with the runway and preferably located at the cab end of the crane. Current from the runway conductors and cab is carried to the trolley in a like manner from conductors mounted parallel to the bridge girder. Festooned multiconductor cables are also used to supply current to crane or trolley.

Electric cranes are built for either alternating or direct current, with the former predominating. The motors for both kinds of current are designed particularly for crane service. Direct-current motors are usually series-wound, and ac motors are generally of the wound-rotor or two-speed squirrel-cage type. The usual ac voltages are 230 and 460, the most common being 460. Variable-frequency drives (VFDs) are used with ac squirrel cage motors to provide precise control of the load over a wide range of speeds. Cranes and hoists equipped with VFDs are capable of delicate positioning and swift acceleration of loads to the maximum speed. Standard, inexpensive squirrel cage motors may be used with VFDs to provide high-performance control of all crane motions. The **capacities** and other dimensions for standard electric cranes are given in Table 10.4.2.

Gantry Cranes

Gantry cranes are modifications of traveling cranes and are generally used outdoors where it is not convenient to erect on overhead runway. The bridge (Fig. 10.4.14) is carried at the ends by the legs *a*, supported by trucks with wheels so that the crane can travel. As with the traveling crane, the bridge carries a hoisting unit; a cover to protect the machinery from the weather is often used. The crane is driven by motor *b* through a gear reduction to shaft *c*, which drives the vertical shafts *d* through bevel gears. Bevel- and spur-gear reductions connect the axles of the wheels with shafts *d*. Many gantry cranes are built without the cross shaft, employing separate motors, brakes, and gear reducers at each end of the crane. Gantry cranes are made in the same sizes as standard traveling cranes.

Special-Purpose Overhead Traveling Cranes

A wide variety can be built to meet special conditions or handling requirements; examples are stacker cranes to move material into and out of racks, wall cranes using a runway on only one side of a building, circular running or pivoting cranes, and semi-gantries. Load-weighing arrangements can be incorporated, as well as special load-handling devices such as lifting beams, grapples, buckets, forks, and vacuum grips.

Rotary Cranes and Derricks

Rotary cranes are used for lifting material and moving it to points covered by a boom pivoted to a fixed or movable structure. **Derricks** are used outdoors (e.g., in quarries and for construction work), being built so that they can be easily moved. Pillar cranes are always fixed and are used for light, infrequent service. Jib cranes are used in manufacturing plants. Locomotive cranes mounted on car wheels are used to handle loads by hook or bulk material by means of tubs, grab buckets, or magnets. Wrecking cranes are of the same general type as locomotive cranes and are used for handling heavy loads on railroads.

Table 10.4.2 Dimensions, Loads, and Speeds for Industrial-Type Cranes[a,e,f]

Capacity main hoist, tons, 2,000 lb	Span, ft	Std. lift, main hoist, ft[c]	Std. hoist speed, ft/min[b]	Dimensions, refer to Fig. 10.4.13							Max load per wheel, lb[d]	Runway rail, lb/yd	X, in	No. of bridge wheels
				A	B min	C	D	E[c]	F	H				
6	40	36	31	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		8′0″	9,470	25	12	4
	60	53	31	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		9′6″	12,410	25	12	4
	80	86	31	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		11′6″	15,440	25	12	4
	100	118	31	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		14′6″	19,590	40	12	4
10	40	36	23	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		8′0″	15,280	25	12	4
	60	53	23	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		9′6″	18,080	40	12	4
	80	86	23	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		11′6″	20,540	40	12	4
	100	118	23	5⅞″	3′9″	3′¼″	29⅞″	31⅞″		14′6″	24,660	60	12	4
16	40	28	19	5⅞″	3′9″	4′0″	28⅛″	38½″		8′0″	20,950	60	12	4
	60	40	19	5⅞″	3′9″	4′0″	28⅛″	38½″		9′6″	23,680	60	12	4
	80	62	19	5⅞″	3′9″	4′0″	28⅛″	38½″		11′6″	26,140	60	12	4
	100	84	19	5⅞″	3′10″	4′0″	28⅛″	38½″		14′6″	30,560	80	12	4
20 5 ton aux	40	22	14	5⅞″	3′9″	4′0″	40⅝″	28⅝″	2′2″	8′0″	26,350	60	18	4
	60	30	14	5⅞″	3′9″	4′0″	40⅝″	28⅝″	2′2″	9′6″	30,000	80	18	4
	80	46	14	6⅜″	3′11″	4′0″	40⅛″	28⅛″	2′2″	11′6″	33,370	60	18	4
	100	63	14	6⅜″	3′11″	4′0″	40⅛″	28⅛″	2′2″	14′6″	38,070	80	18	4
30 5 ton aux	40	22	9	6⅜″	3′11″	4′6″	41⅞″	28⅞″	1′11½″	9′6″	37,300	80	24	4
	60	22	9	6⅜″	3′11″	4′6″	41⅞″	28⅞″	1′11½″	9′6″	40,050	135	24	4
	80	34	9	7⅞″	3′11″	4′6″	40⅜″	27⅜″	1′11½″	11′6″	44,680	80	24	4
	100	48	9	7⅞″	3′11″	4′6″	40⅜″	27⅜″	1′11½″	14′6″	51,000	135	24	4
40 5 ton aux	40	25	7	7⅞″	5′5″	6′6″	46⅞″	17⅝″	2′6¾″	9′6″	48,630	135	24	4
	60	25	7	7⅞″	5′5″	6′6″	46⅞″	17⅝″	2′6¾″	9′6″	52,860	135	24	4
	80	40	7	7⅞″	5′5″	6′6″	46⅞″	17⅝″	2′6¾″	11′6″	59,040	135	24	4
	100	54	7	7⅞″	5′5″	6′6″	46⅞″	17⅝″	2′6¾″	14′6″	65,200	135	24	4
50 10 ton aux	40	25	5	7⅞″	6′10″	7′6″	56⅜″	29¼″	3′5¼″	10′6″	55,810	135	24	4
	60	25	5	7⅞″	6′7″	7′6″	56⅜″	29¼″	3′5¼″	10′6″	62,050	135	24	4
	80	32	5	9″	6′7″	7′6″	55¼″	28⅛″	3′5¼″	11′6″	68,790	135	24	4
	100	46	5	9″	6′7″	7′6″	55¼″	28⅛″	3′5¼″	14′6″	76,160	176	24	4
60 10 ton aux	40	25	4	9″	6′8″	7′6″	55¼″	28⅛″	3′5¼″	10′6″	65,970	135	24	4
	60	25	4	9″	6′8″	7′6″	55¼″	28⅛″	3′5¼″	10′6″	72,330	135	24	4
	80	32	4	9″	6′8″	7′6″	55¼″	28⅛″	3′5¼″	11′6″	79,230	175	24	4
	100	46	4	9″	6′10″	7′6″	55¼″	28⅛″	3′5¼″	14′6″	89,250	175	24	4

[a] Lift-Tech International, Inc.

[b] Trolley speeds 50–70 ft/min and bridge speed 100–150 ft/min.

[c] For each 10 ft extra lift, increase *H* by *X*.

[d] Direct loads, no impact.

[e] These figures should be used for preliminary work only as the data varies among manufacturers.

[f] Multiply ft by 0.30 for m, ft/min by 0.0051 for m/s, in by 25.4 for mm, lb by 0.45 for kg, lb/yd by 0.50 for kg/m.

Derricks are made with either wood or steel masts and booms, are of the guyed or stiff-leg type, and are either hand-slewed or power-swung with a bull wheel. Figure 10.4.15 shows a guyed wooden derrick of the bull-wheel type. The mast *a* is carried at the foot by pivot *k* and at the top by pivot *m*, held by rope guys *n*. The boom *b* is pivoted at the lower end of the mast. The rope *c*, passing over sheaves at the top of the mast and at the end of the boom and through the pivot *k*, is made fast to drum *d* and varies the angle of the boom. The hoisting rope *e*, from which the load is suspended, is made fast to drum *f*. The bull wheel *g* is attached to the mast and swings the derrick by a rope made fast to the bull wheel and passing around the reversible drum *h*. In derricks of the self-slewing type, the engine is mounted on a platform attached to the mast and the derrick is swung by a pinion meshing with a gear attached to the foundation. Either the bull-wheel or the self-slewing type may be made of steel or wood construction and may be of the guyed or stiff-leg type. Figure 10.4.16 shows a **column jib crane,** consisting of pivoted post *a* and carrying boom *b*, on which travels either an electric or a hand hoist *c*. The post *a* is attached to building column *d* so that it can swing through approximately 270°. Cranes of this type are rapidly being replaced by such other methods of handling materials as the mobile lift truck or the automotive-type crane. Column jib cranes are built with radii up to 20 ft (6 m) and for loads up to 5 tons (4.5 tonnes). Yard jib cranes are generally designed to meet special conditions.

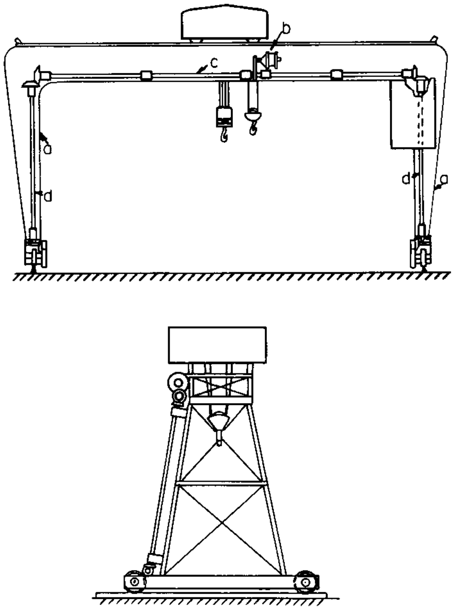


Fig. 10.4.14 Gantry crane.

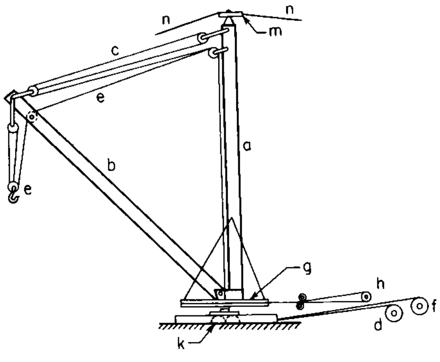


Fig. 10.4.15 Guyed wooden derrick.

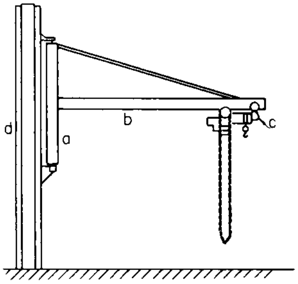


Fig. 10.4.16 Column jib crane.

Locomotive Cranes

The locomotive crane (Fig. 10.4.17) is self-propelled and provided with trucks, brakes, automatic couplers, fittings, and clearances which will permit it to be used or hauled in a train; it can function as a complete unit on any railroad. Locomotive cranes are of the rotating-deck type, consisting of a hinged boom attached to the machinery deck, which is turntable-mounted and operated either by mechanical rotating clutches or by a separate electric or hydraulic swing motor. The boom is operated by powered topping line, with a direct-geared hoisting mechanism to raise and lower it. Power to operate the machinery is deck-mounted, and the machinery deck is completely housed. The crane may be powered by internal-combustion engine or electric motor. The combination of internal-combustion engine, generator, and electric motor makes up the power arrangement for the diesel-electric locomotive crane. Another power arrangement is made up of internal-combustion engines driving hydraulic pumps for hydraulically powered swing and travel mechanisms. The car body and machinery deck are ballasted, thereby adding stability to the crane when it is rotated under load. The basic boom is generally 50 ft (15 m) in length; however, booms range to 130 ft (40 m) in length. Locomotive cranes are so designed that power-shovel, pile-driver, hook, bucket, or magnet attachments can be installed and the crane used in such service. Locomotive cranes are used most extensively in railroad work, steel mills, and scrap yards. The cranes usually have sufficient propelling power not only for the crane itself, but also for switching service and hauling cars.

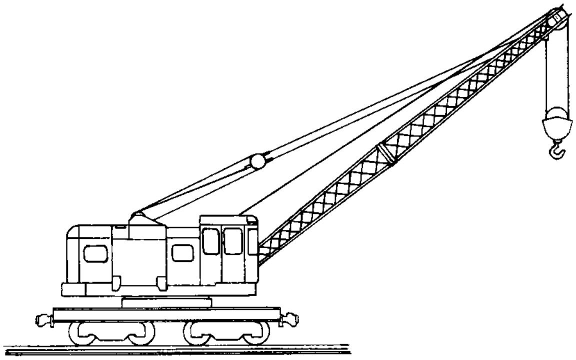


Fig. 10.4.17 Locomotive crane. *(American Hoist and Derrick.)*

Truck Cranes

The advent of the truck crane has changed significantly the methods of lifting and placing heavy items such as concrete buckets, logs, pipe, and bridge or building members. Truck cranes can, without assistance, be rapidly equipped with accessory booms to reach to 260 ft (79 m) vertically—or 180 ft (55 m) vertically with 170 ft of horizontal reach.

Mechanical Models

TOWER CRANE. (Fig. 10.4.18*a* and *b*). Has vertical and horizontal members together with a boom and jib. Permits location close to building with horizontal reach. Without jib, capacity to 27 tons (24.5 tonnes). With jib, reach to 180 ft (55 m). With jib, vertically to 190 ft (58 m). Lifting capacity based upon using outriggers.

CONVENTIONAL CRANE. (Fig. 10.4.18*c*). With boom and with or without jib. Boom plus jib to 260 ft (79 m) and 125 tons (113 tonnes) capacity. Maximum working weight 230,000 lb (104,000 kg).

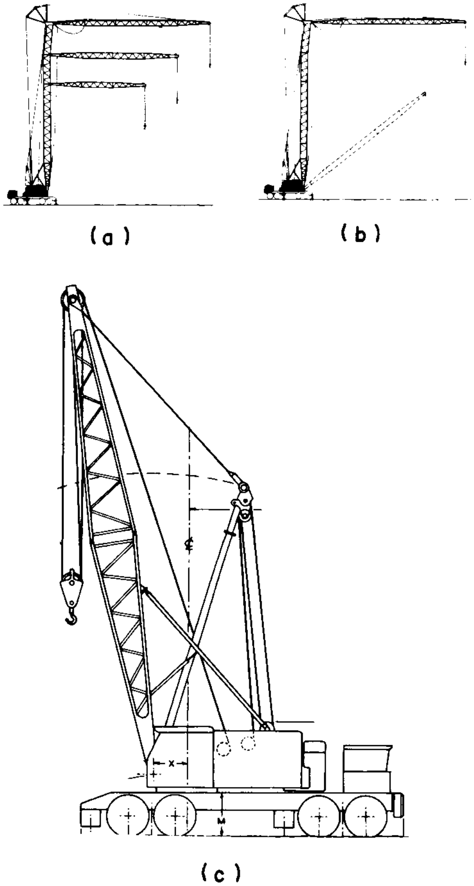


Fig. 10.4.18 Mechanical tower crane with vertical and horizontal extensions. *(a)* Tower working heights; *(b)* normal crane position; *(c)* crane with conventional boom. *(FMC Corp.)*

Table 10.4.3 Conventional Crane* Capacity and Limits of Operation

Boom				On outriggers	
Length, ft	Radius, ft	Angle, deg	Point height, ft	Rear lb	Side lb
30	11	81.0	33.5	250,000	250,000
30	25	46.3	24.5	123,300	123,300
60	16	80.7	63.1	145,100	145,100
60	50	39.7	41.0	52,200	50,100
90	20	81.3	92.9	131,600	131,600
90	80	31.5	49.8	30,500	26,000
180	40	79.2	180.6	46,700	46,700
180	170	21.6	68.9	8,300	6,200
230	50	79.0	229.6	21,000	21,000
230	220	18.9	77.5	2,900	1,800

* Multiply ft by 0.30 for m, lb by 0.45 for kg.

GENERAL CHARACTERISTICS. (Table 10.4.3). 8 × 4 drive wheels with air brakes on all eight wheels. Power hydraulic steering. Removable-pin-connected counterweights front or rear removable for roadability.

Hydraulic Models

SELF-PROPELLED. (Fig. 10.4.19*a*). Short wheelbase, two axle, single cab; 18½ tons (16.8 tonnes) capacity with two telescoping sections to 64 ft. Addition of a jib to 104 ft (32 m) reach.

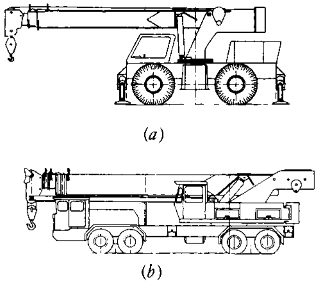


Fig. 10.4.19 Hydraulic crane with *(a)* self-propelled and *(b)* truck-type bases. *(FMC Corp.)*

HYDRAULIC TRUCK. (Fig. 10.4.19*b*). Three or four axle, two cabs, crane functions from upper cab; 45 tons (41 tonnes) capacity with three telescoping sections to 96 ft (29 m). Addition of a jib and boom extension to 142 ft (43 m).

GENERAL CHARACTERISTICS. Hydraulic extensions save setup time and provide job-to-job mobility. Equipment such as this comes under Commercial Standard specification CS90-58, ''Power Cranes and Shovels.'' Similar equipment, called **utility cranes,** without the highway-truck-type cabs, is also available.

Cableways

Cableways are **aerial hoisting and conveying devices** using suspended steel cable for their tracks, the loads being suspended from carriages and moved by gravity or power. The most common uses are transporting material from open pits and quarries to the surface; handling construction material in the building of dams, docks, and other structures where the construction of tracks across rivers or valleys would be uneconomical; and loading logs on cars. The maximum clear **span** is 2,000 to 3,000 ft (610 to 914 m); the usual spans, 300 to 1,500 ft (91 to 457 m). The gravity type is limited to conditions where a grade of at least 20 percent is obtainable on the track cable. Transporting cableways move the load from one point to another. Hoisting transporting cableways hoist the load as well as transport it.

A **transporting cableway** may have one or two fixed track cables, inclined or horizontal, on which the carriage operates by gravity or power. The gravity transporting type (Fig. 10.4.20-I) will either raise or lower material. It consists of one track cable *a* on which travels the wheeled carriage *b* carrying the bucket. The traction rope *c* attached to the carriage is made fast to power drum *d*. The inclination must be sufficient for the carriage to coast down and pull the traction rope after it. The carriage is hauled up by traction rope *c*. Drum *d* is provided with a brake to control the lowering speed, and material may be either raised or lowered. When it is not possible to obtain sufficient fall to operate the load by gravity, traction rope *c* (Fig. 10.4.20-II) is made endless so that carriage *b* is drawn in either direction by power drum *d*. Another type of inclined cableway, shown in Fig. 10.4.20-III, consists of two track cables *aa*, with an endless traction rope *c*, driven and controlled by drum *d*. When material is being lowered, the loaded bucket *b* raises the empty carriage *bb*, the speed being controlled by the brake on the drum. When material is being raised, the drum is driven by power, the descending empty carriage assisting the engine in raising the loaded carriage. This type has twice the capacity of that shown in Fig. 10.4.20-I.

A **hoisting and conveying cableway** (Fig. 10.4.20-IV) hoists the material at any point under the track cable and transports it to any other point. It consists of a track cable *a* and carriage *b*, moved by the endless traction by power drum *e* through fall rope *f*, which raises the fall block *g* suspended from the carriage. The fall-rope carriers *h* support the fall rope; otherwise, the weight of this sagging rope would prevent fall block *g* from lowering when without load. Where it is possible to obtain a minimum inclination of 20° on the track cable, the traction-rope drum *d* is provided with a brake and is not power-driven. The carriage then descends by gravity, pulling the fall and traction ropes to the desired point. Brakes are applied to drum *d*, stopping the carrier. The fall block is lowered, loaded, and raised. If the load is to be carried up the incline, the carriage is hauled up by the fall rope. With this type, the friction of the carriage must be greater than that of the fall block or the load will run down. A novel development is the use of self-filling grab buckets operated from the carriages of cableways, which are lowered, automatically filled, hoisted, carried to dumping position, and discharged.

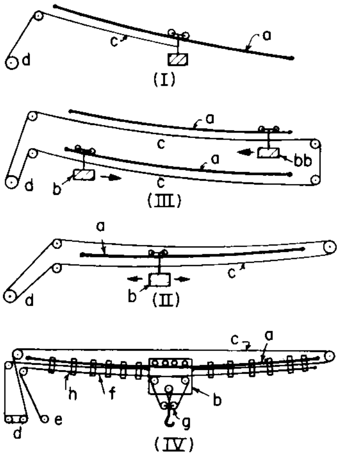


Fig. 10.4.20 Cableways.

The **carriage speed** is 300 to 1,400 ft/min (1.5 to 7.1 m/s) [in special cases, up to 1,800 ft/min (9.1 m/s)]; average hoisting speed is 100 to 700 ft/min. The **average loads** for coal and earth are 1 to 5 tons (0.9 to 4.5 tonnes); for rock from quarries, 5 to 20 tons; for concrete, to 12 yd^3 (9.1 m^3) at 50 tons.

The **deflection of track cables** with their maximum gross loads at midspan is usually taken as 5½ to 6 percent of the span. Let S = span between supports, ft; L = one-half the span, ft; w = weight of rope, lb/ft; P = total concentrated load on rope, lb; h = deflection, ft; H = horizontal tension in rope, lb. Then $h = (wL + P)L/2H$; $P = (2h - wL^2)/L = (8hH - wS^2)/2S$.

For track cables, a **factor of safety** of at least 4 is advised, though this may be as low as 3 for locked smooth-coil strands that use outer wires of high ultimate strength. For traction and fall ropes, the sum of the load and bending stress should be well within the elastic limit of the rope or, for general hoisting, about two-thirds the elastic limit (which is taken at 65 percent of the breaking strength). Let P = load on the rope, lb; A = area of metal in rope section, in^2; E = 29,500,000; R = radius of curvature of hoisting drum or sheave, whichever is smaller, in; d = diameter of individual wires in rope, in (for six-strand 19-wire rope, d = 1⁄15 rope diam; for six-strand 7-wire rope, d = 1⁄9 rope diam). Then load stress per in^2 = $T_1 = P/A$, and bending stress per in^2 = $T_b = Ed/2R$. The radius of curvature of saddles, sheaves, and driving drums is thus important to fatigue life of the cable. In determining the horsepower required, the load on the traction ropes or on the fall ropes will govern, depending upon the degree of inclination.

Cable Tramways

Cable tramways are aerial conveying devices using suspended cables, carriages, and buckets for transporting material over level or mountainous country or across rivers, valleys, or hills (they transport but do not

and their construction cost is insignificant compared with the construction costs of railroads and bridges. Five types are in use:

Monocable, or Single-Rope, Saddle-Clip Tramway Operates on grades to 50 percent gravity grip or on higher grades with spring grip and has capacity of 250 tons/h (63 kg/s) in each direction and speeds to 500 ft/min. Single section lengths to 16 miles without intermediate stations or tension points. Can operate in multiple sections without transshipment to any desired length [monocables to 170 miles (274 km) over jungle terrain are practical]. Loads automatically leave the carrying moving rope and travel by overhead rail at angle stations and transfer points between sections with no detaching or attaching device required. Main rope constantly passes through stations for inspection and oiling. Cars are light and safe for passenger transportation.

Single-Rope Fixed-Clip Tramway Endless rope traveling at low speed, having buckets or carriers fixed to the rope at intervals. Rope passes around horizontal sheaves at each terminal and is provided with a driving gear and constant tension device.

Bicable, or Double-Rope, Tramway Standing track cable and a moving endless hauling or traction rope traveling up to 500 ft/min (2.5 m/s). Used on excessively steep grades. A detacher and attacher is required to open and close the car grip on the traction rope at stations. Track cable is usually in sections of 6,000 to 7,000 ft (1,830 to 2,130 m) and counterweighted because of friction of stiff cable over tower saddles.

Jigback, or Two-Bucket, Reversing Tramway Usually applied to hillside operations for mine workings so that on steep slopes loaded bucket will pull unloaded one up as loaded one descends under control of a brake. Loads to 10 tons (9 tonnes) are carried using a pair of track cables and an endless traction rope fixed to the buckets.

To-and-Fro, or Single-Bucket, Reversing Tramway A single track rope and a single traction rope operated on a winding or hoist drum. Suitable for light loads to 3 tons (2.7 tonnes) for intermittent working on a hillside, similar to a hoisting and conveying cableway without the hoisting feature.

The **monocable tramway** (Fig. 10.4.21) consists of an endless cable *a* passing over horizontal sheaves *d* and *e* at the ends and supported at intervals by towers. This cable is moved continuously, and it both supports and propels carriages *b* and *c*. The carriages either are attached permanently to the cable (as in the **single-rope fixed clip tramway**), in which case they must be loaded and dumped while in motion, or are attached by friction grips so that they may be connected automatically or by hand at the loading and dumping points. When the tramway is lowering material from a higher to a lower level, the grade is frequently sufficient for the loaded buckets *b* to raise the empty buckets *c*, operating the tramway by gravity, the speed being controlled by a brake on grip wheel *d*.

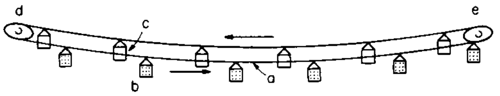


Fig. 10.4.21 Single-rope cable tramway.

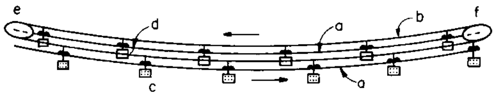


Fig. 10.4.22 Double-rope cable tramway.

The **bicable tramway** (Fig. 10.4.22) consists of two stationary track cables *a*, on which the wheeled carriages *c* and *d* travel. The endless traction rope *b* propels the carriages, being attached by friction grips. Figure 10.4.23 shows the arrangement of the **overhead type**. The track cable *a* is supported at intervals by towers *b*, which carry the saddles *c* in which the track cable rests. Each tower also carries the sheave *d* for supporting traction rope *e*. The self-dumping bucket *f* is suspended from controlled by lever *k*. In the **underhung type,** shown in Fig. 10.4.24, track cable *a* is carried above traction rope *e*. Saddle *c* on top of the tower supports the track cable, and sheave *d* supports the traction cable. The sheave is provided with a rope guard *m*. The lever *h*, with a roller on the end, automatically attaches and detaches the grip by coming in contact with guides at the loading and dumping points. The carriages move in only one direction on each track. On steep downgrades, special hydraulic speed controllers are used to fix the speed of the carriages.

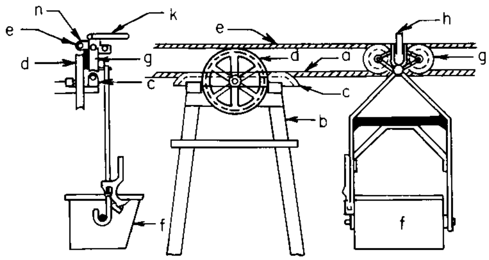


Fig. 10.4.23 Overhead-type double-rope cable tramway.

The **track cables** are of the special locked-joint smooth-coil, or tramway, type. Nearly all wire rope is made of plow steel, with the old cast-steel type no longer being in use. The track cable is usually provided with a smooth outer surface of Z-shaped wires for full lock type or with a surface with half the wires *H*-shaped and the rest round. Special tramway couplers are attached in the shops with zinc or are attached in the field by driving little wedges into the strand end after inserting the end into the coupler. The second type of coupling is known as a **dry socket** and, though convenient for field installation, is not held in as high regard for developing full cable strength. The usual spans for level ground are 200 to 300 ft (61 to 91 m). One end of the track cable is anchored; the other end is counterweighted to one-quarter the breaking strength of the rope so that the horizontal tension is a known quantity. The **traction ropes** are made six-strand 7-wire or six-strand 19-wire, of cast or plow steel on hemp core. The maximum diameter is 1 in, which limits the length of the sections. The traction rope is endless and is driven by a drum at one end, passing over a counterweighted sheave at the other end.

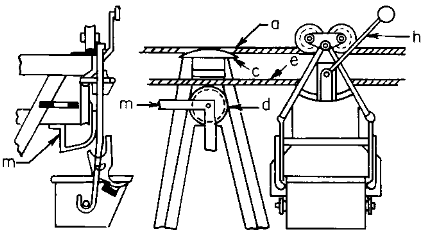


Fig. 10.4.24 Underhung-type double-rope cable tramway.

Fig. 10.4.25 shows a **loading terminal**. The track cables *a* are anchored at *b*. The carriage runs off the cable to the fixed track *c*, which makes a 180° bend at *d*. The empty buckets are loaded by chute *e* from the loading bin, continue around track *c*, are automatically gripped to traction cable *f*, and pass on the track cable *a*. Traction cable *f* passes around and is driven by drum *g*. When the carriages are permanently attached to the traction cable, they are loaded by a moving hopper, which is automatically picked up by the carriage and carried with it a short distance while the bucket is being filled. Figure 10.4.26 shows a **discharge terminal**. The carriage rolls off from the track cable *a* to the fixed track *c*, being automatically ungripped. It is pushed around the 180° bend of track *c*, discharging into the bin underneath and continuing on track *c* until it is automatically gripped to traction cable *f*. The counterweights *h* are attached to track cables *a*, and the counterweight *k* is attached to the carriage of the traction-rope sheave *m*. The **supporting towers** are A frames of steel or wood. At abrupt vertical angles the supports are placed close together and steel tracks installed in place of the cable. Spacing of towers will depend upon the capacity of the track cables and sheaves and upon the terrain as well as the bucket spacing.

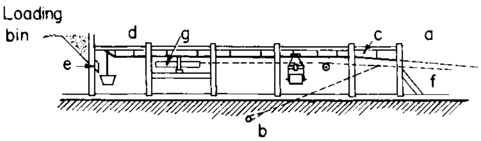


Fig. 10.4.25 Cable-tramway loading terminal.

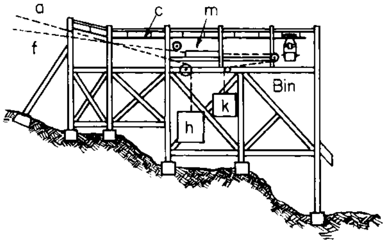


Fig. 10.4.26 Cable-tramway discharge terminal.

Stress In Ropes (Roebling) The deflection for track cables of tramways is taken as one-fortieth to one-fiftieth of the span to reduce the grade at the towers. Let S = span between supports, ft; h = deflection, ft; P = gross weight of buckets and carriages, lb; Z = distance between buckets, ft; W_1 = total load per ft of rope, lb; H = horizontal tension of rope, lb. The formulas given for cableways then apply. When several buckets come in the span at the same time, special treatment is required for each span. For large capacities, the buckets are spaced close together, the load may be assumed to be uniformly distributed, and the live load per linear foot of span = P/Z. Then $H = W_1S^2/8h$, where W_1 = (weight of rope per ft) + (P/Z). When the buckets are not spaced closely, the equilibrium curve can be plotted with known horizontal tension and vertical reactions at points of support.

