

Improving Fatigue Life for Diaphragms

DIAPHRAGM GUIDE By: Atit Shah

Diaphragm improvements:

Fatigue-induced rupture of the rubber diaphragm is one of the most common causes of failure in AODD pumps. In this article, I demonstrate how diaphragm fatigue life can be improved via simulation and new mechanical design.

A selection of a rubber diaphragm with a long working life and good resistance to fatigue failure is important in order to increase the working life of AODD pumps.

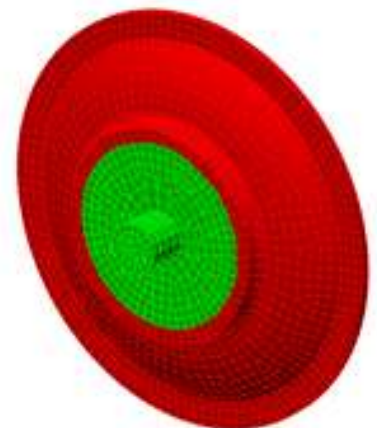
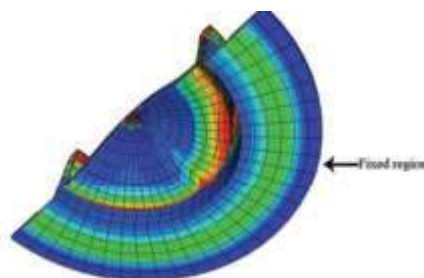
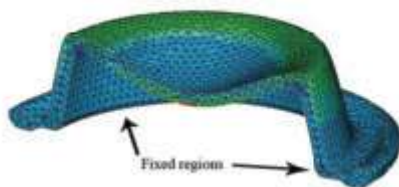
Fatigue behavior:

Since 1850, it has been established that materials fail under fluctuating loads that are smaller than their critical fracture load; this phenomenon is called fatigue. In rubbers and plastics, fatigue is an important failure mechanism. Fatigue failure consists of the nucleation and propagation of cracks from initial defects, leading to the fracture of the material. Fatigue in materials is usually of the brittle type, without any visible warning signs before the fracture.

If a rubber part is machined, fatigue crack growth is facilitated as a result of the surface damage produced. In crystalline polymers, this process takes place because of molecular slip and movements. In molded rubber parts, the presence of molding residues, such as weld lines and mould gates, and particles of reinforcing additives and pigments can accelerate the crack initiation. Moreover, stress concentration areas that are due to the component's shape are one of the most important sources of crack initiation in fatigue.

There are a variety of factors that make the fatigue behavior of rubber diaphragms very complicated. Some of these are:

- Loading factors, including Stress, Strain and Time.
- Viscoelastic behavior such as Loading Rate.



Simulation:

Using simulation software such as the well-known ABAQUS or ANSYS systems, the stress concentration areas can be identified. These areas are the weakest parts of the object; hence, fatigue fracture occurs there due to the high load concentration. Changing the material and the mechanical design are the two main methods of increasing the fatigue life of rubber diaphragms. In most industrial applications, the first approach is to improve the mechanical design to decrease the stress concentration; thereby increasing the component's working life.

Experiments:

In these experiments, two kinds of rubber diaphragms were investigated. These diaphragms were different in shape and design. Both the diaphragms were used in AODD pumps designed by Neoflux. The diaphragm loadings for both designs were analyzed by the finite element analysis method. To identify the areas of stress concentration, the analyses were performed using the static method.

To simulate the tensile behavior, the three-dimensional deformable body treatment was used. To mesh the samples, the free mesh method was employed due to the complicated geometry. For the first design, tetragonal elements were chosen and for the second diaphragm they were hexagonal.

To study the fatigue life of the rubber diaphragms, a fatigue testing machine was constructed capable of working in a fluid environment, changing the velocity and accurately evaluating the number of fatigue cycles before failure. The fatigue testing machine was designed in such a way that when the diaphragm failed, causing water to leak out, water sensitive sensors instantly turned the circuit off and the number of fatigue cycles was thus accurately determined.

