A COMPARATIVE STUDY OF TWO METHODOLOGIES FOR NON LINEAR FINITE ELEMENT ANALYSIS OF KNIFE EDGE GATE VALVE SLEEVE

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ABSTRACT

Knife edge gate valves are used in mineral processing industries for regulating the slurry transportation. Due to the erosive nature of slurry, rubber sleeves are used in place of metal seat rings in these valves. The design of rubber sleeve has to be such that it will withstand the compression and shearing due to gate movement and will also maintain its elasticity as the gate passes forth and back through the sleeves. The results of finite element analysis of the valve assembly can provide insights about rubber sleeve behavior and design modifications required to achieve satisfactory performance. Two methodologies have been used to carry out FE analysis for the valve sleeve. In the first one, full 3D model analysis of rubber sleeves is carried out. This methodology involves solution of FE model with large number of 3D elements; hence requires long durations of solving time and high in-core memory consumption. In the second methodology, axisymmetric element formulation is used; hence it involves solution of FE model with small no of 2D elements. Analysis carried out with the second methodology gives results reasonably similar to those of first one and takes much lesser time for both model preparation and solver running. A detailed comparison of these two methodologies has been provided in this paper.

Key words: Hyperelastic, Axisymmetric, Plane Strain, Precompression.


1. INTRODUCTION

Gate valves are the flow control devices used in petrochemical, chemical, power, mining & minerals processing industries. They are given this name because the flow
control is achieved by linear movement of a component, which acts as a gate to permit or prevent the fluid flow.

In gate valves, the sealing surfaces of gate and seat are planar. The gate might be either wedge shaped or could have parallel faces. In open condition, the gate presents no obstruction in fluid flow, and in closed condition, it completely closes the passage of fluid from one side to the other. Gate valves are generally used only for flow control, not for flow regulation. If used for flow regulation, the gate in its half-closed position offers huge resistance to fluid flow and pressure drop in fluid stream is enormous.

If the fluid being transported is thick or contains large chunks of solids, the knife edged gate is used. This allows easy cutting of thick fluid and in turn easy movement of gate through the fluid.

To avoid the contact of slurry with metallic parts, the seat of the valve comprises of two rubber sleeves. There is a metallic insert in the sleeves to strengthen the rubber against slurry pressure and to prevent sleeves’ excessive deformation during gate movement through the sleeves. This design provides an optimum flexibility while the gate is passing through. As only the rubber sleeves are in contact with the slurry, only these are damaged and can be replaced easily. Expensive metal parts (Valve body) are not damaged and can be used for a longer period of time.

During the assembly of valve, sleeves are precompressed via tightening of bolts between sleeve and body, to establish a permanent contact between them. This ensures flow with minimal leakage in open condition of valve.

When gate moves relative to the sleeves, sleeves experience high frictional forces. Because of friction forces, sleeves are subjected to shear and tend to move with the gate. Metal reinforcement inside the sleeves, having higher stiffness, resists this deformation and tries to keep the sleeves at their original position; hence the stresses are induced in the rubber sleeves and reinforcement. The position and size of reinforcement ring inside the sleeves affect the stresses induced in the sleeves to a great extent. A bad design of sleeves could result in total rupture of rubber sleeves during movement of gate.

In forward stroke of gate (while closing the valve), the frictional forces are reduced by lubricating the sleeve and gate surfaces. In backward stroke of gate, despite the lubrication, the frictional forces are considerably higher between downstream sleeve and corresponding gate surface because of fluid pressure on gate from the upstream side. This results in higher probability of sleeve rupture during backward stroke.

The design of the rubber sleeves should fulfil these criteria- sleeves should maintain the seal when subjected to pressurized slurry (minimal leakage in open condition); leakage should be minimal during piercing of gate (small leading edge gap); sleeves should be elastic enough to retain the leak proof seal after removal of gate (during and after backward stroke).

