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# Determination of Inflation Steps for Rubber Inflatable Seal Using FE Analysis

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**Abstract:**
Finite element analysis and product design when combined together empowers designers to come up with best design solution possible. The work presented in this paper describes the results and procedures of FE analysis performed on basic inflatable seal profile. The analysis result of the inflatable seal are the representation of the simulation of seal under the static condition and shows the steps of inflation of the seal when internal pressure is applied to inflate.

**Keywords:** Inflatable seal, Rubber Material, Inflatable, FEA

## I. INTRODUCTION

An inflatable seal is a type of rubber seal which inflates (rather than compresses) to create an air or watertight barrier. When compared to elastomeric compression seals, inflatable rubber seals are more forgiving of irregular or misaligned surfaces, which boost sealing integrity [Pawling]. An inflatable seal can be compared to a bicycle inner tube, which when inflated expands to fill a void which is contained within the wheel rim (housing) and a tyre (jacket). Once air is let out of the inner tube the tyre runs flat. The internal pressure is usually applied by using air, although some applications require the use of an alternative gas or even a fluid.

## II. RELATION OF RUBBER MATERIAL

The majority of research work is focused on developments of the phenomenological approach, based on the observation of the rubber under various conditions of homogeneous strain. The phenomenological approach assumes rubber to be an isotropic material in its unstrained state, i.e., the long chain molecules of the rubber polymer are assumed to be randomly oriented. Stretching of rubber cause orientation of the rubber molecules in the direction of stretching and hence the assumption of isotropy can be said to remain valid.[Feng,08] This assumption of isotropy is fundamental to the characterization of rubber by a quantity known as the elastic strain energy density (W), the stored strain energy per unit volume. Numerous strain energy density functions have been proposed, and these can be subdivided according to whether W is expressed as a polynomial function of a strain invariants or directly in terms of principal stretch ratios and whether incompressibility is assumed or not. The most commonly referred constitutive model for rubber including finite compressibility, developed by Rivlin [Mooney, 1940] is:

$$W = \sum_{i+j=1}^{N} C_{ij}\ (I_{1^c} - 3)^i\ (I_{2^c} - 3)^j + \sum_i^N (J^c - 1 - R)2i / Di \quad \text{------ } \mathbf{(1)}$$

Where,
$C_{ij}$ = Rivlin Coefficients,
$D_i$ = Material incompressibility,
R = Volumetric expansion with change in temperature

$$I_{1^c} = (\lambda_{1^c})^2 + (\lambda_{2^c})^2 + (\lambda_{3^c})^2$$

$$I_{2^c} = (\lambda_{1^c}\ \lambda_{2^c})^2 + (\lambda_{2^c}\ \lambda_{3^c})^2 + (\lambda_{3^c}\ \lambda_{1^c})^2$$

$$J^c = \lambda_{1^c}\ \lambda_{2^c}\ \lambda_{3^c}$$

$$\lambda_{i^c} = \lambda_i / \sqrt[3]{J^c}$$

For an ideal incompressible material which maintains constant volume

$$J^c = \lambda_{1^c}\ \lambda_{2^c}\ \lambda_{3^c} = J = 1$$

Hence, $\lambda_{i^c} = \lambda_I$ and $I_{1^c} = I_1$
Volumetric series in equation becomes a null series. The first series in equation 1 represents the deviatoric component of the stored energy density, being the contribution that can be associated with shearing type deformations alone. Coefficient $C_{ij}$ are found by regression of the chosen expansion of the first series to collect experimental data. The second series represents the volumetric component of stored energy for rubber. Again $D_i$ and R determined from experimental data.
The Rivlin model, equation **(1)** then becomes

$$W = \sum_{i+j=1}^{N} C_{ij}\ (I_1 - 3)^i\ (I_2 - 3)^j \quad \text{-- } \mathbf{(2)}$$

From this form, the Rivlin model is often further simplified to an expansion using two terms (N=1). This form is known as Mooney-Rivlin form and is given as:

$$W = C_{10}\left(I_1 - 3\right) + C_{0\,1}(I_2 - 3) \quad \text{---------}\mathbf{(3)}$$

