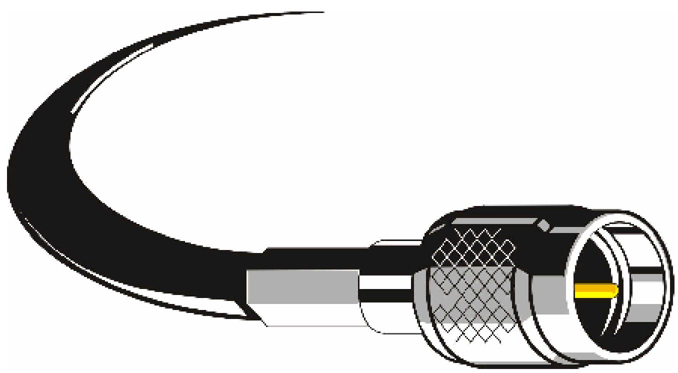
User Manual

Laser Vibrometer

OFV



Controller	OFV-2200
Sensor Head	OFV-303

Man-OFV-2200-9602-e01

Warranty and Service

The warranty for this equipment complies with the regulations in our general terms and conditions in their respective valid version.

This is conditional on the equipment being used as it is intended and as described in this manual.

The warranty does not apply to damage caused by incorrect usage, external mechanical influences or by not keeping to the operating conditions. The warranty also is invalidated in the case of the equipment being tampered with or modified without authorization.

To return the equipment always use the original packaging. Otherwise we reserve the right to check the equipment for transport damage. Please mark the package as FRAGILE and include an explanation of the reason for returning it as well as an exact description of the fault. You can find advice on fault diagnosis in chapter 4.

Trademarks

Brand and product names mentioned in this manual could be trademarks or registered trademarks of their respective companies or organizations.

Identification Labels

Controller

Sensor Head

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1 1.General Information

This chapter provides basic information on the functioning of the instrument and on the safety concerns for laser vibrometers.

1.1 Operating Principle

As mentioned previously, the Polytec Vibrometer System is an instrument which measures surface motion from a remote position using interferometric techniques.

Polytec optical vibrometers are all composed of two basic functional blocks, the interferometer or optical head and the electronic signal processor. The signal processor is linked to the optical head via a cable at the rear of the OFV-2200.

Using the optical head, light from a He-Ne-Laser source is projected at the surface under investigation using a variable focus lens system.
The projecting lens also functions as a collecting lens, and returns the collected light into the interferometer.

The phase of the signal beam is dependent on the path length travelled and therefore also on the instantaneous position of the surface. The interferometer effectively makes an optical phase comparison of the recovered light with an internal reference beam.

In order to distinguish direction, an offset frequency is optically introduced which causes the interferometer output signal to provide an electronic carrier signal (of 40 MHz frequency) on which the phase information rides.

This signal is fed to the electronic signal processor which demodulates the signal, thus providing a voltage proportional to the momentary surface velocity as well as a voltage proportional to the momentary displacement of the target both accessible on the front panel. The sensitivity is determined by the decoder range settings.

Measurements of the motion of surface generally fall into one of three categories in terms of frequency and amplitude. These can be termed

a) Metrological applications
Frequency: Less than 10 Hz
Amplitude: Greater than 1 µm

b) Acoustic measurements
Frequency: 10 Hz - 20 kHz
Amplitude: Greater than 0.1 µm

c) Ultrasonic measurements
Frequency: greater than 20 kHz
Amplitude: Less than 1 µm

with the approximate signal ranges as given. It is important to note that as the frequency range of interest increases, the amplitude range encounters decreases. The Polytec Vibrometer is especially suitable for measurements of type b and c. It is generally found that, in terms of signal processing requirements, the most suitable parameter to measure is velocity rather than amplitude. This can be seen from the equations of simple harmonic motion:

$$\text{Amplitude} = A \sin \omega t$$
$$\text{Velocity} = A\, \omega \cos \omega t$$
$$\text{Acceleration} = -A\, \omega^2 \sin \omega t$$

In these equations, **A** is the peak amplitude of motion at the angular frequency $\omega = 2\pi f$. The magnitude of the velocity signal is then given by the product of angular frequency and mechanical amplitude. Most vibrational signals have high amplitude at low frequency and low amplitude at high frequency. As shown in figure 1.1, the spectrum of velocities then flatters automatically, and thus allows more accurate measurements across a wide frequency span to be made in one process. For example, if we assume that the signal processor has a dynamic range of 1000 (or 60dB), a single measurement of amplitude at low frequency would not be able to resolve the high frequency signals, as shown overleaf.

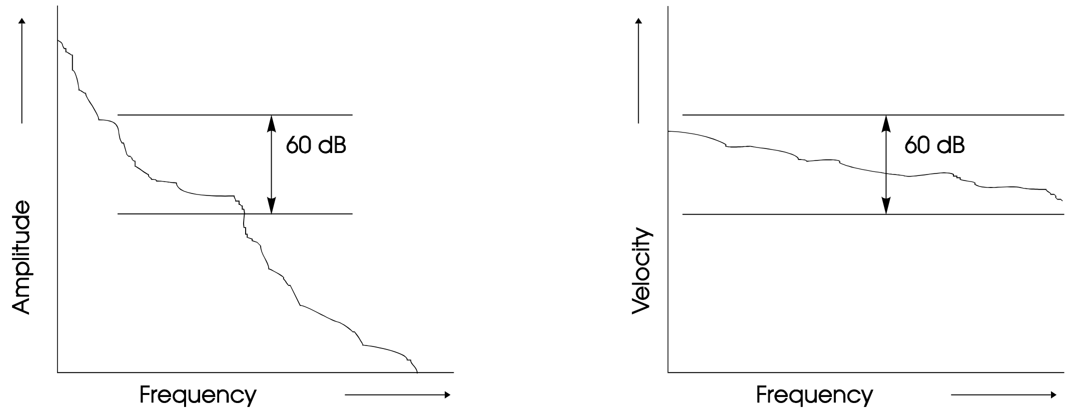


Fig. 1.1: A comparison of natural frequency spectra of vibrations and their equivalent velocities

If an equivalent velocity demodulator were used, the signal information recovered would cover the entire range. The velocity decoder used in the Polytec Vibrometer controller has a highly linear transfer function, high sensitivity (in the order 1 µm/sec when observed in a 10 Hz spectral width) and a high demodulation bandwidth (250 kHz). The lower edge of the band of detectable vibration frequencies is less than 1 Hz.

These specifications make the Polytec Vibrometer System optimum for use within and above the acoustic range of frequencies.

In all measurements made with an optical vibrometer, the signal quality at the output is related to the amount of light recovered by the light collection system of the optical measurement head. The signal level indicator located at the front panel, as well as at the optical head, provides a measure of the light returned by the optical head from the target.

In general, the best collection efficiency, and therefore the best signal quality, is achieved when the head is closest to the surface and the beam direction perpendicular to the surface. The beam direction determines which component of the velocity vector is to be measured in a particular surface point.

1.2 Laser Safety

It is important to understand that laser light has properties different from ordinary light sources. Laser radiation is highly unidirectional. A laser beam cannot be seen unless dust or other particles cross the beam and scatter light in other directions. Laser radiation is generally extremely intense, due to the beam´s low divergence, and care should be taken when handling laser instruments that the direct beam does not enter the eye.

The following is user information pursuant to the Bureau of Radiological Health´s Laser Products Performance Standards, section 1040.10, BS 4803 and DIN IEC 76/VDE 0837.

1.2.1 Optical Head Safety Information

The Polytec OFV-303 optical head is a class II laser product conforming with the US FDA´s code of Federal Regulations 21 1040.10. Although the laser used inside the head is a CW 2mW HeNe laser, the system philosophy implies that the maximum optical output power **never exceeds 1mW.**

The principal advantage of working with this low power is safety.

The laser beam emitted from the head is expanded but can be focused down to a small spot at a variable distance from the lens. Even when optimally focused, the laser radiation is not intense enough to harm the skin. However, looking inward along the beam or via mirrors or optical instruments should be avoided at all times.

1.2.2 Beam Attenuator and Laser Interlock

The OFV-303 optical head is equipped with a beam attenuator permitting the user to block the emitted laser beam without having to switch off the laser. This is particularly important because the laser emission aperture of the optical head is often located significantly far from the main power switch.

A green laser warning light is also integrated into the optical head. It is located on the rear panel of the housing. When lit, the shutter is open and measurements can be performed.

