UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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THE DEVELOPMENT OF PRESSURE SENSOR FOR PIPING SYSTEM

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor in Manufacturing Engineering Technology (Process and Technology) with Honours

by

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This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor in Manufacturing Engineering Technology (Process and Technology) (Hons.). The member of the supervisory is as follow:

……………………………….

(Mohammad Khalid bin Wahid)

ABSTRACT

The purpose of this project is to design and run a finite element analysis (FEA) of pressure sensor which is using diaphragm element. Pressure sensor with diaphragm element is a mechanical type of sensor. This project will overcome the high cost to manufacture the pressure sensor by using lower cost of material but still can give the better result as a pressure sensor. Complexity of design in pressure sensor also adds the process to manufacture it where advance machining or advance engineering processes are need. So, to overcome the process of producing the pressure sensor, the conventional technology in process of production is considered compare of high production technology. The objectives of this project are to design pressure sensor using diaphragm system and aluminium material and run the finite element analysis of pressure sensor. The CAD modeling is drawn using CAD software (CATIA). Then the design has to run the finite element analysis (FEA) using CAE software (HYPERWORK). The finite element analysis conduct for this project is only for mechanical properties of the material for diaphragm pressure sensor. The mechanical properties analyze are strength of the material for deflection, strain based on the deflection and the stress produce from the pressure sensor design.
Conclusions are made for diaphragm pressure sensor where small area of diaphragm is applied with high pressure to produced maximum value of stress and displacement. Design using aluminium material with different thickness of diaphragm showed the different characteristic of material where the sensitivity are changes from thickness of 1mm to 4mm. Due to this situation, the less thickness of diaphragm has the high sensitivity toward the low pressure compare with the thick diaphragm, where thick diaphragm is more suitable with the high pressure.

ABSTRAK

Tujuan projek ini adalah untuk mereka bentuk dan menjalankan analisis unsur terhingga (FEA) sensor tekanan yang menggunakan elemen diafragma. Sensor tekanan dengan unsur diafragma adalah pengesan jenis mekanikal. Projek ini akan mengatasi kos yang tinggi untuk mengeluarkan pengesan tekanan dengan menggunakan kos bahan yang lebih rendah tetapi masih boleh memberikan hasil yang baik sebagai pengesan tekanan. Kerumitan reka bentuk dalam pengesan tekanan juga menambah proses untuk mengeluarkanya di mana pemesinan termaju atau proses kejuruteraan yang lebih maju diperlukan. Jadi , bagi mengatasi proses menghasilkan pengesan tekanan, proses pengeluaran menggunakan konvensional teknologi digunakan berbandinkan teknologi pengeluaran yang tinggi. Reka bentuk pengesan tekanan dilukis menggunakan perisian lukisan komputer terbantu CAD (CATIA). Seterusnya reka bentuk akan menjalani analisis unsur terhingga (FEA) menggunakan perisian komputer kejuruteraan terbantu CAE (HYPERWORK). Analisis unsur terhingga untuk projek ini adalah hanya untuk sifat-sifat mekanik bahan bagi pengesan tekanan diafragma. Sifat-sifat mekanik yang menganalisis kekuatan bahan untuk pesongan, ketegangan berdasarkan pesongan dan hasil tekanan dari reka bentuk pengesan tekanan. Kesimpulan ini dibuat untuk pengesan tekanan diafragma dengan saiz diafragma yang kecil bertindak balas terhadap tekanan yang dikenakan menghasilkan tekanan dan anjakan yang tinggi. Reka bentuk menggunakan bahan aluminium dengan ketebalan diafragma yang berbeza menunjukkan ciri-ciri yang berbeza daripada bahan di mana dari sensitiviti perubahan ketebalan 1mm hingga 4mm. Oleh kerana keadaan ini, diafragma yang kurang ketebalanya mempunyai sensitiviti yang tinggi terhadap tekanan rendah berbanding dengan diafragma tebal, di mana diafragma tebal adalah lebih sesuai dengan tekanan yang tinggi.

