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VIBRATION MEASUREMENT OF FLEXIBLE NARROW TUBE UNDER ACOUSTIC EXCITATION

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***Abstract*— Flexible narrow tubes are used in periodic structures to develop mechanical vibration filters. These structures have very thin walls and measuring modal parameters is quite challenge using electromagnetic excitation methods. This study discusses the acoustic source as vibration excitation to a flexible tube. A test setup is developed by modifying impedance tube and measured vibration response using laser vibrometer.**

Keywords—Narrow tube; laser vibrometer; impedance tube; free-free boundary condition

I. Introduction

Flexible narrow tube structures are used in mechanical filter elements and are sensitive to their shape, size, boundary conditions, loading conditions, and environmental conditions. The measurement of vibration displacement or velocity of such structures is quite challenging. Mehmet Avcar [1] studied the free vibration analysis of square aluminium beam under different geometric characteristics and boundary conditions. The author concluded that, the natural frequency of flexible structures changes with a small change in either geometry or boundary condition. Dynamic characteristics such as modal parameters of these structures to be measured under a controlled environment.

The current study is focused on measuring the vibration of a polypropylene straw sample under external excitations. The considered test sample has inner diameter 10 mm, length 40 mm and thickness of 0.1 mm as shown in Fig. 1.

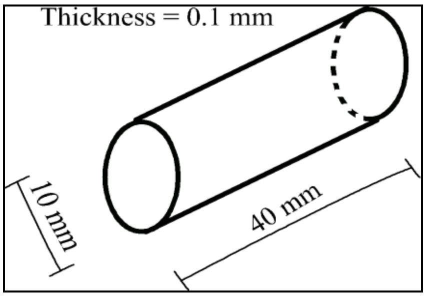

Fig. 1: Dimensions of straw sample

The typical material properties of a prescribed straw sample are as shown in Table 1.

Table 1: Material Properties of Straw

Material	Density(kg/m^3)	Young's modulus (GPa)	Poisson's ratio
Polypropylene	1200	1.15	0.4

Previous studies reported that [P. Castellini et. al. [2]] contact type excitations like a hammer is suitable for rigid structures and may not be suitable for flexible structures. Therefore in this study, the external excitation was used as an acoustic sound source from impedance tube [5] in the interested frequency range. Surface vibrations occur in straw due to excitations are difficult to capture by using contact type sensors such as an accelerometer because it changes the dynamics of the system due higher sensor to system weight. To overcome this difficulty, laser vibrometer was used, which is a non-contact type vibration sensor based on a concept of Laser Doppler Vibrometry [3]. Thus, the vibrations of flexible straw were measured by using non-contact type laser vibrometer under acoustic excitations using impedance tube.

II. Vibration Measurement by Experimental Setup

Impedance tube is a tube-like structure with a speaker at one end to generate the sound. An input was given in the form of a wave such as periodic random noise or sweep sine waves at a particular frequency range and signal gain using function generator. This input was processed in a data acquisition system and sent to the signal generator. A signal generator connected to a speaker in the impedance tube to generate the specified sound type. A four microphone channel impedance tube having inner diameter 100 mm. and excitation frequency range of 63 Hz to 1600 Hz was used to provide acoustic excitation to the straw sample [4].

