Design and Finite element analysis of Fatigue Life for Swivel Joint

[1]Aradya S M, [2]Dr. P L Srinivasa Murthy, [3]Balasubramanya H S, [4]P N Girish Babu
[1]Associate Professor, Kalpataru Institute of Technology, Tiptur 572202
[2,4]Associate professor, Ramaiah Institute of Technology, Bangalore 560054
[3]*Assistant Professor, Ramaiah Institute of Technology, Bangalore 560054

*Corresponding Author: baluhs.md@gmail.com

Abstract: Swivel joints are extensively used for interconnecting pipe sections of articulated fluid transfer equipment, for instance, the pantograph assembly for refueling of helicopters, aircraft. Swivel joints comprise of male and female sections which are rotatable and mounted together by annular ball or roller bearing systems with a continuous fluid passage. Since the male and female sections rotate relative to each other, they cannot be tightly secured at the interface and as a result at their interface the balls and rollers bearing systems get contaminated. Since both bearing systems are manufactured with close tolerances, they are susceptive to binding when contaminated by materials entering either through the path between the male and female sections or while dismantling the swivel joint for service. As a result, the swivel joint may not function properly. During replacement of main seal and ball bearing, swivel joint must be dismantled in such a way the ball and roller bearing systems, as well as the male and female elements of the swivel joint are taken apart. The operation of the main seal replacement and ball bearing therefore becomes time and labor consuming. The present work aims at replacing the main seal and ball bearing without dismantling the swivel joint and evaluation of fatigue life of swivel joint using finite element analysis (FEA).

Keywords: Fatigue life, Dynamic load rating, Conduit

I. INTRODUCTION

There are variety of diversified swivel joints such as flanged, threaded, butt weld and ball bearings etc. The present invention finds particular utility in a built-in flange coupling type swivel joint comprising male and female conduit element as shown in Fig.1.

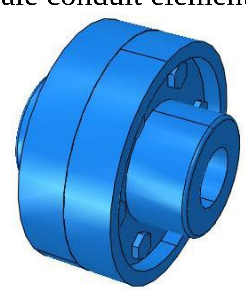

Fig.1: Swivel joint with removable plug.

The swivel joint with removable plug mainly consists of male conduit element, female conduit element, ball bearing, assembly bolts, seals, and removable plug. The male and female conduit elements are coupled together by fastening bolts and nuts. The bolts are pretension to apply the clamping force between the two conduit elements so that there is no clearance and relative motion in the beginning.

Conventional Method of joining of pipe may lead to leakage. These problems may be overcome by swivel joints. It avoid the leakage due to high pressure fluid flow at the joint in the pipe. It can transfer fluids to different units without dismantling of piping system. To reduce vibration caused due to the misalignment between the mating pipes. Torque can be alleviated with the use of ball bearing in the joint, by reducing friction between surfaces providing relative motion between them.

The seal is provided between the two flanges to avoid the leakage, thereby reducing leakage and working condition of swivel joint. The seals are also provided in the removable plug to avoid the entry of fluid into the ball bearing thereby avoiding the contamination and rusting of ball bearing materials that may cause the improper functioning of the swivel joint.

The ball bearings are provided in between the female conduit element and removable to facilitate the relative motion between the two surfaces with less consumption of energy. They serve one important function by alleviating the torque and reducing the friction surfaces and thus provide smooth relative motion between the surfaces.

The first part (inlet pipe) is coupled to the male conduit element and second part (outlet pipe) is coupled to the removable plug there by providing a continuous passage for the flow of fluid to be transported for the given swivel joint. The second part (outlet pipe) can be rotated with respect to female conduit element so that we can transfer the fluids to different units without disassembly of piping system also we can use these swivel joint for loading and unloading condition.

The main seal and ball bearing is supported by the removable plug in tight sealing engagement between the upper surface of the cylindrical body of the plug and the proximal end of the inner diameter of female conduit element, such that the main seal prevents the fluid transported through the swivel joint from entering the bearing chambers. The main seal is preferably a BX seal comprising of substantially annular body made of an elastomeric material.

