Load-deflection analysis of flat & corrugated stainless steel diaphragms by theoretical & finite element method

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ABSTRACT

In this study analytical model for pressure deflection relationship of flat & corrugated stainless steel (SS-304, ASTM A-240) diaphragms has been proposed. The load-deflection analyses of flat and corrugated stainless steel diaphragms are performed to compare the sensitivity of the flat and corrugated diaphragm. The application of corrugated diaphragms offers the possibility to control the sensitivity of thin diaphragms by geometrical parameters. Depth of corrugations, thickness of diaphragms, and number of corrugations plays an important role to increase the mechanical sensitivity of the corrugated diaphragm. Verification of results for load-deflection obtained by analytical formulae compared with finite element analysis.

Keywords: Load deflection Analysis, Corrugated diaphragms, Sensitivity, Geometric parameters, Finite element analysis.

I. INTRODUCTION

Metallic diaphragms are thin circular plates which undergo elastic deformation when subjected to pressure or axial loading. They may be flat or corrugated in a circular pattern. The metallic diaphragms are widely used in the pressure measuring instruments. Thin metal diaphragms are also used in the pressure reducing valves (PRV). In PRV the pressure at downstream (outlet) side of the valve depends on the amount of deflection of metallic diaphragm. So it is very important to analyze the behaviour of metallic diaphragm under applied pressure for precise use of diaphragm for particular application.

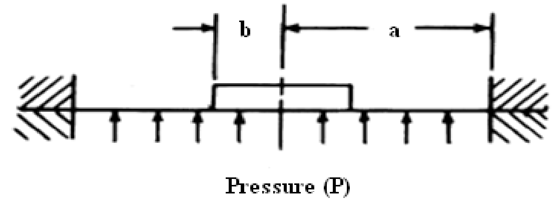
Mullem et al. [3] experimentally shown that, corrugated diaphragms have a larger linear range than flat diaphragms. The larger linear range compared with flat diaphragms made the corrugated diaphragms attractive for specific application with improved sensitivity. The design of corrugated diaphragms may offer the possibility to control the mechanical sensitivity of the diaphragm by means of the geometric parameters of the diaphragms, such as depth of corrugations, thickness of diaphragm and number of corrugations.

II. THE DIAPHRAGM STRUCTURES

The diaphragms used in for this study are of two types. One is flat diaphragm and other is corrugated diaphragm. The material used for both the diaphragms is stainless steel (SS 304 ASTM-240). Flat circular diaphragm with the size of 190 mm in active diameter and 0.25 mm in thickness of sheet with rigid center of 90 mm. For the design of corrugated diaphragms active diameter & thickness kept same as flat diaphragm (190mm & 0.25 mm respectively). In case of corrugated diaphragm geometric parameters such as depth, pitch (frequency) and number of corrugations are decided by the designer as per requirement of load – deflection application. In this study we are going to analyze the load – deflection characteristics of flat & corrugated diaphragm with specific geometry.

III. THEORY

3.1. LOAD- DEFLECTION RELATIONSHIP FOR FLAT DIAPHRAGM WITH RIGID CENTER



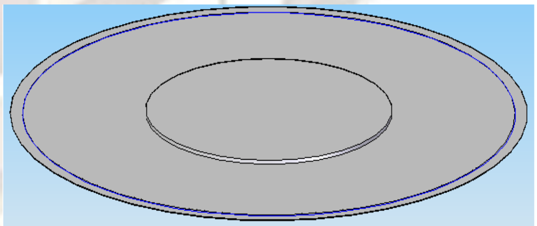


Figure1: flat diaphragm with rigid centre.

The flat diaphragm shown in figure 1, having material of stainless steel (SS-304) & thickness of 0.25 mm with dimensions of ‘a’ & ‘b’ are 95 mm & 45 mm respectively. Therefore solidity ratio (b/a) for given geometry is 0.47. The characteristic equation of a rigid center diaphragm loaded by pressure for any deflection is given by Giovanni [1], We treat the resistance of the diaphragm to an external load as the sum of the resistance to bending and tension, given by equation (1) below,

$$P = \frac{Eh^3}{A_p a^4}(Y) + B_p \frac{Eh}{a^4}(Y^3) \qquad (1)$$

In equation (1), P is applied pressure in N/ Sq.mm, E is Modulus of elasticity of material N/ Sq.mm, h is thickness of diaphragm in mm, a is radius of diaphragm in mm, Y is center deflection in mm, Ap & Bp are the numerical constants depends upon solidity ratio (b/a).
The values of constants mentioned above are taken from Diaphragm design handbook of M. Di Giovanni [1], Constants depend on the material and geometry of the diaphragm. The constants used flat diaphragms are as mentioned in table (1) below,