New Designs:

To decrease the stress in the areas of high stress concentration in the first rubber diaphragm, and thereby increase its fatigue life, two new mechanical designs were produced: the first a fully arched (dome shape) diaphragm and the second a filleted (Flat) diaphragm. In the second of these new designs, the fillet decreases the stress concentration due to the sharp edges in the original sample. In the fully arched design, these stress concentration areas are reduced even further. The chemical composition of the diaphragms consists of equal parts (30%) by weight of natural rubber, Nitrile-butadiene rubber (NBR) and carbon, with the remaining 10% consisting of other components including H₂SO₄ and HNO₃. The mechanical properties of the diaphragms are given in Table-1.

The new mechanical design for the second diaphragm involved removing the sharp corners. For this purpose, a new rubber diaphragm with filleted edges was designed. The chemical composition and mechanical properties of the sample are identical to those of the first diaphragm. Fatigue testing was conducted on the samples using the fatigue testing machine with a velocity of 110 rpm and temperature in the water environment of 28 ±5°C.

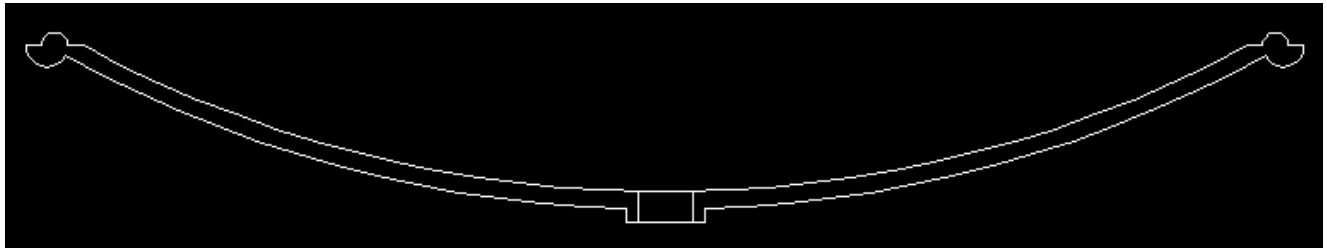
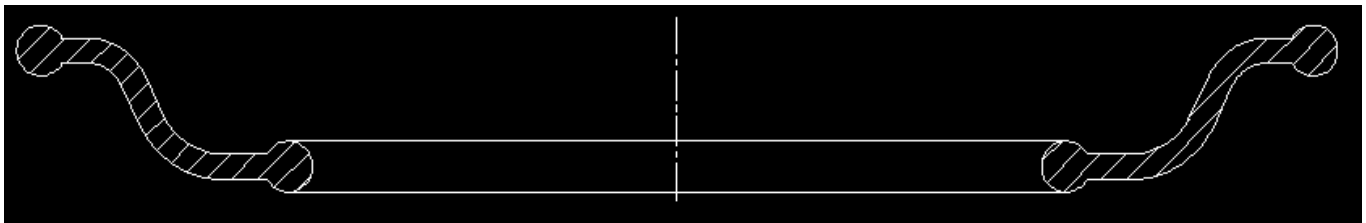
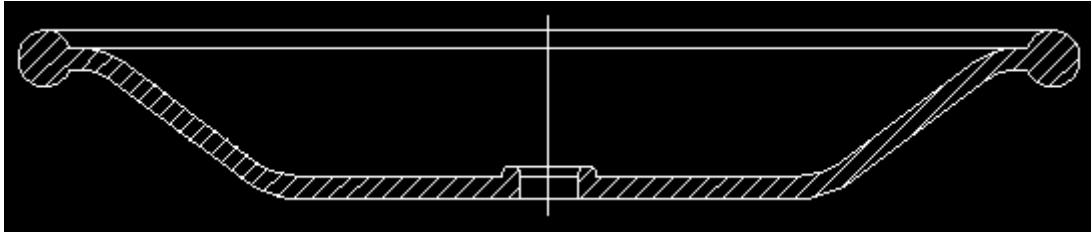
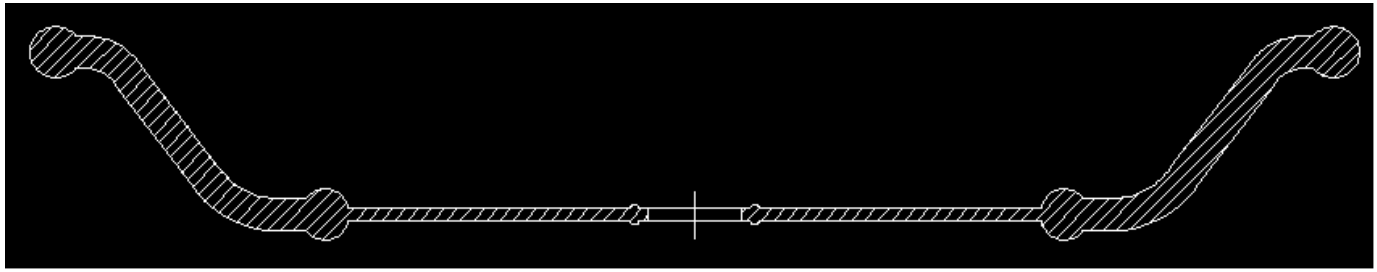