The designing process of gate valve sleeves is facilitated with FEA. The operation of the valve can be simulated and analyzed in different FEA environments. Preliminary designs are analyzed with FEA and required modifications are made to achieve the final design.

Two FEA methodologies were used to simulate and analyze the behavior of rubber sleeves in open and closed conditions. The application of these methodologies for dry run (without pressure) only has been presented here.
2. FIRST METHODOLOGY
The first methodology involves modelling and analysis of a full 3D model with ANSYS Mechanical and provides time-dependent results of gate movement and corresponding sleeve deformation. 3D model of valve is discretized with first order brick elements.

2.1. Input 3D Model

![3D Model of Valve Assembly](image1)

The sleeves are precompressed by 1.6 mm in the given model. To solve the precompression, the sleeves are modelled as touching each other. Then displacement equal to half the precompression value is imposed on both the sleeves towards each other. The reinforcement and LDR (Load Distributing Ring) are modelled as bonded with the rubber sleeve.

Analysis is carried out in two loadsteps. In first step, the precompression is solved. In second step, gate is moved inside the prestressed sleeves to observe the deformation and stress pattern of the sleeves, as the gate passes through.

2.2. FE Model

Loads and boundary conditions are shown in the following image.

![FE Model with BCs](image2)
Here, 1–Imposed displacement (0.8 mm) on left sleeve face in (-) ve Y-direction
2– Imposed displacement (0.8 mm) on right sleeve face in (+) ve Y-direction

Other than these BCs, gate is constrained to move in vertical (X) direction only and a displacement equal to 25% of gate stroke length is imposed on gate (in (-)ve X direction) to simulate gate movement. All the body faces have been constrained in all the DOFs.

2.3. Material Properties

The non-linear behavior of hyperelastic rubber material is defined by Ogden model (order 2) with following parameters.

![Ogden Model Graph](image)

**Figure 3** Approximation of Rubber material properties by Ogden 2<sup>nd</sup> order model

Ogden parameters for rubber material

\[ \mu_1 = 1.023, \mu_2 = 1.345, \alpha_1 = -2.012, \alpha_2 = 3.861 \]

and Poisson's ratio = 0.495

All the metal parts are assigned with steel properties of Young’s Modulus = 2.1E11 Pa and Poisson’s ratio = 0.3

Both approaches use the same material properties.

2.4. Precompression Solution Results

The results after solving the precompression are shown below.

![Axial Displacement of Sleeves](image)

**Figure 4** Axial displacement of sleeves

![Von-Mises Stress in Sleeves](image)

**Figure 5.** Von-Mises stress in sleeves
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2.5. Gate Movement Solution Results
Gate has been moved inside the sleeves and the results of 25% gate stroke have been shown below.

![Figure 6](image1.png) Axial displacement of sleeves  ![Figure 7](image2.png) Von-Mises stress in sleeves

![Figure 8](image3.png) Leading edge gap development during gate penetration

When gate penetrates inside the sleeves, the sleeves get opened slightly ahead of the gate tip. The result shown in fig. 8 allows to see the size of the opening formed, on the basis of which it can be predicted whether significant leakage will occur during gate movement or not. If the opening size is too large, higher precompressive loads will be required to reduce the leakage.

3. SECOND METHODOLOGY
All the components of valve assembly (except gate) and the loading on them (precompression on sleeves, fixity of body) are axisymmetric; hence they can be modelled as axisymmetric elements. For gate, width is much higher than its thickness, so it can be modelled as a plane strain element.

Only the cross-sections (cut by vertical XY plane) of axisymmetric bodies and gate are discretized with first order quad elements. For analysis, appropriate element formulations are assigned to the elements, i.e. plane strain to gate and axisymmetric to rest.
In this methodology, two separate analyses are carried out, unlike the previous one where two loadsteps were combined in a single analysis. The open and closed conditions are analyzed separately in this methodology.

As the FE model for this methodology has only a small no of 2D elements, hence total no of nodes is much lesser than that in previous methodology.

