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# Fiber vibrometer with operating distance extender

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A non-contact optical method is used for vibration measurement. Information about changes in distance between the vibration target and the probe is expressed as changes in the intensity of light backscattered by the target. The combination of fiber vibrometer and the measuring instrument "graphmeter" made by Fluke enables easy measurement of vibration parameters. The optical extender accessory offers the advantage of considerably increased operating distance.

## 1. Introduction

Technology produces a high demand for vibration measurements. A device that performs this kind of measurement is called a vibrometer. The scope of its application is rather vast, *e.g.*, the measurement of vibrations on electro-acoustic transducers (loudspeakers, *etc.*), musical instruments, read-write heads in hard disc mechanisms, videotapes, printed circuit boards and components on these boards, a variety of micro-mechanisms, fuel injector valves of diesel engines, computer printer heads (needle and ink-jet type), ear membrane in hearing disorders (the small size, an important advantage of optical fiber sensor, is vital here), *etc.*

The vibrometer proposed measures such parameters as: the frequency of vibration, the amplitude of vibration (possibly the velocity of vibration), and enables the waveform of vibration to be viewed. It is also possible to measure the phase of vibration (in relation to excitation electrical signal applied to tested transducer).

## 2. Principle of operation

Optical methods for vibration measurement are the most advantageous among all other measurement methods because there is no contact between the instrument and the vibrating target, thus eliminating any effect the instrument might exert on the target. Optical vibrometers use the backscattering of the light beam by the vibrating target. In the intensity-based version of the method discussed [1]–[6], [9], information about changes in the distance between the vibrating target and the probe is expressed as changes in the intensity of the received scattered light. Figure 1 shows the principle of operation of such a vibrometer by the example of a configuration with a single optical fiber emitting light close to the vibrating target and a single receiving optical fiber transmitting the light to a photodiode (PD). In reality, the respective emitting and receiving fiberoptic bundles are used. Light

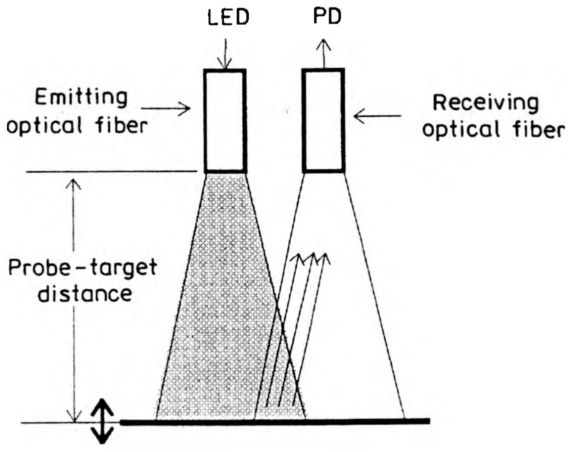



Fig. 1. Fiber vibrometer operating principle.

leaving the emitting optical fiber (emitting bundle) forms an aperture cone of the divergence angle $\Theta$ depending on the fiber's numerical aperture ($\Theta = \arcsin \mathrm{NA}$). The cross-section of the aperture cone grows with the distance from the optical fiber (bundle) end-face. An analogous reasoning applies to the receiving optical fiber's (bundle's) angle of view. Elementary analysis shows that the received optical power depends on the distance of the scattering terget from optical fiber (bundle) faces reaching a peak value at a distance of $1-2$ mm. A typical relation of the power of the received light to the probe-target distance, that is, the static characteristics of the vibrometer, is shown in Fig. 2. The absolute level of the scattered signal depends on the properties of the tested target's surface. If a high conversion efficiency is required, that is, whenever small amplitudes of vibration are being measured (of single μm or less), the front slope of the curve (before peak) is used. When larger vibration

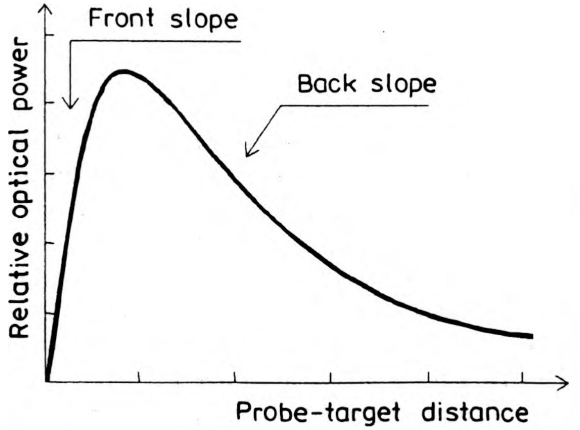



Fig. 2. Relative photodiode power versus probe-target distance.

amplitudes are the case, practical factors give preference to the use of the backslope (after peak) which is less steep and causes lower conversion efficiency.

