Resonance Mode Acoustic Displacement Transducer

Tariq Younes, Mohammad Al Khawaldah, Ibrahim Al-Adwan
Faculty of Engineering Technology, Department of Mechatronics Engineering,
Al Balqa’ Applied University,
15008 Amman, 11134 Jordan
E-mail: tariqmog@hotmail.com, mohammad.alkhawaldah@gmail.com, ibrahim.aladwan@yahoo.com

Received: 14 April 2014  /Accepted: 30 May 2014  /Published: 30 June 2014

Abstract: Several linear displacement transducers are used in industry and many technical applications. In this research, a linear displacement transducer which uses a standing acoustic wave within a tube with variable length is designed, built and tested. A standard PC will be utilized for data processing and storage. The operation principle of this transducer is based measuring the resonance frequency of the created standing acoustic within tube. A relationship between the tube length and the measured frequency is determined. Besides to design and build of a measurement system for this transducer, three models of transducer prototype will be tested to study the effect of ambient temperature and diameter of the tube on resulting measured frequency.

Keywords: Standing wave, Free resonance mode, Acoustic receiver, Acoustic transmitter, LabVIEW.

1. Introduction

Various types of displacement transducers are in use by industry and they play an important role in displacement measurement. Displacement transducers are used in industry to measure, position, distance, direction of moving targets. A position transducer is usually used to measure the distance between a reference point and the present location of the moving targets (the element of which the position or displacement is to be determined). The reference point can be one end, the face of a flange, or a mark on the body of the position transducer (such as a fixed reference datum in an absolute transducer), or it can be a programmable reference datum. Conversely, a displacement transducer measures the distance between the present position of the target and the position recorded previously. Position transducers can be used as displacement transducers by adding circuitry to remember the previous position and subtract the new position, yielding the difference as the displacement.

Alternatively, the data from a position transducer may be recorded into memory by a microcontroller, and differences are calculated to indicate displacement.

Modern information technology has significantly changed the way of measurement and control. The present evolutions of computer technology can be used to develop computer based measurement transducers which are capable to work in industrial environment [1, 2].

In [3], the authors explored the possibility of using the standing wave phenomenon to measure linear displacements in the small – scale range of motion.

The measurement is achieved by transducer was realized by measuring the amplitude of acoustic standing wave generated in the tube filled by air in forced mode of oscillation. The transducers includes: acoustic transmitter which is placed in one end of resonance tube (a speaker type TM-2A, connected to speaker output of sound card), the acoustic receiver which is placed at distance 1/4λ.
at the speaker (a microphone type HCM4530, connected to the MIC input of the sound card), and spindle. The speaker is placed at the end of tube.

The operation of this transducer is as follows; the speaker generates an acoustic signal with fixed frequency value; the signal collides with the spindle and is reflected to travel in the opposite direction towards the speaker with the same amplitude and frequency before hitting the fixed end. In this situation there are two sound waves with the same amplitude and frequency traveling against each other in the same medium. This provides the condition for generating a standing wave. The microphone detects acoustic pressure amplitude. When the spindle is moved to another position the conditions of forming a standing wave will change, creating a new pattern of standing wave and the microphone detects a new value of acoustic pressure amplitude. Similarly, different patterns of standing waves can be generated by manipulating the position of the spindle.

Such arrangement used in transducer design requires two sound cards in order to realize the measurement of linear displacement. In addition to that, the generated frequency is created in forced mode of generation which significantly varied with temperature. This variation of frequency affects on the different patterns of standing waves generated by manipulating the position of the spindle, resulting in nonlinearity of measurement for large scale of displacement measurement.

The aim of the proposed transducer is to simplify the design of acoustic displacement transducer and to eliminate the temperature variation on generated acoustic signal. This can be realized by using the free resonance mode of standing wave generation [4, 5].

2. Overview of the Resonance Mode Acoustic Displacement Transducer

The proposed resonance mode acoustic displacement transducer includes glass tube, an acoustic transmitter (AT) which is placed at one of the tube ends, an acoustic receiver (AR) which fixed on the spindle and located face-to-face with the AT and at the same axis. When the AR and AT are connected to the sound card of PC a standing wave in free resonance mode is created [6]. Using this combination of speaker – microphone, the signal comes from the microphone is filtered, amplified and regenerated to the speaker, where it is directed to microphone again, which makes a closed loop with a positive feedback. The block diagram of proposed transducer is shown in Fig. 1.

![Fig. 1. The schematic design of acoustic Linear displacement transducer.](image)

The block diagram shows that the operating range of proposed transducer is L, this is because of the nonlinear effects which occur near the speaker far at distance Z=L/4 [7].

The resonance frequency is related to the length of the tube, its shape and whether it has closed or open ends. For this case the resonance frequency [3] is expressed is as follows:

\[ f = \frac{C}{2L}, \]

where \( f \) is the frequency of standing wave, \( C \) is the speed of sound, \( L \) is the length of the tube.

To utilize standing wave phenomenon for measuring linear displacement, in work [3] the forced mode of standing wave generation is utilized, furthermore the frequency value is calculated by Formula (1) assuming that the speed of sound is constant and when the spindle is located at the end of the tube.

