Experimental Testing and Analysis of Gas Spring Nitrile Rubber Seal

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Abstract— Gas spring has a wide range of applications and one of the major element is its seal. Nitrile rubber seal is studied in this paper as the failure of seal is due to static and dynamic load conditions. Seal is essential part as it prevents the leakage of gas from cylinder and which is why the spring action is occurred. Main focus of this study is to analyses the failure of gas spring seal and to detect the stresses induced in it. The analysis were carried out by using ANSYS APDL13.1 and observed the effects of stresses induced on seal surface. In this paper studies were carried out by experimental and analytical investigation of Gas spring seal. It was found that the maximum stress occurs at the area of contact between rod outer surface and seal inner diameter, where exactly the seal fails.

Key words: Cycle Testing Machine, Gas Spring, Nitrile Rubber Seal

I. INTRODUCTION

By considering need of manufacturing industry and automobile industry, number of researchers has worked on gas spring seal to improve its lifecycle. Gas spring is simple piston cylinder mechanism in which a high pressured gas is filled and it is been sealed with nitrile rubber seal to maintain the constant pressure inside and hence the spring action is occurred, for smooth action the pressure inside chamber should be constant and for the same the seal should be in healthy condition. Due to constant working the friction between the seal and piston rod increase and the wear comes accordingly the seal fails due to this wear. The entire gas spring will fails as seal failed because the pressure will decreases, goes to atmospheric and hence the gas sprig will not work properly and the desired action not occurs.

In order to improve the quality of lifecycle of the gas spring wide range of work is done in automobile industry. Gas spring is used in automobile industry where the cushioning effect is required as to do the opening action for Dickey.

There are various methods to find out the lifecycle of gas spring, so many researches has investigated effect of stress on different seal composition with different seal designs on gas springs.

B Yang and R F Salant[1] studied the recent development of an elastrohydrodynamic lubrication rod seal, they developed a model which is useful to simulate the seal performance for its design. The work done by Jhon C. Vicic and Kennard A. Reynard [2] found that fluroelatomers are excellent stress strain properties, low temperature flexibility, thermal stability. J.M. Degrange and M. Tomine [3] investigated the influence on nitrile rubber seal by using viscosityas index term. They observed that the Nitrile Butadiene Rubber (NBR) has been frequently used in automobile and manufacture industry for leap seal application. In this study researchers were used Dynamic Mechanical Analysis for experimentation work. Finally they concluded that Nitrile rubbers are used to prevent a leakage in ball bearing application. Yongzhong Song GengtaiZhai [4] proposed that at higher temperature carbon graphite materials seals sustain their strengths than other materials, researchers made the Mesocarbonmicrobeads with heat treatment by changing the pressure. They observed the physical properties and proposed a direction to increase the strength of graphite seals. Author demonstrated and found that by enhancing molding pressure, bulk density goes increased. At 100Mpa pressure seals becomes homogeneous with a fewer voids. The objective of D. W. Wisander and R. L. Johnson [5] was to explore the effectiveness of various impregnantes for mechanical carbon in gaining low wear and low friction for experimenting in cryogenic liquid. Impregnantes consist of material either organic or inorganic. Finally they purposed that organic impregnantes were effective to reduce wear at mechanical carbon at 75^0F and it is not much effective in liquid nitrogen.

II. GAS SPRING SEAL

One of the most essential part of any gas spring system is its sealing, the U cup nitrile rubber is gives a good leakage guard against external leaking. Nitrile Butadiene Rubber (NBR) is wildly used as a seal material which offers great resistance against to abrasion, extrusion, and compression set [6]. Compression set is nothing but after being compressed, inability of a seal to return to its original shape. There are two types of sealing is considered as Static and dynamic. Static is nothing but both surfaces are stationary relative to each other whereas in dynamic at least one surface is in motion relative to other In both applications, a certain amount of squeeze or compression is required upon installation to maintain contact between the sealing surfaces and to prevent fluid leakage.

