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Design and Analysis of Rigid Unprotected Flange Coupling Finding Optimized Design

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Abstract:

Rigid flange couplings are designed for heavy loads. The present study of this paper is to reduce the stress that acting on the bolts by making it uniform strengthen also finding out the safe design vs load. Stresses on the flange coupling joints is predicted using the static analysis. The Finite element simulation is performed on original as well as on different modified designs to optimize the flange coupling joint. The dynamic analysis performed is similar to the torsional analysis of the flange coupling joint and similar boundary condition is applied to the flange coupling. The stress in the threaded part of the bolt will be higher than that in the shank. Hence a greater portion of the will be absorbed at the region of the threaded part which may fracture the threaded portion because of its small length. An axial hole is drilled at the centre of the bolt through the head as far as thread portion such that the stress in the bolt is uniformly distributed along the length of the bolt.

Keywords — **Rigid flange coupling, Safe design, Static Analysis.**

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I. INTRODUCTION

Analysis of flange coupling joint is performed using the finite element method. The static analysis of flange coupling is executed to determine the stress whereas the torsional analysis of flange coupling is to determine the Eigen frequencies and Eigen vector of the bolted flange coupling. Eigen vector is also known as the mode shape of the system which give the modal mass for the corresponding mode.

Analytical calculation is done at original bolted flange coupling. These calculations are done with the intention of validating the FE result with the analytical result. Based on the result of the FE static analysis optimization is performed on the original design to reduce the cost of the bolted flange coupling without compromising its strength. Torsional dynamic analysis is done with purpose to improve the dynamic performance of the flange coupling such that it will dynamically stable at the higher speed or frequency as compared to the original design.

1. To understand the overall design requirement
2. To study of basic design inputs for flange coupling.
3. To design a flange coupling with the analytical calculation and develop the model for the same by using SOLIDWORKS.
4. To develop finite element model of bolted flange coupling by using ANSYS.
5. To determine a maximum Stress in the flange coupling along with the dynamic characteristic of flange such as mode shape and Eigen vectors.

II. DESIGN OF RIGID FLANGE COUPLING

In this work, designing of the coupling joint is done by using the combination of analytical calculation and finite element method. Detailed assembled model of Rigid flange coupling is as shown in below diagram.

