Analysis of a Machine Shaft Using Finite Element

Amit Tiwari[1], Prof. S. C. Gupta[2]
[1]PG Scholar, [2]Assistant Professor
Dept of ME, MIT, Bhopal

Abstract- Shaft is a rotating machine element, circular in cross section which supports elements like rollers, gears, pulleys & it transmits power. The shaft is always stepped with maximum diameter in the middle and minimum at the ends, where Bearings are mounted. To reduce metal fatigue by stress distribute, strain distribute, to reduce cracks of high stress concentration principle by reduce stress concentration level & to minimize deformation and finding natural frequency. It is founded that Fatigue life of designed of shaft is safe at a drive range of stress and stability frequency of design shaft is 0 Hz up to 1325.2 Hz. And principal stress drive up to 62% and displacement up to 35% by these result shaft and shape are safe.

Keywords- FEM, Deformation, Von-misses stress, principal stress life cycles, frequency, Fatigue, Fracture.

I. INTRODUCTION

A structure as a whole, and each individual member, must be designed with reference to the three 'Ss': strength, stiffness and stability:

Strength is the ability to carry the applied loads without yielding or breaking. Examples of strength failures are a cable which snaps, a vehicle body which' crumples, and a glass panel being smashed.

Stiffness is the ability to carry the applied loads without too much distortion. A material can only sustain stress at the expense of some strain ($\sigma = E\varepsilon$). Sometimes the strain, even though very small, may be the limiting factor. For example, a machine tool must be stiff enough to produce the required accuracy in machining, and a camera tripod must be stiff enough to prevent camera shake.

Stability is the ability to carry compressive loads without collapsing or buckling out of shape. For example, a metal rod in compression longitudinally will suddenly bow out of shape under a compressive stress which is well below the compressive yield stress.

The importance of the different types of failure, in considering any particular member, depends on how the loads are applied to it.

ie: A member in tension. Strut: A member in compression

*Beam: A member with loads that causes *bending.*

Shaft: A member in torsion.

In fact the members are categorized according to the way in which the forces are applied. These four type of loading define the four structural components: ties, struts, beams and shafts. Real members often carry a combination of loads.

Fatigue Failure

Fatigue is caused by cyclical stresses, and the forces that cause fatigue failures are substantially less than those that would cause plastic deformation. Confusing the situation even further is the fact that corrosion will reduce the fatigue strength of a material. The amount of reduction is dependent on both the severity of the corrosion and the number of stress cycles.

Once they are visible to the naked eye, cracks always grow perpendicular to the plane of maximum stress. Figure shows the fracture planes caused by four common fatigue forces. Because the section properties will change as the crack grows, it’s crucial for the analyst to look carefully at the point where the failure starts to determine the direction of the forces.

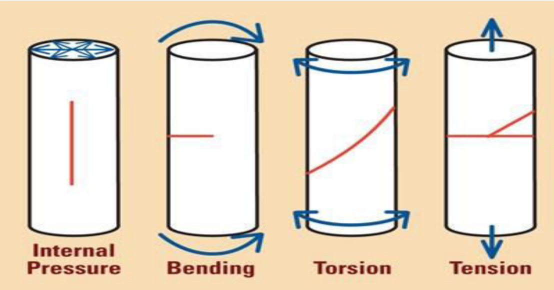


Figure 1 shows the fracture planes caused by four common fatigue forces.

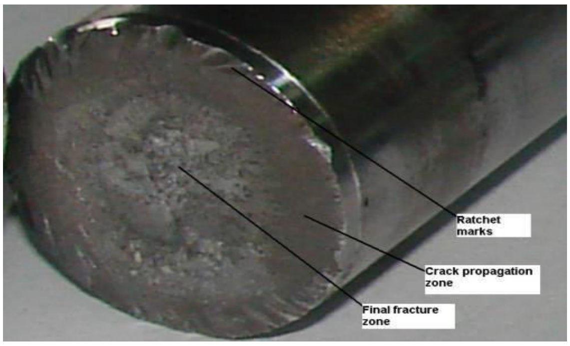


Figure 2 Fracture Surface of a shaft under fatigue loading

II. MODES OF FRACTURE

1. Monotonic Overload

i. Brittle: Brittle fracture may occur at stresses for below the yield strength. In case of materials subjected to impact and shock loads and usually occur without warning. Brittle fractures are most likely to occur on large-sized components or structures as a result of shock loading.

ii. Ductile: If a material is subjected to load above the yield point and the process of deformation continues, fracture eventually occurs. Ductile fractures require a considerable amount of energy to plastically deform the material in necking region. Ductile fractures are very important in metal working operations, such as deep drawing, forging etc.