Meshing and deck preparation are done in HyperMesh-Ansys profile and analysis is carried out in Ansys APDL.

### 3.1. Precompression Solution Analysis

The FE model for precompression solution is shown below

![Figure 9 FE Model for precompression solution](image)

In this methodology also, sleeves are modelled just touching each other and then an equal displacement (0.8 mm) is imposed on both the sleeves, towards each other. This arrangement simulates the real time assembly conditions.

The nodes shown in black represent the nodes on which respective constraints and loads have been applied.

![Figure 10 Constraint in Axial (Y) Direction](image)

![Figure 11 Constraint in Radial (X) Direction](image)

![Figure 12 Displacement in +ve Y direction](image)

![Figure 13 Displacement in –ve Y direction](image)
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3.2. Precompression Solution Results

![Axial displacement of sleeves](image1)
![Von-Mises stress in sleeves](image2)

The stresses induced in metallic parts are very high compared to stresses in rubber sleeves. The area of interest here is behavior of sleeves, so stresses in the metallic parts have not been considered. The highest stress in the sleeve occurs at the contact location between two sleeves.

3.3. Gate Insertion Analysis

![FE model](image3)
![Constraint in axial direction](image4)
![Constraint in radial direction](image5)

![Figure 16](image6)

For gate insertion analysis, each sleeve is further displaced half gate thickness away from each other and gate is placed between the sleeves. Displacement of half gate thickness + half precompression is imposed on both the sleeves towards each other. In addition to the boundary conditions of previous case, gate top surface nodes are fixed axially and radially. Also, the nodes of gate, between and outside of the sleeves at 6 O’clock position are fixed radially and axially as shown in fig. 16(b) & (c).
3.4. Gate Insertion Results

These plots show the deformed shape of the rubber sleeve after insertion of gate through sleeves.
4. COMPARISON AND DISCUSSION

The results of stress and deformation contour by second methodology are similar to those of first methodology. This can be observed by comparing figure no 4 to 14, 5 to 15, 6 to 18 and 7 to19.

The advantages of second methodology over first one can be summarized as-

- This methodology involves lesser number of 2D elements than that of 3D elements in old methodology, hence much lesser number of nodes.
- Deck preparation takes less time than that in first methodology.
- Solver run time is lesser because of less number of nodes; hence total analysis time is much lesser.
- As the FE model is not cumbersome, high end computer memory configuration is not required for faster analysis.
- When used in design development process, this methodology can quickly predict the qualitative and quantitative effect of small changes in design. By observing these effects, required modifications can be incorporated in the next iteration of design and thus final design can be attained quickly.

The advantages of first methodology over second one are as following-

- This methodology can give results of stress and strain contours in sleeves at different positions of gate, while it is passing through the sleeves.
- Animations of gate movement can be created; these provide a better understanding of the overall behavior of valve assembly.
- As shown previously, with this methodology it can be found out whether opening ahead of gate during gate penetration is large or small and will cause leakage or not.
- The probability of sleeve rupture is higher during the backward stroke. Real time simulation and analysis of backward stroke of gate can be carried out with this methodology.
- Because of friction between sleeves and gate, sleeves are subjected to shearing along with compression during gate insertion; this effect can be simulated and analyzed with this methodology.

5. CONCLUSION

The second methodology is a useful tool for analyzing the various design iterations during the design modification stage and helps in quick design finalization. The first methodology provides the results for complete cycle of valve operation and hence is useful to validate the final sleeve design.

6. FUTURE SCOPE

The presented work can be extended to carry out analyses with consideration of pressure on both sleeves and gate, in both methodologies.

In this work only 12 O’clock position cross-section has been considered for second methodology. This can be extended to 6 O’clock position cross-section.

In second methodology, by imposing displacement on top nodes of gate, the gate can be moved instead of moving the sleeves. In this way, both forward and backward stroke of gate can be simulated at both 6 O’clock and 12 O’clock cross-sections.
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