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THE LENGTH OF FLEXIBLE COILED TUBES MEASURED BY USING STANDING WAVES

Iulian LUPEA

Abstract: In the article a method to assess the length of various coiled tubes by using standing waves is presented. The air in the tube is excited using a speaker and sinusoidal signal in the frequency band of interest. The pressure is measured at both tube ends in order to identify the standing waves generated in the tube. From some peaks of the transfer function the length of various tubes is assessed. Corrections has to be applied in order to obtain better results.

Keywords: *flexible tubes, air tube resonance, transfer function, Labview, standing waves.*

1. INTRODUCTION

The measurement of the length of various flexible tubes is a time consuming activity during the production and sale. Often the tubes are not very flexible and of various diameters. As well, to uncoil the tubes of about 10 to 50 meters is uncomfortable and a large space or area is to be occupied and not always available. Some times the tubes are following specific paths, the access along the tube to measure it is restricted.

The interior of the tubes under observation is occupied by the air at the ambient pressure

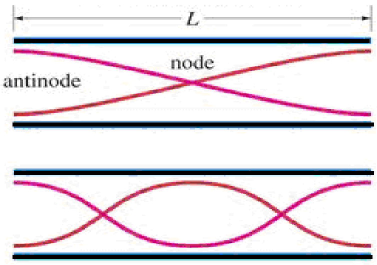

Fig.1. Displacement profile: 1st and 2nd standing waves, both ends opened

and temperature. Compression sound waves can propagate inside the tube. Air tube resonance are to be considered to measure the tube length.

For the first air standing longitudinal wave in the tube (Fig.1) with open ends, a displacement node is present at the tube middle and antinodes at both ends. Vice versa, 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 like in figure 2.

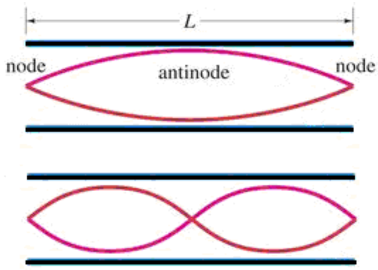

Fig.2. Pressure profile: 1st and 2nd standing waves

Equation (1) states the relation between the tube length and the wavelength of the first harmonic for a tube with both open ends:

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

For the n-th harmonics one have:

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

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

$$c = f\lambda \quad (3)$$

Because we measure frequencies, the frequency of the n-th harmonics can participate to the tube length:

$$L = \frac{nc}{2f_n} \quad (4)$$

Several corrections are 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 [2]. The fact that the tube is curve and has many turns has to be considered too.

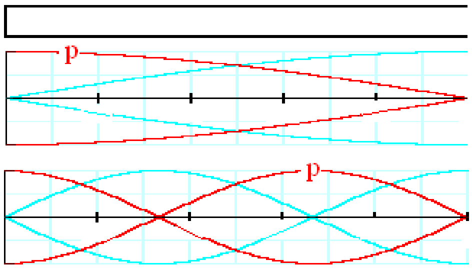

Fig. 3. Pressure (p) profile, close-open end tube

A similar approach can be observed by closing one of the tube end when the pressure profile is depicted in figure 3 for the first two standing waves, excitation of the air column being at the open end [3].

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.

2. THE MEASURING SYSTEM SET-UP

A computer acquisition system is 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 used. The acquisition system was based on the National Instruments dynamic acquisition board PCI 4451 with simultaneous sampling on the input channels. A swept sine wave excitation signal it was used. The frequency of

Fig. 4. The speaker and the accelerometer

the signal is increased in steps covering the frequency band of interest roughly from 50Hz

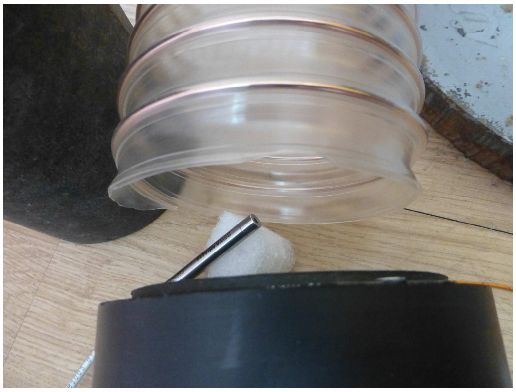

Fig. 5. The speaker and the microphone

to 500Hz. The excitation speaker can be seen in Figure 4, placed at one tube end. The tube is

Fig. 6. Excitation and acquisition channels

wrapped sometimes in protection nylon, only the tube ends are available.

An accelerometer is used in this case for recording the input sound wave. In most of the cases like in Figure 5, the microphone is used to acquire the sound pressure generated by the speaker in order to excite the column of air filling the tube.

At the distal open end of the tube a second microphone is recording the sound pressure. The sensors set-up is shown in figure 6 and a sample of the FRF acquired for a large frequency domain 120 Hz to 300Hz is depicted in figure 7. A Continuous Swept-Sine Frequency Response virtual instrument from Sound and Vibration Measurement Suite with some added and a couple Labview code changes is used.