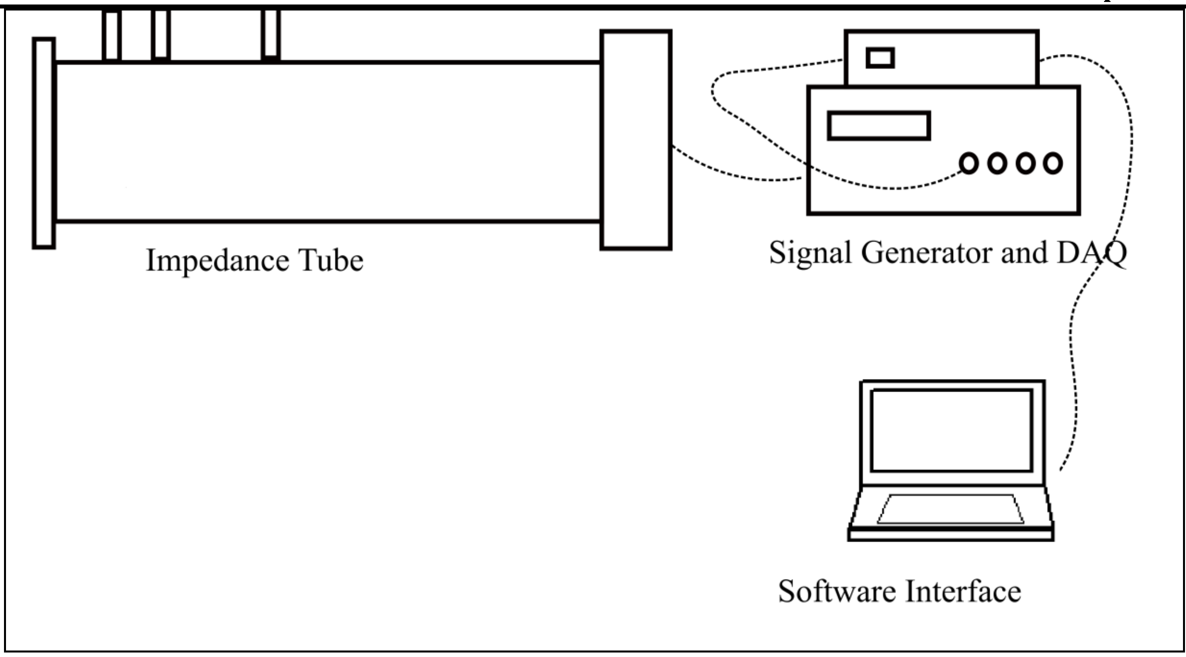

Fig. 2: Schematic diagram of impedance tube setup

Laser vibrometer setup was used to measure the surface vibration velocity in a non-contact mode using Laser Doppler Vibrometry as shown in Fig. 3. A setup of laser vibrometer consists of a laser gun, laser controller, data acquisition system, a software interface to record the vibration data for a particular time period and to get the vibration response in terms of vibration velocity [3].

A laser vibrometer is generally a two-beam laser interferometer that measures the frequency or phase difference between an internal reference beam and a test beam. The test beam is directed to the target, and scattered light from the target is collected and interfered with the reference beam on a photo-detector. This vibrometer works in a heterodyne regime by adding a known frequency shift to one of the beams. This frequency shift is usually generated by a Bragg cell.

