Investigation of Reaction Forces In Diaphragm Using Finite Element Analysis

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Abstract : In wide range of applications like in medical technology, environmental protection/analysis, in the Laboratory or process engineering the use of mechanically driven diaphragm pumps became indispensable. Their particular properties such as oil-free, maintenance-free and uncontaminated operation make them suitable for numerous fields of application. The objective of the present work is to find out the reaction forces to move the diaphragm in forward and backward direction. In this number of load steps are involved in forward and retraction strokes with varying pressure applied on the diaphragm and Calculated the stress imparted on the diaphragm. A global finite element analysis is carried out to arrive at the values of stresses and displacements in critical components and reaction forces, finally from the results it is concluded that the structure is safe and has an adequate margin of safety.

***Index Terms* - Diaphragm, Reaction Forces, Liquifarm, Finite element analysis, Load steps**

I. INTRODUCTION:

The basic construction of a diaphragm pump is simple. An elastic diaphragm , clamped, pressure-tight, between the pump head and the housing, separates the transfer compartment from the interior of the housing[1]. The diaphragm is connected, pressure tight, to the connecting rod with the diaphragm-fixing screw . A drive in the interior of the housing sets the connecting rod in oscillation and causes the diaphragm to move up and down. In the downward thrust, the diaphragm sucks in the medium via the suction valve . In the upward thrust, it forces out the medium via the pressure valve[2] .

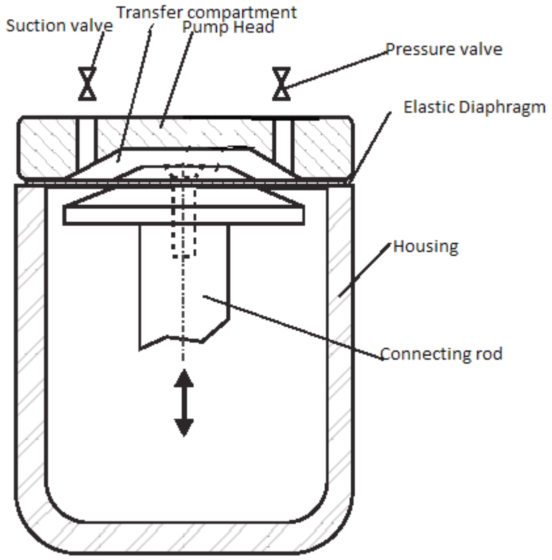

Fig. 1.Basic construction of a diaphragm pump

1.1 Characteristics of diaphragm pumps:

Because of their design principle, diaphragm pumps possess a range of special properties. One of the most important is their being free of oil. In contrast to a piston compressor whose cylinder course must generally be lubricated, a diaphragm pump, thanks to its elastic diaphragm, requires no lubricating[3][4]. Consequently, no grease can come into contact with the gases to be transferred or compressed. They are, therefore, neither contaminated by foreign matter nor by their combustion residue. The oil-free operation of the diaphragm pump has demonstrated itself to be an important property, particularly in medical and analytical instrumentation.

An additional excellent property of diaphragm pumps is their high gas-tightness. Other compressors, working according to the piston principle, require seals for sealing the piston in relation to the compression chamber (e.g., piston rings or lip seals). This also applies in principle to rotating systems, such as multi-cell compressors, roots pumps, or vane pumps. As a result of these seals, a part, however small, of the transferred, compressed, or evacuated gases escapes. Due to the seals wearing and because of arising friction, the sealing properties are reduced so that with an increasing period of operation, the loss of gas increases. With diaphragm pumps, in contrast, the diaphragm is firmly fixed on the connecting rod as well as between the pump housing and pump head, and in both positions practically no fluid can escape. The fixed regions are static and consequently not exposed to wear. In the fixed regions, the diaphragm takes on the function of a flat seal. The double function of the diaphragm as a sealing organ and as a compressing organ allows for the simple and economic construction of the diaphragm pump. With the sealing of vapors and also with use as a vacuum pump, condensate may arise in the compression chamber. In pumps lubricated with oil, this results in contamination of the lubricating oil and often, as a consequence, the damaging of the pump because of increased friction[5]. Working without oil lubrication, the diaphragm pump does not have such difficulties. If, in extreme cases, so much condensate accumulates that, because of the internal resistance of the pump the drive motor is overloaded, it is sufficient to empty the compression chamber[5][6]. The pump will then continue to operate without fault.For applications in which the condensate produces corrosive properties, the Fluid transferring components of the diaphragm pump are made of corrosion resistant materials. For these applications, high-grade steel as well as appropriate plastics that are mechanically durable, non-abrasive, and temperature resistant can be used. Plastics are generally preferred in the case of pumps with less pneumatic performance, whereas with a larger constructional volume, high-grade steel or ceramics are used[7].

