TESLA COIL CONSTRUCTION

The Tesia coil is a high frequency, high voltage, air core resonant transformer. It differs from the more familiar. low' frequency, iron core transformer in many ways including the unique capability of magnifying power (not energy). Tesla invented the Tesia coil in the 1890's and Engineers since then ' have used the concept in many products including Utility high voltage apparatus, radio transmission, and medical equioment.'How

The Tesla transformer has the unique ability to **magnify power** (not energy). It does this by utilizing short time intervals in, the following basic power equation:

For a fixed amciunt of energy, the amount of power produced will vary depending on the time intervals. The time intervals (dt) in Tesla transformer operation are in the neighborhood of 1/10000 second.

The Tesla transformer can be regarded as an engine that uses electrical energy to produce work at different levels of power. Operation is similar to an internal combustion engine that uses fuel energy at different horsepowers'., If the- fuel is burned in a flame only heat is generated. It requires an engine to obtain power to do work with the fuel.

The operation of a, Tesia transformer depends upon high frequency oscillations generated in the primary circuit of the transformer. These oscillations are generated by discharging a capacitor into the tuned-primary coil using a spark gap.

In the early days of radio before the invention of the vacuum tube in 1913, the only way of generating the high frequency oscillations was with a spark gap and tuned circuit. This type of circuit produces pulses of dampened oscillations. The degree of dampening was,called the logarithmic decrement. A high decrement meant a high degree of dampening and was not 'desirable for radio transmissions because of the strong harmonics produced that caused interference at other than the operating frequency. Many ingenious spark gap devices were invented to give a low decrement but were not very successful. It was not until the invention of the vacuum tube that it became possible to build oscillators with almost zero decrements. This Meant that harmonics were eliminated and more important that the wave could be modulated making audio and video transmissions possible. The spark gap, therefore, was abandoned for radio work.

Tesia transformers, however, work very well using spark gaps. To obtain optimum performance with a Tesla transformer, the'spark gap should produce very short pulses of dampened sine waves, have rapid quenching, and have the ability to dissipate large amounts of heat. It has been found very difficult to build this kind of spark gap. The spark gaps of the past including the rotary gap were designed for radio work and not for Tesla transformers. These spark gaps, therefore, do not give optimum performance with Tesia transformers.

The high frequency currents generated by Tesia coils produce radiation that can cause interference in AM/FM, TV, and communication receivers unless properly shielded. This interference would be in violation of FCC Rule **15.**

1. Select the desired secondary voltage (Vs) in KV.
2. Select resonant frequency (Fr) in KHZ -
3. Select power supply RMS voltage (Vp) -
4. Select primary capacitor (Cp) size -
5. Select secondary radius (Rs) -

6. Find 1/4 wavelength (Lf) in feet:

$$Lf \quad 246000 \quad Fr$$

7. Find number of secondary coil turns (Ns):

$$Ns \quad Lf \quad (.523\ Rs)$$

8\. Find the secondary volts per tu rn (VPT):
Compare with Insulation Table -.

$$YPT \;\underset{-}{\cdot}\; 1000\ KVs \qquad Ns$$

9\. Find secondary coil length (Bs) in inches:
TPI Turns per inch -

$$Bs \quad Ns \quad TPI$$

10\. Find secondar y inductance (Ls) in mh:

$$Ls = Rs'N,' \quad [(9Rs + 1OBs)\ 10001$$

11\. Find secondar D.C. resistance (As) in ohms:
Ds = Sec ohms/1000 ft -

$$As \quad LfDs \quad 1000$$

12\.Find secondary reactance (Xs) in ohms-

Secondary Radius - Best results are obtained with a large secondary radius. This radius must also be coordinated with the resonant frequency to obtain the proper coil turns. Note that a small number of coil turns means more volts per turn and the secondary wire insulation or the wire spacing,must be capable of withstanding this stress.

System Percent Efficiency - This parameter determines the total energy and wattage required by the system including losses. The percent efficiency varies from about 80% for small coils'to 10% for large coils.