For figuring the traction rope, t_0 = tension on counterweight rope, lb; t_1, t_2, t_3, t_4 = tensions, lb, at points shown in Fig. 10.4.27; n = number of carriers in motion; a = angle subtended between the line connecting the tower supports and the horizontal; W_1 = weight of each loaded carrier, lb; W_2 = weight of each empty carrier, lb; w = weight of traction rope, lb/ft; L = length of tramway of each grade a, ft; D = diameter of end sheave, ft; d = diameter of shaft of sheave, ft; f_1 = 0.015 = coefficient of friction of shaft; f_2 = 0.025 = rolling friction of carriage wheels. Then, if the loads descend, the maximum stress on the loaded side of the traction rope is

$$t_2 = t_1 + \Sigma(Lw \sin a + \tfrac{1}{2}nW_1 \sin a) - f_2\Sigma(Lw \cos a + \tfrac{1}{2}nW_1 \cos a)$$

where $t_1 = \tfrac{1}{2}t_0[1 - f_1(d/D)]$. If the load ascends, there are two cases: (1) driving power located at the lower terminal, (2) driving power at the upper terminal. If the line has no reverse grades, it will operate by

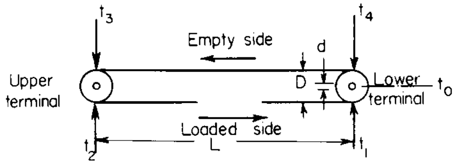


Fig. 10.4.27 Diagram showing traction rope tensions.

gravity at a 10 percent incline to 10 tons/h capacity and at a 4 percent grade for 80 tons/h. The preceding formula will determine whether it will operate by gravity.

The **power required** or developed by tramways is as follows: Let V = velocity of traction rope, ft/min; P = gross weight of loaded carriage, lb; p = weight of empty carriage, lb; N = number of carriages on one track cable; $P/50$ = friction of loaded carriage; $p/50$ = friction of empty carriage; W = weight of moving parts, lb; E = length of tramway divided by difference in levels between terminals, ft. Then, power required is

$$\text{hp} = \frac{NV}{33{,}000}\left(\frac{P-p}{E} \pm \frac{P+p}{50}\right) \pm 0.0000001\,WV$$

Where power is developed by tramways, use 80 instead of 50 under $P + p$.

BELOW-SURFACE HANDLING (EXCAVATION)

Power Shovels

Power shovels stand upon the bottom of the pit being dug and dig above this level. Small machines are used for road grading, basement excavation, clay mining, and trench digging; larger sizes are used in quarries, mines, and heavy construction; and the largest are used for removing overburden in opencut mining of coal and ore. The uses for these machines may be divided into two groups: (1) **loading,** where sturdy machines with comparatively short working ranges are used to excavate material and load it for transportation; (2) **stripping,** where a machine of very great dumping and digging reaches is used to both excavate the material and transport it to the dump or wastepile. The **full-revolving shovel,** which is the only type built at the present (having entirely displaced the old railroad shovel), is usually composed of a crawler-mounted truck frame with a center pintle and roller track upon which the revolving frame can rotate. The revolving frame carries the swing and hoisting machinery and supports, by means of a socket at the lower end and cable guys at the upper end, a boom carrying guides for the dipper handles and machinery to thrust the dipper into the material being dug.

Figure 10.4.28 shows a full-revolving shovel. The dipper *a*, of cast or plate steel, is provided with special wear-resisting teeth. It is pulled through the material by a steel cable *b* wrapped on a main drum *c*. Gasoline engines are used almost exclusively in the small sizes, and diesel, diesel-electric, or electric power units, with Ward Leonard control, in the large machines. The commonly used sizes are from ½ to 5 yd^3 (0.4 to 3.8 m^3) capacity, but special machines for coal-mine stripping are built with buckets holding up to 33 yd^3 (25 m^3) or even more. The very large machines are not suited for quarry or heavy rock work. Sizes up to 5 yd^3 (3.8 m^3) are known as **quarry machines**. Stripping shovels are crawler-mounted, with double-tread crawlers under each of the four corners and with power means for keeping the turntable level when traveling over uneven ground. The crowd motion consists of a chain which, through the rack-and-pinion mechanism, forces the dipper into the material as the dipper is hoisted and withdraws it on its downward swing. On the larger sizes, a separate engine or motor is mounted on the boom for crowding. A separate engine working through a pinion and horizontal gear *g* swings the entire frame and machinery to bring the dipper into position for dumping and to return it to a new digging position. Dumping is accomplished by releasing the hinged dipper bottom, which drops upon the pulling of a latch. With gasoline-engine or diesel-engine drives, there is only one prime mover, the power for all operations being taken off by means of clutches.

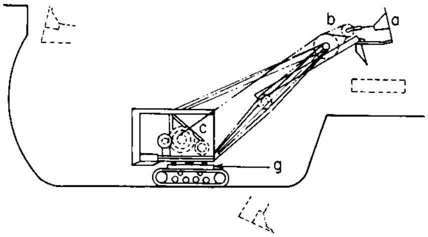


Fig. 10.4.28 Revolving power shovel.

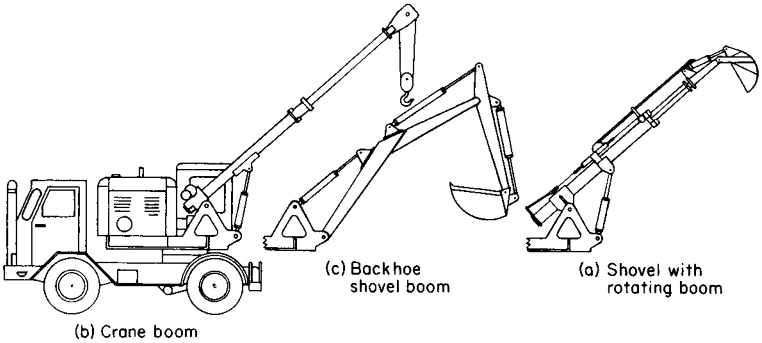
Practically all **power shovels** are readily **converted** for operation as **dragline excavators,** or **cranes.** The changes necessary are very simple in the case of the small machines; in the case of the larger machines, the installation of extra drums, shafts, and gears is required, in addition to the boom and bucket change.

The **telescoping boom,** hydraulically operated excavator shown in Fig. 10.4.29 is a versatile machine that can be quickly converted from the rotating-boom power shovel shown in Fig. 10.4.29*a* to one with a crane boom (Fig. 10.4.29*b*) or backhoe shovel boom (Fig. 10.4.29*c*). It can dig ditches reaching to 22 ft (6.7 m) horizontally and 9 ft 6 in (2.9 m) below grade; it can cut slopes, rip, scrape, dig to a depth of 12 ft 6 in (3.8 m), and load to a height of 11 ft 2 in (3.4 m). It is completely hydraulic in all powerized functions.

Dredges

Placer dredges are used for the mining of gold, platinum, and tin from placer deposits. The usual maximum digging depth of most existing dredges is 65 to 70 ft (20 to 21 m), but one dredge is digging to 125 ft (38 m). The dredge usually works with a bank above the water of 8 to 20 ft (2.4 to 6 m). Sometimes hydraulic jets are employed to break down these banks ahead of the dredge. The excavated material is deposited astern, and as the dredge advances, the pond in which the dredge floats is carried along with it.

The digging element consists of a chain of closely connected buckets passing over an idler tumbler and an upper or driving tumbler. The chain is mounted on a structural-steel ladder which carries a series of


(c) Backhoe shovel boom

(a) Shovel with rotating boom

(b) Crane boom

Fig. 10.4.29 Hydraulically operated excavator. *(Link-Belt.)*

rollers to provide a bearing track for the chain of buckets. The upper tumbler is placed 10 to 40 ft (3 to 13 m) above the deck, depending upon the size of the dredge. Its fore-and-aft location is about 65 percent of the length of the ladder from the bow of the dredge. The ladder operates through a well in the hull, which extends from the bow practically to the upper-tumbler center. The material excavated by the buckets is dumped by the inversion of the buckets at the upper tumbler into a hopper, which feeds it to a revolving screen.

Placer dredges are made with buckets ranging in capacity from 2 to 20 ft^3 (0.06 to 0.6 m^3). The usual speed of operation is 15 to 30 buckets per min, in the inverse order of size.

The digging reaction is taken by stern spuds, which act as pivots upon which the dredge, while digging, is swung from side to side of the cut by swinging lines which lead off the dredge near the bow and are anchored ashore or pass over shore sheaves and are dead-ended near the lower tumbler on the digging ladder. By using each spud alternately as a pivot, the dredge is fed forward into the bank.

Elevator dredges, of which dredges are a special classification, are used principally for the excavation of sand and gravel beds from rivers, lakes, or ocean deposits. Since this type of dredge is not as a rule required to cut its own flotation, the bow corners of the hull may be made square and the digging ladder need not extend beyond the bow. The bucket chain may be of the close-connected placer-dredge type or of the open-connected type with one or more links between the buckets. The dredge is more of an elevator than a digging type, and for this reason the buckets may be flatter across the front and much lighter than the placer-dredge bucket.

The excavated material is usually fed to one or more revolving screens for classification and grading to the various commercial sizes of sand and gravel. Sometimes it is delivered to sumps or settling tanks in the hull, where the silt or mud is washed off by an overflow. Secondary elevators raise the material to a sufficient height to spout it by gravity or to load it by belt conveyors to the scows.

Hydraulic dredges are used most extensively in river and harbor work, where extremely heavy digging is not encountered and spoil areas are available within a reasonable radius of the dredge. The radius may vary from a few hundred feet to a mile or more, and with the aid of booster pumps in the pipeline, hydraulic dredges have pumped material through distances in excess of 2 mi (3.2 km), at the same time elevating it more than 100 ft (30 m). This type of dredge is also used for sand-and-gravel-plant operations and for land-reclamation work. Levees and dams can be built with hydraulic dredges. The usual maximum digging depth is about 50 ft (16 m). Hydraulic dredges are reclaiming copper stamp-mill tailings from a depth of 115 ft (35 m) below the water, and a depth of 165 ft (50 m) has been reached in a land-reclamation job.

The usual type of hydraulic dredge has a **digging ladder** suspended from the bow at an angle of 45° for the maximum digging depth. This ladder carries the suction pipe and cutter, with its driving machinery, and the swinging-line sheaves. The cutter head may have applied to it 25 to 1,000 hp (3.7 to 746 kW). The 20-in (0.5-m) dredge, which is the standard, general-purpose machine, has a cutter drive of about 300 hp. The usual operating speed of the cutter is 5 to 20 r/min.

The material excavated by the cutter enters the mouth of the suction pipe, which is located within and at the lower side of the cutter head. The material is sucked up by a centrifugal pump, which discharges it to the dump through a pipeline. The shore discharge pipe is usually of the telescopic type, made of No. 10 to 3⁄10-in (3- to 7.5-mm) plates in lengths of 16 ft (5 m) so that it can be readily handled by the shore crew. Floating pipelines are usually made of plates from ¼ to ½ in (6 to 13 mm) thick and in lengths of 40 to 100 ft (12 to 30 m), which are floated on pontoons and connected together through rubber sleeves or, preferably, ball joints. The floating discharge line is flexibly connected to the hull in order to permit the dredge to swing back and forth across the cut while working without disturbing the pipeline.

Pump efficiency is usually sacrificed to make an economical unit for the handling of material, which may run from 2 to 25 percent of the total volume of the mixture pumped. Most designs have generous clearances and will permit the passage of stone which is 70 percent of the pipeline diameter. The pump efficiencies vary widely but in general may run from 50 to 70 percent.

Commercial dredges vary in size and discharge-pipe diameters from 12 to 30 in (0.3 to 0.8 m). Smaller or larger dredges are usually special-purpose machines. A number of 36-in (0.9-m) dredges are used to maintain the channel of the Mississippi River. The power applied to pumps varies from 100 to 3,000 hp (75 to 2,200 kW). The modern 20-in (0.5-m) commercial dredge has about 1,350 bhp (1,007 kW) applied to the pump.

Diesel dredges are built for direct-connected or electric drives, and modern steam dredges have direct-turbine or turboelectric drives. The steam turbine and the dc electric motor have the advantage that they are capable of developing full rating at reduced speeds.

Within its scope, the hydraulic dredge can work more economically than any other excavating machine or combination of machines.

Dragline Excavators

Dragline excavators are typically used for digging open cuts, drainage ditches, canals, sand, and gravel pits, where the material is to be moved 20 to 1,000 ft (6 to 305 m) before dumping. They cannot handle rock unless the rock is blasted. Since they are provided with long booms and mounted on turntables, permitting them to swing through a full circle, these excavators can deposit material directly on the spoil bank farther from the point of excavation than any other type of machine. Whereas a shovel stands below the level of the material it is digging, a dragline excavator stands above and can be used to excavate material under water.

Figure 10.4.30 shows a self-contained dragline mounted on crawler treads. The drive is almost exclusively gasoline in the small sizes and diesel, diesel-electric, or electric, frequently with Ward Leonard control, in the large sizes. The boom *a* is pivoted at its lower end to the turntable, the outer end being supported by cables *b*. so that it can be raised or lowered to the desired angle. The scraper bucket *c* is supported by cable *d*, which is attached to a bail on the bucket, passes over a sheave at the head of the boom, and is made fast to the engine. A second cable *e* is attached to the front of the bucket and made fast to the second drum of the engine. The bucket is dropped and dragged along the surface of the material by cable *e* until filled. It is then hoisted by cable *d*, drawn back to its dumping position, *e* being kept tight until the dumping point is reached, when *e* is slacked, allowing the bucket to dump by gravity. After the bucket is filled, the boom is swung to the dumping position while the bucket is being hauled out. A good operator can throw the bucket 10 to 40 ft (3 to 12 m) beyond the end of the boom, depending on the size of machine and the working conditions. The depth of the cut varies from 12 to 75 ft (3.7 to 23 m), again depending on the size of machine and the working conditions. With the smaller machines and under favorable conditions, two or even three trips per minute are possible; but with the largest machines, even one trip per minute may not be attained. The more common sizes are for handing ¾- to 4-yd^3 (0.6- to 3-m^3) buckets with boom lengths up to 100 or 125 ft (30 to 38 m), but machines have been built to handle an 8-yd^3 (6-m^3) bucket with a boom length of 200 ft (60 m). The same machine can

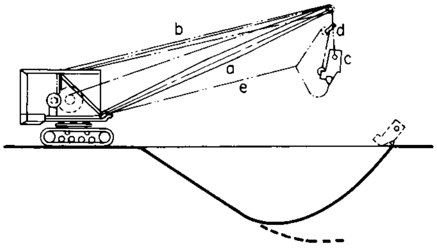


Fig. 10.4.30 Dragline excavator.

handle a 12-yd^3 (9-m^3) bucket with the boom shortened to 165 ft (50 m).

Stackline Cableways

Used widely in sand-and-gravel plants, the **slackline cableway** employs an open-ended dragline bucket suspended from a carrier (Fig. 10.4.31) which runs upon a track cable. It will dig, elevate, and convey materials in one continuous operation.

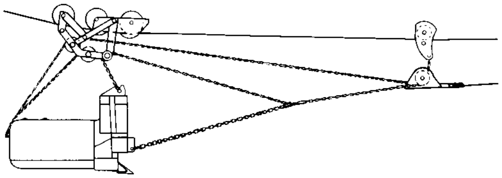


Fig. 10.4.31 Slackline-cable bucket and trolley.

Figure 10.4.32 shows a typical slackline-cableway operation. The bucket and carrier is *a*; *b* is the track cable, inclined to return the bucket and carrier by gravity; *c* is a tension cable for raising or lowering the track cable; *d* is the load cable; and *e* is a power unit with two friction drums having variable speeds. A mast or tower *f* is used to support guide and tension blocks at the high end of the track cable; a movable tail tower *g* supports the lower end of the track cable. The bucket is raised and lowered by tensioning or slacking off the track cable. The bucket is loaded, after lowering, by pulling on the load cable. The loaded bucket, after raising, is conveyed at high speed to the dumping point and is returned at a still higher speed by gravity to the digging point. The cableway can be operated in radial lines from a mast or in parallel lines between two moving towers. It will not dig rock unless the rock is blasted. The depth of digging may vary from 5 to 100 ft.

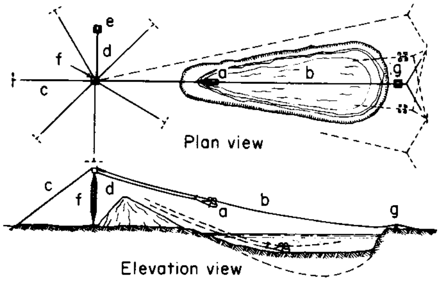


Fig. 10.4.32 Slackline-cable plant. *(Sauerman.)*

10.5 CONVEYOR MOVING AND HANDLING

by Vincent M. Altamuro

OVERHEAD CONVEYORS

by Ivan L. Ross

Acco Chain Conveyor Division

Conveyors are primarily horizontal-movement, fixed-path, constant-speed material handling systems. However, they often contain inclined sections to change the elevation of the material as it is moving, switches to permit alternate paths and ''power-and-free'' capabilities to allow the temporary slowing, stopping, or accumulating of material.

Conveyors are used, not only for transporting material, but also for in-process storage. They may be straight, curved, closed-loop, irreversible, or reversible. Some types of conveyors are:

air blower
apron
belt
bucket
car-on-track
carousel
chain
flight
hydraulic
magnetic
monorail
pneumatic tube
power-and-free
roller
screw
skate wheel
slat
spiral
towline
trolley

Tables 10.5.1 and 10.5.2 describe and compare some of these.

Conveyors are often used as integral components of assembly systems. They bring the correct material, at the required rate, to each worker and then to the next operator in the assembly sequence. Figure 10.5.1 shows ways conveyors can be used in assembly.

Overhead conveyor systems are defined in two general classifications: the basic trolley conveyor and the power-and-free conveyor, each of which serves a definite purpose.

Trolley conveyors, often referred to as overhead power conveyors, consist of a series of trolleys or wheels supported from or within an overhead track and connected by an endless propelling means, such as chain, cable, or other linkages. Individual loads are usually suspended from the trolleys or wheels (Fig. 10.5.2). Trolley conveyors are utilized for transportation or storage of loads suspended from one conveyor which follows a single fixed path. They are normally used in applications where a balanced, continuous production is required. Track sections range from lightweight ''tee'' members or tubular sections, to medium- and heavy-duty I-beam sections. The combinations and sizes of trolley-propelling means and track sections are numerous. Normally this type of conveyor is continually in motion at a selected speed to suit its function.

Power-and-free conveyor systems consist of at least one power conveyor, but usually more, where the individual loads are suspended from one or more free trolleys (not permanently connected to the propelling means) which are conveyor-propelled through all or part of the system. Additional portions of the system may have manual or gravity means of propelling the trolleys.

Worldwide industrial, institutional, and warehousing requirements of in-process and finished products have affected the considerable growth and development of power-and-free conveyors. Endless varieties of size, style, color, and all imaginable product combinations have extended the use of power-and-free conveyors. The power-and-free system combines the advantages of continuously driven chains with the versatile traffic system exemplified by traditional monorail unpowered systems. Thus, high-density load-transportation capabilities are coupled with complex traffic patterns and in-process or work-station requirements to enable production requirements to be met with a minimum of manual handling or transferring. Automatic dispatch systems for coding and programming of the load routing are generally used.

Trolley Conveyors

The load-carrying member of a trolley conveyor is the trolley or series of wheels. The wheels are sized and spaced as a function of the imposed

Table 10.5.1 Types of Conveyors Used in Factories

Type of conveyor	Description	Features/limitations
Overhead		
Power-and-free	Carriers hold parts and move on overhead track. With inverted designs, track is attached to factory floor. Carriers can be transferred from powered to ‘‘free’’ track.	Accumulation; flexible routing; live storage; can hold parts while production steps are performed; can travel around corners and up inclines.
Trolley	Similar to power and free, but carriers cannot move off powered track.	Same as power and free, but flexible routing is not possible without additional equipment
Above-floor		
Roller, powered	Load-carrying rollers are driven by a chain or belt.	Handles only flat-bottomed packages, boxes, pallets or parts; can accumulate loads; can also be suspended from ceiling for overhead handling.
Roller, gravity	Free-turning rollers; loads are moved either by gravity or manual force.	When inclined, loads advance automatically.
Skate wheel	Free-turning wheels spaced on parallel shafts.	For lightweight packages and boxes; less expensive than gravity rollers.
Spiral tower	Helix-shaped track which supports parts or small ‘‘pallets’’ that move down track.	Buffer storage; provides surge of parts to machine tools when needed.
Magnetic	Metal belt conveyor with magnetized bed.	Handles ferromagnetic parts, or separates ferromagnetic parts from nonferrous scrap.
Pneumatic	Air pressure propels cylindrical containers through metal tubes.	Moves loads quickly; can be used overhead to free floor space.
Car-on-track	Platforms powered by rotating shaft move along track.	Good for flexible manufacturing systems; precise positioning of platforms; flexible routing.
In-floor		
Towline	Carts are advanced by a chain in the floor.	High throughput; flexible routing possible by incorporating spurs in towline; tow carts can be manually removed from track; carts can travel around corners.

SOURCE: *Modern Materials Handling,* Aug. 5, 1983, p. 55.

Table 10.5.2 Transportation Equipment Features

Equipment	Most practical travel distance	Automatic load or unload	Typical load	Throughput rate	Travel path	Typical application
Conveyors						
Belt	Short to medium	No	Cases, small parts	High	Fixed	Take-away from picking, sorting
Chain	Short to medium	Yes	Unit	High	Fixed	Deliver to and from automatic storage and retrieval systems
Roller	Short to long	Yes	Unit, case	High	Fixed	Unit: same as chain Case: sorting, delivery between pick station
Towline	Medium to long	Yes	Carts	High	Fixed	Delivery to and from shipping or receiving
Wire-guided vehicles						
Cart	Short to long	Yes	Unit	Low	Fixed	Delivery between two drop points
Pallet truck	Short to long	Yes	Unit	Low	Fixed	Delivery between two drop points
Tractor train	Short to long	Yes	Unit	Medium	Fixed	Delivery to multiple drop points
Operator-guided vehicles						
Walkie pallet	Short	No	Unit	Low	Flexible	Short hauls at shipping and receiving
Rider pallet	Medium	No	Unit	Low	Flexible	Dock-to-warehouse deliveries
Tractor train	Short to long	No	Unit	Medium	Flexible	Delivery to multiple drop points

SOURCE: *Modern Materials Handling,* Feb. 22, 1980, p. 106.

load, the propelling means, and the track capability. The load hanger (carrier) is attached to the conveyor and generally remains attached unless manually removed. However, in a few installations, the load hanger is transferred to and from the conveyor automatically.

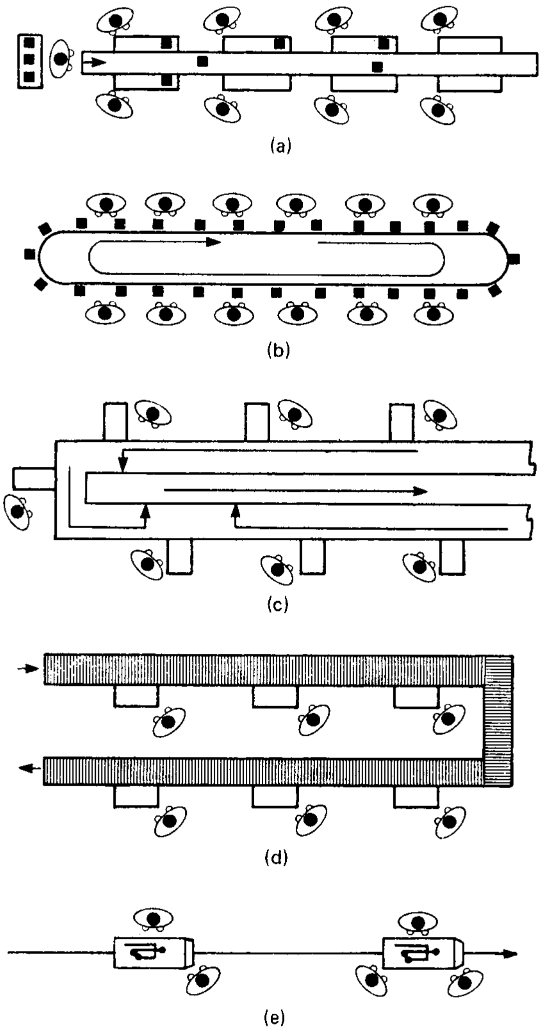


Fig. 10.5.1 Conveyors used in assembly operations. (*a*) Belt conveyor, with diverters at each station; (*b*) carousel circulates assembly materials to workers; (*c*) multiple-path conveyors allow several products to be built at once; (*d*) gravity roller conveyors; (*e*) towline conveyor, moving assemblies from one group of assemblers to another. *(Modern Materials Handling, Nov. 1979, page 116.)*

The trolley conveyor can employ any chain length consistent with allowable propelling means and drive(s) capability. The track layout always involves horizontal turns and commonly has vertical inclines and declines.

When a dimensional layout, load spacing, weights of moving loads, function, and load and unload points are determined, the chain or cable pull can be calculated. Manufacturer's data should be used for frictional values. A classical point-to-point analysis should be made, using the most unfavorable loading condition.

In the absence of precise data, the following formulas can be used to find the approximate drive effort:

$$\text{Max drive effort, lb} = A + B + C$$
$$\text{Net drive effort, lb} = A + B + C - D$$
$$\text{Max drive effort, N} = (A + B + C)\,9.81$$
$$\text{Net drive effort, N} = (A + B + C - D)\,9.81$$

where $A = fw$ [where w = total weight of chain, carriers, and live load, lb (kg) and f = coefficient of friction]; $B = wS$ [where w = average carrier load per ft (m), lb/ft (kg/m) and S = total vertical rise, ft (m)]; $C = 0.017f(A + B)N$ (where N = sum of all horizontal and vertical curves, deg); and $D = w'S'$ [where w' = average carrier load per ft (m), lb/ft (kg/m) and s' = total vertical drop, ft (m)].

For conveyors with antifriction wheels, with clean operating condition, the coefficient of friction f may be 0.13.

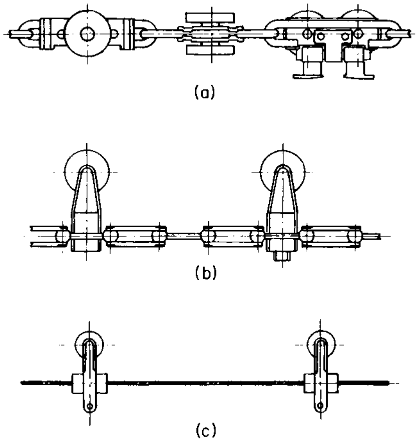


Fig. 10.5.2 Typical conveyor chains or cable.

Where drive calculations indicate that the allowable chain or cable tension may be exceeded, multiple-drive units are used. When multiple drives are used for constant speed, high-slip motors or fluid couplings are commonly used. If variable speed is required with multiple drives, it is common to use direct-current motors with direct-current supply and controls. For both constant and variable speed, drives are balanced to share drive effort. Other than those mentioned, many various methods of balancing are available for use.

Complexities of overhead conveyors, particularly with varying loads on inclines and declines, as well as other influencing factors (e.g., conveyor length, environment, lubrication, and each manufacturer's design recommendations), usually require detail engineering analysis to select the proper number of drives and their location. Particular care is also required to locate the take-up properly.

The following components or devices are used on trolley-conveyor applications:

Trolley Assembly Wheels and their attachment portion to the propelling means (chain or cable) are adapted to particular applications, depending upon loading, duty cycle, environment, and manufacturer's design.

Carrier Attachments These are made in three main styles: (1) enclosed tubular type, where the wheels and propelling means are carried inside; (2) semienclosed tubular type, where the wheels are enclosed and the propelling means is external; and (3) open-tee or I-beam type, where the wheels and propelling means are carried externally.

Sprocket or Traction Wheel Turn Any arc of horizontal turn is available. Standards usually vary in increments of 15° from 15 to 180°.

Roller Turns Any arc of horizontal turn is available. Standards usually vary in increments of 15° from 15 to 180°.

Track Turns These are horizontal track bends without sprockets, traction wheels, or rollers; they are normally used on enclosed-track conveyors where the propelling means is fitted with horizontal guide wheels.

Track Hangers, Brackets, and Bracing These conform to track size and shape, spaced at intervals consistent with allowable track stress and deflection applied by loading and chain or cable tensions.

Track Expansion Joints For use in variable ambient conditions, such as ovens, these are also applied in many instances where conveyor track crosses building expansion joints.

Chain Take-Up Unit Required to compensate for chain wear and/or variable ambient conditions, this unit may be traction-wheel, sprocket, roller, or track-turn type. Adjustment is maintained by screw, screw spring, counterweight, or air cylinder.

Incline and Decline Safety Devices An ‘‘anti-back-up’’ device will ratchet into a trolley or the propelling means in case of unexpected reversal of a conveyor on an incline. An ‘‘anti-runaway’’ device will sense abnormal conveyor velocity on a decline and engage a ratchet into a trolley or the propelling means. Either device will arrest the uncontrolled movement of the conveyor. The anti-runaway is commonly connected electrically to cut the power to the drive unit.

Drive Unit. Usually sprocket or caterpillar type, these units are available for constant-speed or manual variable-speed control. Common speed variation is 1:3; e.g., 5 to 15 ft/min (1.5 to 4.5 m/min). Drive motors commonly range from fractional to 15 hp (11 kW).

Drive Unit Overload. Overload is detected by electrical, torque, or pull detection by any one of many available means. Usually overload will disconnect power to the drive, stopping the conveyor. When the reason for overload is determined and corrected, the conveyor may be restarted.

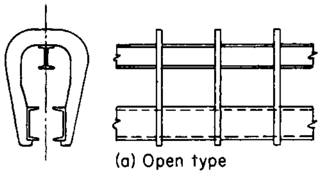
Equipment Guards. Often it is desirable or necessary to guard the conveyor from hostile environment and contaminants. Also employees must be protected from accidental engagement with the conveyor components.

Transfer Devices Usually unique to each application, automatic part or carrier loading, unloading, and transfer devices are available. With growth in the use of power-and-free, carrier transfer devices have become rare.

Power-and-Free Conveyor

The power-and-free conveyor has the highest potential application wherever there is a requirement for other than a single fixed-path flow (trolley conveyor). Power-and-free conveyors may have any number of automatic or manual switch points. A system will permit scheduled transit and delivery of work to the next assigned station automatically. Accumulation (storage) areas are designed to accommodate in-process inventory between operations.

The components and chain-pull calculation discussed for powered overhead conveyors are basically applicable to the power-and-free conveyor. Addition of a secondary free track surface is provided for the work carrier to traverse. This free track is usually disposed directly below the power rail but is sometimes found alongside the power rail. (This arrangement is often referred to as a ‘‘side pusher’’ or ‘‘drop finger.’’) The power-and-free rails are joined by brackets for rail (free-track) continuity. The power chain is fitted with pushers to engage the work-carrier trolley. Track sections are available in numerous configurations for both the power portion and the free portion. Sections will be enclosed, semienclosed, or open in any combinations. Two of the most common types are shown in Fig. 10.5.3.


(a) Open type

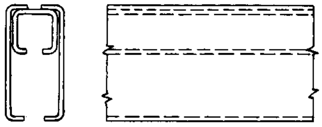

(b) Enclosed type

Fig. 10.5.3 Conveyor tracks.

As an example of one configuration of power-and-free, Fig. 10.5.4 shows the ACCO Chain Conveyor Division enclosed-track power-and-free rail. In the cutaway portion, the pushers are shown engaged with the work-carrier trolley.

The pushers are pivoted on an axis parallel to the chain path and swing aside to engage the pusher trolley. The pusher trolley remains engaged on level and sloped sections. At automatic or manual switching points, the leading dispatch trolley head which is not engaged with the chain is propelled through the switch to the branch line. As the chain passes the switching point, the pusher trolley departs to the right or left from pusher engagement and arrives on a free line, where it is subject to manual or controlled gravity flow.

