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Study of Performance of Shim Coupling Using FEA

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Abstract
In coupling of shafts two shafts are connected for various applications. For connecting the shafts alignment is necessary otherwise misalignment leads to development of stresses in coupling. By using different types of disc with different shapes it is possible to reduce the stresses and deformation. This study focuses mathematical and FEA results of three different load cases which are of three kinds; first is bolt pretension, second is bolt pretension with radial misalignment, and third is bolt pretension with radial misalignment and torque. In FEA study, static structural analysis method is used to find deformation & stresses. Ansys tool is used for FEA study, & discusses which type of disc profile is suitable for Disc coupling. To back up the results obtained by FEA study Mathematical modeling is done to find deformation & stresses.

Keywords: Shim coupling, straight & scalloped disc, FEA of coupling, performance of coupling

1. INTRODUCTION

A coupling is a device is used to connect two shafts together at their ends for the purpose of transmitting power. The main use of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both. Misalignment reduces the life span, reliability of motors & their associated components. Poor choice & design of a flexible coupling results in unwanted mechanical vibration in rotating machinery. The effects of excessive vibration may lead to the premature failure of connected machinery, reduced efficiency and may causes effect on worker's health and comfort.

Flexible couplings are used to transmit torque from one shaft to another when the two shafts are slightly misaligned. Flexible couplings may be accommodating varying degrees of misalignment up to 3° and some parallel misalignment. Further, they can also be used for vibration damping. The uses of flexible coupling in industry are pump sets, compressors, wind turbine, generator sets, general purpose heavy duty applications.

A flexible coupling subjected to torque, misalignment and speed reacts on the connected parts. These reactions not only affect the life of the coupling but the life of the equipment as well. Resulting moments and forces may cause unacceptable loads on the bearings, seals, the equipment shafts and even the equipment support structure that can cause them to wear, twist, deform and even fail prematurely. This can create unexpected downtime and increased maintenance, so increase the operating cost of the equipment.

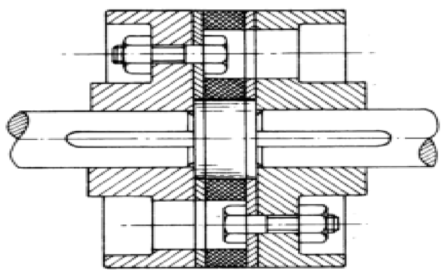


Fig.1 Flexible Rubber Disc Coupling

There are three basic functions of flexible coupling -:

1) Transmit power

2) Accommodate misalignment
3) Compensate for end movement

2. DISC COUPLING

In 1971, Zurns Mechanical drives division developed a multiple diaphragm design, with number of thin plates in parallel, instead of a single thick one. This type of design provides improve flexibility & lower stresses, as the stresses are proportional to the cube of the material thickness. The disc coupling is available in a number of forms, all have the driving & driven bolts on the same bolts on the same bolt circle. The flexibility of misalignment that each type can handle depends upon the length of the material between bolts. Disc coupling on the other hand, use a series of thin laminates to form one ring, or disc pack unit.
In our project we work on the two disc profile, straight sided disc profile & scalloped disc profile. The two most commonly used blade types are Straight-sided and scalloped flex discs. Round discs are still commonly used in many older coupling styles. Because of these designs, less pre-stretch is required than with scalloped designs because there is less torsional windup under load. So less pre-stretch is required, because of this straight-sided discs are easier to assemble. Each type is suited to particular applications. By FEA analysis we have to decide which type of shim is best suitable for coupling.

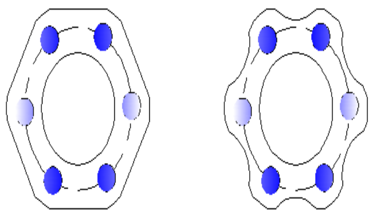


Fig. 2 Common Blade Types

3.0 OBJECTIVES, PROBLEM DEFINITION, SCOPE

3.1 Objectives

Many researchers had done analysis to find out shim failure and however in the different applications disc failures are different also causes are different, therefore it need to study the misalignment problem to improve shim coupling life. Main objectives are

- Prepare a Finite element Analysis for Straight sided & Scalloped Shim profile.
- Check the deformation & Stresses of two different shim profiles for same loading & boundary condition.
- Prepare Mathematical Modeling for Radial Misalignment.
- Find out the optimum one for Shim Coupling.