2 Subcritical Crack Growth

A. Failure under static load Parts under static loading may fail due to:

i. Ductile behavior: Failure is due to bulk yielding causing permanent deformations that are objectionable. These failures may cause noise, loss of accuracy, excessive vibrations and eventual fracture. In machinery bulk yielding is the criteria for failure. Tiny areas of yielding are in ductile behavior in static loading.

ii. Brittle behavior: Failure is due to fracture. This occurs when the materials (or conditions) do not allow much yielding such as ceramics, grey cast iron, or heavily cold-worked parts.

B. Dynamic loading:

Under dynamic loading, materials fail by fatigue. Fatigue failure is a familiar phenomenon fatigue life is measured by subjecting the material to cyclic loading. The loading is usually uniaxial tension, but other cycles such as torsion or bending can be used as well.

Fatigue failures are caused by slow crack growth through the material. The failure process involves four stages

1. Crack initiation

2. Micro-crack growth (with crack length less than the materials grain size) (Stage I)

3. Macro crack growth (crack length between 0.1mm and 10mm) (Stage II)

4. Failure by fast fracture.

Cracks initially propagate along the slip bands at around 45 degrees to the principal stress direction this is known as Stage I fatigue crack growth. When the cracks reach a length comparable to the materials grain size, they change direction and propagate perpendicular to the principal stress. This is known as Stage II fatigue crack growth.

III. PROBLEM IDENTIFICATION

Various review papers have also been published periodically by various researchers like:

Li-Hui Zhao et.al. (2019), This paper investigates the failure mode and root cause of drive shaft failure in a vehicle through examination of the macroscopic and microscopic morphologies of the fracture surface, the chemical composition, metallographic analysis, and mechanical properties of the material, and theoretical finite element calculations of the drive shaft. The results show that fatigue was the dominant mechanism of drive shaft failure due to obvious benchmarks on the fracture surfaces. Fatigue cracks initiated from the root fillet region of the spline gear.

Jae-ung Lee et.al.,(2018) Since selecting a case ship subjected to the damage on the stern tube bearing, it investigated the actual cause of the damage, thereby finding a practical way to enhance the sustainability of the propulsion shaft system using the single stern tube bearing. Results of the analysis suggested that the degree of slope be taken into account when estimating the effective supporting point of the bearing. Finally, this paper pointed out that the establishment of a shaft installation guideline considering the effect of the shaft slope, thereby preventing wiping damage of the aft stern tube bearing would be an urgent task.

Mahmoud T.El-Sayed (2017) The objective of the present work was to estimate the effect of internal torsional resistance in shafts which is caused by deflection, for the reason that it has the upper hand on misalignment problem. With the aim of fulfilling this objective, an experimental rig has been constructed to verify the existence of the torsional resistance in deflected shafts and its variation with the rotation angle.

Samuel O. Afolabi et.al.(2017) In materials engineers, it is important to determine the cause of failure of a machine component, to prevent prospect occurrences and increase the performance of the component structure. In this study, the parameters of the fatigue life of machine shafts are investigated.

K.R Rushton (2016) A detailed investigation into the stress concentration factors arising in the torsion of grooved shafts is described. The results were obtained on an electrical analogue, which solves the finite difference form of the governing differential equation. The method was first tested by a comparison with the analytical solution for shafts containing deep hyperbolic grooves, and was then used to provide numerous numerical results for solid and hollow shafts containing parallel-sided and "V" grooves

M.J. Miller (2015) As with any technology, progression of the product application has adapted to the needs of the vehicle driveline layout. We discuss the fundamental layouts where propshafts are applied, the key enablers for propshaft design, critical calculations, variations of propshaft products, and current trends for propshafts and the interfaces with the torque products they interact with.

M.Banuta, I. Tarquini(2013) The drive shaft in the propulsion system of a boat broke, while the vessel was sailing along the Western Canadian coast. This part was made from a low-alloy steel grade 4340 quenched and tempered. Fractographic investigation at macro scale revealed that the shaft failed under low rotating-bending variable stress. Fatigue propagation occurred on about 95% of the total cross section of the shaft, under both low-cycle and high-cycle fatigue mechanisms.

M. Savković, M. Gašić,(2011) The common design of the bucket wheel drive mechanism in some bucket wheel excavators (BWE) consists of a gearbox and a hollow shaft, while the bucket wheel is supported by the axle passing through the hollow shaft. Improper maintenance and inadequate elimination of axis misalignment of the hollow shaft and the bucket wheel axle are the main causes of excavator failure and axle fracture.