The only wearing parts of a diaphragm pump are the diaphragms and, to a small extent, the valves. In the case of pumps with an eccentric-operated diaphragm, the ball bearings can be added to this list and to linear pumps the armature spring. When correctly operated, diaphragm pumps can be considered maintenance-free. With the corresponding design of the pump (e.g., with durable ball bearings) only the diaphragms and perhaps the valves will require replacement after long intervals.

1.2 Fundamentals concerning diaphragms:

The heart of the diaphragm pump is the diaphragm. It not only gives the pump its name, but also provides it with the specific properties such as with the elimination of oil and fluid-tightness.The main function of the diaphragm is to displace the working fluid from the compression chamber. At the same time, it has to take over control of part of the connecting rod on the membrane side, in order to effect a linear movement. The importance of this control function should not be underestimated. For example, the greater the maximum flow required from a diaphragm pump, the greater the required compression ratio of the pump. This requires, at the upper dead point of the diaphragm, smaller distances between the diaphragm with the diaphragm fixing disk and the wall of the compression chamber. An exact linear guidance of the connecting rod ensures that neither the diaphragm nor its fixing plate strike the wall.In addition to the pressure force PD, the diaphragm must also take up the tractive power PF; this results from the stretching of the diaphragm Elastomers, as well as the diaphragm, deform under the transmission of forces, as the result of their elastic properties. If, in the neutral position of the diaphragm, the length between the diaphragm retainer on the pump head and on the connecting rod/retainer plate lo is at the lower dead point of the diaphragm roughly.

$$l_{UT}=\sqrt{(l_o^2+h_u^2)},$$

With the traverse h_u between the neutral position and the lower dead point. The deformation of the diaphragm resulting from this prevents the necessary precise linear guidance of the upper connecting rod component. In the vicinity of the upper dead point, there is consequently the danger that the diaphragm retaining plate may strike the housing or the inner wall of the compression chamber. If so, fracture of the connecting rod and mechanical damage to the diaphragm can be the consequence. In order to avoid such problems, diaphragms are equipped with a tissue insert to improve the absorption of the forces. The tissue is vulcanized in, in the neutral region of the diaphragm.

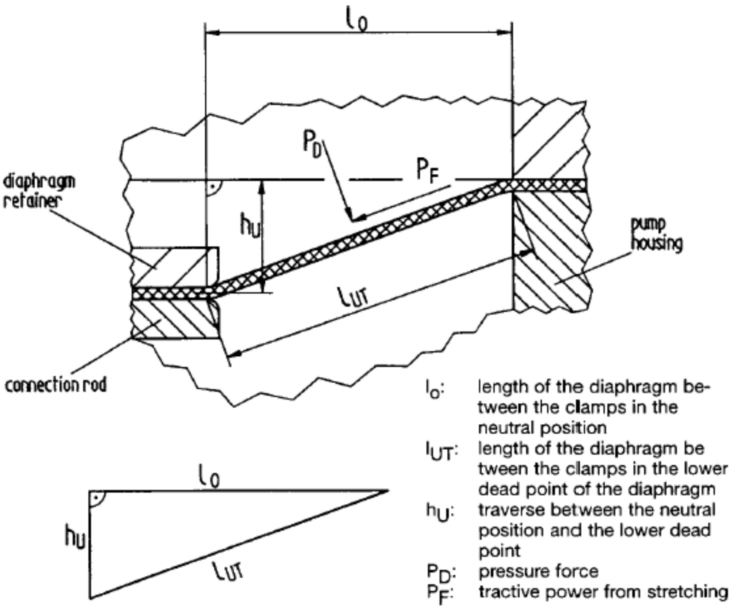

Fig.2 Length and force relationships on the diaphragm

Tissue with synthetic fibers has almost taken the place of natural fibers such as cotton or silk, in the technical field. Illustrates the most commonly used tissue materials and their physical properties. Deep-drawing quality and tensile strength refer to the processing of the tissue material.In the diaphragm, longitudinal stretching causes tensions. These can be calculated approximately using Hook's law for springs:

$$\sigma = E \times \varepsilon$$

(tension = elasticity modulus x extension)

$$\varepsilon = \frac{\Delta l}{l_o} = \frac{l_{UT} - l_o}{l_o}$$

(Extension = lengthening / initial length)

An exact calculation of the total strain on a diaphragm is very complicated. The most diverse factors having an effect are diaphragm strength, diaphragm hardness, operating temperature and type of tissue. All should be taken into account. What is also relevant is that the elasticity modulus of rubber-elastic materials is not constant, but can, for example, increase as well as decrease with stretching. In practice, diaphragm materials have stood the test with Shore A hardness values of between 50 and 60. When such materials are additionally equipped with a polyamide tissue, the longitudinal extension of e = 4% should not be exceeded. Lower extension values have a positive effect on the service life of the diaphragm. With diaphragm pumps with high outputs or low maximum pressures in the dead point of the diaphragm, the outer diaphragm region lies on the inner wall of the compression chamber because of the necessary small dead volume. In order that this 'touching' does not result in heavy wearing of the diaphragm, materials very resistant to abrasion must be used.