To position the head safely, it is recommended that the user switches the shutter to the "OFF" position so that no laser light comes through the lens (light will go off). Once the head is in place and pointed at the desired target, switch the shutter to the "ON" position. Following this simple procedure will ensure that no-one's eyes are exposed to direct laser light.

It is not necessary to open the housing of the OFV-303 optical head. Should the interferometer require alignment, please contact your local representative. The optical head, if opened, reveals a class IIIa (IIIb in Europe) laser system which for safety reasons is switched off via an interlock switch as soon as the cover housing is lifted.

1.2.3 Warning labels on the OFV-303 optical head

A number of laser-related warning labels are attached to Polytec interferometers. These are reproduced in fig. 1.2. Their respective positions are shown in fig. 1.3.

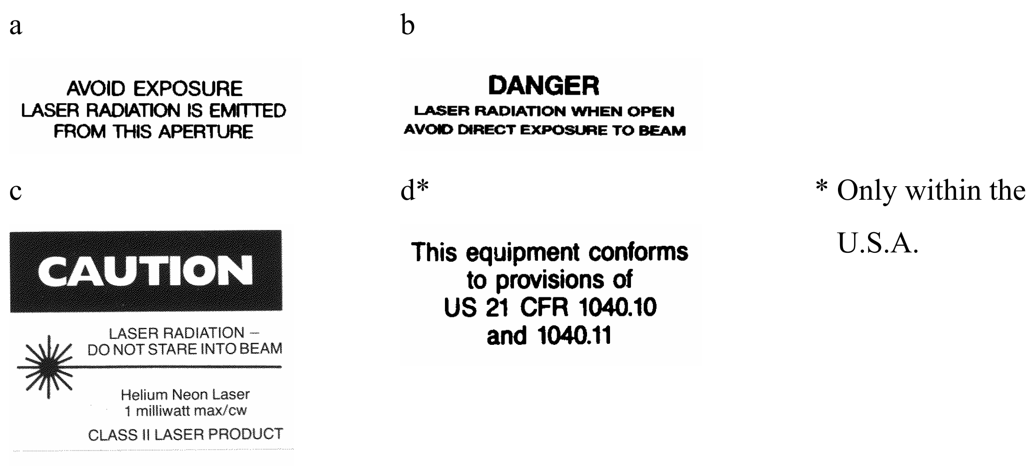


Fig. 1.2: Warning labels on Polytec interferometers

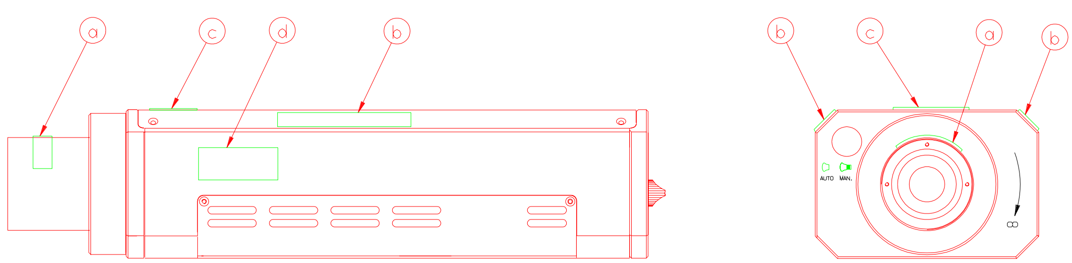


Fig. 1.3: Labels on the OFV-303

1.2.4 Summary Safety Precautions

- The OFV-303 optical head contains a beam attenuator. USE IT when interchanging the optical heads or output lenses, moving the heads around or when the instrument is on but not in use.

- When positioning the optical head, keep the attenuator closed until it is time to do fine adjustment of the laser beam on the surface to make a measurement.

- Caution should be exercised especially when pointing the head at mirrored surfaces which could reflect a significant percentage of the incident light towards an unwary observer.

- When the measurement has been carried out, close the attenuator to prevent stray beams from travelling through the room.

2 OPERATING THE VIBROMETER

2.1 Preparation for Use

Before installing the hard-clad, flexible cable between the OFV-303 head and the OFV-2200 controller, make sure that:

* The OFV-2200 power key switch is at the "OFF" position (located on front panel)
* The mains voltage selector is set correctly (located on rear panel)
* Shutter switch on OFV-303 head is OFF

Having taken the above precautions, plug the cable into the "CONTROLLER" socket on the OFV-303 head and into the "INTERFEROMETER" socket on the rear panel of the OFV-2200.

Switch on the OFV-2200 power switch. On the front panel, the "POWER" LED will light up and the 7-segment LCD displays will be activated. Laser light will be emitted from the optical head only after you have rotated the shutter knob to its "ON" position. This will also cause the green LED to light up, indicating that laser emission is taking place. Place a piece of diffusely reflecting material, e.g. matt aluminium into the laser beam, at a distance of approx. 0.6 m from the optical head. Adjust the front lens to get the minimum spot diameter. The level indicators on the OFV-2200 front panel and on the head should be lit up at a certain length. This shows that the optics and the input section are working correctly.

Under certain conditions, the level check might not immediately prove satisfactory. If this is the case, repeat the test after 20 minutes to give the laser time to reach its steady state operating condition.

Response of the output signals may be checked using an oscilloscope connected to the BNC sockets at the front panel. Increasing the reflected light level (use different surface materials) should cause a decrease in noise level at the velocity output. The noise minimum indicates exactly the optimum alignment under given surface conditions.

If the target moves, the velocity output voltage should respond to velocity and direction of movement. A "HI" readout at the velocity decoder LCD display indicates a peak velocity that is too high and is overdriving the selected measurement range. The same symbol may occur just for a few seconds after switching over to a different range setting.

At the displacement output, an arbitrary voltage level is measured after the system has been switched on. After pressing the CLEAR button, the voltage level must return to zero and then follow up the target displacement. When the relatively small displacement limits of the particular ranges have been overdriven, the output voltage sign jumps to its opposite. Therefore, on an oscilloscope screen, a sawtooth-like signal is displayed when the target displacement is too large for the selected measurement range.

2.2 Optical Sensor Head

2.2.1 Operational Elements

The OFV-303 optical head contains the interferometer described in detail in chapter 3. Front, side and rear views of the optical head are shown in fig. 2.1. The main elements are described below with reference to the numbering in fig. 2.1.

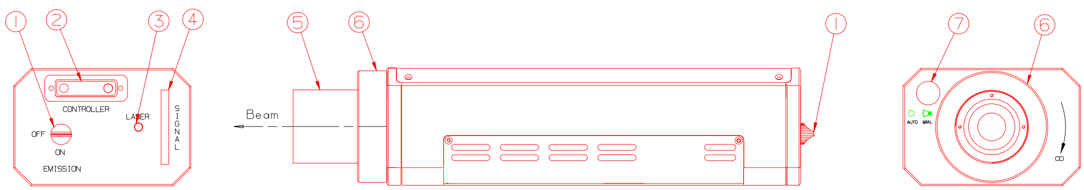


Fig. 2.1: The optical head

1. Shutter on/off knob.

2. D-Sub connector for connecting the head to the controller processor.

3. Laser indicator. Is lit when laser is <u>on</u>.

4. Bar graph level indicator. Allows observation of the returned light level, while adjusting the focus of the objective lens.

5. Objective lens "Polytec". Can be removed and exchanged, see below.

6. Revolving ring for manual focus of the objective lens.

7. "AUTO-MAN" knob for switching between remote focus and normal (manual) operation, see below.

The hand-held remote control unit OFV-310, shown in fig. 2.2, is a useful optional extra for the OFV-303. This unit must be connected with the specific connector on the OFV-2200 rear panel.

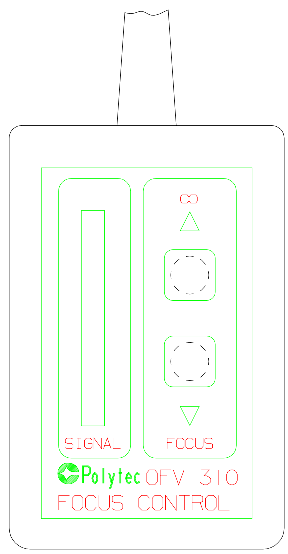


Fig. 2.2: Remote focus control unit OFV-310

Operation is quite straightforward: Pressing either of the two keys on the OFV-310 causes the focus motor to start running in the desired direction. A bar graph "SIGNAL" indicator (the level of which is a reproduction of the one on the OFV-303 head, see above, and the one on the OFV-2200 front panel, see 2.6) allows for easy optimization of the light return level.

