A NON-CONTACTING OPTICAL DISPLACEMENT TRANSDUCER

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ABSTRACT

A non-contacting optical system is described which can measure not only absolute displacements like comparable, more traditional transducers but also relative displacements. It can be cheap and, even under normal lighting conditions, operated non-intrusively at some distance from a test object which need not be reflective. Several examples are presented to illustrate the system's versatility in applications involving frequencies below 100 Hz.

RÉSUMÉ

Une méthode optique pour mesurer les déplacements dans un système est discuter. Les mesures peuvent être fait a une distance du système et il n'y a aucun contact avec le système. Un environnement sombre n'est pas nécessaire et la méthode donne non seulement des résultats absolus mais aussi relatives. Plusieurs applications sont inclu qui démontre la flexibilité de la méthode pour mesurer les déplacements en bas de 100 Hz.

1. INTRODUCTION

A non-contacting transducer, unlike an accelerometer, does not have to be placed on a vibrating object to determine the dynamic characteristics. This feature is particularly useful for lightweight objects whose behaviour would be influenced by the additional weight of a contacting probe. However, conventional non-contacting transducers like lasers or capacitive probes are either quite expensive or have to be located very close to the vibrating object [1]. Furthermore, they are only able to measure absolute displacements. A non-contacting optical transducer will be described which largely overcomes these disadvantages. Four examples of its use will be presented to portray various applications.

2.PRINCIPLE OF OPERATION AND EXPERIMENTAL IMPLEMENTATION

The principle of measuring an absolute displacement with the optical transducer is illustrated in Figure 1(a). A light source is used to form a slit of light on the opening created between the object, vibrating about an equilibrium position, and a stationary reference post. The additional iris and collimator in Figure 1(a) are optional components which may be introduced to improve the unifomity of this slit of light. If uniform, light passing through the opening will fluctuate by an amount which is proportional to the movement of the vibrating object. Such fluctuations can be determined by using a biconvex lens to focus the transmitted light on a photocell and measuring the photocell's amplified electrical output on an oscilloscope. However, it is beneficial to place the photocell not quite at the biconvex lens' focal point so that the light image is formed over the photocell's entire surface. This precaution alleviates the consequences of slight misalignments between the the optical components. Furthermore, if a displacement is needed at more than one location of the vibrating object, as in a modal analysis, openings first formed at the different locations with the object at rest should be preferably identical. Then the initial light transmissions associated with each location will be the same so that the gain of the optical system will be constant. Finally, if the reference post itself was to move then the same procedures may still be used to determine the vibrating object's displacement relative to the post.

The first embodiment of the optical transducer was made from availible components and is shown in Figure 1(b). The light source was a small, high intensity bulb with an internal coil and the iris and collimator were absent. Reasonable accuracy was obtained providing peak-to-peak absolute or relative displacements were smaller than 1.0 mm. Larger displacements would need better and more costly components. The following components were purchased primarily from Ealing Scientific Limited[†] :

1. A very high intensity halogen light bulb, Type 28-8407.
2. An iris with a 2mm opening, Type 22-8601, to transmit only the most homogeneous centre section of the light source.
3. A collimator, Type 28-8506, with a focal length of 95 mm to transpose diverging light into parallel rays. (The inclusion of a collimator made sure that the sensitivity of the optical transducer did not change when the distances between the collimator to opening and opening to biconvex lens were varied. However, the distances between the source and iris, iris and collimator and biconvex lens and photocell must then be kept constant.)