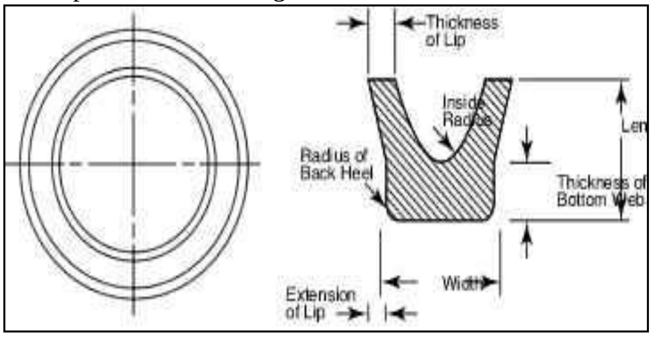


Fig. 1: Typical cross section of U cup seal

The common type of u cup seal can be easily understood with above figure. As the leap angle and inside radius goes increasing the stability of seal is somewhat affected but it took an advantage of becoming seal with a less friction [6]. The lifecycle of any seal can be improved with reducing wear, increasing extrusion resistance, decreasing compression set and the rate of chemical attack.

III. EXPERIMENTAL DETAILS

A. *U Cup Seal Material and parameters*

The seal material is a polymer called Nitrile with the inner diameter of rod insert is 8.25 mm with the outer one is of 15.70mm. Some of other parameters can be listed in bellow Table 1

Parameters	Existing values
Hardness SHORE-A	82±4
Specific gravity	1.34±0.05
Compression set	25% max
Tensile strength	17.15 ±2.45 N/mm^2
Elongation	175%min
Heat ageing	24 hrs @100^{0}C

Table 1: Parameters of the nitrile rubber seal

There are leaps which ensure a leak proof sealing and hence the diameter can be decreased at rod end and increased towards the outer side that is area which is coming contact with cylinder wall. The inner diameter can be taken with 7.35±.0mm 1 and outer one with 16.80±0.5mm.

B. *Gas Spring Parameters*

Gas spring is an assembly of two main parts that is a piston and a cylinder. It is a simple pneumatic cylinder with a constant pressure and effective sealing. Surface properties of rood have an adequate effect on seal life which affects the entire gas spring life. The outer diameter of piston and inner of seal are in contact with each other and due to motion of piston, frictional force is generated. The seal life is depends upon the surface quality of piston rod. According to F. Klocke and J. Liermann[7] Roller Burnishing can be effectively used for surface quality improvement of rod. The high pressured ceramic balls are rolled over the surface. It provides an alternate way for hard turning which has some limitations such as to withstand against rolling stresses. The roller burnished rod of surface roughness 0.290 Ra is used on which a Nitrile rubber seal is installed.

The second most essential part of gas spring is cylinder which is powder coated tube with a surface roughness 0.592 Ra.

C. *Design of Experiments*

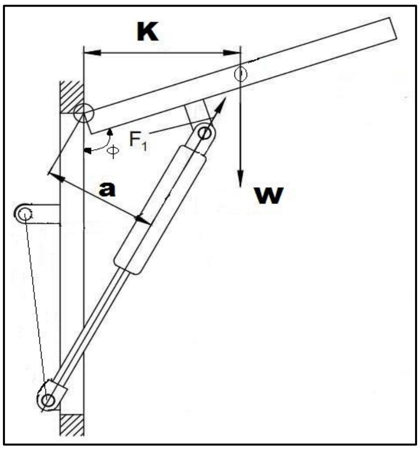


Fig. 2: Design of gas spring

Surface roughness of rod plays very important role while conducting the experimental trails. The stability of seal is also takes account when it comes to lifecycle of gas spring. The ideal surface finished rod was used. The experiment was carried out on a cycle testing machine, which is used to test the endurance of a component. This tests the components ability to sustain the effectiveness. Basically it is measure of persistence of gas spring. Entire experiment was designed on bellow schematic view, and abbreviations given below.

