Determination of Pressure Distribution at Interface for Hyper-elastic Material Using FEA

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Abstract

An elastomer is a polymer which shows non-linear elasticstress-strain behavior. The term elastomer isoften used torefer to materials which show a rubber-like behavior. Elastomeric materials are elastic in the classical sense. Uponunloading, the stress-strain curve isretraced and there is nopermanent deformation. Elastomeric materials are initiallyisotropic.

For electric appliances such as autoclosures, there is always use of hyper elastic materials such as elastosil for zero gap formation between pole and assembly. So it is necessary to check with different model designs, how contact pressure created between interface for hyper elastic material and pole surface.

Keywords

Hyper Elastic Material, Mooney Rivlin Parameters, Uniaxial and Biaxial Loading

I. Introduction

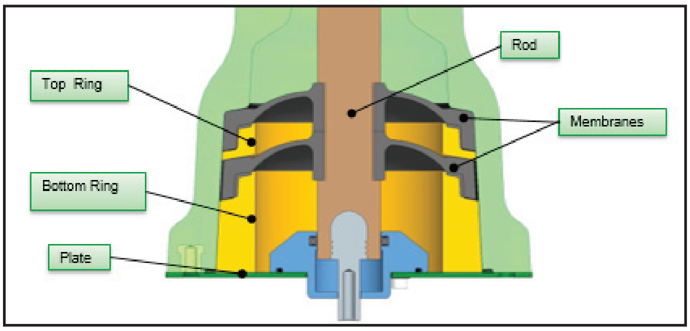

Fig. 1: Assembly for Auto-closure

The function of the membranes at the bottom of the pole is to insulate between the Sliding Contact and the Pole Plate.The membrane also needs to be flexible enough not to add too much resistance to the movement of the rod which in turn will impact the movement of the actuator.The pole and rod is made of epoxy material, while rings are made up of Plastic material. Bottom plate is made of steel. The Membranes are made from Elastosil material silicon rubber.

During operation, top membrane is pushed over rod. Top ring is pushed into bottom of top membrane. Bottom membrane stretched over rod and pushed against top membrane. Bottom locating ring pushed into bottom of bottom membrane.Plate assembled to base of rod using bolts.This will compress all the membranes against each the pole and locating rings.The rod is pulled by an actuator at the base of the pole to open the contacts.When the rod moves down, the Membrane inside moves together with the rod while the Membrane outside remains static.The rode is expected to manage 20000 open and close operations of over the switches life time.

II. Theory for Hyper Elastic Material

Hyperelastic material also is Cauchy-elastic, which means that the stress is determined by the current state of deformation, and not the path or history of deformation The difference to linear elastic Material is, that in Hyperelastic material the stress-strain relationship derives from a strain energy density function, and not a constant factor This definition says nothing about the Poisson's ratio or the amount of deformation that a material will undergo under loading However, often elastomers are modeled asHyperelastic. Hyperelastic Material models predict large-scale material deflection and deformations. Different material models Basically 2 types,

- Incompressible (Mooney-Rivlin Arruda-Boyce Ogden)
- Compressible (Blatz-Ko Hyperfoam)

Mooney-Rivlin works with incompressible elastomers with strain up to 200%. For example, rubber for an automobile tyre.Arruda-Boyce is well suited for rubbers such as silicon and neoprene with strain up to 300%. this model provides good curvefitting even when test data are limited. Ogden works for any incompressible material with strain up to 700%. This model gives better curve fitting when data from multiple tests are available.Hyperfoam can simulate any highly compressible material suchas a cushion, sponge or padding.As Membranes are showing strains up to 200%, we have decided to prepare Mooney Rivlin model.

III. Tests to Determine Hyperelastic Material Parameters

For Hyperelastic materials, simple deformation tests (consisting of six deformation models) can be used to determine the Mooney-Rivlin Hyperelastic material.Accurate modelling of Hyperelastic materials require material properties data measured to large strains under different states of stress. In Hyper elasticity the strain energy density is modelled as a function of the deviatoric (shear) and volumetric components of the strain tensor. A common assumption made, particularly for rubbers, is that the material is incompressible. Therefore, the volumetric terms can be set to zero. Only the shear terms need be considered.However, this assumption may not strictly hold for all flexible materials.

