Vibration Analysis of Driveshaft with Crack Using Experimental Modal Analysis and FEA

Prof. M. M. Jadhav
Assistant Professor,
Department of Mechanical Engineering
Annasaheb Dange College of Engineering & Technology
Ashta, India

Mr. Ashish R. Jadhav
P.G. Student,
CAD / CAM Engineering
Annasaheb Dange College of Engineering & Technology
Ashta, India

***Abstract*:- In automobiles, driveshaft (or axel) is used to connect wheel and differential at their ends for the purpose of transmitting power and rotational motion. In the operation, driveshaft is generally subjected to tensional stress and bending stress due to self-weight, weights of components and possible misalignment between journal bearings. Vibration is one of the common sources of failure in such driveshaft. Mainly, these vibrations are caused by critical speed. Different types of vibrations can propagate crack and ultimately this crack could lead to catastrophic failure of the shaft if not detected in a timely manner. Hence, vibration analysis of driveshaft becomes inevitable to monitor health of rotating machinery. A crack on a structural member introduces a local flexibility which is a function of the crack depth. Major characteristics of structures, which undergo change due to presence of crack, are the natural frequency, the amplitude response due to vibration, mode shape and type of material component.**

Keywords — Drive Shaft, Vibration, FEA, ANSYS.

I. INTRODUCTION

Drive shaft transmits power system from the engine to the differential gear of a rear wheel drive vehicle. The drive shaft is operated usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length in constant dimension and proportional to the square root of specific modulus which increases the total weight of an automotive vehicle and decreases fuel efficiency. So, a single piece drive shaft operation work is preferred here and the material of it is considered to be Titanium alloy because of its high strength and low density. Drive shafts are carriers of torque in the process and are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress, whilst avoiding too much additional weight as that would in turn increase their inertia. In mechanical engineering, a guaranteed life time of a mechanical drive is an issue which we need to pay more attention. Generally, a dangerous state of mechanical drives becomes when a failure creation occurs during guaranteed lifetime of part of that drive. Such type of the failure can cause serious consequences for technical equipment otherwise for safety of machine operator. Problems may occur when the vehicle accelerates. Therefore, it is very important to properly identify the cause of the failure and then take appropriate actions. A design of mechanical drive to operate in failure-free state for a guaranteed life is challenging especially in multi-engine rotary drives, also known as n-mass mechanical system. Any such n-mass mechanical system can have (n-1) natural frequencies. Mechanical drive consists of drive and driven device. Each of these devices can be a source of excitation and thus a mechanical system can be excited by the k – excitation frequencies. Subsequently, each of the excitation frequencies may be equal to one of the natural frequencies and therefore (n-1).k resonance can occurs. In fact, the resonances cause an increase of stress of drive components and thus a significant reduction in life time of the drive.

II. LITERATURE REVIEW

D. Koteswara Rao [1] represented the dynamic analysis of functionally graded (FG) rotor shaft system. Power law gradation is adopted for mathematical material modeling of FG rotor shaft. Timoshenko beam theory is also been used for the finite element modeling of the FG shaft. The FG shaft model has been verified by comparing critical speeds with the available literature. Different analyses have been carried out (such as Campbell diagram, Stability speed limit and damping ratio) by considering shear deformation, rotary inertia, gyroscopic effects, strain, the kinetic energy of shaft, and internal damping.

Debabrata Gayen et al. [2] represented the analytical determination of local flexibility coefficients for a functionally graded cracked shaft. Finite element analysis has been performed using two nodded beam element having six degrees of freedom at each node has been used. Material properties are assumed to be graded in radial direction following linear, power law and exponential law gradation respectively. In the present analysis, the mixture of Aluminum Oxide (Al_2O_3) and Stainless Steel (SUS304) is considered as functionally graded material where metal content is considered decreasing towards the outer diameter of shaft. The local flexibility coefficient of a cracked shaft is derived using Castigliano’s theorem and Paris’s equations in conjunction with the expression for stress intensity factors. A complete code has been developed using MATLAB program and validated with the existing results available in literatures.

Osman Asi [3]described the failure analysis of a rear axle shaft used in an automobile which had been involved in an accident. The axle shaft was found broken into two pieces. An evaluation of the failed axle shaft was undertaken to assess its integrity that included a visual examination, photo documentation, chemical analysis, micro hardness measurement, tensile testing and metallographic examination. The failure zones were examined with the help of a scanning electron microscope equipped with EDX facility.