Bearing life is characterized as aggregate number of unrest or the quantity of hours that you can anticipate that your ball bearing will work at standard working condition.

According to information provided, the Basic Dynamic Radial Load Rating (Cr) is 57252N, Radial load is 20,000n, axial load is 8000N. Basic rating life is calculated as below

$$L_{10} = \frac{10^6}{60n}\left(\frac{C_r}{P_r}\right)^2 \qquad (1)$$

Where

L_{10}= hours (h)

N=speed (rpm)

C_r= Basic Dynamic Radial Load Rating

P_r= Dynamic Equivalent Radial Load

1.1 Male to female conduit element contact

Surface contact is defined between male and female conduit element shown in Fig 2 and Fig 3 are coupled together by bolt and nut with the application of pretension. The male conduit element is made master and female conduit element is made slave as it has course mesh.

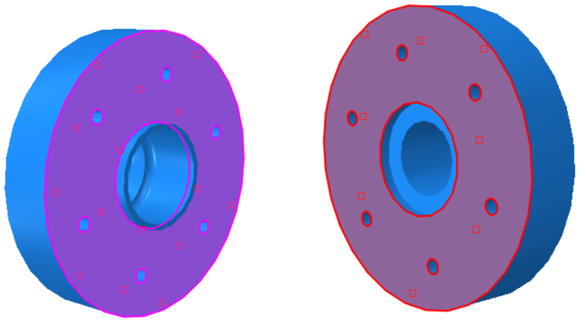

Fig.2 Male and female conduit elements

1.2 Nut to female conduit element contact

To apply correct pre-tension the contact between the nuts and female conduit is very important. Tie contact is sandwiched between the bottom head exterior surface of the nut and outer surface of female conduit element, assuming that there is no relative motion between them when bolt interacts. The female conduit element is made master because it will have course mesh and stiffer than bolts.

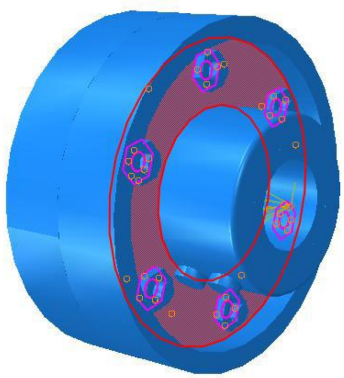

Fig. 3**:** Contact between nut and female conduit element.

Tie contact is made assuming that the nuts and bolts are connected rigidly and there is no relative motion between the parts, also neglecting the stress concentrations in the thread region.

II. MATERIAL MODELS

There are four different materials used in the swivel joint model. The properties are described as shown below.

Table.I: Models of different materials.

Material	Young's modulus	Yield strength	Poisons ratio	Used for
80K SI Steel	204 GPa	471 GPa	0.3	Removable, Male and Female conduit elements

Titanium	102 GPa	249MPa	0.3	BX seal
ASTM A320 L7M	198GPa	502MPa	0.3	Nuts, bolts
ASTM 52100	208GPa	420MPa	0.3	Ball bearings

2.1 Boundary conditions

A problem in structural mechanics is not completed unless we specify the boundary conditions properly. In fact without defining the boundary conditions the element stiffness matrix and global stiffness matrix are singular i.e, their determinant vanishes and vice-varsa is not true. The physical significance of boundary condition is that structure or body can experience the rigid body motion unless some support or constrains are applied that will ensure equilibrium of loads. The boundary condition has to be defined properly according to physical phenomenon of problem as shown in Fig 4.