II. MATERIALS AND METHODOLOGY

In this work total five materials were used in diaphragm. In these there are five materials are used:

PTFE: Friction co efficient:0.6, Young's modulus:264.3 Mpa, Poisson's ratio:0.38, Yield strength:10.548 Mpa.

NYLON: Young's modulus:643.015 Mpa, Poisson's ratio:0.38

DACRON: Young's modulus: 140.797Mpa,Poisson's ratio:0.38

PFA: Young's modulus:60.76Mpa, Poisson's ratio:0.38

STEEL: Young's modulus:250 Mpa, Poisson's ratio : 0.38

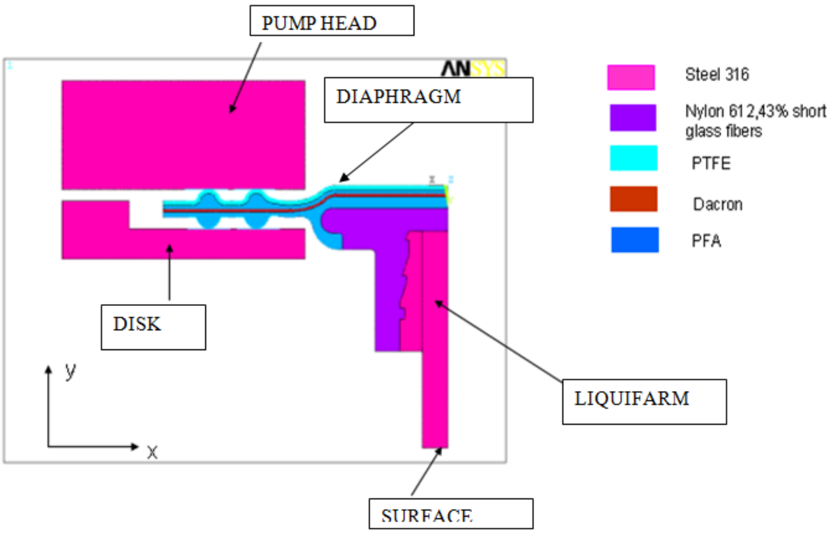

Fig 3. Model of the diaphragm

III.EXPERIMENTAL PROCEDURE:

In the analysis of the diaphragm under different strokes (forward & retraction) and number of load steps are involved. The objective of the present work is to determine the following:

"Pre load that would oppose forward movement of the diaphragm that resulted from the sealing bead installation clamping."

3.1 STEPS INVOLVED SOLVING PROBLEM:

Step1: Installation: Analysis will determine the stress imparted to the diaphragm as a result of the installation “clamping process” Installation as follows.

1. Diaphragm threaded onto solenoid shaft.
2. Position of diaphragm’s centre core monitored via “indicator”.
3. When final position of diaphragm reached, threading stops. Diaphragm is now position for clamp -up.

When diaphragm &head have been installed, stresses have been imparted to the diaphragms sealing bead. The stresses imparted cause “pre load” of the diaphragm. The pre load either helps or opposes the diaphragm movement.

Determine:

1. Stresses present in diaphragm after initial clamping.
2. Axial pre load force that is imparted to the solenoid shaft

Step 2: Forward stroke: This analysis will be iterative. Take the stresses present after clamp-up and move the diaphragm by 0.12mm forward. Re-calculate the stresses. Move the diaphragm forward another 0.12mm.Recalculate the stresses. Repeat this until diaphragm has traveled through its normal range. Normal range is defined as initial installed position, then travels through...3.80mm total displacement during forward stroke. For each.0.12mm increment, calculate:

1. The force required to move the diaphragm

The segment of the analysis should be performed repeatedly for various pressures. Normal operating pressure for the diaphragm in this study ranges up to 1.723 Mpa maximum. Please perform this segment analysis at 0.35 Mpa increments.

Step 3: Retraction stroke: Analysis will be identical to the forward stroke with the exception that the diaphragm will start in the “full forward” position and will now travel in the opposite direction. Again,use.0.12mm increments for displacement. This will take the diaphragm backs to its initial position. For this portion of the analysis, pressure should be .084 Mpa and should be calculated at this pressure.

3.2 METHODOLOGY:

The Methodology involves as explained in the following steps.

a. Geometric Construction: Creating a model of the tank in ANSYS.
b. Discretization of structure involves dividing the continuum system into discrete elements. This is done by dividing the body structure into an equivalent system of smaller bodies or elements. Discretization of a body structure involves deciding number and size of the elements used for modeling.
c. Defining material properties of the structural material like Young’s modulus, Poisson’s ratio and density.
d. Applying constraints.
e. Applying loads as per given.