After 1 second of travel, the electronics switches the motor to high-speed mode. The motor automatically stops when either end of the objective's range is reached.

2.2.2 Manual Operation

To manually focus the laser beam to "∞", turn the revolving ring (6) in clockwise direction. For focusing at short distances, turn the revolving ring (6) in the anti-clockwise direction. Knob (7) must be noticeably locked in outer position (pulled).

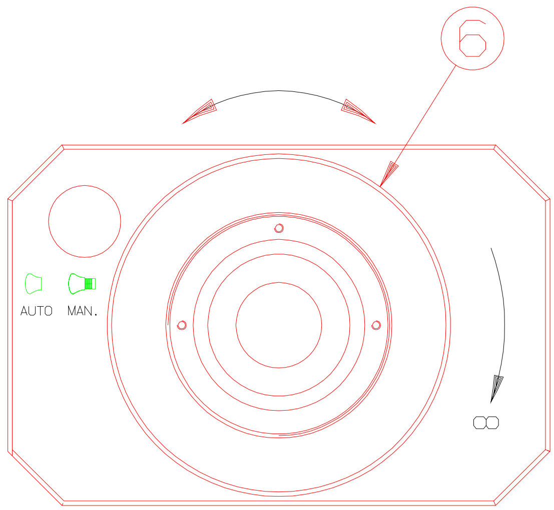
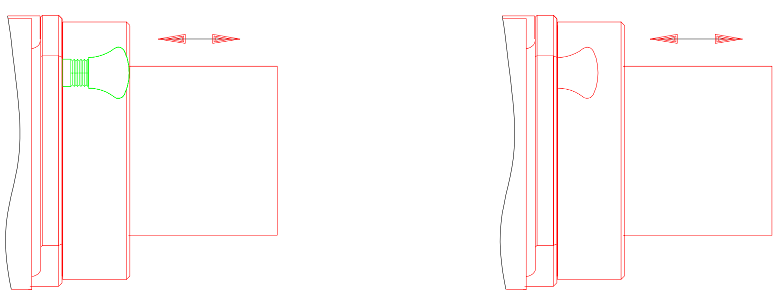


Fig. 2.3: Manual Focusing

2.2.3 Remote Focus Operation

For "remote focus" operation press the knob (7) right in towards the front panel and operate the motor via the remote control unit OFV 310 if available.



a) Manual operation

b) Remote focus operation

Fig. 2.4

2.2.4 Exchanging the Lens

One of the important features of the OFV-303 head is the possibility of using different front objectives (3) to address different applications. To obtain high light-collecting efficiency at large working distances, for example, it would be desirable to use a "fast" (meaning large aperture) telephoto objective.

To exchange the objectives, please proceed as follows:

- Turn the threaded cap (5) in anti-clockwise direction until it can be removed.
- Remove the λ/4 mount (4) from the objective and put it aside.
- Pull the objective (3) out of the objective mount (1).
- Take the new objective and slide it carefully into the objective mount (1). Turn it in the objective mount until the nose (2) matches up with the slit in the objective and push the objective fully into position.
- Then put the λ/4 mount (4) in the objective in such a way that the nose (2) locks in the slit of the λ/4 mount (4).
- Then mount the threaded cap to secure the lens assembly.

Important !!!

Please take extreme care when changing the objective that no dirt enters the instrument and that no optical parts are damaged.

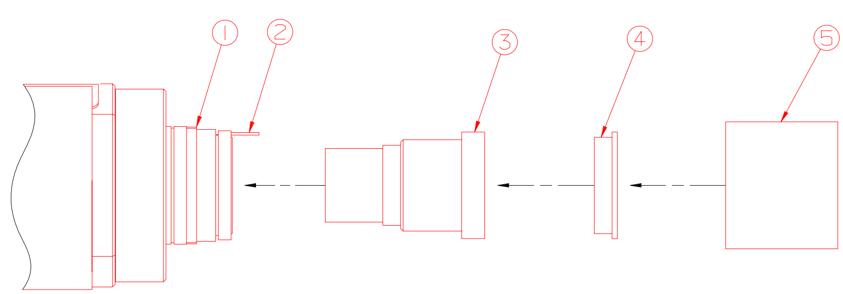


Fig. 2.5: Changing the objective

2.3 Controller Unit

2.3.1 Front Panel Description

Fig. 2.6 shows the OFV-2200 front panel. Numbering of elements refers to the explanations given in the following.

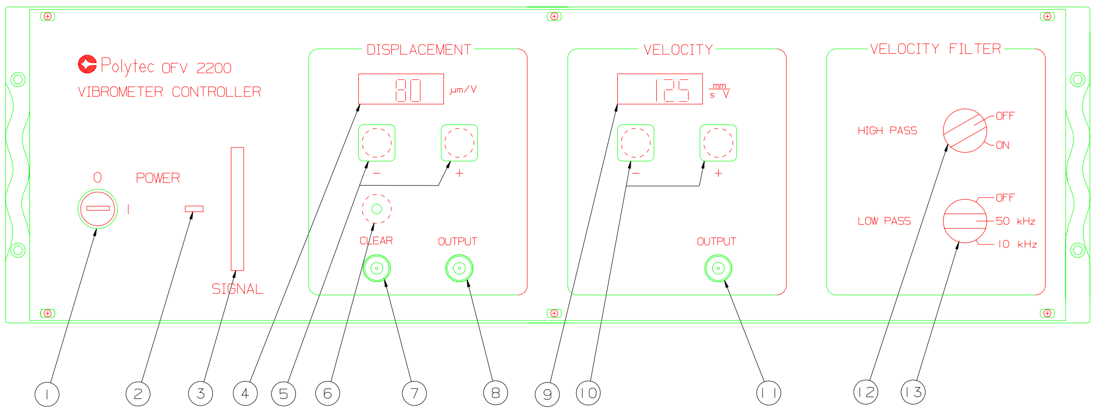


Fig. 2.6: OFV-2200 controller front panel

1: Main power switch. Key switch allows for prevention of unauthorized use of the instrument.

2: "Power" LED. Indicates that system is connected to the supply and that the power switch is on.

3: "Signal" light bar. Indicates strength of optical power returned to the interferometer from the target. Use it to adjust optical head front lens to optimum pointing efficiency and light collecting efficiency.

4: Displacement decoder range indicator LCD. Shows selected scale factor in µm/V. Available ranges are 0.5, 2, 8, 20 and 80 µm/V.

5: Displacement range selection keys. Pressing +/- key increases/decreases scale factor of displacement decoder.

6: "Displacement CLEAR" button. Allows manual reset of the fringe counter (displacement decoder).

7: "Displacement CLEAR" BNC socket. Allows for synchronized resetting of the fringe counter. Synchronized resetting is helpful for eliminating slow drift effects from periodic signals.

8: Displacement output BNC socket. Provides demodulated output signal proportional to displacement of target.

9: Velocity decoder range indicator LCD. Shows selected scale factor in $mm \cdot s^{-1}/V$. Available ranges are 5, 25 and 125 $mm \cdot s^{-1}/V$.

10: Velocity range selection keys. Pressing +/- key increases/decreases scale factor of velocity decoder.

11: Velocity output BNC socket. Provides demodulated output signal proportional to velocity of target.

12: High-pass selection knob. "ON" position enables a 100 Hz high-pass for the velocity output.

13: Low-pass selection knob. Allows for selection of two different cutoff frequencies and bypass.

2.3.2 Rear Panel Description

The rear panel is shown in fig. 2.7. In the following, the rear panel functions will be described with reference to the numbering shown in fig. 2.7.

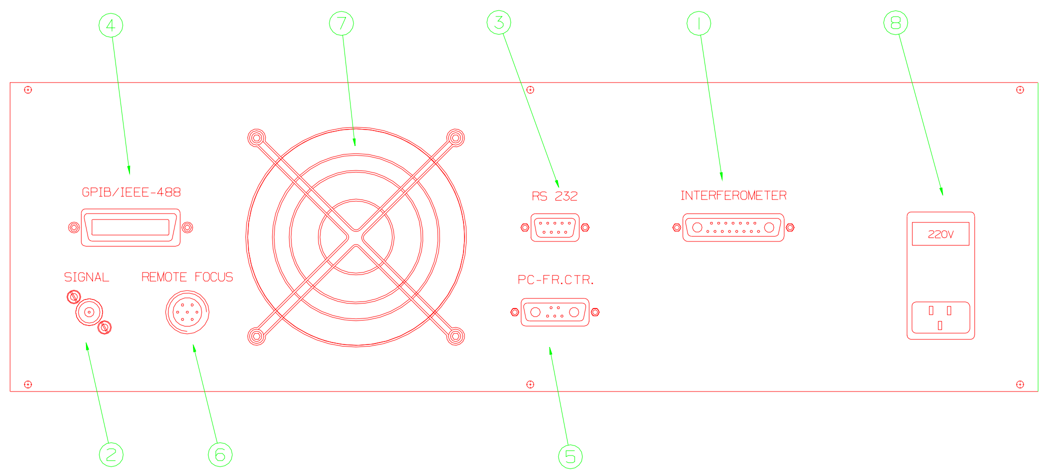


Fig. 2.7: OFV-2200, rear panel of the controller processor

1. "Interferometer" D-SUB connector. Connects with the optical sensor (either OFV-303, -501 or -502 type) by means of the OFA-300 main cable. Provides power, RF and signal level information to the interferometer and accepts the return signal from the interferometer.