Breaks Per Second This is the number of times that the primary capacitor is charged and discharged per second. For a 60 hertz power supply use 120 breaks per ' second. For systems over 2000, KV the power required can be very large. One way to lower the wattage required is to use a high voltage D.C. power supply with I to 10 breaks per second. Note, however, the limitation that the wattage must be large enough to provide for both the capacitor and the losses. -

The spark gap serves as a switch to charge and discharge the primary capacitor. The capacitor is charged when the spark is off and the capacitor discharge occurs when the spark is,on (spark duration). The spark begins when the voltage across the gap is sufficient to ionize the air and initiate a spark. The spark then becomes a,low resistance arc. On discharging, the capacitor creates a dampened wave oscillating current at RF frequencies in the Tesia primary circuit. These are very high surge currents that pass through the Tesla primary coil and induce a voltage in the secondary coil according to Faraday's

During the discharge period it is important to stop (quench) the arc as quickly as possible. In practice the lquench time is always much greater than the theoretical ideal time. Fast quenching is important because when the secondary coil is energized by the primary coil it also becomes a source of dampened wave currents. These currents feed back a voltage into the primary coil that creates currents in the primary circuit as long as the spark is on. This condition increases the losses of the energy transfer and reduces the overall efficiency of the system. It is obvious that spark gap operation is very complex and can only be dealt with by empirical design methods.

There are many types of spark gaps but normally only five types are used for T,esla coils. These are as follows:

1. The flxed gap consists of two fixed electrodes mounted on insulating posts. Metal rods, bolts, etc. are used for the elec trodes and the gap is made adjustable. They are easy to build and work good for Tesla coils up to 1000 watts.

2. The multiple spark gap consists of several electrodes that divide the gap into several small gaps. The electrodes are a series of short metal rods arranged in a parallel formation, or metal balls. The quenching of the arc is faster than the fixed gap because the arc is broken up into several parts. The total gap distance of the multiple gaps should equal the distance of the single fixed gap.

3. The quenched gap consists of 10 or more small gaps with electrodes that are in an air tight enclosure. The theory behind this gap is that the oxygen is quickly burned up,at the start and the arc is then operating only in nitrogen. This gives faster quenching and quiet operation. These gaps are difficult to build and have overheating problems and are seldom used.

4. The rotary gap consists of two or more movable electrodes mounted on a rotating disk. These electrodes move between two stationary electrodes. The spark is formed when the electrodes come close enough together to cause a sp,4k. This type of gap has the advantage that cooling is better because of the moving electrodes. They are more difficult to build but give better results with medium and large Tesia coils.

S. The air blast spark gap depends upon a blast of air to quickly extinguish the arc. They are easier to build than the rotary gap and produce about the same results in the smaller systems.

'Tbe number of times per second that the primary capacitor is charged and discharged is ,dependent upon the number of **breaks per second.'For the** first three gaps listed above the number of breaks per second is 120 when used with the electric utility 60 Hz lines. The breaks occur when the voltage across the gap is enough to cause a spark,,to bridge the gap. This is an adjustment that can be controlled by the operator. To determine the approximate gap distance, divide the power transformer secondary voltage by 70000. For example, at 7000 volts the gap distance would be I I 0 inch. Use, dril I bits to measure the distance.

The spark is also part of the tuning for the primary circuit so changing the gap distance can affect the length of the spark from the secondary terminal. For optimum secondary spark length, the gap adjustment'must,be made after the coil is built and tested.

Note that the tuning coil should be only a small part of the primary circuit inductance because it does not surround and provide induced voltage to the secondary coil. A trade off is required between having enough tuning adjustment and having enough primary coil turns surrounding the .Secondar coil. Tuning coils work best with coil type priniaries with about 6 to 8 turns.

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'A homemade tuning coil is shown on page 12-3. This coil. was made for the 70 KV system shown in Section 15. The full tuning range for this coil is about 3 microhenries and can also be used with the 250 KV system shown in Section 16. The, tuning range is enough to go from no @spark to maximum spark.