3.2.1 Elements used: a) PLANE42 is used for 2-D modeling of solid structures, b) TARGE169 is used to represent various 2-D "target" surfaces for the associated contact elements, c) CONTA 172 is used to represent contact and sliding between 2-D “target” surfaces and a deformable surface, defined by this element

Now the model is ready for static analysis. The model is transformed into its equivalent Finite Element Model. The nodal displacements and stresses are determined.

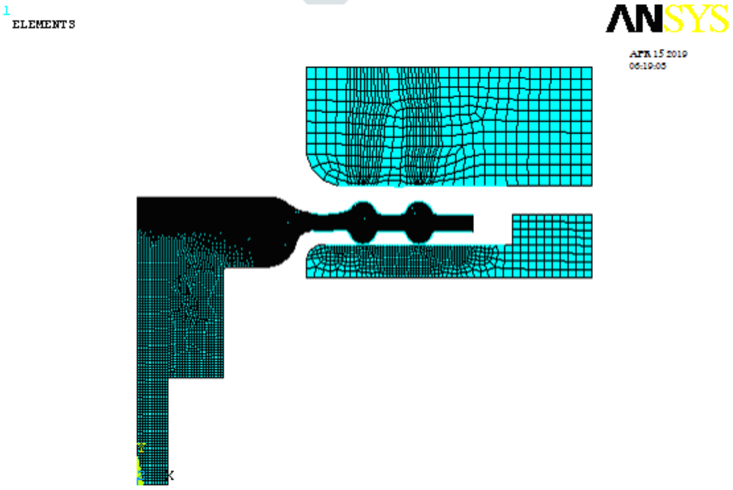

Fig 4 Meshed Model of the Diaphragm

In this meshed model total no of elements are 16952, and total no of nodes are 15414. And mesh converged at 22453 elements.

IV. RESULTS AND DISCUSSION

The analysis carried out in two different strokes (forward and retraction) to obtain reaction forces under various no of load steps are involved in these forward and retraction strokes.

4.1 FORWARD STROKE:

In forward stroke the diaphragm move in upward direction at this time here calculated the steress imparted on the diaphragm and reaction forces also.

FORWARD STROKE				
	SURFACE (mm)	PUMP HEAD (mm)	PRESSURE ON DIAPHRAGM(Mpa)	REACTION FORCE(N)
LOAD STEP 1	-0.3302	0.0	.344	-9.738492
LOAD STEP 2	-0.3302	-1.538	.689	-0.7258608
LOAD STEP 3	-0.4572	-1.538	1.03	- 8.281699
LOAD STEP 4	-0.5842	-1.538	1.378	-16.22133
LOAD STEP 5	-0.7112	-1.538	1.723	- 24.62802

Table 1 Boundary conditions of forward stroke

4.1.1 BOUNDARY CONDITIONS FOR LOAD STEP1:

In the first load step the pressure acted on the diaphragm is 0.344Mpa and displacements at shaft is -0.332 mm &at pump head 0.0mm constrained in y- direction, all these boundary conditions clearly shown in fig 4