## 3. Emitting-receiving bundle

An optical fiber emitting and receiving bundle plays the key role in the vibrometer. The important parameters of the instrument such as the optimum quiescent point on the front and back slope of the static characteristics (*i.e.*, the optimum probe-target distance) and conversion efficiency depend on the type of the bundle. In the course of experimental work, the best parameters were found to be available when using a concentric emitting and receiving bundle (Fig. 3), whose central part functions as the emitting bundle and the outer layer performs the receiving function. The static characteristic of this bundle is shown in Fig. 4. The diameter of the bundle (without the sleeve) is about 2 mm. The bundle was made of optical fibers with the numerical aperture 0.54, core diameter 32 μm and the cladding diameter 40 μm (without the protecting layer) manufactured by the Biaglass Co. (Białystok, Poland). The length of emitting-receiving bundle is 60 cm.

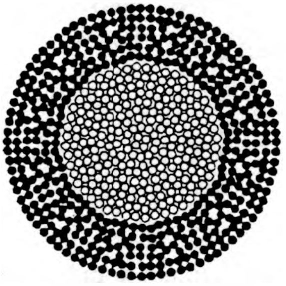


Fig. 3. Cross-section of concentric version of transmitting/receiving bundle (computer processed): o – transmitting optical fibers, • – receiving optical fibers.

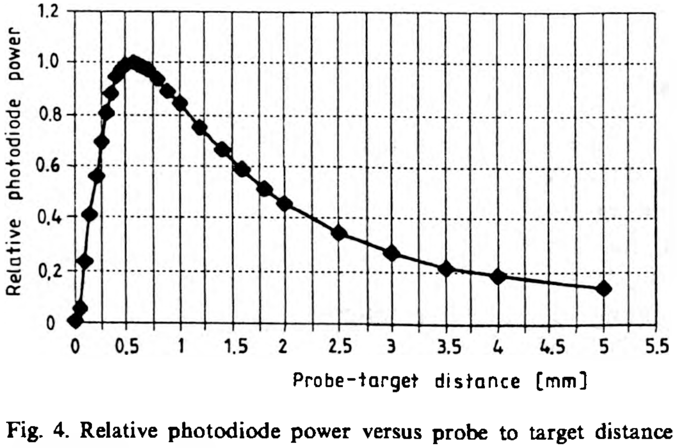



Fig. 4. Relative photodiode power versus probe to target distance for concentric version of transmitting/receiving bundle.

## 4. Measuring head

The tip of the optical fiber emitting and receiving bundle, that is the probe, is fitted in the measuring head. It consists of an adjustable angle mount, a precision stage (linear) positioning mechanism with a micrometer screw (made by Mitutoyo, Japan), an extension arm permitting the adjustment of reach and tilt in two planes, and a vertical post which can be fixed in the post holder-carrier mounted on optical bench or in a post holder with magnetic clamp established on steel table. It is understood that for measurements of small objects or mechanisms, both the measurement head and the tested object are fixed to the same optical bench or a steel table. Other cases may require an individual approach, allowing for their specificity but a firm positioning of the probe in relation to the vibrating surface is always necessary. Figure 5 shows the layout of the fiber vibrometer. Technical specification applies to a combination of vibrometer and measuring instrument "graphmeter" made by Fluke.

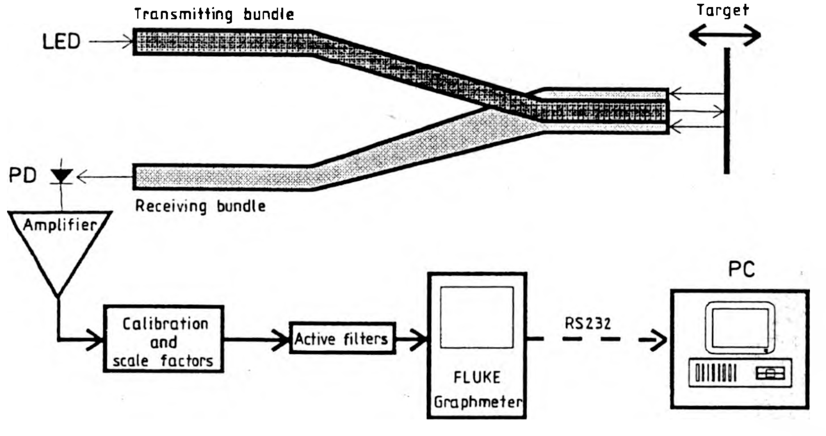



Fig. 5. Layout of the fiber vibrometer.