DEDICATION

To my parents loved that never cease to teach me how to stand with their feet but never tired to stand behind me and prayed that I managed to spend learning the bachelor's degree level. Thanks also to my colleagues where you are constantly helping me and encouraging me when are in distress. I wish a thousand thanks to friends at home I never give up to provide translation and enlightening for me to understand the problems that I have faced. I went through all this is a challenge to myself to be successful in the future. Thanks goes to lecturers who have taught me, since the first day I set foot in UTeM. Do not forget also to assistant engineer who helped me during the workshop. In addition I also say thousands of thanks to the people who helped me and I regard you all as a family on my own. We are all one big family.

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CHAPTER 1

INTRODUCTION

1.0 Background

Over the years technologies for measuring pressure have been developed. Each technology has its own strengths and weaknesses. The key design parameters of accuracy, long term stability, operating temperature range, and price are used to identify which type of pressure sensor is best suited for a particular task. There are technologies with sensors function and the technology includes the bellows, the diaphragm, and the bourdon tube. Piston technology uses a sealed piston to measure changes in pressure while mechanical deflection uses an elastic or flexible element to mechanically deflect with a change in pressure, for example a diaphragm and Bourdon tube. Figure 1.1 below show example one of the mechanical pressure sensing element technologies.

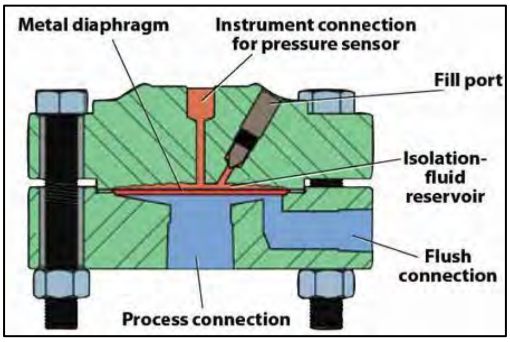

Figure 1.1: Diaphragm Pressure Sensor.

Piezo-electric pressure sensors as shown on figure 1.2 consist of ceramic materials which have naturally occurring electrical properties. They are capable of converting stress into an electric potential and vice versa. The operation are charge mode, which generates a high impedance charge output and voltage mode, which uses an amplifier to convert the high impedance charge into a low impedance output voltage. The sensors can only be used for verifying pressures.

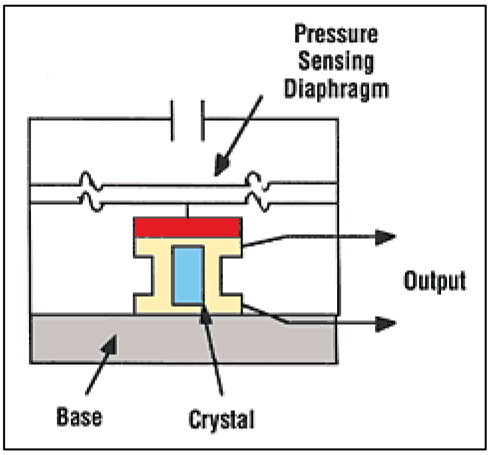

Figure 1.2: Piezo-electric Pressure Transducer

Hence, pressure technologies of Micro Electro Mechanical systems (MEMS) are typically micro systems manufactured by silicon surface using micro machining that use in very small industrial or biological systems. Vibrating elements use a vibrating element technology, such as silicon. Variable capacitance pressure instruments use the capacitance change results from the movement of a diaphragm element to measure pressure. Depending on the type of pressure, the capacitive transducer can be either an absolute, gauge, or differential pressure transducer. The device uses a thin diaphragm as one plate of a capacitor. The applied pressure causes the diaphragm to deflect and the capacitance to change. The deflection of the diaphragm causes a change in capacitance that is detected by a bridge circuit.

The difficulty with pressure sensors lies primarily in choosing the best compromise between:

i. Price.
ii. Performance.
iii. Production technology.
iv. Used materials.