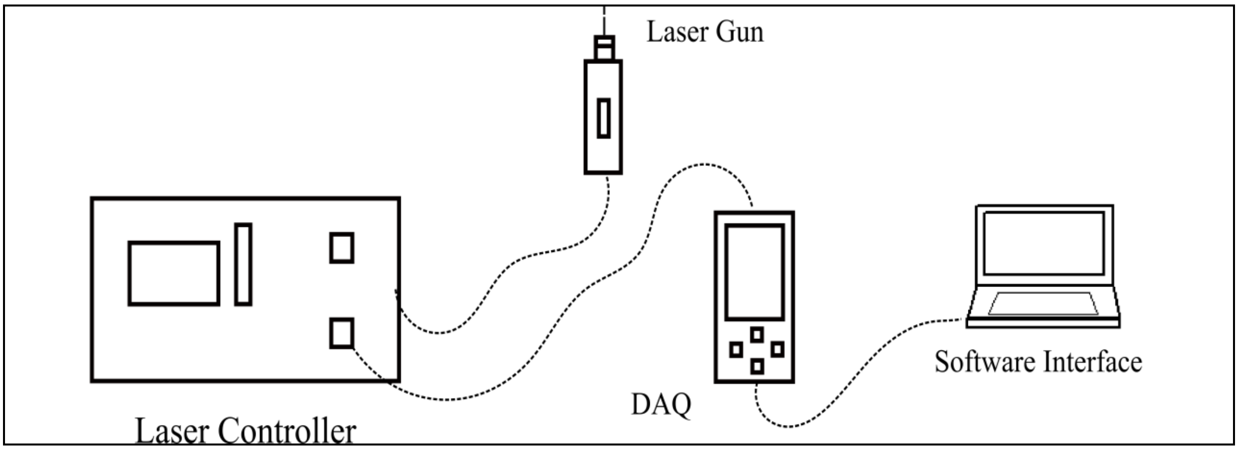

Fig. 3: Schematic diagram of laser vibrometer setup

Before proceeding for measuring a precise calibration of Laser vibrometer was carried out with the use of single frequency handheld shaker. The frequency generated by the hand-held shaker was 1g rms at 159.2 Hz. The Fig. 4 shows a laser beam which was focused on handheld shaker and vibrations are measured to calibrate laser. The frequency generated by hand-held shaker exactly matches with the frequency response measured by a laser vibrometer, as shown in Fig. 5 and confirms the calibration of a laser vibrometer.