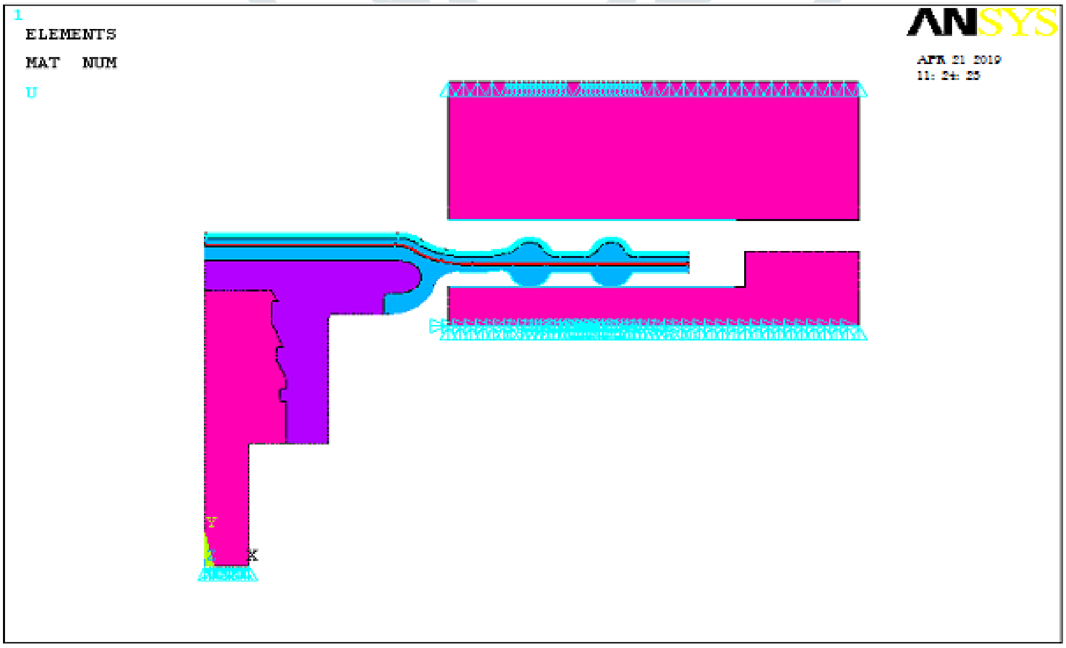

Fig 5 Boundary conditions for load step 1

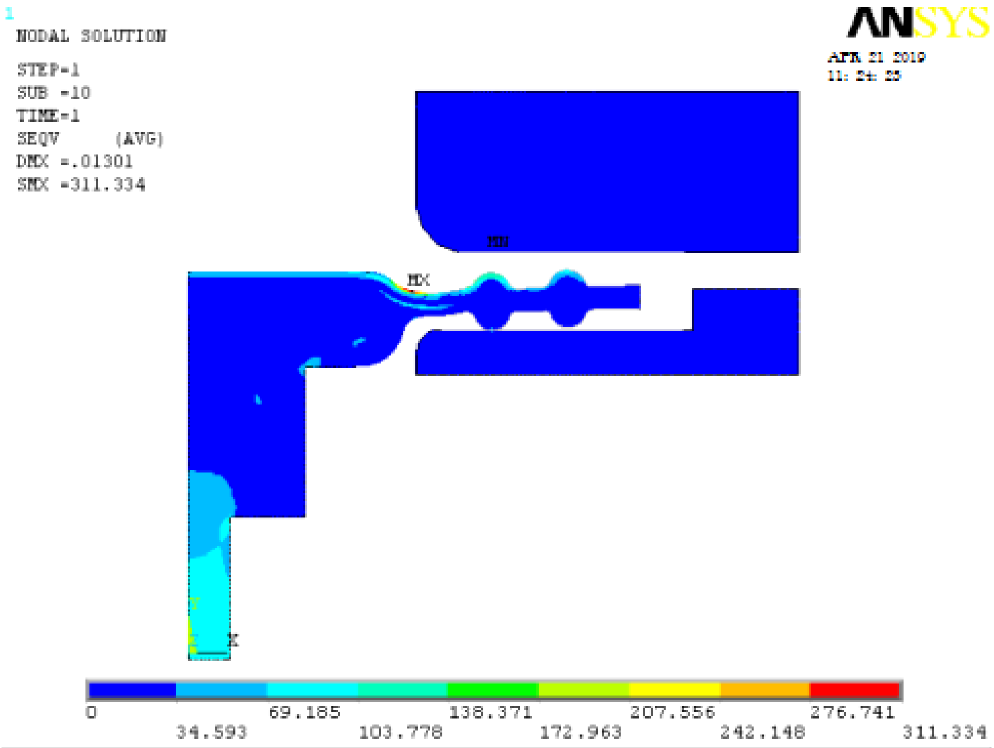

Fig 6. Von-Misses stress

From the above boundary conditions these results are drawn, the reaction force is -9.738492 N to move the diaphragm in upward direction and the Von Misses stress is 2.144.Mpa.(311.334 psi).

4.1.2 BOUNDARY CONDITIOND FOR LOAD STEP 5:

In fifth load step the pressure acted on the diaphragm is 1.723 Mpa and displacement at shaft is-0.7112 mm and pump head displacement is -1.538 mm. in y- direction.