Note !!!

Always install the interconnection cable to interferometer before switching on the main power switch.

2. "SIGNAL" out. Provides a DC voltage proportional to the logarithm of the RF carrier signal strength.

3. "RS-232". Not installed.

4. "GPIB/IEEE-488". Not installed.

5. "PC-Fringe Counter". Interface required for operation of OFV-600 PC fringe counter card. This card allows for an increase of the standard 12 bit-range of the

displacement decoder up to 32 bits. It provides comfortable signal evaluation features, e.g. an FFT of the displacement signal.

6. "Remote Focus". Interface for connecting the optional hand-held control unit OFV-310 for operation with OFV-303.

7. Cooling fan.

Caution !!!

Always make sure that sufficient space is left behind the instrument in order to allow for a good cooling air flow ! We recommend a minimum clearance of 50 mm.

8. Line connector / fuse holder / voltage selector combi element.

Caution !!!

Before applying AC line power to your instrument, ensure that the voltage selector is set to your national voltage and that the correct line fuses are installed. Rated fuses are 2.5 A time delay for 100/115 V mains voltage and 1.25 A time delay for 230 V.

Line voltage selector. Line voltage can be set to nominal values 100, 115 and 230 VAC. Voltage variations within the range - 10 % to + 10 % can be tolerated.

Caution !!!

If, for any reason, you have to open the instrument, always make sure that the mains cable is disconnected. This warning is reproduced as a label on the rear panel of the controller and shown in fig. 2.8.

WARNING !
Disconnect Mains
before opening

Fig. 2.8: Warning label on the OFV-2200 rear panel

2.4 Making a Measurement

This section provides initial instructions on how to perform a vibration measurement using the laser vibrometer. Proper alignment of the optical setup and suitable selection of the measurement range will ensure accurate results of the vibration investigation.

2.4.1 Aligning the Optical Head

Place the sensor head approximately 60 cm from the surface under investigation. The laser beam must be directed along the velocity vector of interest, in general orthogonal to the surface element. Rotate the lens ring to closest focus distance.

Switch the instrument on at the key switch and rotate the beam attenuator to "on", allowing the laser beam to exit the measurement head.

Now focus the laser beam slightly by rotating the lens ring. Optimum alignment is indicated when the signal level display is at maximum bar length. However, even when no dot of the indicator is on, the system is still able to measure in many cases.

It might prove necessary to change the operating distance in order to optimize the signal strength, as observed at the signal level display. This is explained by the cyclic nature of the visibility function generated by the presence of several modes in the laser:

In all cases where the signal level is weak or undergoes strong low frequency fluctuations, reset the system using an operating distance which is about 11 cm different to the current value. (Ref. chpt. 3.1.4).

2.4.2 Choosing the Measurement Range

Once a good signal level has been obtained, connect the velocity output to an oscilloscope and switch the velocity range to 125 mm/s/V. Provided the object vibrates, a sinusoidal trace should be observed on the screen. With a stationary object, a noise-free base line should occur.

If the velocity signal is smaller than 4 $V_{p\text{-}p}$, the lower ranges may be used to upscale the velocity trace. Otherwise, if the velocity signal is too large, a "HI" symbol on the LCD will indicate an overdrive.

Using a dual beam oscilloscope, the displacement output signal can be observed simultaneously. To begin with, the CLEAR button should be pressed to reset the fringe counter. With a stationary object, the scope should show a noise-free base line after resetting. In this state, the maximum peak-to-peak measurement range for a vibrational displacement is available.

If the experimental setup suffers from thermal drift or other slow relative motion between target and optical sensor, the scope will truly reproduce this behaviour by showing a drifting base line. To prevent this, a cyclic reset should be applied by either pressing the CLEAR button repeatedly or by feeding a suitable TTL pulse to the corresponding CLEAR BNC socket. For CLEAR signal conditions ref. to chpt. 5.4.

An overdrive of the selected displacement measurement range is indicated by a sawtooth-like signal with a 16 V peak-to-peak magnitude at the displacement output. This is caused by a cyclic overflow of the internal counter when the number of interferometric fringes is too large. In this case, the next decoder range must be selected if available.

2.1.1 2.4.3 Choosing Optimum Filter Settings

The velocity decoder section of the OFV-2200 vibrometer is equipped with switchable high- and low-pass filters which adapt the measurement bandwidth to the application.

Filters are generally very useful for the signal analysis in the time domain, as they can suppress unwanted, interfering components or noise in the measurement signal. For a signal analysis in the frequency domain, as performed with spectrum analyzers, filters play an insignificant role.

As technically realizable filters, especially analog filters, do not have ideal properties, their employment in measurement applications which demand high accuracy must be considered carefully.

Each type of filter represents a certain compromise between the behaviour in the pass band and the stop band or between amplitude and phase accuracy. A further aspect is the transmission behaviour for pulse-shaped signals which is closely linked to the phase response.

The OFV-2200 uses high-quality Butterworth-type filters which are optimized for a high amplitude accuracy in the biggest part of the pass band combined with a good phase response. Despite this, using these filters always implies unavoidable transmission errors in the pass band, which increase with the proximity of the measurement frequency to the cutoff frequency of the filters. A good rule of thumb for the installed 3rd order Butterworth-type low-pass filters is the 70 %-rule:

At 70 % of the cutoff frequency the amplitude error is approximately -5 % and the phase lag is -90°. This range can be used for exact amplitude determination at good phase linearity. The top 30 % of the filter pass band should only be used for orientating measurements.

Special care should be exercised when using the high-pass filter. A 4th order Butterworth-type filter with 100 Hz cutoff frequency was installed in order to suppress the range of low frequency ambient disturbances efficiently. With this filter the range for exact amplitude measurements (-5 % error) starts at approximately 150 Hz. Note the phase lead in the range 100 Hz to 1,000 Hz. The filters and especially the high-pass filter should be switched off in applications where phase shift is unwanted.

When using the high-pass filter there is an additional risk of an internal saturation of the velocity decoder when a small measurement signal is superimposed by large low frequency spurious components. An unwanted frequency component below 100 Hz, that comes, for instance, from a machine vibration, can be suppressed effectively in the output signal with the help of the filter. In order to detect the higher-frequency signal under investigation with a better resolution, the next measurement range with a higher sensitivity might be chosen. However, the higher amplitude of the interfering signal can lead to an internal saturation of the velocity decoder in this range which is indicated by the "HI"-symbol in the display. Given this, a distortion-free decoding of the measurement signal is no longer possible.

A further filter, installed in the instrument's RF section is the so-called TRACKING FILTER. This filter improves the RF signal quality, especially when the returned optical signal is weak or suffers from drop-outs. The action of this special filter is not switchable by the operator, but coupled to the velocity range setting.

Because this filter effectively reduces the bandwidth available for the modulated RF carrier, it limits the slew rate for the demodulated signals at the same time. With respect to the velocity information, this means an acceleration limit and with respect to the displacement signal, this means a velocity limit. The limits for the individual measurement ranges are given with the decoder specifications (ref. to chpt. 5).

Because the Tracking Filter affects both signal decoders and its setting is coupled to the velocity range setting, the latter must be taken into account even when only the displacement output is used:

In order to prevent an unwanted slew rate limit but at the same time benefit from a optimum tracking filter efficiency, the velocity decoder should be set to the lowest possible, non-saturated, range (no "HI" symbol). This should be taken into account especially when making measurements in the higher displacement ranges at frequencies in the kHz range.