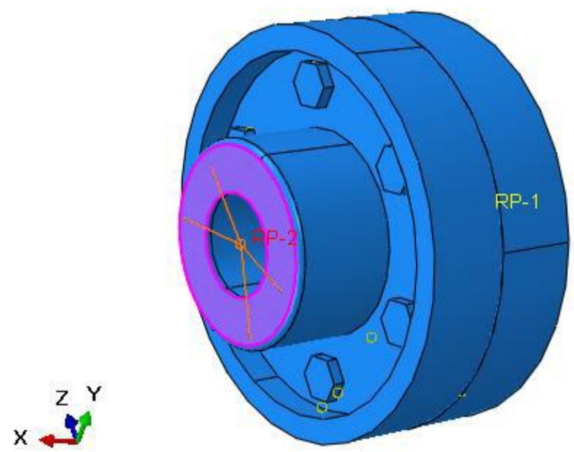

Fig.4: Surface applied with encastre boundary condition is marked in red colour.

In the present study male conduit element is connected to inlet pipe, the inlet pipe cannot be rotated so that the female conduit element is applied with encastre boundary conditions at reference point that locks all the translation and rotation degree of freedom.

2.1.1 Loads

In order to replicate actual working condition of swivel joint, it is subjected to a variety of loads. The tensile load is applied in order replicate the tension behavior of swivel joint. The bending load is applied in order to determine the maximum bending capacity of swivel joint. The torque is applied to removable plug in order to simulate exact working behavior of swivel joint. The pressure is applied in order to replicate the flowing of high pressure fluid. The reference points are used to apply the loads. In addition to the above loads the bolts pretension act as the clamping force to male and female conduit element there by secure seal tightly.

2.1.2 Internal pressure

The internal surfaces of the swivel joint are subjected to pressure load as shown in Fig 5, Due to applied pressure radial forces will be acting on the inner surfaces of swivel joint which are perpendicular to axis. Applied pressure also try to separate the male and female conduit elements.

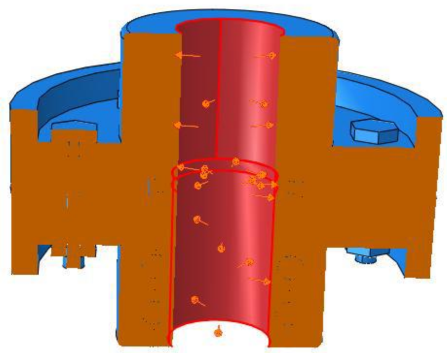

Fig.5: Area subjected to pressure.

III. RESULT AND DISCUSSION

3.1 Capacity of swivel joint in tension

The maximum capacity of the swivel joint with removable plug in tension is 707.82 kN. When the load of 707.82 kN was applied to the reference point as explained earlier, due to the applied load the maximum stress developed in bolts as shown in the Fig 6. But when the load is decreased to 692 kN the stress developed in the bolts is less than the yield strength of the bolt material [9,10] as shown in Fig 7. In Comparison to analytical results the percentage error is 2.23 %. By finite element analysis we can conclude that the maximum capacity of swivel joint in tension is 692kN.

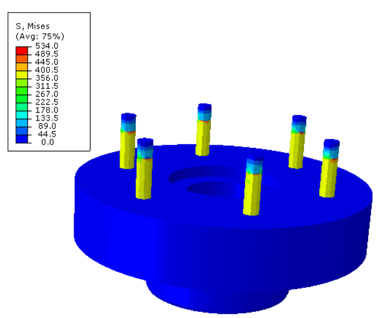

Fig.6: Yielding of bolts due to applied load of 707.82 kN.

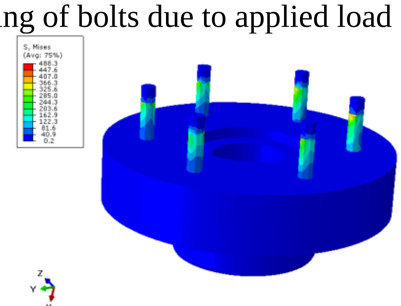

Fig.7: Von-misses stress due to applied load of 692 kN.