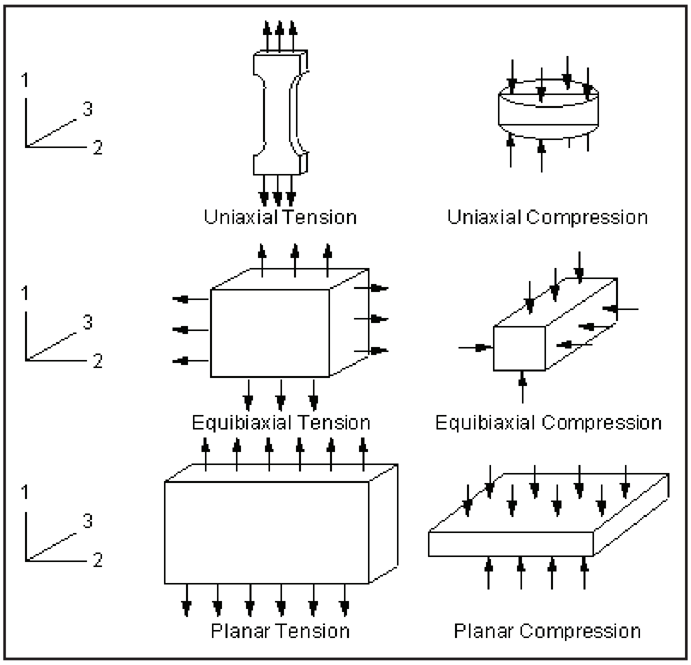

Fig. 2: Deformation Test

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Test data are required under conditions of plane stress (uniaxial tension), plane strain (planar tension) and equi-biaxial stress (equi-biaxial tension) in order to accurately model the Hyperelastic materials under multi-axial states of stress. Even though the superposition of tensile or compressive hydrostatic stresses on a loaded incompressible body results in different stresses it does not alter deformation of a material. Upon the addition of hydrostatic stresses ,the following modes of deformation are found to be identical.

1. Uniaxial tension and Equibiaxial compression,
2. Uniaxial compression and Equiaxial tension, and
3. Planar tension and Planar Compression.

It reduces to 3 independent deformation states for which we can obtain experimental data.

FEA software can calculate model coefficients from least squares fits to this data. Checks should be made on the quality ofthe agreement between the derived material models and the input data.Materials such as flexible adhesives are likely to have strain rate and temperaturedependent properties. Tests for characterising the properties for the Hyper-elasticmodels mustbe carried out at the same temperature and at comparable strain rates.

For incompressible materials, the state of strain in the material is the same as that in simple compression (if free from friction!). The measured experimental parameters are radial strain and stress. These biaxial strains and biaxial stresses can be converted directlyto compression strains and compression stresses as follows:

$\boldsymbol{\sigma}_c = \boldsymbol{\sigma}_b\,(1 + \varepsilon_b)^3$

$\varepsilon_c = 1/\,(1 + \varepsilon_b)^2 - 1$

$\boldsymbol{\sigma}_c$: nominal compression stress

$\boldsymbol{\sigma}_b$: nominal biaxial extension stress

ε_c : nominal compression strain

ε_b : nominal biaxial extension strain

IV. Determining Constants for Mooney Rivlin

Hyper elastic material used for membrane is Elastosil. The test laboratory provided the values for uniaxial loading (Tensile and compression) and Volumetric loading for three different temperatures for this material (at -40, Ambient, 100 °C). Using these values, Mooney Rivlin parameters are calculated. Ansys uses least square method to fit best possible curve for material modelling.

