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THE LENGTH OF FLEXIBLE COILED TUBES MEASURED BY USING A SOUND CARD AND FRF

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Abstract: In the paper a procedure to assess, at low cost, the length of various coiled tubes by using standing waves is presented. The air in the tube is excited by using a speaker and random signal in the frequency band of interest. The pressure is measured at both tube ends by using a two input channels sound card, in order to evaluate the frequency response function (FRF). From the peaks of the frequency response function (magnitude), the frequency values of the standing waves generated in the tube are identified and the length of the tube is evaluated. The acquisition system and the calculations are managed by a Labview application. Corrections can be applied in order to obtain better results.

Keywords: *flexible tubes, standing waves, sound card, frequency response function, Labview.*

1. INTRODUCTION

The interior of the flexible tubes under observation in this article is occupied by the air at the ambient pressure and temperature. The target is the measurement of the length of various tubes which often is a time consuming activity during the production and sale. The tubes are of various diameters. Compression sound waves can propagate inside the tube. Air tube resonance is to be considered to measure the tube length. In a previous article [6] the procedure of finding the length of such tubes has been presented; the acquisition system set-up is shown in Figure 1. In the present approach the same procedure is followed but slightly different set up and low cost instrumentation is used.

For the first air standing longitudinal wave in the tube with open ends, a displacement node at the middle of the tube is found and antinodes at both ends. For the pressure variation along the tube the nodes are at both ends and an antinode or a peak of pressure is located at the middle of the tube [4, 6]. Equation (1) states the relation between the tube length and the wavelength of the first harmonic for a tube with both open ends:

$$L = \lambda_1 / 2 \tag{1}$$

For the n-th harmonics the relation (2) is valid:

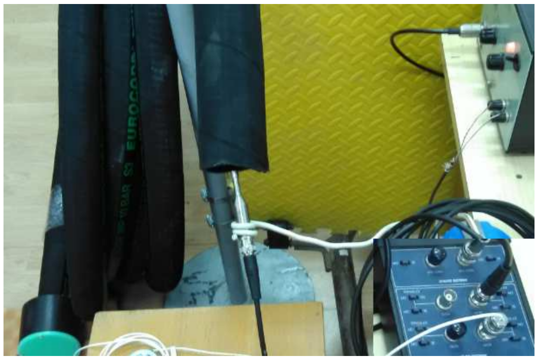

Fig. 1. Set up with NI dynamic acquisition board simultaneous sample on channels

$$L = n\lambda_n / 2 \tag{2}$$

In a time second the sound of frequency f counts c/f wavelengths, hence:

$$c = f\lambda \tag{3}$$

Because the measured frequency response function (FRF) has peaks at equally distant frequency lines, the frequency of the n-th harmonics can participate to the tube length (L) calculation as follows:

$$L = \frac{nc}{2f_n} \tag{4}$$

A typical measured FRF with many peaks in a large frequency band is depicted in Figure 2. A zoom with a reduced number of peaks is shown in the figure, too.

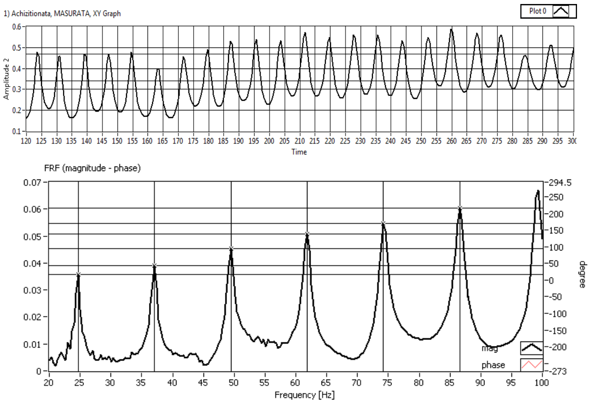

Fig. 2. Typical FRFs - large and narrow frequency bands; magnitude vs. frequency

Several corrections has to be considered in order to improve the precision of the measured tube length. One is the end correction caused by the fact that the air movement exceed both tube ends like in a Helmholtz oscillator [1], [3]. The speed of the air in a tube is slightly influenced by the tube diameter [1]. The fact that the tube is curve and has many turns, has to be considered too.