[†]
Ealing Scientific Limited
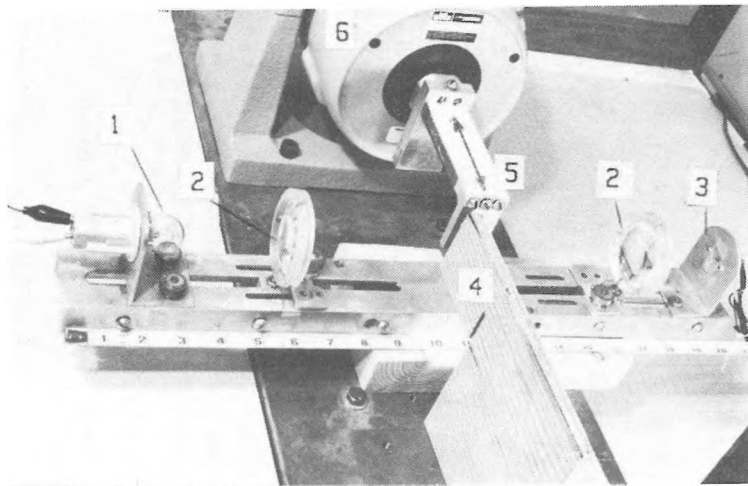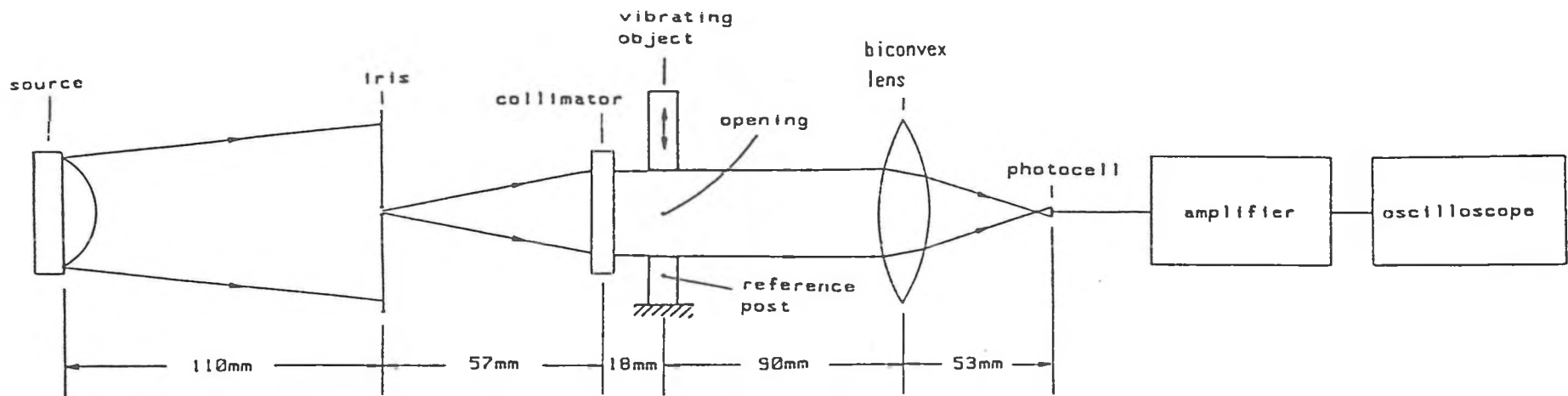6010 Vanden Abeele, Saint-Laurent, Quebec, Canada H4S 1R9.

Figure 1. Showing (a) a general arrangement and (b) the components of the $50 system.

(1)Light source (2)biconvex lens (3) photocell
(4)stationary reference post (5)vibrating bracket
(6)electromagnetic shaker.

(b)

4. A good quality biconvex lens, Type 23-8972, with a focal length of 50 mm to better focus the light on the photocell,MRD Type 3055 [5].

These additions brought the total cost of the optical components from $50 to under $1500 and extended the working displacement range approximately five times.

The sensitivity and linearity of the upgraded optical system were found from comparisons with reference absolute displacements measured independently by using a Wayne Kerr MEI capacitive probe and meter. Easily detectible displacements with various amplitudes and frequencies were created by firmly securing a solid metal bracket to an electromagnetic shaker controlled by a power amplifier and a sinewave generator. An opening was formed between the bracket and an adjacent stationary post in a similar fashion to that shown in Figure 1(b).Signals from both tranducer systems were displayed simultaneously on a Tektronix 7313 storage oscilloscope to facilitate calculation of the upgraded system's sensitivity. Percentage deviations[+] from 24 mV/mm, the average sensitivity in the frequency range 1 to 100 Hz, are presented in Figure 2. The greatest deviations of 11 % from the linear abscissa of this figure happen, regardless of the peak absolute displacement, at frequencies above 40 Hz. They were caused by resonances of the structure supporting the optical components. Experiments also indicated that linearity was reasonably preserved when the bracket's displacement was changing the size of the opening (between the bracket and post) by 4% to 30%.

3.TYPICAL APPLICATIONS

3.1 Bilinear Hysteretic Oscillator

The upgraded optical system was used, as illustrated in Figure 3, to measure the absolute displacement history of an experimental bilinear hysteretic oscillator. In addition, the displacement was processed electronically in a feedback loop to give the required bilinear hysteretic features. Details may be found in references 2 and 3.