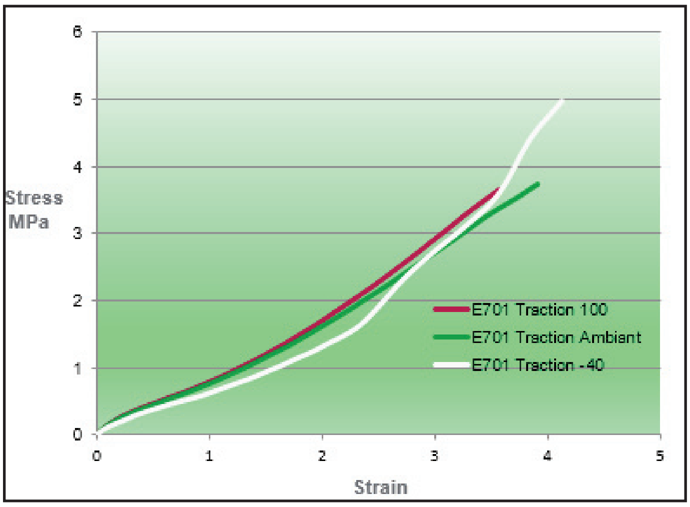


Fig. 3: Stress Strain Values for Traction Case

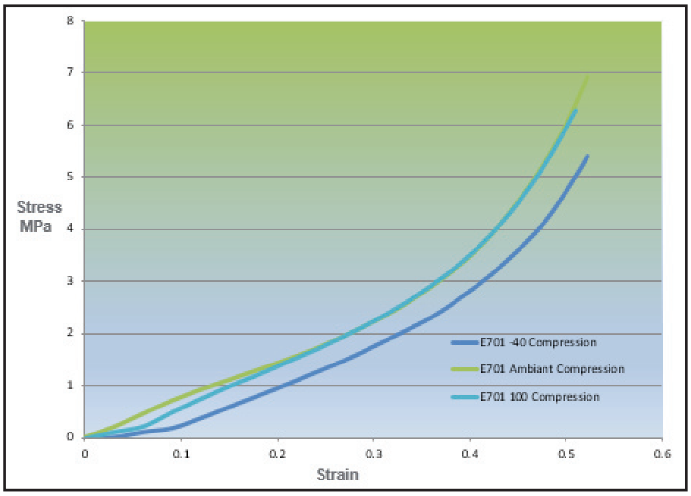


Fig. 4: Stress Strain Values for Compression Case

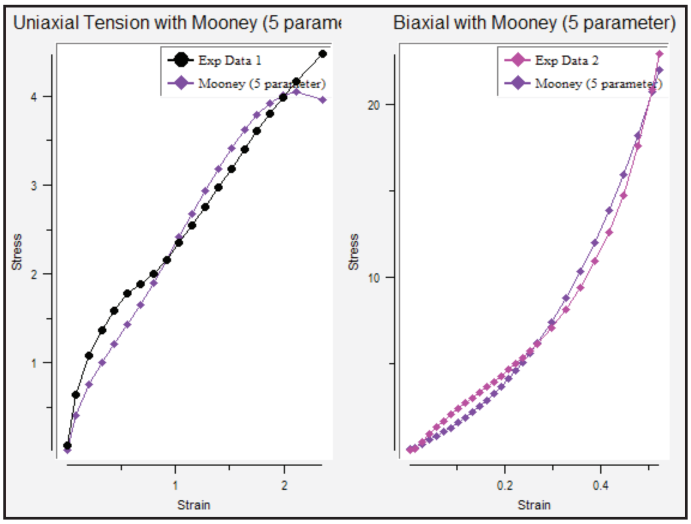


Fig. 5: Fitting Curve in Ansys for Mooney Rivlin

Based on above data, following values for Mooney Rivlin 5 parameter has been derived for 3 different cases of temperature.

Table 1. Mooney Rivlin Parameters

Temperature	Material Constant C10 (MPa)	Material Constant C01 (MPa)	Material Constant C20 (MPa)
-40	-0.17104	0.36474	-0.0079191
23	-0.49309	0.9696	-0.048568
100	-0.51146	1.0118	-0.056089
Temperature	Material Constant C11 (MPa)	Material Constant C02 (MPa)	Imcompressibility Parameter D1
-40	0.079957	-0.008509	0.010325
23	0.29794	-0.2279	0.0041972
100	0.33236	-0.25616	0.0039976

Table 2: Thermal Coefficient of Expansion for Epoxy

	A	B
1	Temperature (C)	Coefficient of Thermal Expansion (C^-1)
2	-40	3.2E-05
3	23	3.75E-05
4	100	4.4E-05

For Elastocil, thermal coefficient of expansion does not change with temperature and value considered is 0.000289 / C.