Table 1: Constants used for flat diaphragms

Parameter	Value
E (N/mm^2)	1.93 * 10^5
'h' (mm)	0.25
'a' (mm)	95
'b' (mm)	45
'b/a'	0.47
Ap	0.05
Bp	9.8

Solve the equation (1) by putting corresponding values from table 1. It gives the pressure – deflection plot for flat diaphragm as shown in fig. (2).

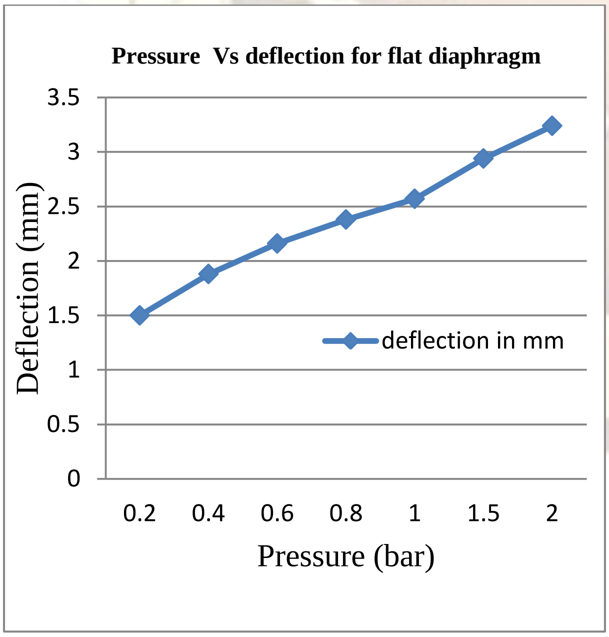


Figure 2: Pressure- deflection plot for flat diaphragm with rigid centre

3.2 LOAD- DEFLECTION RELATIONSHIP FOR CORRUGATED DIAPHRAGM:

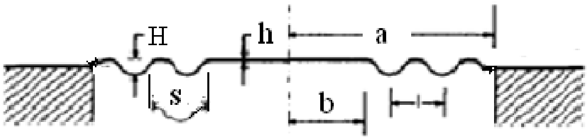


Figure 3: Cross section of corrugated diaphragm with rigid centre

The Cross-section of a circular corrugated diaphragm is as shown in figure 2. The characteristic equation for the corrugated diaphragm with rigid center is different from flat diaphragm taken from Giovanni [1] as below,

$$\frac{Pa^4}{Eh^4} = K_P A_P \frac{Y}{h} + L_P B_P \frac{Y^3}{h^3} \qquad (2)$$

In above equation Ap, Bp, Kp & Lp are the numerical constants depends on the geometry of the corrugated diaphragm, Values of these constants are taken from Giovanni [1]. As mentioned in table (2) below,

Table 2: Constants used for corrugated diaphragms

Parameter	Value
E (N/ mm^2)	1.93 * 10^5
H (mm)	2
'a' (mm)	95
'b' (mm)	45
'h' (mm)	0.25
'q'	10
Ap	96
Bp	0.052
Kp	1.4
Lp	4.3

3.3 CORRUGATION PARAMETERS

Scheeper et al. (1994) [2] indicated that the behaviour of a corrugated diaphragm is determined by the profile factor *q*. The number of corrugations has only little influence on the profile factor whereas *q* is nearly proportional with the corrugation depth (H). Therefore, the corrugation depth is the most effective parameter to influence the behaviour of corrugated diaphragms. Dissanayake et al.2009 mentioned that Depth of corrugation (H), sheet thickness (h), pitch (frequency) of corrugation (l), numbers of corrugations are considered to be critical parameters in the design of sinusoidal corrugations as shown in figure (3). For corrugated design proposed here sheet thickness (h) is 0.25 mm, choose profile factor (q) as 10, Provide two sinusoidal corrugations of pitch 18 mm each with depth of corrugation (H) as

2mm between rigid center and clamping region as shown in figure (3). Solve the equation (2) by putting corresponding values from table 2. It gives the pressure – deflection plot for corrugated diaphragm as shown in figure (4).