3.2 Modal Analysis

The fundamental mode shape of an inverted brass T-plate, standing on two rubber strips, was determined by using the optical system. The plate was excited sinusoidally at its fundamental natural frequency by connecting it through a light spring to an electromagnatic shaker. To avoid interference with

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+

Sensitivity at any one frequency - Average sensitivity

$$\left(\frac{\text{Sensitivity at any one frequency} - \text{Average sensitivity}}{\text{Average sensitivity}} \right) \times 100\%$$
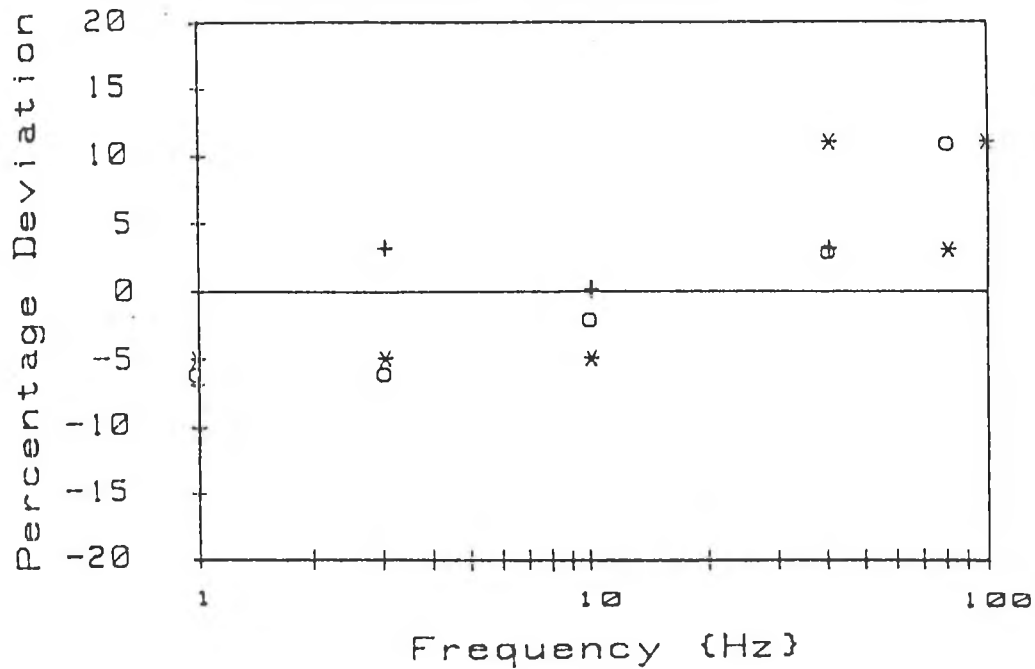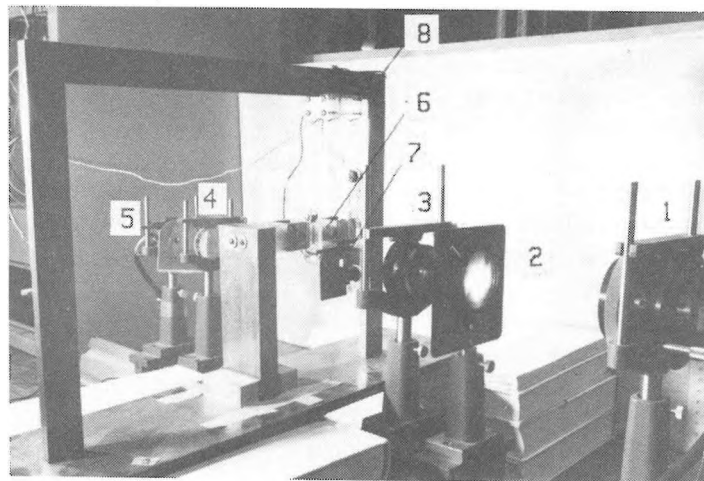
Figure 2. Frequency sensitivity of the upgraded optical system for peak absolute displacements of 1.50 mm (+), 1.00 mm (o) and 0.25 mm (*).

(1)Light source (2) iris (3) collimator (4) biconvex lens (5) photocell (6) vibrating mass (7) opening (8) fixed reference frame.