V. Simulation Methodology

Rod bolted to sliding contact.top membrane stretched over rod. Top Ring pushed into bottom of top membrane.Bottom membrane stretched over rod and pushed against top membrane.Bottom ring pushed into bottom of bottom membrane.Plate assembled to base of Pole using bolts – this will compress all the membranes against each the Pole and locating rings.Rod is pulled by an Actuator at the base of the pole (not shown) to open contacts.When the rod moves down, the membrane inside moves together with the rod while the membrane outside remains static.The travel of the rod is 19 mm.The speed of travel is 1.3 m/sec.The pole is expected to manage 20000 open and close operations of over the switches life time.

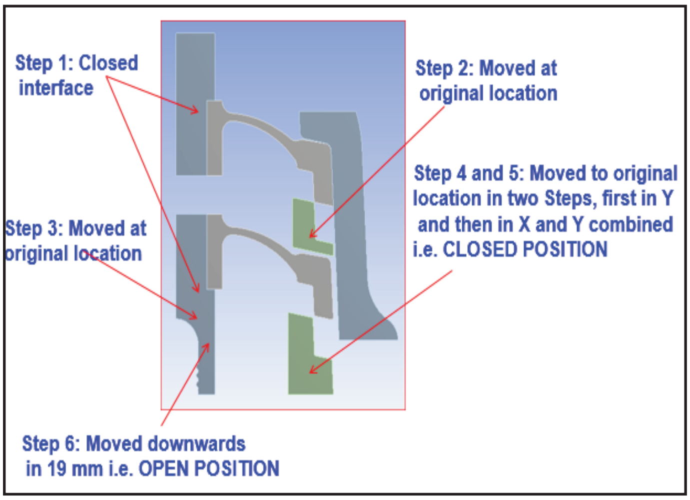


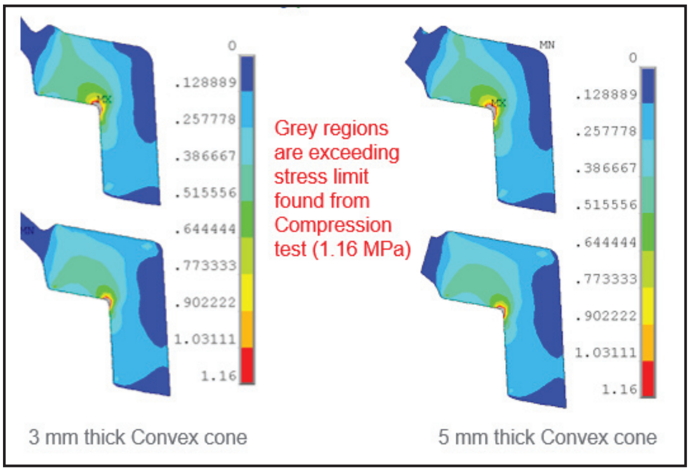
Fig. 6: Simulation sequence

VI. Result Discussion

Two types of membranes for this analysis has been considered, one with 3 mm convex cone and other with 5 mm convex cone. We have used same material properties for these two cases, same boundary conditions and same pushing displacement.

For comparison we have used following parameters:

1. Displacement Pattern
2. Von Misses Stress Results
3. Von Misses Strain Results
4. Interface Pressures
5. Pulling Force Generated for Applied Displacement
6. Radial Force Generated for Applied Displacement



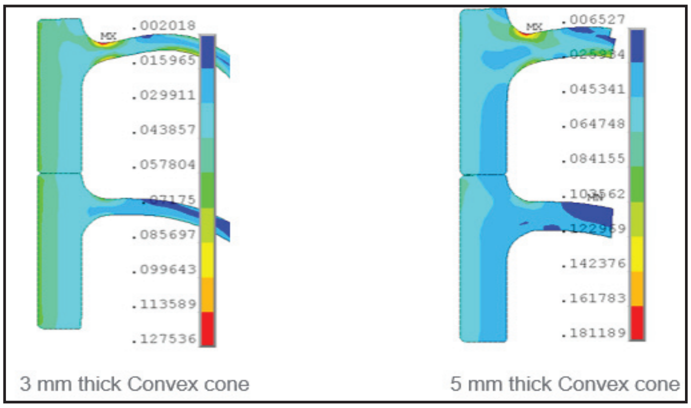


Fig. 7: Von-mises stress (Assembly)

To consider the effects of different temperature conditions on gap creation for elastic material, 4 cases created in analysis.