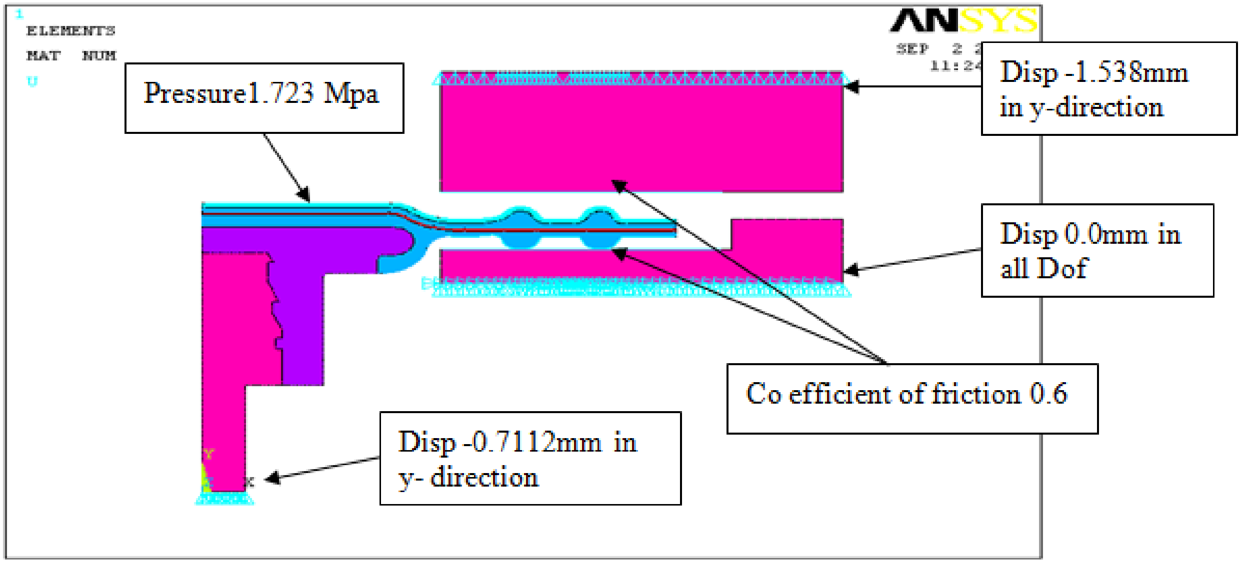

Fig.7 Boundary conditions for load step 5

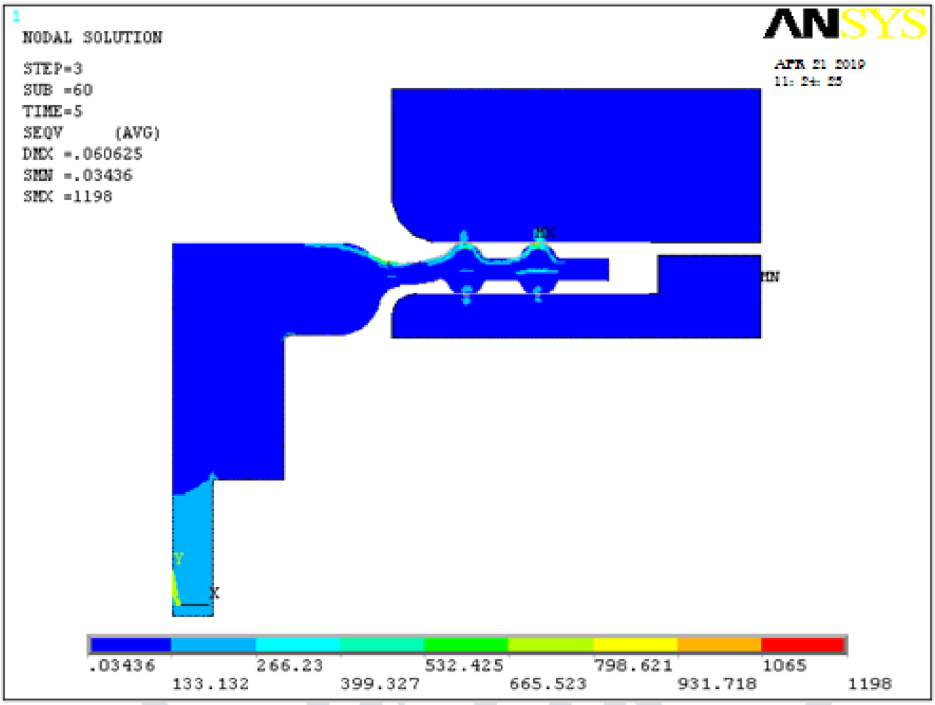

Fig 8. Von Misses stress

From the above boundary conditions these results are drawn, the reaction force is - 24.62802 to move the diaphragm in upward direction and the Von- Misses stress 8.259 Mpa (1198 psi).

4.2 *RETRACTION STROKE*:

In retraction stroke the diaphragm move in downward direction at this time here calculated the stress imparted on the diaphragm and reaction forces also.

RETRACTION STROKE				
	SURFACE(mm)	PUMP HEAD(mm)	PRESSURE ON DIAPHRAGM (Mpa)	REACTION FORCE(N)
LOAD STEP 1	-0.3302	0.0	.0842	-9.7384 N
LOAD STEP 2	-0.3302	-1.539	.0842	-0.7286
LOAD STEP 3	0.0762	-1.539	.0842	13.8523
LOAD STEP 4	0.1778	-1.539	.0842	28.524
LOAD STEP 5	0.4318	-1.539	.0842	44.245
LOAD STEP 6	0.6858	-1.539	.0842	61.836
LOAD STEP 7	0.9398	-1.539	.0842	81.723

Table 2. Boundary conditions of retraction stroke

4.2.1. BOUNDARY CONDITIONS FOR LOAD STEP 1:

In the first load step the pressure acted on the diaphragm is 0.084Mpa and displacements at shaft is -0.332 mm & at pump head 0.0mm constrained in y- direction, all these boundary conditions clearly shown in fig 7.

