Load-Deflection Analysis of Flat and Corrugated Stainless Steel Diaphragms

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Abstract- In this study analytical model for flat and corrugated stainless steel (SS-304, ASTM A240) diaphragm 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 and experimental results.

Keywords – Corrugated diaphragm, PRV (Pressure Reducing Valve), geometry of diaphragms, stainless steel diaphragms, load-deflection characteristics

I. INTRODUCTION

Flat diaphragms show a nonlinear relation between the deflection and the applied pressure. For relatively small deflections, this relation is approximately linear. The nonlinearity for large deflections is caused by stress due to stretching of the diaphragm. It has been experimentally shown that corrugated diaphragms have a larger linear range than flat diaphragms, because of the achieved reduction of the radial stress in the diaphragm. The larger linear range compared with flat diaphragms; make 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. DIAPHRAGM STRUCTURE

The diaphragms used in this experiment are of two types. One is flat (planer) diaphragm and other is corrugated one. The material used for both the diaphragms is stainless steel (SS 304 ASTM-240). Flat circular diaphragm the size is 190 mm in diameter and 0.25 mm in thickness. For the corrugated diaphragms depth, pitch and number of corrugations are 2mm, 18 mm and 2 respectively. The solidity ratio used for both the diaphragm is 0.50.

III. THEORY

A. *Load deflection relationship in flat diaphragm –*

The pressure - deflection relationship for a pressure loaded diaphragm is linear for only small deflections as already indicated. When diaphragm rigidly clamped at the edge, is deflected even 10 % of its thickness, tensile stresses begin to appear. As the load continues to increase, the deflection increases at a slower rate and load - deflection relationship becomes nonlinear.

$$P = \frac{Eh^3}{A_p a^4}(y) + \frac{B_pEh}{a^4}(y^3)$$

Where P is applied pressure, E is Modulus of elasticity of material h is thickness of diaphragm, a is radius of diaphragm, Y is center deflection, Ap is Stiffness coefficient for the linear term which depends upon solidity ratio (b/a) and Bp is Stiffness coefficient for nonlinear term which depends upon solidity ratio (b/a).

Table -1 Pressure versus deflection- flat diaphragm

Y (mm)	1.5	1.88	2.16	2.38	2.57	2.94	3.24	5
P (Bar)	0.2	0.4	0.6	0.8	1	1.5	2	7.3

B. Load deflection relationship in corrugated diaphragm --

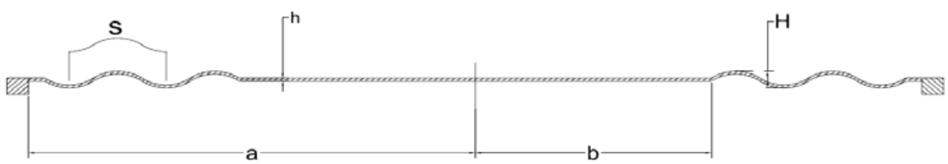

Figure 1. Cross section of circular corrugated diaphragm and characteristic parameters

The characteristic equation for the corrugated diaphragm with rigid center is different from flat diaphragms; the Cross- section of a circular corrugated diaphragm is as shown in FIGURE-1. The pressure –deflection relationship for corrugated diaphragm is as below,

$$\frac{Pa^4}{Eh^4} = \frac{K_pA_p(y)}{h} + \frac{LpBp(y^3)}{h^3}$$

In above equation the values of constants Ap & Bp which are bending and tension coefficient respectively depends upon the profile factor (q). The values of constants Kp & Lp which are bending and tension stiffness coefficients respectively depends on the profile factor (q) & solidity ratio (b/a). Values of these constants are taken from graphs. P is applied pressure, E is Modulus of elasticity of material h is thickness of diaphragm, a is radius of diaphragm, Y is center deflection.

Table -2 Pressure versus deflection- corrugated diaphragm

Y (mm)	2.85	4.5	5.65	6.5	7.25	8.65	9.8	16.05
P (Bar)	0.2	0.4	0.6	0.8	1	1.5	2	7.3

IV. SIMULATION

The load-deflection analyses are performed to obtain load-deflection relationship of both flat and convoluted diaphragms. FE analysis is necessary in order to model and simulate the flat and corrugated diaphragm in order to validate the results obtained from the theoretical load deflection analysis. The commercial finite element simulation software ANSYS is used for the simulation.