Microelectronic technology adapted to micro systems allows bold, highly integrated and very economic designs. In addition, the progress made in the quality of materials, and the increasing power of data processing, allows the simplification of the geometry of the sensing element. Thus, most pressure sensors today use cylindrical or diaphragm elements. Table 1.1 below shows that the different types of pressure sensor that normally used in industries. (Pavel Ripka, 2007)

Type	Physical principle	Applications
Mechanical	Bourdon tube gauge	Very low cost, low accuracy Recommended for static installations
	Active diaphragm gauge	Low cost, low accuracy, fast, durable. Recommended for rough vacuum
	Piezo-resistive diaphragm gauge	Industrial vacuum measurements especially for vacuum safety systems
Electrical	Ionization	Recommended for vacuum measurements up to 10-8 Pa in protected environments like laboratories. Relatively bulky.
Thermal	Pirani gauge	Recommended for very deep vacuum measurements in relatively protected environments. Fragile.
	Thermocouple gauge	Low precision, small size.

Table 1.1 Different types of pressure sensor.

1.1 Problem Statement

Pressure sensor nowadays is more sensitive and advances but the more the more complex of production technology need for the production process. The sensitivity of the pressure sensor is not only depending on the type of the sensor but also the material use. So, this project will overcome the cost to manufacture the pressure sensor by using low cost of material which is aluminium but still can give the better result as a pressure sensor. Complexity of design in pressure sensor also adds the process to manufacture it where advance machining or advance engineering processes are need. So, to overcome the process of producing the pressure sensor, the conventional technology in process of production is considered compare of high production technology.

1.2 Objective

To overcome the problem of pressure sensor production, these are the objective of this project:

I. To design a pressure sensor using diaphragm system and aluminium material.
II. To run the finite element analysis of diaphragm pressure sensor.

1.3 Scope

There are will be 3 scopes carry out in this experiment and below are the scope:

1. Design of the pressure sensor is base on the diaphragm system using aluminium material.

2. Design is draw using CAD software (CATIA) and the complete design of pressure sensor is run for simulation, which is CAE software (HYPERWORK) to analysis the finite element. The finite element analysis conduct is only to analyze base on the mechanical characteristic of the diaphragm pressure sensor and not involve any of electrical function on it.

3. The process of manufacturing the pressure sensor is using of lathe machine where aluminium is one of the materials that have the capability to be machine, so the design will show the ability of conventional technology to manufacture the pressure sensor.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction of Diaphragm Pressure Sensor

At present time the semiconductor pressure sensors are most wide spread. These sensors consist of the thin diaphragm made from monocrystalline silicon as an elastic member and tensoresistors on the diaphragm as a sensitive member. The wide spread of the such sensors is caused by high quality of mechanical characteristics of monocrystalline silicon and high piezoresistive effect of silicon, the opportunity of sensor production by microelectronic technology methods. However, silicon diaphragm manufacturing technique contains nonplanar operations bilateral lithography and deep anisotropic etching of a silicon technological substrate.

These operations entail a cost increase and an essential technical draw back of sensors wide scatter of pressure sensitivity, which is caused by scatter of rigidity of thin diaphragms as a result of initial substrate depth difference and non uniform deep etching by geometrical scatter of tensoresistors position relative to diaphragm side. The pressure sensitivity scatter may be reducing by placing amplifiers on hard periphery of diaphragm. However, amplifier gain correction requires pressure tests that result in essential rise of sensor price. Fabrication of diaphragms by silicon evaporation reduces mechanical quality of diaphragms and yields not smaller rigidity scatter as the result of stream inhomogeneity of an evaporated material. (N.P. Krivorotov, 2003)

Sensors that measure the level of gas or liquid pressure employ an elastically deformable diaphragm, with an integrated sensing element. The measuring principle of these pressure level sensors can be divided into detecting resistance change, by attaching strain gauges on the surface of diaphragms, or detecting changes in the capacitance between the diaphragm and another electrode. The unification of pressure sensitivity can be achieved by replacement a diaphragm type principle of pressure sensor fabrication on a multiplicative principle. Multiplicative sensor includes a hard pressure concentrator of the greater area, which connected with the hard sensitive of the smaller area. The ratio of the greater area to the smaller area defines the pressure sensitivity.