H. Bayrakceken [4] studied failure analysis of the differential pinion shaft, Mechanical characteristics of the material, the microstructure and chemical compositions. Also fractographic studies for assessing the fatigue and fracture conditions have been carried out. Differential is used to decrease the speed and to provide moment increase for transmitting the movement coming from the engine to the wheels by turning it according to the suitable angle in vehicles and to provide that inner and outer wheels turn differently. Pinion gear and shaft at the entrance are manufactured as a single part whereas they are in different forms according to automobile types. Mirror gear which will work with this gear should become familiar before the assembly. In case of any breakdown, they should be changed as a pair. Generally, in these systems there are wear damages in gears. The gear inspected in this study has damage as a form of shaft fracture.

J Vogwell [5] investigated a failed wheel or drive shaft component used on an unmanned or remotely operated vehicle for maneuvering military targets. A study of the broken shaft shows how vulnerable such a rotating component can be to failure by fatigue or even when operating under steady conditions, if basic preventative design actions are not taken. The analysis considers the effects of both transmissions torque and weight thus upon stress levels and assesses their individual effect on the breakage and upon any subsequent modifications needed to improve the design. The drive shaft arrangement is compared with the feasible alternative of using a drivenwheel arrangement rotating on a stationary axle. Findings confirm the importance of recognizing in advance the salient factors leading to fatigue and the necessity in paying adequate attention to detail during design and manufacture if long service life is to be achieved.

G.K. Nanaware et al. [6] studied rear axle shafts of 575 DI tractors failed before completion of warranty period. Most of the shaft (nearly 80–85%)failures occur during puddeling operations. Rear axle shafts fail in the spline portion. Cracks were found at the root of the splines.

S.K. Bhaumik et al. [7] investigated micro hairline crack. The crack was noticed on a low speed, hollow shaft of a single stage helical gearbox during service. Though this had not resulted in a catastrophic failure, the shaft was withdrawn from service because of leakage of oil. Investigation revealed that the crack had initiated by fatigue at one of the keyway edges and progressed about 3/4 of the shaft periphery in a helical manner but had not given rise to final fracture of the shaft. The fatigue crack initiation was due to stress concentration arising from a depression mark at the keyway end surface. The problem was further aggravated due to inadequate radius at the keyway edges and rough machining marks.

H. Bayrakceken et al. [8]studied power transmission system of vehicles, which has several components which sometimes encounter unfortunate failures.Some common reasons for the failures may be manufacturing and design faults, maintenance faults raw material faults, material processing faults as well as the user originated faults. In this study, fracture analyses of a universal joint yoke and a drive shaft of an automobile power transmission system were carried out. Spectroscopic analyses, metallographic analyses and hardness measurements are carried out for each part. For the determination of stress conditions at the failed section, stress analyses are also carried out by the finite element method.

F. Jimenez Espadaforet al. [9]analyzed a catastrophic crankshaft failure of a four-stroke 18 V diesel engine of a power plant for electrical generation when running at a nominal speed of 1500 rpm. The rated power of the engine was 1.5 MW, and before failure it had accumulated 20,000 him services operating mainly at full load. The fracture occurred in the web between the2ndJournal and the 2ndcrankpin. The mechanical properties of the crankshaft including tensile properties and surface hardness (HV1) were evaluated. Fractographic studies show that fatigue is the dominant mechanism of crankshaft failure, where the beach marks can be clearly identified. A thin and very hard zone was discovered in the template surface close to the fracture initiation point, which suggests that this was the origin of the fatigue fracture. A finite element model of the crankshaft has predicted that the most heavily loaded areas match the fractured zone.

V. Veloso a et al. [10]studied the failure analysis of a longitudinal stringer of a prototype vehicle. Failure took place at the bumpers fixation points of the vehicle suspension during durability tests. Crack was created and has grown causing fracture of the component. Stress analysis was performed using finite element method. A reinforcement model to solve the problem was proposed. Experimental quasi-static and durability tests were carried out and failures were no longer observed.