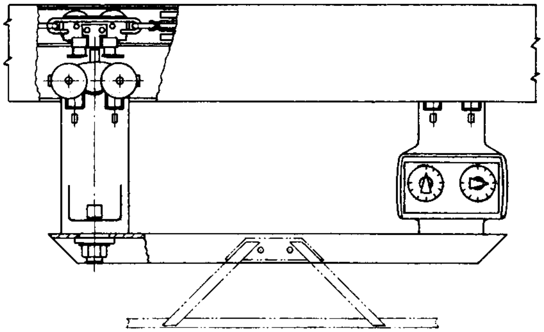


Fig. 10.5.4 Power-and-free conveyor rail and trolley heads. *(ACCO Chain Conveyor Division.)*

The distance between pushers on the chain for power-and-free use is established in accordance with conventional practice, except that the minimum allowable pusher spacing must take into account the wheelbase of the trolley, the bumper length, the load size, the chain velocity, and the action of the carrier at automatic switching and reentry points. A switching headway must be allowed between work carriers. An approximation of the minimum allowable pusher spacing is that the pusher spacing will equal twice the work-carrier bumper length. Therefore, a 4-ft (1.2-m) work carrier would indicate a minimum pusher spacing of 8 ft (2.4 m).

The load-transmission capabilities are a function of velocity and pusher spacing. At the 8-ft (2.4-m) pusher spacing and a velocity of 40 ft/min (0.22 m/s), five pushers per minute are made available. The load-transmission capability is five loads per minute, or 300 loads per hour.

Method of Automatic Switching from a Powered Line to a Free Line Power-and-free work carriers are usually switched automatically. To do this, it is necessary to have a code device on the work carrier and a decoding (reading) device along the track in advance of the track switch. Figure 10.5.5 shows the equipment relationship. On each carrier, the free trolley carries the code selection, manually or automatically introduced, which identifies it for a particular destination or routing. As the free trolley passes the reading station, the trolley intelligence is decoded and compared with a preset station code and its current knowledge of the switch position and branch-line condition; a decision is then reached which results in correct positioning of the rail switch.

In Fig. 10.5.5, the equipment illustrated includes a transistorized readout station *a*, which supplies 12 V direct current at stainless-steel code brushes *b*. The code brushes are ‘‘matched’’ by contacts on the encoded trolley head *c*. When a trolley is in register and matches the code-brush positioning, it will be allowed to enter branch line *d* if the line is not full. If carrier *e* is to be entered, the input signal is rectified and amplified so as to drive a power relay at junction box *f*, which in turn actuates solenoid *g* to operate track switch *h* to the branch-line position. A memory circuit is established in the station, indicating that a full-line condition exists. This condition is maintained until the pusher pin of the switched carrier clears reset switch *j*.

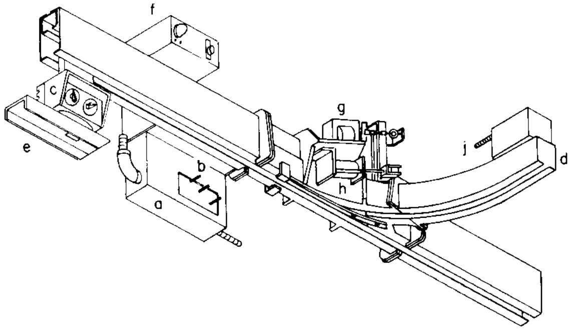


Fig. 10.5.5 Switch mechanism exiting trolley from power rail to free rail. *(ACCO Chain Conveyor Division.)*

The situations which can be handled by the decoding stations are as follows: (1) A trolley with a matching code is in register; there is space in the branch line. The carrier is allowed to enter the branch line. (2) A trolley with a matching code is in register; there is no space in the branch line. The carrier is automatically recirculated on the powered system and will continue to test its assigned destination until it can be accommodated. (3) A trolley with a matching code is in register; there is no space in the branch line. The powered conveyor is automatically stopped, and visual and/or audible signals are started. The conveyor can be automatically restarted when the full-line condition is cleared, and the waiting carrier will be allowed to enter. (4) A trolley with a nonmatching code is in register; in this case, the decoding station always returns the track switch to the main-line position, if necessary, and bypasses the carrier.

Use and Control of Carriers on Free and Gravity Lines Free and gravity lines are used as follows: (1) To connect multiple power-and-free conveyors, thus making systems easily extensible and permitting different conveyor designs for particular use. (2) To connect two auxiliary devices such as vertical conveyors and drop-lift stations. (3) As manned or automatic workstations. In this case, the size of the station depends on the number of carriers processed at one time, with additional space provision for arriving and departing carriers. (Considerable knowledge of work-rate standards and production-schedule requirements is needed for accurate sizing.) (4) As manned or automatic storage lines, especially for handling production imbalance for later consumption.

Nonmanned automatic free lines require that the carrier be controlled in conformance with desired conveyor function and with regard to the commodity being handled. The two principal ways to control carriers in nonmanned free rails are (1) to slope the free rail so that all carriers will start from rest and use incremental spot retarders to check velocity, and (2) to install horizontal or sloped rails and use auxiliary power conveyor(s) to accumulate carriers arriving in the line.

In manned free lines, it is usual to have slope at the automatic arrival and automatic departure sections only. These sections are designed for automatic accumulation of a finite number of carriers, and retarding or feeding devices may be used. Throughout the remainder of the manned station, the carrier is propelled by hand.

Method of Automatic Switching from a Free Line to a Powered Line Power-and-free work carriers can be reentered into the powered lines either manually or automatically. The carrier must be integrated with traffic already on the powered line and must be entered so that it will engage with a pusher on the powered chain. Figure 10.5.6 illustrates a typical method of automatic reentry. The carrier *a* is held at a rest on a slope in the demand position by the electric trolley stop *b*. The demand to enter enables the sensing switches *c* and *d* mounted on the powered rail to test for the availability of a pusher. When a pusher that is not propelling a load is sensed, all conditions are met and the carrier is released by the electric trolley stop such that it arrives in the pickup position in advance of the pusher. A retarding or choke device can be used to keep the entering carrier from overrunning the next switch position or another carrier in transit. The chain pusher engages the pusher trolley and departs the carrier. The track switch *f* can remain in the branch-line position until a carrier on the main line *g* would cause the track switch to reset. Automatic reentry control ensures that no opportunity to use a pusher is overlooked and does not require the time of an operator.

Power-and-Free Conveyor Components All components used on trolley conveyors are applied to power-and-free conveyors. Listed below are a few of the various components unique to power-and-free systems.

TRACK SWITCH. This is used for diverting work carriers either automatically or manually from one line or path to another. Any one system may have both. Switching may be either to the right or to the left. Automatically, stops are usually operated pneumatically or electromechanically. Track switches are also used to merge two lines into one.

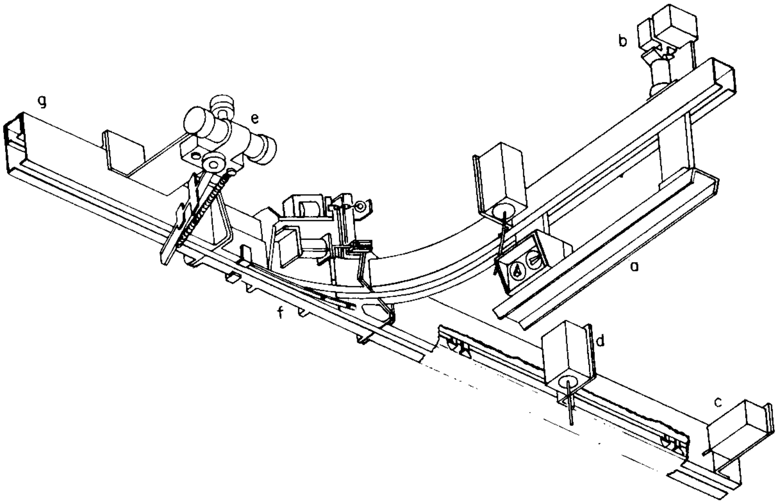


Fig. 10.5.6 Switch mechanism reentering trolley from free rail to power rail. *(ACCO Chain Conveyor Division.)*

Trolley Stops. Used to stop work carriers, these operate either automatically or manually on a free track section or on a powered section. Automatically, stops are usually operated pneumatically or electromechanically.

Storage. Portions or spurs of power-and-free conveyors are usually dedicated to the storage (accumulation) of work carriers. Unique to the design, type, or application, storage may be accomplished on (1) level hand-pushed lines, (2) gravity sloped lines (usually with overspeed-control retarders), (3) power lines with spring-loaded pusher dogs, or (4) powered lines with automatic accumulating free trolleys.

Inclines and Declines. As in the case of trolley conveyors, vertical inclines and declines are common to power-and-free. In addition to safety devices used on trolley conveyors, similar devices may be applied to free trolleys.

Load Bars and Carriers. The design of load bars, bumpers, swivel devices, index devices, hooks, or carriers is developed at the time of the initial power-and-free investigation. The system will see only the carrier, and all details of system design are a function of its design. How the commodity is being handled on or in the carrier is carefully considered to facilitate its use throughout the system, manually, automatically, or both.

Vertical Conveyor Sections. Vertical conveyor sections are often used as an accessory to power-and-free. For practical purposes, the vertical conveyor can be divided into two classes of devices:

Drop (Lift) Section. This device is used to drop (or lift) the work carrier vertically to a predetermined level in lieu of vertical inclines or declines. One common reason for its use is to conserve space. The unit may be powered by a cylinder or hoist, depending on the travel distance, cycle time, and load. One example of the use of a drop (lift) section is to receive a carrier on a high level and lower it to an operations level. The lower level may be a load-unload station or processing station. Automatic safety stops are used to close open rail ends.

Interfloor Vertical Conveyor. When used for interfloor service and long lifts, the vertical conveyor may be powered by high-speed hoists or elevating machines. In any case, the carriers are automatically transferred to and from the lift, and the dispatch control on the carrier can instruct the machine as to the destination of the carrier. Machines can be equipped with a variety of speeds and operating characteristics. Multiple carriers may be handled, and priority-call control systems can be fitted to suit individual requirements.

NONCARRYING CONVEYORS

Flight Conveyors **Flight conveyors** are used for moving granular, lumpy, or pulverized materials along a horizontal path or on an incline seldom greater than about 40°. Their principal application is in handling coal. The flight conveyor of usual construction should not be specified for a material that is actively abrasive, such as damp sand and ashes. The **drag-chain conveyor** (Fig. 10.5.7) has an open-link chain, which serves, instead of flights, to push the material along. With a hard-faced concrete or cast-iron trough, it serves well for handling ashes. The return run is, if possible, above the carrying run, so that the dribble will be back into the loaded run. A feeder must be provided unless the feed is otherwise controlled, as from a tandem elevator or conveyor. As the feeder is interlocked, either mechanically or electrically, the feed stops if the conveyor stops. Flight conveyors may be classified as **scraper type** (Fig. 10.5.8), in which the element (chain and flights) rests on the trough; **suspended-flight type** (Fig. 10.5.9), in which the flights are carried clear of the trough by shoes resting on guides; and **suspended-chain type** (Fig. 10.5.10), in which the chain rests on guides, again carrying the flights clear of the trough. These types are further differentiated as **single-strand** (Figs. 10.5.8 and 10.5.9) and **double-strand** (Fig. 10.5.10). For lumpy material, the latter has the advantage since the lumps will enter the trough without interference. For heavy duty also, the double strand has the advantage, in that the pull is divided between two chains. A special type for simultaneous handling of several materials may have the trough divided by longitudinal partitions. The material having the greatest coefficient of friction is then carried, if possible, in the central zone to equalize chain wear and stretch.

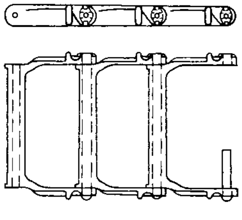


Fig. 10.5.7 Drag chain.

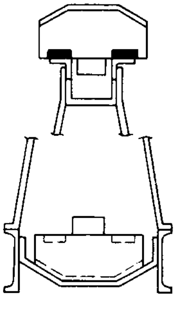


Fig. 10.5.8 Single-strand scraper-flight conveyor.

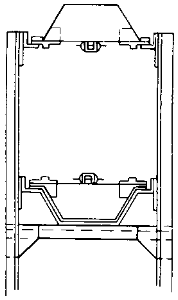


Fig. 10.5.9 Single-strand suspended-flight conveyor.

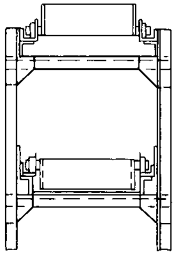


Fig. 10.5.10 Double-strand roller-chain flight conveyor.

Improvements in the welding and carburizing of welded-link chain have made possible its use in flight conveyors, offering several significant advantages, including economy and flexibility in all directions. Figure 10.5.11 shows a typical scraper-type flight cast from malleable iron incorporated onto a slotted conveyor bed. The small amount of fines that fall through the slot are returned to the top of the bed by the returning flights. Figure 10.5.12 shows a double-chain scraper conveyor in which the ends of the flights ride in a restrictive channel. These types of flight conveyors are driven by pocket wheels.

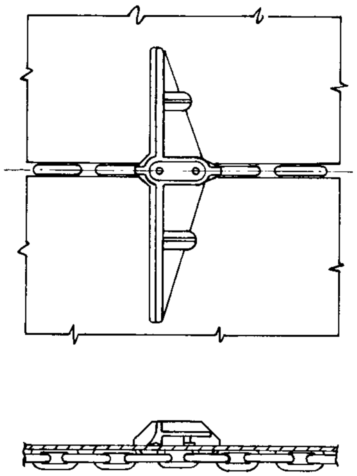


Fig. 10.5.11 Scraper flight with welded chain.

Flight conveyors of small capacity operate usually at 100 to 150 ft/min (0.51 to 0.76 m/s). Large-capacity conveyors operate at 100 ft/min (0.51 m/s) or slower; their long-pitch chains hammer heavily against the drive-sprocket teeth or pocket wheels at higher speeds. A conveyor steeply inclined should have closely spaced flights so that the material will not avalanche over the tops of the flights. The capacity of a given conveyor diminishes as the angle of slope increases. For the heaviest duty, hardened-face rollers at the articulations are essential.

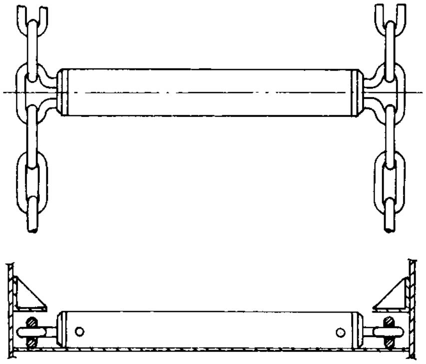


Fig. 10.5.12 Scraper flight using parallel welded chains.

Cautions in Flight-Conveyor Selections With abrasive material, the trough design should provide for renewal of the bottom plates without disturbing the side plates. If the conveyor is inclined and will reverse when halted under load, a solenoid brake or other automatic backstop should be provided. Chains may not wear or stretch equally. In a double-strand conveyor, it may be necessary to shift sections of chain from one side to the other to even up the lengths.

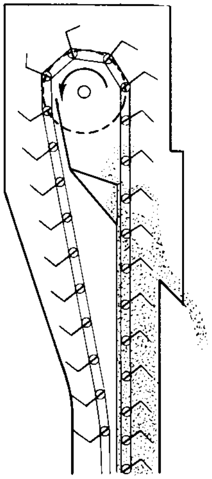


Fig. 10.5.13 Bulk-flow continuous-flow elevator.

Intermediate slide gates should be set to open in the opposite direction to the movement of material in the conveyor.

The **continuous-flow conveyor** serves as a conveyor, as an elevator, or as a combination of the two. It is a slow-speed machine in which the material moves as a continuous core within a duct. Except with the **Redler** conveyor, the element is formed by a single strand of chain with closely spaced impellers, somewhat resembling the flights of a flight conveyor.

The **Bulk flo** (Fig. 10.5.13) has peaked flights designed to facilitate the outflow of the load at the point of discharge. The load, moved by a positive push of the flights, tends to provide self-clearing action at the end of a run, leaving only a slight residue.

The **Redler** (Fig. 10.5.14) has skeletonized or U-shaped impellers which move the material in which they are submerged because the resistance to slip through the element is greater than the drag against the walls of the duct.

Materials for which the continuous-flow conveyor is suited are listed below in groups of increasing difficulty. The constant C is used in the power equations below, and in Fig. 10.5.16.

$C = 1$: clean coal, flaxseed, graphite, soybeans, copra, soap flakes
$C = 1.2$: beans, slack coal, sawdust, wheat, wood chips (dry), flour
$C = 1.5$: salt, wood chips (wet), starch
$C = 2$: clays, fly ash, lime (pebble), sugar (granular), soda ash, zinc oxide
$C = 2.5$: alum, borax, cork (ground), limestone (pulverized)

Among the materials for which special construction is advised are bauxite, brown sugar, hog fuel, wet coal, shelled corn, foundry dust, cement, bug dust, hot brewers' grains. The machine should not be specified for ashes, bagasse, carbon-black pellets, sand and gravel, sewage sludge, and crushed stone. Fabrication from corrosion-resistant materials such as brass, monel, or stainless steel may be necessary for use with some corrosive materials.

Where a single **runaround conveyor** is required with multiple feed points and some recirculation of excess load, the Redler serves. The U-frame flights do not squeeze the loads, as they resume parallelism after separating when rounding the terminal wheels. As an elevator, this machine will also handle sluggish materials that do not flow out readily. A pusher plate opposite the discharge chute can be employed to enter between the legs of the U flights to push out such material. When horizontal or inclined, continuous-flow elevators such as the Redler are normally self-cleaning. When vertical, the Redler type can be made self-cleaning (except with sticky materials) by use of special flights.

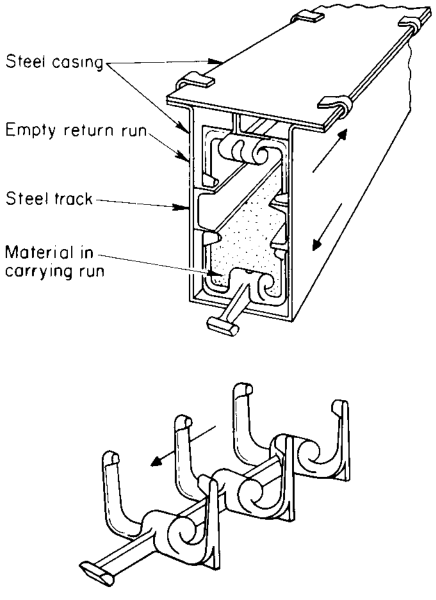


Fig. 10.5.14 Redler U-type continuous-flow conveyor.

Continuous-flow conveyors and elevators do not require a feeder (Fig. 10.5.15). They are self-loading to capacity and will not overload, even though there are several open- or uncontrolled-feed openings, since the duct fills at the first opening and automatically prevents the entrance of additional material at subsequent openings. Some special care may be required with free-flowing material.

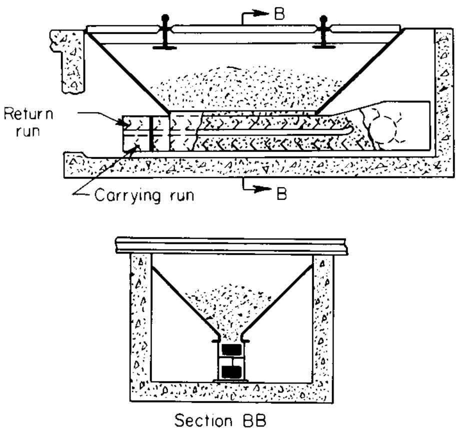


Fig. 10.5.15 Shallow-track hopper for continuous-flow conveyor with feed to return run.

The duct is easily insulated by sheets of asbestos cement or similar material to reduce cooling in transit. As the duct is completely sealed, there is no updraft where the lift is high. The material is protected from exposure and contamination or contact with lubricants. The handling capacity for horizontal or inclined lengths (nearly to the angle of repose of the material) approximates 100 percent of the volume swept through by the movement of the element. For steeper inclines or elevators, it is between 50 and 90 percent.

If the material is somewhat abrasive, as with wet bituminous coal, the duct should be of corrosion-resistant steel, of extra thickness, and the chain pins should be both extremely hard and of corrosion-resistant material.

A long horizontal run followed by an upturn is inadvisable because of radial thrust. Lumpy material is difficult to feed from a track hopper. An automatic brake is unnecessary, as an elevator will reverse only a few inches when released.

The motor horsepower *P* required by continuous-flow conveyors for the five arrangements shown in Fig. 10.5.16 is given in the accompanying formulas in terms of the capacity *T*, in tons per h; the horizontal run *H*, ft; the vertical lift *V*, ft; and the constant *C*, values for which are given above. If loading from a track hopper, add 10 percent.

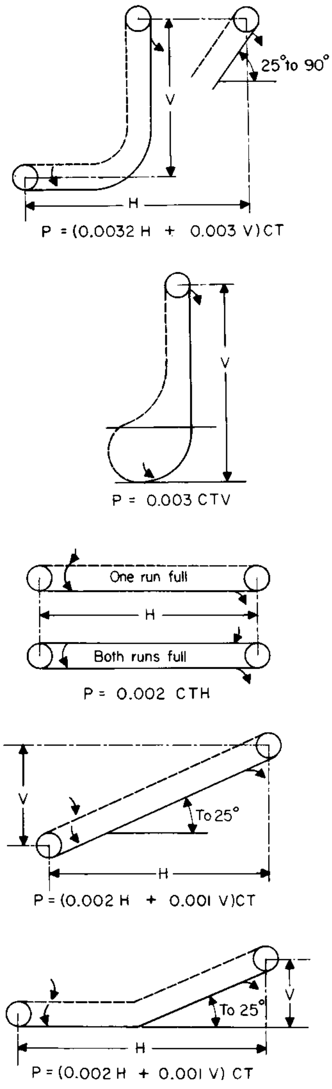


Fig. 10.5.16 Continuous-flow-conveyor arrangements.

Screw Conveyors

The screw, or spiral, conveyor is used quite widely for pulverized or granular, noncorrosive, nonabrasive materials when the required capacity is moderate, when the distance is not more than about 200 ft (61 m), and when the path is not too steep. It usually costs substantially less than any other type of conveyor and is readily made dusttight by a simple cover plate.

The conveyor will handle lumpy material if the lumps are not large in proportion to the diameter of the helix. If the length exceeds that advisable for a single conveyor, separate or tandem units are readily arranged. Screw conveyors may be inclined. A standard-pitch helix will handle material on inclines up to 35°. The reduction in capacity as compared with the capacity when horizontal is indicated in the following table:

Inclination, deg	10	15	20	25	30	35
Reduction in capacity, percent	10	26	45	58	70	78

Abrasive or corrosive materials can be handled with suitable construction of the helix and trough.

The standard screw-conveyor helix (Fig. 10.5.17) has a pitch approximately equal to its outside diameter. Other forms are used for special cases.

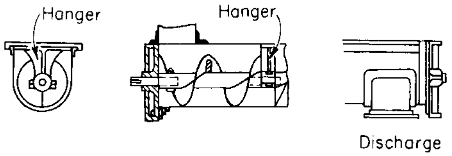


Fig. 10.5.17 Spiral conveyor.

Short-pitch screws are advisable for inclines above 29°.

Variable-pitch screws, with short pitch at the feed end, automatically control the flow to the conveyor so that the load is correctly proportioned for the length beyond the feed point. With a short section either of shorter pitch or of smaller diameter, the conveyor is self-loading to capacity and does not require a feeder.

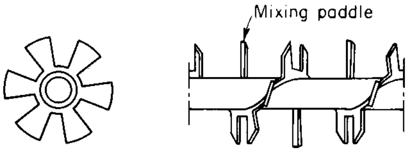


Fig. 10.5.18 Cut-flight conveyor.

Cut flights (Fig. 10.5.18) are used for conveying and mixing cereals, grains, and other light materials.

Ribbon screws (Fig. 10.5.19) are used for wet and sticky materials, such as molasses, hot tar, and asphalt, which might otherwise build up on the spindle.

Paddle screws are used primarily for mixing such materials as mortar and bitulithic paving mixtures. One typical application is to churn ashes and water to eliminate dust.

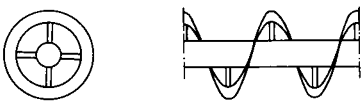


Fig. 10.5.19 Ribbon conveyor.

Standard constructions have a plain or galvanized-steel helix and trough. For abrasives and corrosives such as wet ashes, both helix and trough may be of hard-faced cast iron. For simple abrasives, the outer edge of the helix may be faced with a renewable strip of Stellite or

Table 10.5.3 Capacities and Speed of Spiral Conveyors

Group	Max percent of cross section occupied by the material	Max density of material, lb/ft³ (kg/m³)	Max r/min for diameters	
			6 in (152 mm)	20 in (508 mm)
1	45	50 (800)	170	110
2	38	50 (800)	120	75
3	31	75 (1,200)	90	60
4	25	100 (1,600)	70	50
5	12½		30	25

Group 1 includes light materials such as barley, beans, brewers grains (dry), coal (pulv.), corn meal, cottonseed meal, flaxseed, flour, malt, oats, rice, wheat. The value of the factor F is 0.5.

Group 2 includes fines and granular materials. The values of F are alum (pulv.), 0.6, coal (slack or fines), 0.9; coffee beans, 0.4; sawdust, 0.7; soda ash (light), 0.7; soybeans, 0.5; fly ash, 0.4.

Group 3 includes materials with small lumps mixed with fines. Values of F are alum, 1.4; ashes (dry), 4.0; borax, 0.7; brewers grains (wet), 0.6; cottonseed, 0.9; salt, course or fine, 1.2; soda ash (heavy), 0.7.

Group 4 includes semiabrasive materials, fines, granular and small lumps. Values of F are acid phosphate (dry), 1.4; bauxite (dry), 1.8; cement (dry), 1.4; clay, 2.0; fuller's earth, 2.0; lead salts, 1.0; limestone screenings, 2.0; sugar (raw), 1.0; white lead, 1.0; sulfur (lumpy), 0.8; zinc oxide, 1.0.

Group 5 includes abrasive lumpy materials which must be kept from contact with hanger bearings. Values of F are wet ashes, 5.0; flue dirt, 4.0; quartz (pulv.), 2.5; silica sand, 2.0; sewage sludge (wet and sandy), 6.0.

similar extremely hard material. For food products, aluminum, bronze, monel metal, or stainless steel is suitable but expensive.

Table 10.5.3 gives the capacities, allowable speeds, percentages of helix loading for five groups of materials, and the factor F used in estimating the power requirement.

Table 10.5.4 gives the handling capacities for standard-pitch screw conveyors in each of the five groups of materials when the conveyors are operating at the maximum advised speeds and in the horizontal position. The capacity at any lower speed is in the ratio of the speeds.

Power Requirements The power requirements for horizontal screw conveyors of standard design and pitch are determined by the Link-Belt Co. by the formula that follows. Additional allowances should be made for inclined conveyors, for starting under load, and for materials that tend to stick or pack in the trough, as with cement.

$$H = \text{hp at conveyor head shaft} = (ALN + CWLF) \times 10^{-6}$$

where A = factor for size of conveyor (see Table 10.5.5); C = quantity of material, ft³/h; L = length of conveyor, ft; F = factor for material (see Table 10.5.3); N = r/min of conveyor; W = density of material, lb/ft³.

The motor size depends on the efficiency E of the drive (usually close to 90 percent); a further allowance G, depending on the horsepower, is made:

H	1	1–2	2–4	4–5	5
G	2	1.5	1.25	1.1	1.0

$$\text{Motor hp} = HG/E$$

When the material is distributed into a bunker, the conveyor has an open-bottom trough to discharge progressively over the crest of the pile so formed. This trough reduces the capacity and increases the required power, since the material drags over the material instead of over a polished trough.

If the material contains unbreakable lumps, the helix should clear the trough by at least the diameter of the average lump. For a given capacity, a conveyor of larger size and slower speed is preferable to a conveyor of minimum size and maximum speed. For large capacities and lengths, the alternatives—a flight conveyor or a belt conveyor—should receive consideration.

EXAMPLES. 1. Slack coal 50 lb/ft³ (800 kg/m³); desired capacity 50 tons/h (2,000 ft³/h) (45 tonnes/h); conveyor length, 60 ft (18 m); 14-in (0.36-m) conveyor at 80 r/min. F for slack coal = 0.9 (group 2).

$$H = (255 \times 60 \times 80 + 2{,}000 \times 50 \times 60 \times 0.9)/1{,}000{,}000 = 6.6$$
$$\text{Motor hp} = (6.6 \times 1.0)/0.90 = 7.3 \qquad (5.4\ \text{kW})$$

Use 7½-hp motor.

2. Limestone screenings, 90 lb/ft³; desired capacity, 10 tons/h (222 ft³/h); conveyor length, 50 ft; 9-in conveyor at 50 r/min. F for limestone screenings = 2.0 (group 4).

$$H = (96 \times 50 \times 50 + 222 \times 90 \times 50 \times 2.0)/1{,}000{,}000 = 2.24$$
$$\text{Motor hp} = (2.24 \times 1.25)/0.90 = 2.8$$

Use 3-hp motor.

Chutes

Bulk Material If the material is fragile and cannot be set through a simple **vertical chute,** a **retarding chute** may be specified. Figure 10.5.20 shows a ladder chute in which the material trickles over shelves instead of falling freely. If it is necessary to minimize breakage when material is fed from a bin, a vertical box chute with flap doors opening inward, as shown in Fig. 10.5.21, permits the material to flow downward only from the top surface and eliminates the degradation that results from a converging flow from the bottom of the mass.

Straight inclined chutes for coal should have a slope of 40 to 45°. If it is found that the coal accelerates objectionably, the chute may be provided with cross angles over which the material cascades at reduced speed (Fig. 10.5.22).

Lumpy material such as coke and large coal, difficult to control when flowing from a bin, can be handled by a chain-controlled feeder chute with a screen of heavy endless chains hung on a sprocket shaft (Fig. 10.5.23). The weight of the chain curtain holds the material in the chute. When a feed is desired, the sprocket shaft is revolved slowly, either manually or by a motorized reducer.

Unit Loads **Mechanical handling of unit loads,** such as boxes, barrels, packages, castings, crates, and palletized loads, calls for methods and

Table 10.5.4 Screw-Conveyor Capacities
(ft³/h)

Group	Conveyor size, in*							
	6	9	10	12	14	16	18	20
1	350	1,100	1,600	2,500	4,000	5,500	7,600	10,000
2	220	700	950	1,600	2,400	3,400	4,500	6,000
3	150	460	620	1,100	1,600	2,200	3,200	4,000
4	90	300	400	650	1,000	1,500	2,000	2,600
5	20	68	90	160	240	350	500	650

*Multiply by 25.4 to obtain mm.

Table 10.5.5 Factor *A*
(Self-lubricating bronze bearings assumed)

Diam of conveyor, in	6	9	10	12	14	16	18	20	24
mm	152	229	254	305	356	406	457	508	610
Factor *A*	54	96	114	171	255	336	414	510	690

mechanisms entirely different from those adapted to the movement of bulk materials.

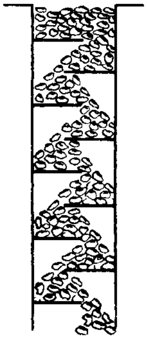


Fig. 10.5.20 Ladder chute.

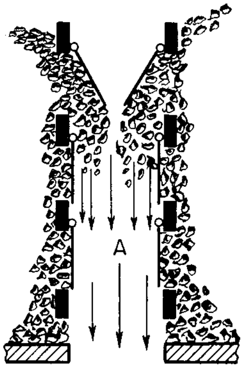


Fig. 10.5.21 Box chute with flap doors. Chute is always full up to discharging point.

Spiral chutes are adapted for the direct lowering of unit loads of various shapes, sizes, and weights, so long as their slide characteristics do not vary widely. If they do vary, care must be exercised to see that items accelerating on the selected helix pitch do not crush or damage those ahead.