250KV SETUP

This Tesla transformer is considerably more powerful than the 70 Kv system. It produces 225 watts and shocks from the secondary are dangerous. Note that both sides of the primary winding are hot because the neon sign transformer is grounded at the midpoint of the high voltage secondary winding.

The power supply is a standard neon transformer rated 120 to 7500 volts, 30 milliamps. A variac is shown in the wiring diagram to make it possible to bring the voltage up gradually but this is an optional feature.

The Tesia primary coil is the pancake type. It is made of 6 1/2 turns of 3/16" wide ribbon cut from a -.015" thick copper sheet.: The inner circle is 5 1/2" ' diam and the outer circle is 9 1/2" diam. The, ribbon is held in place by 4 pieces of: 1/8' plastic s ' upport 3/4" x 2 1/2" cemented to a 1/8" hardboard base. A #12 AWG wire with an alligator clip is connected from the capacitor to one of the turns of the,primary coil for tuning. The bare copper pancake coil has the advantage that t,uning'adjustments can be very precise, something that cannot be done with insulated primary coils.

The Tesia secondary coil is the same coil used for the 70 KV system. However, much can be learned with this system by building and testing other types of secondary coils. Note that the resonant frequency has to be recalculated and the primary capacitor may have to be changed.

The multigap washer spark gap seems to work best with this system,but other spark gaps can be used. The radio frequency choke (RFC) is 30 turns of #18 enameled magnet wire wound on a I inch diam x 2" long form. The capacitor consists of two 0025 uf homemade capacitors connected in parallel. Homemade capacitors should be tested with a meter to verify their calculated capacitance. The base to hold the Tesla coil is made from 1/4" plywood that has been varnished.

Note in the wiring diagram that if the secondary coil bottom connection is connected to one of the hot leads of the neon transformer this arrangement will give a' longer spark but the secondary should **not be touched** because of the **shock hazard.** If desired ' the secondary can be connected only to ground to eliminate the shock hazard but the spark will be short er

100KV SETUP

The construction of this size of Tesia coil should be attempted only by experienced Tesla coil builders. This system produces up to 3000 watts of input power and shocks are, not only dangerous but can be fatal. The sparks and streamers are very powerful and can jump several feet so adequate clearances must always be maintained.

A 3000 watt load at 230 volts is 13 average amperes but larger surges are possible so the fuses should be 2 1 0 amp' slow-blo@ type. See Section 6 for additional, precautions on radiation and shielding. The 3000 watts can be obtained by using several neon transformers in parallel.

The Tesla primary coil is the pancake type. It is made of 6 turns of 5/16" copper tubing wound in a spiral. The inner circle is 16' diam and the outer circle is 26" diam. The tubin is held in place by 1/4"thick plastic supports 1 1/2" x 7' long cemented to a 1/2" thick varnished plywood base. Provision should be made so the coil can be tapped at different turns for tuning.

The Tesla secondary coil is 400 turns of #20 AWG stranded 3 KV insulated wire on a 12" diam x 40" long coilform. The coilform can be 12" white PVC water pipe, Space the last 3 top turns about 1/4" to reduce the high voltage corona stress. The secondary terminal is a 4" **k** 16" toroid. A different size toroid can be used but the primary coil will have to be retumed by changing the number of turns.

$Xs \quad 6.283\ Fr\ Iy$

13. Find secondary 'Q' Factor (Qs):,

$Qs \quad Xs\ As$

14., Find secondary capacitance (Cs): in pf:

$Cs\ (9.5\ Fr\ LS)$

15. Find primary inductance (Lp) in uh:

$Ls\ Cs\ \ (1000\ Cp)$

16. Find number of primary turns (N
This is approximate a I nd exact number is found by constructing the,primary coil with taps for tuning during startup tests.

