A LASER POSITION-SENSING SYSTEM FOR THE STUDY OF VIBRATION SHAKER TILTING

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1. INTRODUCTION

The calibration of accelerometers requires the use of a vibration shaker to generate sinusoidal accelerations in a main axis that is precisely defined, usually perpendicular to the mounting surface for accelerometers. Ideally, there should be no acceleration in other directions. In practice, unwanted transverse motion, tilting and tumbling cannot be avoided. Such movements occur under asymmetrical loading conditions primarily at higher frequencies. The output of the accelerometer under test increases or decreases in response to these unwanted movements. This increase or decrease in output becomes a source of measurement uncertainty in accelerometer calibration. For this reason, the international standards for calibration of accelerometers, such as ISO 16063-11[1], require that the tilting be kept sufficiently small to prevent excessive effects on the calibration results. For high accuracy calibration of accelerometers, the tilt of the shaker must be determined.

Laser-based interferometers are the most commonly used tools for accurate non-contact tilt measurement [2-6]. In these systems, a laser beam is incident on a reflective surface and the tilt of this surface is measured from the interference between the reflected beam and the reference beam. These systems, however, are not applicable to the measurement of tilt of shakers as the reference point for the reference beam is the point where the shaker is either not moving (no tilt) or at its equilibrium (only available at a specific time instance). This paper proposes a modified approach for small tilt measurement using a lateral effect position-sensitive detector (PSD). A laser position-sensing system is implemented such that the tilt measurement is displayed in real time while the shaker is operating. Loading conditions can then be adjusted in real time to reduce the tilting.

2. CONCEPT

If the relative positions of three points on the mounting surface of a shaker are described by the two-dimensional orientation of a plane joining them, then tilt is the angular amount that the orientation of the plane has changed from a previous orientation (or reference orientation). A measurement system for tilt is proposed as illustrated in Fig. 1. The measurement system is modified from a Michelson interferometer with the photo-detector replaced by the PSD and the reference beam removed.

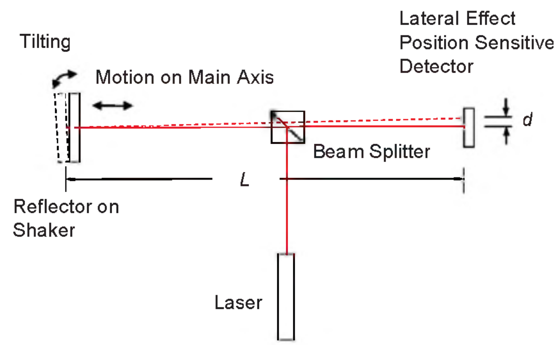

Fig. 1. Laser position sensing system for measuring angular tilt.

The angular tilt of the reflector on a shaker could be measured by measuring the displacement *d*, the shift of the returning beam on the PSD from its original position when the shaker is not moving, and the distance *L* between the reflector and the PSD. The angular tilt θ is given by $\theta = \tan^{-1}(d/L)$. However, the distance *L* is varying while the shaker is moving. This presents some difficulties in measuring the distance *L*. Furthermore, the position sensitivity of the PSD must be calibrated in measuring the displacement *d*. Therefore, it is proposed to directly calibrate the tilt sensitivity of the tilt measuring system by using a cantilever beam as a source of tilt.

3. IMPLEMENTATION

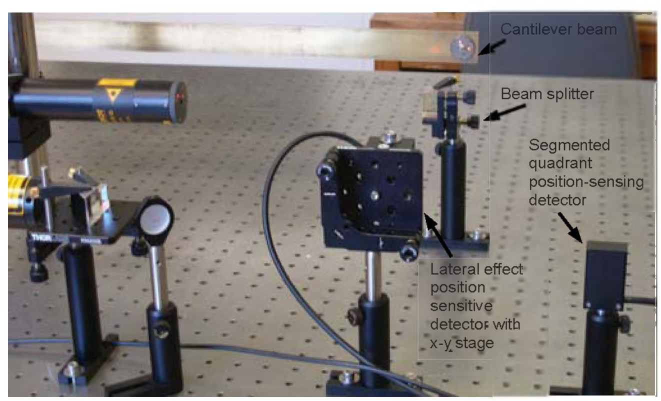

Fig.2. Calibration setup for the laser position-sensing system.