3.2 Capacity of swivel joint in bending

The maximum capacity of swivel joint with removable plug in bending is 4246.2 kN-mm. When the load of 4246.2 kN-mm is applied to the reference point the bolt assembly has yielded as shown in Fig 8. Compared to theoretical results analytical solution differed by 17.5%. These difference between the theoretical and the FE-results are due to conduit elements complex behavior in bending.

As well, the theoretical calculation only uses bolt circle diameter and tension capacity as parameters, without considering the geometry of swivel joint. So by finite element analysis we can conclude the maximum bending capacity of swivel joint is 3500 kN-mm.

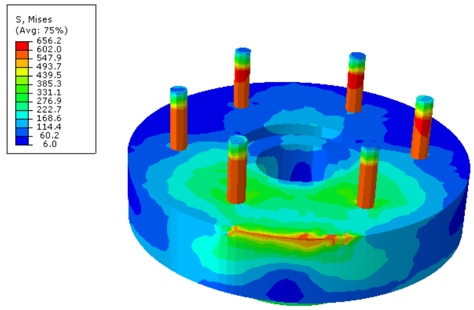

Fig.8: Von-misses stress due to bending applied load of 4246.2 kN-mm.

3.3 Capacities of swivel joint in torque

The maximum capacity of swivel joint with removable plug in torque is 37192.3 kN-mm. When a torque of 37192.3 kN-mm was applied the stress developed in the swivel joint assembly is well below the yield strength as shown in Fig 13. Compared to analytical and FEM results were harmonized. Thus the swivel joint can sustain the torque of 37192.3 kNmm without plastic deformation or yielding. Since the ball bearings are placed between the female conduit elements and removable plug, due to applied torque at point ball bearings provided relative motion of removable plug with respect to conduit element by consuming little amount of energy. Even though the applied torque is high the stress developed in conduit elements are comparable due to the presence of ball bearing.

3.4 Capacities of swivel joint in torque

The maximum capacity of swivel joint with removable plug in torque is 37192.3 kN-mm. When a torque of 37192.3 kN-mm was applied the stress developed in the swivel joint assembly is well below the yield strength as shown in Fig 9. Compared to analytical and fem results were harmonized so the swivel joint can sustain the torque of 37192.3 kNmm without plastic deformation or yielding. Since the ball bearings are placed between the female conduit elements and removable plug, due to applied torque to reference point ball bearings provided relative motion of removable plug with respect to conduit element by consuming little amount of energy. Even though the applied torque is high the stress developed in conduit elements are comparable due to the presence of ball bearing.

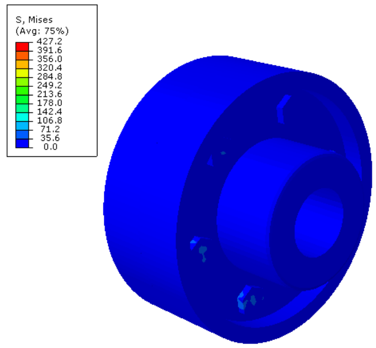

Fig.9: Von-misses stress due to applied torque 37192.3kN-mm.

IV. FATIGUE ANALYSIS OF SWIVEL JOINT

Fatigue analysis results were presented in this section. The critical bending moment carrying capacity of swivel joints was 4246.2 kN-mm. Still it being a high moment range the number of cycles required to failure is high. In order to predict the fatigue life of swivel joint the high stress point or hot spot point have to be identified. The hot spot is a point where the stress is critical and crack will most likely to grow. The hotspot in the each components were indentified with respect to integration points were the maximum effective stress induced which are used to calculate the fatigue life. The figure shows the hot spot region in the male and female conduit elements.

