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THE LENGTH OF FLEXIBLE COILED TUBES BY OBSERVING THE SOUND PROPAGATION TIME

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Abstract: A procedure to assess the length of coiled tubes by using the time of sound propagation along the tube, is presented. At one end of the tube a sine wave is generate using a speaker. The sine wave is recorded at both tube ends by using two microphones connected to the input channels of the acquisition system, in order to evaluate the time delay between the two waves. The acquisition system and the calculation of the tube length are managed by a Labview application. The sound speed in the tube is observed in function of the frequency and the tube diameter.
Keywords: *flexible tubes, sound velocity in tube, LabView.*

1. INTRODUCTION

The measurement of the length of various flexible tubes or hoses filled by air at the ambient pressure and temperature is under observation. The tubes are of various diameters. Compression sound waves can propagate inside the tube. The time propagation through the tube of a short wave of constant frequency generated by a speaker is measured and used to assess the tube length. In previous articles [6], [7] the procedure of finding the length of such tubes by using standing waves, has been presented. For the first air standing longitudinal wave in the tube with open ends, a displacement node at the middle of the tube is present 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:

$$L = \lambda_1 / 2 \qquad (1)$$

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

$$L = n\lambda_n / 2 \qquad (2)$$

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:

$$L = nc/(2 f_n) \qquad (3)$$

A typical measured FRF with many peaks in a large frequency band is depicted in figure 1.

A computer acquisition system has been 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

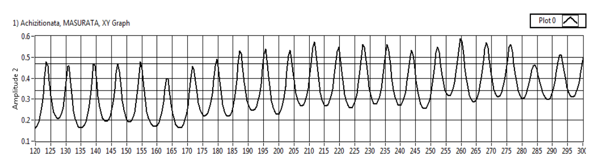

Fig. 1. Typical FRFs, magnitude vs. frequency

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, depicted in figure 2, 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 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.

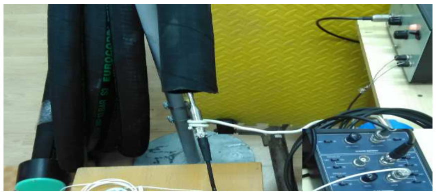

Fig. 2. Set-up with NI dynamic

In a less expensive version, a second acquisition system based on an external sound board shown in figure 3, was used as an alternative setup.

Several corrections have to be considered in order to improve the precision of the measured tube length. One is the end correction

Fig. 3. Set-up with two channels USB

Fig. 4. Speaker, microphone and the tube

caused by the fact that the air movement exceeds both tube ends like in a Helmholtz oscillator [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.

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

In the present approach a different procedure is observed, and the acquisition system can be either one employed in the previous work.

2. THE MEASURING SYSTEM SET-UP

At the present experiment, either hardware, the one with PCI 4451 acquisition board or the external sound card, can be used. The external Steinberg UR22 mkII sound card was attached to the laptop by USB connection. At the two channels of the sound card two Behringer B-5 condenser microphones (omni directional 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 4. At the other end of the tube the second microphone is recording the sound pressure.

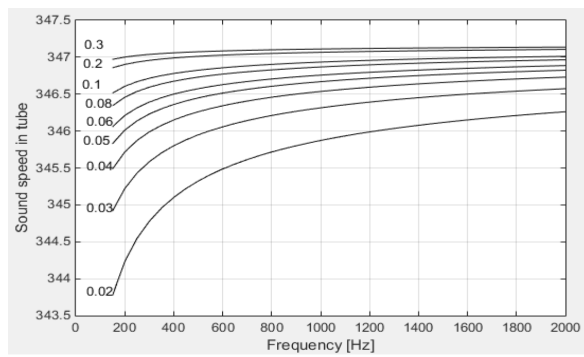

Fig. 5. Sound speed vs. frequency and D

The acquisition system, the tube and the setup of the rest of the components is similar to that depicted in figure 3.

The excitation signal entering in the speaker can be selected between Sine waveform, Square waveform or other periodic waveforms. The sine waveform is preferred.

Short time tone generation on the speaker, the sound pressure measurement at two channels and the signal processing in order to graph the sound measured at the tube ends are managed by a Labview application written for that purpose.

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

$$c_{oe} = 331 + 0.6 \cdot T \ \ [\mathrm{m/s}] \qquad (4)$$

where T is the temperature in Celsius degrees.

The speed of sound in cylindrical tubes is observing the relation (5) [1]:

$$v = c(1 - \frac{\sqrt{\eta}}{D\sqrt{\pi f}}) \quad (5)$$

where c is the sound speed in open air (environmental temperature), η is the viscosity coefficient of air filling the tube (at the environmental temperature), f is the frequency of the observed sound and D is the tube diameter. The speed of sound in tubes is decreasing as the tube diameter is smaller for the same sound frequency. Similarly, for a constant tube diameter the speed of sound is decreasing with the reduction of the sound frequency (Fig. 5).

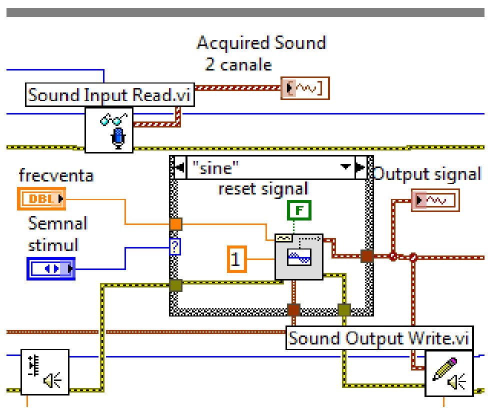

Fig. 6. Labview application - detail

3. THE LABVIEW APPLICATION

For sound generation the built-in function Sound Output Configure.vi is applied, while for the sound acquisition the built-in function Sound Input Configure.vi [7]. The type of excitation signal can be chosen by selecting the proper waveform. Sound format and Number of samples/channel for both configuration functions are correlated with the Sampling Info of the Noise waveform.vi [8]. A while loop is ensuring the sound write of the selected periodic signal and the record and graph of the sound at both ends, to take place periodically. The frequency, volume and the number of samples of the short excitation signal can be adjusted interactively (Fig. 6).

