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6. AUTHOR(S)
Yves H. Berthelot

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Georgia Institute of Tcehnology
Atlanta, GA 30332

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A laser-based system has been designed, built, tested, and used to measure non-invasively and accurately the dynamic response of microvoided visco-elastic samples in the 0.3 - 3 kHz range.

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laser Doppler interferometry, acoustic material characterization.

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FY 95 Report to the Office of Naval Research

Title: Laser Doppler Interferometry for Material Characterization

P.I: Yves H. Berthelot, associate professor of mechanical engineering
Tel (404) 894-7482 - Fax: (404) 894-7790 - e-mail: *yves.berthelot@me.gatech.edu*

Institution: Georgia Institute of Technology

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Scientific Officer: Dr. G. L. Main (Code 334)

1. Objectives and Rationale

The main objective of the research program is to develop a versatile laboratory for laser Doppler interferometric characterization of acoustic materials. It is critical to develop a reliable noncontact technique to measure accurately the dynamic response of complex materials such as microvoided polymers because standard measurements with miniature accelerometers have clearly shown the limitations imposed by such contact techniques. Optical interferometry offers the possibility of measuring acurately and noninvasively both in-plane and out-of-plane displacements at the surface of an acoustic material. The emphasis of the research is on obtaining reliable, consistent data on the linear response of soft acoustic materials. This experimental data will be used by the NRL-USRD team (headed by M. McCollum) to extract the complex frequency dependent properties of the samples. (See MIME FY95 progress report).

2. Technical Approach

A laser system dedicated to acoustic material characterization has been designed, built, and tested. It consists of 5 independent fiberoptic compact interferometers, each capable of measuring either in-plane or out-of-plane motion. The system is designed to measure the dynamic response of a sample simultaneously at 5 points in the 100 - 5000 Hz frequency range for CW excitation, (or up to 60 kHz, with transients excitation). The sample is excited by a shaker. The minimum detectable surface velocity is of the order of a few μm/s, while the maximum detectable surface velocity is in the range of a few cm/s so that, at present, the system is not designed to measure the response of very large strains occuring under shock conditions but instead in the linear regime of deformations.

The sample currently being tested is a nominally 1 in x 2 in x 3 in black polymer voided with microspheres. The location of the 5 laser probes is shown in Figure 1. At present the shaker used is a small B&K 4810 shaker.

3. Significant results

Consistency between measurements taken over several days on a given sample has been established. Figure 2 shows on the left column experimental results measured with the 5 laser probes and, on the right column, numerical predictions based on the finite element model used at NRL-USRD with material parameters estimated with the DTRC model. The quantity plotted is, on a logarithmic scale, the velocity measured at each probe normalized by the measured based velocity as a function of frequency. The base velocity is measured with an accelerometer (Kistler 8616, 0.5g). The agreement between data and model is good, considering that the B&K shaker provided uniform base motion only to within ±1 dB below 2 kHz, and ±1.5 dB below 3.5 kHz.

The consistency of the data from one day to another under nominally similar conditions is encouraging. Three sets of data were recorded over a span of 3 days and in each case the temperature was recorded at the time of measurements. The temperature fluctutated by 0.2 °C. The experimental data shown in Fig 2 shows the results of the three data sets: solid line (22.4°C), dotted line (22.5 °C), and dashed line (22.6°C). The results are very consistent, except for probe number 4, where the signal to noise ratio was very low. (Probe 4 is not an interesting point to measure and will not be used in future experiments).

4. Plans for future work

- *painting the sample*: Currently, measurements are made using small pieces of reflective tape glued to the sample at each measurement point. Instead, we will paint the sample with a thin coating of Kilz (which has been shown to give good results in other LDV experiments) and repeat the experiment reported above.
- *measurements with the Ling shaker:* Plans are being made to use the Ling shaker (from USRD) instead of the B&K shaker. The Ling shaker has a very flat response below 3.5 kHz and, unlike the B&K shaker, it provides a nominally flat piton-like motion of the base. Replacing the shaker will require some changes in the arrangement of the optical bench, but the system should be in place and operational before January 96.
- *automated data analysis*: To analyze the data in a meaningful way for the MIME project (NRL-USRD), it is necessary to automate the data acquisition system so as to collect enough data to obtain a meaningful standard deviation.
- *relative humidity*: It appears that, at least on thin samples, relative humidity is an important factor in determining acoustical properties. Relative humidity (and temperature) will be monitored during all future experiments.