3 MORE DETAILED DESCRIPTION OF THE SYSTEM

3.1 The Optical Sensor Head

3.1.1 Interferometry Basics

The Polytec OFV-303 optic vibrometer head uses an interferometric technique to measure vibration. Optical interferometry allows the measurement of displacements much smaller than the wavelength of light by utilising the sinusoidal relationship between the output of an interferometer and the difference in optical path lengths traversed by its beams. By allowing the motion of the surface of interest to modulate the path lengths travelled by the laser beams, the interferometer can be used to detect vibrational signals of sub-nanometer amplitude.

Interference is a phenomenon observed when two beams of light (from a common origin) are made to coincide. The resultant intensity after re-combination is seen to vary sinusoidally with the relative phase difference between the beams.

A typical arrangement to generate this situation artificially is the well-known Mach-Zehnder interferometer as shown in fig. 3.1.

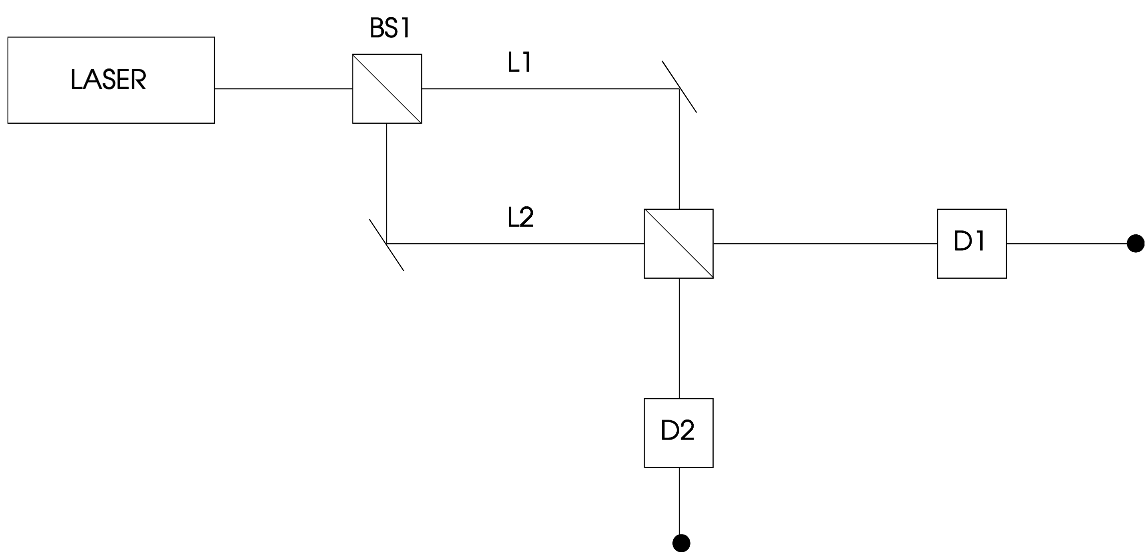


Fig. 3.1: The Mach Zehnder Interferometer as the working principle of a laser vibrometer

Light from a laser source is divided at BS1 into two beams, of approximately equal intensity. Beam 1 travels along a path of length L1, equivalent to an optical phase (θ) given by L1/λ. Similarly, beam 2 travels an equivalent phase θ_2 given by L2/λ

The sinusoidal dependence of the interferometer outputs then produce intensities given by I(1) and I(2) at the detectors D1 and D2. I_0 is the original input laser intensity.

$$I(1) = \tfrac{1}{2} I_0 (1 - \cos(\theta_2 - \theta_1)) \tag{3.1}$$

$$I(2) = \tfrac{1}{2} I_0 (1 + \cos(\theta_2 - \theta_1)) \tag{3.2}$$

We can see that simple interferometers of this kind can be used to measure the path length difference Δz between two light beams. The cosinusoidal relationship reveals two problems still to be resolved in a practical realization of an interferometer:

A) The interference signal does not provide directional information.

B) The sensitivity of the system is a function of phase. When the output intensity is zero or a maximum, the sensitivity given by output intensity against phase shift will be zero.

How this problem is solved in the Polytec Vibrometer optical heads is described below.

3.1.2 Optics Scheme

To allow object motion to affect the interferometer phase, one beam must be allowed to exit from the "inner" interferometer cell, hit the target and be coupled back into the interferometer. An arrangement that satisfies these requirements is shown in fig. 3.2. This is the basic arrangement of the Polytec optical heads.

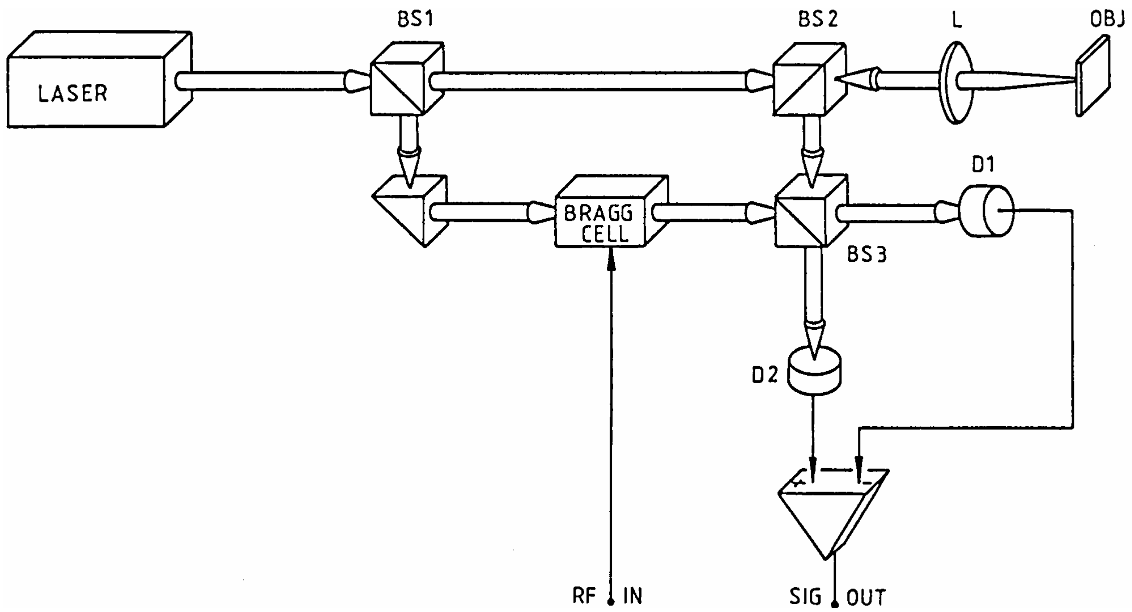


Fig. 3.2: The Polytec Optical Head: A modified Mach-Zehnder interferometer

The arrangement differs from fig. 3.1 in two respects:

- Use of a polarising beam splitter BS2, in conjunction with a quarterwave plate (not shown), provides a directional coupler function: The light beam coming from the laser is allowed to travel straight through to the target, whereas the return beam is directed downwards to BS3.

- Use of a Bragg Cell modulator in the reference arm of the interferometer.

The Bragg cell is a type of optical modulator that frequency-shifts the traversing light beam by an amount f_B that is determined by an electrical drive signal (denoted RF_{in} in fig. 3.2). This frequency shift f_B results in a modulation of the detected interference signal with the RF carrier used. With this modification taken into account, the intensities from equations (3.1) and 3.2) can be rewritten as:

$$I_{(1)} = \tfrac{1}{2} A^2 \{1 + \cos [2\pi (f_B t + 2\Delta z/ \lambda)]\} \qquad (3.3)$$

$$I_{(2)} = \tfrac{1}{2} A^2 \{1 - \cos [2\pi (f_B t + 2\Delta z/ \lambda)]\} \qquad (3.4)$$

Δz denotes the displacement of the target with respect to a fixed reference position.

Subtracting the output signals from the photodetectors by an operational amplifier and removing the DC content of the signal by capacitive coupling yields a SIG OUT voltage **u** that reads

$$u = K \cos [2 \pi (f_B t + 2 \Delta z / \lambda)] \qquad (3.5)$$

It is the output signal of the sensor head and the input signal to the OFV-2200 that must be processed to extract the displacement information Δz. **K** is a proportionality constant taking into account detector efficiency and amplifier gain.

3.1.3 The Doppler Effect

Equation (3.5) relates the output voltage **u** from the optical head to a displacement of the target; displacing the target by an amount Δz phase-shifts the detected RF-signal by

$$\theta_{RF} = 4\pi \; \Delta z / \lambda \qquad (3.6)$$

If the target moves towards the head at a constant speed $v = \Delta z / \Delta t$, the output phase shift turns into an output frequency shift, the well-known Doppler shift f_D with

$$f_D = 2 \; v \; / \; \lambda \qquad (3.7)$$

Thus, the output frequency of the head can be expressed as:

$$f_{out} = f_B + f_D \qquad (3.8)$$

Depending on the direction of the movement, the sign of **v** changes (and so does that of f_D): Positive **v** is defined as a movement towards the head, negative **v** denotes a movement away from the head.

