MEMS PRESSURE RELIEF VALVE: DESIGN, MODEL AND STATIC ANALYSIS

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Abstract – In this paper, the utility and applications of a MEMS Pressure Relief Valve (MPRV) are discussed. In addition, the design of a new MPRV is presented and modeled. Simulating stress analysis has proven the valve useful for driving pressures up to 10atm.

Keywords: Pressure relief valve, MEMS, Simulation, Analysis.

1. INTRODUCTION

In any microfluidic system, valves play an important role. Nowadays, an increasing number of microfluidic systems are devoted to the fluidic analysis and classification, especially in biological, chemical and medical fields.

MPRV is a safety device for a pressurized system. MPRV is designed to safely relief pressure in a system in case of an unexpected pressure increase. It can be operated either actively with the help of an electric signal or passively, by using a diaphragm (burst membrane). This device is commonly used in pressurized systems onboard satellites and biomedical instruments. This paper puts forward a novel approach in designing and analyzing an MPRV.

2. SYSTEM ARCHITECTURE AND WORKING

The proposed model has a uniquely designed diaphragm (Refer Fig.4). The diaphragm divides the casing into two chambers, each having a diaphragm. The upper chamber acts as the set pressure holding chamber while the lower chamber acts as the exhaust chamber. The lower diaphragm has a smaller diameter when compared to the upper diaphragm. The lower diaphragm is subjected to the line pressure.

The valve is placed in-line with the pressure line. When the pressure in the line of flow exceeds the set pressure, the diaphragm is forced upwards and the fluid escapes through the bypass provided at the center of the diaphragm. Once the pressure equalizes, the diaphragm returns to the initial position. The set pressure acting on the upper diaphragm acts as an aid to retract faster. (Refer Fig 1.1)

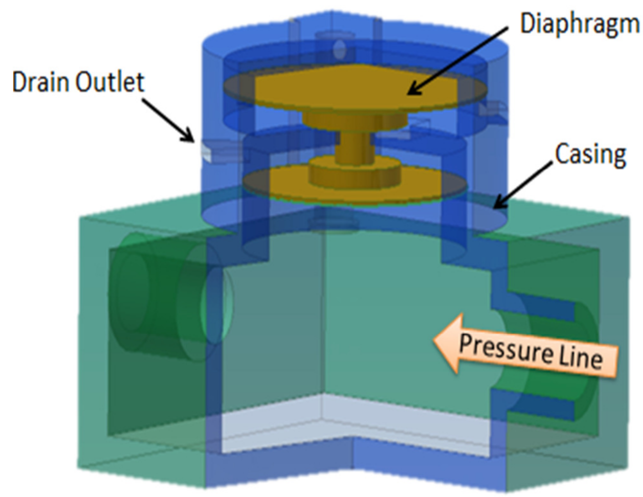

Figure 1 Valve Model

2.1 Details of Valve

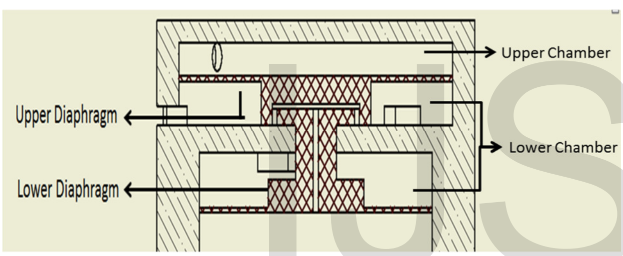

Figure 3 Valve cross-section

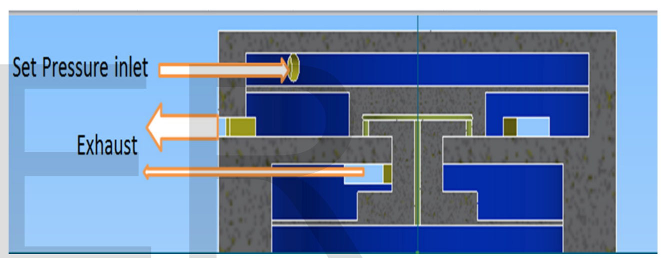

Figure 4 Valve cross section

2.2 Details of Diaphragm Material

TABLE I

Name	Silicon Nitride	
General	Mass Density	3.18 g/cm^3
	Yield Strength	610 MPa
	Ultimate Tensile Strength	610 MPa
Stress	Young's Modulus	427.18 GPa
	Poisson's Ratio	0.23
	Shear Modulus	173.65 GPa

2.3 Fundamental Formulas

The following fundamental formulas have been used in obtaining the design parameters of the valve. In the case of bending of thin plates, when in the plate is circular,

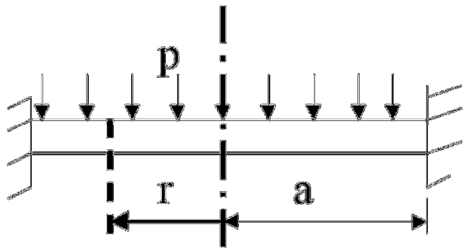

Figure 5 Pressure acting on circular diaphragm.