The force F can be calculated using the bellow formula

$$F=\frac{W\times K}{a\times n}\times W \qquad (9)$$

W= Weight of flap in Kg
L= distance of center of gravity from hinge in mm
a= Effective lever arm of gas spring in mm
13= Constant
K= effective lever arm of center of gravity.
n= No of gas springs used.
∅= Opening angle

The entire concept of experimental setup is upon above schematic, the gas spring was designed according to force F which will act upon it. The gas spring can carry the load with reference to its designed force bearing capacity. Only chance of failure chance is the seal fails due to continues friction. Seal experiences not only the static friction between cylinder wall and its outer diameter but also the dynamic friction between its inner diameter and piston rods outer surface. There is more chance of extrusion failure[8], which can be more accurately can be stated as the generation of clearance between the piston rod and seal. This leads to leakage of compressed gas from cylinder and thus failure of the entire gas spring.

IV. EXPERIMENTAL PROCEDURE

Gas spring test was carried out on a simple Cycle testing machine. Sample test specimen was selected with the specified gas spring seal. While testing the cycle speed was kept constant. Cycle testing machine is a vertical hydraulic arrangement and a space provided to load a gas spring specimen for its testing.

Fig. 3: Experiment set up

During the total test the cycle speed was kept constant as 6 to 7 cycles per minute. The force necessary was provided by the hydraulic means. Gas spring kept in open position that is the piston rod facing downwards. The hydraulic machine compresses spring till it completely closed. Then due to the compressed gas inside the cylinder the actual spring effect created and gas spring opens on its own pressure force. The cycle testing machine measures the no of cycles which it perform during the experiments, during a certain period after specified no of cycles were completed we took gas spring to load cell which is another machine where the actual force applied on gas spring is measured. Load cell measured the force applied on gas spring. These forces were measured at after gas spring performed no of cycles. Force reading can be taken from a digital monitor who constantly gives trace on forces that applied on the specimen. The main trigger which we monitored for the signs of failure is the oil seepage. The percentage drop in the force was calculated. The highest drop in percentage drop will indicate that the spring is not working efficiently, which is sign of leakage of gas through seal. The pressure hence drops inside the gas spring and spring action cannot be continued as desired.

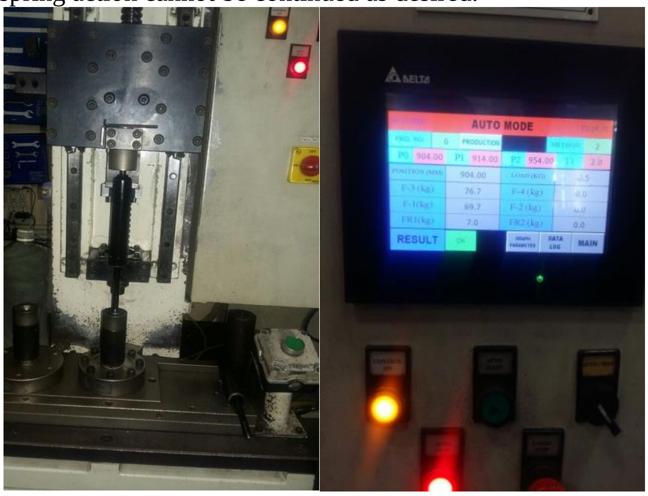


Fig. 4: Load cell arrangement and force measurement

When we recorded forces from the load cell after certain cycles that data can be tabulated as follows.

No of cycles	F1 compression	F3	F2 compression	F4	FR1	FR2	FD1	FD2
3000	36.6	37.5	50.7	52.3	0.9	1.6	3.43	2.68
10000	36.8	37.7	49.6	57.5	0.9	1.9	2.90	4.79
20000	35.6	38.0	49.6	50.6	2.4	1.0	6.06	4.79
30000	33.6	34	45.2	46.8	0.4	1.6	11.34	13.24
40000	34.1	34.4	45.6	47.3	0.3	1.7	10.02	12.47