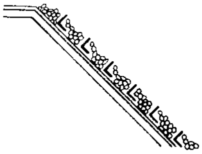


Fig. 10.5.22 Inclined chute with cross angles.

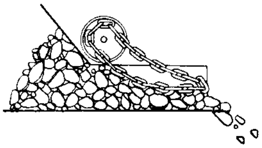


Fig. 10.5.23 Chain-controlled feeder chute.

A spiral chute may extend through several floors, e.g., for lowering parcels in department stores to a basement shipping department. The opening at each floor must be provided with automatic closure doors, and the design must be approved by the Board of Fire Underwriters.

At the discharge end, it is usual to extend the chute plate horizontally to a length in which the loads can come to rest. A tandem gravity roll conveyor may be advisable for distribution of the loads.

The **sheet-metal spiral** (Fig. 10.5.24) has a fixed blade and can be furnished in varying diameters and pitches, both of which determine the maximum size of package that can be handled. These chutes may have receive and discharge points at any desired floors. There are certain kinds of commodities, such as those made of metal or bound with wire or metal bands, that cannot be handled satisfactorily unless the spiral chute is designed to handle only that particular commodity. Sheet-metal spirals can be built with double or triple blades, all mounted on the same standpipe. Another form of sheet-metal spiral is the open-core type, which is especially adaptable for handling long and narrow articles or bulky classes of merchandise or for use where the spiral must wind around an existing column or pass through floors in locations limited by beams or girders that cannot be conveniently cut or moved. For handling bread or other food products, it is customary to have the spiral tread made from monel metal or aluminum.

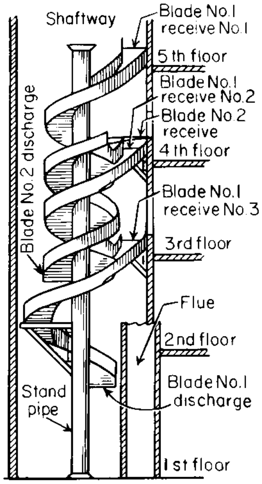


Fig. 10.5.24 Metal spiral chute.

CARRYING CONVEYORS

Apron Conveyors

Apron conveyors are specified for granular or lumpy materials. Since the load is carried and not dragged, less power is required than for screw or scraper conveyors. Apron conveyors may have stationary skirt or side plates to permit increased depth of material on the apron, e.g., when used as a feeder for taking material from a track hopper (Fig. 10.5.25)

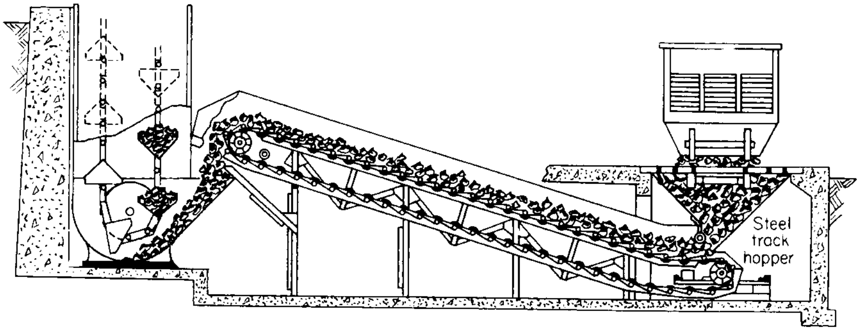


Fig. 10.5.25 Track hopper and apron feeder supplying a gravity-discharge bucket-elevator boot.

with controlled rate of feed. They are not often specified if the length is great, since other types of conveyor are substantially lower in cost. Sizes of lumps are limited by the width of the pans and the ability of the conveyor to withstand the impact of loading. Only end discharge is possible. The apron conveyor (Fig. 10.5.26) consists of two strands of roller chain separated by overlapping apron plates, which form the carrying surface, with sides 2 to 6 in (51 to 152 mm) high. The chains are driven by sprockets at one end, take-ups being provided at the other end. The conveyors always pull the material toward the driving end. For light duty, flangeless rollers on flat rails are used; for heavy duty, single-flanged rollers and T rails are used. Apron conveyors may be run without feeders, provided that the opening of the feeding hopper is made sufficiently narrow to prevent material from spilling over the sides of the conveyor after passing from the opening. When used as a conveyor, the **speed** should not exceed 60 ft/min (0.30 m/s); when used as a feeder, 30 ft/min (0.15 m/s). Table 10.5.6 gives the capacities of apron feeders with material weighing 50 lb/ft^3 (800 kg/m^3) at a speed of 10 ft/min (0.05 m/s).

Chain pull for horizontal-apron conveyor:

$$2LF(W + W_1)$$

Chain pull for inclined-apron conveyor:

$$L(W + W_1)(F \cos \theta + \sin \theta) + WL(F \cos \theta - \sin \theta)$$

where L = conveyor length, ft; W = weight of chain and pans per ft, lb; W_1 = weight of material per ft of conveyor, lb; θ = angle of inclination, deg; F = coefficient of rolling friction, usually 0.1 for plain roller bearings or 0.05 for antifriction bearings.

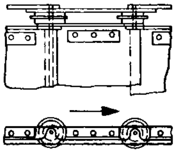


Fig. 10.5.26 Apron conveyor.

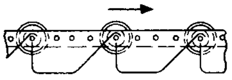


Fig. 10.5.27 Open-top carrier.

Bucket Conveyors and Elevators

Open-top bucket carriers (Fig. 10.5.27) are similar to apron conveyors, except that dished or bucket-shaped receptacles take the place of the flat or corrugated apron plates used on the apron conveyor. The carriers will operate on steeper inclines than apron conveyors (up to 70°), as the buckets prevent material from sliding back. Neither sides extending above the tops of buckets nor skirtboards are necessary. **Speed,** when loaded by a feeder, = 60 ft/min (max)(0.30 m/s) and when dragging the load from a hopper or bin, $\leqq$ 30 ft/min. The **capacity** should be calculated on the basis of the buckets being three-fourths full, the angle of inclination of the conveyor determining the loading condition of the bucket.

V-bucket carriers are used for elevating and conveying nonabrasive materials, principally coal when it must be elevated and conveyed with one piece of apparatus. The length and height lifted are limited by the strength of the chains and seldom exceed 75 ft (22.9 m). These carriers can operate on any incline and can discharge at any point on the horizontal run. The size of lumps carried is limited by the size and spacing of the buckets. The carrier consists of two strands of roller chain separated by V-shaped steel buckets. Figure 10.5.28 shows the most common form, where material is received on the lower horizontal run, elevated, and discharged through openings in the bottom of the trough of the upper horizontal run. The material is scraped along the horizontal trough of the conveyor, as in a flight conveyor. The steel guard plates *a* at the right prevent spillage at the bends. Figure 10.5.29 shows a different form, where material is dug by the elevator from a boot, elevated vertically, scraped along the horizontal run, and discharged through gates in the bottom of the trough. Figure 10.5.30 shows a variation of the type shown in Fig. 10.5.29, requiring one less bend in the conveyor. The troughs are of steel or steel-lined wood. When feeding material to the horizontal run, it is advisable to use an automatic feeder driven by power from one of the bend shafts to prevent overloading. Should the buckets of this type of conveyor be overloaded, they will spill on the vertical section. The drive is located at *b*, with take-up at *c*. The speed should not exceed 100 ft/min (0.51 m/s) when large material is being handled, but when material is small, speed may be increased to 125 ft/min (0.64 m/s). The best results are obtained when speeds are kept low. Table 10.5.7 gives the **capacities** and **weights** based on an even and continuous feed.

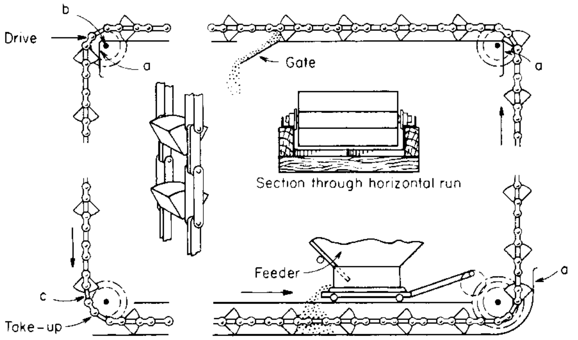


Fig. 10.5.28 V-bucket carrier.

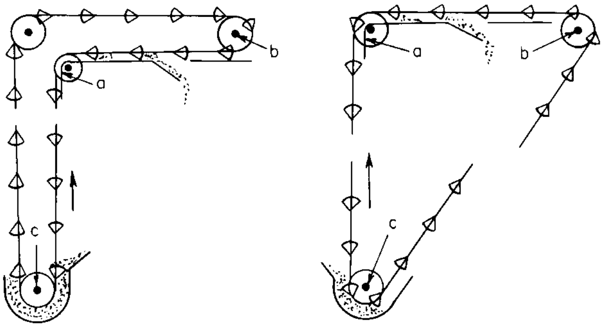


Fig. 10.5.29 and 10.5.30 V-bucket carriers.

Pivoted-bucket carriers are used primarily where the path is a run-

Table 10.5.6 Capacities of Apron Conveyors

Width between skirt plates		Capacity, 50 lb/ft^3 (800 kg/m^3) material at 10 ft/min (0.05 m/s) speed			
		Depth of load, in (mm)			
in	mm	12 (305)	16 (406)	20 (508)	24 (610)
24	610	22 (559)	30 (762)		
30	762	26 (660)	37 (940)	47 (1,194)	56 (1,422)
36	914	34 (864)	45 (1,143)	56 (1,422)	67 (1,702)
42	1,067	39 (991)	52 (1,321)	65 (1,651)	79 (2,007)

Table 10.5.7 Capacities and Weights of V-Bucket Carriers*

Buckets				Capacity, tons of coal per hour at 100 ft/min	Weight per ft of chains and buckets, lb
Length, in	Width, in	Depth, in	Spacing, in		
12	12	6	18	29	36
16	12	6	18	32	40
20	15	8	24	43	55
24	20	10	24	100	65
30	20	10	24	126	70
36	24	12	30	172	94
42	24	12	30	200	105
48	24	12	36	192	150

* Multiply in by 25.4 for mm, ton/h by 0.25 for kg/s or by 0.91 for tonnes/h.

around in a vertical plane. Their chief application has been for the dual duty of handling coal and ashes in boiler plants. They require less power than V-bucket carriers, as the material is carried and not dragged on the horizontal run. The length and height lifted are limited by the strength of the chains. The length seldom exceeds 500 ft (152 m) and the height lifted 100 ft (30 m). They can be operated on any incline and can discharge at any point on the horizontal run. The size of lumps is limited by the size of buckets. The maintenance cost is extremely low. Many carrier installations are still in operation after 40 years of service. Other applications are for hot clinker, granulated and pulverized chemicals, cement, and stone.

The carrier consists of two strands of roller chain, with flanged rollers, between which are pivoted buckets, usually of malleable iron. The drive (Fig. 10.5.31) is located at *a* or *a′*, the take-up at *b*. The material is fed to the buckets by a feeder at any point along the lower horizontal run, is elevated, and is discharged on the upper horizontal run. The tripper *c*, mounted on wheels so that it can be moved to the desired dumping position, engages the cams on the buckets and tips them until the material runs out. The buckets always remain vertical except when tripped. The chain rollers run on T rails on the horizontal sections and between guides on the vertical runs. Speeds range from 30 to 60 ft/min (0.15 to 0.30 m/s).

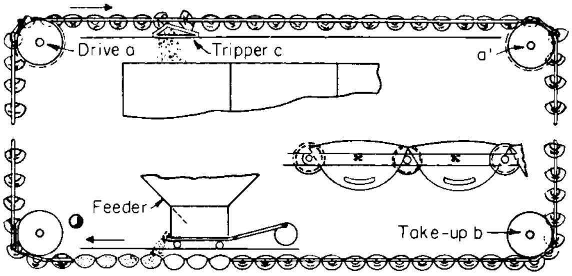


Fig. 10.5.31 Pivoted-bucket carrier.

After dumping, the overlapping bucket lips are in the wrong position to round the far corner; after rounding the take-up wheels, the lap is wrong for making the upturn. The Link-Belt **Peck** carrier eliminates this by suspending the buckets from trunnions attached to rearward cantilever extensions of the inner links (Fig. 10.5.32). As the chain rounds the turns, the buckets swing in a larger-radius curve, automatically unlatch, and then lap correctly as they enter the straight run.

The pivoted-bucket carrier requires little attention beyond periodic lubrication and adjustment of take-ups. For the dual service of coal and ash handling, its only competitor is the skip hoist.

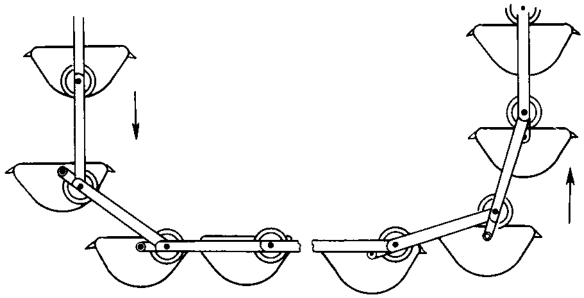


Fig. 10.5.32 Link-Belt Peck carrier buckets.

Table 10.5.8 shows the capacities of pivoted-bucket carriers with materials weighing 50 lb/ft^3 (800 kg/m^3), with carriers operating at 40 to 50 ft/min (0.20 to 0.25 m/s), and with buckets loaded to 80 percent capacity.

Bucket elevators are of two types: (1) chain-and-bucket, where the buckets are attached to one or two chains; and (2) belt-and-bucket, where the buckets are attached to canvas or rubber belts. Either type may be vertical or inclined and may have continuous or noncontinuous buckets. Bucket elevators are used to elevate any bulk material that will not adhere to the bucket. Belt-and-bucket elevators are particularly well adapted to handling abrasive materials which would produce excessive wear on chains. Chain-and-bucket elevators are frequently used with perforated buckets when handling wet material, to drain off surplus water. The length of elevators is limited by the strength of the chains or belts. They may be built up to 100 ft (30 m) long, but they average 25 to 75 ft (7.6 to 23 m). Inclined-belt elevators operate best on an angle of about 30° to the vertical. At greater angles, the sag of the return belt is excessive, as it cannot be supported by rollers between the head and foot pulleys. This applies also to single-strand chain elevators. Double-strand chain elevators, however, if provided with roller chain, can run on an angle, as both the upper and return chains are supported by rails.

Table 10.5.8 Capacities of Pivoted-Bucket Carriers with Coal or Similar Materials Weighing 50 lb/ft^3 (800 kg/m^3) at Speeds Noted

Bucket pitch × width		Capacity of coal		Speed	
in	mm	Short ton/h	tonne/h	ft/min	m/s
24 × 18	610 × 457	35–45	32–41	40–50	0.20–0.25
24 × 24	610 × 610	50–60	45–54	40–50	0.20–0.25
24 × 30	610 × 762	60–75	54–68	40–50	0.20–0.25
24 × 36	610 × 914	70–90	63–82	40–50	0.20–0.25

The size of lumps is limited by the size and spacing of the buckets and by the speed of the elevator.

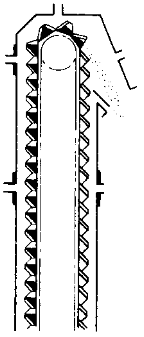


Fig. 10.5.33 Continuous bucket.

Continuous-bucket elevators (Fig. 10.5.33 and Table 10.5.9) usually operate at 100 ft/min (0.51 m/s) or less and are single- or double-strand. The contents of each bucket discharge over the back of the preceding bucket. For maximum capacity and a large proportion of lumps, the buckets extend rearward behind the chain runs. The elevator is then called a supercapacity elevator (Fig. 10.5.34 and Table 10.5.10).

Gravity-discharge elevators operate at 100 ft/min (0.51 m/s) or less and are double-strand, with spaced V buckets. The path may be an L, an inverted L, or a runaround in a vertical plane (Fig. 10.5.28). Along the horizontal run, the buckets function as pushers within a trough. An elevator with a tandem flight conveyor costs less. For a runaround path, the pivoted-bucket carrier requires less power and has lower maintenance costs.

Table 10.5.9 Continuous Bucket Elevators*

Bucket size in	Max lump size, in		Capacity with 50 lb material at 100 ft/min tons/h
	All lumps	10% lumps	
10 × 5 × 8	¾	2½	17
10 × 7 × 12	1	3	21
12 × 7 × 12	1	3	25
14 × 7 × 12	1	3	30
14 × 8 × 12	1¼	4	36
16 × 8 × 12	1½	4½	42
18 × 8 × 12	1½	4½	46

* Multiply in by 25.4 for mm, lb by 0.45 for kg, tons by 0.91 for tonnes.

As bucket elevators have no **feed control,** an interlocked feeder is desirable for a gravity flow. Some types scoop up the load as the buckets round the foot end and can take care of momentary surges by spilling the excess back into the boot. The continuous-bucket elevator, however, must be loaded after the buckets line up for the lift, i.e., when the gaps between buckets have closed.

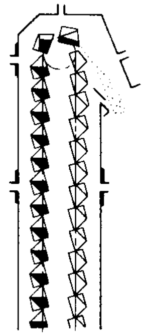


Fig. 10.5.34 Supercapacity bucket.

Belt-and-bucket elevators are advantageous for grain, cereals, glass batch, clay, coke breeze, sand, and other abrasives if the temperature is not high enough to scorch the belt [below 250°F (121°C) for natural rubber].

Elevator casings usually are sectional and dusttight, either of 3⁄16-in (4.8-mm) sheet steel or, better, of aluminum. If the elevator has considerable height, its cross section must be sufficiently large to prevent sway contact between buckets and casing. Chain guides extending the length of both runs may be provided to control sway and to prevent piling up of the element, at the boot, should the chain break. **Caution:** Indoor high elevators may develop considerable updraft tending to sweep up light, pulverized material. Provision to neutralize the pressure differential at the top and bottom may be essential. Figure 10.5.35 shows the **cast-iron boot** used with centrifugal-discharge and V-bucket chain elevators and belt elevators. Figure 10.5.36 shows the general form of a belt-and-bucket elevator with **structural-steel boot and casing.** Elevators of this type must be run at sufficient speed to throw the discharging material clear of the bucket ahead.

Table 10.5.10 Supercapacity Elevators*
(Link-Belt Co.)

Bucket, in length × width × depth	Max lump size, large lumps not more than 20%, in	Capacity with 50 lb material tons/h
16 × 12 × 18	8	115
20 × 12 × 18	8	145
24 × 12 × 18	8	175
30 × 12 × 18	8	215
24 × 17 × 24	10	230
36 × 17 × 24	10	345

* Multiply in by 25.4 for mm, lb by 0.45 for kg, tons by 0.91 for tonnes.

Capacity Elevators are rated for capacity with the buckets 75 percent loaded. The buckets must be large enough to accommodate the lumps, even though the capacity is small.

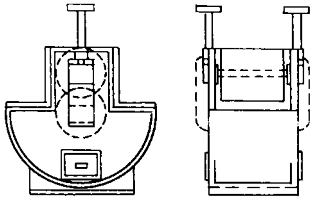


Fig. 10.5.35 Cast-iron boot.

Power Requirements The motor horsepower for the continuous-bucket and supercapacity elevators can be approximated as

$$\text{Motor hp} = (2 \times \text{tons/h} \times \text{lift, ft})/1{,}000$$

The motor horsepower of gravity-discharge elevators can be approximated by using the same formula for the lift and adding for the horsepower of the horizontal run the power as estimated for a flight conveyor. For a vertical runaround path, add a similar allowance for the lower horizontal run.

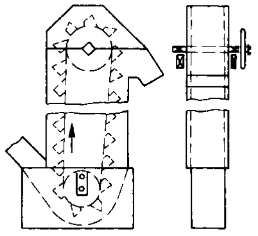


Fig. 10.5.36 Structural-steel boot and casing.

Belt Conveyors

The belt conveyor is a heavy-duty conveyor available for transporting large tonnages over paths beyond the range of any other type of mechanical conveyor. The capacity may be several thousand tons per hour, and the distance several miles. It may be horizontal or inclined upward or downward, or it may be a combination of these, as outlined in Fig. 10.5.37. The limit of incline is reached when the material tends to slip on the belt surface. There are special belts with molded designs to assist in keeping material from slipping on inclines. They will handle pulverized, granular, or lumpy material. Special compounds are available if material is hot or oily.

In its simplest form, the conveyor consists of a head or drive pulley, a take-up pulley, an endless belt, and carrying and return idlers. The spacing of the carrying idlers varies with the width and loading of the belt and usually is 5 ft (1.5 m) or less. Return idlers are spaced on 10-ft (3.0-m) centers or slightly less with wide belts. Sealed antifriction idler bearings are used almost exclusively, with pressure-lubrication fittings requiring attention about once a year.

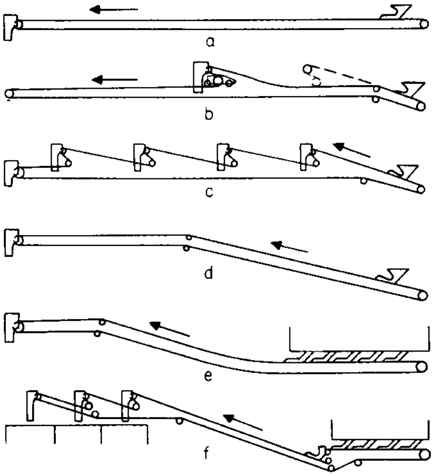


Fig. 10.5.37 Typical arrangements of belt conveyors.

Belts Belt width is governed by the desired conveyor capacity and maximum lump size. The standard rubber belt construction (Fig. 10.5.38) has several plies of square woven cotton duck or synthetic fabric such as rayon, nylon, or polyester cemented together with a rubber compound called ''friction'' and covered both top and bottom with rubber to resist abrasion and keep out moisture. Top cover thickness is determined by the severity of the job and varies from $\frac{1}{16}$ to ¾ in (1.6 to 19 mm). The bottom cover is usually $\frac{1}{16}$ in (1.6 mm). By placing a layer of loosely woven fabric, called the breaker strip, between the cover and outside fabric ply, it is often possible to double the adhesion of the cover to the carcass. The belt is rated according to the tension to which it may safely be subjected, and this is a function of the length and lift of the conveyor. The standard Rubber Manufacturers Association (RMA) multiple ply ratings in lb/in (kg/mm) of width per ply are as follows:

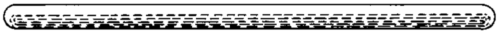


Fig. 10.5.38 Rubber-covered conveyor belt.

RMA multiple ply No.	MP35	MP43	MP50	MP60	MP70
Permissible pull, lb/in (kg/mm) of belt width per ply, vulcanized splice	35 (0.63)	43 (0.77)	50 (0.89)	60 (1.07)	70 (1.25)
Permissible pull, lb/in (kg/mm) of belt width per ply, mechanical splice	27 (0.48)	33 (0.60)	40 (0.71)	45 (0.80)	55 (0.98)

Thus, for a pull of 4,200 lb (1,905 kg) and 24-in (0.61-m) belt width, a five-ply MP35 could be used with a vulcanized splice or a five-ply MP50 could be used with a mechanical splice.

High-Strength Belts For belt conveyors of extremely great length, a greater strength per inch of belt width is available now through the use of improved weaving techniques that provide straight-warp synthetic fabric to support the tensile forces (Uniflex by Uniroyal, Inc., or Flexseal by B. F. Goodrich). Strengths go to 1,500 lb/in width tension rating. They are available in most cover and bottom combinations and have good bonding to carcass. The number of plies is reduced to two instead of as many as eight so as to give excellent flexibility. Widths to 60 in are available. Other conventional high-strength fabric belts are available to somewhat lower tensile ratings of 90 (1.61), 120 (2.14), 155 (2.77), 195 (3.48), and 240 (4.29) lb/in (kg/mm) per ply ratings.

The B. F. Goodrich Company has developed a steel-cable-reinforced belt rated 700 to 4,400 lb/in (12.5 to 78.6 kg/mm) of belt width. The belt has parallel brass-plated 7 by 19 steel airplane cables ranging from $\frac{5}{32}$ to $\frac{3}{8}$ in (4.0 to 9.5 mm) diameter placed on ½- to ¾-in (12.7- to 19.0-mm) centers.

These belts are used for long single-length conveyors and for high-lift, extremely heavy duty service, e.g., for taking ore from deep open pits, thus providing an alternative to a spiraling railway or truck route.

Synthetic rubber is in use for belts. Combinations of synthetic and natural rubbers have been found satisfactory. Synthetics are superior under special circumstances, e.g., neoprene for flame resistance and resistance to petroleum-based oils, Buna N for resistance to vegetable, animal, and petroleum oils, and butyl for resistance to heat (per RMA).

Belt Life With lumpy material, the impact at the loading point may be destructive. Heavy lumps, such as ore and rock, cut through the protective cover and expose the carcass. The impact shock is reduced by making the belt supports flexible. This can be done by the use of idlers with cushion or pneumatic tires (Fig. 10.5.39) or by supporting the idlers on rubber mountings. Chuting the load vertically against the belt should be avoided. Where possible, the load should be given a movement in the direction of belt travel. When the material is a mixture of lumps and fines, the fines should be screened through to form a cushion for the lumps. Other destructive factors are belt overstressing, belts running out of line and rubbing against supports, broken idlers, and failure to clean the belt surface thoroughly before it comes in contact with the snub and tripper pulleys. Introduction of a 180° twist in the return belt (B. F. Goodrich Co.) at both head and tail ends can be used to keep the clean side of the belt against the return idlers and to prevent buildup. Using one 180° twist causes both sides of the belt to wear evenly. For each twist, 1 ft of length/in of belt width is required.

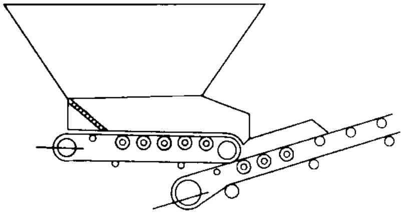


Fig. 10.5.39 Pneumatic-tired idlers applied to belt feeder at loading point of belt conveyor.

Idler Pulleys Troughing idlers are usually of the three-pulley type (Fig. 10.5.40), with the troughing pulleys at 20°. There is a growing tendency toward the use of 35 and 45° idlers to increase the volume capacity of a belt; 35° idlers will increase the volume capacity of a given belt 25 to 35 percent over 20° idlers, and 45° idlers, 35 to 40 percent.

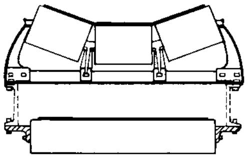


Fig. 10.5.40 Standard assembly of three-pulley troughing idler and return idler.

The bearings, either roller or ball type, are protected by felt or labyrinth grease seals against the infiltration of abrasive dust. A belt running out of line may be brought into alignment by shifting slightly forward one end or the other with a few idler sets. **Self-aligning idlers** (Fig. 10.5.41) should be spaced not more than 75 ft (23 m) apart. These call attention to the necessity of lining up the belt and should not serve as continuing correctives.

Drive Belt slip on the conveyor-drive pulley is destructive. There is little difference in tendency to slip between a bare pulley and a rubber-lagged pulley when the belt is clean and dry. A wet belt will adhere to a lagged pulley much better, especially if the lagging is grooved. Heavy-duty conveyors exposed to the possibility of wetting the belt are generally driven by a head pulley lagged with a ½-in (12.7-mm) rubber belt and with ¼- by ¼-in (6.4- by 6.4-mm) grooves spaced ½ in (12.7 mm) apart and, preferably, diagonally as a herringbone gear. A snub pulley can be employed to increase the arc of contact on the head pulley, and since the pulley is in contact with the dirty side of the belt, a belt cleaner is essential. The belt cleaner may be a high-speed bristle brush, a spiral rubber wiper (resembling an elongated worm pinion), circular disks mounted slantwise on a shaft to give a wiping effect when rotated, or a scraper. Damp deposits such as clay or semifrozen coal dirt are best removed by multiple diagonal scrapers of stainless steel.

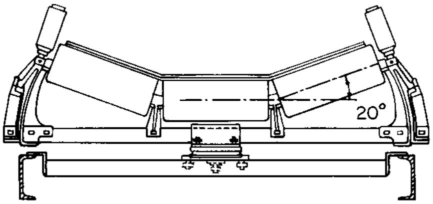


Fig. 10.5.41 Self-aligning idler.

A belt conveyor should be emptied after each run to avoid a heavy starting strain. The motor should have high starting torque, moderate starting-current inrush, and good characteristics when operating under full load. The double-squirrel-cage ac motor fulfills these requirements.

Heavy-Duty Belt-Conveyor Drives For extremely heavy duty, it is essential that the drive torque be built up slowly, or serious belt damage will occur. The hydraulic clutch, derived from the hydraulic automobile clutch, serves nicely. The best drive developed to date is the **dynamatic clutch** (Fig. 10.5.42). This has a magnetized rotor on the extended motor shaft, revolving within an iron ring keyed to the reduction gearing of the conveyor. The energizing current is automatically built up over a period that may extend to 2 min, and the increasing magnetic pull on the ring builds up the belt speed.

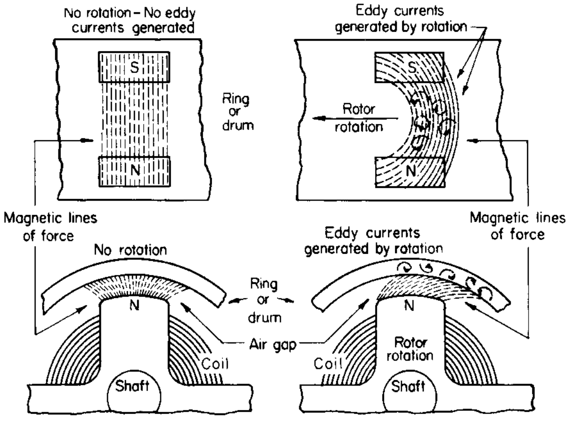


Fig. 10.5.42 Operating principle of the dynamic clutch.

Take-ups For short conveyors, a screw take-up is satisfactory. For long conveyors, the expansion and contraction of the belt with temperature changes and the necessity of occasional cutting and resplicing make a weighted gravity take-up preferable, especially if a vulcanized splice is used. The take-up should, if possible, be located where the slack first occurs, usually just back of the drive except in a conveyor inclined downward (retarding conveyor), when the take-up is located at the downhill end.

Trippers The load may be removed from the belt by a diagonal or V plow, but a tripper that snubs the belt backward is standard equipment. Trippers may be (1) stationary, (2) manually propelled by crank, or (3) propelled by power from one of the snubbing pulleys or by an independent motor. The discharge may be chuted to either side or back to the belt by a deflector plate. When the tripper must move back to the load-receiving end of the conveyor, it is usual to incline the belt for about 15 ft (4.6 m) to match the slope up to the tripper top pulley. As the lower tripper snub pulleys are in contact with the dirty side of the belt, a cleaner must be provided between the pulleys. A scraper in light contact with the face of the pulley may be advisable.

Belt Slope The slopes (in degrees) given in Table 10.5.11 are the maximum permissible angles for various materials.

Table 10.5.11 Maximum Belt Slopes for Various Materials, Degrees

Coal: anthracite, sized; mined, 50 mesh and under; or mined and sized	16
Coal, bituminous, mined, run of mine	18
Coal: bituminous, stripping, not cleaned; or lignite	22
Earth, as excavated, dry	20
Earth, wet, containing clay	23
Gravel, bank run	20
Gravel, dry, sharp	15–17
Gravel, pebbles	12
Grain, distillery, spent, dry	15
Sand, bank, damp	20–22
Sand, bank, dry	16–18
Wood Chips	27

SOURCE: Uniroyal, Inc.