The maximum stresses in the r and θ-directions are:

$$(\sigma_{\theta\theta}) = \frac{3F}{4\pi t^2}$$

$$(\sigma_{rr}) = \frac{3vF}{4\pi t^2}$$

Where,
'F' is the force acting on diaphragm
F=P(Pressure).A(Area)
't' is the thickness of the diaphragm
The maximum deflection of the plate occurs at the center of the plate:

$$\delta_{\max} = \frac{3F(1-\nu^2)a^2}{16\pi E t^3}$$

'ν' is the Poisson's ratio
'a' is the radius of diaphragm
'E' is the young's modulus
To determine the pressure difference:

$$P_{set}.A_{upper} = (P_{set} + \Delta P).A_{lower}$$

$$\Delta P = \frac{P_{set}(A_{upper} - A_{lower})}{A_{lower}}$$

When ΔP is known ΔA can be found. From ΔA , ΔD can be found.

3. STATIC ANALYSIS AND SIMULATION

The model created in Autodesk Inventor was analysis was done focusing on the diaphragm. The normal working pressure was assumed to be 4bar and any pressure above 5.53bar would lift the diaphragm, thus relieving the pressure. We have analysed the system assuming an instance where the line pressure shoots to 7bar.

3.1. Operating Conditions

TABLE II

Load Type	Line Pressure	Set Pressure
Magnitude	0.700 MPa	0.400 MPa

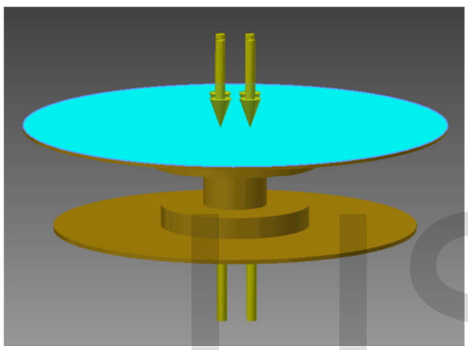

Figure 6 Area subjected Set Pressure.

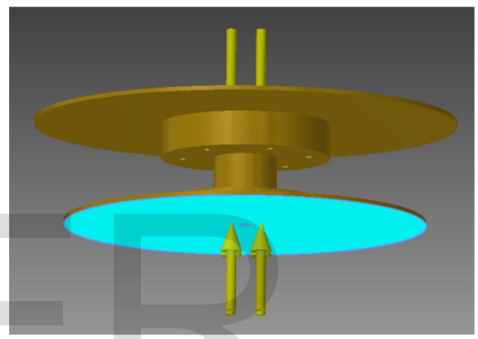

Figure 7 Area subjected Line Pressure.

Fixed Constraint

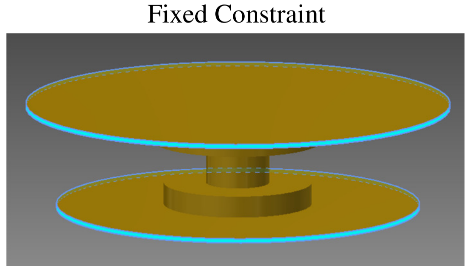

Figure 8 Constraint Face(s)

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TABLE III
Reaction force and momentum on constraints

Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Upper Diaphragm	0.14356 N	3366.36 μ N	1.2687 μ N m	0.968913 μ N m
		3904.56 μ N		-0.819067 μ N m
		0.143474 N		0 N m
Lower Diaphragm	0.23201 N	-3363.13 μ N	0 N m	0 N m
		-3858.49 μ N		0 N m
		-0.231962 N		0 N m

TABLE IV
Result summary

Name	Minimum	Maximum
Volume	0.0293192 mm^3	
Mass	93.235x10^-9 kg	
Von Mises Stress	0.861291 MPa	149.862 MPa
Displacement	0 mm	0.000374492 mm
Safety Factor	4.07041	15
1st Principal Stress	-49.0547 MPa	173.943 MPa
3rd Principal Stress	-178.318 MPa	45.6228 MPa
X Displacement	-0.000185.658 mm	0.0000223681 mm
Y Displacement	-0.0000313374 mm	0.000266646 mm
Z Displacement	-0.000191179 mm	0.0000223041 mm