Yimin Shao et al.[11]commented on failure of drive axle housing. It is difficult to calculate exactly the fatigue failure life of the drive axle housing based on bench testing or pure computer simulation due to the differences between practical road conditions such as slope and roughness and simplified boundary conditions. To increase the reliability of analysis results a new analysis method based on dynamic strain measurement from practical mine road surface conditions combined with finite element analysis is proposed in his paper. The dynamic strain and stress on the drive axle housing is obtained by strain measurements while the truck travels over normal mine road surface conditions. The dynamic stress was analyzed using the rain flow counting method, which can determine the amplitudes and mean values of counted cycles. The influence of the stress mean value was taken into consideration with the Morrow's model.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 07, July-2019

According to the assumption of a linear PalmgrenMiner hypothesis of damage accumulation and using typical fatigue characteristics of the material, the fatigue failure life was calculated. Analysis of the measurements showed that the dynamic stress experienced by the axle housing was far greater than expected. In order to find the factors affecting the dynamic stress of the drive axle housing, the slope of the road surface, any uneven loading and eccentricities were analyzed using the finite element method.

M.A. Badie et al. [12]studied the effect of fiber orientation angles and stacking sequence on the tensional stiffness, natural frequency, buckling strength, fatigue life and failure modes of composite tubes. Finite element analysis has been used to predict the fatigue life of composite drive shaft using linear dynamic analysis for different stacking sequence. Experimental program on scaled woven fabric composite models was carried out to investigate the tensional stiffness. FEA results showed that the natural frequency increases with decreasing fiber orientation angles. The CDS has a reduction equal to 54.3% of its frequency when the orientation angle of carbon fibers at one layer, among other three glass ones, transformed from 0^0 to 90^0. On the other hand, the critical buckling torque has a peak value at 90^0 and lowest at a range of 20^0to40^0 when the angle of one or two layers in a hybrid or all layers in non-hybrid changed similarly. Experimentally, composite tubes of fiber orientation angles of $\pm45^0$ experience higher load carrying capacity and higher tensional stiffness. Specimens of carbon and epoxy or glass and epoxy composites with fiber orientation angles of $\pm45^0$ show catastrophic failure mode. In a hybrid of both materials, $\pm45^0$ configuration influenced the failure mode.

OBJECTIVES

- Carry out theoretical analysis to find out critical parameters to be analyzed for driveshaft.
- To study the effect of vibration on driveshaft with and without crack.
- Experimental determination of the natural frequency of drive shaft with and without crack.
- Determination of the natural frequency of drive shaft with and without crack by using FEA.
- Determination of effect cracks on natural frequency of drive shaft.

METHODOLOGY

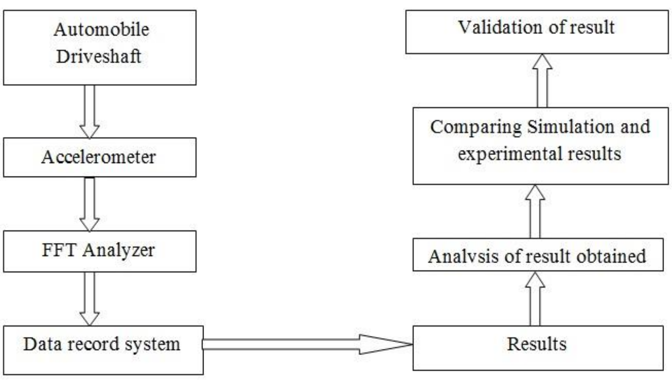


Fig.No.1 Flowchart for the Methodology

VIBRATION ANALYSIS OF CRACKED DRIVESHAFT

Model analysis of driveshaft without cracked

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modu...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Fig.No.2 Material properties of driveshaft without crack

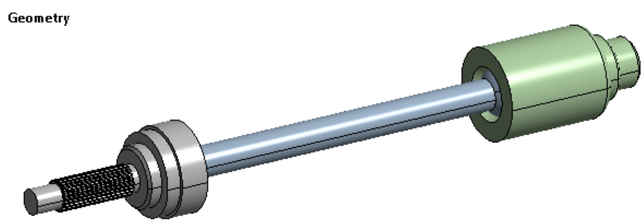
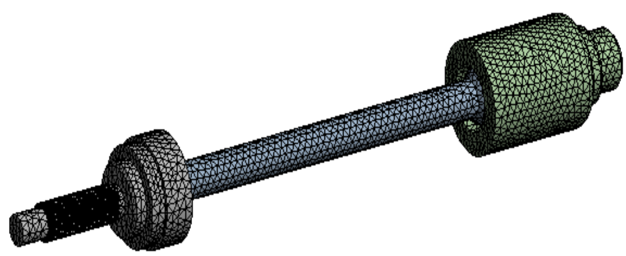


Fig.No.3 Geometry of driveshaft without crack

MESH

ANSYS Meshing is a general-purpose, intelligent, automated high-performance product. It produces the most appropriate mesh for accurate, efficient Multiphysics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it. The power of parallel processing is automatically used to reduce the time you have to wait for mesh generation.