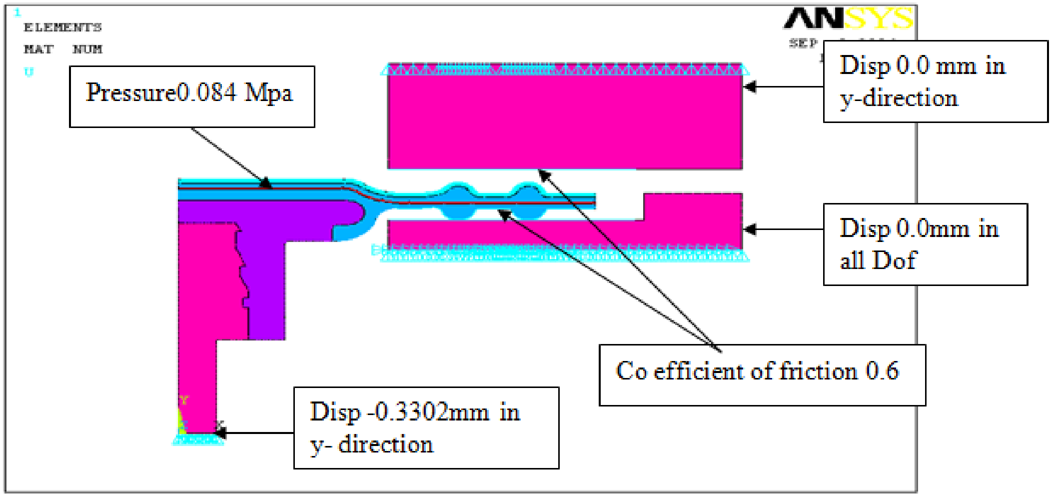

Fig 9. Boundary conditions for load step 1

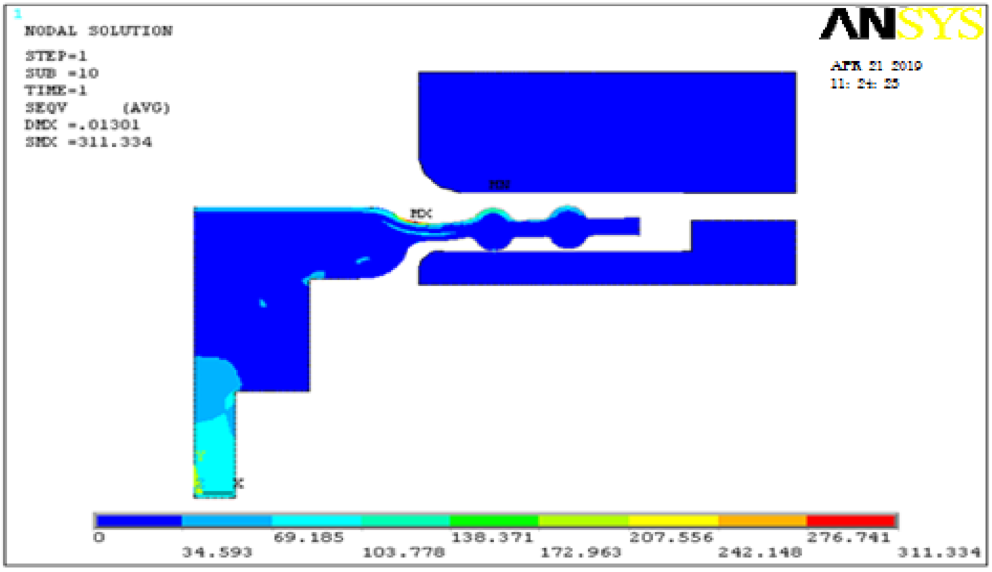

Fig 10. Von Misses Stress

From the above boundary conditions these results are drawn, the reaction force is -9.738492N to move the diaphragm in downward direction and the Von- Misses stress 2.144 Mpa (311.334 psi).