Table-1:

Mechanical Properties of Neo-Flex Rubber Diaphragms		
Test Name	Units	Test Results
Hardness	Shore A	60 ±5
Tensile Strength	N/mm ³	Min. 15
Elongation	%	Min. 389
Tear Resistance	Kgf / m ³	Min. 47
Pressure	%	Max. 25
Wear Resistance	mm ³	Max. 137
Resilience	%	Min. 28



Stress Analysis Result:

In the stress analysis of the original *Neo-Flex* diaphragm, stresses were analyzed using the Tresca criterion. The highest and lowest principal stresses were applied to the material. It should be mentioned that the principal stresses are the stresses applied to the material in the principal directions (x, y and z) without the existence of any shear stress. The stress concentration areas are shown in green. In this analysis, all of the fixed regions (that is, regions that do not move at all during

the pump's work cycle and are fixed by other parts of the pump) are introduced as surfaces (places that do not show any movement during simulation) to the software; hence, there is no stress concentration at the bottom of the diaphragm. As shown, as the distance from the edges increases, the stress concentration decreases.

For the second **Neo-Flex** design rubber diaphragm, the stress analysis is different from the first diaphragm due to the more complicated geometrical shape. In this analysis, the fixed regions are treated as the surface; therefore, there is no stress at the base. Stress analysis showed that the stress is concentrated at the bottom and top edges.

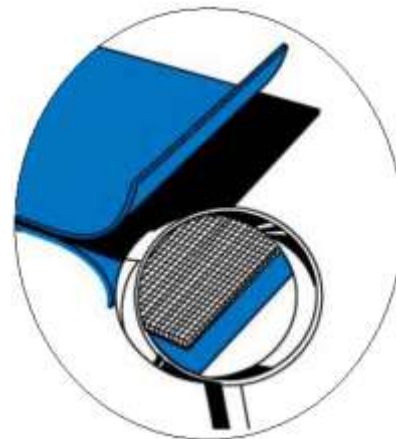
Fatigue Test Result:

To reduce the stress concentration in the Neo-Flex rubber diaphragm, two new diaphragms were produced. In the first new sample, the sharp edges were replaced with smooth ones and in the second one the sharp edges were replaced by fully arched edges. The fatigue test results showed drastic reductions in the stress concentration areas due to the fully arched design.

This new design leads to significantly improved fatigue life. In the fillet-edged sample, the fatigue life increases by 1.7 times but in the fully arched samples fatigue life almost doubles. To decrease the areas of stress concentration in the **Neo-Flex** diaphragm, a new rubber diaphragm of the same composition and with fillet edges was manufactured; the sharp edges were replaced with filleted edges. Fatigue testing was conducted on the new samples and it was shown that, due to the reduced stress concentration at the edges, the fatigue life of the sample was improved by 1.3 times.



Neo-Flex Diaphragm Cross-Section



Neo-Flex Double Coat Diaphragm Design with Fabric Reinforcement

Conclusion:

In the first rubber diaphragm, using the fully arched (Dome Shape) alternative diaphragm instead of the traditional design approximately doubles the fatigue life. The main reason for this increase is a large reduction in the stress concentration magnitudes. Moreover, this new design increases the strength of the diaphragm. In the flat- edged diaphragm design, this increase was 1.7 times compared with the original sample. This improvement is due to the reduction in stress concentration magnitude and the replacement of the sharp edges.

In the second rubber diaphragm, the new design with the filleted edges increases the fatigue life of the sample by 1.3 times. This increase was due to the reduced stress concentration in the filleted samples.

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