Statistics	
Nodes	67066
Elements	43358

Fig.No.4 Meshing of original Driveshaft

BOUNDARY CONDITION

A boundary condition for the model is the setting of a known value for a displacement or an associated load. For a

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 07, July-2019

particular node you can set either the load or the displacement but not both.
The main types of loading available in FEA include force, pressure and temperature. These can be applied to points, surfaces, edges, nodes and elements or remotely offset from a feature.

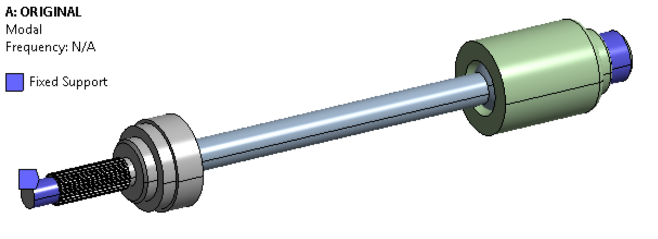


Fig.No.5 boundary condition of original Driveshaft

TOTAL DEFORMATION

The total deformation & directional deformation are general terms in finite element methods irrespective of software being used. Directional deformation can be put as the displacement of the system in a particular axis or user defined direction. Total deformation is the vector sum all directional displacements of the systems.

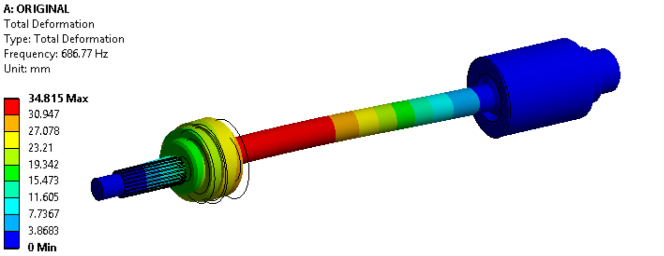