3.2 Definition of problem

In shim coupling different types of shim profiles are used to transfer power from one shaft to the other by taking different misalignment. In running condition, transmitting power with misalignment the disc bend & various stresses are induced into the shim profile. The intensity of various stresses induced in shim is depending upon shim profile. In circular disc stresses are more as compare to straight sided disc. In case of straight sided shim the stresses are less at the edges between two bolts. And failure of disc is occurs at the portion between two bolts. If material is removed from the edges then it becomes scalloped shim. Due to the shim can bent very easily, so it can take more misalignment with minimum torque. The problem under consideration is to investigate the Deformation & Various Stresses in Shim profile due to

- Bolt pretension
- Radial Misalignment
- Peak Torque

3.3 Scope of the project

In shim coupling we used two types of shim profile i.e. straight sided & scalloped shim. Shim coupling subjected to axial misalignment, angular misalignment & radial misalignment.
The scope of the project focus -:

- Create a model of shim coupling assembly using Pro-E (wild fire 5.0).
- Analysis the Shim/Disc using FEA software (ANSYS 13).
- Mathematical Modeling for disc.
- Comparative study for both straight sided & scalloped shim/disc.

4.0 INTRODUCTION OF PRO-E MODELING

Total assembly of Shim coupling has done in the software Pro-engineer. Pro-engineer is a parametric, integrated 3D CAD/CAM/CAE solution maufactured by Parametric Technology Corporation (PTC). Pro-engineer was leading successful, parametric, feature-based, associative solid modeling software in the market. The application run on Microsoft Window, Linux and UNIX platforms, and provides assembly modeling, solid modeling and drafting, finite element analysis, and NC and too long functionality for mechanical engine.

Pro-E is modeling tool used for the modeling of the component and assembly for analysis purpose. This tool also used for analysis purpose. By using this software we can construct different models.

5.0 FINITE ELEMENT ANALYSIS

The Finite Element Method (FEM) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as of integral equations. Its practical application often known as Finite Element Analysis (FEA). Finite Element Analysis is a simulation technique which evaluates the behavior of various parts, equipment and structures for various loading conditions including applied forces, temperatures & pressures. So a complex engineering problem with non-standard shape and geometry can be solved using finite element analysis where a closed form solution is not available.
The finite element method has become a powerful tool for the numerical solutions of a wide range of engineering problems. It was developed simultaneously with the increasing use of the high-speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis.

5.1 General description of the method

In engineering problems there are some basic unknowns. If these unknowns can found, the behavior of the entire structure can be predicted. Basic unknowns or the Field variables which are encountered in the engineering problems are velocities in fluid mechanics, displacements in solid mechanics, temperatures in heat flow problems and electric and magnetic potentials in electrical engineering. In a continuum, these unknowns are infinite. In the finite element procedure reduces such unknowns to a finite number by dividing the solution region into small parts called elements and by expressing the unknown field variables in terms of assumed approximating functions (Interpolating functions/Shape functions) within each element. In this method approximating functions are defined in terms of field variables of specified points called nodes or nodal points. So in the finite element analysis the unknowns are the field variables of the nodal points. If these are found then field variables at any point can be found by using interpolation functions.
The no. of steps involved in the finite element analysis are

1) Chose suitable field variables and the elements.
2) Discritise the continua.
3) Select interpolation functions.
4) Find the element properties.
5) Arrange element properties to get global properties.
6) Impose the boundary conditions.
7) Solve the system equations to get the nodal unknowns.
8) Do the additional calculations to get the required value

5.2 Boundary conditions

In this analysis pump end hub keep fixed & torque is applied at the spacer as shown in figure. Also gives the bolt pretension at six bolts. This coupling can take 0.5^{o} angular misalignment, 1.4 mm Radial misalignment & 1mm axial misalignment.

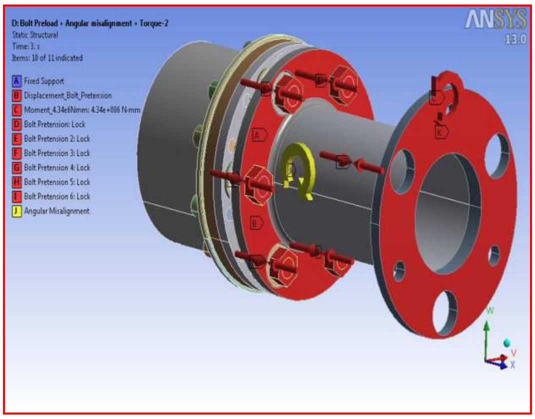


Fig. 3 Boundary Conditions

5.2 Stress analysis

Stress analysis is the determination of various stresses i.e. equivalent stress, Principal stress & Shear stress etc in the straight & scalloped disc coupling. After finding the stresses in disc we select the suitable disc for coupling. For that purpose we select the area between two bolts. Because that area just bent by taking actual Axial misalignment, Angular misalignment & Radial misalignment. At this area stress is minimum at outer edges. So we can reduce this area so the straight sided disc becomes scalloped disc.