V. EXPERIMENT

The experimental setup for measuring load- deflection of a diaphragm is as shown in Figure 2. The diaphragm is mounted in between two pressure chambers and clamped with bolts. These diaphragms are tested under various pressures and then the corresponding deflection is measured using mechanical dial gauge. The dial gauge has least count of 0.01 mm. The applied pressure is monitored by a pressure gauge as shown in FIGURE-2.

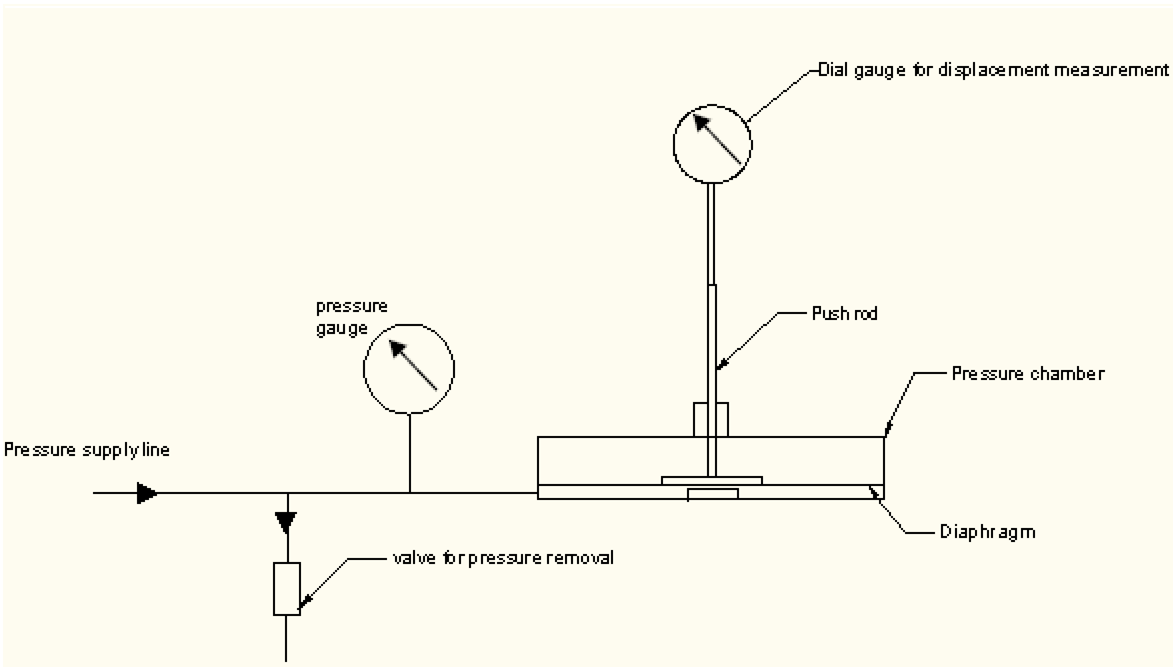

Figure 2. Schematic of test setup for pressure deflection analysis of diaphragm

VI. CONCLUSION

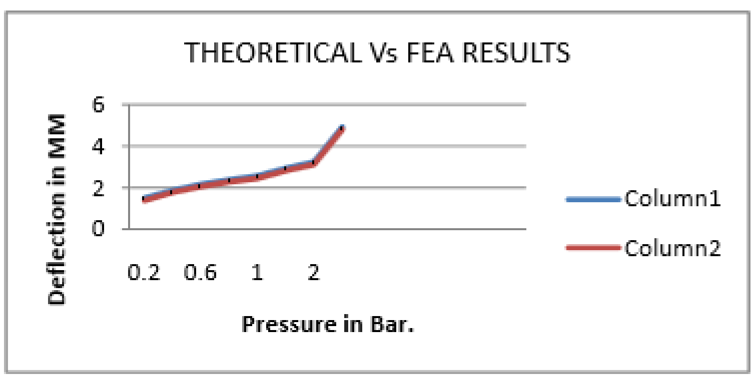

Figure 3. Theoretical vs. FEA results

Above graph shows that good agreement of theoretical and F. E. analysis results of load- deflection for flat diaphragm. Based on results, the convoluted diaphragms are more sensitive than flat diaphragms of same size. Sensitivity can be controlled by changing geometric parameters such as depth of corrugations & thickness of diaphragms.

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