Fig.No.6 Total deformation of mode 1original Driveshaft

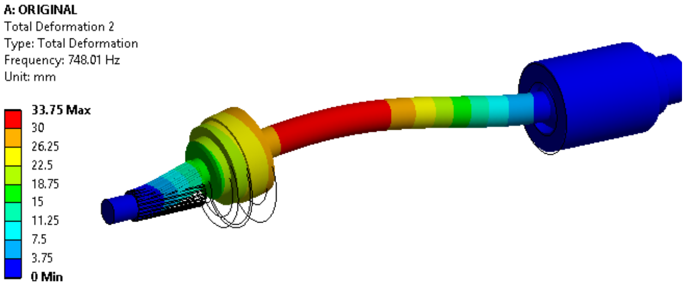


Fig.No.7 Total deformation of mode 2original Driveshaft

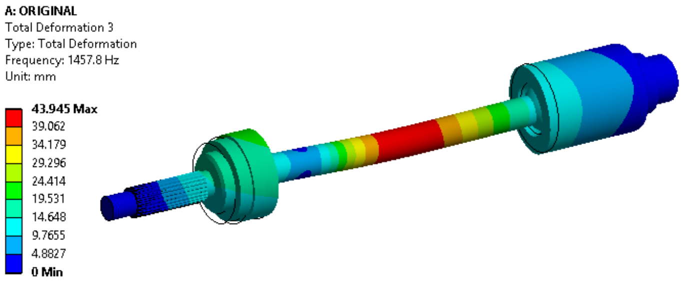


Fig.No.8 Total deformation of mode 3original Driveshaft

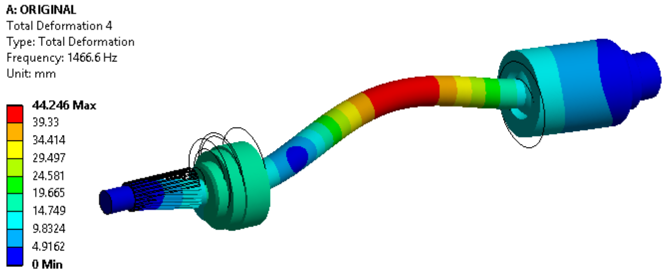


Fig.No.9 Total deformation of mode 4 original Driveshaft

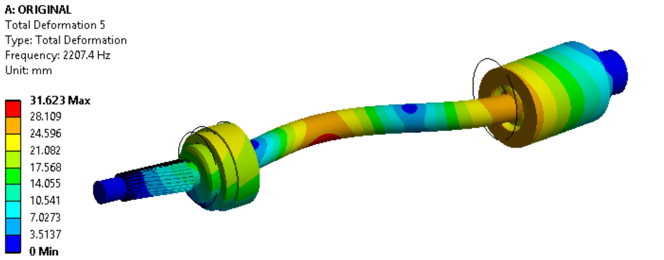


Fig.No.10 Total deformation of mode 5original Driveshaft

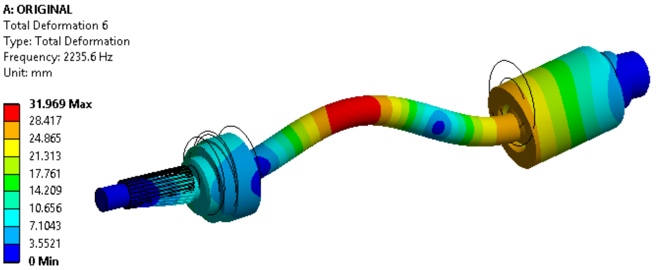


Fig.No.11 Total deformation of mode 6original Driveshaft

Tabular Data

	Mode	Frequency [Hz]
1	1.	686.77
2	2.	748.01
3	3.	1457.8
4	4.	1466.6
5	5.	2207.4
6	6.	2235.6

MODEL ANALYSIS OF DRIVESHAFT WITH CRACK

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modu...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Fig.No.12 Material properties of Driveshaft with crack

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 07, July-2019

GEOMETRY OF DRIVESHAFT WITH CRACK

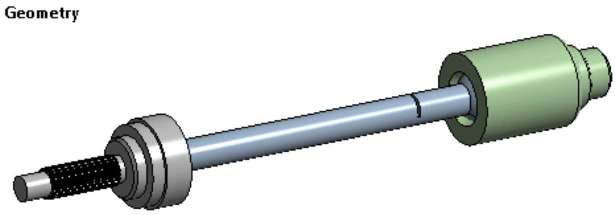
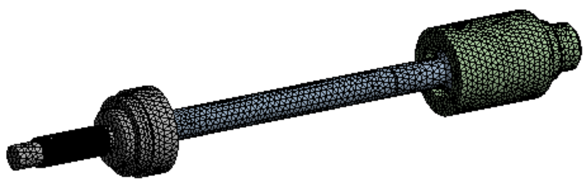