The equivalent stress obtained using calculating the equation

$$\sigma_{eq}=\sqrt{\frac{1}{2}\left\{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\sigma^2{}_{xy}+\sigma^2{}_{yz}+\sigma^2{}_{zx}\right\}} \quad (2)$$

σ_{eq} =543.18 MPa

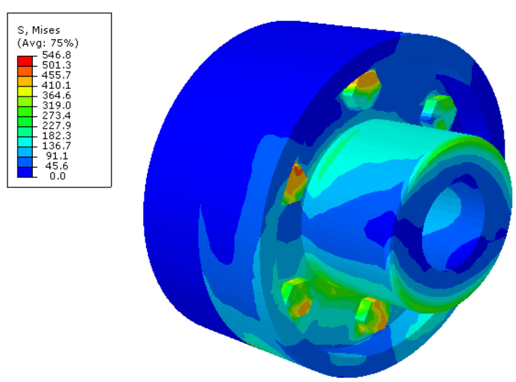

Fig 10 Von-misses stress due to applied torque 37192.3 kN-mm.

Fatigue life estimation was carried differently for conduit elements and bolts and nuts as shown in Fig 10. The stress developed in the conduits elements due to applied bending loads are above 106.97 MPa by using the Equation 1 the life of conduit elements is 5.36×10^6. In order to find the life of bolts and nuts due to applied bending load the load from the pretension step as to be subtracted. The stress developed in the bolts are above 36.84MPa and the life of bolts and nuts are 4×10^6.

V. CONCLUSION

The capacities of swivel joint under tension, bending, torsion, and pressure were evaluated using theoretical and numerical methods. Swivel joints used in oil, gas and petroleum industries were evaluated according to the industrial standards. When the swivel joint was applied with tension load the deviation from analytical to theoretical is 2.23%. Hence we can conclude that maximum tensile load capacity of swivel joint is 692 kN. Beyond these load bolts begins to yield were as the stress developed in the male and female conduit elements were significantly less than the yield stress.

When swivel joint was subjected to bending load the difference between theoretical and numerical results is 17.57%. These difference between the theoretical and the FE-results are due to conduit elements complex behavior in bending, additionally the bending equation consider bolt circle diameter and tension capacity as parameter without considering the geometry of swivel joint.

When the torque of 37192.3 kN-mm was applied to swivel joint and the stress developed in the swivel joint assembly were significantly below the yield stress of the materials. Compared to analytical and fem results were harmonized so the swivel joint can sustain the torque of 37192.3kN-mm without plastic deformation or yielding. Since the ball bearings are placed between the female conduit elements and removable plug, due to applied torque to reference point ball bearings provided relative motion of removable plug with respect to conduit element by consuming little amount of energy. Even though the applied torque is high the stress developed in conduit elements are comparable due to the presence of ball bearing.

The modified design of swivel joints in the present project helps us to remove the seal and ball bearing without the dismantling of the conduit elements. There by reducing the cycle time and labor requirements to disassembly of swivel joints.

REFERENCES

[1] Swivel Joint For Pipes: William George Luke; David Pender Datson.

[2] Swivel joints with uniform ball bearing requirements: Brian Witkowski (Weatherford, TX, US) Mark D. Matzner (Burleson, TX, US).

[3] Elastomeric subsea flex joint and swivel for offshore risers: Edward J Arit,III, Benton Baugh, David C Riggs.

[4] Swivel Joint: S. H. B. Zachariassen.

[5] Ball Bearing in Swivel Joints for Hoist Blocks: F Hooker. Dowling, Norman E. (2013). Mechanical Behavior of Materials. 4th ed. Upper Saddle River, NJ: Pearson Education Limited. isbn: 978-0-273-76455-7.

[6] Petroleum and natural gas industries - Design and operation of subsea production systems - Part 7:Completion/workover riser systems (ISO 13628-7:2005). (2005). International Organization for Standardization.

[7] Sun, Eric Qiulu. Shear Locking and Hourglassing in MSC Nastran, ABAQUS, and ANSYS.

[8] Fatigue Design of Offshore Steel Structures, Recommended Practice DNV-RP C203. (2010). Det Norske Veritas.

[9] Takagi, Yoshio et al. (2013). FEM Stress Analysis and the Sealing Performance Prediction of Pipe Flange Connections under External Bending Moments and Internal Pressure. Journal of Solid Mechanics and Material Engineering 7 (4), 486{495.