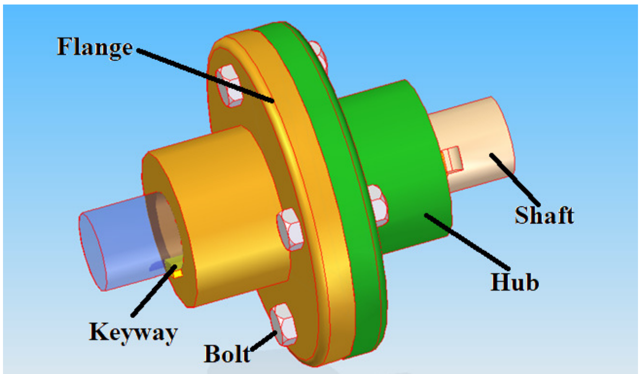

Fig.1: Assembled model of Rigid Flange coupling

Some of different parts detailed dimensions

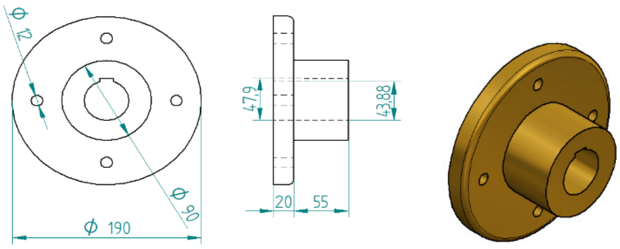

Fig.2: Rigid Flange dimensions

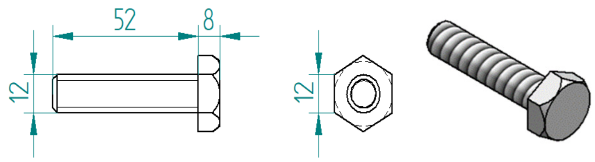

Fig.3 Bolt dimensions

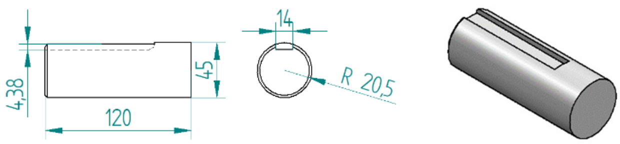

Fig.4 Shaft dimensions

From all the papers it is observed that to calculate the stresses and dynamic performance of the coupling joint difficult work. Hence to develop the FE procedure without the experimental reading is research topic in the field of designing of the flange joints or bolted coupling joints. Various authors suggested the method of static calculation and some on the analytic calculation. Develop the method of designing the FE method for the flange coupling joint which does not require the experimental runs.

III. ANALYTICAL CALCULATION

Table.1 Dimensions of all parts of flange coupling

Sl.No	Description of parts	Dimensions
1	Shaft Diameter	45 mm
2	Flange inner diameter	45 mm
3	Flange Outer Diameter	190 mm
4	Bolt diameter	12 mm
5	Shaft length	120 mm
6	Flange length	75 mm
7	Hub Length	55 mm
8	Design Power	60 kW
9	Speed of Drive	500 rpm

To perform the analytical calculations, the following parameters are assumed:

- **Material**: Cast iron flange coupling with a steel shaft
- **Power Transmission**: 60 kW
- **Speed**: 500 rpm
- **Maximum Allowable Shear Stress in the Shaft**: 40 MPa

The torque transmitted by shaft,

$$T=\frac{(P\times 60)}{(2\pi N)}$$

$=1527.7\times 10^3$ N.mm

Considering strength of the shaft, we know that,

$$\tau=\frac{T\times 16}{(\pi\times d^3)}$$

$=85.371$ N.mm

Von-Mises stress is given by

$$\sigma=\sqrt{\frac{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_x-\sigma_z)^2+6(\sigma_{xy}{}^2+\sigma_{yz}{}^2+\sigma_{zx}{}^2)}{2}}$$

σ_{eq} = 147.86 MPa

σ_x=Radial Stress

σ_y=Tangential Stress or shear stress in the component

σ_z=Axial Stress

As the bolted flange coupling joint is subjected to the pure torsion load, shear stress (σ_{xy}) will be generated on the component. Whereas Tension component (σ_x, σ_y and σ_z) and other two shear component (σ_{yz} and σ_{xz}) will be zero. By substituting the above stresses in the equivalent stress equation or it can be also calculated by dividing the shear component by 0.58 as per shear stress theory.

Design for hub,

Outer diameter of hub = 2d = 160 mm

Length of hub =L= 120 mm.

$$T = \frac{\pi}{16 \times T_s \left(\frac{D^4 - d^4}{D}\right)}$$

$T = \pi/16 \times T_s ((D^4 - d^4)/D$

Design for key,

Width of key (w) = 25mm

Thickness of key (t) = 14mm

Length of key (l) = 120mm

T = l×w×Tsk× (d/2)

IV. FINITE ELEMENT MODEL OF FLANGE COUPLING

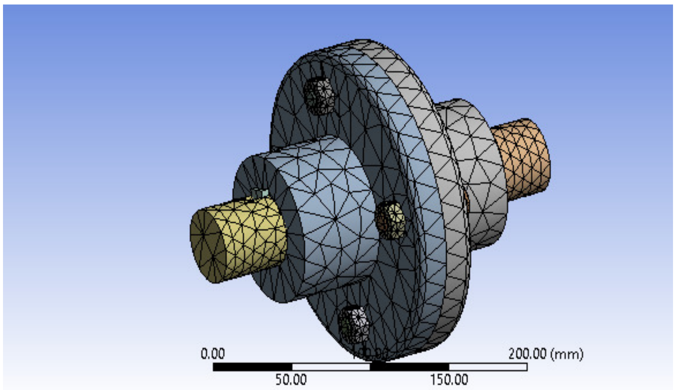

Fig.5 Finite Element mesh: Complete assembly

Table.2: FE Details

Sl.No	Component	FE Detail
1	Shaft	Shaft 3D solid element
2	Flange & Hub	3D solid Element
3	Bolt	1D beam element

Analytical calculation is done to calculate the shear stress and the average stress or the von-misses stress. FE calculation is performed on the original as well as on the optimised design. Iterations were performed in which the optimisation is done step by step. Based on the analysis result for each step or optimised design, further optimisation is done.

