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LASER MEASUREMENT OF TORSIONAL VIBRATION: A NEW INSTRUMENT

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INTRODUCTION

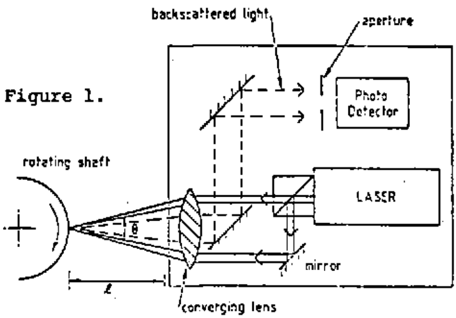
An important problem which an engineer must overcome in the design of rotating machinery components is the suppression of torsional oscillations. If incorrectly or insufficiently controlled, these produce rapid bearing wear and quickly lead to fatigue failure of the component itself. Particularly severe problems arise in engine crankshaft design, where torsional dampers are tuned to maintain oscillation at an acceptable level for specific engine speeds. Several methods, e.g. slip rings, slotted discs, are available to monitor torsional oscillation but these all require contact with the rotating member which necessitates engine 'downtime'. In many cases physical access is very limited, making their use impractical and unless great care is taken in fitting, results are often erroneous. An alternative non-contact method which overcomes some of these disadvantages is the Laser Doppler Velocimeter. A standard 'cross beam' velocimeter [1,2] has been successfully used at ISVR to study torsional damper performance and the optical geometry of this instrument is shown in Fig. 1. The beam from a small He-Ne laser is split in a conventional manner to form two beams which are focussed by a convex lens so that they intersect at the surface of the rotating shaft. Light which is scattered from this intersection region undergoes a Doppler shift (f_D) which is in linear proportion to the tangential surface velocity (U) according to

$$f_D = \frac{2\mu U}{\lambda} \sin\frac{\theta}{2} \qquad (1)$$

where θ = intersection angle, λ = laser wavelength, μ = refractive index of air. A photodetector measures this Doppler shift and a frequency tracking filter then produces a voltage analogue of surface velocity.

Although this device avoids the need for mounting slip rings or slotted discs and has a superior accuracy, dynamic range and frequency response for general engineering use, it still suffers from severe disadvantages. The velocimeter must be arranged so that the rotating surface always traverses the intersection region which is typically only a fraction of a millimeter in length. Accurate positioning is therefore required which prohibits gross radial movement, thus preventing hand-held use and presenting problems in situations of limited access. Further to this, it is desirable that the mean Doppler frequency should be within the optimum range for the subsequent electronic processing. This frequency ultimately depends on the convergence angle θ, shaft speed and diameter. Versatility of use if therefore more difficult with this optical geometry.

Figure 1.



There is a real need for a compact hand-held laser tool which is robust, safe, inexpensive, easy to use and which the engineer can simply point at the rotating surface to assess the torsional oscillation level.

THE NEW INSTRUMENT (Pat. Pend.)

Figure 2 shows a schematic diagram of the optical geometry for the new instrument. The laser beam is split into two parallel beams of separation d, which impinge on the shaft surface at points A and B. The instantaneous shaft surface velocity is V and the shaft is also oscillating radially with instantaneous velocities V_x and V_y as shown. Backscattered light from the point B undergoes a Doppler shift f_B, given by

$$f_B = \frac{2\mu}{\lambda} (V\cos\phi - V_x \sin\alpha + V_y \cos\alpha). \tag{2}$$

Similarly

$$f_A = \frac{2\mu}{\lambda} (V_y \cos\alpha - V_x \sin\alpha - V\cos\phi). \tag{3}$$

When this light is heterodyned onto the surface of the photodetector, the corresponding current output is modulated at the difference frequency f, given by

$$f = \frac{2\mu}{\lambda} V(\cos\theta + \cos\phi), \tag{4}$$

but

$$(\cos\theta + \cos\phi) = \frac{(a + b)\sin\alpha}{r},$$

where r is the shaft radius and hence

$$f = \frac{2\mu}{\lambda}\,\frac{d}{r}\,V = \frac{\pi\mu}{15\lambda}\,Nd, \qquad (5)$$

where N is shaft revolutions per minute. With this optical geometry the instrument is insensitive to radial movements of the shaft (or operator) and will only respond to variations in N, i.e. torsional oscillations. A further advantage offered is the ability to tailor the mean Doppler frequency by simply adjusting the beam separation.