Figure 3. Measuring the absolute displacement history of a bilinear hysteretic oscillator with the upgraded system.

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the metal plate, the elements of the optical system could not be set in a single row as before. Instead, two rows were formed on each side and perpendicular to the plate's vertical component as shown in Figure 4(a). Light was transferred between the rows by employing two off-set but parallel mirrors each positioned at 45° to the plate's vertical component. Absolute deflections and phases at regularly spaced points of the plate were found with the help of a movable cardboard strip appended consecutively to each point. This arrangement may be seen in Figure 4(a) together with the stationary reference post. Reasonable agreement is shown in Figure 4(b) with the mode shape determined conventionally [4] by traversing a Bruel and Kjaer Type 4344 accelerometer across the much heavier plate.

3.3 Vibroimpact Damper

A vibroimpact damper is essentially a rigid mass (m) whose motion, upon collision, opposes and reduces that of a larger resonant mechanical system. It is important, therefore, to know the relative displacement when "tuning" the damper. This measurement was achieved straightforwardly by employing the optical system and stiff, lightweight cards fixed firmly to both the damper and an oscillator representation of a mechanical system to exaggerate their intermediate gap. Typical relative and absolute displacement measurements are presented in Figure 5 together with a schematic of a vibroimpact damper.

3.4 Multi-exposure Photography

The optical system was employed as a trigger for a 35 mm camera when photographing the progressive deformation of a pendulum impacting a rigid wall. The pendulum cut the optical system's light beam just before the collision. Then the sudden change in the electrical output of the system's photocell triggered a stroboscope. By leaving the camera's aperture open, the ensuing stroboscopic light flashes produced multi-exposed photographs around the instant of collision. Resulting photographs like that shown in Figure 6 gave a visual representation of the pendulum's deformation history.

4.CONCLUSIONS

A non-contacting optical system has been developed to accurately measure both absolute and relative displacements below 100 Hz. The system's cost depends upon the peak displacement to be measured but remains very competitive when compared with alternatives. Several typical examples have been presented to illustrate the potentially wide range of the system's applications.