Fig.No.13 Geometry of Driveshaft with crack

MESH



Statistics	
Nodes	67090
Elements	43320

Fig.No.14 Meshing of Driveshaft with crack

BOUNDARY CONDITION

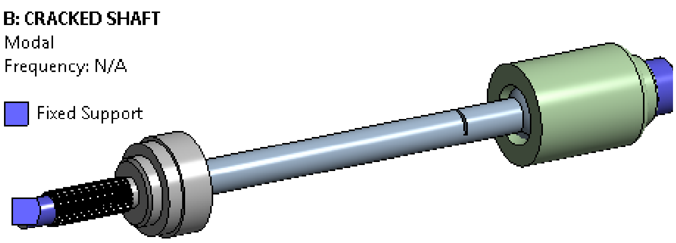


Fig.No.15 Boundary condition of Driveshaft with crack

TOTAL DEFORMATION

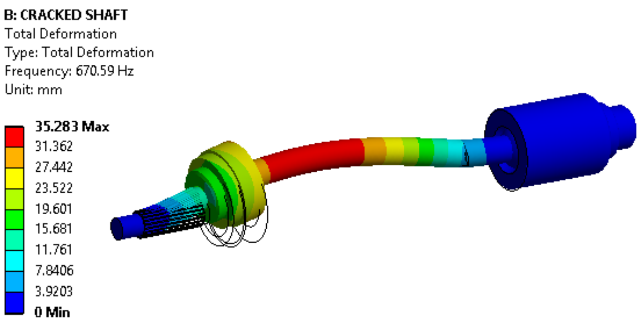


Fig.No.16 Total deformation of Mode 1 Driveshaft with crack

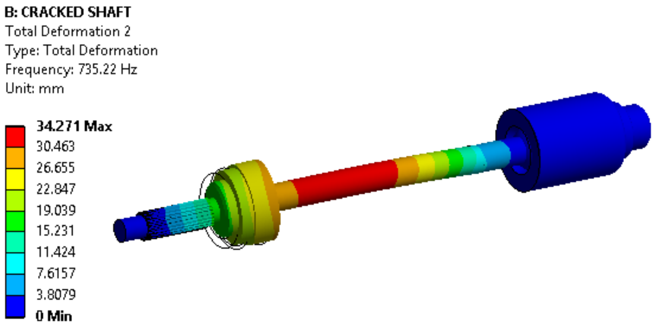


Fig.No.17 Total deformation of Mode 2 Driveshaft with crack

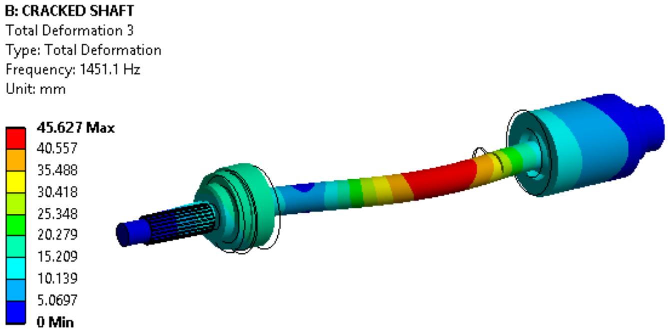


Fig.No.18 Total deformation of Mode 3 Driveshaft with crack

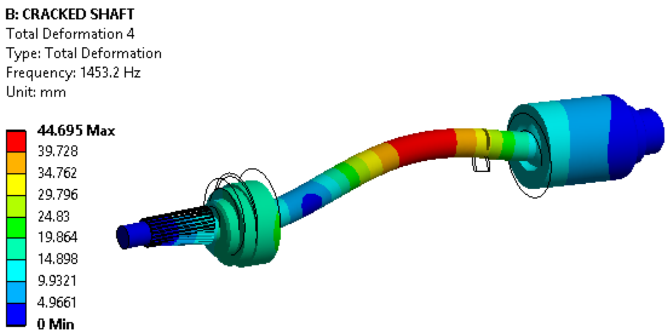


Fig.No.19 Total deformation of Mode 4 Driveshaft with crack

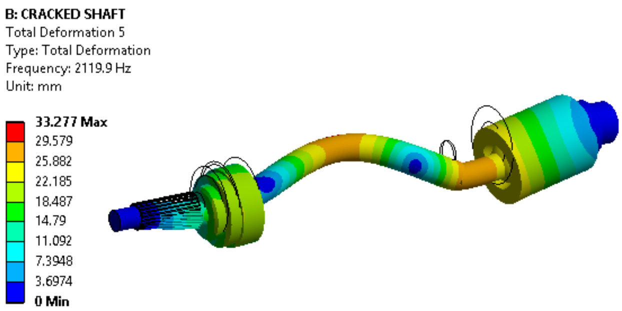


Fig.No.20 Total deformation of Mode 5 Driveshaft with crack

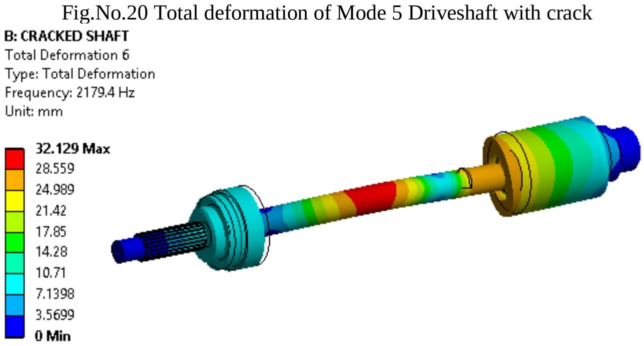


Fig.No.21 Total deformation of Mode 6 Driveshaft with crack

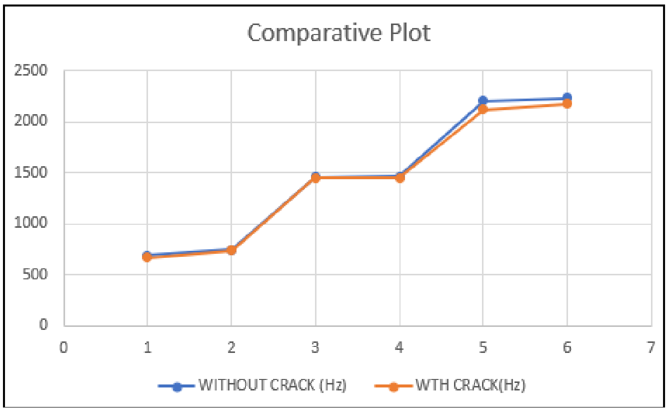
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 07, July-2019

Tabular Data

	Mode	Frequency [Hz]
1	1.	670.59
2	2.	735.22
3	3.	1451.1
4	4.	1453.2
5	5.	2119.9
6	6.	2179.4

COMPARATIVE PLOT

MODE NO	WITHOUT CRACK (Hz)	WTH CRACK(Hz)
1	686.77	670.59
2	748.01	735.22
3	1457.8	1451.1
4	1466.6	1453.2
5	2207.4	2119.9
6	2235.6	2179.4



EXPERIMENTAL RESULTS

FFT Analysis

FFT is one main property in any sequence being used in general. To find this property of FFT for any given sequence, many transforms are being used. The major issues to be noticed in finding this property are the time and memory management. Two different algorithms are written for calculating FFT and Autocorrelation of any given sequence. Comparison is done between the two algorithms with respect to the memory and time managements and the better one is pointed. Comparison is between the two algorithms written, considering the time and memory as the only main constraints. Time taken by the two transforms in finding the fundamental frequency is taken. At the same time the memory consumed while using the two algorithms is also checked. Based on these aspects it is decided which algorithm is to be used for better results

DEWE-43 Universal Data Acquisition Instrument

When connected to the high speed USB 2.0 interface of any computer the DEWE-43 becomes a powerful measurement instrument for analog, digital, counter and CAN-bus data capture. Eight simultaneous analog inputs sample data at up to 204.8 kS/s and in combination with DEWETRON Modular Smart Interface modules (MSI) a wide range of sensors are supported Voltage Acceleration Pressure Force Temperature Sound Position RPM Torque Frequency Velocity And more The included DEWESoft application software adds powerful measurement and analysis capability, turning the DEWE-43 into a dedicated recorder, scope or FFT analyzer.