Determination of Motor Horsepower The power required to drive a belt conveyor is the sum of the powers required (1) to move the empty belt, (2) to move the load horizontally, and (3) to lift the load if the conveyor is inclined upward. If (3) is larger than the other two, an automatic brake must be provided to hold the conveyor if the current fails. A solenoid brake is usual. The power required to move the empty belt is given by Fig. 10.5.43. The power to move 100 tons/h horizontally is given by the formula hp = 0.4 + 0.00325*L*, where *L* is the distance between centers, ft. For other capacities the horsepower is proportional.

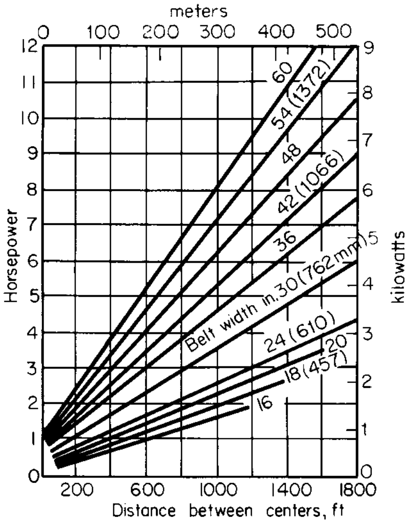


Fig. 10.5.43 Horsepower required to move belt conveyor empty at 100 ft/min (0.15 m/s).

Table 10.5.12 Troughed Conveyor-Belt Capacities*

Tons per hour (TPH) with belt speed of 100 ft/min (0.51 m/s).

Belt width, in	Belt shape:	Equal length, 3 roll										Long center, 3 roll						
	Idler angle:	20°			35°			45°				35°			45%			
	SCA†:	0°	10°	30°	0°	10°	30°	0°	10°	30°	CED‡	0°	10°	30°	0°	10°	30°	CED‡
12		10	14	24	16	20	28	19	29	35	.770							
24		52	74	120	83	102	143	98	115	150	1.050	82	101	141	96	113	149	1.05
30		86	121	195	137	167	232	161	188	244	1.095	111	144	212	133	163	225	1.12
42		177	249	400	282	345	476	332	386	500	1.130	179	248	394	216	281	417	1.22
60		375	526	843	598	729	1,003	702	815	1,053	1.187	266	417	734	324	468	772	1.35
72		548	768	1,232	874	1,064	1,464	1,026	1,190	1,535	1.205	291	516	987	356	573	1,030	1.44

* Tons per hour (TPH) $= \text{value from table} \times \frac{\text{(actual material wt., lb/ft}^3\text{)}}{100} \times \frac{\text{(actual belt speed, ft/min)}}{100}$

† Surcharge angle (see Fig 10.5.44).

‡ Capacity calculated for standard distance of load from belt edge: $(0.55\,b + 0.9)$, where b = belt width, inches. For constant 2-in edge distance (CED) multiply by CED constant as given in this table.

For slumping materials (very free flowing), use capacities based upon 2-in CED. This includes dry silica sand, dry aerated portland cement, wet concrete, etc., with surcharge angle 5° or less. For metric units multiply in by 25.4 for mm; tons per hour by 0.91 for tonne per hour; ft/min by 0.0051 for m/s.

Table 10.5.13 Minimum Belt Width for Lumps

Belt width,	in	12	18	24	30	42	60	72
	mm	305	457	610	762	1,067	1,524	1,829
Sized material,	in	2	4	5	6	8	12	14
	mm	51	102	127	152	203	305	356
Unsized material,	in	4	6	8	10	14	20	24
	mm	102	152	203	254	356	508	610

SOURCE Uniroyal, Inc.

Table 10.5.14 Maximum Belts Speeds, ft/min, for Various Materials*

Width of belt, in	Light or free-flowing materials, grains, dry sand, etc.	Moderately free-flowing sand, gravel, fine stone, etc.	Lump coal, coarse stone, crushed ore	Heavy sharp lumpy materials, heavy ores, lump coke
12–14	400	250		
16–18	500	300	250	
20–24	600	400	350	250
30–36	750	500	400	300
42–60	850	550	450	350

* Multiply in by 25.4 for mm, ft/min by 0.005 for m/s.

The capacity in tons per hour for materials of various weights per cubic foot is given by Table 10.5.12. Table 10.5.13 gives minimum belt widths for lumps of various sizes. Table 10.5.14 gives advisable maximum belt speeds for various belt widths and materials. The speed should ensure full-capacity loading so that the entire belt width is utilized.

Drive Calculations From the standpoint of the application of power to the belt, a conveyor is identical with a power belt. The determining factors are the coefficient of friction between the drive pulley and the belt, the tension in the belt, and the arc of contact between the pulley and the belt. The arc of the contact is increased up to about 240° by using a snub pulley and up to 410° by using two pulleys geared together or driven by separate motors and having the belt wrapped around them in the form of a letter S. The resistance to be overcome is the sum of all the frictional resistances throughout the length of the conveyor plus, in the case of a rising conveyor, the resistance due to lifting the load. The sum of the conveyor and load resistances determines the working pull that has to be transmitted to the belt at the drive pulley. The total pull is increased by the slack-side tension necessary to keep the belt from slipping on the pulley. Other factors adding to the belt pull are the component of the weight of the belt if the conveyor is inclined and a take-up pull to keep the belt from sagging between the idlers at the loading point. These, however, do not add to the working pull. The maximum belt pull determines the length of conveyor that can be used. If part of the conveyor runs downgrade, the load on it will reduce the working pull. In moderate-length conveyors, stresses due to acceleration or deceleration are safely carried by the factor of safety used for belt-life calculations.

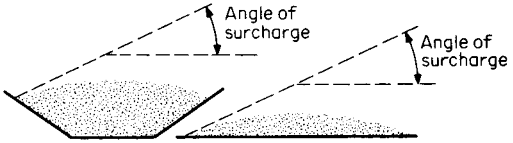


Fig. 10.5.44 (*a*) Troughed belt; (*b*) flat belt. *(Uniroyal, Inc.)*

The total or maximum tension T_{max} must be known to specify a suitable belt. The effective tension T_e is the difference between tight-side tension and slack-side tension, or $T_e = T_1 - T_2$. The coefficient of friction between rubber and steel is 0.25; with a lagged pulley, between rubber and rubber, it is 0.55 for ideal conditions but should be taken as 0.35 to allow for loss due to dirty conditions.

Except for extremely heavy belt pulls, the tandem drive is seldom used since it is costly; the lagged-and-grooved drive pulley is used for most industrial installations.

For a belt with 6,000-lb (26,700-N) max tension running on a bare pulley drive with 180° wrap (Table 10.5.15), $T = 1.85T_e = 6{,}000$ lb; $T_e = 3{,}200$ lb (14,200 N). Such a belt, 30 in wide, might be a five-ply MP50, a reduced-ply belt rated at 200 lb/in, or a steel-cable belt with 5⁄32-in (4-mm) cables spaced on 0.650-in (16.5-mm) centers. The last is the most costly.

Table 10.5.15 Ratio T_1 to T_e for Various Arcs of Contact with Bare Pulleys and Lagged Pulleys

(Coefficients of friction 0.25 and 0.35, respectively)

Belt wrap, deg	180	200	210	215	220	240
Bare pulley	1.85	1.72	1.67	1.64	1.62	1.54
Lagged pulley	1.50	1.42	1.38	1.36	1.35	1.30

In an inclined belt with single pulley drive, the T_{max} is lowest if the drive is at the head end and increases as the drive shifts toward the foot end.

Allowance for Tripper The belt lifts about 5 ft to pass over the top snub pulley of the tripper. Allowance should be made for this lift in determining the power requirement of the conveyor. If the tripper is propelled by the belt, an allowance of 1 hp (0.75 kW) for a 16-in (406-mm) belt, 3 hp (2.2 kW) for a 36-in (914-mm) belt, or 7 hp (5.2 kW) for a 60-in (1,524-mm) belt is ample. If a rotary cleaning brush is driven from one of the snub shafts, an allowance should be made which is approximately the same as that for the propulsion of the tripper.

Magnetic pulleys are frequently used as head pulleys on belt conveyors to remove tramp iron, such as stray nuts or bolts, before crushing; to concentrate magnetic ores, such as magnetic or nickeliferous pyrrhotite, from nonmagnetic material; and to reclaim iron from foundry refuse. A chute or hopper automatically receives the extracted material as it is drawn down through the other nonmagnetic material, drawn around the end pulley on the belt, and finally released as the belt leaves the pulley. Light-duty permanent-magnet types [for pulleys 12 to 24 in (305 to 610 mm) in diameter] will separate material through a 2-in (51-mm) layer on the belt. Heavy-duty permanent-magnet units (12 to 24 in in diameter) will separate material if the belt carries over 2 in of material or if the magnetic content is very fine. Even larger units are available for special applications. So effective and powerful are the permanent-magnet types that **electromagnetic pulleys** are available only in the larger sizes, from 18 to 48 in in diameter. The permanent-magnet type requires no slip rings, external power, or upkeep.

Overhead magnetic separators (Dings), both electromagnetic and Ceramox permanent-magnet types, for suspension above a belt conveyor are also available for all commercial belt widths to pull magnetic material from burden as thick as 40 in and at belt speeds to 750 ft/min. These may or may not be equipped with a separately encompassing belt to be self-cleaning. Wattages vary from 1,600 to 17,000. The permanent-magnet type requires no electric power and have nonvarying magnet strength. An alternate type of belt protection is to use a Ferro Guard Detector (Dings) to stop belt motion if iron is detected.

Trippers of the fixed or movable type are used for discharging material between the ends of a belt conveyor. A **self-propelling tripper** consists of two pulleys, over which the belt passes, the material being discharged into the chute as the belt bends around the upper pulley. The pulleys are mounted on a frame carried by four wheels and power-driven. A lever on the frame and stops alongside the rails enable the tripper, taking power from the conveyor belt, to move automatically between the stops, thus distributing the material. Rail clamps are provided to hold the tripper in a fixed position when discharging. Motor-driven trippers are used when it is desirable to move the tripper independently of the conveyor belt. Fixed trippers have their pulleys mounted on the conveyor framework instead of on a movable carriage.

Shuttle conveyors are frequently used in place of trippers for distributing materials. They consist of a reversible belt conveyor mounted upon a movable frame and discharging over either end.

Belt-Conveyor Arrangements Figure 10.5.37 shows **typical arrangements of belt conveyors.** *a* is a level conveyor receiving material at one end and discharging at the other. *b* shows a level conveyor with traveling tripper. The receiving end of the conveyor is depressed so that the belt will not be lifted against the chute when the tripper is at its extreme loading end. *c* is a level conveyor with fixed trippers. *d* shows an inclined end combined with a level section. *e* is a combination of level conveyor, vertical curve, and horizontal section. The radius of the vertical curve depends upon the weight of the belt and the tension in the belt at the point of tangency. This must be figured in each case and is found by the formula: min radius, ft = belt tension at lowest point of curve divided by weight per ft of belt. The belt weight should be for the worn belt with not over 1⁄16-in (1.6-mm) top cover. *f* is a combination of level conveyor receiving material from a bin, a fixed dump, and inclined section, and a series of fixed trippers.

Portable conveyors are widely used around retail coal yards, small power plants, and at coal mines for storing coal and reclaiming it for loading into trucks or cars. They are also used for handling other bulk materials. They consist of a short section of chain or belt conveyors mounted on large wheels or crawler treads and powered with a gasoline engine or electric motor. They vary in length from 20 to 90 ft and can handle up to 250 tons/h (63 kg/s) of coal. For capacities greater than what two people can shovel onto a belt, some form of power loader is necessary.

Sectional-belt conveyors have come into wide use in coal mines for bringing the coal from the face and loading it into cars in the entry. They consist of short sections (6 ft or more) of light frame of special low-type construction. The sections are designed for ease of connecting and disconnecting for transfer from one part of the mine to another. They are built in lengths up to 1,000 ft (305 m) or more under favorable conditions and can handle 125 tons/h (32 kg/s) of coal.

Sliding-belt conveyors use belts sliding on decks instead of troughed belts carried on rollers. Sliding belts are used in the shipping rooms of department stores for handling miscellaneous parcels, in post offices for handling mail bags, in chemical plants for miscellaneous light waste, etc. The decking preferably is of maple strips. If of steel, the deck should be perforated at intervals to relieve the vacuum effect between the bottom of the belt and the deck. Cotton or balata belts are best. The speed should be low. The return run may be carried on 4-in straight-face idlers. The power requirement is greater than with idler rollers.

The **oscillating conveyor** is a horizontal trough varying in width from 12 to 48 in (305 to 1,219 mm), mounted on rearward-inclined cantilever supports, and driven from an eccentric at 400 to 500 r/min. The effect is to ‘‘bounce’’ the material along at about 50 ft/min (0.25 m/s) with minimum wear on the trough. The conveyor is adapted to abrasive or hot fragmentary materials, such as scrap metals, castings, or metal chips. The trough bottom may be a screen plate to cull fine material, as when cleaning sand from castings, or the trough may have louvers and a ventilating hood to cool the moving material. These oscillating conveyors may have unit lengths up to 100 ft (30 m). Capacities range from a few tons to 100 tons/h (25 kg/s) with high efficiency and low maintenance.

Feeders

When material is drawn from a hopper or bin to a conveyor, an **automatic feeder** should be used (unless the material is dry and free-running, e.g., grain). The satisfactory operation of any conveyor depends on the material being fed to it in an even and continuous stream. The automatic feeder not only ensures a constant and controlled feed, irrespective of the size of material, but saves the expense of an operator who would otherwise be required at the feeding point. Figure 10.5.45 shows a **reciprocating-plate feeder,** consisting of a plate mounted on four wheels and forming the bottom of the hopper. When the plate is moved forward, it carries the material with it; when moved back, the plate is withdrawn from under the material, allowing it to fall into the chute. The plate is moved by connecting rods from cranks or eccentrics. The capacity of this feeder is determined by the length and number of strokes, width of plate, and location of the adjustable gate. The number of strokes should not exceed 60 to 70 per min. When used under a track hopper, the material remaining on the plate may freeze in winter, as this type of feeder is not self-clearing.

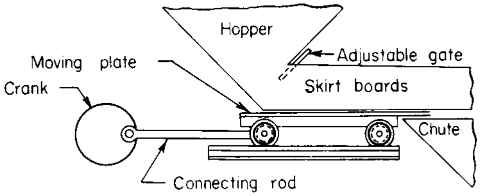


Fig. 10.5.45 Reciprocating-plate feeder.

Vibrating Feeders The vibrating feeder consists of a plate inclined downward slightly and vibrated (1) by a high-speed unbalanced pulley, (2) by electromagnetic vibrations from one or more solenoids, as in the Jeffrey Manufacturing Co. feeder, or (3) by the slower pulsations secured by mounting the plate on rearward-inclined leaf springs.

The **electric vibrating feeder** (Fig. 10.5.46) operates magnetically with a large number of short strokes (7,200 per min from an alternating current in the small sizes and 3,600 from a pulsating direct current in the larger sizes). It is built to feed from a few pounds per minute to 1,250 tons/h (315 kg/s) and will handle any material that does not adhere to the pan. It is self-cleaning, instantaneously adjustable for capacity, and controllable from any point near or remote. It is usually supported from above with spring shock absorbers *a* in each hanger, but it be may supported from below with similar springs in the supports. A modified form can be set to feed a weighed **constant amount** hourly for process control.

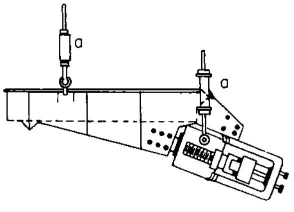


Fig. 10.5.46 Electric vibrating feeder.

Roller Conveyors

The principle involved in **gravity roller conveyors** is the control of motion due to gravity by interposing an antifriction trackage set at a definite grade. Roller conveyors are used in the movement of all sorts of package goods with smooth surfaces which are sufficiently rigid to prevent sagging between rollers—in warehouses, brickyards, building-supply yards, department stores, post offices, and the manufacturing and shipping departments of industrial manufacturers.

The **rollers vary in diameter** and strength from 1 in, with a capacity of 5 lb (2.3 kg) per roller, up to 4 in (102 mm), with a capacity of 1,800 lb (816 kg) per roller. The heavier rollers are generally used in foundries and steel mills for moving large molds, castings, or stacks of sheet steel. The small roller is used for handling small, light objects. The spacing of the rollers in the frames varies with the size and weight of the objects to be moved. Three rollers should be in contact with the package to prevent hobbling. The grade of fall required to move the object varies from 1½ to 7 percent, depending on the weight and character of the material in contact with the rollers.

Figure 10.5.47 shows a typical cross section of a roller conveyor. Curved sections are similar in construction to straight sections, except that in the majority of cases multiple rollers (Fig. 10.5.48) are used to keep the package properly lined up and in the center of the conveyor.

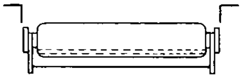


Fig. 10.5.47 Gravity roller conveyor.

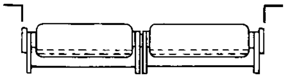


Fig. 10.5.48 Multiple-roller conveyor.

Figure 10.5.49 illustrates a **wheel conveyor,** used for handling bundles of shingles, fruit boxes, bundles of fiber cartons, and large, light cases. The wheels are of ball-bearing type, bolted to flat-bar or angle-frame rails.

Fig. 10.5.49 Wheel-type conveyor.

When an installation involves a **trunk line with several tributary runs,** a simple two-arm deflector at each junction point holds back the item on one run until the item on the other has cleared. **Power-operated** roller conveyors permit handling up an incline. Usually the rolls are driven by sprockets on the spindle ends. An alternative of a smooth deck and pusher flights should be considered as costing less and permitting steeper inclines.

Platform conveyors are single- or double-strand conveyors (Fig. 10.5.50) with plates of steel or hardwood forming a continuous platform on which the loads are placed. They are adapted to handling heavy drums or barrels and miscellaneous freight.

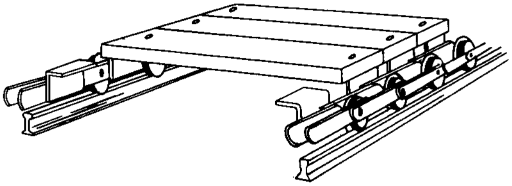


Fig. 10.5.50 Double-strand platform conveyor.

Pneumatic Conveyors

The pneumatic conveyor transports dry, free-flowing, granular material in suspension within a pipe or duct by means of a high-velocity airstream or by the energy of expanding compressed air within a comparatively dense column of fluidized or aerated material. Principal uses are (1) dust collection; (2) conveying soft materials, such as grain, dry foodstuff (flour and feeds), chemicals (soda ash, lime, salt cake), wood chips, carbon black, and sawdust; (3) conveying hard materials, such as fly ash, cement, silica metallic ores, and phosphate. The need in processing of bulk-transporting plastic pellets, powders, and flour under contamination-free conditions has increased the use of pneumatic conveying.

Dust Collection All pipes should be as straight and short as possible, and bends, if necessary, should have a radius of at least three diameters of the pipe. Pipes should be proportioned to keep down friction losses and yet maintain the air velocities that will prevent settling of the material. Frequent cleanout openings must be provided. Branch connections should go into the sides of the main and deliver the incoming stream as nearly as possible in the direction of flow of the main stream. Sudden changes in diameter should be avoided to prevent eddy losses.

When **vertical runs** are short in proportion to the horizontal runs, the size of the riser is locally restricted, thereby increasing the air velocity and producing sufficient lifting power to elevate the material. If the vertical pipes are comparatively long, they are not restricted, but the necessary lifting power is secured by increased velocity and suction throughout the entire system.

The area of the main at any point should be 20 to 25 percent in excess of the sums of the branches entering it between the point in question and the dead end of the main. Floor sweepers, if equipped with efficient blast gates, need not be included in computing the main area. The diameter of the connecting pipe from machine to main and the section required at each hood are determined by experience. The sum of the volumes of each branch gives the total volume to be handled by the fan.

Fan Suction The maintained resistance at the fan is composed of (1) suctions of the various hoods, which must be chosen from experience, (2) collector loss, and (3) loss due to pipe friction.

The **pipe loss** for any machine is the sum of the losses in the corresponding branch and in the main from that branch to the fan. For each elbow, add a length equal to 10 diameters of straight pipe. The total loss in the system, or static pressure required at the fan, is equal to the sum of (1), (2), and (3).

For conveying soft materials, a fan is used to create a suction. The suspended material is collected at the terminal point by a separator upstream from the fan. The material may be moved from one location to another or may be unloaded from barge or rail car. Required conveying velocity ranges from 2,000 ft/min (10.2 m/s) for light materials, such as sawdust, to 3,000 to 4,000 ft/min (15.2 to 20.3 m/s) for medium-weight materials, such as grain. Since abrasion is no problem, steel pipe or galvanized-metal ducts are satisfactory. Unnecessary bends and fittings should be avoided to minimize power consumption.

For conveying hard materials, a water-jet exhauster or steam exhauster is used on suction systems, and a positive-displacement blower on pressure systems. A mechanical exhauster may also be used on suction systems if there is a bag filter or air washer ahead of the exhauster. The largest tonnage of hard material handled is fly ash. A single coal-fired, steam-electric plant may collect more than 1,000 tons (907 tonnes) of fly ash per day. Fly ash can be conveyed several miles pneumatically at 30 tons (27 tonnes) or more per h using a pressure conveyor. Another high-tonnage material conveyed pneumatically is cement. Individual transfer conveyors may handle several hundred tons per hour. Hard materials are usually also heavy and abrasive. Required conveying velocities vary from 4,000 to 5,000 ft/min (20.3 to 25.4 m/s). Heavy cast-iron or alloy pipe and fittings are required to prevent excessive wear.

Vacuum pneumatic ash-handling systems have the airflow induced by steam- or water-jet exhausters, or by mechanical blowers. Cyclone-type Nuveyor receivers collect the ash for storage in a dry silo. A typical Nuveyor system is shown in Fig. 10.5.51. The conveying velocity is dependent upon material handled in the system. Fly ash is handled at approximately 3,800 ft/min (19.3 m/s) and capacity up to 60 tons/h (15.1 kg/s). Positive-pressure pneumatic ash systems are becoming more common because of higher capacities required. These systems can convey fly ash up to 1½ mi (2.4 km) and capacities of 100 tons/h (25.2 kg/s) for shorter systems.

The **power requirement** for pneumatic conveyors is much greater than for a mechanical conveyor of equal capacity, but the duct can be led along practically any path. There are no moving parts and no risk of injury to the attendant. The vacuum-cleaner action provides dustless

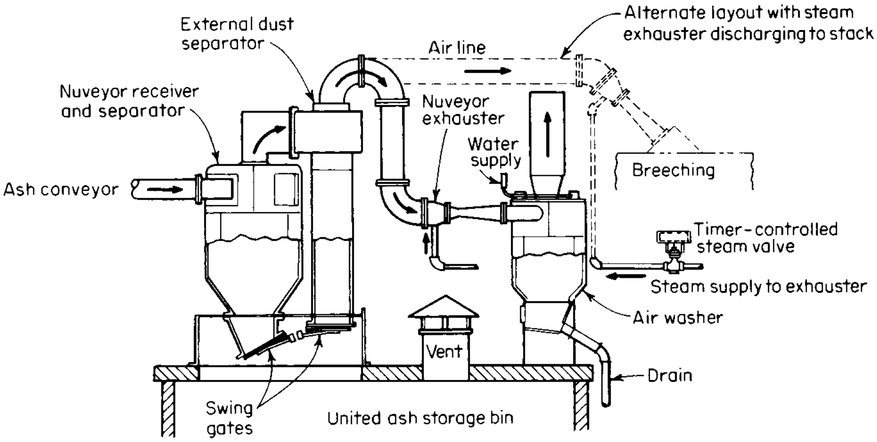


Fig. 10.5.51 Nuveyor pneumatic ash-handling system. *(United Conveyor Corp.)*

operation, sometimes important when pulverized material is unloaded from boxcars through flexible hose and nozzle. A few materials build up a state-electric charge which may introduce an explosion risk. Sulfur is an outstanding example. Sticky materials tend to pack at the elbows and are unsuitable for pneumatic handling.

The performance of a pneumatic conveyor cannot be predicted with the accuracy usual with the various types of mechanical conveyors and elevators. It is necessary to rely on the advice of experienced engineers.

The **Fuller-Kinyon system** for transporting dry pulverized material consists of a motor- or engine-driven pump, a source of compressed air for fluidizing the material, a conduit or pipe-line, distributing valves (operated manually, electropneumatically, or by motor), and electric bin-level indicators (high-level, low-level or both). The impeller is a specially designed differential-pitch screw normally turning at 1,200 r/min. The material enters the feed hopper and is compressed in the decreasing pitch of the screw flights. At the discharge end of the screw, the mass is introduced through a check valve to a mixing chamber, where it is aerated by the introduction of compressed air. The fluidized material is conveyed in the transport line by the continuing action of the impeller screw and the energy of expanding air. Practical distance of transportation by the system depends upon the material to be handled. Cement has been handled in this manner for distances up to a mile. The most important field of application is the handling of portland cement. For this material, the Fuller-Kinyon pump is used for such operations as moving both raw material and finished cement within the cement-manufacturing process; loading out; unloading ships, barges, and railway cars; and transferring from storage to mixer plant on large construction jobs.

The **Airslide** (registered trademark of the Fuller Company) **conveyor system** is an air-activated gravity-type conveyor using low-pressure air to aerate or fluidize pulverized material to a degree which will permit it to flow on a slight incline by the force of gravity. The conveyor comprises an enclosed trough, the bottom of which has an inclined air-permeable surface. Beneath this surface is a plenum chamber through which air is introduced at low pressure, depending upon the application. Various control devices for controlling and diverting material flow and for controlling air supply may be provided as part of complete systems. For normal conveying applications, the air is supplied by an appropriate fan; for operation under a head of material (as in a storage bin), the air is supplied by a rotary positive blower. The Airslide conveyor is widely used for horizontal conveying, discharge of storage bins, and special railway-car and truck-trailer transport, as well as in stationary blow-tank-type conveying systems. An important feature of this conveyor is low power requirement.

Hydraulic Conveyors

Hydraulic conveyors are used for handling boiler-plant ash or slag from an ash hopper or slag tank located under the furnace. The material is flushed from the hopper to a grinder, which discharges to a jet pump or a mechanical pump for conveying to a disposal area or a dewatering bin (Fig. 10.5.52). Water requirements average 1 gal/lb of ash.

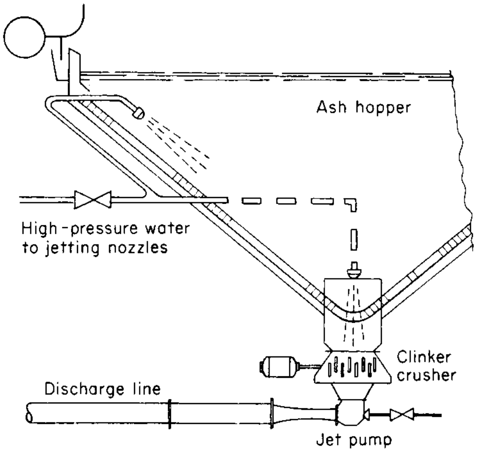


Fig. 10.5.52 Ash-sluicing system with jet pump. *(United Conveyor Corp.)*

CHANGING DIRECTION OF MATERIALS ON A CONVEYOR

Some material in transit can be made to change direction by being bent around a curve. Metal being rolled, wire, strip, material on webs, and the like, can be guided to new directions by channels, rollers, wheels, pulleys, etc.

Some conveyors can be given curvatures, such as in overhead monorails, tow car grooves, tracks, pneumatic tube bends, etc. Other, straight sections of conveyors can be joined by curved sections to accomplish directional changes. Figures 10.5.53 to 10.5.56 show some examples of these. In some cases, the simple intersection, or overlapping, at an angle of two conveyors can result in a direction change. See Figs. 10.5.57 and 10.5.58. When not all of the material on the first section of conveyor is to be diverted, sweeps or switches may be used. Figure 10.5.59 shows how fixed diverters set at decreasing heights can direct boxes of certain sizes onto other conveyors. Switches allow the material to be sent in one direction at one time and in another at other times. In Fig. 10.5.60 the diverter can swing to one side or the other. In Fig. 10.5.61, the switching section has a dual set of wheels, with the set being made higher at the time carrying the material in their angled direction. Pushers, as shown in Fig. 10.5.62 can selectively divert material, as can air blasts for lightweight items (Fig. 10.5.63) and tipping sections (Fig. 10.5.64).

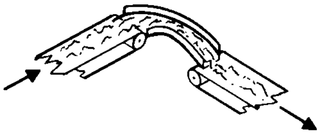


Fig. 10.5.53 Fixed curve turn section. Joins two conveyors and changes direction and level of material flow.

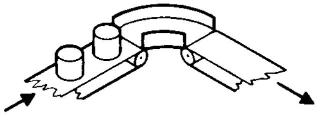


Fig. 10.5.54 Fixed curve turn section. Joins two conveyors and changes direction of material flow. Turn section has no power. Incoming items push those ahead of them around curve. Wheels, balls, rollers, etc. may be added to turn section to reduce friction of dead plate section shown.

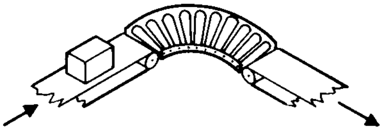


Fig. 10.5.55 Fixed curve turn section. Uses tapered rollers, skate wheels, balls, or belt. May be level or inclined, ''dead'' or powered.

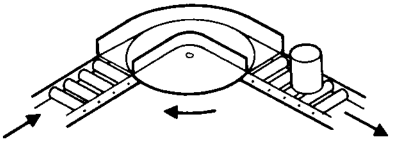


Fig. 10.5.56 Fixed curve turn section. Disk receives item from incoming conveyor section, rotates it, and directs it onto outgoing conveyor section.

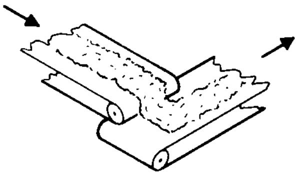


Fig. 10.5.57 Simple intersection. Incoming conveyor section overlaps outgoing section and merely dumps material onto lower conveyor.

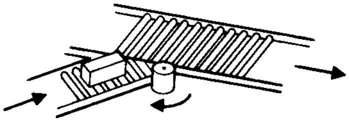


Fig. 10.5.58 Simple intersection. Both incoming and outgoing sections are powered. Rotating post serves as a guide.

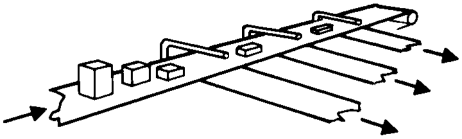


Fig. 10.5.59 Fixed diverters. Diverters do not move. They are preset at heights to catch and divert items of given heights.

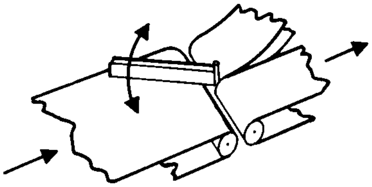


Fig. 10.5.60 Moving diverter. Material on incoming conveyor section can be sent to either outgoing section by pivoting the diverter to one side or the other.

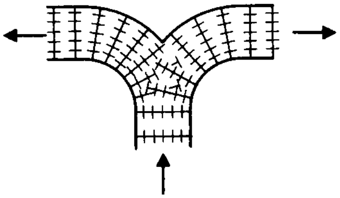


Fig. 10.5.61 Wheel switch. Fixed wheels carry material on incoming conveyor to outgoing conveyor until movable set of wheels is raised above the fixed set. Then material is carried in the other direction.