Attention has to be paid to the sound wavelength used to excite the air in the tube. The wavelength is important to be long compared to the diameter of the tube. Hence, the wave propagates along the axis of the tube and the one dimension approximation for the sound propagation is acceptable.

A computer acquisition system was used to generate the signal for the speaker followed by a sound amplifier. To acquire the sound at one tube end where the speaker is present a microphone is required. A second microphone is used to measure the pressure at the opposite end of the tube under observation. Hence, an output channel and two input channels are needed. The acquisition system was based on the National Instruments dynamic acquisition board PCI 4451 with simultaneous sampling on the input channels [2-5]. A swept sine wave excitation signal it was employed. The frequency of the signal is increased in steps covering the frequency band of interest roughly from 50Hz to 500Hz. An accelerometer on the speaker can be used to assess the input sound wave. In most of the cases, the microphone is used to acquire the sound pressure generated by the speaker in order to excite the column of air filling the tube.

2. THE MEASURING SYSTEM SET-UP WITH THE SOUND CARD

At the present experiment, an external Steinberg UR22 mkII sound card is attached to the laptop by USB connection. At the two channels of the sound card two Behringer B-5 condenser microphones (omni directional/ cardioid exchangeable capsules, 48V supply voltage, 20 Hz - 20 kHz frequency response), are connected. A speaker will generate the excitation sound using a MT Swissonic SA33 mixer amplifier and connected to the sound card, as well. One of the microphone is placed in front of the speaker in order to record the sound pressure variation at one of the ends of the tube, like in figure 3. At the other end of the tube the second microphone is recording the sound pressure. The acquisition system, the tube and the setup of the rest of the components are depicted in figure 4.

Fig. 3. The speaker and one microphone

The excitation signal feeding the speaker can be selected from the following list: Uniform white noise (Uwn), Gaussian white noise (Gwn) and Periodic random noise (Prn).

The sound generation on the speaker, the sound pressure measurement at two channels and the signal processing in order to calculate the frequency response function (FRF) is managed by a Labview application written for that purpose. The measured FRF presents the harmonics of the fundamental sound generated by the tube or standing waves of the tube with both open ends.

Fig. 4. Set-up with two channels USB sound card and sound amplifier

Standing waves in real tubes involve a movement of the air that exceed the ends of the tube at both sides. This aspect is causing an error in the wavelength estimation in comparison with the ideal tubes. For the open-open tubes two end corrections have to be applied, while for open-closed tubes only one end correction is needed. The pressure node at each end (for the fundamental mode) is a little bit out of the end of the tube by an amount of about:

$$\text{added length} = 0.6 \cdot \text{tube radius} \qquad (5)$$

This gives the impression the tube is longer.

The velocity of sound in open air is depending on the temperature:

$$c_{oe} = 331\text{m/s} + (0.6\text{m/(sC}^{o}))\cdot T \qquad (6)$$

where T is the temperature in Celsius degrees.

The speed of sound in cylindrical tubes is obeying to the following relation [1]:

$$v = c\left(1 - \frac{\sqrt{\eta}}{D\sqrt{\pi f}}\right) \qquad (7)$$

where c is the sound speed in open air, η is the viscosity coefficient of air filling the tube (at the environmental temperature), f is the frequency of the observed sound, D is the tube diameter. The speed of sound in tubes is decreasing as the tube diameter is smaller.

