DEFORMATION ANALYSIS OF A DIAPHRAGM TYPE PRESSURE SENSOR FOR AUTOMOTIVE SAFETY APPLICATIONS

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ABSTRACT: Monitoring pressure plays a vital role in automotive safety applications. This paper reports on the deformation analysis of a diaphragm type pressure sensor. There are two kinds of diaphragms, square type and circular type have been considered for the analysis. In this sense, diaphragms with equivalent cross sectional area have been selected for the simplicity. The proposed diaphragms has been simulated to get maximum deformation for an input pressure by using COMSOL and it is compared with the theoretical analysis. In addition, stress analysis along the mid line of the square type and circular type membranes also has been obtained by using FEM simulation. Based on the deformation, circular type diaphragm is preferable than square type. Even though, the design layout costs more in fabricating circular diaphragms which indeed increases the cost of the sensor and the fabrication costs are higher compared to the square shaped diaphragm.

Keywords: Pressure Sensor, Diaphragm Deflection, Automotive

1. INTRODUCTION

Pressure monitoring plays a vital role in automotive safety applications. Presently, there is potential to fabricate pressure sensors in micro scale. Micro-Electro-Mechanical Systems is a technological process used to create tiny integrated devices which combine mechanical and electrical components. These devices have the ability to sense, control and actuate on the micro scale and generate effects on the macro scale [Heeren & Salomon.2007]. Through the use of these systems several kinds of sensing is possible.

Micromachining has been demonstrated in a variety of materials including glasses, ceramics, polymers, metals, and various other alloys. Single crystal silicon is elastic and lighter than aluminum, it has a modulus of elasticity similar to stainless steel. Silicon has desirable mechanical properties and economical to produce single crystal substrates.

The silicon based pressure sensors are mostly available in product market. These kinds of sensors have wide-range of applications in various fields, from automotive industry to medical equipment's. They have the advantages of small size, low power, good performance and massive production for the micro machined process. Nowadays, silicon piezo-resistive pressure sensor is a matured technology in industry and its measurement accuracy is more rigorous in many advanced applications. Basic element and operating principle of pressure sensor is shown in Figure 1.

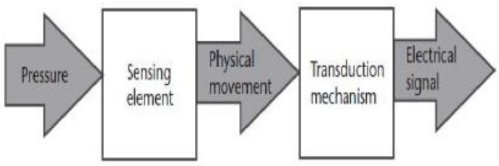

Figure 1: Basic element and operating principle of pressure sensor [Zahra et.al.2015]

Piezoresistive pressure sensor is one of the major applications of the pressure sensor in automotive safety applications. Many researchers have been investigated different techniques to improve the sensitivity of these sensors [Beeby et.al.2004, Johari et.al.2003 & Chattopadhyay et.al.2007].

Micro pressure sensor works on the principle of mechanical bending of a thin diaphragm caused by the contact media such as gases and liquids. Mechanical changes that occur at the diaphragm are usually detected by a piezoresistive or capacitive methods. On the other hand, piezoresistive sensors were widely used as they are able to overcome the limitations observed in other sensing technologies such as the non-linearity, relatively large size, low sensitivity [Bangera & Kulkarni.2013 and Kumar & Pant.2014].
A successful realization of a micro pressure sensor requires development of high performance diaphragm structure, provided the parameters such as diaphragm thickness are adjusted according to the pressure range applied. Thus, choosing the suitable structural parameter will assist the optimization of diaphragm sensitivity [9]. To produce a highly sensitive pressure sensor, a pressure magnification designed diaphragm is needed so that the sensor might detect even a small pressure change. This can be achieved by carefully designing the diaphragm shape to utilize the pressure magnification scheme.
In this paper, two kinds of diaphragms such as square type and circular type with identical cross section of a typical pressure sensor have been introduced to measure the pressure. FEM analysis is carried out with these two kinds of structures to propose a better structure with maximum deflection.

2. METHODOLOGY

The proposed research develops a general methodology for the deformation analysis of a diaphragm type pressure sensor and it is carried in the following manner.
Initially, literature survey is carried out to distinguish the several pressure sensing principles used for industrial applications in order to choose locally not available or not applicable pressure sensor. In this step, the design principles, governing laws and parameters for each and every pressure sensing principles are addressed. Also the applicability, suitability, feasibility, cost effectiveness as well as the pros and cons of pressure sensors with different sensing principles are also recognized.
By analyzing afore mentioned factors, a suitable structure for a pressure sensor is proposed. In addition, the theoretical analysis also out to compare the results. In order to carry out the deformation analysis, proposed diaphragm structures are simulated with the Finite Element software such as COMSOL.