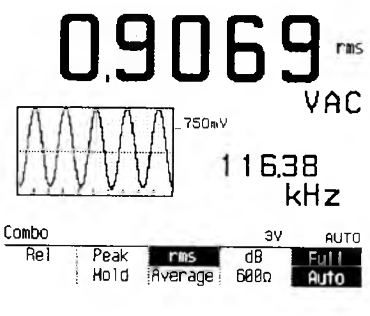
## 5. Technical specification*

- Light source LED, $\lambda = 0.66$ µm, $P_0 = 2$ mW
- Measured amplitudes 0.1 – 500 µm
- Amplitude measurement ranges:
  on front slope 1, 10, 100 µm
  on back slope 10, 100, 1000 µm
- Scale factors corresponding to the above ranges:
  on front slope 1, 10, 100 µm/V
  on back slope 10, 100 1000 µm/V

* For sufficiently intensive backscattering of vibrating surface enabling calibration of the vibrometer.

- Error of amplitude measurement $\sim 1\%$
- Nominal frequency range 10 Hz – 300 kHz
- Frequency dependent errors:
  for frequencies from 50 Hz to 200 kHz $<1\%$
  for frequencies from 10 Hz to 300 kHz $<5\%$
- Active filters (cut-off frequencies defined for a 1% drop of level):
  high-pass filters 50, 500, 5000 Hz
  low-pass filters 1, 10, 50, 300 kHz
- Error of frequency measurement $<0.05\% \pm 1$
- Waveform display on a screen
- RS 232 Interface (with optically isolated cable/adapter for downloading data to a PC or printer).

When determining the measurement error, the potential effect of the photodiode dark current noise and other disturbances (*e.g.*, strong stray light especially using the 50 Hz mains supply illumination) were not taken into consideration. These kinds of disturbances may influence the measurements of very small vibration amplitudes. Their effect can be reduced by limiting the vibrometer's bandwidth and by avoiding excessive stray light over the area of the probe-target interaction. The effect of dark noise is also minimized by measuring the r.m.s. value of the output voltage from the vibrometer. In such a case the powers of signal and noise add up. If the signal/noise ratio is not too small, the effect of noise on output voltage is negligible (for example, if voltage signal/noise ratio equals 10, then the relative measurement error is 0.5%). Moreover the noise power can be treated as systematic error, so it can be deducted from the vibrometer output power. Figure 6 shows the sample of the presentation made on the screen of "graphmeter". The presentation can be transmitted by a serial connection (RS 232 Interface) to a printer or a PC. The photo of the measurement setup can be seen in Fig. 7.



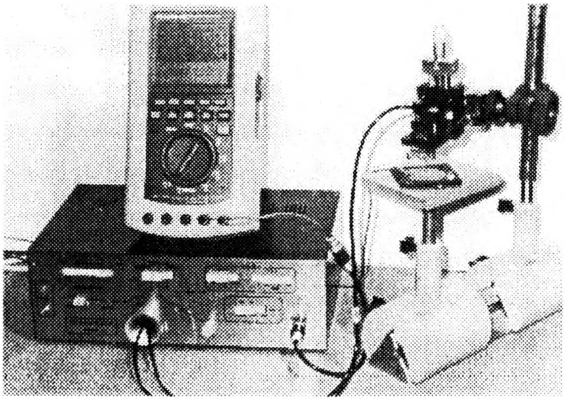



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Fig. 6. Example of presentation made on the screen of Fluke's "graphmeter".

Fig. 7. Photo of the measurement setup.

## 6. Optional extender accessory

The measurement at an increased operating distance offers some advantages as, for instance, the reduced possibility of an accidental contact of the fiber bundle probe end with the target. This is extremely important for applications in which the target is the human tissue or a delicate substance like, for example, a semi-conductor material. It may also be advantageous in situations where the terget cannot be placed close to the probe.