COIL $Np\ Rp$

PANCAKE $Np \qquad Rp$

17. Find primary wire length (Gp) in ft:

$Gp = 6.283\ Rp\ Np \quad 12$

18. Find primary D.C. resistance (Ap) in ohms:

DP Pri ohms/ I 000 ft -

$Ap \quad Gp\ Dp \quad 1000$

19. Find primary reactance,(Xp) in ohms:

$Xp \quad .00628\ Fr\ Lp$

20.,Find primary 'Q' Factor (Qp)-

$Qp \quad Xp \quad Ap$

21. Find power supply in watts (Wp):
BKS Breaks per second EFF = Percent efficiency

$Wp \quad 5xl\ 0 \quad Cp\ VP'\ BKS \quad EFF$

22. Find power supply current

WP

Frequency Kilohertz - This graph is coordinated with, the secondary radius graph to give about 400 to 600 turns for all coils at 1/4 of the resonant frequency wavelength. Jt has been found by tests that this range of coil turns gives the best results,.

Power Suppl' Volts - The power supply volts graph is designed to give Vs/Vp ratios from about 20 at 50 KV to 160 at 5000 KV secondary volts. These ratios have been found by tests to give the best results with the least cost.

Primary Capacitor - The size of the primary capacitor determines the amount of energy that can be stored and transferred, to the Tesla secondary coil. This energy is one, of the parameters that determines the amount of the secondary voltage

Tesia discovered that the length of the secondary wire should be 1/4 of the wavelength of the primary circuit resonant frequency. The actual length is slightly less than this because of the velocity factor and other variables that have a minor effect on the length. The primary coil roormallyhasbuiltintapstoallowforthesevariablesand,toobtal optimumtuningadjustments.

Once the secondary, wire length and the radius is selected, all the other secondary parameters such as coil turns, coil length, inductance, etc., are then found by the calculations shown in Section 7. Note that the half wave coil is the same as two 1/4 wave coils connected together with their center point grounded.

Secondary coils can be made in the form of cylinders or cones. They can be made from tnailing tubes, plastic tubes, rolled cardbciard sheets, etc. The larger tubes are made from sonotube piping, PVC water pipe, or cylindrical frames made -with wood/ strips.

Secondary wire 'sizes range from #28 AWG for small coils to #16 AWG for large coils. Windings with spaced turns reduces the coil capacitance which is desirable but this also reduces the inductance which is not desirable. The last few top turns, of the windings should be spread out to reduce the corona voltage stress on the top turns. After the coils are wound, they should ,be painted with varnish or shellac to protect the windings. Paraffin wax.can also be used to cover the windings but this is a soft cover and gives less protection.

The secondary voltage output is increased by increasing the.inductance and/or the 'Q' factor of the coil. Inductance is increased by increasing the radius/ or turns. The' 'Q' factor is increased by using larger wire sizes to reduce resistance. Experience has shown that 400 to 600 turns is the best turn range. Also the'coil aspect ratio (coil length /diameter) should be less than 4 for best results.

The electrostatic field of the Tesia secondary coil is most intense at the top of the coil. This field intensity and the resultant loss es can be reduced by installing the proper type,of terminal above the coil. The terminal can be in-the shape of a sphere, toroid, or cylinder with hemispherical ends. The diameter of, the sphere should be at least equal to the diameter of the coil. For small systems, a standard 2 inch,diameter brass door knob can be used. For other small systems, a plastic playball covered with aluminum foil and carefully,smoothed down will work reasonably well.

For larger systems, a toroid should, be used.. The major diameter of the toroid should be about ,40% larger than the diameter of the secondary coil. As an alternative, a cylinder can be used but must have no sharp edges so the ends must be round. The terminal adds capacitance to the secondary circuit and varying the terminal can ' be used as a method of tuning the system. The toroid should be mounted with the bottom about 1/3 the diameter of the secondary coil above the coil.

PRIMARYAND TUNING COILS

The Tesla primary, coil is designed to resonate with the primary:capacitor at a frequency that is the resonant frequency of the secondary circuit. Because the primary capacitor must have a high capacitance to store enough energy to operate the system, the I pr imary coil can be a relatively small inductance. The primary coil, therefore, can be only a few microhenries and have only a few turns. However, this coil should be constructed of large wire size so it can carry the high primary pulse currents.