Fig.No.22 Experimental setup of FFT

TEST FFT RESULTS

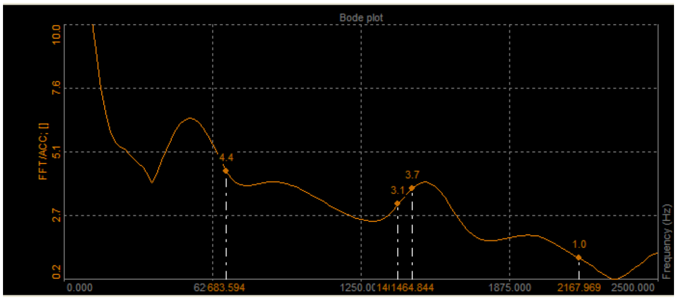


Fig.No.23 Testing result of Driveshaft without crack

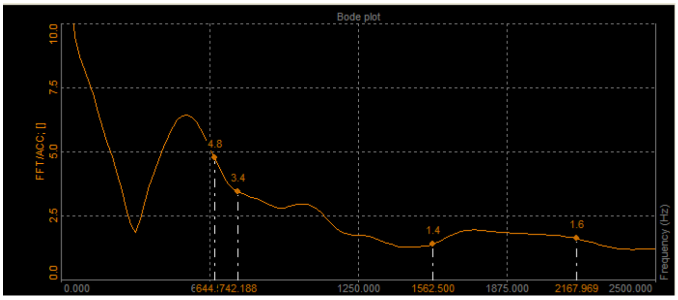


Fig.No.24 Testing result of Driveshaft with crack

DRIVESHAFT WITH CRACK

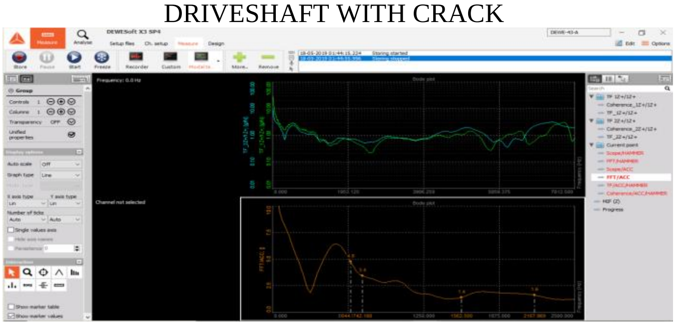


Fig.No.25 Testing result of Driveshaft with crack

VALIDATION OF RESULT

Driveshaft without crack

MODE NO	WITHOUT CRACK (Hz)-FEA	WITHOUT CRACK (Hz)-TEST
1	686.77	683.59
2	1457.8	1406.25
3	1466.6	1464.84

Driveshaft with crack

MODE NO	WTH CRACK(Hz)-FEA
1	670.59
2	735.22
3	2179.4

CONCLUSION

- The finite element analysis is used in this work to predict the deformation of shaft.
- The relationship between the frequency and the vibration modal is explained by the modal analysis of Driveshaft.
- The results obtained from this model is an useful approximation to help in the earlier stages of the development, saving development time and helping in the decision making process to optimize a design, before going into a detailed finite element analysis

REFERENCES:

[1] D. KoteswaraRao, Tarapada Roy., 2016, *Vibration Analysis of Functionally Graded Rotating Shaft System*, Journal of Procedia Engineering, Vol.144, pp. 775- 780.
[2] DebabrataGayen, DebabrataChakraborty., 2016, *Variation of Local Flexibility Coefficients of Functionally Graded Cracked Shaft*, Journal of Procedia Engineering, Vol.144, pp. 1443-1450.
[3] H. Bayrakceken, S. Tasgetiren, I. Yavuz., 2007, *Two cases of failure in the power transmission system on vehicles: A universal joint yoke and a drive shaft*,Journal of Engineering Failure Analysis, Vol. 14, pp.716-724.
[4] Osman Asi., 2006, *Fatigue failure of a rear axle shaft of an automobile*, Journal of Engineering Failure Analysis, Vol.13, pp. 1293 - 1302.
[5] H. Bayrakceken., 2006, *Failure analysis of an automobile differential pinion shaft*, Journal of Engineering Failure Analysis, Vol.13, pp. 1422 – 1428.
[6] J Vogwell., 1998, *Analysis of a vehicle wheel shaft failure*, Journal of Engineering Failure Analysis, Vol.5, No. 4. Pp. 271-277.
[7] G.K. Nanaware, M.J. Pable., 2003, *Failures of rear axle shafts of 575 DI tractors*, Journal of Engineering Failure Analysis, Vol. 10, pp.719-724.
[8] S.K. Bhaumik, R. Rangaraju, M.A. Parameswara, M.A. Venkataswamy, T.A. Bhaskaran, R.V. Krishnan., 2002, *Fatigue failure of a hollow power transmission shaft*, Journal of Engineering Failure Analysis, Vol.9. pp. 457 - 467.
[9] F. Jimenez Espadafor, J. Becerra Villanueva, M. Torres Garcia., 2009.*Analysis of a diesel generator crankshaft failure*,Journal of Engineering Failure Analysis,Vol.16. pp. 2333 - 2341.
[10] V. Veloso, H.S. Magalhaes, G.I. Bicalho, E.S. Palma., 2009,*Failure investigation and stress analysis of a longitudinal stringer of an automobile chassis*, Journal of Engineering Failure Analysis,Vol.16. pp. 1696 - 1702.
[11] YiminShao,JingLiu,Chris K. Mechefske., 2011, *Drive axle housing failure analysis of a mining dump truck based on the load spectrum*, Journal of Engineering Failure Analysis,Vol.18. pp. 1049 - 1057.
[12] M.A. Badie, E. Mahdi, A.M.S. Hamouda., 2011. *An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft*, Journal of Materials and Design, Vol.32. pp. 1485 - 1500.