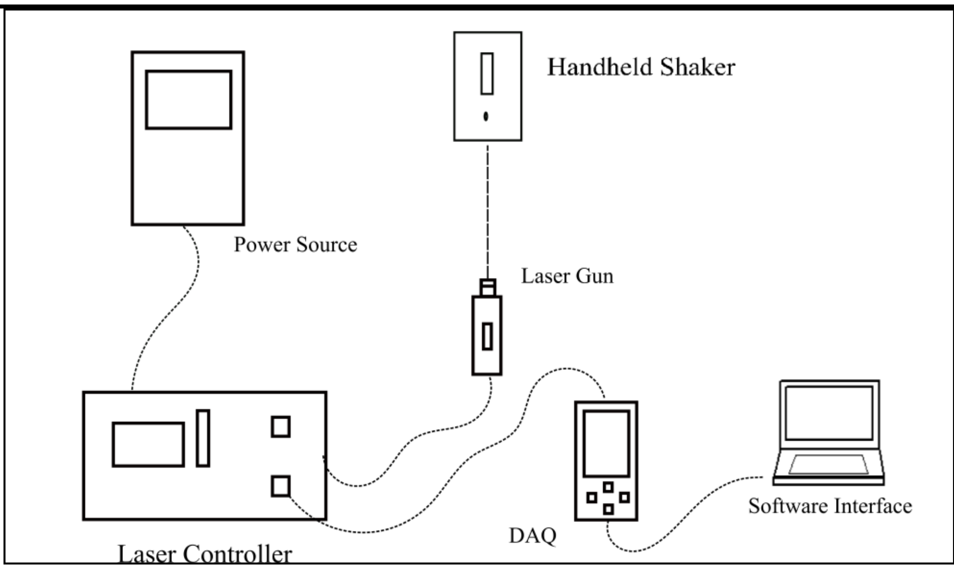

Fig. 4: Schematic diagram of laser vibrometer calibration setup

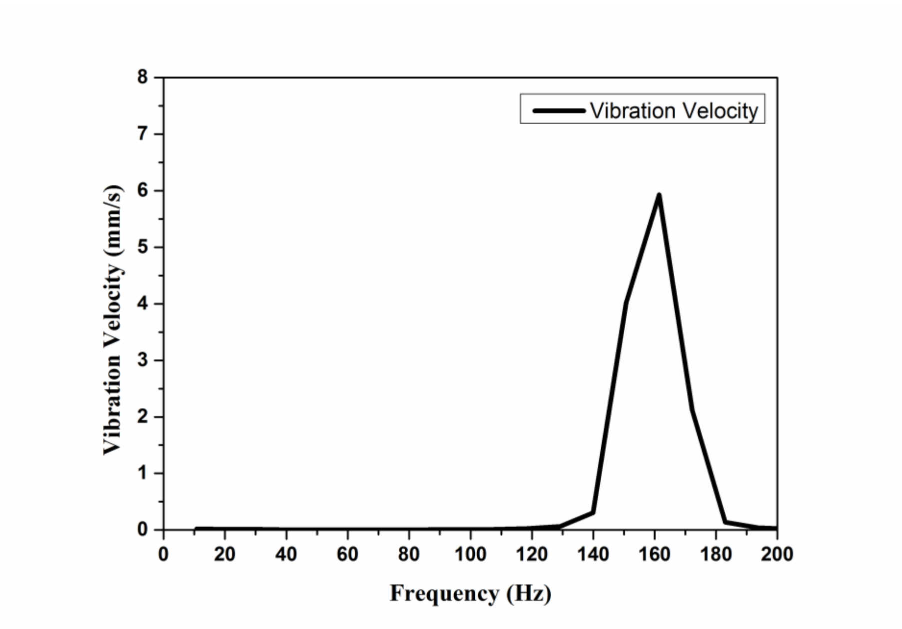

Fig. 5: Vibration measurement on shaker using laser vibrometer

The experimental setup consists of a laser vibrometer which captures the surface vibrations on any small area of straw sample, an impedance tube to provide the non-contact type excitations (sound waves) to the straw sample, sample holder to hold a straw as a free-free boundary condition, data acquisition system, a signal generator to generate the signal of specified wave type with corresponding frequency range, and the software interface to extract the vibration data in the form of velocity.

A straw sample was hanged with thin threads to straw-holder at its two ends to establish free-free boundary conditions. The mounting arrangement schematic diagram is shown in Fig. 6. A special care is taken to avoid the influence of supporting system on straw natural frequencies. The mass of used thread was negligible compared to the mass of straw. The laser vibrometer used produces a visible red beam and has maximum velocity range above 0.5 m/s and minimum resolution less than 0.05 microns/sec [5, 6]. A laser vibrometer of 5 mm/s/V was used to sense the surface vibrations in the form of velocity, because the straw vibrations with acoustic excitations are very less and that need to be sensed with high accuracy. To sense the vibrations the vibrating material should reflect light. As a straw sample is made of polypropylene which is non-reflective, a reflective sticker was used on straw where the vibration measurement needs to be carried out.