4.2.2 BOUNDARY CONDITIONS FOR LOAD STEP 7:

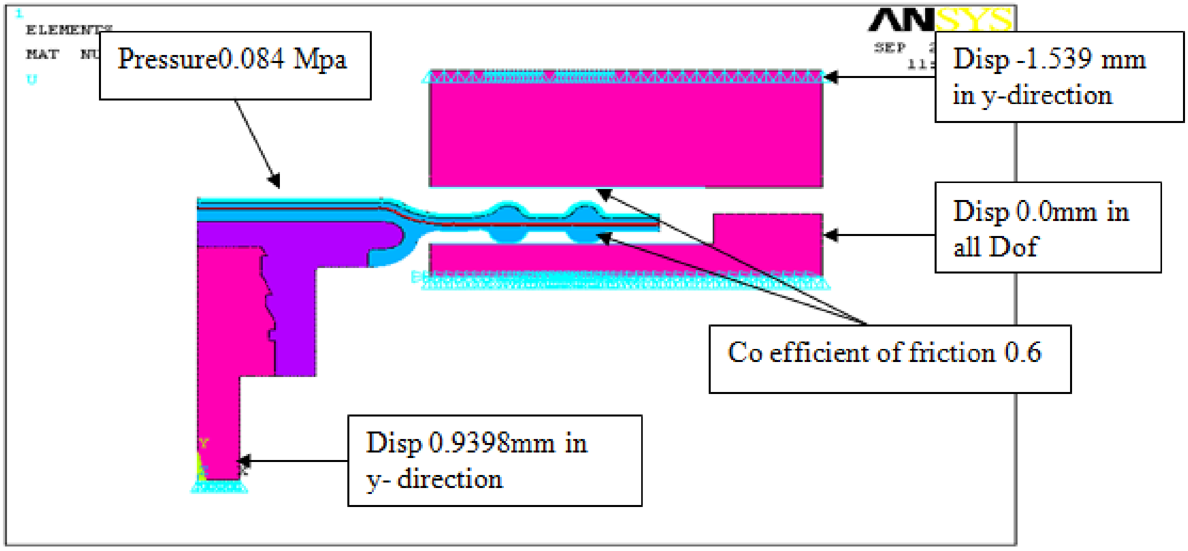

Fig 11. Boundary conditions for load step 7

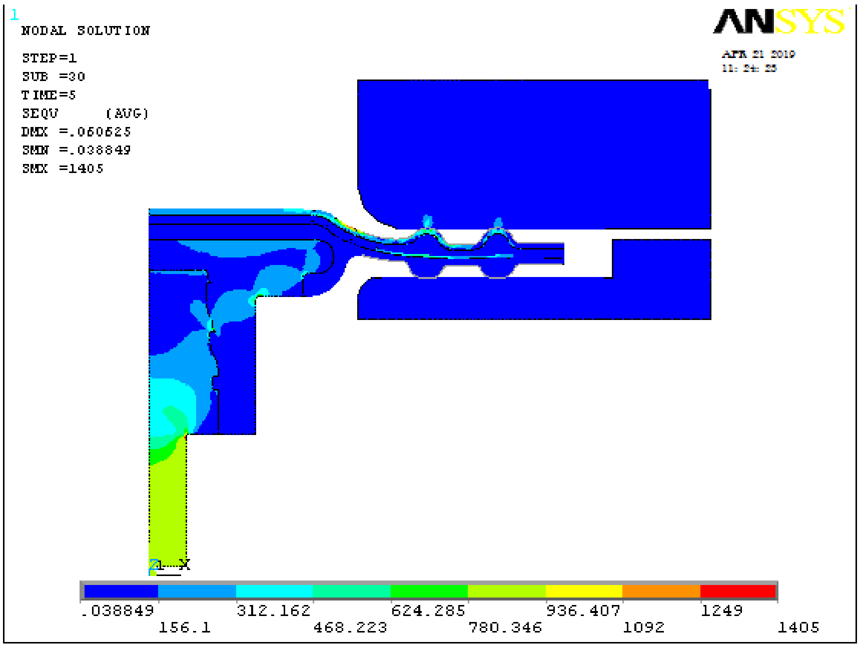

Fig 12. Von Misses stress

From the above boundary conditions these results are drawn, the reaction force is 81.72273 N to move the diaphragm in downward direction and the Von- Misses stress 9.687 Mpa. (1405.334 psi).

V CONCLUSIONS:

In this work Static analysis is carried out over the diaphragm. The diaphragm is analyzed for different load cases in forward and retraction strokes. In forward stroke the pressure (0.344mpa to1.723mpa) acted on the diaphragm and displacement at shaft (-0.3302 to -0.7112mm) is varying for every load step. Using these boundary conditions the analysis is carried out to find out the reaction forces. The reaction forces obtained in forward and retraction strokes are as shown hereunder.

5.1 The reaction forces in forward stroke:

Load step	Reaction forces
1	-9.7384 N
2	-0.7286 N
3	-8.281 N
4	-14.868 N
5	-24.6280 N

Table 3. Reaction forces in forward stroke

In retraction stroke the pressure acted on the diaphragm is 0.084 Mpa and displacement at shaft is -0.3302 mm to0.09398 mm.

5.2 The reaction forces in retraction strokes:

Load step	Reaction forces
1	-9.7384 N
2	-0.7286 N
3	13.8523 N
4	28.524 N
5	44.245 N
6	61.836 N

7	81.723 N

Table . Reaction forces in retraction stroke

In forward stroke the von Misses stresses are:

a) The Von Misses stress is minimum at load step 1 2.144 Mpa

b) The Von Misses stress is maximum at load step 5 8.259 Mpa

In retraction stroke the Von Misses stresses are:

a) The Von Misses stress is minimum at load step 1 2.144 Mpa

b) The Von Misses stress is maximum at load step 7 9.687 Mpa

Maximum yield strength of the PTFE material is 10.548 Mpa

And all load cases are converged with coefficient of friction of 0.6.

From the above results it is concluded that the structure is safe under given load conditions.

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