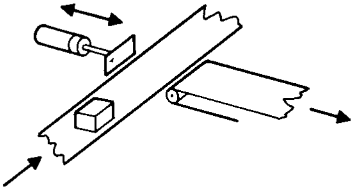


Fig. 10.5.62 Pusher diverter. When triggered, the pusher advances and moves item onto another conveyor. A movable sweep can also be used.

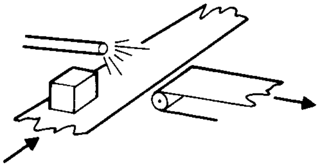


Fig. 10.5.63 Air diverter. When activated, a jet of air pushes a lightweight item onto another conveyor.

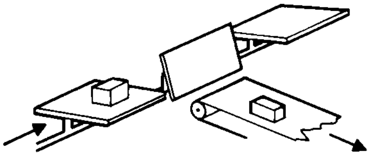


Fig. 10.5.64 Tilting section. Sections of main conveyor move along, level, until activated to tilt at chosen location to dump material onto another conveyor.

10.6 AUTOMATIC GUIDED VEHICLES AND ROBOTS

by Vincent M. Altamuro

AUTOMATIC GUIDED VEHICLES

Driverless towing tractors guided by wires embedded into or affixed onto the floor have been available since the early 1950s. Currently, the addition of computer controls, sensors that can monitor remote conditions, real-time feedback, switching capabilities and a whole new family of vehicles have created automatic guided vehicle systems (AGVs) that compete with industrial trucks and conveyors as material handling devices.

Most AGVs have only horizontal motion capabilities. Any vertical motion is limited. Fork lift trucks usually have more vertical motion capabilities than do standard AGVs. Automatic storage and retrieval systems (AS/RS) usually have very high rise vertical capabilities, with horizontal motions limited only to moving to and down the proper aisle. Power for the automatic guided vehicle is usually a battery, like that of the electric industrial truck. Guidance may be provided several ways. In *electrical* or *magnetic* guidance, a wire network is usually embedded in a narrow, shallow slot cut in the floor along the possible paths. The electromagnetic field emitted by the conductor wire is sensed by devices on-board the vehicle which activate a steering mechanism, causing the vehicle to follow the wire. An *optical* guidance system has a similar steering mechanism, but the path is detected by a photosensor picking out the bright path (paint, tape, or fluorescent chemicals) previously laid down. The embedded wire system seems more popular in factories, as it is in a protective groove, whereas the optical tape or painted line can get dirty and/or damaged. In offices, where the AGV may be used to pick up and deliver mail, the optical system may be preferred, as it is less expensive to install and less likely to deteriorate in such an environment. However, in carpeted areas, a wire can easily be laid under the carpet and operate invisibly.

In a **laser beam** guidance system, a laser scanner on the vehicle transmits and receives back an infrared laser beam that reads passive retroreflective targets that are placed at strategic points on *x* and *y* coordinates in the facility. The vehicle's on-board computers take the locations and distances of the targets and calculate the vehicle's position by triangulation. The locations of the loads to be picked up, the destinations at which they are to be dropped off, and the paths the vehicle is to travel are transmitted from the system's base station. Instructions are converted to inputs to the vehicle's steering and driving motors. A variation of the system is for the laser scanner to read bar codes or radio-frequency identification (RFID) targets to get more information regarding their mission than merely their current location. Other, less used, guidance methods are **infrared,** whereby line-of-sight signals are sent to the vehicle, and **dead reckoning,** whereby a vehicle is programmed to traverse a certain path and then turned loose.

The directions that an AGV can travel may be classified as unidirectional (one way), bidirectional (forward or backward along its path), or omnidirectional (all directions). Omnidirectional AGVs with five or more on-board microprocessors and a multitude of sensors are sometimes called **self-guided vehicles** (SGVs).

Automatic guided vehicles require smooth and level floors in order to operate properly. They can be weatherized so as to be able to run outdoors between buildings but there, too, the surface they travel on must be smooth and level.

AGV equipment can be categorized as:

1. Driverless tractors
2. Guided pallet trucks
3. Unit load transporters and platform carriers
4. Assembly or tool bed robot transporters

Driverless tractors can be used to tow a series of powerless material handling carts, like a locomotive pulls a train. They can be routed, stopped, coupled, uncoupled, and restarted either manually, by a programmed sequence, or from a central control computer. They are suited to low-volume, heavy or irregularly shaped loads which have to be moved over longer distances than would be economical for a conveyor.

Guided pallet trucks, like the conventional manually operated trucks they replace, are available in a wide range of sizes and configurations. In operation, they usually are loaded under the control of a person, who then drives them over the guide wire, programs in their desired destination, then switches them to automatic. At their destination, they can turn off the main guidepath onto a siding, automatically drop off their load, then continue back onto the main guidepath. The use of guided pallet trucks reduces the need for conventional manually operated trucks and their operators.

Unit load transporters and platform carriers are designed so as to carry their loads directly on their flat or specially contoured surface, rather than on forks or on carts towed behind. They can either carry material or work-in-process from workstation to workstation or they can be workstations themselves and process the material while they transport it.

The assembly or tool bed type of AGV is used to carry either work-in-process or tooling to machines. It may also be used to carry equipment for an entire process step—a machine plus its tooling—to large, heavy, or immovable products.

Robot transporters are used to make robots mobile. A robot can be fitted atop the transporter and carried to the work. Further, the robot can process the work as the transporter carries it along to the next station, thereby combining productive work with material handling and transportation.

Most AGVs and SGVs have several safety devices, including flashing in-motion lights, infrared scanners to slow them down when approaching an obstacle, sound warnings and alarms, stop-on-impact bumpers, speed regulators, and the like.

ROBOTS

A robot is a machine constructed as an assemblage of links joined so that they can be articulated into desired positions by a reprogrammable controller and precision actuators to perform a variety of tasks. Robots range from simple devices to very complex and ''intelligent'' systems by virtue of added sensors, computers, and special features. See Figure 10.6.1 for the possible components of a robotic system.

Robots, being programmable multijointed machines, fall between humans and fixed-purpose machines in their utility. In general, they are most useful in replacing humans in jobs that are dangerous, dirty, dull, or demeaning, and for doing things beyond human capabilities. They are usually better than conventional ''hard'' automation in short-run jobs and those requiring different tasks on a variety of products. They are ideal for operations calling for high consistency, cycle after cycle, yet are changeable when necessary.

There are several hundred types and models of robots. They are available in a wide range of shapes, sizes, speeds, load capacities, and other characteristics. Care must be taken to select a robot to match the requirements of the tasks to be done. One way to classify them is by their intended application. In general, there are industrial, commercial, laboratory, mobile, military, security, service, hobby, home, and personal robots. While they are programmable to do a wide variety of tasks, most are limited to one or a few categories of capabilities, based on their construction and specifications. Thus, within the classification of industrial robots, there are those that can paint but not assemble products, and of those that can assemble products, some specialize in assembling very small electronic components while others make automobiles.

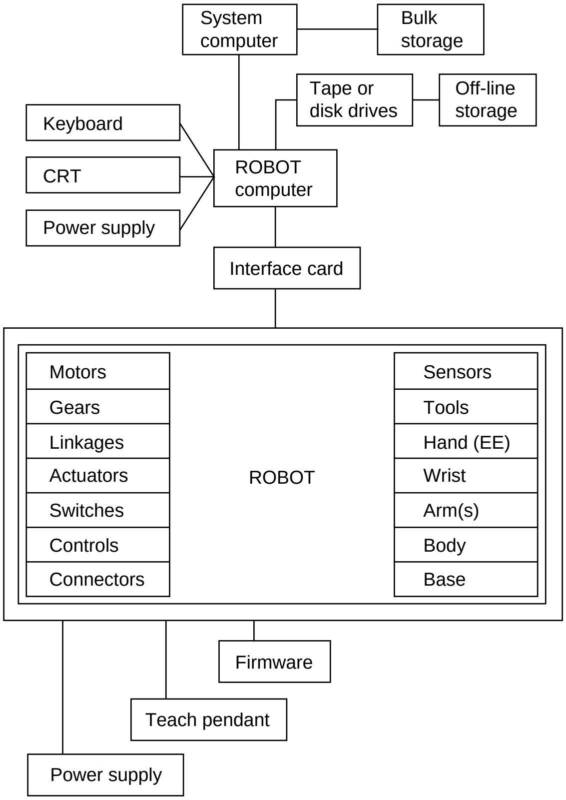


Fig. 10.6.1 Robotic system schematic. *(Robotics Research Division, VMA, Inc.)*

Some of the common uses of industrial robots include: loading and unloading machines, transferring work from one machine to another, assembling, cutting, drilling, grinding, deburring, welding, gluing, painting, inspecting, testing, packing, palletizing, and many others.

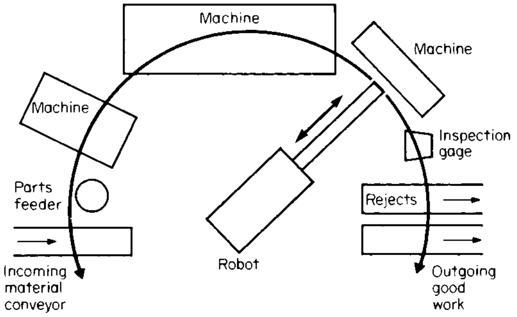


Fig. 10.6.2 Robot work cell. Robot is positioned to service a number of machines clustered about it.

Rather than have a robot perform only one task, it is sometimes possible to select a model and its tooling so that it can be positioned to do several jobs. Figure 10.6.2 shows a robot set in a work cell so that it can service the incoming material, part feeders, several machines, inspection gages, reject bins, and outgoing product conveyors arranged in an economical cluster around it. Robots are also used in chemical mixing and measuring; bomb disassembly; agriculture; logging; fisheries; department stores; amusement parks; schools; prisons; hospitals; nursing homes; nuclear power plants; space vehicles; underwater; surveillance; police, fire, and sanitation departments; inside the body; and an increasing number of innovative places.

Robot Anatomy

All robots have certain basic sections, and some have additional parts that give them added capabilities. All robots must have a power source, either mechanical, electrical, electromechanical, pneumatic, hydraulic, nuclear, solar, or a combination of these. They all must also have a means of converting the source of power to usable power and transmitting it: motors, pumps, and other actuators, and gears, cams, drives, bars, belts, chains, and the like. To do useful work, most robots have an assemblage of links arranged in a configuration best-suited to the tasks it is to do and the space within which it is to do them. In some robots this is called the *manipulator,* and the links and the joints connecting them are sometimes referred to as the robot's *body, shoulder, arm,* and *wrist.* A robot may have no, one, or multiple arms. Multiarmed robots must have control coordination protocols to prevent collisions, as must robots that work very close to other robots. Some robots have an immovable base that connects the manipulator to the floor, wall, column, or ceiling. In others the base is attached to, or part of, an additional section that gives it mobility by virtue of components such as wheels, tracks, rollers, ''legs and feet,'' or other devices.

All robots need an intelligence and control section that can range from a very simple and relatively limited type up to a very complex and sophisticated system that has the capability of continuously interacting with varying conditions and changes in its environment. Such advanced control systems would include computers of various types, a multitude of microprocessors, memory media, many input/output ports, absolute and/or incremental encoders, and whatever type and number of sensors may be required to make it able to accomplish its mission. The robot may be required to sense the positions of its several links, how well it is doing its mission, the state of its environment, and other events and conditions. In some cases, the sensors are built into the robots; in others they are handled as an adjunct capability—such as machine vision, voice recognition, and sonic ranging—attached and integrated into the overall robotic system.

Other items that may be built into the robots or handled as attachments are the **tooling**—the things that interface the robot's arm or wrist and the workpiece or object to be manipulated and which accomplish the intended task. These are called the robot's *end effectors* or *end-of-arm tooling* (EOAT) and may be very simple or so complex that they become a major part of the total cost of the robotic system. A gripper may be more than a crude open or closed clamp (See Fig. 10.6.3), jaws equipped with sensors (See Figure 10.6.4), or a multifingered hand complete with several types of miniature sensors and capable of articulations that even the human hand cannot do. They may be binary or servoed. They may be purchased from stock or custom-designed to do specific tasks. They may be powered by the same type of energy as the basic robot or they may have a different source of power. A hydraulically powered robot may have pneumatically powered grippers and tooling, for example, making it a hybrid system. Most end effectors and EOAT are easily changeable so as to enable the robot to do more tasks.

Another part of the anatomy of many robots is a safety feature. Many robots are fast, heavy, and powerful, and therefore a source of danger. Safety devices can be both built into the basic robot and added as an adjunct to the installation so as to reduce the chances that the robot will do harm to people, other equipment, the tooling, the product, and itself.

The American National Standards Institute, New York City, issued ANSI/RIA R 15.06-1986 that is supported as a robot safety standard by the Robotic Industries Association, Dearborn, MI.

Finally, ways of programming robots, communicating with them, and monitoring their performance are needed. Some of the devices used for these purposes are teach boxes on pendants, keyboards, panels, voice recognition equipment, and speech synthesis modules.

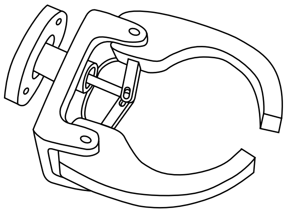


Fig. 10.6.3 A simple nonservo, no-sensor robot gripper.

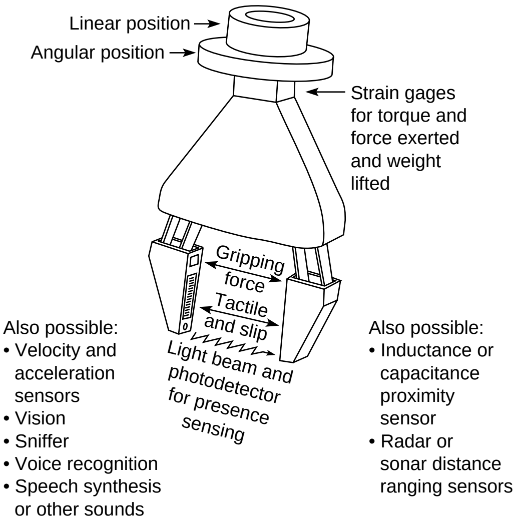


Fig. 10.6.4 A complex servoed, multisensor robot gripper.

Robot Specifications

While most robots are made ‘‘to stock’’ and sold from inventory, many are made ‘‘to order’’ to the specifications required by the intended application.

Configuration The several links of a robot’s manipulator may be joined to move in various combinations of ways relative to one another. A joint may turn about its axis (rotational axis) or it may translate along its axis (linear axis). Each particular arrangement permits the robot’s control point (usually located at the center of its wrist flange, at the center of its gripper jaws, or at the tip of its tool) to move in a different way and to reach points in a different area. When a robot’s three movements are along translating joints, the configuration is called *cartesian* or *rectangular* (Fig. 10.6.5). When one of the three joints is made a rotating joint, the configuration is called *cylindrical* (Fig. 10.6.6). When two of the three joints are rotational, the configuration is called *polar* or *spherical* (Fig. 10.6.7). And if all three joints are rotational, the robot is said to be of the *revolute* or *jointed-arm* configuration (Fig. 10.6.8). The selective compliance assembly robot arm (SCARA) is a special type of revolute robot in which the joint axes lie in the vertical plane rather than in the horizontal (Fig. 10.6.9).

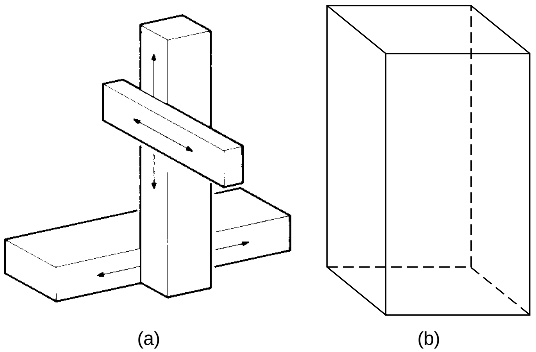

(a) (b)

Fig. 10.6.5 Cartesian- or rectangular-coordinate robot configuration. (*a*) Movements; (*b*) work envelope.

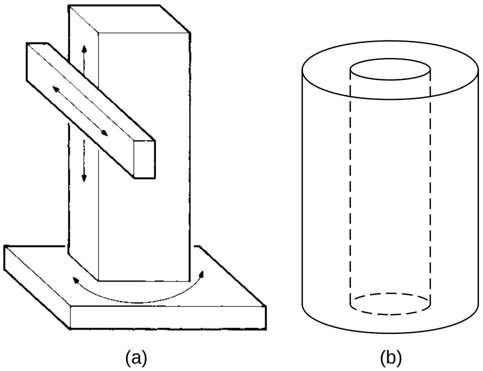
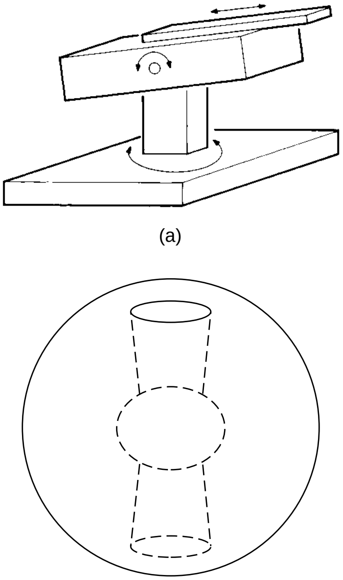

(a) (b)

Fig. 10.6.6 Cylindrical-coordinate robot configuration. (*a*) Movements; (*b*) work envelope.

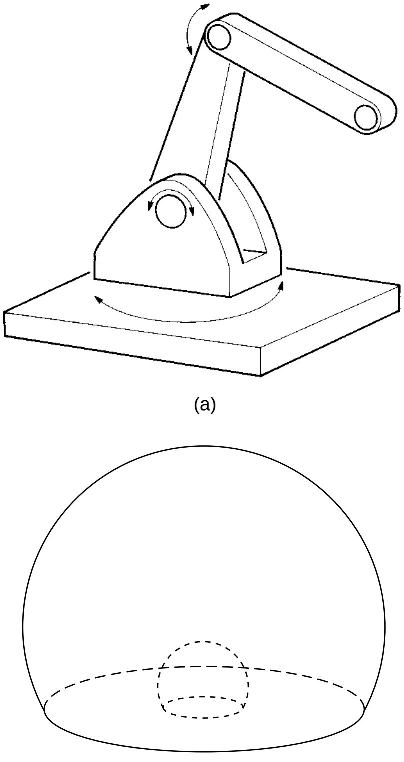
Articulations A robot may be described by the number of articulations, or jointed movements, it is capable of doing. The joints described above that establish its configuration give the typical robot three degrees of freedom (DOF) and at least three more may be obtained from the motions of its wrist—these being called *roll*, *pitch*, and *yaw* (Fig. 10.6.10). The mere opening and closing of a gripper is usually not regarded as a degree of freedom, but the many positions assumable by a servoed gripper may be called a DOF and a multifingered mechanical hand has several additional DOFs. The added abilities of mobile robots to traverse land, water, air, or outer space are, of course, additional degrees of freedom. Figure 10.6.11 shows a revolute robot with a three-DOF wrist and a seventh DOF, the ability to move in a track along the floor.

Size The physical size of a robot influences its capacity and its capabilities. There are robots as large as gantry cranes and as small as grains of salt—the latter being made by micromachining, which is the same process used to make integrated circuits and computer chips. Some robots intended for light assembly work are designed to be approximately the size of a human so as to make the installation of the robot into the space vacated by the replaced human as easy and least disruptive as possible.


(a)

(b)

Fig. 10.6.7 Polar- or spherical-coordinate robot configuration. (*a*) Movements; (*b*) work envelope.


(a)

(b)

Fig. 10.6.8 Revolute– or jointed-arm–coordinate robot configuration. (*a*) Movements; (*b*) work envelope.

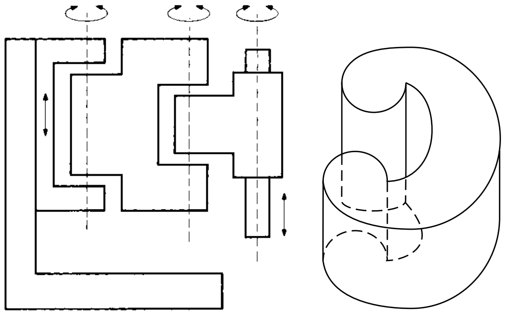

(a) (b)

Fig. 10.6.9 SCARA coordinate robot configuration. (*a*) Movements; (*b*) work envelope.

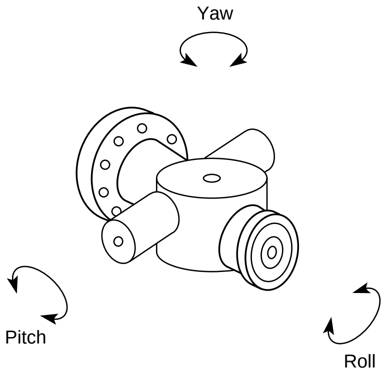


Fig. 10.6.10 A robot wrist able to move in three ways: roll, pitch, and yaw.

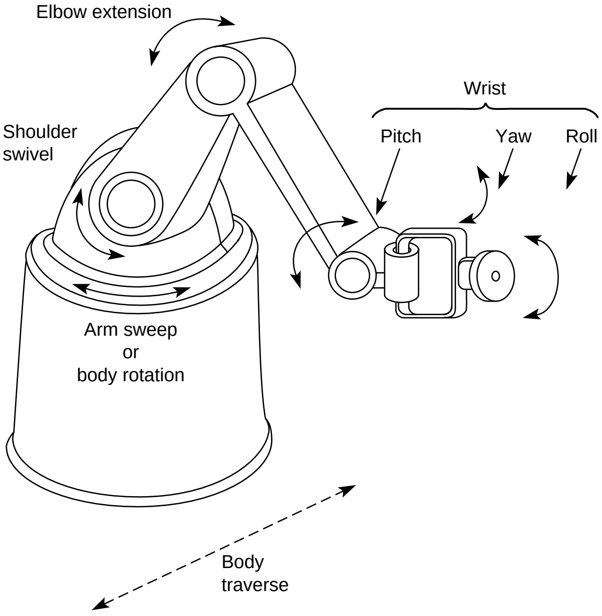


Fig. 10.6.11 A typical industrial robot with three basic degrees of freedom, plus three more in its wrist, and a seventh in its ability to move back and forth along the floor.

Workspace The extent of a robot's reach in each direction depends on its configuration, articulations, and the sizes of its component links and other members. Figure 10.6.12 shows the side and top views of the points that the industrial robot in Fig. 10.6.11 can reach. The solid geometric space created by subtracting the inner (fully contracted) from the outer (full extended) possible positions of a defined point (e.g., its control point, the center of its gripper, or the tip of its tool) is called the robot's *workspace* or *work envelope.* For the rectangular-coordinate configuration robot, this space is a rectangular parallelepiped; for the cylindrical-configuration robot, it is a cylinder with an inaccessible space hollowed out of its center; for the polar and revolute robots, it consists of spheres with inaccessible spots at their centers; and for the SCARA configuration, it is the unique solid shown in the illustration. See Fig. 10.6.5 to 10.6.9 for illustrations of the work envelope of robots of the various configurations. For a given application, one would select a robot with a work envelope slightly larger than the space required for the job to be done. Selecting a robot too much larger than is needed could increase the costs, control problems, and safety concerns. Many robots have what is called a *sweet spot:* that smaller space where the performance of most of the specifications (payload, speed, accuracy, resolution, etc.) peaks.

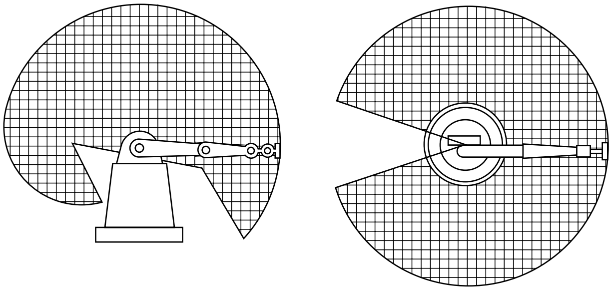


Fig. 10.6.12 Side and top views of the points that the robot in Fig. 10.6.11 can reach. The three-dimensional figure generated by these accessible end points is shown in Fig. 10.6.8*b*.

Payload The payload is the weight that the robot is designed to lift, hold, and position repeatedly with the accuracy advertised. People reading robot performance claims should be aware of the conditions under which they are promised, e.g., whether the gripper is empty or at maximum payload, or the manipulator is fully extended or fully retracted. Payload specifications usually include the weight of the gripper and other end-of-arm tooling, therefore the heavier those devices become as they are made more complex with added sensors and actuators, the less workpiece payload the robot can lift.

Speed A robot's speed and cycle time are related, but different, specifications. There are two components of its speed: its acceleration and deceleration rate and its slew rate. The acceleration/deceleration rate is the time it takes to go from rest to full speed and the time it takes to go from full speed to a complete stop. The slew rate is the velocity once the robot is at full speed. Clearly, if the distance to go is short, the robot may not reach full speed before it must begin to slow to stop, thus making its slew rate an unused capability. The cycle time is the time it takes for the robot to complete one cycle of picking a given object up at given height, moving it a given distance, lowering it, releasing it, and returning to the starting point. This is an important measure for those concerned with productivity, or how many parts a robot can process in an hour. Speed, too, is a specification that depends on the conditions under which it is measured—payload, extension, etc.

Accuracy The accuracy of a robot is the difference between where its control point goes and where it is instructed or programmed to go.

Repeatability The repeatability or precision of a robot is the variance in successive positions each time its control point returns to a taught position.

Resolution The resolution of a robot is the smallest incremental change in position that it can make or its control system can measure.

Robot Motion Control

While a robot's number of degrees of freedom and the dimensions of its work envelope are established by its configuration and size, the paths along which it moves and the points to which it goes are established by its control system and the instructions it is given. The motion paths generated by a robot's controller are designated as point-to-point or continuous. In point-to-point motion, the controller moves the robot from starting point *A* to end point *B* without regard for the path it takes or of any points in between. In a continuous-path robot controller, the path in going from *A* to *B* is controlled by the establishment of *via* or *way points* through which the control point passes on its way to each end point. If there is a conditional branch in the program at an end point such that the next action will be based on the value of some variable at that point, then the point is called a *reference point.*

Some very simple robots move only until their links hit preset stops. These are called *pick-and-place* robots and are usually powered by pneumatics with no servomechanism or feedback capabilities.

The more sophisticated robots are usually powered by hydraulics or electricity. The hydraulic systems require pumps, reservoirs, and cylinders and are good for lifting large loads and holding them steady. The electric robots use stepper motors or servomotors and are suited for quick movements and high-precision work. Both types of robots can use harmonic drives (Fig. 10.6.13), gears, or other mechanisms to reduce the speed of the actuators.

The **harmonic drive** is based on a principle patented by the Harmonic Drive unit of the Emhart Division of the Black & Decker Corp. It permits dramatic speed reductions, facilitating the use of high-speed actuators in robots. It is composed of three concentric components: an elliptical center (called the *wave generator*), a rigid outer ring (called the *circular spline*), and a compliant inner ring (called the *Flexspline*) between the two. A speed-reduction ratio equal to one-half of the number of teeth on the Flexspline is achieved by virtue of the wave generator rotating and pushing the teeth of the Flexspline into contact with the stationary circular spline, which has two fewer teeth than the Flexspline. The result is that the Flexspline rotates (in the opposite direction) the distance of two of its teeth (its circular pitch × 2) for every full rotation of the wave generator.

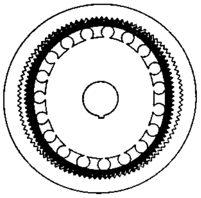


Fig. 10.6.13 A harmonic drive, based on a principle patented by the Harmonic Drive unit of the Emhart Division of the Black & Decker Corp. As the elliptical center wave generator revolves, it deforms the inner toothed Flexspline into contact with the fixed outer circular spline which has two more teeth. This results in a high speed-reduction ratio.

Robots also use various devices to tell them where their links are. A robot cannot very well be expected to go to a new position if it does not know where it is now. Some such devices are potentiometers, resolvers, and encoders attached to the joints and in communication with the controller. The operation of a rotary-joint resolver is shown in Fig. 10.6.14. With one component on each part of the joint, an excitation input in one part induces sine and cosine output signals in coils (set at right angles in the other part) whose differences are functions of the amount of angular offset between the two. Those angular displacement waveforms are sent to an analog-to-digital converter for output to the robot's motion controller.

Encoders may be of the contact or noncontact type. The contact type has a metal brush for each band of data, and the noncontact type either reflects light to a photodetector or lets the light pass or not pass to a photodetector on its opposite side, depending on its pattern of light/dark or clear/solid marks. Both types of encoders may be linear or rotary—that is, shaped like a bar or a disk—to match the type of joint to which they are attached. The four basic parts of a rotary optical encoder (the light sources, the coding disk, the photodetectors, and the signal processing electronics) are all contained in a small, compact, sealed package.

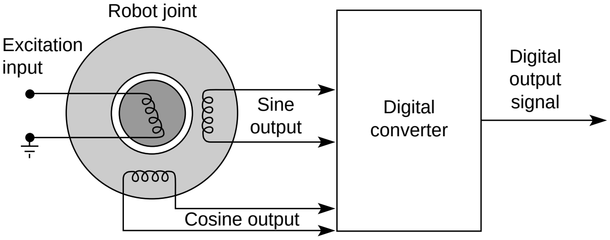


Fig. 10.6.14 Rotary-joint resolver. Resolver components on the robot's joint send analog angular displacement signals to a digital converter for interpretation and output to the robot's controller.

Encoders are also classified by whether they are incremental or absolute. Figure 10.6.15 shows two types of incremental optical encoder disks. They have equally spaced divisions so that the output of their photodetectors is a series of square waves that can be counted to tell the amount of rotational movement of the joint to which they are attached. Their resolution depends on how many distinct marks can be painted or etched on a disk of a given size. Disks with over 2,500 segments are available, such that the counter recording 25 impulses would know that the joint rotated 1/100 of a circle, reported as either degrees or radians, depending on the type of controller. It can also know the speed of that movement if it times the intervals between incoming pulses. It will not be able to tell the direction of the rotation if it uses a single-track, or tachometer-type, disk, as shown in Fig. 10.6.15*a*. A quadrature device, as shown in Fig. 10.6.15*b*, has two output channels, A and B, which are offset 90°, thus allowing the direction of movement to be determined by seeing whether the signals from A lead or lag those from B.

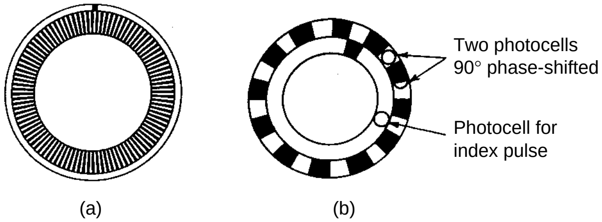


Fig. 10.6.15 Two types of incremental optical encoder disks. Type *a*, a single track incremental disk, has a spoke pattern that shutters the light onto a photodetector. The resulting triangular waveform is electronically converted to a square-wave output, and the pulses are counted to determine the amount of angular movement of the joint to which the encoder components are attached. Type *b*, a quadrature incremental disk, uses two light sources and photodetectors to determine the direction of movement.

The major limitation of incremental encoders is that they do not tell the controller where they are to begin with. Therefore, robots using them must be sent ''home,'' to a known or initial position of each of its links, as the first action of their programs and after each switch-off or interruption of power. Absolute encoders solve this problem, but are more complex and more expensive. They have a light source, a photodetector, and two electrical wires for each track or concentric ring of marks. Each mark or clear spot in each ring represents a bit of data, with the whole word being made up by the number of rings on the disk. Figure 10.6.16 shows 4-bit-word and 8-bit-word disks. Each position of the joint is identified by a specific unique word. All of the tracks in a segment of the disk are read together to input a complete coded word (address) for that position. The codes mostly used are natural binary, binary-coded decimal (BCD), and Gray. Gray code has the advantage that the state (ON/OFF or high/low) of only one track changes for each position change of the joint, making error detection easier.