3.1.4 Multimode Laser Effects

The Polytec series of vibration measuring interferometers all use a multimode Helium-Neon laser as coherent light source. These lasers are longitudinally multimode and linearly polarised with an output power between 2.2 and 3.0 mW. Due to the fact that these lasers are multimode, there is a cyclic dependence of signal quality on operating distance. The optimum signal quality is obtained when the optical path length difference is an integer multiple of 2 x laser cavity length. In this case, the optical path length extends twice as fast as the operating distance, as the beam travels there-and-back. Thus a peak signal is obtained once per cavity length, in this case 205 mm. In practice, it is not usually necessary to search out the maximum, as firstly the system is usually sensitive enough to measure adequately even near the minimum, and secondly, the true minimum is only actually present when two adjacent modes are of equal power. The mode distribution is mainly affected by thermal expansion of the laser tube, and passes through this balanced condition repeatedly during the warm-up period. The mode distribution, which is obtained once the laser tube reaches thermal equilibrium, is thus almost random.

Should a signal level minimum be encountered, indicated by a fluctuation of signal level during laser warm-up, then changing the operating distance by half laser cavity length
(=105 mm) should resolve the problem.

The optimum operating distances for the OFV-303 sensor head:
approx. 232, 437, 642 mm etc. as measured from the front surface of the head's front plate.

3.2 Signal Processing Unit

3.2.1 Signal Flow

The signal flow of the vibrometer unit is relatively straightforward and can be discussed with reference to fig. 3.3. In order to clarify the interrelation between optics and electronics, the diagram comprises both the sensor head and the signal processor arrangement schematically.

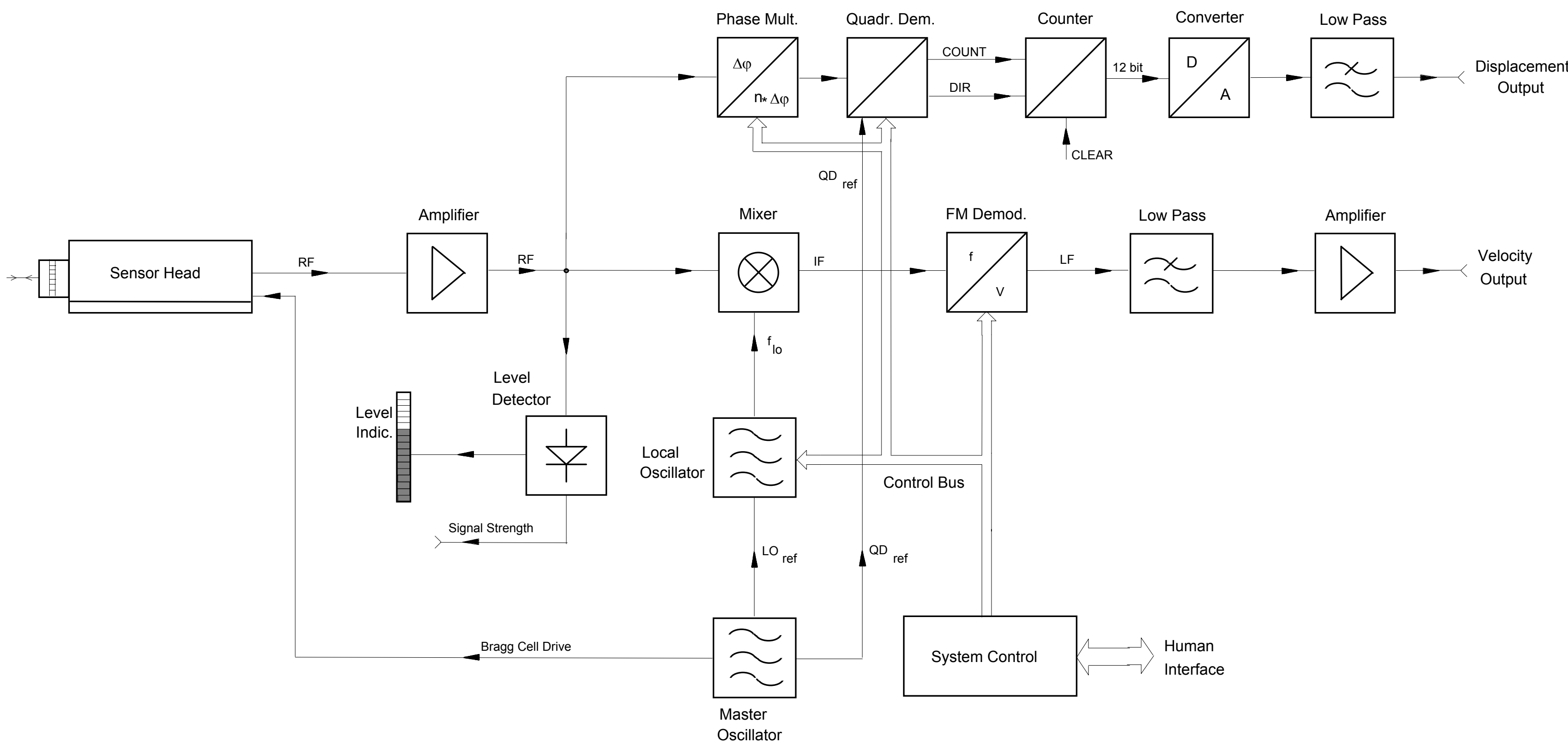


Fig. 3.3: Block diagram of the OFV-2200 electronics

A MASTER OSCILLATOR provides an RF signal, used to drive the Bragg cell modulator at a frequency of 40 MHz, and various reference frequencies for the LOCAL OSCILLATOR stage and the QUADRATUR DEMODULATOR unit.

The frequency and phase modulated RF signal returned from the optical head contains measurement information on both vibration velocity and displacement. After signal conditioning, this RF signal (initially 40 MHz carrier frequency) is fed directly to the displacement decoder. Another part of this signal carrier is downmixed, using the local oscillator frequency f_{Lo}, to the lower IF value. The IF signal contains the same modulation as an input for the velocity decoder section.
A LEVEL DETECTOR provides a DC voltage proportional to the logarithm of the RF signal strength. This voltage drives a level indicator on front panel and is also fed to the "SIGNAL" socket on rear panel for external use.

The vibration velocity information is recovered by an FM DEMODULATOR stage, the so-called velocity decoder. The velocity decoder provides 3 measurement ranges of high linearity and frequency bandwidth, covering the entire velocity range from less than 1 µm/s to 1.25 m/s. The decoder ranges are controlled from the front panel via the internal CONTROL BUS, which also controls the local oscillator frequency corresponding to the velocity range.

The LF output of the velocity demodulator passes through a switchable HIGH-PASS/LOW-PASS filter section.

The displacement information is recovered by a digital PHASE DEMODULATOR unit. Five measurement ranges are selectable covering a peak-to-peak displacement range from 8 µm through 1.3 mm. The decoder is controlled from a separate front panel section via the internal CONTROL BUS.

The displacement decoder output signal passes a fixed low-pass filter with a 250 kHz cutoff frequency.

3.2.2 Front Panel Control

All system functions are controlled from individual front panel sections (ref. to fig. 2.6). Each decoder has its own section including range display, range keys and output socket. In addition, the DISPLACEMENT control section includes a CLEAR key and socket for output voltage reset to zero.

Range selections are made by simply pressing the "+" or "-" RANGE key. The scale factor of the current range is displayed by the individual LCD in $mm \cdot s^{-1}/V$ and µm/V respectively. In cases where the peak velocity is too large for the range, a "HI" symbol is displayed instead of a number in the VELOCITY range display.

For ease of adjustment, a SIGNAL LEVEL light bar is also provided at the front panel. The display is fed with the output signal from a LEVEL DETECTOR that measures the RF signal level entering the processor unit from the sensor head. Adjustment of the measuring beam on the target should always be such that the returning light power (and thus the displayed RF SIGNAL LEVEL) is at a maximum.

The VELOCITY FILTER section allows for selection of HIGH-PASS and LOW-PASS filters for the velocity output. If the individual knob is in "OFF" position, the filter is bypassed.