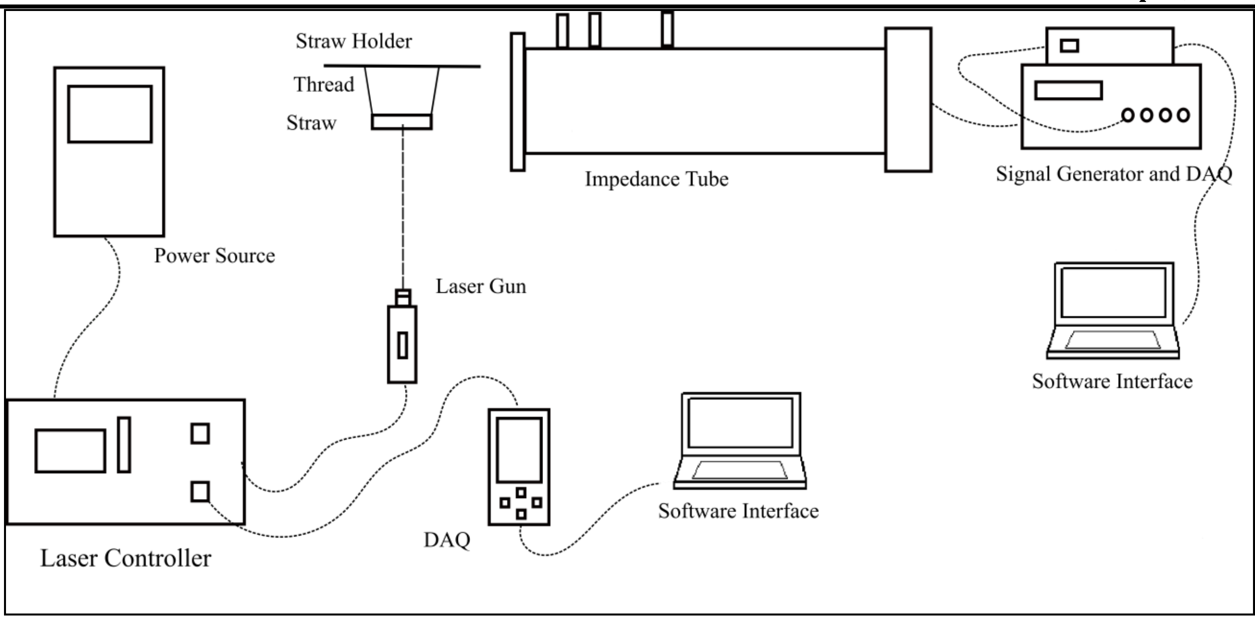

Fig. 6: Schematic diagram of the experimental setup

III. Results and Discussion

The measurement was carried out for a single straw sample as shown in Fig.1. The sound waves were provided as excitations from impedance tube in the form of periodic random noise to vibrate the straw. While carrying out the measurement, the distance of approximately 1 meter was maintained between laser gun and the straw sample was. The measurement was recorded for approximately 10 seconds and the recorded data was extracted in the form of vibration velocity in mm/s corresponding to excitation frequency in Hz. The Fig. 7 shows the vibration response of straw sample over corresponding excitation frequency.

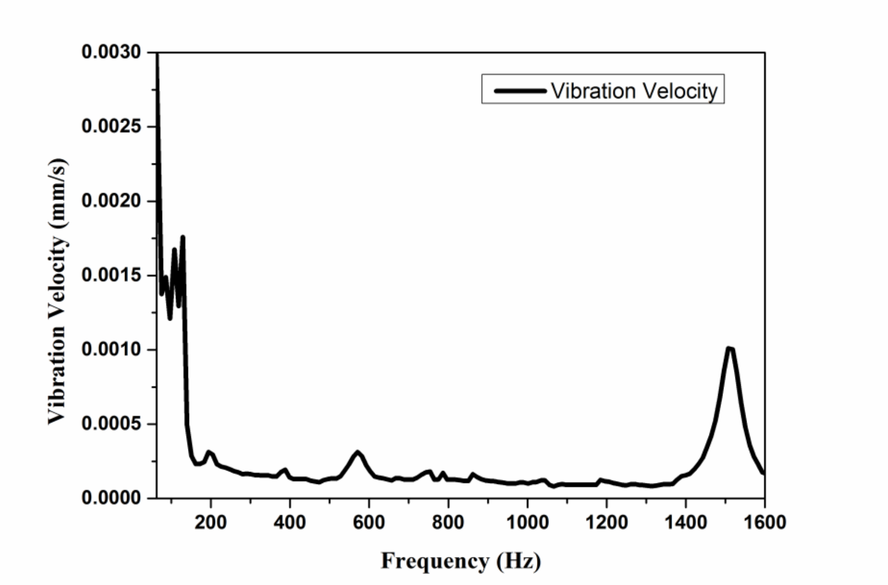

Fig. 7: Vibration velocity (mm/s) spectrum on the straw sample under periodic random noise excitation

The frequency range considered measurement was 63 Hz to 1600 Hz which is plane wave excitation range of impedance tube, the measured amplitude of vibration velocity ranges from 0.0001 mm/s to 0.003 mm/s, as shown in Fig. 7.

Table 2 shows the occurred peak frequencies in the measurements

No.	Peak frequencies observed (Hz)
1st	581.39
2nd	1528.85

TABLE 2: PEAK FREQUENCIES IN MEASURED STRAW VIBRATION VELOCITY SPECTRUM

As, the amplitude of vibration velocity is in the order of 10^{-4} mm/s, the precaution to be taken that the room must be silent in which vibration measurement is carried out and other nearby equipment vibrations should not vibrate the straw sample.

Thus, this study describes the measurement procedure of flexible straw sample, the challenges involved in the measurements and the selection and use of non-contact type sensors. The method presented in this study can be applied to measure the vibration characteristics of thin structures like mechanical filters and thin membranes of acoustic metamaterials under external excitations where traditional contact type sensors may not be feasible to use.

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