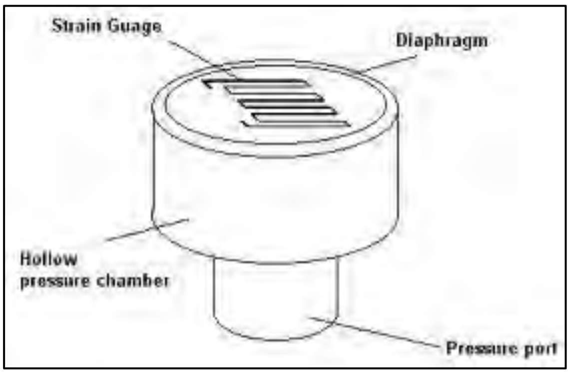

Figure 2.1: Diaphragm pressure sensor

2.1 Design of Diaphragm Structure

2.1.1 Flat Structure

In the first approach, the diaphragm is usually modelled as a thin plate or a membrane as shown in Figure 2.2. A geometric compatibility condition of diaphragm that is continuous displacement when interface. In previous investigation the use of kinetic energy of the diaphragm relative to the air cavity distinguish the predominantly structural modes from the predominantly acoustic modes. It should be noted these models mostly focus on the free vibration problem and the viscous effect is neglected. For some small pressure sensors, when the air cavity is short, the large damping due to the squeeze film effect can significantly reduce the sensor band width, which is typically designed to be the flat region of the response spectrum below the fundamental natural frequency of the air backed diaphragm.

Figure 2.2: Flat structure diaphragm (Xian Huang, 2014)

Although in the structural acoustic coupling of the air backed diaphragm has been considered, few have studied this problem from the perspective of pressure sensor design, in which practical guidelines are needed to predict the performance characteristics of a pressure sensor. In particular, it is not clear in the literature how three effects (stiffness, mass, and damping) of the air cavity scale differently with the cavity length. Based on the frequency response to external pressure stimulus, we can characterize the sensor performance in terms of its static sensitivity and band width. we focus on how the sensitivity and band width are affected by the air cavity length of a large range from orders of magnitudes larger than the diaphragm size to orders of magnitudes smaller.

For example, when the film thickness (i.e. the cavity length) is larger than or comparable to the diaphragm size, the pressure cannot be assumed to be uniform in the direction perpendicular to the film, and the air flow cannot be considered planar. Without loss of generality, consider a typical pressure sensor configuration shown in Figure 2.3, which consists of a circular diaphragm of radius (a) and thickness (h) and an air backed cylindrical cavity length (l). The circular diaphragm is modeled as a plate with in-plane tension. Depending on a normalized tension parameter, this diaphragm model can capture the behaviours of a pure plate with zero tension, a pure membrane with a large initial tension, and the in-between cases. (H.Liu et al., 2013)

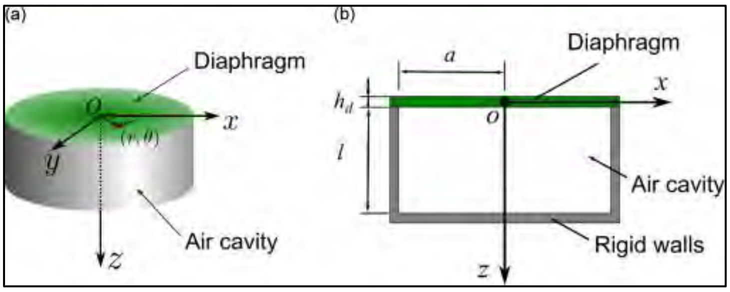

Figure 2.3: Schematic of a flat pressure sensor diaphragm (Haijun Liu, 2013)

In this study, natural rubber latex (NRL) and polyethylene terephthalate (PET) film are considered for the material of the diaphragm and the air in the cavity is assumed to be expanded. Each sensor has different material of the diaphragm and thus different flexural rigidity, D although the dimensions of each sensor are same. Observing the results of the canter deflections of the diaphragm, w0, of the sensors 1 and 2 are very close to each other. This indicates the compressed air or gas within the cavity induced by diaphragm deflection is dominantly affecting the sensitivity of a conventional air-sealed capacitive pressure sensor particularly having a sufficiently flexible diaphragm. (H.Y.Lee, 2014)

In addition, Figure 2.4 shows the flexible NRL diaphragm deflection is significantly different according to whether the compressed air in the cavity is considered or not, where as a slight decrease in the deflection of the PET diaphragm is resulted by considering the air compression within the cavity shown in Figure 2.5.