- **CASE 1:** Assembled, in the closed position and then change states to the open position in ambient temperature.
- **CASE 2:** Assembled in ambient temperature, then drop temperature to -40°C for the closed position then change states to the open position.
- **CASE 3:** Assembled in ambient temperature, then raise temperature to +100°C for the closed position then change states to the open position.
- **CASE 4:** Assembled in ambient temperature, then raise temperature to +100 while in closed position, then drop to -40°C, then change states to open while at -40°C.

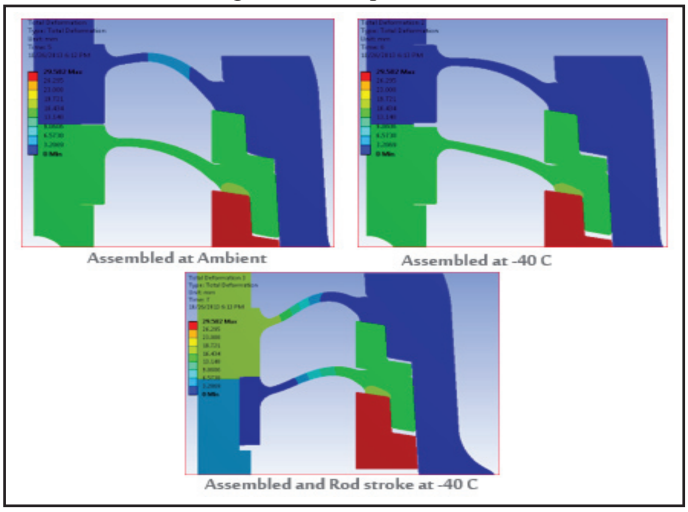


Fig. 7: Total Deformation at -40 C (Assembly)

It can be clearly seen that; gap is increased in size due to thermal condition of -40 C.

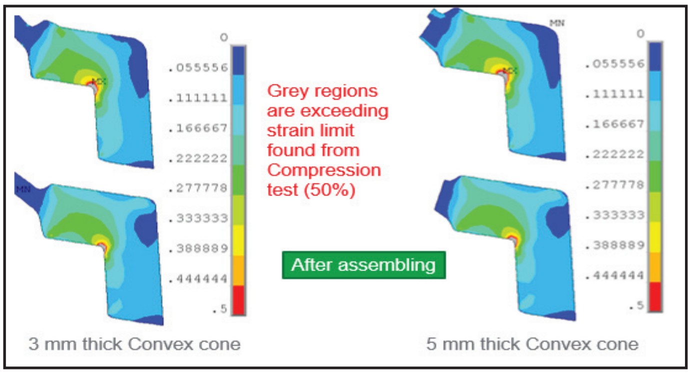


Fig. 8: Strain Pattern After Assembling

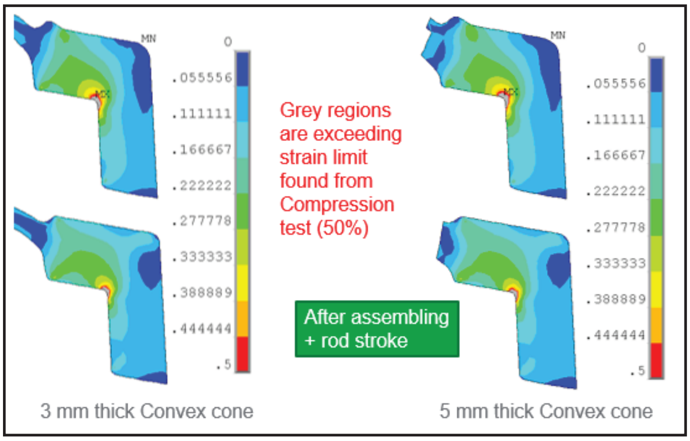


Fig. 9: Strain Pattern After Assembling and Rod Stroke

The strain valuehas been observed with more than 50 %. After pole stroke (opening of contact) we can see gray region which is showing strain values above 50 %.