Shown in Fig. 2 is a photo of the calibration setup. The shaker is replaced by the cantilever with a mirror placed at the exact position of the shaker reflector. To ensure this positioning an additional alignment system is used as shown in Fig. 3. The position of the cantilever is adjusted such that the returning beam hits the quadrant detector in the same place as that reflected from the shaker reflector.

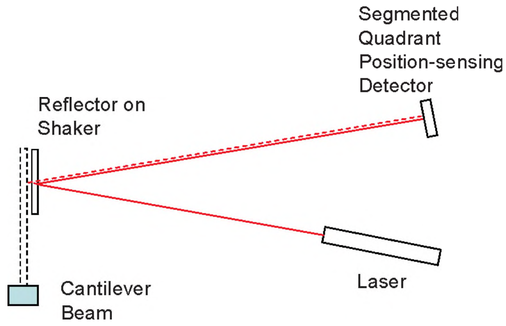

Fig. 3. System for aligning the cantilever.

Cantilevers are well-studied in literature [7]. Either the static beam equation (the Euler-Bernoulli equation) or the dynamic beam equation (the Euler-Lagrange equation) can be used to determine the deflection y of a cantilever at any position x along the cantilever. The slope of the cantilever dy/dx is the angular tilt $\theta(x)$ of the cantilever at the position x. If the static beam equation is used, the applied load can be a known force at the end of the cantilever. By changing the force applied, the desired angular tilt at the laser beam sensing point on the cantilever can be generated, which is then used to calibrate the PSD. If the dynamic beam equation is used with no transverse load on the cantilever, free harmonic vibrations can be started with a non-zero initial defection at the end of the cantilever. The acceleration at the laser beam sensing point can be measured by a calibrated accelerometer mounted at the back. Ohm et al. show that the bending (tilting) of the cantilever does not influence the main-axis (flexural) acceleration measured by the accelerometer [8]. Therefore, the tilt of the moving cantilever can be determined directly from the output of the accelerometer, the calibrated sensitivity of the accelerometer, and the physical property of the cantilever.

The laser position-sensing system is implemented using a helium-neon laser (05 STP 901, Melles Griot) operated in the intensity-stabilized mode, a 50/50 beam splitter, a lateral-effect PSD (SPOTANA-4-USB-Low, Duma), and a 24-Bit, 204.8 kS/s, 4-channel digitizer (NI PXI-1033 and NI PXI-4461, National Instruments) to measure the outputs of the PSD. The PSD has a resolution of 0.1 µm that results in a tilt resolution of 0.04 arc-second for the system if the distance L is 0.5 m. An x-y translation stage is used to align the PSD such that the mean values of the PSD outputs are close to zero. These mean values are then used to remove the bias in the output of the PSD. Fig. 4 shows the PSD outputs when the beam is freely vibrating after an initial deflection at the end of the cantilever. The x-axis output of the PSD has a typical amplitude of about 3 V which slowly decays as the vibration amplitude decays. Torsional vibration of the cantilever is observed from the y-axis output of the PSD at a level of 0.05 V. This is caused from the unbalanced loads (mirror and accelerometer) at the end of the cantilever. Better modeling for the cantilever will be considered in future [9].

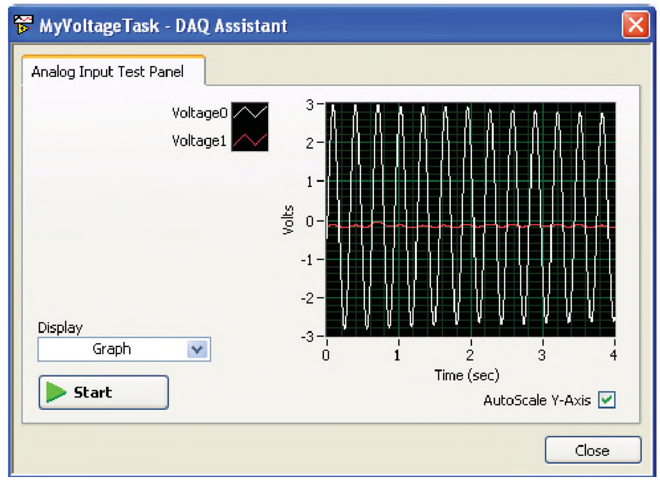

Fig. 4. PSD outputs when the cantilever is freely vibrating after an initial deflection.

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