- *consistency between several samples*: Consistency between measurements taken over several days on a given sample has been established. The next step is to establish whether or not measurements taken from various samples are repeatable or not. Several samples will be provided by Tracor, through Walt Madigowski.

5. Publications, Conference Presentations, and Research Dissemination

- R. L. Willis, T. S. Stone, and Y. H. Berthelot, "Acoustic material characterization by laser interferometry," 130th meeting of the Acoustical Society of America (Washington DC, November 30, 1995)
- M. Yang, J. Jarzynski, and Y. Berthelot, "The effect of surface characterization and laser beam polarization on laser Doppler vibrometry" 128th meeting of the Acoustical Society of America (Austin, TX, November 1994) J. Acoust. Soc. Am. Vol 96, No. 5, part 2, 3292 (1994).
- Y. H. Berthelot, J. Jarzynski, H. G. Kil, L. Willis, and M. Yang, "Laser interferometry for structural acoustics". (Invited paper) 129th meeting of the Acoustical Society of America (Washington DC, June 1, 1995). J. Acoust. Soc. Am. Vol 97, No. 5, part 2, 3347 (1995).
- F. Guillot, J. Jarzynski, and E. Balizer, "A fiber optic dual-beam laser Doppler vibrometer for measurement of electrostrictive and piezoactive response of thin films". 129th meeting of the Acoustical Society of America (Washington DC, June 1, 1995). J. Acoust. Soc. Am. Vol 97, No. 5, part 2, 3251 (1995).

6. Personnel

The DoD-AASERT grant is used to support graduate and undergraduate students in the area of laser interferometry for stuctural acoustics.

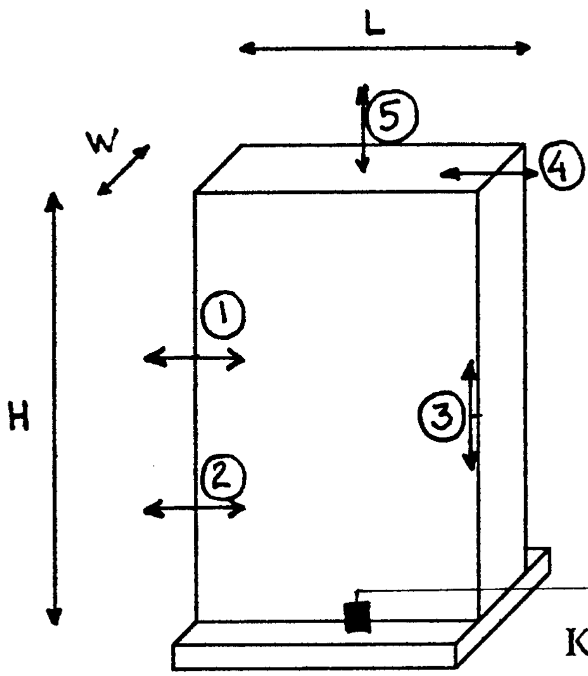
1) material characterization project
   - R. L. Willis, MS student (expected graduation Fall 1995)
   - T. S. Stone, Ph.D. student (Starting Fall 1995)
   - A. Moore, M.S. student (starting Fall 1995)
   - E. Hamilton, undergraduate (Minority student) (Fall 1995)

2) other structural acoustics projects
   - M. Yang, Ph.D. student (female) (expected graduation Winter 1996)
   - H-G. Kil, Ph.D, student (Graduated Summer 1995)
   - Faculty supervision by Professors Berthelot and Jarzynski.

EXPERIMENTAL CONFIGURATION

location of the 5 laser probes

Voided polymer
H = 2.985 in
L = 1.970 in
W= 0.991 in



Aluminum base

accelerometer
Kistler 8616 (0.5 gram, 0.2 in diam)

shaker
B&K 4810

CW: f_0 (0.1 - 5 kHz)
or transients (tone bursts)

$$\text{Measurement: } \frac{\text{rms} - \text{velocity at probe \# (optical)}}{\text{rms} - \text{velocity at base (accelerom.)}}$$

Assumption: piston-like motion of the base

Figure 1

EXPERIMENTAL RESULTS and FEM MODEL (with DTRC properties)