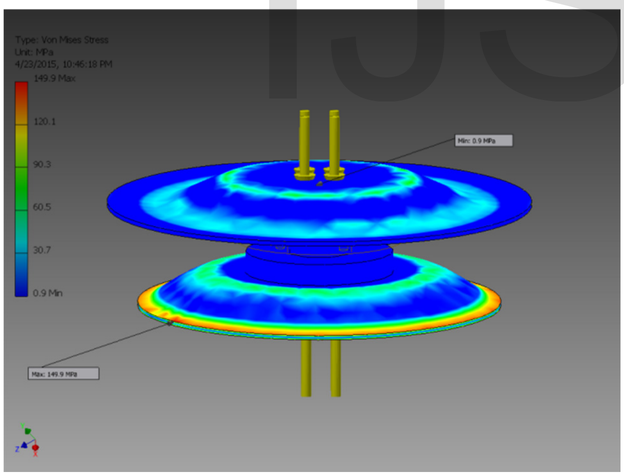

Figure 9 Von Mises Stress (isometric top view)

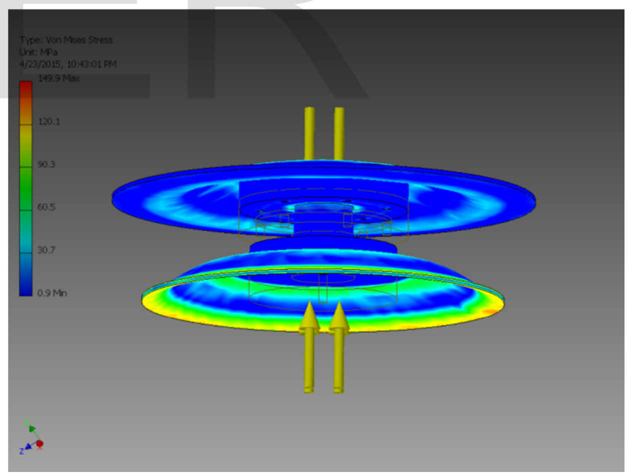

Figure 10 Von Mises Stress (isometric bottom view)