Table 2: Endurece Test report

Where, FR1=F3-F1 and FR2=F4-F2, FD1=% force drop in F1 and FD2=%force drop in F2

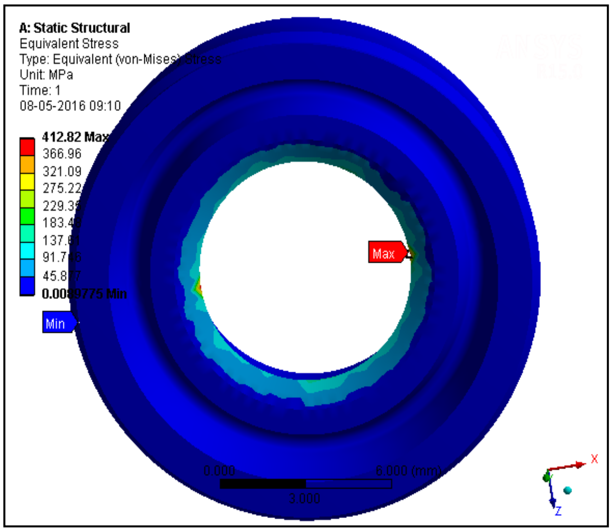
The oil seepage was first detected after the 20000 cycles of gas spring has been completed which is starting of leakage of gas through cylinder. After 30000 cycles of its life time oil seepage was considerable and percentage drop in force is high which is confirmation of gas leak and decreased spring effect of gas spring.

V. Result and Discussion

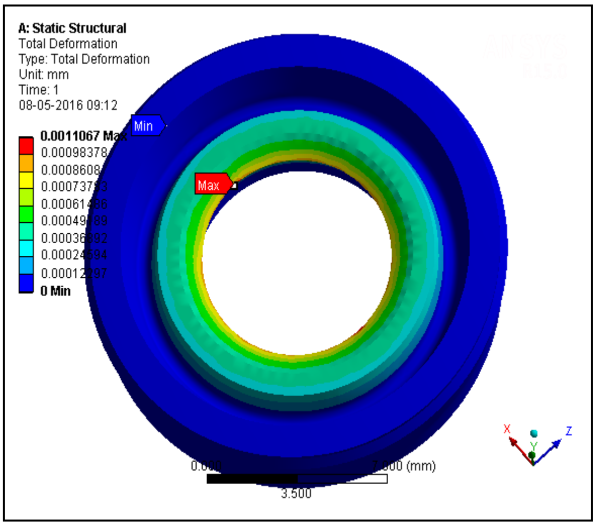
After the experiment was completed, the seal is failed to sustain more of its sealing effect hence the desired spring effect was unavailable. The entire gas spring was dismantled to know the exact are of failure and it was observed that the inner diameter has been worn out by a continuously in contact with the moving piston rod surface.


Fig. 5: Gas spring seal failure area

The design for the gas spring seal was modeled in software CREO which was most suitable for the analysis which was to be done in ANSYS. The seal is designed and then its analysis was carried out with ANSYS APDL-13. Non-linear material was chosen for analysis with a gasket material type. Pressure of 18 N/mm^2 was applied to inner diameter of seal, the surface area affected mostly with dynamic friction. The outer surface of seal was kept as stationary, where no dynamic friction was acted. The results were obtained and it was clearly seen, that the failure area was the same where maximum stress was occurred.



(a)



(b)

Fig. 6: ANSYS results of gas spring for (a) Von-misses stress (b) Total deformation

Results which obtained was indicating the area of inner diameter of seal has a maximum equivalent or Von misses stress of 412.82MPa, the colour coding which started from blue as a minimum stress to red as a maximum stress can be easy to detect the more effected area. The maximum deformation of 0.0011 was obtained exactly to that portion where the seal get warn out and actual failure occurs.

VI. Conclusion

In this paper, experimental testing of gas spring seal is carried out. In addition the analysis of seal is done to find out the maximum stress and deformation zone. Obtained experimental results indicated that after certain number of cycles oil seepage of gas spring seal increases due to constant surface interaction between seal and piston rod. The analysis in ANSYS software showed the surface which was under maximum stress and deformation that was exactly the same area which was failed due to constant friction. Results obtained from experimental and analysis showed that area of failure is the same inner diameter of gas spring seal and improvement can be done. It was found that the maximum stress occurs at the area of contact between rod outer surface and seal inner diameter, where exactly the seal fails. These results will be helpful to concentrate the area of research for effective sealing. This will certainly increase the life cycle of gas spring further.

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