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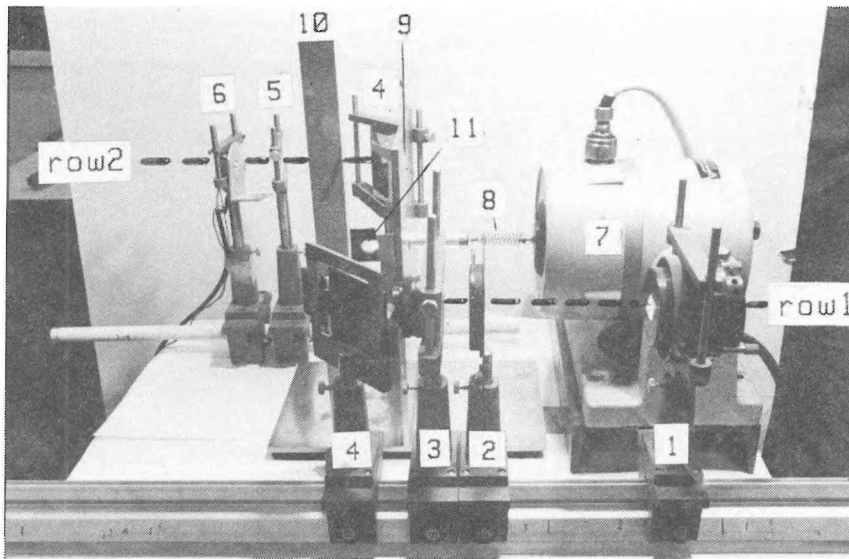
(1) Light source (2) iris (3) collimator (4) mirror (5) biconvex lens (6) photocell (7) electromagnetic shaker (8) light spring (9) inverted T-plate (10) fixed reference post (11) cardboard strip (secured to the edge of the plate).
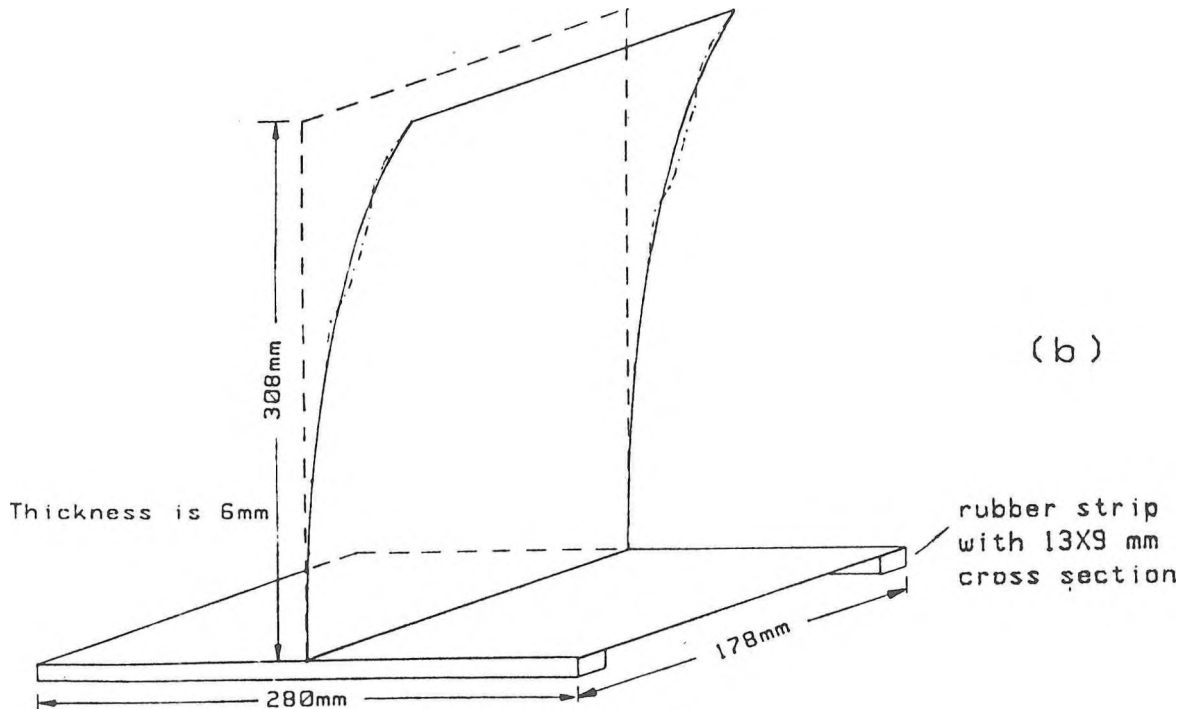
Figure 4. Modal analysis of an inverted T-plate. Illustrating (a) the two row optical set-up and (b) the comparison of the resulting fundamental mode shape (-·-·) with that determined