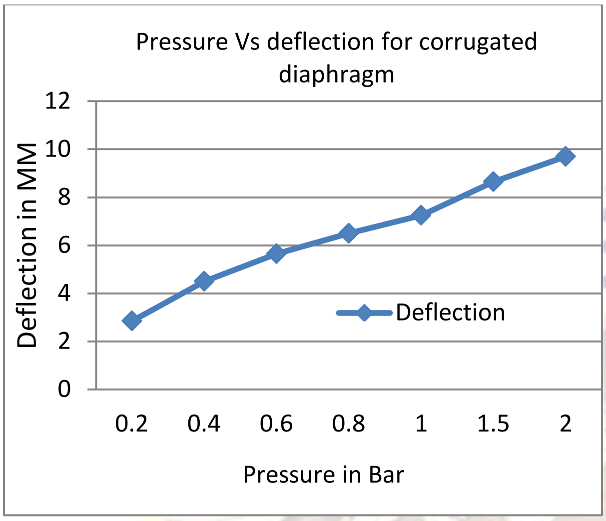


Figure 4: Pressure- deflection plot for corrugated diaphragms

IV. SIMULATION

For both the diaphragm models finite element analysis (FEA) is carried out with the help of ANSYS simulation software. Results obtained from the ANSYS based FEA of flat & corrugated diaphragm are presented and analyzed in this section. Additionally, analytical model based preliminary results are used to validate the FEA simulations. Deformation results achieved from FEA and the analytical model for both flat & corrugated are presented in figure (5) & figure (6) respectively.

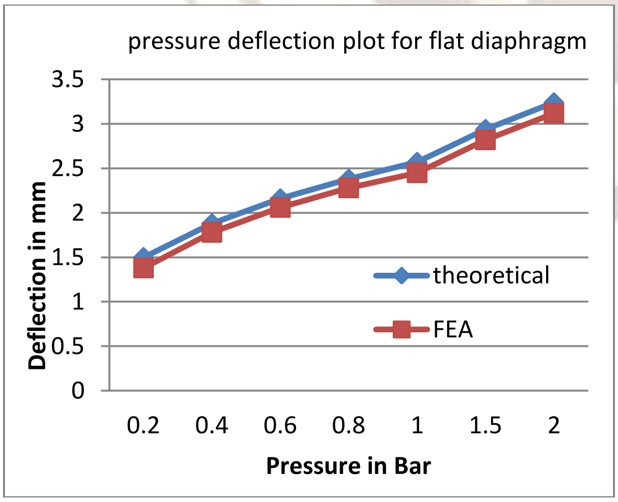


Figure 5: Theoretical & FEA results of deflection plot for flat diaphragm

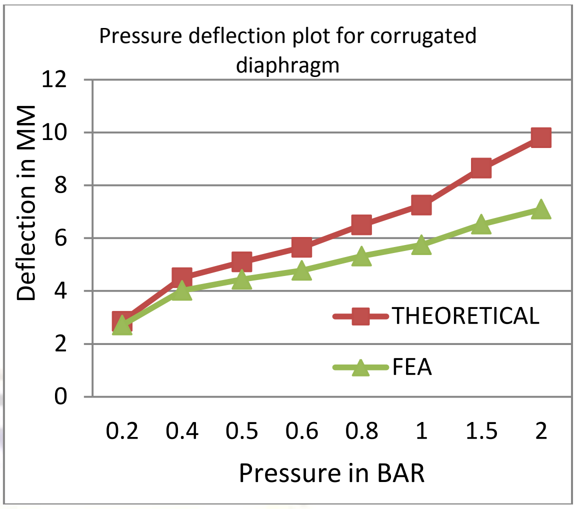


Figure 6: Theoretical & FEA results of deflection plot for corrugated diaphragm

V. RESULTS AND DISCUSSION

Pressure deflection relationships for flat & corrugated diaphragms have been presented in figure 2 & 4 respectively. Results shows that corrugated diaphragms give larger deflection than flat diaphragm at same working pressure. Following figure shows deflection obtained for flat & corrugated by using ANSYS simulation software at pressure of 0.2 Bar. It shows flat diaphragm deflects 1.3 mm while corrugated diaphragm deflects 2.7 mm at 0.2 bar pressure.