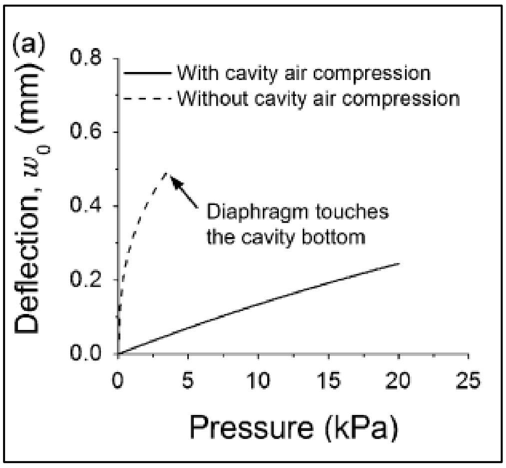

Figure 2.4: Analytical NRL diaphragm deflection (Ho Young Lee, 2014)

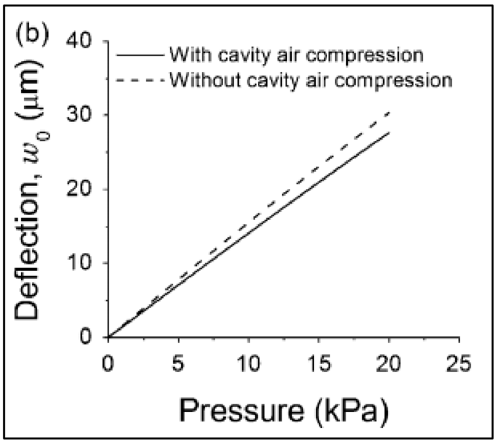

Figure 2.5: Analytical PET diaphragm deflection (Ho Young Lee, 2014)

The fundamental natural frequency studied in the previous sections, damping ratio is another important parameter that affects the sensor performance, especially the bandwidth. The damping due to the air cavity is related to the viscous boundary layer thickness. At 15 kHz, the viscous boundary layer thickness is estimated to be about18 μm. When the cavity length is comparable to or smaller than this thickness, the squeeze film effect has to be considered in order to determine the sensor bandwidth. Table 2.1 show the parameter of representative sensor.

Parameters of a representative pressure sensor	
Diaphragm	silicon
Young's modulus	169 GPa
Poisson's ratio	0.25
Density	2.3 103 kg/m3
Radius	500 µm
Thickness	0.5 µm
Pressure	1.01 105 Pa
Sound speed	343 m

Table 2.1: Parameters of a representative pressure sensor

When the air cavity is completely trapped in the boundary layer, the damping is approaching the critical damping. This result indicates that for a particular sensor configuration that the equivalent damping should be treated differently in the different cavity length regions. From the perspective of sensor design, there is no benefit to have a cavity length less than 0.04a, due to the reduced sensitivity and bandwidth as evidenced in the results shown in Figure 2.6.

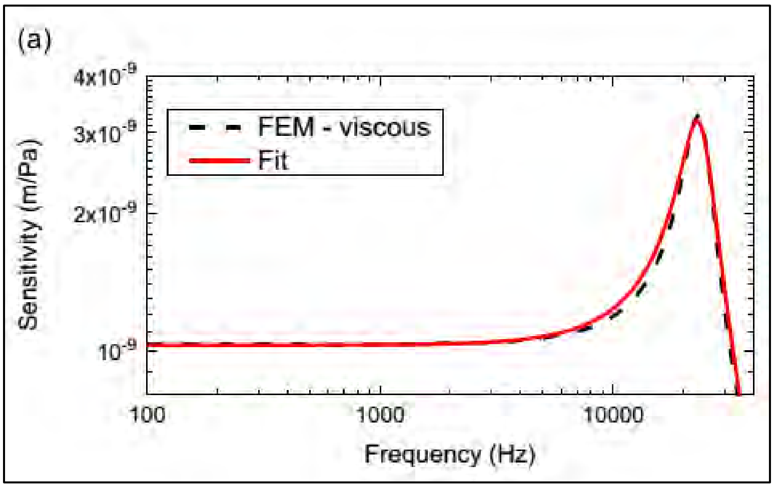

Figure 2.6: Frequency response curves using the viscous FEM model