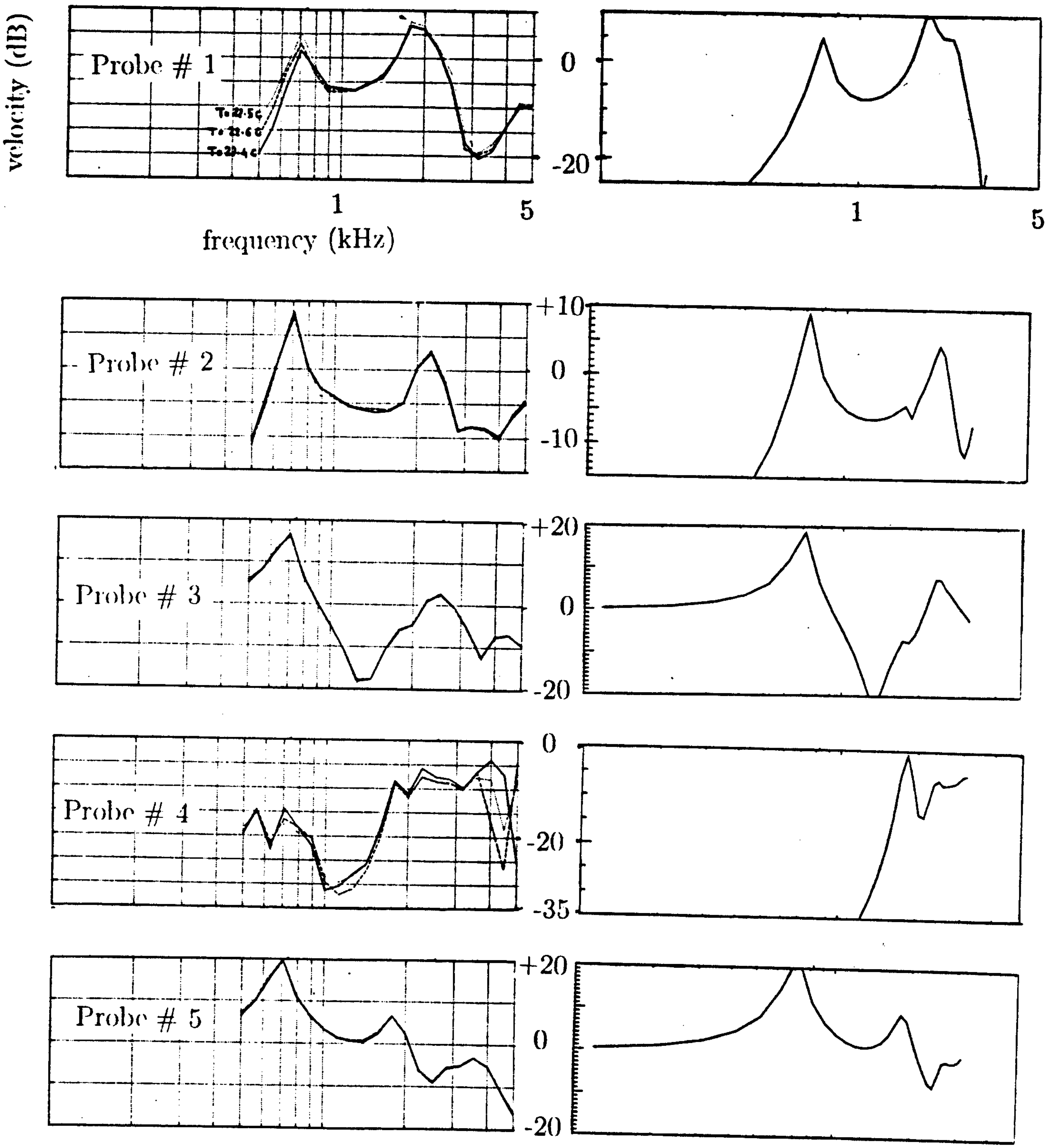


Figure 2

SYSTEM PERFORMANCE

- PLL frequency response:
  flat from DC to 63 kHz (w/o 10 kHz LP filter)

- In-plane interferometers:
  - sensitivity: 23 (μm/s) / mv
  - minimum detectable velocity:
    65 μm/s w/o averaging
    5 μm/s with 64 averages
  - maximum detectable velocity:
    35 mm/s (speckle and surface dependent)

- Out-of-plane interferometers:
  - sensitivity: 11.5 (μm/s) / mv
  - minimum detectable velocity:
    35 μm/s w/o averaging
    3.5 μm/s with 64 averages
  - maximum detectable velocity: 12 mm/s

- Probe mounting resonance: ~30 Hz