The problems identified from the study of literature review are as follows:

1. Overload failures are caused by forces that exceed the yield strength or the tensile strength of a material. The appearance of an overload failure depends on whether the shaft material is brittle or ductile.

2. Metal fatigue is caused by repeated cycling of the load .It is a progressive localized damage due to fluctuating stresses and strains on the material. It is mainly occur when stress more serve due to strain.

3. The cause of a broken shaft is almost always fatigue. A crack starts at a stress concentration

from a keyway or a sharp radius, or, in rare cases, from a material impurity. Flaws in the surface of a shaft, such as scratches, indents or corrosion, may also be the starting point of a fatigue crack. Loads that drive a crack are normally torsion loads from direct online starts or bending loads from the pulley or coupling end.

IV. METHODOLOGY

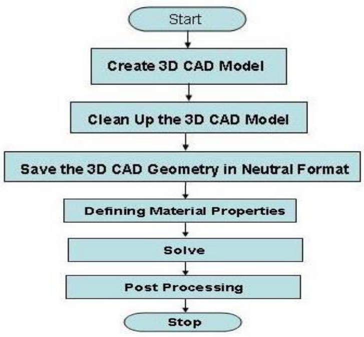
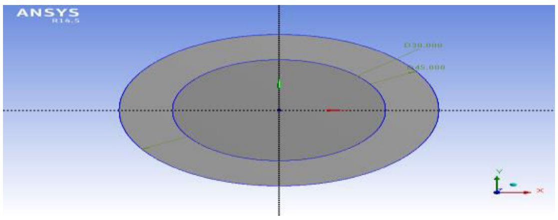


Figure 3: Flowchart of FEM analyses

Geometry Description

The Geometrical model has been generated on Ansys 14.5. And the dimension is taken as it was used in references paper. The figure shows the geometrical model of machine shaft.



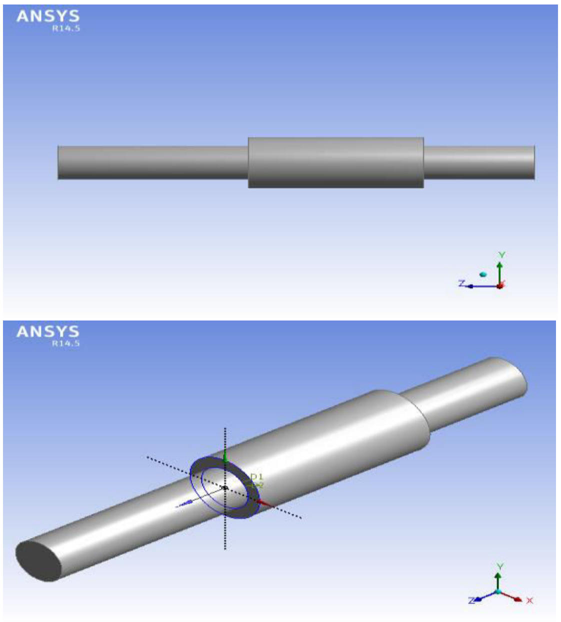


Figure 4: Geometry of shaft in 2D and 3D with dimension in mm.

Meshing

Meshing is a critical operation in FEM, this process the CAD geometry is divided into numbers of small
pieces. The small pieces are called mesh.
The analysis accuracy and calculation duration depends on the mesh size and orientations. By, default, a coarse mesh is generated by ANSYS software. Mesh contains mixed cells per unit area (ICEM Tetrahedral cells) having triangular faces at the boundaries. Number of nodes-15086 and Number of elements 8430 Curvature- On and Smooth – Fine meshing.

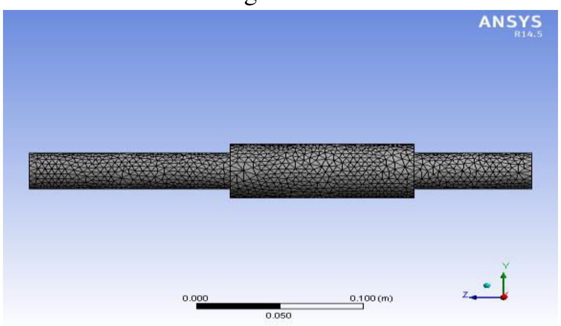


Figure 5: Meshing of Machine shaft.

V. RESULT AND DISCUSSIONS

After putting the boundary conditions, the solution is initialized and then iteration is applied so that the values of all parameters can be seen in a curve or line graph. After the iteration gets completed final result could be seen.