5.3 FEA result

The aim of this project is to find out the suitable Shim profile for Shim coupling. In our project we select two types of Shim profile i.e. straight sided & Scalloped Shim profile. Scalloped profile is the modification in the straight sided profile as. In this project we study the stress analysis of shim profile by software Ansys 13 & validate the result of Straight sided Shim profile with mathematical modeling.

5.4 FEA result for three steps

FEA results are the get for both straight sided & scalloped Shim. In this result we find principle stress, shear stress, equivalent stress & total deformation. For this analysis there are three cases i.e. axial misalignment, radial misalignment & angular misalignment. And for each case we tabulate the result in three steps. In first step we find the result for bolt pretension. In second step we find result for bolt pretension + Radial misalignment. In third case we find the result for bolt pretension + Radial misalignment + torque applied.

6.0 RADIAL MISALIGNMENT

In this project for analysis purpose, Radial misalignment takes 1.4 mm. In Radial misalignment axis of one shaft is misalign with 1.4 mm along axis.

For bolt pretension following results are obtained -:

6.1 Total deformation -:

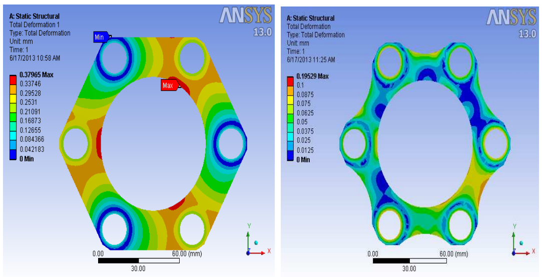


Fig. 4 Total deformation for straight sided & scalloped disc

The deformation at area in between two bolts is 0.2531 mm & for scalloped shim is 0.0625 mm. The deformation at area in between two bolts is 0.26215 mm & for scalloped shim is 0.046013mm. From above analysis we conclude that for same input, deformation is minimum in scalloped shim profile as compared to straight side shim profile.

6.2 Maximum principle stress -:

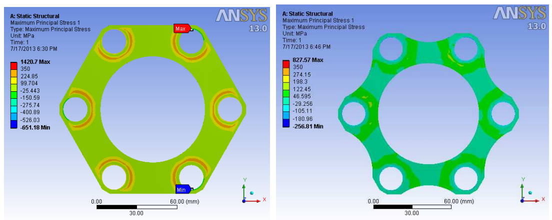


Fig. 5 Max. Principle Stresses for straight sided & scaloped disc

Maximum principle stress developed in straight shim is 99.704 N/mm^2 & for scalloped shim is 46.595 N/mm^2. Principle stress developed at area between two bolts is 100.12 N/mm^2 for straight sided shim & for scalloped shim it is 46.81 N/mm^2. So we conclude that for same input, maximum principle stress developed in scalloped shim is less as compared to straight sided shim.

6.3 Shear stresses -:

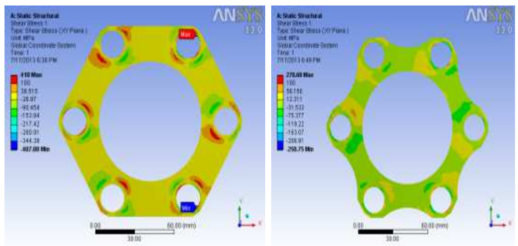


Fig. 6 Shear Stresses for straight sided & scalloped disc

Shear stress developed in straight shim is 36.515 N/mm^2 & for scalloped shim is 12.311 N/mm^2. Shear stress developed at area between two bolts is 30.926 N/mm^2 for straight sided shim & for scalloped shim it is 12.307 N/mm^2. So we conclude that for same input, shear stress developed in scalloped shim is less as compared to straight sided shim.