Pressure distribution can be evaluated from analysis for interference between membrane parts and rod assembly. When pressure value at interface goes below 0 MPa, we can conclude that, there is possibility of formation of gap.

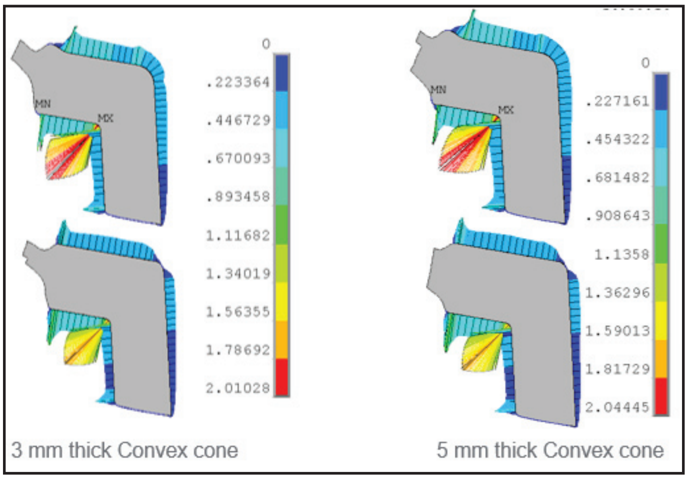


Fig. 10: Pressure Distribution Pattern After Assembling

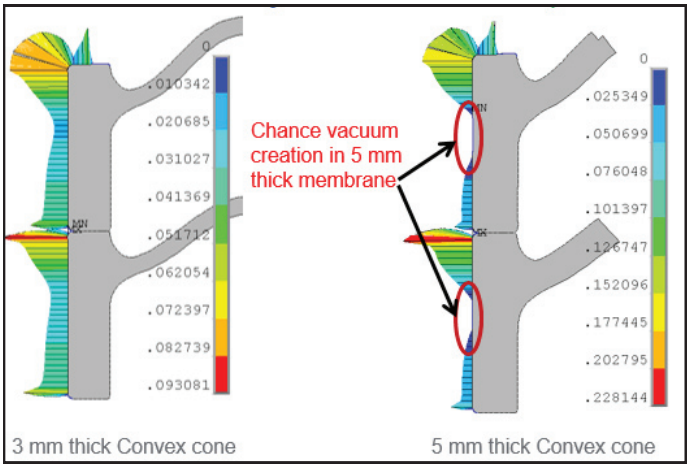


Fig. 11: Pressure Distribution Pattern After Assembling and Rod Stroke

From fig. 8, It can be observed that, there is chance of vacuum creation at interface between rod and membrane.

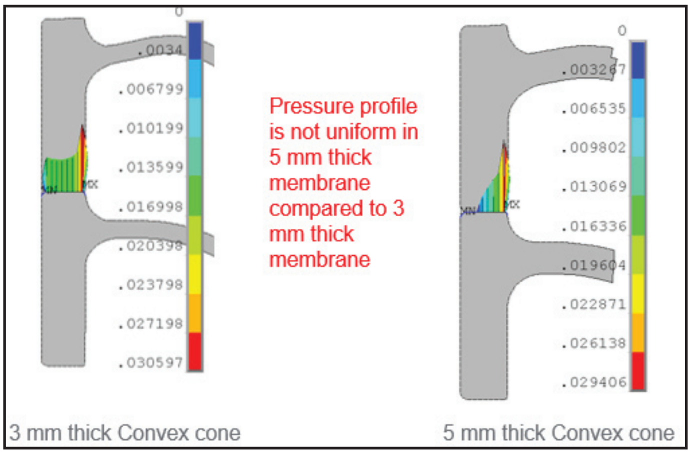
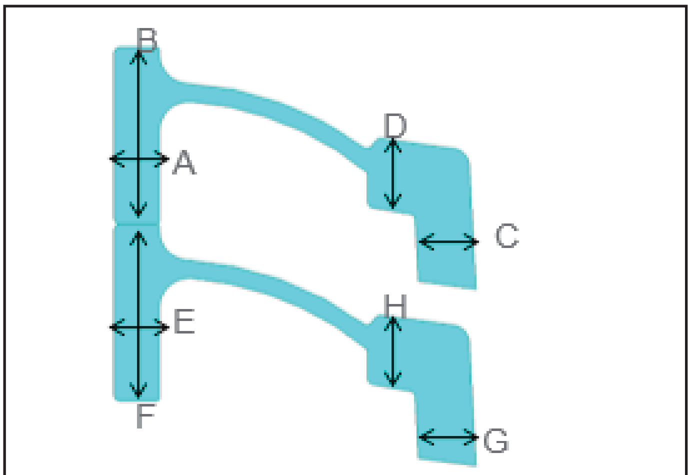