conventionally (———). The dashed lines give the plate's undeformed configuration.
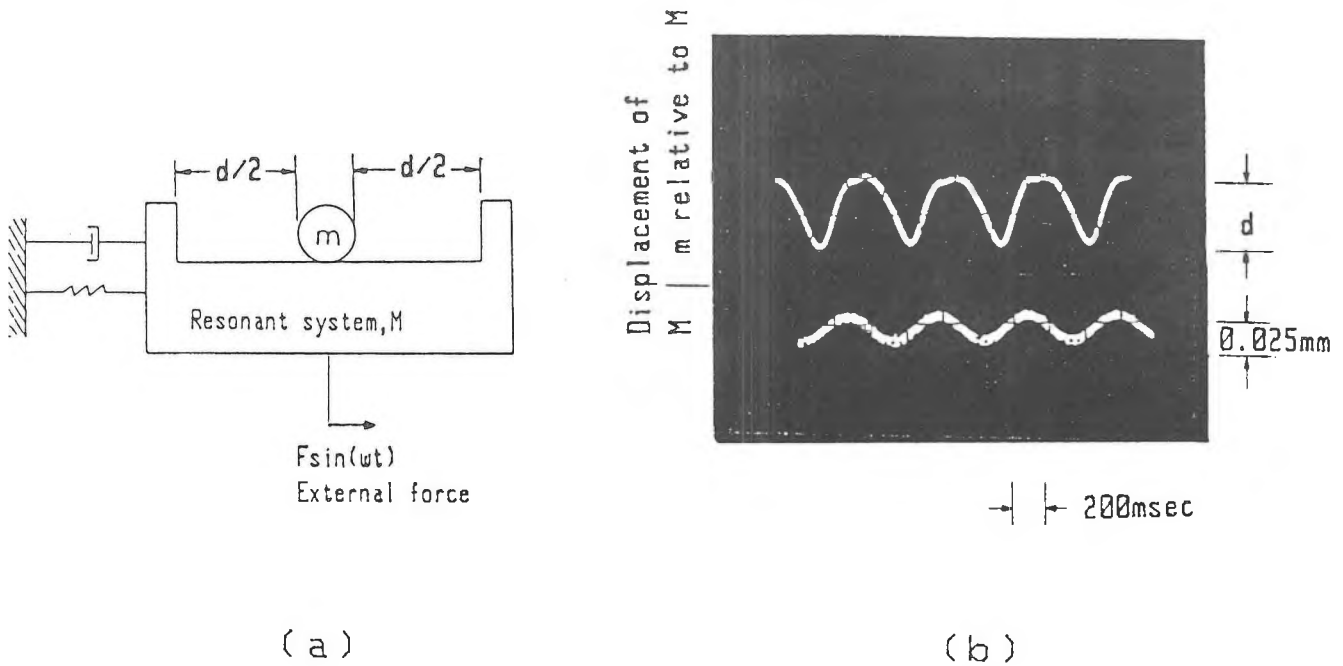
Figure 5. Showing (a) a schematic and (b) the displacement histories of the masses in a vibroimpact system.
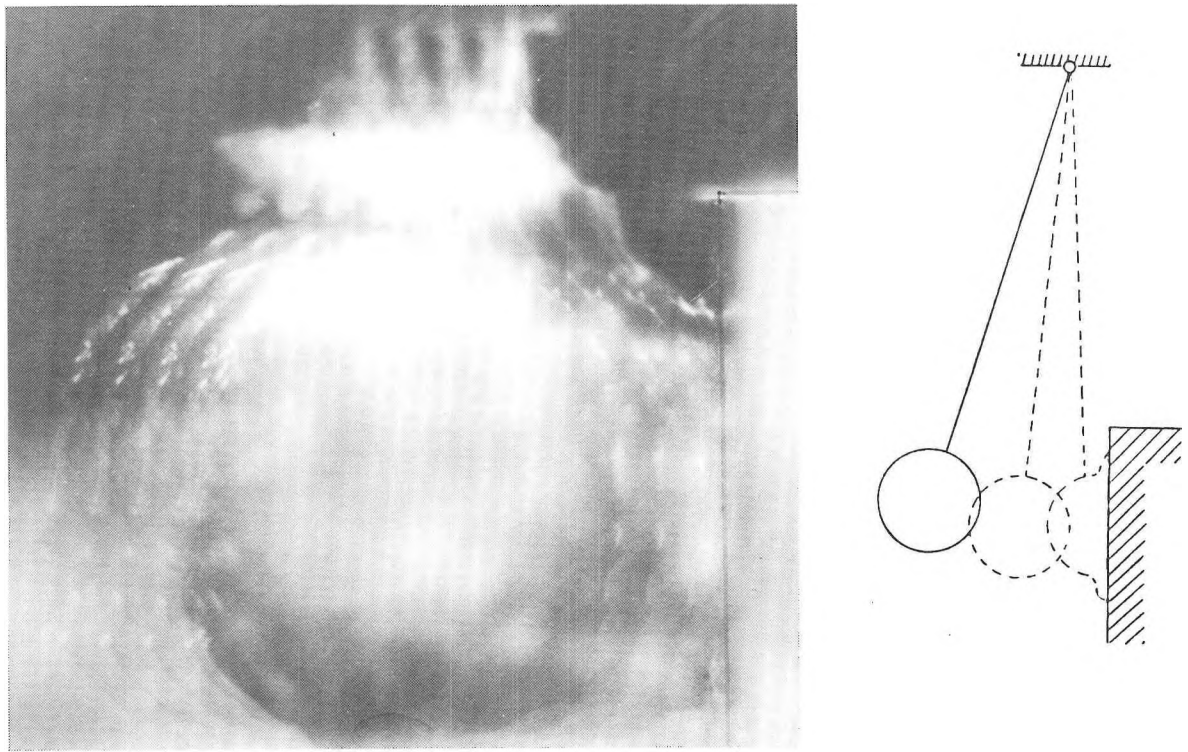

Figure 6. A multi-exposed photograph showing the deformation history of a resilient pendulum. The interval between exposures was 2.4 msec.

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5.REFERENCES

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ACKNOWLEDGEMENTS