Where,
W=Strain energy density function
$C_{10}$, $C_{01}$=Mooney-Rivlin material constants

$$I_1 = (\lambda_1)^2 + (\lambda_2)^2 + (\lambda_3)^2$$

$$I_2 = (\lambda_1\ \lambda_2)^2 + (\lambda_2\ \lambda_3)^2 + (\lambda_3\ \lambda_1)^2$$

Where λ is known as the stretch ratio and is defined as the ratio of current length to original length. Subscript 1 to 3 denote three mutually orthogonal directions x, y and z. Material property was found best fit with the Mooney-Rivilin material model. Mooney-Rivlin works well with in compressible elastomers with large strain up to 200% [kao, 1986]. The non-linear stress-strain curve of the present elastomer was obtained using the uniaxial test data obtained from DMSRDE, the curve is shown in Fig1 below.

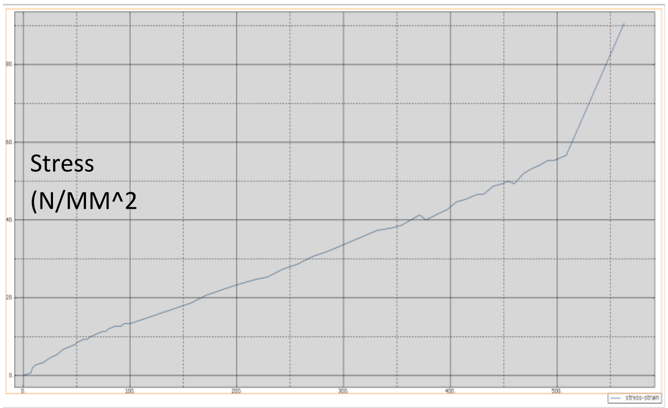


**Figure.1. Stress- Strain curve for Silicon Rubber**

## III. FE MODEL OF INFLATABLE SEAL

The rubber-seal has been modeled as an axis-symmetric case. The triangular element shape is used. Geometric order of the element used is linear. The element used for seal is CAX3H, which is a 3node linear axis-symmetric triangle, hybrid, constant pressure element appropriate for the present problem.

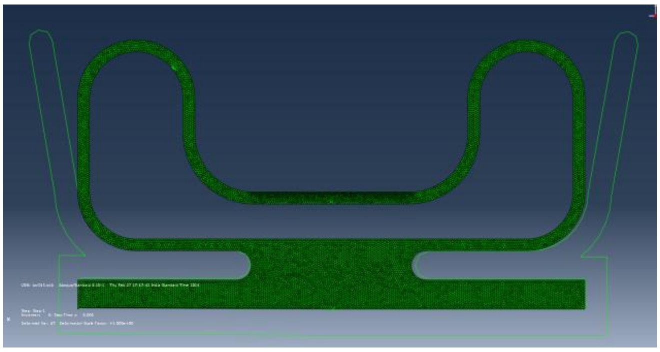

**Figure.2. Meshed model of Seal**

## IV. RESULT ANALYSIS OF FEA SIMULATION & CONCLUSIONS

The simulation of rubber seal is done to determine the steps of inflation of rubber seal under inflating pressure which is applied by using either gas or any liquid from inside. The Fig-2 shown above shows the initial condition of the seal which is having no pressure inside and is in deflated mode. The simulation study of the seal carried out here highlights the stages of inflation of the seal. The inflation of the seal can be understood and achieved in the 3 different stages which are described in this section of paper-

**Stage-1:**
At this stage the internal pressure of the seal is increased gradually from zero bar and seal to supposed to start inflating.

