International Journal of Current Science, Engineering & Technology
ISSN : 2581-4311
Original Research Article | Open Access | AMCT 2017 Malaysia | *Special Issue*

Measurement of Pipe Strain Using an Ultrasonic System

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ABSTRACT. Ultrasonic sensors can be used to measure strain occurring on an object. In this investigation, an ultrasonic signal utilized the reflected signal as a means of monitoring the condition of a pipe. This is an alternative to the strain gage which is commonly used but has a limited life span. The ultrasonic signal was transmitted to a specific location on the pipe, and then reflected by the pipe surface which experienced strain towards the ultrasonic receiver. Collimation of the transmitted and received signals is performed by aluminum probe cones attached to both ultrasonic transducers. Changes in the strain due to the pipe bending will result in changes in the electric signal due to the changes in the sound intensity. The received electric signal was processed by a signal conditioning circuit consisting of preamplifier, amplifier, band-pass filter and rectifier before being displayed. Two experiments were conducted to establish the relationship between strain on the pipe and the ultrasonic intensity. In order to verify the results, an experiment was conducted using a strain gage and the results were identical. The results show that the system is able to measure strain when the pipe bends.

Keywords: Deformation, Pipe, Sensor, Strain, Ultrasound;

Received: 15.10.2017, Revised: 15.12.2017, Accepted: 30.02.2018, and Online: 20.03.2018;

DOI: ***10.30967/ijcrset.1.S1.2018.384-389***

Selection and/or Peer-review under responsibility of Advanced Materials Characterization Techniques (AMCT 2017), Malaysia.

1. INTRODUCTION

Industries used pipes to convey substances such as liquids and gases, slurries, powders and masses of small solids [1]. The use of pipes provides the safest means of transporting oil, gases and other types of fluids [2]. To enable pipes to perform long distance transportation, the pipes must be able to fulfil the requirements of safety, reliability and efficiency [3]. It is vital to continuously monitor the condition of pipes in order to ensure that it is safe to be used. Industries made use of pipes to convey various types of flow such as high-temperature, high-pressure, inflammable gas/liquid flow. In order to extend the life span of pipes it is important that they are properly maintained. Pipe leakages are mainly as a result of damage from excavation equipment which is located nearby. Pipes which are not maintained properly can corrode gradually, especially at construction joints or at deformation on the pipe [4]. These defects or leaks must be identified as early as possible and corrected before they became serious [5]. Other causes of leaks or deformations include accidents, earth movement, or sabotage.

There are various ways of measuring pipe deformation. One of the common methods of doing it is by installing strain gages on the pipe's surface. When the pipe deformed, changes in the pipe strain resulted in the change in gage's resistance [6]. Nevertheless the use of strain gage has some limitations. Since the strain gage has a small and limited size it is capable of making point measurement only [7]. As such it does not give a wider picture of what actually happened to the pipe. Another disadvantage is that the electrical strain gage can only be utilized for a limited time especially after it has exceeded its elastic limit and after that it has to be disposed. The same thing does not happen to the ultrasonic system which can be used repeatedly and thus it has a longer life span compared to strain gage [8]. Ultrasonic sensors are widely used in the industry due to its advantages such as non-destructive, accurate, reliable, easy to use, inexpensive, long term stability, low power consumption, and its capability in reproducing defects caused by strain [9].

2. MATERIALS AND METHODS

2.1 Pipe Deformation. Stress on a pipe can be investigated using a circular long pipe which bent at certain angles. When a pipe is subjected to a particular force, there will be a certain amount of strain. Besides the shape and size at certain parts of the pipe will change [10]. The size of the deformation maybe too small to be observed by the naked eye or the shape and the size of the whole body might change completely due to the existence of a large deformation. Temperature fluctuation can also cause the body to deform whereby an increase in temperature caused an expansion of the body and vice versa. The ultrasonic system was used with the aim of detecting a small range of deformation. Deformation due to bending happens when a force perpendicular to the longitudinal axis is imposed on a long solid body. By applying load at the other end of a pipe beam, the beam at the support or the pivot tries to firmly maintain its position whereas the force attempts to change the position of the extrude beam. As a result of the force being imposed on the pipe beam, shear stress will be exerted on the pipe.

There are two components of strains namely normal strain and shear strain. Normal strain represents the change in length along a particular direction. Shear strain is due to opposing forces acting in a direction parallel to to a surface [10]. Each material will experience different value of strain. If a metal is subjected to a deformation caused by a force or pressure of the same value, the value of deformation will not be as big as deformation experienced by a non-metallic material. Pressure and modulus of elasticity influence the value of strain on an object. It is difficult to deform an object if it possess a large value of elastic modulus and as such a large value of force is needed to cause the material to deform. The same applies to pressure. Each material has a limit on how much it can deform. When the yield limit of a material is exceeded, it will disobey Hooke's law.