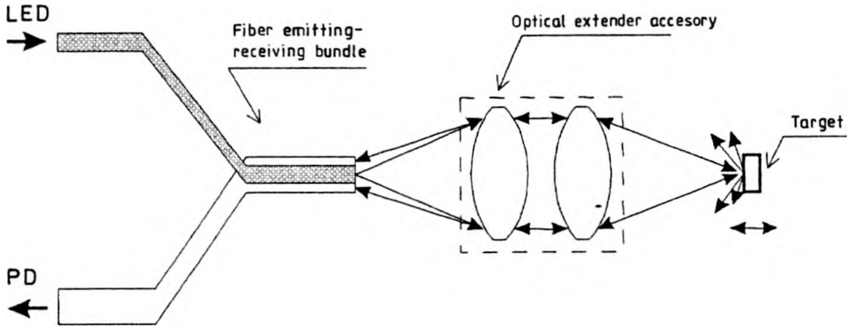


Fig. 8. Fiber vibrometer with optional extender accessory.

The fiber vibrometer can function at an increased instrument to target distance through the use of an optical extender accessory [7], [8], (Fig. 8) which contains two lenses. If the distances from the lenses to the fiber probe and the target are equal to

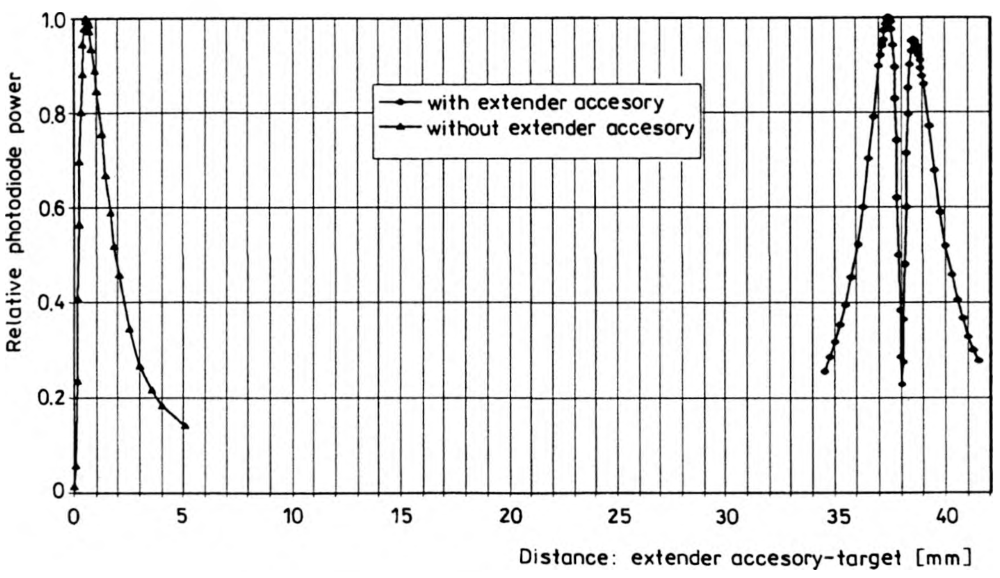


Fig. 9. Relative photodiode power versus probe-target and/or extender accessory-target distance. Note a considerable increase of the operating distance obtained using the extender accessory.

their focal lengths, the image of the probe end face will appear on the surface of the target. This image is retransmitted back to the probe face in its original form. It is evident that the light enters back into the transmitting fibers of the probe and a very sharp null occurs in the photodiode power versus the extender accessory to target distance characteristics (Fig. 9). A displacement of the target in any direction causes the defocusing of the image, so the light enters the receiving fibers and the photodiode. The shape of the photodiode power versus the displacement characteristic remains similar to the case when the extender accessory is not used, except that the operating distance (the distance between the end surface of the extender accessory and the target becomes a little smaller than the focal length of the output lens) significantly increases.

The extender accessory should be equipped with high quality lenses characterized by a small spherical aberration and a great numerical aperture (similar to the numerical aperture of the fibers used), *i.e.*, a small *f*/number. In turn a large operating distance results for long focal length. Most camera lenses meet these requirements. We have used lenses 1.8/50 (*f*/1.8, 50 mm focal length) mounted in a special housing (their original housings were removed). The obtained operating distance was 48 mm.

## 7. Conclusion

We have developed a fiber vibrometer of intensity-based version capable of measuring vibrations from 0.1 μm to 0.5 mm when the vibration frequency ranges between 10 Hz and 300 kHz. Due to combination of fiber vibrometer and measuring instrument "graphmeter" made by Fluke we can easily measure the amplitude of vibration, the frequency of vibration, and to view the vibration waveform. The optical extender accessory allows measurement from a considerably increased operating distance of 48 mm. An RS 232 Interface is provided downloading data to a printer or a PC.

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