6.4 Equivalent stresses (von-mises)

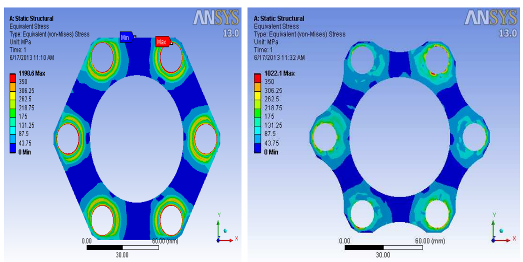


Fig. 7 Equivalent Stresses for straight sided & scaloped disc

Equivalent stress developed in straight shim is 43.75 N/mm^2 & for scalloped shim is 43.75 N/mm^2.

7.0 BOLT PRETENSION + RADIAL MISALIGNMENT

This is the second step of analysis. In this analysis bolt pretension & particular misalignment input given to coupling & results are tabulated. The results of second step are as follows:

7.1 Total deformation

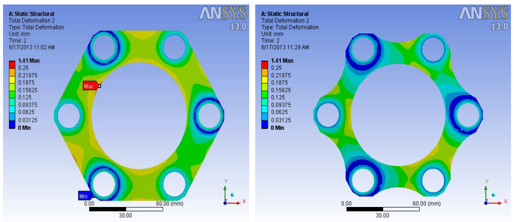


Fig. 8 Total deformation for straight sided & scaloped disc

The deformation at area in between two bolts is 0.1875 mm & for scalloped shim is 0.15625 mm.

7.2 Maximum principle stress

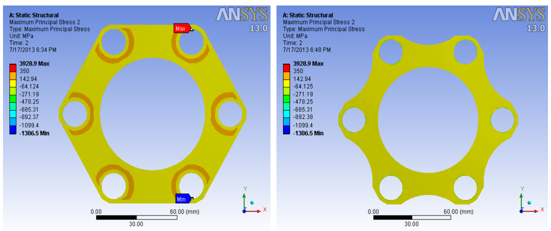


Fig. 9 Max. Principle Stresses for straight sided & scaloped disc

Principle stress developed at area between two bolts is 142.94 N/mm^2 for straight sided shim & for scalloped shim it is 142.94 N/mm^2

7.3 Shear stress

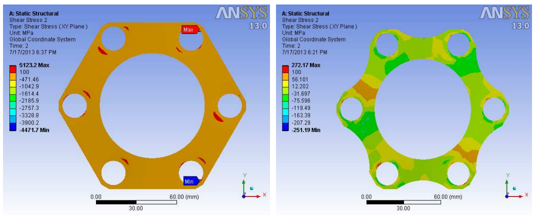


Fig. 10 Shear Stresses for straight sided & scaloped disc

Shear stress developed at area between two bolts is 100 N/mm^2 for straight sided shim & for scalloped shim it is 100 N/mm^2.

7.4 Equivalent stresses (von-mises)

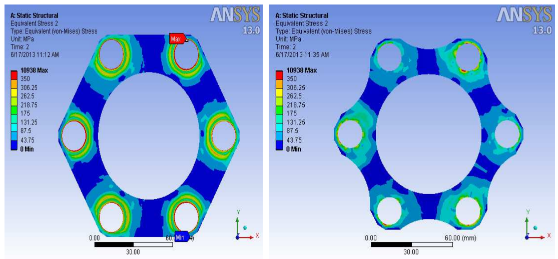


Fig. 11 Equivalent Stresses for straight sided & scaloped disc

Equivalent stress developed at area between two bolts is 43.75 N/mm^2 for straight sided shim & for scalloped shim it is 43.75 N/mm^2.

8.0 BOLT PRETENSION + RADIAL MISALIGNMENT + TORQUE

This is the third step of analysis. In this step bolt pretension value, particular misalignment & torque inputs are given to coupling & results are tabulated. For all three cases bolt pretension & torque remains constant.

8.1 Total deformation

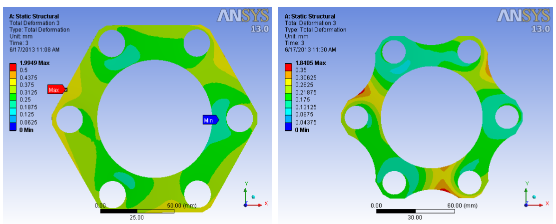


Fig. 12 Total deformation for straight sided & scaloped disc

The deformation at area in between two bolts is 0.375 mm & for scalloped shim is 0.2625mm

8.2 Maximum principle stress

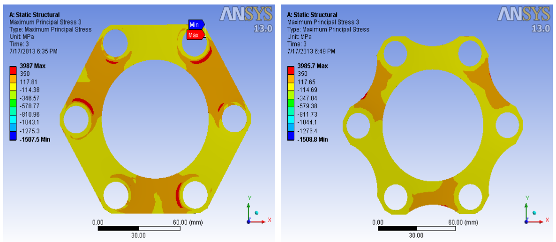


Fig. 13 Max. Principle Stresses for straight sided & scaloped disc

Principle stress developed at area between two bolts is 117.81 N/mm^2 for straight sided shim & for scalloped shim it is 117.81 N/mm^2.