In work [1], it was shown that the speed of sound could be utilized to measure temperature, for this case the speed of sound is expressed as follows

\[ C = \sqrt{\frac{\gamma R T}{M}}, \]

where

- \( M \) is the molecular weight of gas;
- \( C \) is the speed of sound [m/s];
- \( \gamma \) is the specific heat ratio;
- \( R \) is the specific gas constant;
- \( T \) is the atmospheric temperature [K].

With an ideal gas, the speed of sound \( (C) \) depends on temperature only, not on the pressure [8]. Air is almost an ideal gas. For air: \( \gamma = 1.402 \) and \( R/M = 287 J/(kg.K) \).

This formula shows that the speed of sound depends on the temperature, as a result the generated acoustic standing is also will vary with temperature change.
Measuring temperature using acoustic standing wave phenomenon was based on measuring the frequency of generated acoustic wave when the speaker and the microphone are located at fixed length L and the free resonance mode was applied.

To overcome the temperature effect on acoustic linear displacement transducer, the resonance mode also will be applied to measure displacement and only one sound card will be used to interface such transducer to the sound card of PC.

3. Experimental Setup

The experimental setup is shown in Fig. 2. It consists of sound card (type Creative CT4810) speaker which is connected to the speaker output of sound card, microphone which is plugged in MIC input of sound card, PC with installed LabVIEW 2010 software. In addition, a spindle on which the microphone is fixed is used in order to perform position variation. The housing of the transducer is a tube made of glass and could be made of any other materials having high acoustic impedance. Furthermore, a ruler is used as reference for position measurement. The combination of speaker – microphone allows to generate an acoustic standing wave with a frequency value dependent on distance between the speaker and microphone. In order to study the produced acoustic signal, the signal is analyzed using a customized program under LabVIEW environment [8, 9], it continuously measures the frequency of generated sound signal. The measured frequency which is displayed on a VI indicator gives the desired information about the relationship between displacement and resonance frequency. Fig. 3 shows the LabVIEW program created to measure the resonance frequency.

In this program the data acquisition is performed using a standard MIC VI. This VI allows acquiring signal from microphone input. Then the Tone Measurements VI is utilized to measure the frequency of the signal, i.e. the resonance frequency. The measured frequency is introduced to band pass filter in order to remove higher order harmonics of the signal and keeping only the first harmonic, smoothing filter VI is used to smooth and reduce disturbance in the measured frequency and displayed on indicator.

4. Experiment Design

In order to investigate the static characteristics of transducer, the transducer is tested in the following conditions:
- The surrounding temperature varies from 20 °C to 40 °C,
- The diameter of the tube varies from 2.5 mm to 10 mm,
- The material of the tube is glass.

The first condition is necessary to determine the operating range of transducer and to determine the drift of output signal. The second condition is required to investigate the possibility of building such transducer in compact form.

The transducer tubes have been designed in four dimensions, to get the most out of the characteristics of the transducer. The lengths and inner diameters are as follows:
* Model A: length=300 mm, inner diameter=2.5 mm,
* Model B: length=300 mm, inner diameter=5 mm,
* Model C: length=300 mm, inner diameter=7.5 mm,
* Model D: length=300 mm, inner diameter=10 mm.

5. Experimental Results

After assembling the experimental setup at the laboratory of transducer at Al Balq’a Applied University, Mechatronics Engineering Department, testing of static and characteristics took place. The static characteristics demonstrate the relationship between displacement and the resonance frequency.

The experimental results are presented in Fig. 4, Fig. 5, Fig. 6 and Fig. 7. To represent the data, the method of data regression is used by utilizing Matlab curve Fitting Toolbox. The exponential model \( f(x) = a \exp(b \cdot x) + c \exp(d \cdot x) \) is used to fit the regression model of the transducer. The model coefficients of fitting for each model (A, B, C, D) at temperature different temperatures are given in Table 1. Based on these experimental results the general mathematical model can be implemented to all of proposed models.

6. Conclusions

In this paper, a simple computerized displacement transducer based on acoustic resonance measurement was developed. It could be integrated with other primary non electrical sensors and order to get an electrical read out and to realize computer data logging and automatic positional control. The experimental results revealed that the generated acoustic signal is related to the measured displacement. More importantly, a regression model based on curve fitting technique was obtained for all models of transducer.
Table 1. The model coefficients of fitting for each model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Coefficients (with 95% confidence bounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td>A</td>
<td>20 °C</td>
</tr>
<tr>
<td></td>
<td>30 °C</td>
</tr>
<tr>
<td></td>
<td>40 °C</td>
</tr>
<tr>
<td>B</td>
<td>20 °C</td>
</tr>
<tr>
<td></td>
<td>30 °C</td>
</tr>
<tr>
<td></td>
<td>40 °C</td>
</tr>
<tr>
<td>C</td>
<td>20 °C</td>
</tr>
<tr>
<td></td>
<td>30 °C</td>
</tr>
<tr>
<td></td>
<td>40 °C</td>
</tr>
<tr>
<td>D</td>
<td>20 °C</td>
</tr>
<tr>
<td></td>
<td>30 °C</td>
</tr>
<tr>
<td></td>
<td>40 °C</td>
</tr>
</tbody>
</table>

References