The instrument will also perform successfully if the beams are simply pointed at the end of a rotating shaft and 'angled' until an appropriate Doppler frequency is achieved commensurate with shaft diameter and speed. In some practical cases this may be preferable to measuring on the shaft side (as shown in Fig. 2). However, the former does make the instrument more sensitive to axial movement and tilt due to the cosine term which is introduced into the theory. A full theoretical analysis of the instrument, including a discussion of speckle pattern effects and noise floor spectra, will be published in a later paper.

INSTRUMENT TESTING

In order to test the accuracy of the new instrument, it was necessary to establish a means of controlling known values of torsional oscillation. A small, brushless d.c. motor driven by a sinusoidal voltage achieved this purpose. When the driving frequency was varied, it was possible to achieve a dynamic range of 80 dB for torsional displacements which encompassed the range which is typically found in practice. The standard cross-beam vibrometer (Fig. 1) was used to calibrate the displacements produced. A comparison of the results from both instruments is shown in Fig. 3. Agreement to within 0.5 dB was demonstrated for the range tested.

Tests were also conducted to measure the torsional

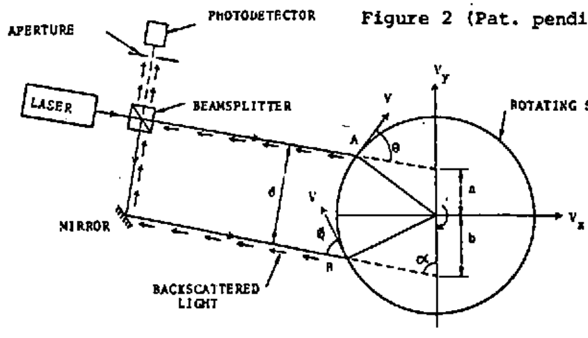


Figure 2 (Pat. pending)

displacements of the crankshaft of a six-cylinder turbocharged diesel engine. The new instrument was compared with the more traditional 'slotted disc' means of measuring torsional oscillation. The dominant order of rotation for the engine tested was the sixth and the variation in the level of this order is shown in Fig. 4. The two methods demonstrate the same trends and agreement is to within 3 dB at worst. For these results the instrument was used on the crankshaft pulley face and angled to provide a mean Doppler frequency of typically 2 MHz.

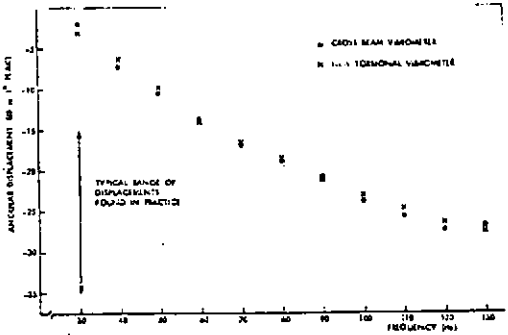


Figure 3

CONCLUSIONS

The optical geometry suggested (Patent pending) offers great potential in producing a hand-held torsional vibrometer which the operator can simply 'point' at the surface of interest. The proposed instrument will only respond to variations in rotational speed and ignore operator or shaft radial movement.

REFERENCES

[1] N.A. Halliwell, L. Pullen and J. Baker, "Laser tools for diesel engine development", The Automotive Engineer (I.Mech.E.) (to be published April 1983).

[2] N.A. Halliwell, L. Pullen and J. Baker, "Diesel Engine Health: laser diagnostics", ISVR Memorandum No. 637 (1983). Also to be presented S.A.E. Conference, Milwaukee, U.S.A. (September 1983).

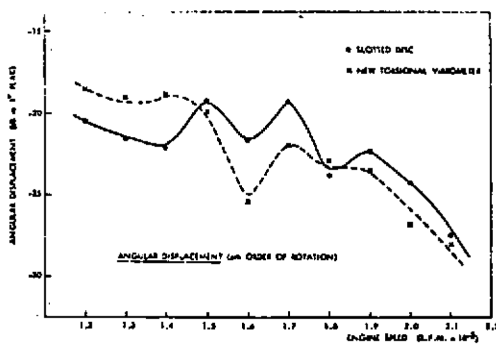


Figure 4.