8.3 Shear stress

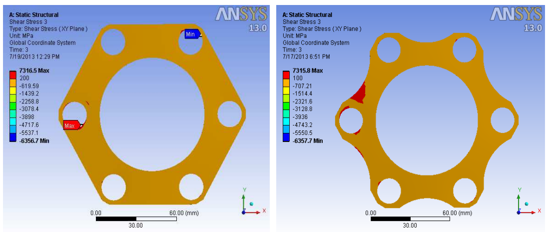


Fig. 14 Shear Stresses for straight sided & scaloped disc

Shear stress developed at area between two bolts is 100 N/mm^2 for straight sided shim & for scalloped shim it is 100 N/mm^2.

8.4 Equivalent stresses (von-mises)

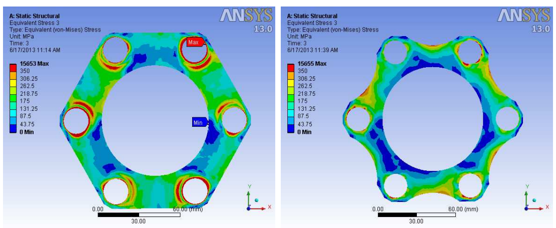
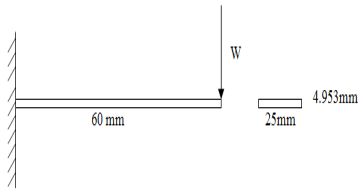


Fig. 15 Equivalent Stresses for straight sided & scaloped disc

Equivalent stress developed at area between two bolts is 218.75 N/mm^2 for straight sided shim & for scalloped shim it is 218.75 N/mm^2.

9.0 MATHEMATICAL RESULT-:

9.1 For bolt pretension (time-1) -:



Maximum deflection $\delta f = 0.33746$ mm.

We Know,

$$\delta f = \frac{wl^3}{3EI}$$

$$0.33746 = \frac{w \times 60^3}{3 \times 193257 \times (\frac{25 \times 4.953^3}{12})}$$

W= 229.29 N

$$M = w \times l = 229.29 \times 60 = 13757.4 \text{ N.mm}$$

We know that

$$\frac{M}{I} = \frac{\sigma b}{y} = \frac{E}{R}$$

$$I = \frac{25 \times 4.953^3}{12} = 253.14 \text{ mm}^4, \quad y = \frac{4.953}{2} = 2.4765 \text{ mm}$$

$$\sigma b = \frac{13757.4}{253.14} \times 2.4765 = 134.59 \text{ N/mm}^2.$$

We have the formulae for Principle stress-:

$$\text{Principle Stress} = \frac{P}{2} \pm \sqrt{\left(\frac{\sigma b}{2}\right)^2 + \tau^2}$$

Where τ = Shear Stress But $\tau = \frac{Say}{Ib}$

S= Shear force

For cantilever beam S = W

S0 S = W = 229.29 N

Shear stress is given by

$$\tau = \frac{229.29 \times (25 \times 4.953) \times 1.2382}{253.14 \times 25}$$

$\tau = 5.554$ N/mm^2.

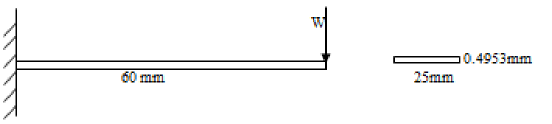
Principle stresses are given by-:

$$\text{Principle Stress} = \frac{\sigma b}{2} \pm \sqrt{\left(\frac{\sigma b}{2}\right)^2 + \tau^2}$$

$$= \frac{134.59}{2} \pm \sqrt{\left(\frac{134.59}{2}\right)^2 + (5.554)^2}$$

Principle stresses = 134.818 N/mm^2

9.2 For bolt pretension + axial misalignment (time-2)



Maximum deflection $\delta f = 0.15625$ mm.