2.1 Theoretical Analysis of Diaphragms

The analysis are done for square and circular shaped diaphragm deflection. Considering a square shaped diaphragm with the side length ɑ and thickness h,

Maximum stress at the center of each Edge

$$\sigma_{max} = \frac{0.308 p a^2}{h^2} \qquad \text{.....(1)}$$

Maximum deflection at the center of the plate

$$w_{max} = -\frac{0.0138 p a^2}{E h^3} \qquad \text{.....(2)}$$

Stress at the center of the plate

$$\sigma = \frac{(6p(m+1)a^2}{47 m h^2} \qquad \text{.....(3)}$$

Considering a circular diaphragm with radius b and thickness h,

Maximum radial stress at edge

$$(\sigma_{rr})_{max} = \frac{3W}{4\pi h^2} \quad \text{...(4)}$$

Maximum tangential stress at edge

$$(\sigma_{\Theta\Theta})_{max} = \frac{3\nu W}{4\pi h^2} \quad \text{...(5)}$$

Maximum stress at the center of the diaphragm

$$(\sigma_{rr})_{max} = (\sigma_{\Theta\Theta})_{max} = \frac{3\nu W}{8\pi h^2} \quad \text{...(6)}$$

Maximum Deflection at the center of the plate

$$w_{max} = -\frac{3W(m^2-1)b^2}{16\pi E m^2 h^3} \quad \text{...(7)}$$

Where, 1/m = ν = Poisson's ratio, E = Young's Modulus, W = Equivalent load

It is clear from the above mathematical relations that maximum deflection is directly proportional to square of length or radius of the diaphragms and inversely proportional to thickness of those diaphragms.

2.2 Introduced Models and Simulation

In order to compare the results for one unit area, Equivalent cross sectional areas of diaphragms has been considered for both structures. These models are simulated using COMSOL and the results are compared with theoretical parameters. Figure 2 and Figure 3 represent deflection and stress variation along the mid lines of square type and circular type diaphragms respectively.

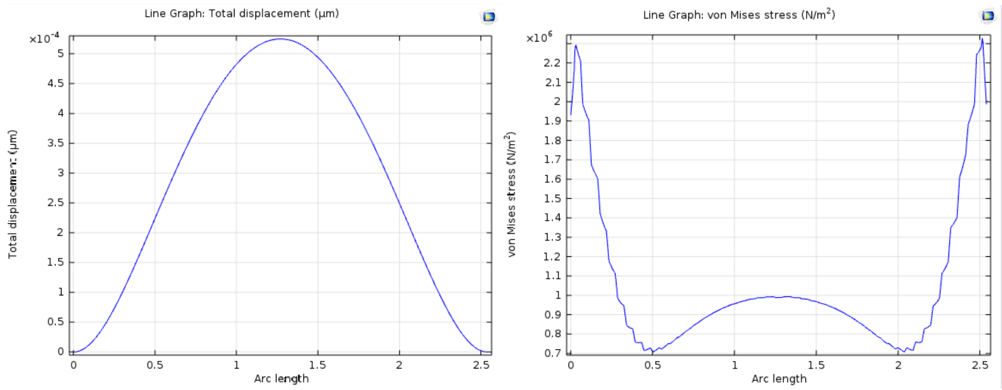

Figure 2: Deflection and stress variation along the mid line of the square type diaphragm

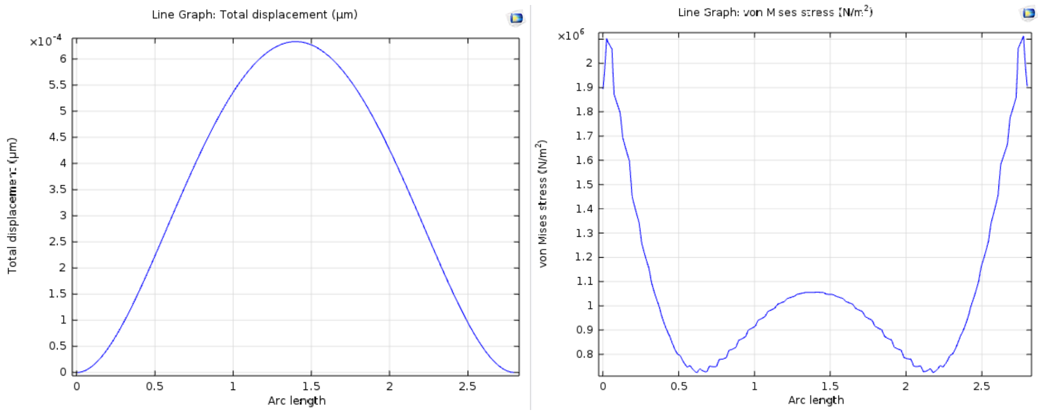

Figure 2: Deflection and stress variation along the mid line of the circular type diaphragm

3. RESULTS AND DISCUSSION

From the above figures it is analyzed that the circular diaphragm exhibits maximum deflection at the center compared to the square diaphragm. In addition, circular diaphragm has higher stresses along perimeter and it is lesser than the stresses created along the sides of the square diaphragm. Also stresses at the center of the circular diaphragm is higher than the stress at the center of the square diaphragm. Therefore in order to achieve maximum deflection for a corresponding pressure, circular diaphragms are most preferable than the square diaphragm.

4. CONCLUSION

Even though the deflection is higher in the circular diaphragm, fabricating this diaphragm with existing techniques is difficult. Also the design of layouts cost more for circular layouts which indeed increases the cost of the sensor and the fabrication costs are higher compared to the square shaped diaphragm.

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