Table.3: Material Property

	Flange Coupling		
Material	Unit	Flange, Hub	Shaft
E-modulus	MPa	1,10,000	2,00,000
Poisson Ratio		0.28	0.3
Density	Kg/m^3	7200	7800
Yield Limit	MPa	151	250
Ultimate Limit	MPa	240	360

Table. 4: Summary- Load Cases.

Load Cases	Load	Boundary Condition
Static Analysis	Moment, Preload	One end of Flange coupling shaft is constraint in all DOF (Constraint in X, Y and Z)
Modal Analysis	No Load	Flange coupling shaft both end is constrained in all DOF except the rotary DOF about rotation axis i.e. rotation about Z axis is not constraint

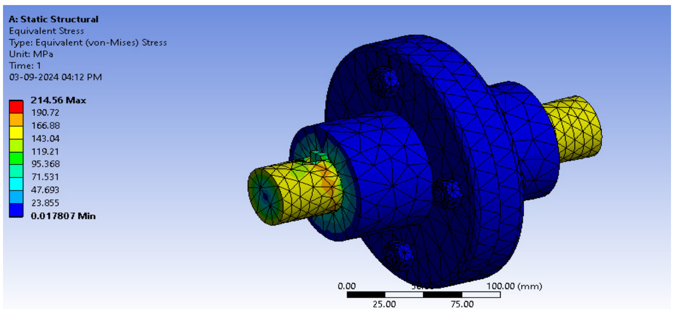

Fig.6 Von-Mises stresses

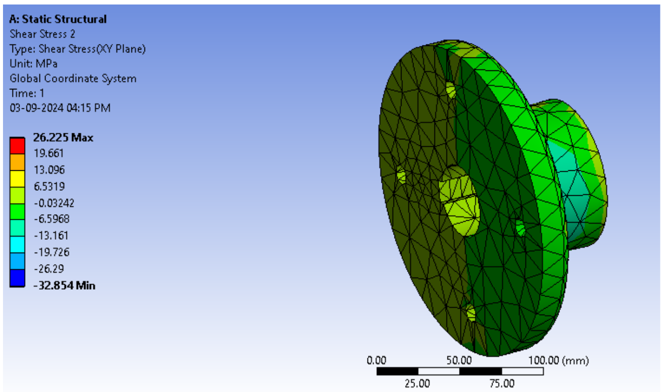

Fig.7 Maximum shear stress on flange

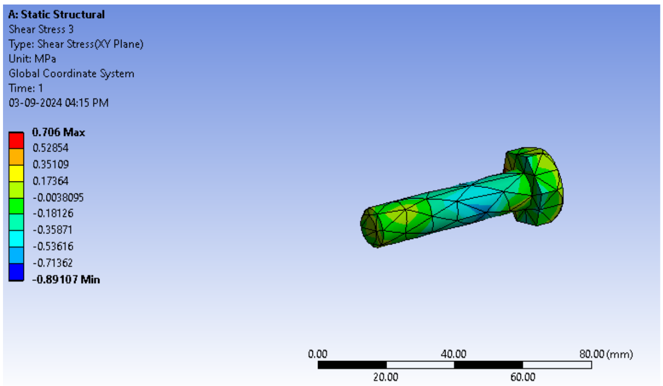

Fig.8 Maximum shear stress on bolt

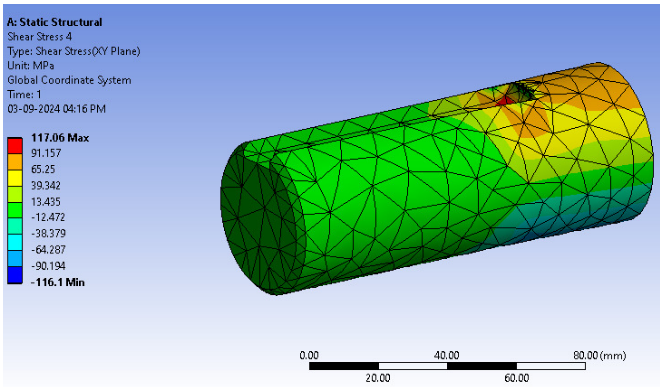

Fig.9 Maximum shear stress on shaft

- Average Stress of 8 MPa is observed on flange1 and 7 MPa on flange 2.
- Average stress on both the flanges is 4 MPa.
- Average stress on the shaft key is in range of 50-57 MPa.
- Average stress on the shaft is 60 MPa.