The fundamental concept governing strain that occurred on a pipe is based on the Hooke's law which can be expressed as,

$$\sigma = \varepsilon E. \tag{1}$$

in which stress, σ, is proportional to strain, ε , as well as the modulus of elasticity, E. Changes in the structure of the pipe such as bending resulted in changes in stress which can be formulated as [10],

$$\sigma = \frac{My}{I}. \tag{2}$$

in which M represents the moment, y is the distance from the neutral axis, and I is the moment of inertia.

Since (1) and (2) are the same parameter, by equating them the following can be obtained,

$$\varepsilon = \frac{My}{EI}. \tag{3}$$

The relationship between moment and force, P, and length of the pipe, *l,* can be expressed as

$$M = Pl. \tag{4}$$

By substituting (3) into (4) the following expression is obtained,

$$\varepsilon = \frac{Ply}{EI}. \tag{5}$$

When the pipe is bent, strain is generated and this parameter was investigated in this project.

2.2 The Ultrasonic System and the Experimental Work. The frequency of the ultrasonic sensor was 40 kHz. The receiver circuit comprised a pre-amplifier, an amplifier, a band-pass filter and a rectifier. The signals from the ultrasonic transmitter dispersed at a wide angle [11]. In order to collimate the signals from the ultrasonic sensor several cones were constructed so that the ultrasonics can be directed towards the point of interest. Fig. 1 shows the design of the cone. The left-hand of the cone is the region where the ultrasonic trasnducer is attached whereas the right-hand part is region where the cone is directed towards the measurement point. In order to hold the ultrasonic sensors inside the cone, hot melt adhesive was used. The cone is made of aluminum. Both ultrasonic receiver and transmitter used cones which have identical dimensions. The acoustic impedance for aluminum is 17064000 kg/m²s.

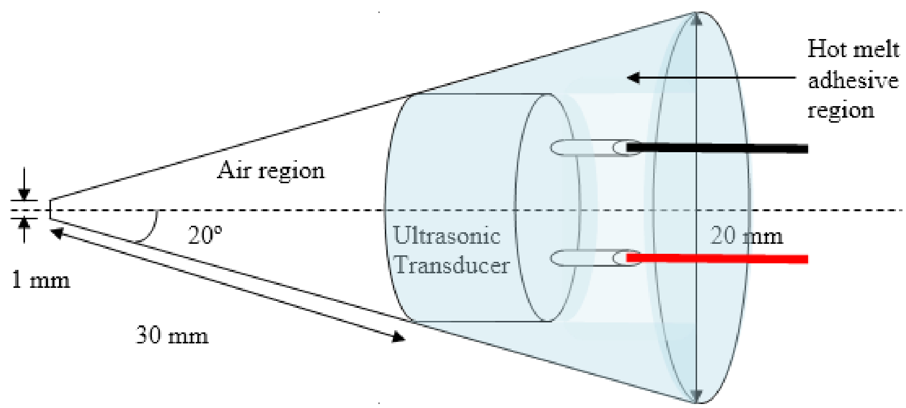

Fig. 1 The dimensions of the cone. The red and black lines are the wires to the ultrasonic transducer

The ultrasonic signal coming out of ultrasonic transmitting sensor is transmitted at a wide angle [12]. By using the cone as in Fig. 2, the ultrasonic wave can be confined to an acute angle which enabled it to be collimated towards the measurement point in which bending occurs. By doing this the signal can be fully optimized rather than the case where the signal is dispersed widely.

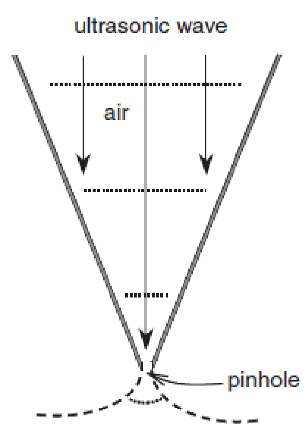

Fig. 2 The propagation of ultrasonic signal in the cone

The experimental setup is shown in Fig. 3 where a load of 15 kg was placed at one of the pipe caused the pipe to bend. The load is placed at the right hand side of the pipe. The ultrasonic transmitter and receiver are placed at the left hand side of the pipe. The aluminum cone was placed in such a manner so that a maximum strain was obtained when a load was placed at the other end of the pipe. A scale was placed at the right hand side in order to measure the deflection caused by the pipe bending. Initially a load of 1 kg is measured and the load was gradually increased. The maximum load being measured was 15 kg.

Fig. 3 Experimental setup

3. RESULTS AND DISCUSSION

Fig. 4 represents the graph of voltage versus strain when the pipe was subjected to a tensile strain. The graph has a regression coefficient of 0.99 which is almost linear and the voltage, y, is related to the strain, x, by y = -0.003x + 186.6. Increasing the strain caused a decrease in the output voltage. A further displacement in strain caused an increase in the range from transmitter to receiver but there is a decrease in the sound pressure level. This affects the receiver transducer reception against the voltage. It can be expected that if the pipe is subjected to compressive strain, the voltage will be proportional to strain.