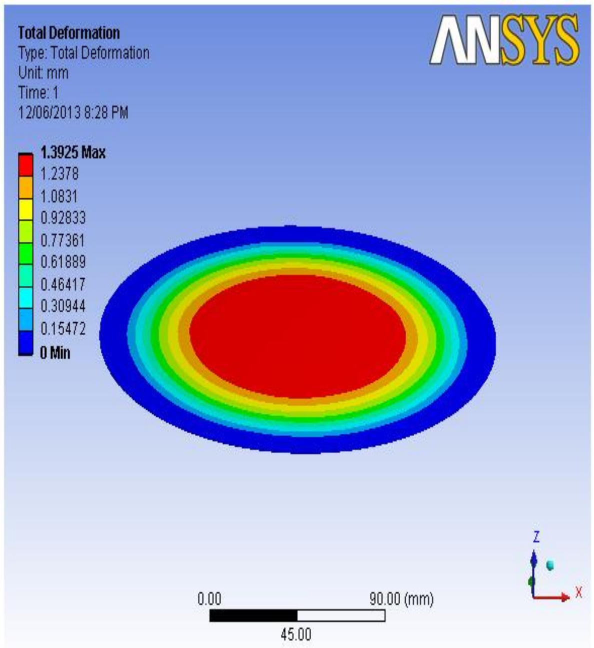


Figure 7: Deflection analysis of flat diaphragm at pressure of 0.2 bar using ANSYS 11 workbench simulation

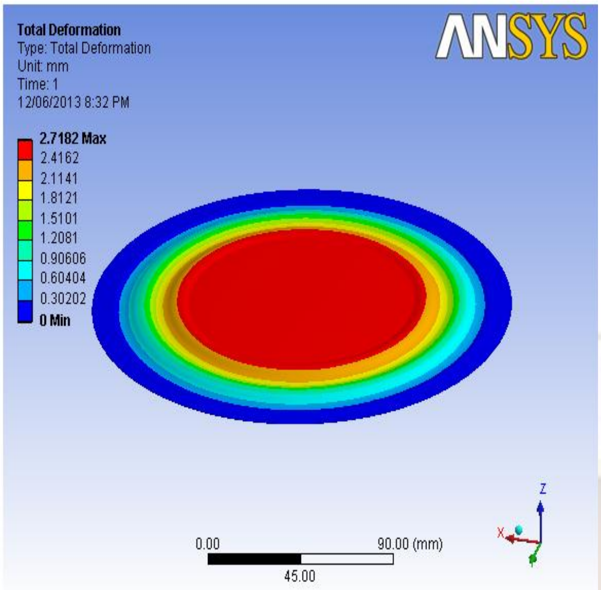


Figure 7: Deflection analysis of corrugated diaphragm at pressure of 0.2 Bar using ANSYS 11 workbench simulation

VI. CONCLUSIONS

Corrugated diaphragm deflects more than flat at same working pressure. The sensitivity of corrugated diaphragm can be easily controlled as per application by changing the geometric parameters such as thickness of sheet (h), depth of corrugation (H), Pitch of corrugation (l). Simulation result has good agreement with theoretical result.

REFERENCES

[1] M. Di Giovanni, "Flat and Corrugated Diaphragm Design Handbook", Marcel Dekker, New York, 1982.

[2] Patrick R. Scheeper, Wouter Olthuis, Piet Bergveld, "The Design, Fabrication, and Testing of Corrugated Silicon Nitride Diaphragms", journal of microelectromechanical systems, vol. 3, no. I, 1994.

[3] C. J. Van Mullem, K. J. Gabriel, H. Fujita, "Large deflection performance of surface micro machined corrugated diaphragms," Dig.Tech. Papers, Transducers 91, San Francisco, June 1991.

[4] Don W Dissanayake, Said Al- Sarawi, Tien-Fu Lu & Derek Abbott, "Finite element modeling of surface acoustic wave device based corrugated Micro diaphragms", Smart materials and structures, 2009.

[5] Wonchul Sim, Byungkyu Kim, Bumkyoo Choi, Jong-Oh Park, "Thermal and load-deflection FE analysis of Parylene diaphragms", Technical Proceedings of Fifth International Conference on Modeling and Simulation of Microsystems USA, 2002.

[6] Ansys Inc., Structural analysis online tutorial, Help document available with ANSYS 11.