We Know, $\delta f = \frac{wl^3}{3EI}$

$$0.15625 = \frac{w*60^3}{3*193257*(\frac{25*4.953^3}{12})}$$

W= 106.166 N

M = w × l = 106.166 × 60

M = 6369.975 N.mm

We know that

$$\frac{M}{I} = \frac{\sigma b}{y} = \frac{E}{R}$$

I= $\frac{25 \times 4.953^3}{12}$, I = 253.14 mm^4, y = $\frac{4.953}{2}$ = 2.4765 mm

$\sigma b = \frac{6369.975}{253.14} \times 2.4765 = 62.318$ N/mm^2.

We have the formulae for Principle stress-:

$$Principle\ Stress = \frac{\sigma b}{2} \pm \sqrt{\left(\frac{\sigma b^2}{2}\right) + \tau^2}$$

Where $\tau = Shear\ Stress$, But $\tau = \frac{Say}{Ib}$, S= Shear force, For cantilever beam S = W

S0 S = W = 106.166 N

Shear stress is given by

$$\tau = \frac{106.166 \times (25 \times 4.953) \times 1.2382}{253.14 \times 25}$$

τ = 2.57N/mm^2.

Principle stresses are given by-:

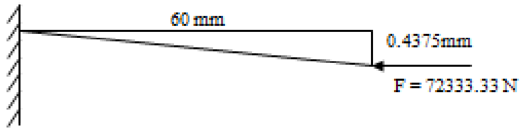
$$Principle\ Stress = \frac{\sigma b}{2} \pm \sqrt{\left(\frac{\sigma b}{2}\right)^2 + \tau^2}$$

$$= \frac{62.318}{2} \pm \sqrt{\left(\frac{62.318}{2}\right)^2 + (2.57)^2}$$

Principle stresses = 62.42 N/mm^2

9.3 For bolt pretension + axial misalignment + torque (time-3)

For Torque Consideration-:



We have the formula for Torque required,

$T = Force * r$

Here, T = 4.34×10^6 N-mm, r = 60 mm.

Therefore $4.34 \times 10^6 = F \times 60$ 0.4375mm

F = 72333.33 N.

M = w × l, M = 72333.33 × 0.4375= 31645.83 N.mm

$\sigma b = \frac{M}{I} \times y$

$\sigma b = \frac{31645.83}{253.14} \times 2.4765 = 309.59$ N/mm2

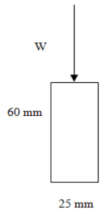
W

Shear stress is given by-:

$\tau = \frac{Say}{Ib}$

S=72333.33N

60 mm



a = 25×60

y = 15 mm

$$I = \frac{bd^3}{12}$$

$I = \frac{25 \times 60^3}{12}$ = 450000 mm^4

25 mm

$$\tau = \frac{72333.33 \times (25 \times 60) \times 15}{450000 \times 25}$$

$\tau = 144.66\ N/mm^2$

Principle stresses are given by-:

$$Principle\ Stress = \frac{\sigma b}{2} \pm \sqrt{\left(\frac{\sigma b}{2}\right)^2 + \tau^2}$$

$$= \frac{309.59}{2} \pm \sqrt{\left(\frac{309.59}{2}\right)^2 + (144.66)^2}$$

Principle stresses = 366.6629 N/mm^2

10. RESULT AND DISCUSSION:

A result shows the comparative study of stresses, deformation in straight sided disc and scalloped disc. Load cases are of three kinds first is bolt pretension, second is bolt pretension with radial misalignment, and third is bolt pretension with radial misalignment and torque.

Shear stress developed in straight sided shim by mathematical calculation is 144.66N/mm^2 & by FEA 146.17 N/mm^2. This shows that mathematical results & FEA results are approximately same. Also results for principal stresses and equivalent stresses are approximately same.

11. CONCLUSIONS

From above results, it is observed that the stress concentration is less at the middle portion between two bolts. Stress concentration is very less at the outer edge middle portion of the disc. If we compare the FEA results of both straight sided & scalloped disc, then it is observed that various induced stresses (Equivalent stresses, Shear stresses, Principal stresses) are less in scalloped disc as compare to straight sided disc. So vibrations induced & load acting on both driven & driving equipment are reduced. Therefore overall life, efficiency, cost & working ability of coupling will be improved. Scalloped discs are failing in the center section between the bolts and not at the flex point near the bolts. FEA analysis shows that higher working stresses are observed in the scalloped disc between and near the bolts. Therefore failure should typically occur at the flexing points near the bolts. Failure in the center of the disc may be more related to stress concentrations resulting from the manufacturing process than to the application conditions.

It is concluded that the use of scalloped disc instead of straight sided disc gives better results in the application of Disc coupling from FEA analysis.

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