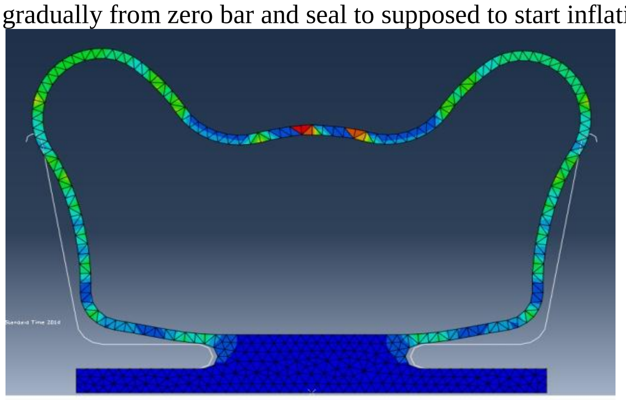

**Figure.3. 1st Stage Inflation of Seal**

**Stage-1** of inflating comprises of the inflation at which the lipped sealing surface of the rubber seal is inflated enough to come approximately at the height of the supporting groove boundary.

**Stage-2:**
At this stage the inflation pressure in the seal lead the lipped surface of the seal above the groove boundary region but below the top sealing surface which has to be sealed by the inflatable seal, at this stage the required sealing is neither achieved nor started.

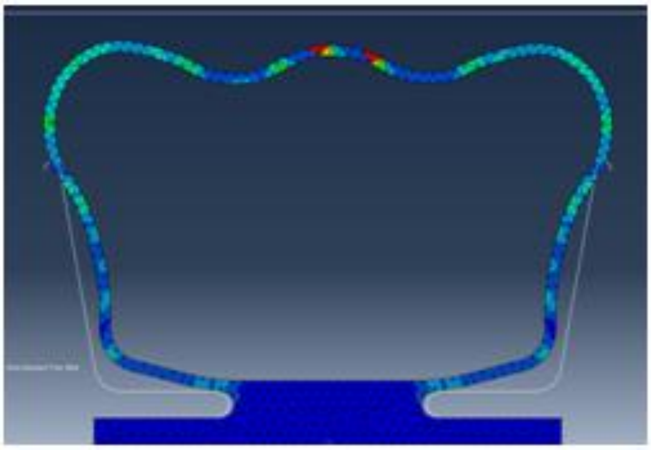

**Figure.4. 2nd Stage of Seal Inflation**

This stage is very important to monitor as the threshold of this stage gives the value of the inflation pressure required for normal contact pressure of the seal profile with the surface to be sealed.

**Stage-3:**
At this final stage the seal starts touching the upper sealing surface which is to be sealed by the inflatable seal, at this stage the seal starts exerting pressure to the sealing surface and the sealing starts and

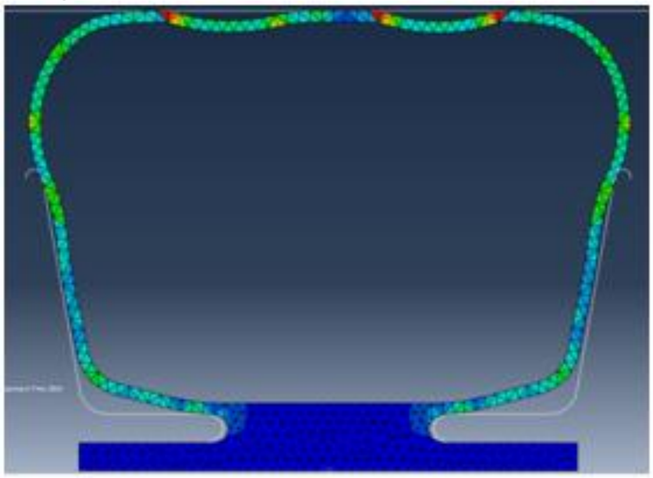

**Figure.5. Fully Inflated Seal**

Required sealing is achieved by controlling the inflation pressure of the seal which directly influences the contact pressure of the seal and sealing surface.

## V. CONCLUSION AND FUTURE SCOPE:

Determination of inflating steps is an important study to understand the possible deformation patterns of the rubber under the effect of inflation pressure. Study provides information to the designers about the possible failures which can occur in case seal fails to inflate during the process. Study result also helps industry engineers to train their subordinates for inflation mechanism, this also helps academicians to educate their students to understand the mechanism of inflatable seal and help them to come up with more effective designs.

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