3.2.3 The Velocity Decoder

As described in chapter 3.1, the Doppler effect due to the motion of the surface under investigation causes a frequency shift of the interferometer output signal. This Doppler frequency shift is directly proportional to the velocity of the surface and therefore, when decoded using an FM demodulator (= frequency to voltage converter), produces a velocity-dependent output voltage. For vibration applications, the range, linearity, slew rate and bandwidth of conventional radio-based FM demodulators are not sufficient and more complex techniques are required. The advanced FM demodulator used in this Polytec Vibrometer employs a down-mixing process and a high-precision demodulation circuitry to provide velocity decoding in a wide measurement range with high linearity and large bandwidth.

The demodulation circuitry itself as well as the oscillator for the down-mixing are switched over via the system control bus dependent on range setting.

A fixed low-pass filter with 250 kHz cutoff frequency limits the maximum vibrational frequency to this value, also preventing spurious higher frequencies from emerging at the output.

An additional low-pass filter of 3rd order Butterworth type can be set at either 10 kHz or 50 kHz cutoff frequency, providing optimum noise suppression if higher frequencies are not of interest.

A 4th order high-pass filter with fixed 100 Hz cutoff frequency can be advantageously used to suppress ambient vibrations. Both high-pass- and low-pass filters can be bypassed via the system control bus. In this case, the velocity decoder covers a vibration frequency range from < 0.5 Hz through 250 kHz.

3.2.4 The Displacement Decoder

The phase of the interferometer output signal is the carrier of the displacement information. A displacement of the object by $\pm \frac{\lambda}{2}$ produces a full modulation period at the interferometer output, namely a fringe passage. Therefore the electrical signal also undergoes a phase shift at the photoelectric receiver by one period or 2π rad. The amount of complete signal periods is consequently an incremental measure for the total object displacement with a resolution of $\frac{\lambda}{2}$, for HeNe laser therefore 316,4 nm. As the interferometric phase changes continuously with the object displacement, displacements smaller than $\frac{\lambda}{2}$ can also be evaluated by a phase demodulation of the electrical interferometer signal. This is realized in the high-resolution displacement decoder of the Polytec vibrometer 2200, using a special circuitry called Phase Multiplier.

As mentioned above, Polytec vibrometers operate on the basis of the heterodyne interferometer, therefore the phase information of the interference signal, as with the Doppler frequency shift, is modulated onto the 40 MHz carrier signal. The required information rides on the phase difference between Bragg cell driver signal and the modulated signal at the photo detector. With the help of a so-called quadrature demodulator, the interferometric phase information can be reconstructed from these two signals.

Please refer to fig. 3.3 to understand the function of the displacement decoder. Its function will be explained first without considering the block PHASE MULTIPLIER.

The quadrature demodulator reconstructs the phase information in a digital form out of the 40 MHz reference signal (PM Ref) and the interferometer signal (RF). At its output the pulse sequences COUNT and DIRECTION develop. A COUNT pulse corresponds to each 2 π period of the interferometer signal and an object displacement of $\frac{\lambda}{2}$. The binary value of the DIRECTION signal informs on the direction of the phase shift, i.e. on the motion direction of the object. Both pulses are led to a binary up-/down counter whose counter status is consequently a measure for the present position of the object. The counter range is 12 bit, i.e. 4096 steps. As each step corresponds to an object displacement of 316.4 nm, a range of approximately 1.3 mm with a resolution of 0.3164 µm can be detected in the so-called Direct Count Mode. In order to make full use of the counter range, the counter is set to zero in the resting position with the help of an external CLEAR pulse. Thus, with a vibrational motion of the object, the maximum amplitude can be 0.65 mm.

In order to observe the displacement signal in real time, for instance with the help of an oscilloscope, the digital counter status is converted via a fast 12 bit D/A converter into a voltage signal. At the output of the D/A converter, a voltage signal approximated by steps originates according to the resolution of the converter. This is flattened by a low-pass filter at higher vibration frequencies.

The chosen working principle of the displacement decoder determines its accuracy. As long as the optical signal shows no drop-outs, the interferometer output signal is phase-continuous and at the output of the quadrature demodulator, a COUNT pulse generates for each 2 π phase cycle of the interferometer. The accuracy of the corresponding displacement of 316.4 nm is only determined by the wavelength stability of the laser which is of the order of 10^{-5}. It is known that HeNe lasers constitute an acknowledged standard for length measurements.

Therefore the change of the digital fringe counter status corresponds fairly exactly to the displacement of the object, independent of ageing effects. However, a part of the physically provided accuracy is lost again by the following analog components, as it is known that these can cause static and dynamic amplitude- and phase errors in the output signal. Especially with vibrational movements above 100 kHz, dynamic errors caused by the low-pass filter may occur which should not be neglected.

It is often desirable to have available an even higher resolution. In the high-resolution displacement decoder installed in the OFV-2200 system, this is achieved by the additional component "Phase Multiplier" (ref. fig. 3.3). In this functional block the RF-signal is pre-processed before the quadrature demodulation in the frequency domain. By means of digital procedures, an integer, up to a 160-fold, multiplication factor of the instantaneous phase deviation compared to the direct signal, is achieved.

In the lowest measuring range the incremental counter value is therefore around
2 nm.
As the counting capacity is always 12 bit, the total measuring range is reduced by the multiplication factor when the phase multiplier is applied. In the lowest measuring range with a scale factor of 0.5 µm/V, displacements up to approximately 8 µm (vibrational amplitude ± 4 µm) can be detected.

Unfortunately, an increase of the original bandwidth of the modulated signal and the pulse frequency at the counter is involved with the phase multiplication. The technical limits of the system are reached in the Direct Count mode (80 µm/V) at a motion velocity of 1.6 m/s. In the higher resolving measurement ranges, starting from this value, the limiting velocity decreases, approximately according to the multiplication factor.

Fig. 3.4 shows the limits for all displacement measurement ranges of the OFV-2200.

Fehler! Kein gültiger Dateiname.

Fig. 3.4: Operating range diagram of OFV-2200 displacement decoder

For a harmonic vibration the following equation applies:

$V_{peak} = 2\,\pi\, f_v \cdot x_{peak}$

whereas x_{peak} = vibration amplitude

v_{peak} = peak velocity

f_v = vibrational frequency

Because of the velocity limits according to the bandwidth, the full scale amplitude of the corresponding ranges can therefore only be made use of up to a certain frequency. For higher frequencies, a proportional derating of the maximum amplitude occurs.

With higher motion velocities, counting losses would occur which present themselves as a distortion of the measuring signal.

4 FAULT DIAGNOSIS

4.1 Introduction

If there is any malfunction of the instrument, please first ensure that the connection cable between optics and controller is correctly installed (with screws fixed), that the controller is plugged into the mains, that the power switch is on and that the shutter is open (ref. chapter 2.2.1).

The "power" LED on the front of the controller and "Laser" LED on the optical head should be lit. If they are not, a faulty mains voltage supply could be the cause. In this case check the fuses at rear panel.

Warning: To avoid an electric shock, do not remove the covers while the instrument is connected to the mains!

If the fault is not corrected, the following tests should be performed to locate the defective unit. On completion, please contact our service personnel for further information and assistance.

4.2 Checking the Optics

Failure of an optical head can be caused by either a faulty laser, damage to or misalignment of the optical components or the electronic circuitry. If an optical power meter and/or a polarisation analyser is available, it is possible to quickly test some basic functions of the interferometer.

a) Is a laser beam emitted from the front lens ?

If not:

Possible sources of failure could be the laser tube, the laser HV supply (inside interferometer unit), or a missing -15V supply voltage. To check the latter, continue with 4.3.

A failure can also occur if the controller power switch was switched on prior to connecting the interferometer to the controller. If so, switch off controller and switch on again.

b) Does the "SIGNAL" display (on interferometer controller front panel or optical head) respond to changes in the reflectivity of a target ?

To check, place a sheet of well reflecting material in the laser beam. Optimum distance to position the target from the front lens is about 60 cm.

c) What power is emitted from the optical head ?
(Typically > 0.8 mW).

d) Is the laser power stable ?
(Typically < 5 % variation after the instruments have warmed up).

e) Is the polarisation okay ?
The correct polarisation state for the output beam is circular, which means that when a polariser is rotated in the beam, the power should remain constant.
(Typical fluctuations are < 20 %).

4.3 Checking the Signal Processor

Failure analysis on the signal processor is restricted to measurement of low voltages on connectors located on the front and rear panels. These include time-variable signals (decoder output), which should be analysed using an oscilloscope as well as DC power supply voltages. The latter should be measured using a multimeter, as reading an oscilloscope trace is generally not precise enough.