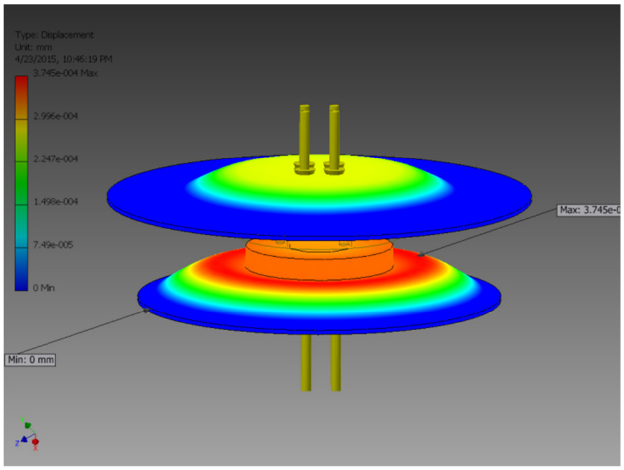

Figure 11 Displacement

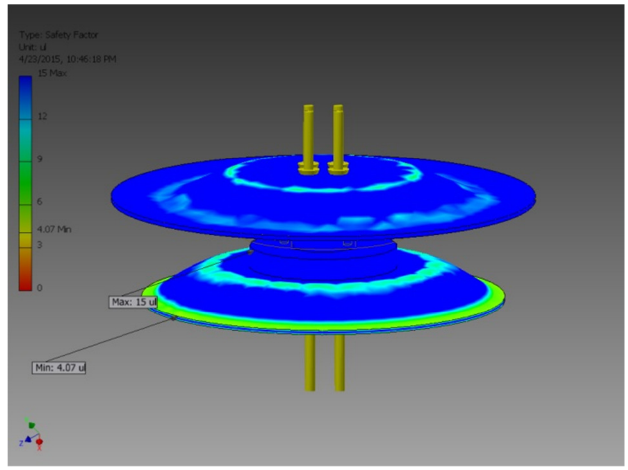

Figure 12 Safety Factor

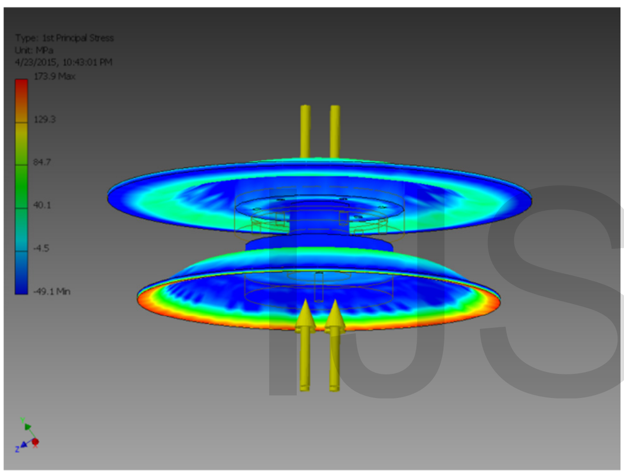

Figure 13 1st Principal Stress

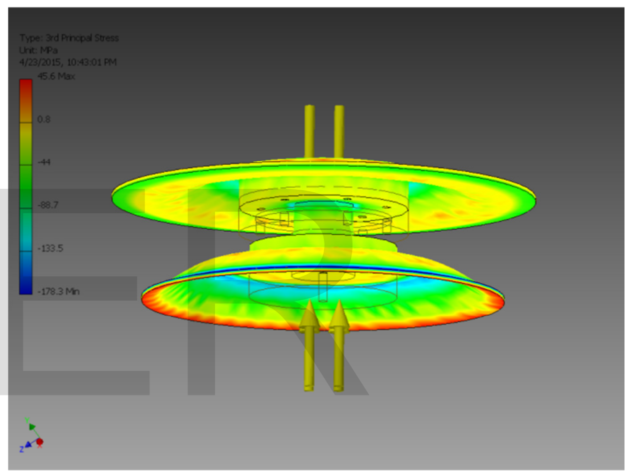

Figure 14 3rd Principal Stress

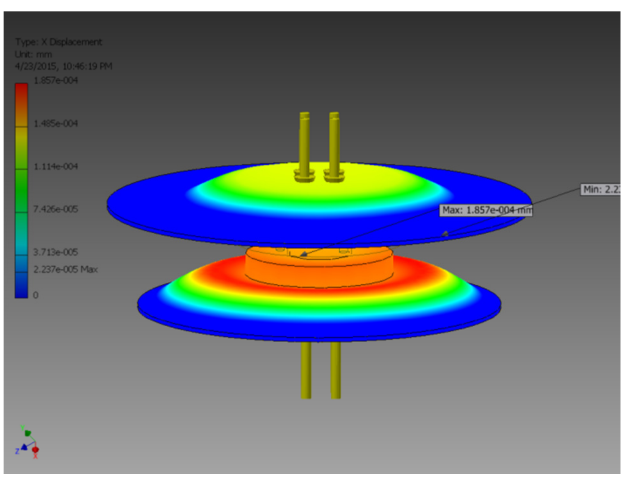

Figure 15 X Displacement

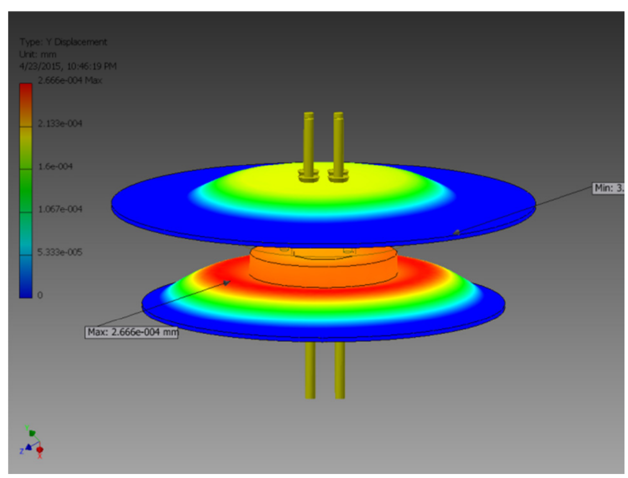

Figure 16 Y Displacement

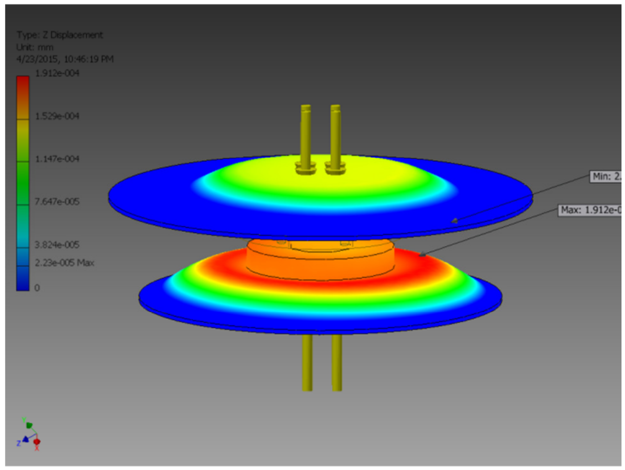

Figure 17 Z Displacement

4. CONCLUSIONS

A valve capable of maintaining pressure has been presented. The valve actuation is based on the principle of pressure difference. The difference in pressure will be accounted by the area difference. Thus a wide range of pressure control can be achieved.

Also, formulating the design specifications static analysis of the model has been presented and simulated.

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