3. THE LABVIEW APPLICATION

Built-in functions are used for the preparation of sound generation (Sound output configure.vi) and sound acquisition (Sound input configure.vi) [7]. The type of random excitation signal can be chosen, as well. Sound format and Number of samples/channel for both configuration functions are correlated with the Sampling Info of the Noise waveform.vi [7] in order to have a proper frequency interval for the excitation noise. After the configuration is done a while loop is ensuring the sound write of the selected random signal and sound read. The sound output volume can be adjusted. The SVFA Frequency Response (Mag-Phase).vi function (Fig. 5) is ensuring the generation of the averaged frequency response function (version H1) with the averaging parameters and the windowing type selected by the operator in the front panel of the application. The averaging process can be delayed by specifying a number of loops to be done before the averaging starts in order the speaker and the

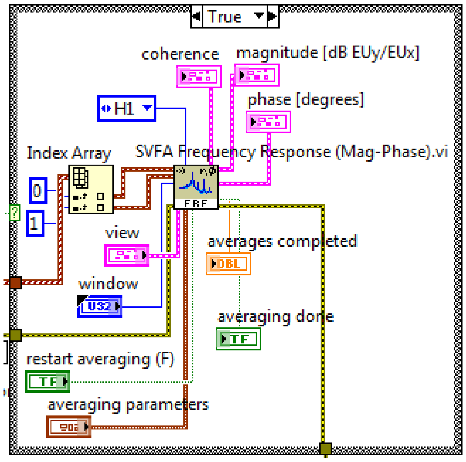

Fig. 5. The Labview FRF function

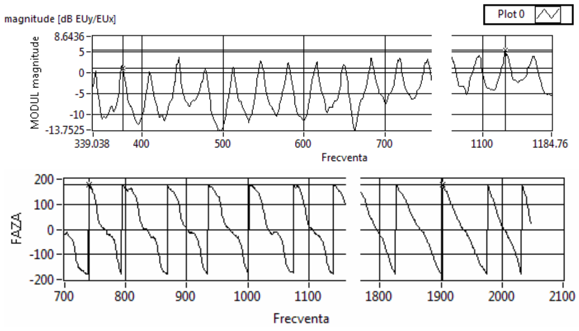

Fig. 6. Typical FRF magnitude and phase

microphones to function properly. In case an unexpected sound event is happening, the restart averaging button is pushed. The sound signals acquired and packed into 1D array of waveforms are separated representing the stimulus channel and response channel and feed into the SVFA Frequency Response.vi function. On the front panel the magnitude and phase of the FRF are graphed. The coherence function is displayed in order to appreciate the quality of the measured FRF. When the averages entirely done the FRF graph is not changing any more on the front panel but the generation and the recording of the sound is continuing. In case a new measurement is desired the restart averaging button has to be pushed. Once the averaged FRF graph is on the screen the two cursors of the graph allow to read the frequencies of the first and the last chosen peaks of the FRF (Fig. 6) placed in the frequency band where the Coherence function is closed to one. The mean frequency span between two adjacent peaks is resulted and used in relation (4) for n=1. Hence, the tube length L is evaluated.

4. CONCLUSIONS

A method to assess the length of various coiled flexible tubes by using standing waves and a two channels USB connection sound card is presented. The air in the tube is excited at one open end by using a speaker and random excitation signal. The averaged frequency response function is measured quicker compared to the sinusoidal case. The pressure is recorded by using two microphones, one at each tube end, in order to identify the standing waves generated along the tube length. From several adjacent peaks of the transfer function the length of various tested tubes are assessed by observing a mean span between peaks. In order to get better results a couple corrections has to be applied.

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Măsurarea lungimii unor tuburi flexibile folosind funcţii de transfer şi placa de sunet

Rezumat: *In articol este prezentată o metodă de evaluare prin experiment şi măsurarea lungimii unor tuburi lungi de diametre diverse aflate adunate la diferite raze de înfăsurare. Aerul din tub este excitat printr-un difuzor extern folosind semnal aleator pentru excitarea modurilor acustice. Sistemul de achizitie folosit este la cost redus format dintr-o placă de sunet externă, două microfoane şi un amplificator pentru difuzor. Presiunea la ambele capete ale tubului este măsurată simultan. Din vârfurile funcţiei de răspuns în frecvenţă (FRF) măsurate între capete sunt puse in evidenţă frecvenţele la care se formează unde staţionare în tub. Aplicaţia pentru achiziţia de semnale de la microfoane, generarea de semnal aleator la difuzor şi calculul FRF mediată a fost scrisă în Labview.*

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