The location of the connectors in question can be seen from fig. 4.1.

a) *Measurement of decoder output*

The sensor head must be connected to the controller and a sufficient level of light coupled back from a retro-reflective target.

a1) Is a signal indicated by the front panel LED indicator ?

a2) Does the decoder output respond to vibration at all ?

a3) If the output does not respond: Is a significant DC offset to be observed ?

a4) Is the output signal noisy or does the scope show a clear straight line when the object does not vibrate ?
(Note: Noise must occur when no light is reflected or when the laser beam is blocked).

b) *Measurement of power supply voltage levels*

Before performing these measurements using a multimeter, the processor/interferometer connection cable should be disconnected. Then, the D-type connector on the instrument rear panel labelled "INTERFEROMETER" becomes accessible and the correct operation of the power supply module can be checked by measuring the voltages -15/-5/+5/+16 Volts as referred to ground. The permitted tolerance levels are ± 5 %. Fig. 4.1 shows the pin assignment of the connector.

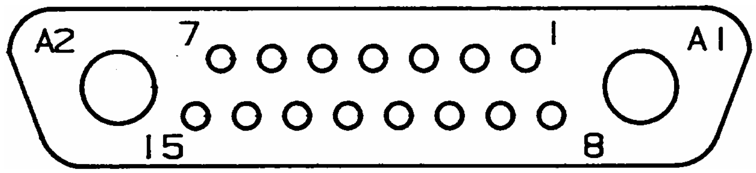


Fig. 4.1: Pin assignment of the "Interferometer" D-type connector on the instrument's back panel.

<u>Pin No.</u>	<u>Volts</u>
1, 4, 7, 8, 15	Ground
3, 6, 9	+ 16
2	+ 5
13	- 5,2
5, 10	- 15
12	(Sig. Level)
11, 14	N.C.

5 SPECIFICATIONS

5.1 GENERAL DATA / OPERATING CONDITIONS

Power requirements

Voltage:	100 / 115 / 230 VAC, ± 10 %, 50/60 Hz; selectable on rear panel
Power cons.:	max. 140 VA
Fuses:	2.5 A / 250 V time delay for 100 V or 115 V
	1.25 A / 250 V time delay for 230 V

Environmental conditions

Operating temperature:	+5 °C to +40 °C (41 °F to 104 °F)
Storage temperature:	-5 °C to +60 °C (23 °F to 140 °F)
Rel. humidity:	max. 80 %, non-condensing
Dimensions:	450 mm x 360 mm x 135 mm (19" x 14" x 5.3")
Weight:	10.5 kg (controller only)
Protection class:	I (protective grounding)
Safety standards applied:	EN 60950 (IEC 950), DIN VDE 0805, EN 61010 (IEC 1010)
Conforms to EMC standards	
for emission:	EN 55011 / EN 55022, Class B (DIN VDE 0871 Class B, FCC Class B)
for immunity:	EN 50082-1 EN 50082-2 (IEC 801-1...-5)

5.2 Optical Sensor Head

Laser type:	Helium Neon
Laser wavelength:	633 nm
Cavity length:	205 mm
Laser output power/classification:	2.3 mW/ IIIb (USA IIIa)
System output power/classification	< 1mW / II
Meets laser safety requirements:	CFR 1040.10, BS 4803, DIN VDE 0837, IEC 825
Environmental temperature:	+ 5 °C to + 40 °C (41 °F to 104 °F)
Humidity	20 % to 80 %
Power requirements: as supplied by Polytec controller processors	± 5 Volts, ± 15 V
Range of standoff distances (depending on front lens used):	30 cm to 30 m
Dimensions (incl. front lens):	34.4 x 12.0 x 8.0 (13.5 x 4.7 x 3.2")
Weight:	3.5 kg

Fig. 5.1: Dimensions OFV-303 (all dimensions in mm)

5.3 Velocity Decoder Specifications

Measurement Ranges:

Range	Full Scale Output peak-to-peak	Resolution[1]	Max. Vibration Frequency (-3 dB)	Max. Acceleration
5 mm/s/V	100 mm/s	0.5 µm/s	250 kHz	8 000 g
25 mm/s/V	500 mm/s	2 µm/s	250 kHz	25 000 g
125 mm/s/V	2 500 mm/s	5 µm/s	250 kHz	200 000 g

Voltage Output:

Output swing: ± 10 V

Output Impedance: 50 Ω

Min. load resistance: 10 kΩ (-0.5 % add. error)

Overrange indicator threshold: 95 % of fullscale ± 5 %

Calibration Accuracy:

± 1.5 % of rms reading @T = (25 ± 5) °C

± 2.5 % of rms reading in full operating temperature range

Conditions: sinusoidal vibration of frequency 1 kHz and amplitude 70 % of FSR

load resistance ≥ 1 MΩ

[1] Resolution is defined as the signal amplitude at which the signal-to-noise ratio is 0 dB in a 10 Hz spectral resolution bandwidth.

Amplitude Linearity:

max. linearity error [2]

	one particular range:	± 1 %
	overall:	± 2.5 %

Frequency Response: (all filters off)

Additional maximum error referred to calibration conditions:

10 Hz - 10 kHz	± 0,2 dB
10 kHz - 50 kHz	+ 0,2 dB/- 0,5 dB
50 kHz - 250 kHz	+ 0,2 dB/- 3 dB

Filter Characteristics:

High-pass:	cutoff frequency:	100 Hz (-3 dB)
	- 5 % point:	150 Hz (typ.)
	Type:	Butterworth, 4th order
	Frequency rolloff:	-80 dB/dec.
Low-pass:	cutoff frequency:	10 kHz / 50 kHz (-3 dB)
	- 5 % point:	7 kHz / 33 kHz (typ.)
	Type:	Butterworth, 3rd order
	Frequency rolloff:	-60 dB/dec.
	Phase rolloff:	-12/-2.4 deg/kHz (typ.)

[2] Linearity error is defined as the amplitude-dependent, relative deviation of the scale factor referred to the nominal scale factor calibrated at reference conditions.

5.4 Displacement Decoder Specifications

Measurement Range	Full Scale Output (Peak-to-Peak)	Resolution[1]	Max. Vibration Frequency	Max. Velocity
µm/V	mm	µm	kHz	m/s
0.5	0.008	0.002	25	0.06
2	0.032	0.008	75	0.25
8	0.13	0.032	75	1.0
20	0.32	0.08	250	1.6
80	1.3	0.32	250	1.6

Calibration accuracy: ± 2 % of reading ± 1 step (up to 100 kHz) (1 step corresponds to the resolution limit of the selected range)

Linearity error: ± 2 steps

Output swing: ± 8 Volts

Output impedance: 50 Ω

Min. load resistance: 10 kΩ (0.5 % add. error)

Manual triggering is possible using the CLEAR button on the front panel. Sychronized triggering is possible feeding TTL pulses to the related BNC connector.

Trigger (clear input):

Standard logic signal: TTL
Trigger threshold: + 0.7 V (typ.). falling edge
max. input voltage: + 12 V
min. input voltage: **- 7** V
max. pulse rate: 50 kHz
min. pulse width: 10 µs

[1] The resolution is defined as one digit of the fringe counter output.

Appendix A: Size of Measurement Spot

The size of the laser beam generated on the surface of the test object is sufficiently well defined by a simple "magnification" calculation. To calculate the image spot size we must know

1) the object spot size
2) the lens focal length
3) the image distance.

The object spot size is in the case of fiber systems given by the core (mode field) diameter and in the case of 302, 352, 303, 353 systems by the internally focused spot size.

The focusing lens within the 300 series heads is identical to that used to launch the laser beam into the fiber and produces roughly the same spot size, taken to be 5 microns in diameter.

The imaging lens is different depending on the system used and given by the table below

Head Type	Focal Length
302 std	50 mm (Nikon)
352 std	50 mm (Nikon)
302 sv	85 mm (Nikon)
501/2/8 std	16 mm (Polytec)
OFV-100	20 mm (Polytec)
303/353 std	60 mm (Polytec)
303/353 long range	100 mm (Polytec)

The "image" distance is then given by the distance between lens and test object.

The spot size on the test object is then given approximately by

$$D_{image} = \frac{\text{Image distance}}{\text{Object distance}} \cdot 5\ \mu m$$

in which we can roughly take object distance = focal length, provided the image distance is much greater than the focal length. Assuming this is the case we can define spot sizes per meter distance as follows:

303 std:	84 microns/meter
303 long range:	50 microns/meter

500 series std: 312 microns/meter
OFV-100: 250 microns/meter