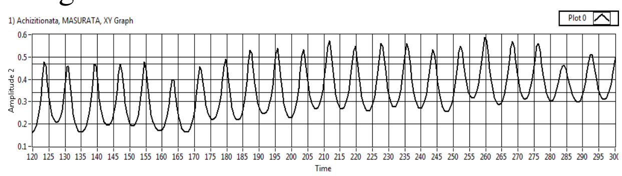

Fig. 7. Typical FRF - large frequency band

The measured frequency response function (magnitude and phase in function of the frequency) is saved and processed later in a new Labview application in order to find out the tube length.

3. RESULTS FOR VARIOUS TUBES TYPES

Various tubes have been measured. The assessed length without corrections for tubes with smooth interior wall and thick walls (figures 4 and 6) is good for short (meters) to

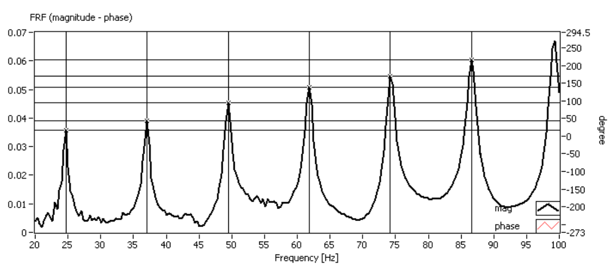

Fig.8. FRF magnitude vs. frequency

long (tens of meters) tubes, errors being at the level of several centimeters. A typical FRF magnitude versus frequency is depicted in figure 8.

For large diameter tubes with non smooth interior wall and thin wall, like the one in figure 5, the precision without corrections is lower, being at the level of one to three tens of centimeters at the total tube length of 20-30 meters. The FRF magnitude versus frequency is shown in figure 9. The list of the frequencies of the FRF magnitude peaks is presented in Table 1. These are harmonics of the fundamental sound generated by the tube or standing waves of the tube with both open ends.

Standing waves in real tubes involve a movement of the air that exceed the end of the tube at both ends. 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.

Table 1

Standing wave no./overtone	Frequency [Hz]	Cont.	[Hz]
harmonics no.n	300.5	n+5	341.21
harmonics no.n+1	309.05	n+6	349.25
harmonics no.n+2	317.09	n+7	357.29
harmonics no.n+3	324.62		etc.
harmonics no.n+4	332.66		

The pressure node at each end 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.

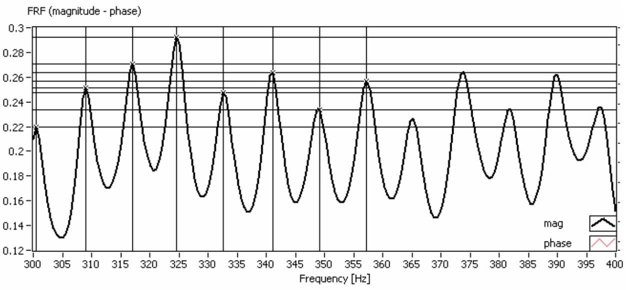

Fig. 9. FRF - large diameter, short tube

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 [2]:

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

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.

4. CONCLUSIONS

A method to assess the length of various coiled flexible tubes by using standing waves is presented. The air in the tube is excited at one open end by using a speaker. The signal is sinusoidal and the frequency of the signal is increasing in steps in the frequency band of interest. The pressure is measured by using two microphones, one at each tube end in order to identify the standing waves generated in the tube. From several adjacent peaks of the transfer function the length of various tubes is assessed by observing a mean span between peaks. The estimation of the length of the tubes with smooth interior surface is better then for the tubes with wavy interior surface. In order to get better results a couple corrections has to be applied. A Labview application that loads the measured frequency response function and evaluates the tube length including corrections has been developed.

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Măsurarea lungimii unor tuburi flexibile folosind moduri acustice

Rezumat: *In articol este prezentată o metodă de evaluare prin experiment şi măsurarea lungimii unor tuburi de diametre diverse aflate adunate în pachete la diferite raze de înfăsurare. Aerul din tub este excitat printr-un difuzor folosind semnal sinusoidal cu baleere în frecvenţă iar presiunea este măsurată la ambele capete deschise ale tubului analizat. Sunt puse in evidenţă frecvenţele la care se formează unde staţionare în tub. Din vârfurile funcţiei de transfer măsurate între capete folosind un sistem de achiziţie şi o aplicaţie de procesare este evaluată lungimea tubului considerând de asemenea anumite corecţii.*

Iulian LUPEA, Professor Ph.D., Technical University of Cluj-Napoca, Department of Mechanical Systems Engineering, 103-105 Muncii Blvd., 400641 Cluj-Napoca, ☎+40-264-401691, e-mail: iulian.lupea@mep.utcluj.ro ; www.viaclab.utcluj.ro