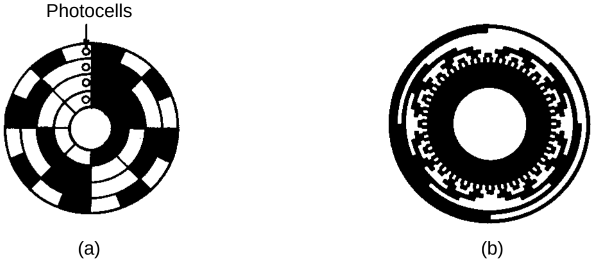


Fig. 10.6.16 Two types of absolute optical encoder disks. Type *a* is for 4-bit-word systems, and type *b* is for 8-bit-word systems. Absolute encoders require a light source and photodetector set for each bit of word length.

All robot controllers require a number of input and output channels for communication and control. The number of I/O ports a robotic system has is one measure of its capabilities. Another measure of a robot's sophistication is the number and type of microprocessors and microcomputers in its system. Some have none; some have a microprocessor at each joint, as well as one dedicated to mathematical computations, one to safety, several to vision and other sensory subsystems, several to internal mapping and navigation (if they are mobile robots), and a master controller micro- or minicomputer.

Programming Robots

The methods of programming robots range from very elementary to advanced techniques. The method used depends on the robot, its controller, and the task to be performed. At the most basic level, some robots can be programmed by setting end stops, switches, pegs in holes, cams, wires, and so forth, on rotating drums, patch boards, control panels, or the robot's links themselves. Such robots are usually the pick-and-place type, where the robot can stop only at preset end points and nowhere in between, the number of accessible points being 2^N, where N is the robot's number of degrees of freedom. The more advanced robots can be programmed to go to any point within their workspace and to execute other commands by using a teach box on a tether (called a *teach pendant*) or a remote control unit. Such devices have buttons, switches, and sometimes a joystick to instruct the robot to do the desired things in the desired sequence. Errors can be corrected by simply overwriting the mistake in the controller's memory. The program can be tested at a slow speed, then, when perfected, can be run at full speed by merely turning a switch on the teach box. This is called the *walk-through* method of programming.

Another way some robots can be programmed is to physically take hold of it (or a remote representation of it) and lead it through the desired sequence of motions. The controller records the motions when in *teach mode* and then repeats them when switched to *run mode.* This is called the *lead-through* method of programming. The foregoing are all *teach-and-repeat* programming methods and are done on-line, that is, on a specific robot as it is in place in an installation but not doing other work while it is being programmed.

More advanced programming involves the use of a keyboard to type in textual language instructions and data. This method can be done on line or off line (away from and detached from the robot, such that it can be working on another task while the program is being created). There are many such programming languages available, but most are limited to use on one or only a few robots. Most of these languages are explicit, meaning that each of their instructions gives the robot a specific command to do a small step (e.g., open gripper) as part of a larger task. The more advanced higher-level implicit languages, however, give instructions at the task level (e.g., assemble 200 of product XYZ), and the robot's computer knows what sequence of basic steps it must execute to do that. These are also called *object-level* or *world-modeling languages* and *model-based systems.* Other ways of instructing a robot include spoken commands and feedback from a wide array of sensors, including vision systems.

Using Robots

The successful utilization of robots involves more than selecting and installing the right robot and programming it correctly. For an assembly robot, for example, care must be taken to design the product so as to facilitate assembly by a robot, presenting the component piece parts and other material to it in the best way, laying out the workplace (work cell) efficiently, installing all required safety measures, and training programming, operating, and maintenance employees properly.

10.7 MATERIAL STORAGE AND WAREHOUSING

by Vincent M. Altamuro

The warehouse handling of material is often more expensive than in-process handling, as it frequently requires large amounts of space, expensive equipment, labor, and computers for control. Warehousing activities, facilities, equipment, and personnel are needed at both ends of the process—at the beginning as receiving and raw materials and purchased parts storage, and at the end as finished goods storage and shipping. These functions are aided by various subsystems and equipment—some simple and inexpensive, some elaborate and expensive.

The rapid and accurate identification of materials is essential. This can be done using only human senses, humans aided by devices, or entirely automated. Bar codes have become an accepted and reliable means of identifying material and inputting that data into an information and control system.

Material can be held, stacked, and transported in simple devices, such as shelves, racks, bins, boxes, baskets, tote pans, pallets and skids, or in complex and expensive computer-controlled systems, such as automated storage and retrieval systems.

IDENTIFICATION AND CONTROL OF MATERIALS

Materials must be identified, either by humans or by automated sensing devices, so as to:

1. Measure presence or movement
2. Qualify and quantify characteristics of interest
3. Monitor ongoing conditions so as to feed back corrective actions
4. Trigger proper marking devices
5. Actuate sortation or classification mechanisms
6. Input computing and control systems, update data bases, and prepare analyses and summary reports

To accomplish the above, the material must have, or be given, a unique code symbol, mark, or special feature that can be sensed and identified. If such a coded symbol is to be added to the material, it must be:

1. Easily and economically produced
2. Easily and economically read
3. Able to have many unique permutations—flexible
4. Compact—sized to the package or product
5. Error resistant—low chance of misreading, reliable
6. Durable
7. Digital—compatible with computer data formats

The codes can be read by contact or noncontact means, by moving or stationary sensors, and by humans or devices.

There are several technologies used in the identification and control of materials. The most important of these are:

1. Bar codes
2. Radio-frequency identification (RFID)
3. Smart cards
4. Machine vision
5. Voice recognition
6. Magnetic stripes
7. Optional character recognition (OCR)

All can be used for automatic data collection (ADC) purposes and as part of a larger electronic data interchange (EDI), which is the paperless, computer-to-computer, intercompany, and international communications and information exchange using a common data language. The dominant data format standard in the world is Edifact (Electronic Data Interchange for Administration, Commerce, and Transportation).

Bar codes are one simple and effective means of identifying and controlling material. Bar codes are machine-readable patterns of alternating, parallel, rectangular bars and spaces of various widths whose combinations represent numbers, letters, or other information as determined by the particular symbology, or language, employed. Several types of bar codes are available. While multicolor bar codes are possible, simple black-and-white codes dominate because a great number of permutations are available by altering their widths, presence, and sequences. Some codes are limited to numeric information, but others can encode complete alphanumeric plus special symbols character sets. Most codes are binary digital codes, some with an extra parity bit to catch errors. In each bar code, there is a unique sequence set of bars and spaces to represent each number, letter, or symbol. One-dimensional, or linear, codes print all of the bars and spaces in one row. Two-dimensional stacked codes arrange sections above one another in several rows so as to condense more data into a smaller space. To read stacked codes, the scanner must sweep back and forth so as to read all of the rows. The most recent development is the two-dimensional matrix codes that contain much more information and are read with special scanners or video cameras. Many codes are of the *n* of *m* type, i.e., 2 of 5, 3 of 9, etc. For example, in the **2-of-5 code,** a narrow bar may represent a 0 bit or OFF and a wide bar a 1 or ON bit. For each set of 5 bits, 2 must be ON—hence, 2 of 5. See Table 10.7.1 for the key to this code. A variation to the basic 2 of 5 is the **Interleaved 2-of-5,** in which the spaces between the bars also can be either narrow or wide, permitting the reading of a set of bars, a set of spaces, a set of bars, a set of spaces, etc., and yielding more information in less space. See Fig. 10.7.1. Both the 2-of-5 and the Interleaved 2-of-5 codes have ten numbers in their character sets.

Code 39, another symbology, permits alphanumeric information to be encoded by allowing each symbol to have 9 modules (locations) along the bar, 3 of which must be ON. Each character comprises five bars and four spaces. Code 39 has 43 characters in its set (1-10, A-Z, six symbols, and one start/stop signal). Each bar or space in a bar code is called an element. In Code 39, each element is one of two widths, referred to as *wide* and *narrow.* As in other bar codes, the narrowest element is referred to as the *X* dimension and the ratio of the widest to narrowest element widths is referred to as the *N* of the code. For each code, *X* and

Table 10.7.1 Bar Code 2-of-5 and I 2/5 Key

	Code				
Character	1	2	4	7	P
0	0	0	1	1	0
1	1	0	0	0	1
2	0	1	0	0	1
3	1	1	0	0	0
4	0	0	1	0	1
5	1	0	1	0	0
6	0	1	1	0	0
7	0	0	0	1	1
8	1	0	0	1	0
9	0	1	0	1	0

Wide bars and spaces = 1
Narrow bars and spaces = 0

N are constants. These values are used to calculate length of the bar code labels. The *Y* dimension of a bar code is the length (or height) of its bars and spaces. It influences the permissible angle at which a label may be scanned without missing any of the pattern. See Table 10.7.2 for the Code 39 key. The patterns for the Code 39 bars and spaces are designed in such a way that changing or misreading a single bit in any of them results in an illegal code word. The bars have only an even number of wide elements and the spaces have only an odd number of wide elements. The code is called *self-checking* because that design provides for the immediate detection of single printing or reading errors. See Fig. 10.7.2. Code 39 was developed by Intermec (Everett, WA), as was **Code 93,** which requires less space by permitting more sizes of bars and spaces. Code 93 has 128 characters in its set (the full ASCII set) and permits a maximum of about 14 characters per inch, versus Code 39's maximum of about 9. Code 39 is *discrete,* meaning that each character is printed independently of the other characters and is separated from the characters on both sides of it by a space (called an intercharacter gap) that is not part of the data. Code 93 is a *continuous* code, meaning that there are no intercharacter gaps in it and all spaces are parts of the data symbols.

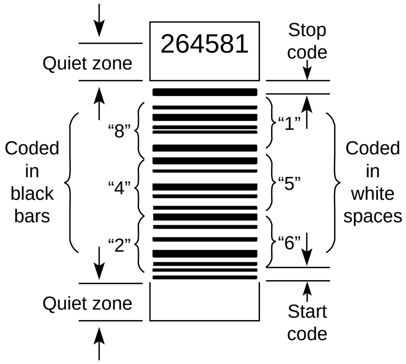


Fig. 10.7.1 A sample of a Uniform Symbology Specification Interleaved 2-of-5 bar code (also called I 2/5 or ITF).

Table 10.7.2 Uniform Symbology Specification Code 39 Symbol Character Set

Char.	Encodation Pattern	bsbsbsbsb	ASCII
0		000110100	48
1		100100001	49
2		001100001	50
3		101100000	51
4		000110001	52
5		100110000	53
6		001110000	54
7		000100101	55
8		100100100	56
9		001100100	57
A		100001001	65
B		001001001	66
C		101001000	67
D		000011001	68
E		100011000	69
F		001011000	70
G		000001101	71
H		100001100	72
I		001001100	73
J		000011100	74
K		100000011	75
L		001000011	76
M		101000010	77
N		000010011	78
O		100010010	79
P		001010010	80
Q		000000111	81
R		100000110	82
S		001000110	83
T		000010110	84
U		110000001	85
V		011000001	86
W		111000000	87
X		010010001	88
Y		110010000	89
Z		011010000	90
–		010000101	45
.		110000100	46
SPACE		011000100	32
$		010101000	36
/		010100010	47
+		010001010	43
%		000101010	37
S/S		010010100	none

Note: "S/S" denotes special Code 39 Start and Stop Character.

Note: In the columns headed "b" and "s" 1 is used to represent a wide element and 0 is used to represent a narrow element.

SOURCE: Uniform Symbology Specification Code 39, Table 2: Code 39 Symbol Character Set, © Copyright 1993 Automatic Identification Manufacturers, Inc.

Code 128, a high-density alphanumeric symbology, has 128 characters and a maximum density of about 18 characters per inch (cpi) for numeric data and about 9 cpi for alphanumeric data. A Code 128 character comprises six elements: three bars and three spaces, each of four possible widths, or modules. Each character consists of eleven 1*X* wide modules, where *X* is the width of the narrowest bar or space. The sum of the number of bar modules in any character is always even (even parity), while the sum of the space modules is always odd (odd parity), thus permitting self-checking of the characters. See Table 10.7.3 for the Code 128 key. Code 128 is a continuous, variable-length, bidirectional code.

The **Universal Product Code** (U.P.C.) is a 12-digit bar code adopted by the U.S. grocery industry in 1973. See Figure 10.7.3 for a sample of the U.P.C. standard symbol. Five of the six digits in front of the two long bars in the middle [called the *center guard pattern* (CGP)] identify the item's manufacturer and five of the six digits after the CGP identifies the specific product. There are several variations of the U.P.C., all controlled by the Uniform Code Council, located in Dayton, OH. One variation is an 8-digit code that identifies both the manufacturer and the specific product with one number. The U.P.C. uses prefix and suffix digits separated from the main number. The prefix digit is the *number system character.* See Table 10.7.4 for the key to these prefix numbers. The suffix is a ''modulo-10'' check digit. It serves to confirm that the prior 11 digits were read correctly. See Figure 10.7.4 for the method by

Table 10.7.3 Uniform Symbology Specification Code 128 Symbol Character Set

Value	Code set A	Code set B	Code set C	Encodation Pattern	bsbsbs
0	SP	SP	00		212222
1	!	!	01		222122
2	*	*	02		222221
3	#	#	03		121223
4	$	$	04		121322
5	%	%	05		131222
6	&	&	06		122213
7	'	'	07		122312
8	(	(	08		132212
9	)	)	09		221213
10	*	*	10		221312
11	+	+	11		231212
12	,	,	12		112232
13	-	-	13		122132
14	.	.	14		122231
15	/	/	15		113222
16	0	0	16		123122
17	1	1	17		123221
18	2	2	18		223211
19	3	3	19		221132
20	4	4	20		221231
21	5	5	21		213212
22	6	6	22		223112
23	7	7	23		312131
24	8	8	24		311222
25	9	9	25		321122
26	:	:	26		321221
27	;	;	27		312212
28	<	<	28		322112
29	=	=	29		322211
30	>	>	30		212123
31	?	?	31		212321
32	@	@	32		232121
33	A	A	33		111323
34	B	B	34		131123
35	C	C	35		131321
36	D	D	36		112313
37	E	E	37		132113
38	F	F	38		132311
39	G	G	39		211313
40	H	H	40		231113
41	I	I	41		231311
42	J	J	42		112133
43	K	K	43		112331
44	L	L	44		132131
45	M	M	45		113123
46	N	N	46		113321
47	O	O	47		133121
48	P	P	48		313121
49	Q	Q	49		211331
50	R	R	50		231131
51	S	S	51		213113
52	T	T	52		213311
53	U	U	53		213131
54	V	V	54		311123
55	W	W	55		311321
56	X	X	56		331121
57	Y	Y	57		312113
58	Z	Z	58		312311
59	[	[	59		332111
60	\	\	60		314111
61	]	]	61		221411
62	^	^	62		431111
63	_	_	63		111224
64	NUL	'	64		111422
65	SOH	a	65		121124
66	STX	b	66		121421
67	ETX	c	67		141122
68	EOT	d	68		141221
69	ENQ	e	69		112214
70	ACK	f	70		112412
71	BEL	g	71		122114
72	BS	h	72		122411
73	HT	i	73		142112
74	LF	j	74		142211
75	VT	k	75		241211
76	FF	l	76		221114
77	CR	m	77		413111
78	SO	n	78		241112
79	SI	o	79		134111
80	DLE	p	80		111242
81	DC1	q	81		121142
82	DC2	r	82		121241
83	DC3	s	83		114212
84	DC4	t	84		124112
85	NAK	u	85		124211
86	SYN	v	86		411212
87	ETB	w	87		421112
88	CAN	x	88		421211
89	EM	y	89		212141
90	SUB	z	90		214121
91	ESC	{	91		412121
92	FS	|	92		111143
93	GS	}	93		111341
94	RS	~	94		131141
95	US	DEL	95		114113
96	FNC 3	FNC 3	96		114311
97	FNC 2	FNC 2	97		411113
98	SHIFT	SHIFT	98		411311
99	CODE C	CODE C	99		113141
100	CODE B	FNC 4	CODE B		114131
101	FNC 4	CODE A	CODE A		311141
102	FNC 1	FNC 1	FNC 1		411131

			bsbsbs
103	START A		211412
104	START B		211214
105	START C		211232

		bsbsbsb
STOP		2331112

Note: The numeric values in the "b" and "s" columns represent the number of modules in each of the symbol characters' bars and spaces.

Note: Dashed line indicates leading edge of adjacent character.

SOURCE: Uniform Symbology Specification Code 128, Table 2: Code 128 Symbol Character Set, © Copyright 1993 Automatic Identification Manufacturers, Inc.

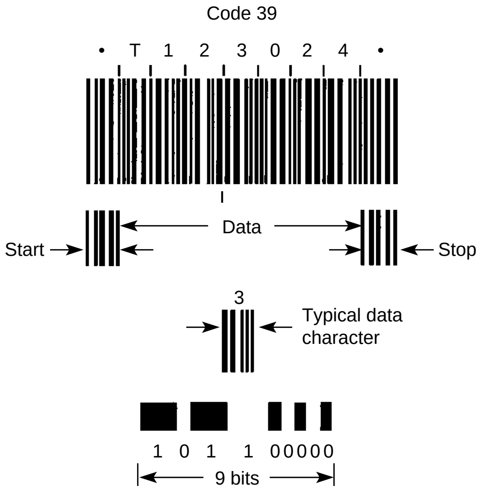


Fig. 10.7.2 A sample of Uniform Symbology Specification Code 39 bar code.

which the check digit is calculated. Each U.P.C. character comprises two bars and two spaces, each of which may be one, two, three, or four modules wide, such that the entire character consumes a total of seven modules of space. See Table 10.7.5 for the key to the code. It will be noted that the codes to the left of the CGP all start with a zero (a space) and end with a one (a bar) while those to the right of the CGP all start with a one and end with a zero. This permits the code to be scanned from either left to right or right to left (that is, it is omnidirectional) and allows the computer to determine the direction and whether it needs to be reversed before use by the system. The U.P.C. label also has the number printed in human-readable form along the bottom.

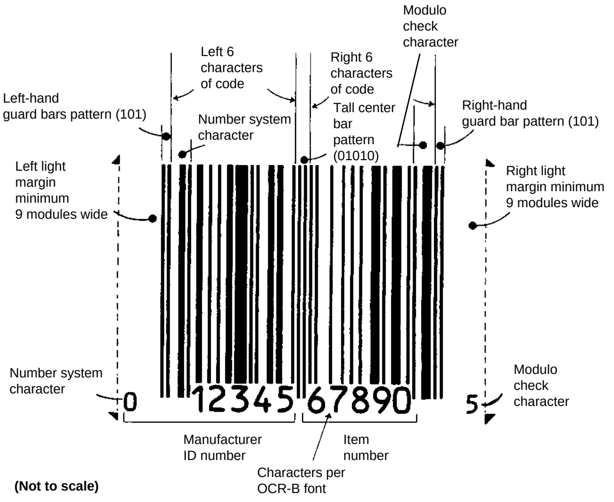


Fig. 10.7.3 A sample of the Universal Product Code Standard Symbol. *(U.P.C. Symbol Specification Manual, January 1986, Copyright© 1986 Uniform Code Council, Inc. The Uniform Code Council prohibits the commercial use of their copyrighted material without prior written permission.)*

When integrated into a complete system, the U.P.C. can serve as the input data point for supermarket pricings, checkouts, inventory control, reordering stock, employee productivity checks, cash control, special promotions, sales analyses, and management reports. Its use increases checkout speed and reduces errors. In some stores, it is combined with a speech synthesizer that voices the description and price of each item scanned. It is a vital component in a fully automated store.

Table 10.7.4 U.P.C. Prefix Number System Character Key
The human-readable character identifying the encoded number system will be shown in the left-hand margin of the symbol as per Fig. 10.7.3.

Number system character	Specified use
0	Regular U.P.C. codes (Versions A and E)
2	Random-weight items, such as meat and produce, symbol-marked at store level (Version A)
3	National Drug Code and National Health Related Items Code in current 10-digit code length (Version A). Note that the symbol is not affected by the various internal structures possible with the NDC or HRI codes.
4	For use without code format restriction with check digit protection for in-store marking of nonfood items (Version A).
5	For use on coupons (Version A).
6, 7	Regular U.P.C. codes (Version A).
1, 8, 9	Reserved for uses unidentified at this time.

SOURCE: U.P.C. Symbol Specification Manual, January 1986, © Copyright 1986 Uniform Code Council, Inc. The Uniform Code Council prohibits the commercial use of their copyrighted material without prior written permission.

The following example will illustrate the calculation of the check character for the symbol shown in Fig. 10.7.3. Note that the code shown in Fig. 10.7.3 is in concurrent number system 0.

Step 1: Starting at the left, sum all the characters in the *odd* positions (that is, first from the left, third from the left, and so on), *starting with the number system character.*

(For the example, $0 + 2 + 4 + 6 + 8 + 0 = 20$.)

Step 2: Multiply the sum obtained in Step 1 by 3.

(The product for the example is 60.)

Step 3: Again starting at the left, sum all the characters in the *even* positions.

(For the example, $1 + 3 + 5 + 7 + 9 = 25$.)

Step 4: Add the product of step 2 to the sum of step 3.

(For the example, the sum is 85.)

Step 5: The modulo-10 check character value is the smallest number which when added to the sum of step 4 produces a multiple of 10.

(In the example, the check character value is 5.)

The human-readable character identifying the encoded check character will be shown in the right-hand margin of the symbol as in Fig. 10.7.3.

Fig. 10.7.4 U.P.C. check character calculation method. *(U.P.C. Symbol Specification Manual, January 1986, Copyright© 1986 Uniform Code Council, Inc. The Uniform Code Council prohibits the commercial use of their copyrighted material without prior written permission.)*

Over the years, nearly 50 different one-dimensional bar code symbologies have been introduced. Around 20 found their way into common use at one time or another, with six or seven being most important. These are the Interleaved 2-of-5, Code 39, Code 93, Code 128, Codabar, Code 11, and the U.P.C. Table 10.7.6 compares some of the characteristics of these codes. The choice depends on the use by others in the same industry, the need for intercompany uniformity, the type and amount of data to be coded, whether mere numeric or alphanumeric plus special symbols will be needed, the space available on the item, and intracompany compatibility requirements.

Some bar codes are limited to a fixed amount of data. Others can be extended to accommodate additional data and the length of their label is variable. Figure 10.7.5 shows a sample calculation of the length of a Code 39 label.

Table 10.7.5 U.P.C. Encodation Key

Encodation for U.P.C. characters, number system character, and modulo check character.

Decimal value	Left characters (Odd parity—O)	Right characters (Even parity—E)
0	0001101	1110010
1	0011001	1100110
2	0010011	1101100
3	0111101	1000010
4	0100011	1011100
5	0110001	1001110
6	0101111	1010000
7	0111011	1000100
8	0110111	1001000
9	0001011	1110100

The encodation for the left and right halves of the regular symbol, including UPC characters, number system character and modulo check character, is given in this following chart, which is applicable to version A. Note that the left-hand characters always use an odd number (3 or 5) of modules to make up the dark bars, whereas the right-hand characters always use an even number (2 or 4). This provides an ''odd'' and ''even'' parity encodation for each character and is important in creating, scanning and decoding a symbol.

SOURCE: U.P.C. Symbol Specification Manual, January 1986, © Copyright 1986 Uniform Code Council, Inc. The Uniform Code Council prohibits the commercial use of their copyrighted material without prior written permission.

Example used:

Symbology: Code 39

System: Each bar or space = one element
Each character = 9 elements (5 bars and 4 spaces)
Each character = 3 wide and 6 narrow elements
(That is, 3 of 9 elements must be wide)

Width of narrow element = X dimension = 0.015 in (0.0381 cm)
Wide to narrow ratio = N value = 3 : 1 = 3
Length segments per data character = 3(3) + 6 = 15
Number of data characters in example = 6
Length of data section = 6 × 5 = 90.0 segments of length
Start character = 15.0
Stop character = 15.0
Intercharacter gaps (at 1 segment per gap):
No. of gaps = (data characters − 1) + start + stop
= (6 − 1) + 1 + 1 = 7 = 7.0
Quiet zones
(2, each at least 10 segments) = 20.0
Total segments = 147.0
Times X, length of each segment × 0.015
= 2.205 in (5.6007 cm)

Fig. 10.7.5 Calculation of a bar code label length.

Table 10.7.6 Comparison of Bar Code Symbologies

	Interleaved	Code 39	Codabar	Code 11	U.P.C./EAN	Code 128	Code 93
Date of inception	1972	1974	1972	1977	1973	1981	1982
Industry-standard specification	AIM ANSI UPCC AIAG	AIM ANSI AIAG HIBC	CCBBA ANSI	AIM	UPCC IAN	AIM	AIM
Government support		DOD					
Corporate sponsors	Computer Identics	Intermec	Welch Allyn	Intermec		Computer Identics	Intermec
Most-prominent application area	Industry	Industry	Medical	Industry	Retail	New	New
Variable length	No[a]	Yes	Yes	Yes	No	Yes	Yes
Alphanumeric	No	Yes	No	No	No	Yes	Yes
Discrete	No	Yes	Yes	Yes	No	No	No
Self-checking	Yes	Yes	Yes	No	Yes	Yes	No
Constant character width	Yes	Yes	Yes[b]	Yes	Yes	Yes	Yes
Simple structure (two element widths)	Yes	Yes	No	No	No	No	No
Number of data characters in set	10	43/128	16	11	10	103/128	47/128
Density[c]:							
Units per character	7–9	13–16	12	8–10	7	11	9
Smaller nominal bar, in	0.0075	0.0075	0.0065	0.0075	0.0104	0.010	0.008
Maximum characters/inch	17.8	9.4	10	15	13.7	9.1	13.9
Specified print tolerance at maximum density, in							
Bar width	0.0018	0.0017	0.0015	0.0017	0.0014	0.0010	0.0022
Edge to edge					0.0015	0.0014	0.0013
Pitch					0.0030	0.0029	0.0013
Does print tolerance leave more than half of the total tolerance for the scanner?	Yes	Yes	No	Yes	No	No	Yes
Data security[d]	High	High	High	High	Moderate	High	High

[a] Interleaved 2 of 5 is fundamentally a fixed-length code.

[b] Using the standard dimensions Codabar has constant character width. With a variant set of dimensions, width is not constant for all characters.

[c] Density calculations for interleaved 2 of 5, Code 39, and Code 11 are based on a wide-to-narrow ratio of 2.25 : 1. Units per character for these symbols are shown as a range corresponding to wide/narrow ratios from 2 : 1 to 3 : 1. A unit in Codabar is taken to be the average of narrow bars and narrow spaces, giving about 12 units per character.

[d] High data security corresponds to less than 1 substitution error per several million characters scanned using reasonably good-quality printed symbols. Moderate data security corresponds to 1 substitution error per few hundred thousand characters scanned. These values assume no external check digits other than those specified as part of the symbology and no file-lookup protection or other system safeguards.

[e] AIM = Automatic Identification Mfrs Inc (Pittsburgh)
ANSI = American National Standards Institute (New York)
AIAG = Automative Industry Action Group (Southfield, MI)
IAN = Intl Article Numbering Assn (Belgium)
DOD = Dept of Defense
CCBBA = Committee for Commonality in Blood Banking (Arlington, VA)
UPCC = Uniform Product Code Council Inc (Dayton, OH)

SOURCE: Intermec—A Litton Company, as published in the March, 1987 issue of *American Machinist* magazine, Penton Publishing Co., Inc.

The foregoing one-dimensional, linear bar codes are sometimes called *license plates* because all they can do is contain enough information to identify an item, thereby permitting locating more information stored in a host computer. Two-dimensional stacked codes contain more information. The stacked codes, such as **Code 49,** developed by Dr. David Allais at Intermec, **Code 16K,** invented by Ted Williams, of Laserlight Systems, Inc., Dedham, MA, and others are really one-dimensional codes in which miniaturized linear codes are printed in multiple rows, or tiers. They are useful on small products, such as electronic components, single-dose medicine packages, and jewelry, where there is not enough space for a one-dimensional code. To read them, a scanner must traverse each row in sequence. Code 49 (see Fig. 10.7.6) can arrange all 128 ASCII encoded characters on up to eight stacked rows. Figure 10.7.7 shows a comparison of the space required for the same amount (30 characters) of alphanumeric information in three bar code symbologies: Code 39, Code 93, and Code 49. Code 16K (Fig. 10.7.8), which stands for 128 squared, shrinks and stacks linear codes in from 2 to 16 rows. It offers high-data-density encoding of the full 128-character ASCII set and double-density encoding of numerical data strings. It can fit 40 characters of data in the same space as eight would take in Code 128, and it can be printed and read with standard printing and scanning equipment.

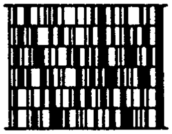


Fig. 10.7.6 Code 49. *(Uniform Symbology Specification Code 49, Copyright© 1993 Automatic Identification Manufacturers, Inc.)*

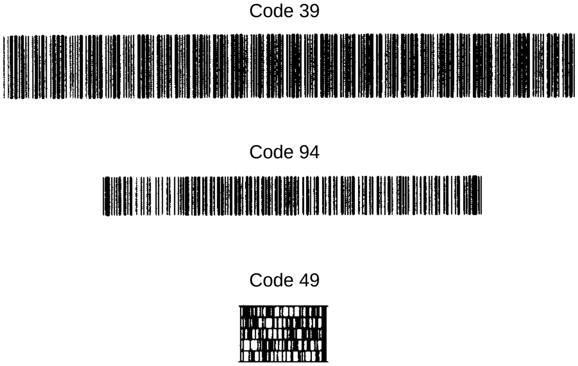


Fig. 10.7.7 A comparison of the space required by three bar codes. Each bar code contains the same 30 alphanumeric characters.

Two-dimensional codes allow extra information regarding an item's description, date and place of manufacture, expiration date, lot number, package size, contents, tax code, price, etc. to be encoded, rather than merely its identity. Two-dimensional matrix codes permit the encoding of very large amounts of information. Read by video cameras or special laser scanners and decoders, they can contain a complete data file about the product to which they are affixed. In many cases, this eliminates the need to access the memory of a host computer. That the data file travels with (on) the item is also an advantage. Their complex patterns and interpretation algorithms permit the reading of complete files even when part of the pattern is damaged or missing.

Fig. 10.7.8 Code 16K with human-readable interpretation. *(Uniform Symbology Specification Code 16K, Copyright© 1993 Automatic Identification Manufacturers, Inc.)*

Code PDF417, developed by Symbol Technologies Inc., Bohemia, NY (and put in the public domain, as are most codes), is a two-dimensional bar code symbology that can record large amounts of data, as well as digitized images such a fingerprints and photographs. To read the high-density PDF417 code, Symbol Technologies Inc. has developed a rastering laser scanner. This scanner is available in both a hand-held and fixed-mount version. By design, PDF417 is also scannable using a wide range of technologies, as long as specialized decoding algorithms are used. See Fig. 10.7.9 for an illustration of PDF417's ability to compress Abraham Lincoln's Gettysburg Address into a small space. The minimal unit that can represent data in PDF417 is called a *codeword.* It comprises 17 equal-length modules. These are grouped to form 4 bars and 4 spaces, each from one to six modules wide, so that they total 17 modules. Each unique codeword pattern is given one of 929 values. Further, to utilize different data compression algorithms based on the data type (i.e., ASCII versus binary) the system is multimodal, so that a codeword value may have different meanings depending on which of the various modes is being used. The modes are switched automatically during the encoding process to create the PDF417 code and then again during the decoding process. The mode-switching instructions are carried in special codewords as part of the total pattern. Thus, the value of a scanned codeword is first determined (by low-level decoding), then its meaning is determined by virtue of which mode is in effect (by high-level decoding). Code PDF417 is able to detect and correct errors because of its sophisticated error-correcting algorithms. Scanning at angles is made possible by giving successive rows of the stacked code different identifiers, thereby permitting the electronic ''stitching'' of the individual codewords scanned. In addition, representing the data by using codewords with numerical values that must be interpreted by a decoder permits the mathematical correction of reading errors. At its simplest level, if two successive codewords have values of, say, 20 and 52, another codeword could be made their sum, a 72. If the first codeword were read, but the second missed or damaged, the system would subtract 20 from 72 and get the value of the second codeword. More complex high-order simultaneous polynomial equations and algorithms are also used. The PDF417 pattern serves as a portable data file that provides local access to large amounts of information about an item (or person) when access to a host computer is not possible or economically feasible. PDF417 provides a low-cost paper-based method of transmitting machine-readable data between systems. It also has use in WORM (written once and read many times) applications. The size of the label and its aspect ratio (the shape, or relationship of height to width) are variable so as to suit the user's needs.