,If the system is a 1/4 wavelength type, the primary coil is located at the bottom of the secondary coil. This arrangement is referred to as the classical Tesla coil. If it is of the 1/2 wavelength type, the primary coil is located at the center of the secondary coil. In either, case, the primary must have sufficient clearance from the secondary to prevent flashovers between the coils. With the 114 wavelength it may be necessary to flare out the top of the 'rimary coil to prevent pflashovers to the secondary coil.

There are two main primary coil designs, the single layer coil and the pancake, spiral. The s ingle layer coil is used mostly for small systems and the pancake design is used for medium and large. systems. The pancake design gives less coupling than the coil type which is one reason it is used with the larger systems. The rimary coil is normally made with copper strap or tubing bent as p
a coil or spiral. The spacing between, turns depends on the voltage of the power input transformer secondary. Bare conductors are generally used to make it easier to tune the system precisely.

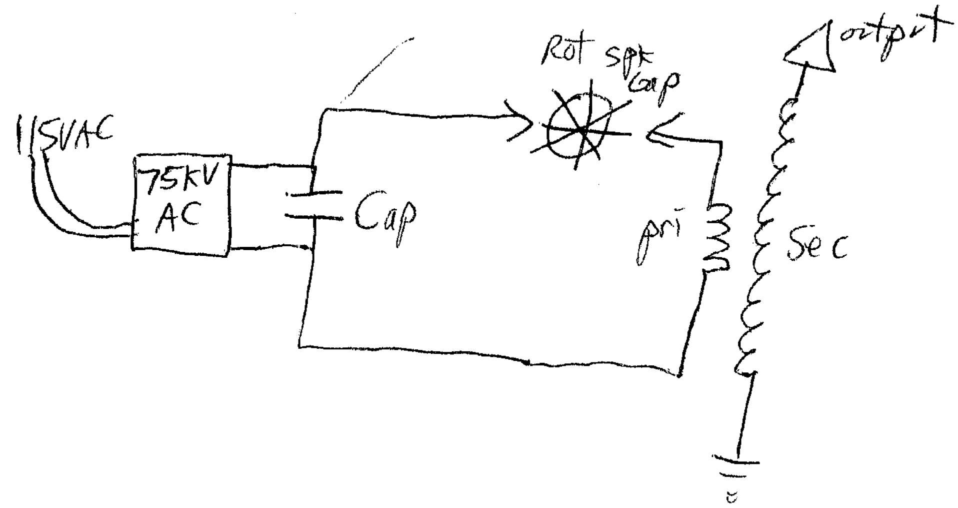
,In general, systems up, to 100 KV use #12 AWG wire. Larger systems use 1/4 inch copper tubing and larger depending on the-size of the system.

Tesla used tuning coils in his tests to obtain more precise tuning of his primary coils. Some of his primary coils were very large and could be tuned much easier with a tuning coil. Because of the high voltages it is not possible to change the taps on the primary coil during operation. A tuning coil makes tuning during operation possible.

The spark gap is theROtary gap or air blast gap as shown on pages 1 1@-4 and II -5. The capacitor should be a pulse type rated at .05 uf, 30 KIV or higher. The RF chokes are 30 turns of #14 AWG type TW wire space wound on a 2" diam x 6" long fiber tube.

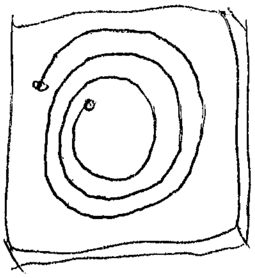
A separate enclosure is recommended to house the circuit breaker, variac, and line filter to i I solate the operator and control . s from , the secondary high voltage. The neon transformers can be,below the Tesla 'coil or can be installed between the enclosure and the Tesia coil.

BASIC TESLA COIL DESIGN



Primary Design Pic's

Spiral



Coil