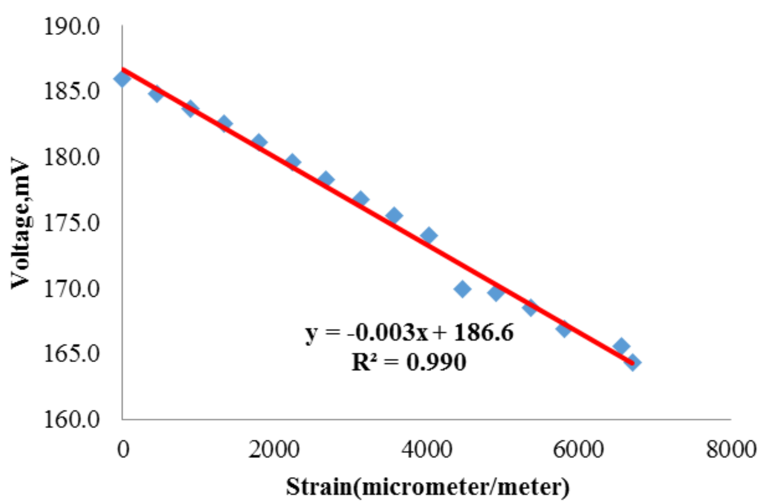

Fig. 4 Graph of voltage versus strain

Fig. 5 shows two graphs representing the results from an experiment conducted using a strain gage and an ultrasonic system. There is only a slight difference between the graphs. Both graphs show that when the pipe is subjected to an increasing load, the value of strain increased. The graph obtained from the strain gage is a straight line whereas the graph representing the ultrasonic system is not as smooth as the strain gage. This can be probably be attributed to the fact the measurement area of the strain gage has a narrow boundary whereas in the case of the ultrasonic system, the angle of the ultrasonic receiver has a wider measurement area compared to the strain gage.

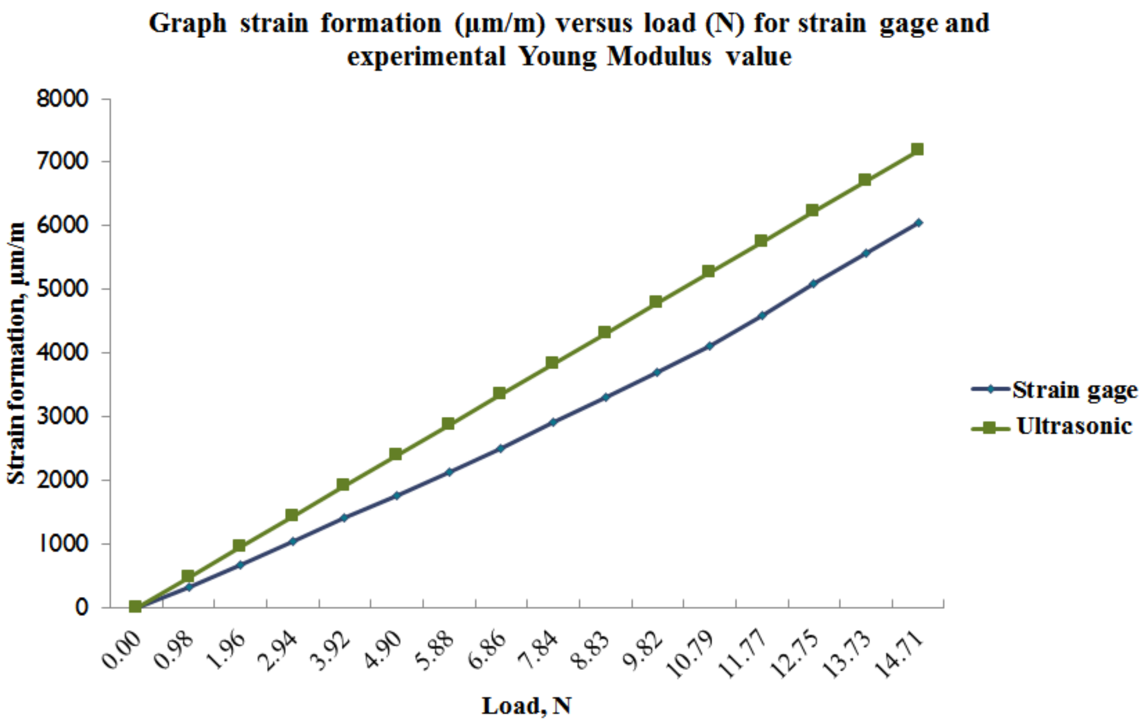

Fig. 5 Results obtained using a strain gage and an ultrasonic system

4. SUMMARY

The investigation shows the capability of an ultrasonic system in measuring the performance of a pipe when it is subjected to a certain amount of strain. Results from the ultrasonic system are identical with that obtained using a strain gage. The output voltage is inversely proportional to strain. As such the change in the electrical signal represented by the output voltage can be used to indicate a change in the strain experienced by the pipe. Further experiments can be conducted using other ultrasonic frequencies. An improvement in the processing of the signal could enhance the system.

ACKNOWLEDGMENT

The authors would like to thank Universiti Teknologi Malaysia for their assistance under the vote 15H85 in providing the fund and the facilities in conducting this research.

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