Fig.12: Pressure Distribution Pattern After Assembling

It can be observed that for 3 mm thickness membrane, pressure is more uniform as compared to 5 mm thickness membrane.

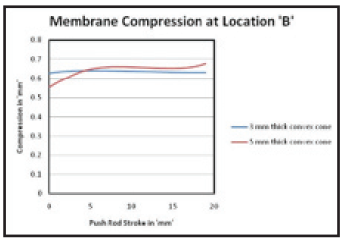
A. Membrane parameters before and after assembling

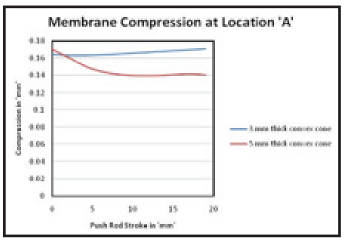
Table 3: Thickness Parameters for Membranes



	Value in 'mm'	
	3 mm thick convex cone	5 mm thick convex cone
Location 'A'	0.16	0.17
Location 'B'	0.63	0.55
Location 'C'	0.77	0.77
Location 'D'	1.94	1.94
Location 'E'	0.20	0.21
Location 'F'	0.46	0.31
Location 'G'	0.75	0.75
Location 'H'	1.79	1.88

As it is observed that, during rod stroke, there is possibility of vacuum creation, it will be good to check the thickness change in membranes after rod stroke.





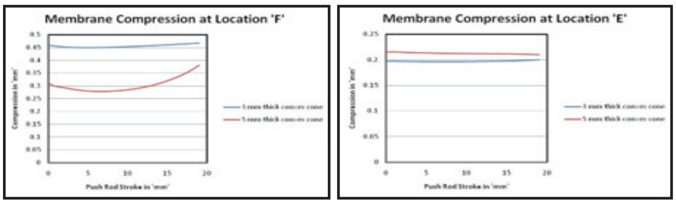


Fig. 13: Thickness Change in Assembling After Rod Stroke

No dimensional change has been observed for C, D, H, G parameters. As membrane gets compressed between plastic rings and pole, there will be resistance force from membrane on rod and pole.

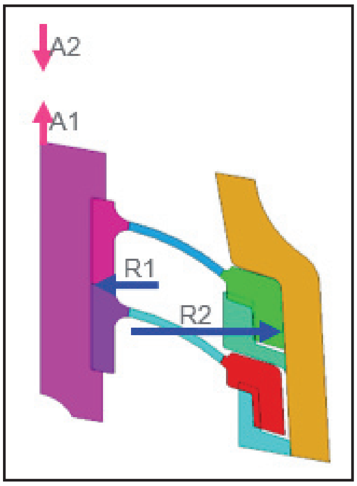


Table 4: Force resistance from Membrane

	Values in "N"	
	3 mm Thick convex cone	5 mm thick convex cone
Radial force on Rod : R1	226	279
Axial force on Rod : A1	12	44
Radial force on Plastic ring : R2	841	941
Axial force on Plastic ring : A2	12	44

VI. Conclusion

Rod pushing force required almost 3 to 3.5 times more for 5 mm thick membrane compared to 3 mm thick membrane. Membrane stress and strain is exceeding limit of compression test results at location ring corner for both 3mm and 5mm thick and both top and bottom membranes. Rod side pressures are not uniform in 5 mm thick membrane compared to 3 mm thick membrane.Rod pushing force required almost 3 to 3.5 times more for 5 mm thick membrane compared to 3 mm thick membrane.

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