Visualization of Vibrating Systems Using a Scanning Laser Doppler Vibrometer

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How a Vibrometer Measures Vibrations
Polytec PSV-400 Scanning Laser Vibrometer: $300,000

- A laser is directed at the object being excited.
- Doppler shift of reflected light used to obtain velocity
- Similar to laser radar used to measure speed of car: more accurate
  - Measures 20 million times/second
  - Detects displacements smaller than single atom!
- Laser scanned to many locations on surface of object to determine deflection shape

Vibrational Modes of Glass Beaker
Goal:
Measure vibrational modes of beaker used in “beaker breaker” setup.

The spout on the beaker breaks the geometric symmetry. Leads to the lowest resonance exhibiting a pair of frequencies.

Beaker had to be excited at the same location while vibrometer measurements were performed around the rim.

To achieve this the beaker and the driving speaker were placed on a rotation stage with the center of the beaker on the axis of rotation. This way the speaker rotated with the beaker always striking the beaker at the same location.

Each vibrational mode shows nodes and antinodes about 20 to 45 degrees from spout.

Organ Reed Pipe

Measurement of Sound Fields Using Vibrometer
- Vibrometer beam directed through repetitive sound field at reflective surface
- Variations in index of refraction of air cause variations of optical path length
- After measuring hundreds or thousands of scan points, can display the sound field

Ultrasound Radiation Force Excitation
When a pair of ultrasound frequencies $f_1$ and $f_2$ are incident on an object, the ultrasound radiation force goes as the square of the pressure distribution. This allows excitation of vibrations of an object at the difference frequency $f_2 - f_1$ that can be at much lower frequency, for example in the audio region.

Acoustic Pressure: $P(t) = P_1 \cos(2\pi f_1 t) + P_2 \cos(2\pi f_2 t)$
where $f_1 = f_c - \frac{f_m}{2}$ and $f_2 = f_c + \frac{f_m}{2}$

$F_{\text{Acoustic}} = \left[ \frac{P(r,t)^2}{\rho c^2} \right] d(r)dS$
P. Westervelt, JASA, 23, 312 (1951)

Component of Radiation Force at difference frequency allows “low frequency” excitation using high-frequency (700 kHz) transducers.

Combining Radiation Force Excitation with the Scanning Laser Doppler Vibrometer allows for completely non-contact modal vibration testing

Very Wide Bandwidth: Same transducer used for exciting vibration of face of classical guitar at ~100 Hz and a microcantilever with frequency > 1 MHz

Microcantilever 240 μm x 50 μm
478 kHz 2nd bending
1150 kHz torsion

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