For 30mm diameter machine shaft at phase angle zero degree

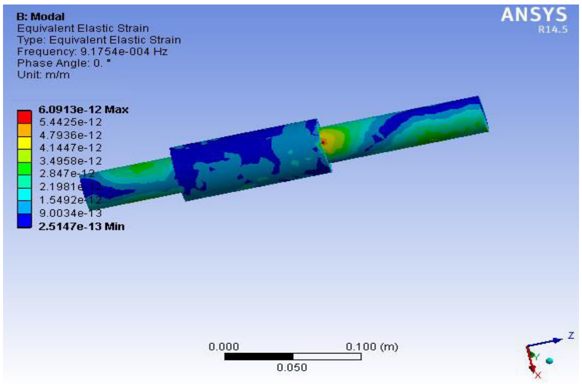


Figure 6: Equivalent elastic strain at 0 degree phase angle.

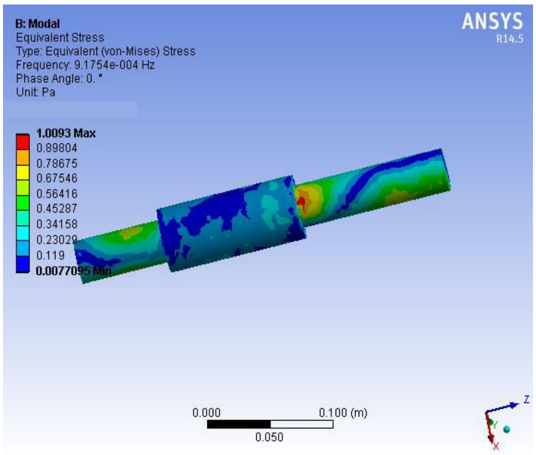


Figure 7: Von-mises stress at 0 degree phase angle.

For 30mm diameter machine shaft at phase angle One degree

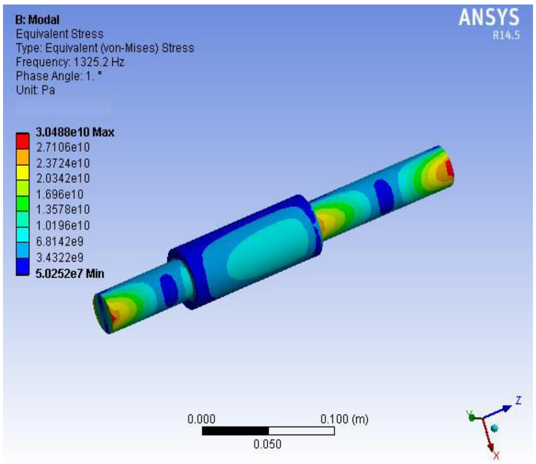


Figure 8: Equivalent Von-mises stress at 1degree phase angle. 26

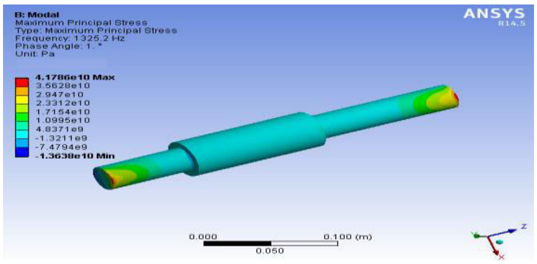
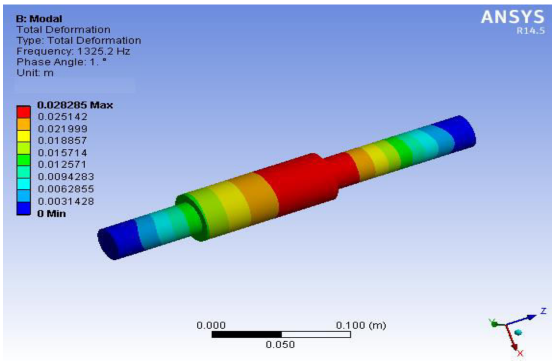


Figure 9: Maximum Principal Stress at 1 degree phase angle.



VI. CONCLUSIONS

- In this research work it has been found that the principal stresses are decreased up to 62% by which stress concentration reduced and our design are safe then the previous work.
- In this observation that principal strain is 17.6% less then equilateral strain, So we can conclude that metal fatigue reduces in this case because no strain server.
- It has been observed that deformation is reduced because of displacement increases up to 35% by which crack would not occur.
- According to result stability frequency of design shaft is founded 0 Hz to 1325.2 Hz which is less from the previous research by which negative effect of cyclic load reduces.