The pressure is recorded by using two microphones, one for each tube end, in order to graph the two signals in time domain and to observe the delay of the propagated through the tube waveform with respect to the excitation waveform. Proper correlations for sound velocity in function of the ambient temperature, the frequency of the excitation waveform and the tube diameter observing relation (5), has to be done (Fig. 5). Correlations between the sound format of the Sound Output Configure.vi, the *sampling info* entrance of the Sine waveform.vi (which is the input data for the Sound Output Write.vi), are observed. In the same manner the sound format entrance of the Sound Input Configure.vi is correlated with the Sound Input Read.vi in order to graph the two waveforms (1D array of waveforms).

In the sequel, sine waveforms of selectable frequencies are generated at one tube end. The first tube is 5 m long and the diameter is 0.03m (Fig. 3). On the same graph window, the records from the two microphones are shifted in time.

A first sine waveform of 400 Hz having an acceptable number of cycles and the associated

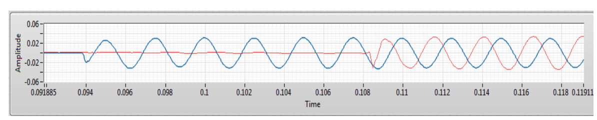

Fig. 7. Waveform delay, 400 Hz

number of samples of the signal, is generated. The signal (red color) traveling through the tube is delayed with respect to the one recorded close to the speaker (Fig. 7). Roughly we count 5.75 cycles, hence L=5.75·λ resulting about 4.98 meters for the tube length (L), where λ=c/f and c=347 m/s at the ambient temperature. The experiment is repeated for sine waveforms of 500Hz, 600Hz, 700Hz and so forth up to 3 kHz.

For f=700Hz the graph is shown in figure 8, resulting the delay of about ten cycles (10*347/ 700=4.95 [m]).

For higher frequencies it is easier to take directly the time difference of the two cursors

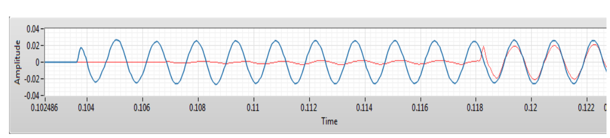

Fig. 8. Waveform delay, 700 Hz

pointing the first sine peaks of the two signals, like in figure 9 (0.11605-0.10158)*347, where the sound frequency is of 2000 Hz. Changing the excitation frequency, the time delay of the recorded sounds is almost the same. In figure

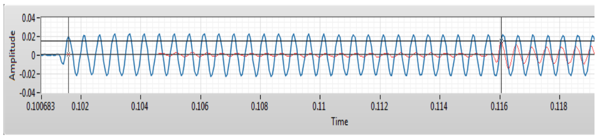

Fig. 9. Waveforms delay, 2000 Hz

10 the frequency of the signal is 4 kHz.

Shorter sine waves of about 7 cycles (300

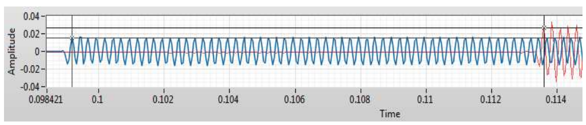

Fig. 10. Waveform delay, 4 kHz

samples) at various frequencies can be used.

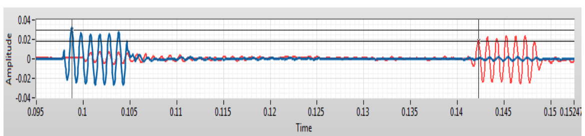

Fig. 11. Short waveform, 1.kHz, L=15m

For a longer tube of 15m length, such a short sine wave of 1kHz frequency is graphed in figure 11. The measured delay of the two signals is 0.14226-0.09882 resulting L=15.04m for a sound speed of 346.3 m/s.

An alternate approach can use the correlation of the two records to find the delay time of the through tube traveling wave.

4. CONCLUSIONS

A method to assess the length of various coiled flexible tubes by using the time of sound propagation along the tube, is presented. At one end of the tube a short sine wave is generated which is traveling all along the tube length. The sine wave is recorded at both tube ends by using two microphones connected to the input channels of the acquisition system, in order to evaluate the time delay between the two waves and resulting the tube length. The tube diameter and the sound frequency is influencing the sound speed through the tube and is considered for the tube length evaluation. The method is observed as an alternatative to the standing wave tube length measuring approach.

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Măsurarea lungimii unor tuburi flexibile folosind timpul de propagare a sunetului prin tub

Rezumat*: In articol este prezentată o metodă experimentală de măsurare a lungimii unor tuburi de diametre diverse aflate adunate la diferite raze de înfăşurare. La un capăt al tubului este generat un scurt sunet armonic care se propagă prin tub. 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. Se determină timpul în care sunetul parcurge tubul rezultând lungimea tubului. Aplicaţia pentru achiziţia de semnale de la microfoane, generarea de semnal la difuzor şi calculul lungimii a fost scrisă în Labview. Este observată variaţia vitezei sunetului cu diametrul tubului şi cu frecvenţa sunetului folosit.*

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