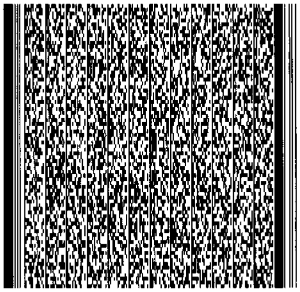


Fig. 10.7.9 A sample of PDF417 Encoding: Abraham Lincoln's Gettysburg Address. *(Symbol Technologies, Inc.)*

Data Matrix, a code developed by International Data Matrix Inc., Clearwater, FL, is a true matrix code. It may be square or rectangular, and can be enlarged or shrunk to whatever size [from a 0.001-in (0.254-mm), or smaller, to a 14-in (36-cm), or larger, square] suits the user and application. Figure 10.7.10 shows the code in three sizes, but with the same contents. Its structure is uniform—square cells all the same size for a given pattern. To fit more user data into a matrix of a specific size, all the internal square cells are reduced to a size that will accommodate the amount of data to be encoded. Figure 10.7.11 shows five patterns, all the same size, containing different amounts of data. As a user selects additional data, the density of the matrix naturally increases. A pattern can contain from 1 to 2000 characters of data. Two adjacent sides are always solid, while the remaining two sides are always composed of alternating light and dark cells. This signature serves to have the video [charge-coupled device (CCD)] camera locate and identify the symbol. It also provides for the determination of its angular orientation. That capability permits a robot to rotate the part to which the code is affixed to the proper orientation for assembly, test, or packaging. Further, the information it contains can be program instructions to the robot. The labels can be printed in any combination of colors, as long as their difference provides a 20 percent or more contrast ratio. For aesthetic or security reasons, it can be printed in invisible ink, visible only when illuminated with ultraviolet light. The labels can be created by any printing method (laser etch, chemical etch, dot matrix, dot peen, thermal transfer, ink jet, pad printer, photolithography, and others) and on any type of computer printer through the use of a software interface driver provided by the company. The pattern's binary code symbology is read with standard CCD video cameras attached to a company-made controller linked to the user's computer system with standard interfaces and a Data Matrix Command Set. The algorithms for error correction that it uses create data values that are cumulative and predictable so that a missing or damaged character can be deduced or verified from the data values immediately preceding and following it.

01234567890123456789

01234567890123456789

01234567890123456789

Fig. 10.7.10 Three sizes of Data Matrix patterns, all with the same contents. *(International Data Matrix, Inc.)*

0123456789
0123456789

0123456789
ABCDEFGHIJKLMN
OPQRSTUVWXYZ

0123456789ABCD
EFGHIJKLMNOPQ
RSTUVWXYZabcd
efghijklmnopqrstuv
wxyz

0123456789ABCD
EFGHIJKLMNOPQ
RSTUVWXYZabcd
efghijklmnopqrstuv
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Fig. 10.7.11 Five Data Matrix patterns, all the same size but containing different amounts of information. *(International Data Matrix, Inc.)*

Code One (see Fig. 10.7.12), invented by Ted Williams, who also created Code 128 and Code 16K, is also a two-dimensional checkerboard or matrix type code read by a two-dimensional imaging device, such as a CCD video camera, rather than a conventional scanner. It can be read at any angle. It can encode the full ASCII 256-character set in addition to four function characters and a pad character. It can encode from 6 to over 2000 characters of data in a very small space. If more data is needed, additional patterns can be linked together.

12345678901234567890I2

Fig. 10.7.12 Code One. *(Laserlight Systems, Inc.)*

Figure 10.7.13 shows a comparison of the sizes of four codes—Code 128, Code 16K, PDF-417, and Code One—to illustrate how much smaller Code One is than the others. Code One can fit 1000 characters into a 1-in (2.54-cm) square of its checkerboard-like pattern. All Code One patterns have a finder design at their center. These patterns serve several purposes. They permit the video camera to find the label and determine its position and angular orientation. They eliminate the need for space-consuming quiet zones. And, because the internal patterns are different for each of the versions (sizes, capacities, and configurations) of the code, they tell the reader what version it is seeing. There are 10 different versions and 14 sizes of the symbol. The smallest contains 40 checkerboard-square type bits and the largest has 16,320. Code 1H, the largest version, can encode 3,550 numeric or 2,218 alphanumeric characters, while correcting up to 2240 bit errors. The data is encoded in rectangular tile groups, each composed of 8-bit squares arranged in a four-wide by two-high array. Within each tile, each square encodes one bit of data, with a white square representing a zero and a black square representing a one. The squares are used to create the 8-bit bytes that are the symbol's characters. The most significant bit in the character pattern is in the top left corner of the rectangle, proceeding left to right through the upper row and then the lower row, to the least significant bit in the bottom right corner of the pattern. The symbol characters are ordered left to right and then top to bottom, so that the first character is in the top left corner of the symbol and the last character is in the bottom right corner.

The fact that the patterns for its characters are arrays of spots whose images are captured by a camera, rather than the row of bars that one-dimensional and stacked two-dimensional codes have, frees it from the *Y*-dimension scanning angle restraint of those codes and makes it less susceptible to misreads and no-reads. The size of each square data bit is controlled only by the smallest optically resolvable or printable spot.

Bar codes may be printed directly on the item or its packaging or on a label that is affixed thereon. Some are scribed on with a laser. In many cases, they are printed on the product or package at the same time other printing or production operations are being performed, making the cost of adding them negligible. Labels may be produced in house or ordered from an outside supplier.

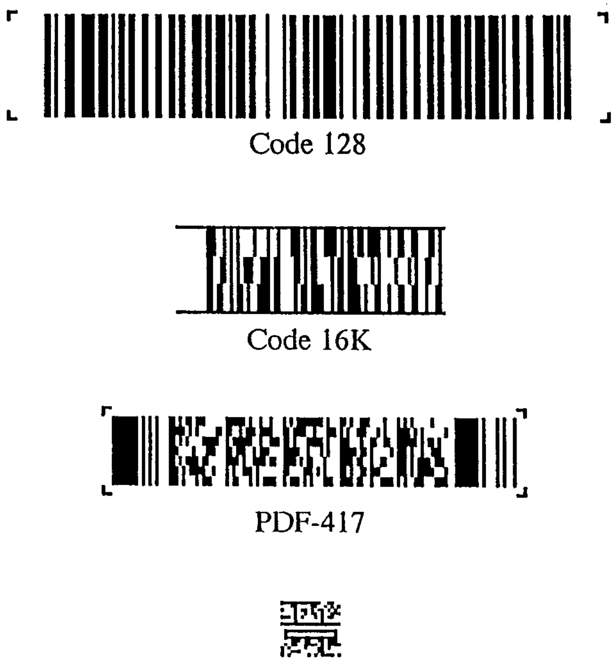

Fig. 10.7.13 Comparative sizes of four symbols encoding the same data with the same *x* dimension. *(Laserlight Systems, Inc.)*

In addition to the bar code symbology, an automatic identification system also requires a scanner or a video camera. A scanner is an electrooptical sensor which comprises a light source [typically a light-emitting diode (LED), laser diode, or helium-neon-laser tube], a light detector [typically a photodiode, photo–integrated circuit (photo-IC), phototransistor, or charge-coupled device], an analog signal amplifier, and (for digital scanners) an analog-to-digital converter. The system also needs a microprocessor-based decoder, a data communication link to a computer, and one or more output or actuation devices. See Fig. 10.7.14.

The scanner may be hand-held or mounted in a fixed position, but something must move relative to the other, either the entire scanner, the scanner's oscillating beam of light, or the package or item containing the bar code. For moving targets, strobe lights are sometimes used to freeze the image while it is being read.

The four basic categories of scanners are: hand-held fixed beam, hand-held moving beam, stationary fixed beam, and stationary moving beam. Some scanners cast crosshatched patterns on the object so as to catch the bar code regardless of its position. Others create holographic laser patterns that wrap a field of light beams around irregularly shaped articles. Some systems require contact between the scanner and the bar code, but most are of the noncontact type. A read-and-beep system emits a sound when a successful reading has been made. A specialized type of scanner, a slot scanner, reads bar codes on badges, cards, envelopes, documents, and the like as they are inserted in the slot and swiped.

In operation, the spot or aperture of the scanner beam is directed by optics onto the bar code and reflected back onto a photodetector. The relative motion of the scanner beam across the bar code results in an analog response pattern by the photodetector as a function of the relative reflectivities of the dark bars and light spaces. A sufficient contrast between the bars, spaces, and background color is required. Some scanners see red bars as white. Others see aluminum as black, requiring the spaces against such backgrounds to be made white.

The system anticipates an incoming legitimate signal by virtue of first receiving a zero input from the ''quiet zone''—a space of a certain width (generally at least 10 times the code's *X* dimension) that is clear of all marks and which precedes the start character and follows the stop character. The first pattern of bars and spaces (a character) that the scanner sees is the start/stop code. These not only tell the system that data codes are coming next and then that the data section has ended, but in bidirectional systems (those that can be scanned from front to back or from back to front) they also indicate that direction. In such bidirectional systems, the data is read in and then reversed electronically as necessary before use. The analog signals pass through the scanner's signal conditioning circuitry, were they are amplified, converted into digital form, tested to see whether they are acceptable, and, if so, passed to the decoder section microprocessor for algorithmic interpretation.

The decoder determines which elements are bars and which are spaces, determines the width (number of modules) of each element, determines whether the code has been read frontward or backward and reverses the signal if needed, makes a parity check, verifies other criteria, converts the signal into a computer language character—the most common of which is asynchronous American Standard Code for Information Interchange (ASCII)—and sends it, via a data communication link, to the computer. Virtually all automatic identification systems are computer-based. The bar codes read become input data to the computer, which then updates its stored information and/or triggers an output.

Other types of automatic identification systems include radio-frequency identification, smart cards, machine vision, voice recognition, magnetic stripes, and optical character recognition.

Radio-frequency identification has many advantages over the other identification, control, and data-collection methods. It is immune to factory noise, heat, cold, and harsh environments. Its tags can be covered with dirt, grease, paint, etc. and still operate. It does not require line of sight from the reader, as do bar codes, machine vision, and OCR. It

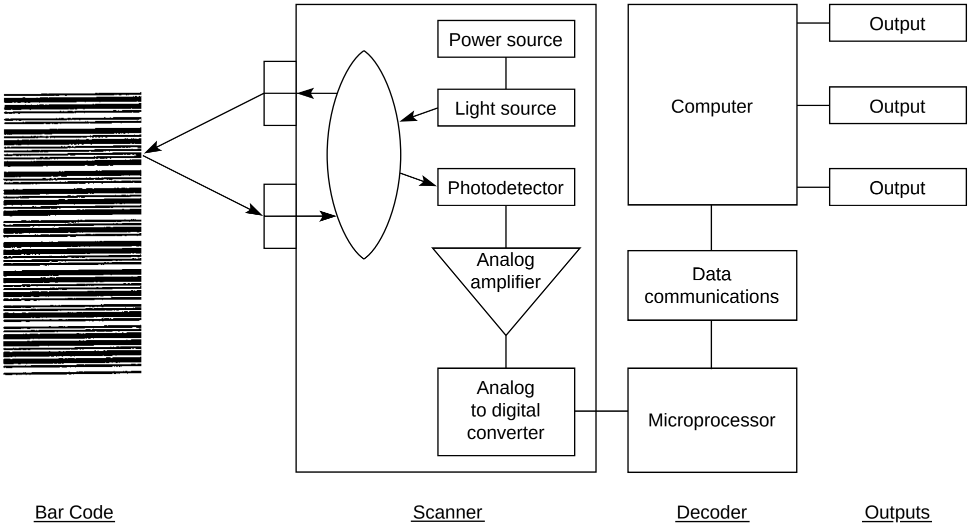

Fig. 10.7.14 Components of a bar code scanner.

can be read from a distance, typically 15 ft (4.6 m). Its tags can both receive and send signals. Many types have higher data capacities than one-dimensional bar codes, magnetic stripes, and OCR. Some tags can read/write and process data, much like smart cards. However, RFID also has some disadvantages, compared to other methods. The tags are not human-readable and their cost for a given amount of data capacity is higher than that of some other methods. The RFID codes are currently closed—that is, a user's code is not readable by suppliers or customers—and there are no uniform data identifiers (specific numeric or alphanumeric codes that precede the data code and that identify the data's industry, category, or use) like the U.P.C. has.

An RFID system consists of a transceiver and a tag, with a host computer and peripheral devices possible. The transceiver has a coil or antenna, a microprocessor, and electronic circuitry, and is called a *reader* or *scanner*. The tag can also have an antenna coil, a nonvolatile type of memory, transponder electronic circuitry, and control logic—all encapsulated for protection.

The system's operations are very simple. The reader transmits an RF signal to the tag, which is usually on a product, tote bin, person, or other convenient carrier. This signal tells the tag that a reader is present and wants a response. The activated tag responds by broadcasting a coded signal on a different frequency. The reader receives that signal and processes it. Its output may be as simple as emitting a sound for the unauthorized removal of an item containing the tag (retail theft, library books, and the like), flashing a green light and/or opening a door (employee ID badges), displaying information on a human-readable display, directing a robot or automatic guided vehicle (AGV), sending a signal to a host computer, etc. The signals from the reader to the tags can also provide energy to power the tag's circuitry and supply the digital clock pulses for the tag's logic section.

The tags may be passive or active. Passive tags use power contained in the signal from the reader. The normal range for these is 18 in (0.46 m) or less. Active tags contain a battery for independent power and usually operate in the 3- to 15-ft (0.9- to 4.6-m) range. Tags programmed when made are said to be *factory programmed* and are read-only devices. Tags programmed by plugging them into, or placing them very near, a programmer are called *field-programmed* devices. Tags whose program or data can be changed while they are in their operating locations are called *in-use programmed* devices. The simplest tags contain only one bit of code. They are typically used in retail stores to detect shoplifting and are called *electronic article surveillance* (EAS), *presence sensing*, or *Level I* tags. The next level up are the tags that, like bar codes, identify an object and serve as an input code to a database in a host computer. These ‘‘electronic license plates’’ are called *Level II* tags and typically have a capacity of between 8 and 128 bits. The third level devices are called *Level III*, or *transaction/routing* tags. They hold up to 512 bits so that the item to which they are attached may be described as well as identified. The next level tags, *Level IV*, are called *portable databases*, and, like matrix bar codes, carry large amounts of information in text form, coded in ASCII. The highest current level tags incorporate microprocessors, making them capable of data processing and decision making, and are the RF equivalent of smart cards.

Smart cards, or memory cards, are the size of credit cards but twice as thick. They are composed of self-contained circuit boards, stacked memory chips, a microprocessor, a battery, and input/output means, all laminated between two sheets of plastic which usually contain identifiers and instructions. They are usually read by inserting them into slots and onto pins of readers. The readers can be free-standing devices or components of production and inventory control systems, computer systems, instruments, machines, products, maintenance records, calibration instruments, vending machines, telephones, automatic teller machines, road toll booths, doors and gates, hospital and patient records, etc. One smart card can hold the complete data file of a person or thing and that data can be used as read and/or updated. Cards with up to 64-Mbytes of flash memory are available. They are made by tape-automated bonding of 20 or more blocks of two-layered memory chips onto both sides of a printed-circuit board.

Machine vision can be used to:

1. Detect the presence or absence of an entire object or a feature of it, and sort, count, and measure.
2. Find, identify, and determine the orientation of an object so that a robot can go to it and pick it up.
3. Assure that the robot or any other machine performed the task it was supposed to do, and inspect the object.
4. Track the path of a seam so that a robot can weld it.
5. Capture the image of a matrix-type bar code for data input or a scene for robotic navigation (obstacle avoidance and path finding).

In operation, the machine-vision system's processor digitizes the image that the camera sees into an array of small square cells (called picture elements, or pixels). It classifies each pixel as light or dark or a relative value between those two extremes. The system's processor then employs methods such as pixel counting, edge detection, and connectivity analysis to get a pattern it can match (a process called *windowing and feature analysis*) to a library of images in its memory, triggering a specific output for each particular match. Rather than match the entire image to a complete stored pattern, some systems use only common-feature tests, such as total area, number of holes, perimeter length, minimum and maximum radii, and centroid position. The resolution of a machine vision system is its field of view (the area of the image it captures) divided by its number of pixels (e.g., $256 \times 256 = 65{,}536$, $600 \times 800 = 480{,}000$). The system can evaluate each pixel on either a binary or a gray scale. Under the binary method, a threshold of darkness is set such that pixels lighter than it are assigned a value of 1 and those darker than it are given a value of 0 for computer processing. Under the gray scale method, several intensity levels are established, the number depending on the size of the computer's words. Four bits per pixel permit 16 levels of gray, 6 bits allow 64 classifications, and 8-bit systems can classify each pixel into any of 256 values, but at the cost of more computer memory, processing time, and expense. As the cost of vision systems drops, their use in automatic identification increases. Their value in reading matrix-type bar codes and in robotics can justify their cost.

Voice recognition systems process patterns received and match them to a computer's library of templates much like machine vision does. Memory maps of sound pattern templates are created either by the system's manufacturer or user, or both. A *speaker-dependent* system recognizes the voice of only one or a few people. It is taught to recognize their words by having the people speak them several times while the system is in the teach mode. The system creates a speech template for each word and stores it in memory. The system's other mode is the recognition mode, during which it matches new input templates to those in its memory. *Speaker-independent* systems can recognize anyone's voice, but can handle many fewer words than speaker-dependent systems because they must be able to recognize many template variations for each word. The number of words that each system can recognize is constantly being increased.

In operation, a person speaks into a microphone. The sound is amplified and filtered and fed into an analyzer, thence to a digitizer. Then a synchronizer encodes the sound by separating its pattern into equal slices of time and sends its frequency components to a classifier where it is compared to the speech templates stored in memory. If there is a match, the computer produces an output to whatever device is attached to the system. Some systems can respond with machine-generated speech. The combination of voice recognition and machine speech is called *speech processing* or *voice technology.* Products that can ''hear'' and ''talk'' are called *conversant products.* Actual systems are more complicated and sophisticated than the foregoing simplified description. The templates, for example, instead of having a series of single data points define them, have numerical fields based on statistical probabilities. This gives the system more tolerant template-to-template variations. Further, and to speed response, neural networks, fuzzy logic, and associative memory techniques are used.

Some software uses expert systems that apply grammatical and context rules to the inputs to anticipate that a word is a verb, noun, number, etc. so as to limit memory search and thereby save time. Some systems are adaptive, in that they constantly retrain themselves by modifying the templates in memory to conform to permanent differences in the speakers' templates. Other systems permit the insertion by each user of an individual module which loads the memory with that person's particular speech templates. This increases the capacity, speed, and accuracy of the system and adds a new dimension: security against use by an unauthorized person. Like fingerprints, a person's voice prints are unique, making voice recognition a security gate to entry to a computer, facility, or other entity. Some systems can recognize thousands of words with almost perfect accuracy. Some new products, such as the VCP 200 chip, of Voice Control Products, Inc., New York City, are priced low enough, by eliminating the digital signal processor (DSP) and limiting them to the recognition of only 8 or 10 words (commands), to permit their economic inclusion in products such as toys, cameras, and appliances.

A major use of voice recognition equipment is in industry where it permits assemblers, inspectors, testers, sorters, and packers to work with both hands while simultaneously inputting data into a computer directly from the source. They are particularly useful where keyboards are not suitable data-entry devices. They can eliminate paperwork, duplication, and copying errors. They can be made to cause the printing of a bar code, shipping label, or the like. They can also be used to instruct robots—by surgeons describing an operation, for example—and in many other applications.

Magnetic stripes encode data on magnetic material in the form of a strip or stripe on a card, label, or the item itself. An advantage to the method is that the encoded data can be changed as required.

Optical character recognition uses a video camera to read numbers, letters, words, signs, and symbols on packages, labels, or the item itself. It is simpler and less expensive than machine vision but more limited.

The industry's trade group is the Automatic Identification Manufacturers, Inc. (AIM), located in Pittsburgh.

STORAGE EQUIPMENT

The functions of storage and handling devices are to permit:

The greatest use of the space available, stacking high, using the ''cube'' of the room, rather than just floor area

Multiple layers of stacked items, regardless of their sizes, shapes, and fragility

''Unit load'' handling (the movement of many items of material each time one container is moved)

Protection and control of the material

Shelves and Racks Multilevel, compartmentalized storage is possible by using shelves, racks, and related equipment. These can be either prefabricated standard size and shape designs or modular units or components that can be assembled to suit the needs and space available. Variations to conventional equipment include units that slide on floor rails (for denser storage until needed), units mounted on carousels to give access to only the material wanted, and units with inclined shelves in which the material rolls or slides forward to where it is needed.

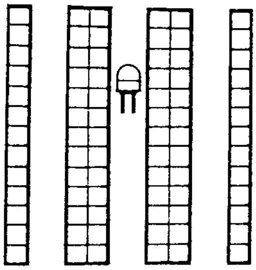

Fig. 10.7.15 Pallet racks. *(Modern Materials Handling, Feb. 22, 1980, p. 85.)*

Figure 10.7.15 shows a typical arrangement of pallet racks providing access to every load in storage. Storage density is low because of the large amount of aisle space. Figure 10.7.16 shows multiple-depth pallet racks with proportionally smaller aisle requirement. Figure 10.7.17 shows cantilever racks for holding long items. Figure 10.7.18 shows flow-through racks. The racks are loaded on one side and emptied from the other. The lanes are pitched so that the loads advance as they are

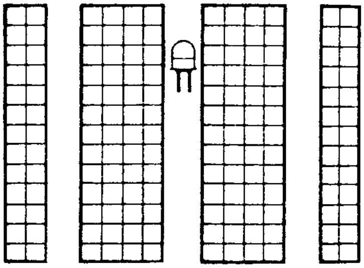

Fig. 10.7.16 Multiple-depth pallet racks. *(Modern Materials Handling, Feb. 22, 1980, p. 85.)*

removed. Figure 10.7.19 shows mobile racks. Here the racks are stored next to one another. When material is required, the racks are separated and become accessible. Figure 10.7.20 shows racks where the picker passes between the racks. The loads are supported by arms attached to uprights. Figure 10.7.21 shows block storage requiring no rack. Density is very high. The product must be self-supporting or in stacking frames. The product should be stored only a short time unless it has a very long shelf life.

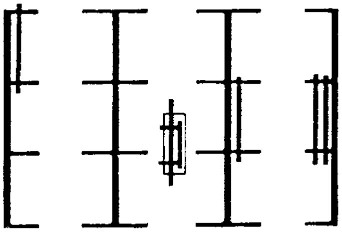

Fig. 10.7.17 Cantilever racks. *(Modern Materials Handling, Feb. 22, 1980, p. 85.)*

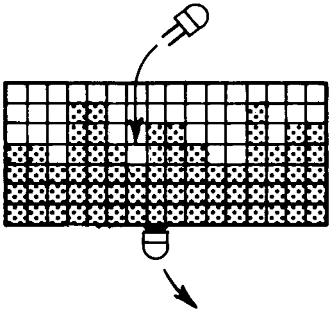

Fig. 10.7.18 Flow-through racks. *(Modern Materials Handling, Feb. 22, 1980, p. 85.)*

Bins, Boxes, Baskets, and Totes Small, bulk, odd-shaped, or fragile material is often placed in containers to facilitate unit handling. These bins, boxes, baskets, and tote pans are available in many sizes, strength grades, and configurations. They may be in one piece or with hinged flaps for ease of loading and unloading. They may sit flat on the floor or be raised to permit a forklift or pallet truck to get under them. Most are designed to be stackable in a stable manner, such that they nest or interlock with those stacked above and below them. Many are sized to fit (in combination) securely and with little wasted space in trucks, ships, between building columns, etc.

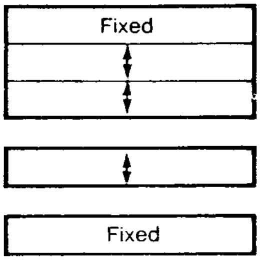

Fig. 10.7.19 Mobile racks and shelving. *(Modern Materials Handling, Feb. 22, 1980, p. 85.)*

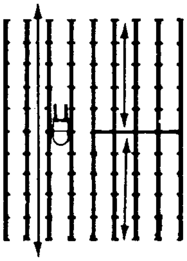

Fig. 10.7.20 Drive-in drive-through racks. *(Modern Materials Handling, Feb. 22, 1980, p. 85.)*

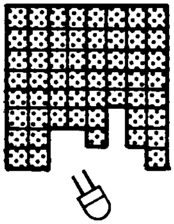

Fig. 10.7.21 Block storage. *(Modern Materials Handling, Feb. 22, 1980, p. 85.)*

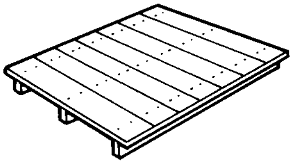

Fig. 10.7.22 Single-faced pallet.

Pallets and Skids Pallets are flat, horizontal structures, usually made of wood, used as platforms on which material is placed so that it is unitized, off the ground, stackable, and ready to be picked up and moved by a forklift truck or the like. They can be single-faced (Fig. 10.7.22), double-faced, nonreversible (Fig. 10.7.23) double-faced, reversible (Fig. 10.7.24), or solid (slip pallets). Pallets with overhanging stringers are called *wing pallets,* single or double (Figs. 10.7.25 and 10.7.26).

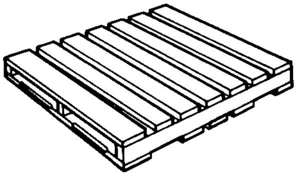

Fig. 10.7.23 Double-faced pallet.

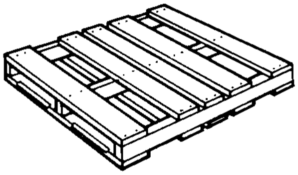

Fig. 10.7.24 Double-faced reversible pallet.

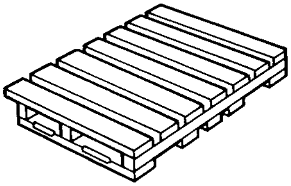

Fig. 10.7.25 Single-wing pallet.

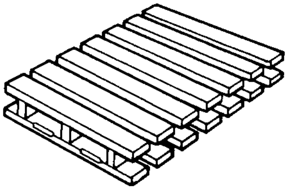

Fig. 10.7.26 Double-wing pallet.

Skids typically stand higher off the ground than do pallets and stand on legs or stringers. They can have metal legs and framing for extra strength and life (Fig. 10.7.27), be all steel and have boxes, stacking alignment tabs, hoisting eyelets, etc. (Fig. 10.7.28).

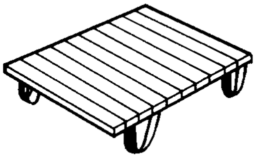

Fig. 10.7.27 Wood skid with metal legs.

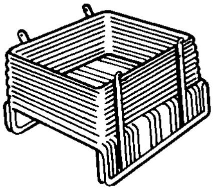

Fig. 10.7.28 Steel skid box.

AUTOMATED STORAGE/RETRIEVAL SYSTEMS

An automated storage/retrieval system (AS/RS) is a high-rise, high-density material handling system for storing, transferring, and controlling inventory in raw materials, work-in-process, and finished goods stages. It comprises:

1. Structure
2. Aisle stacker cranes or storage-retrieval machines and their associated transfer devices
3. Controls

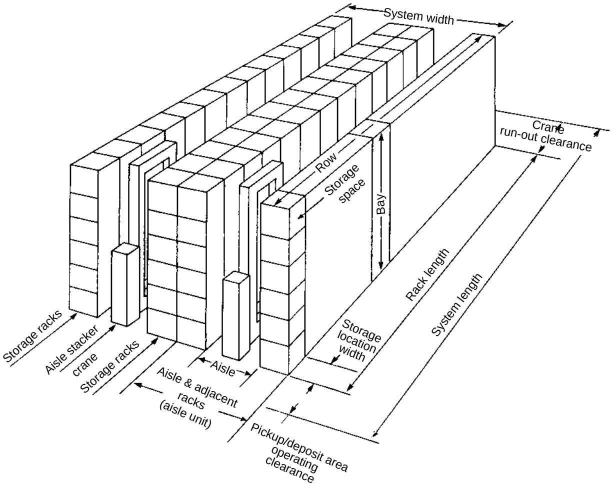

Fig. 10.7.29 Schematic diagram of an automated storage and retrieval system (AS/RS) structure. *(Harnischfeger Corp.)*

The AS/RS structure (see Fig. 10.7.29) is a network of steel members assembled to form an array of storage spaces, arranged in bays, rows, and aisles. These structures typically can be 60 to 100 ft (18 to 30 m) high, 40 to 60 ft (12 to 18 m) wide and 300 to 400 ft (91 to 121 m) long. Usually, they are erected before their protective building, which might be merely a ‘‘skin’’ and roof wrapped around them.

The AS/RS may contain only one aisle stacker crane which is transferred between aisles or it may have an individual crane for each aisle. The function of the stacker crane storage-retrieval machine is to move down the proper aisle to the proper bay, then elevate to the proper storage space and then, via its shuttle table, move laterally into the space to deposit or fetch a load of material.

AS/RS controls are usually computer-based. Loads to be stored need not be given a storage address. The computer can find a suitable location, direct the S/R machine to it, and remember it for retrieving the load from storage.

ORDER PICKING

Material is often processed or manufactured in large lot sizes for more economical production. It is then stored until needed. If the entire batch is not needed out of inventory at one time, order picking is required. Usually, to fill a complete order, a few items or cartons of several different materials must be located, picked, packed in one container, address labeled, loaded, and delivered intact and on time.

In picking material, a person can go to the material, the material can be brought to the person doing the packing, or the process can be automated, such that it is released and routed to a central point without a human order picker.

When the order picking is to be done by a human, it is important to have the material stored so that it can be located and picked rapidly, safely, accurately, and with the least effort. The most frequently picked items should be placed in the most readily accessible positions. Gravity racks, with their shelves sloped forward so that as one item is picked, those behind it slide or roll forward into position for ease of the next picking, are used when possible.

LOADING DOCK DESIGN

In addition to major systems and equipment such as automatic guided vehicles and automated storage/retrieval systems, a material handling capability also requires many auxiliary or support devices, such as the various types of forklift truck attachments, slings, hooks, shipping cartons, and packing equipment and supplies. Dock boards to bridge the gap between the building and railroad cars or trucks may be one-piece portable plates of steel or mechanically or hydraulically operated leveling mechanisms. Such devices are required because the trucks that deliver and take away material come in a wide variety of sizes. The shipping-receiving area of the building must be designed and equipped to handle these truck size variations. The docks may be flush, recessed, open, closed, side loading, saw tooth staggered, straight-in, or turnaround.