Table 1: Comparative table of stresses and deformation (Displacement) from proposed & previous work shaft 30mm37

Name	Minimum Previous work at 1 degree (30mm)	Maximum Previous work at 1 degree (30mm)	Minimum Present work at 0 degree (30mm)	Maximum Present work at 0 degree (30mm)	Minimum Present work at 1 degree (30mm)	Maximum Present work at 1 degree (30mm)	Result
Von-mises Stress Pa	8.361	19.65	0.0077	1.0093	5.0252	30.48	Increase in 55%
Principal Stress Pa	-0.13214	11.16	-0.25463	1.0857	-1.363	4.78	Decrease in 62%
Deformation (Displacement in mm)	0	2.58	0	2.82	0	2.82	Increase in 35%

REFRENCES

[1] Li-Hui Zhao, Failure and root cause analysis of vehicle drive shaft, Engineering Failure Analysis 99 (2019) 225–234.

[2] Jae-ung Lee, Application of strain gauge method for investigating influence of ship shaft, Measurement 121 (2018) (Marine structure ER-VL- 64) 261-275.

[3] Francisco Sanchez-Marin, A new analytical model to predict the transversal deflection under load of stepped shafts movement by hydrodynamic propeller forces on shaft alignment, (International Journal of Mechanical Sciences (2018) Pg.1-23)

[4] Mahmoud T. El-Sayed, Internal torsion resistance in deflected shafts, (Alexandria Engineering Journal (2017) 56, 213–223).

[5] K.R. Rushton, Torsional stress concentration factors for grooved shafts, Aeronaut. J. 71 (2016) 40–43.

[6] S.-s. Sun, X.-l.Yu, X.-p. Chen, Study of component structural equivalent fatigue based on a combined stress gradient approach and the theory of critical distance, Eng. Fail. Anal. 60 (2016) 199–208.

[7] J.-M. Shin, D.-S.Han, K.-H.Lee, S.-H. Han, Using stress relief grooves to reduce stress concentration on axle drive shaft, J. Mech. Sci. Technol. 28 (2014)2121–2127.

[8] M.J. Miller, Propshafts (Driveshaft), Encyclopaedia of Automotive Engineering, John Wiley & Sons, Ltd, 2014.

[9] M. Banuta, I. Tarquinii, Fatigue failure of a drive shaft, J. Fail. Anal. Prev. 12 (2012) 139–144.

[10] M. Savković, M. Gašić, D. Petrović, N. Zdravković, R. Pljakić, Analysis of the drive shaft fracture of the bucket wheel excavator, Eng. Fail.Anal. 20 (2012)105–117.

[11] M. Savković, M. Gašić, D. Petrović, N. Zdravković, R. Pljakić, Analysis of the drive shaft fracture of the bucket wheel excavator, Eng. Fail.Anal. 20 (2012) 105–117

[12] M. Savković, M. Gašić, D. Petrović, N. Zdravković, R. Pljakić, Analysis of the drive shaft fracture of the bucket wheel excavator, Eng. Fail.Anal. 20 (2012) 105–117.

[13] H. Naunheimer, B. Bertsche, J. Ryborz, W. Novak, Automotive Transmissions, Springer, Berlin Heidelberg, 2011.

[14] Lech Sitnik, Monika Magdziaket. Al. „Comparative analysis of the vibration of different kind of engine mounted in the same new motor vehicle", Journal of KONESP power train & transport Vol.18,No.4 2011.

[15] A. Göksenli, I.B. Eryürek, Failure analysis of an elevator drive shaft, Eng. Fail. Anal. 16 (2009) 1011–1019.

[16] M. Godec, D. Mandrino, M. Jenko, Investigation of the fracture of a car's drive shaft, Eng. Fail.Anal. 16 (2009) 1252–1261.

[17] L. Barelli , G. Bidini, C.Burati, R.Marioni in their paper entitled „Diagnosis of internal combustion engine through vibration acoustic pressure noninstructive measurement"; Applied Engineering 29 (2009):1707-1713

[18] S.Vulli, J.F.Dunne, R.Potenza, D.richardson „Time frequency analysis of single point engine block vibration measurement for multiple excitation-event identification", Journal of sound and vibration; Oct.2008:1129-1139

[19] Arthur Lee, Directorate of engineering science, „Portable generator vibration measurement", January 2007: 5-19

[20] H.C. Seherr-Thoss, Graf Von, F. Schmelz, E. Aucktor, Universal Joints and Driveshaft : Analysis, Design, Applications, Springer, 2006.

[21] O. Asi, Fatigue failure of a rear axle shaft of an automobile, Eng. Fail. Anal. 13 (2006) 1293–1302.

[22] D. Richards, D.J. Pines, Passive reduction of gear mesh vibration using a periodic drive shaft, J. Sound Vib. 264 (2003) 317–34