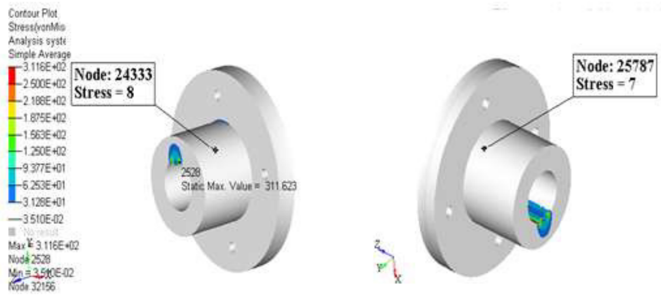

Fig.10 Original Design: Von-Misses Stress [MPa] - Hub

As stress value is too low for the flanges and hub, then the flange coupling can be optimised further.

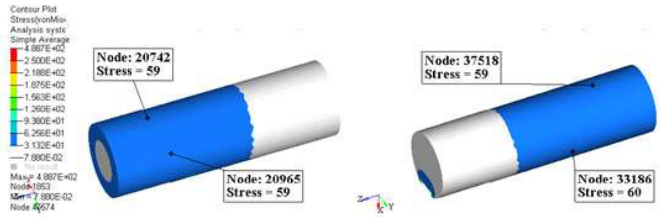

Fig.11 Original Design: Von-Misses Stress [MPa] - Shaft

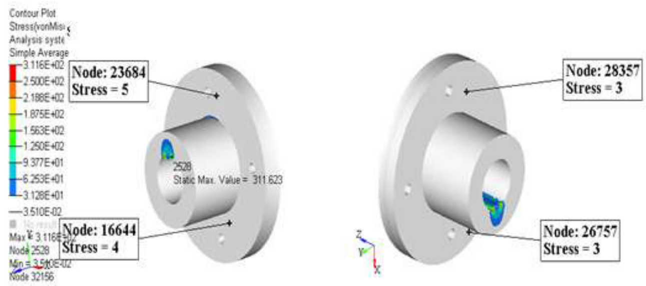

Fig.12 Original Design: Von-Misses Stress [MPa] - Flange

Analytical calculation is done and it is compared with the Finite element result. Detail correlation between the analytical and FE result is tabulated in Table.5. Deviation between the analytical and FE result is also calculated. From the comparison, it is observed that the analytical result is closely matching with the FE result. Maximum deviation of 8% is observed in the flange, this deviation is less as the stress value is very less. Actual deviation of 1.4% is observed on the shaft. FE results are validated with the analytical result.

Table 5: Original Design-Result Table

Sr. No.	Components	FE Result	Analytical Result	Deviation
		Von-Mises [MPa]	Von-Mises [MPa]	%
1	Shaft	60.0	59.2	1.4
2	Keyway	54.0	49.4	1.2
3	Flange	4.0	3.7	8.1
4	Hub	8.5	7.86	1.8

V. CONCLUSIONS

Design of bolted flange coupling is done using the analytical and FE method. Analytical calculation is the base for validating the design and FE calculation for the further optimization and improvement in the dynamic performance. Results of the analytical calculation are matching close to the FE analysis results so the design is safe. Different parts of rigid flange coupling such as shaft, unprotected flange, keyways, Bolt and Nut using ANSYS workbench is better than that of calculations using analytical method. Minimum factor of safety of three is observed for the flange coupling. It was found that the crushing stress for bolts and shear stress in bolts, keys obtained from the Ansys software is slightly less than the crushing and shear stress obtained in the theoretical calculation and for the shaft deviation is of 1.4% and for flange its 8.1%, due to nonlinear profile meshed as coarse. From calculations it is found that the design is safe and it is validated through analysis software.

VI. REFERENCES

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