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DESIGN MANUFACTURING AND VIBRATIONAL ANALYSIS OF DEFECTS IN SPUR GEAR BOX

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Abstract – *A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed path in order to transmit torque. Two or more gears working in tandem are used a transmission and can produce mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, torque, find direction of a power source. Gears can be grouped according to their usage types like spur, bevel , worm etc. Spur gears are the most common type of gears. They have straight teeth and are mounted on parallel shafts. Sometimes, mini spur gears are used at once to create very large gear reductions. Spur gears are used in many devices like electric screwdriver, wind up alarm clock, washing machine and clothes dryer. Each time a gear tooth engages a tooth on the other gear, the teeth collide, and this impact makes a noise. It also increases the stress on the gear teeth. This can lead to many issues like increasing noise, vibrations and many types of defects. These defects can be reduced by taking proper care and maintenance during working and at design stages.it needs to identify the types of defects and its root causes to overcome the decreasing efficiency at manufacturing, inspection for design stages. This project work focuses on inducing possible causes of gear defects and its analysis with the help of FFT and FEA methods, find out the possible solutions and for diagnosis the gear defects. The possible defects considered are decrease in gear tooth height, crack initiation at root of the gear tooth, holes of different size and shape at different location etc.*

Keywords: *spur gears, Noise, Vibrations, Gear defects, FEA, FFT.*

1. INTRODUCTION

Vibration analysis is a process of looking for anomalies and monitoring change from the established vibration signature of a system. The vibration of any object in motion is characterized by variations of amplitude, intensity, and frequency. These can correlate to physical phenomena, making it possible to use vibration data to gain insights into the health of equipment. Vibration analysis can be used to:

- Find a developing problem that can be repaired to increase machine lifetime
- Detect and monitor a problem that cannot be repaired and will only get worse.
- Establish acceptance testing criteria to ensure that repairs are properly conducted
- 24/7 continuous vibration monitoring can be use to predict failures as part of a predictive maintenance program.

Condition Monitoring

The monitoring of a gearbox condition is a vital activity because of its importance in power transmission in any industry. Therefore, improvement is needed to monitor techniques and analysis tools for finding the gear ratios, gear faults, shaft misalignments in the gearbox and the current passing through the motor running the gearbox. Industry environment, background noise, structural vibration etc. may hamper the quality and efficiency of these techniques. Hence, there is a need to monitor the gearbox away from its actual location, which can be achieved through Motor current signature analysis (MCSA) which has already been successfully applied to condition monitoring of induction motor. Condition monitoring can save money through increased maintenance efficiency and by reducing the risk of serious accidents by preventing breakdowns.

Condition monitoring is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure. Machine condition monitoring can be realized by monitoring characteristics like, vibration, aural, visual, operational variables (state of the system), and temperature and wear debris (e.g. oil analysis), In the process of channeling energy into the job to be performed forces are generated which will excite the individual parts of the machine directly or via the structure. During operation, machine parts are subjected to fatigue, wear, deformation and foundation settlement. When faults begin to develop some of dynamical processes in the machine are changed influencing vibrations produced by the machine (vibration magnitudes in various directions, vibration time domain recording and frequency spectrum and dynamic range).

Problem Definition

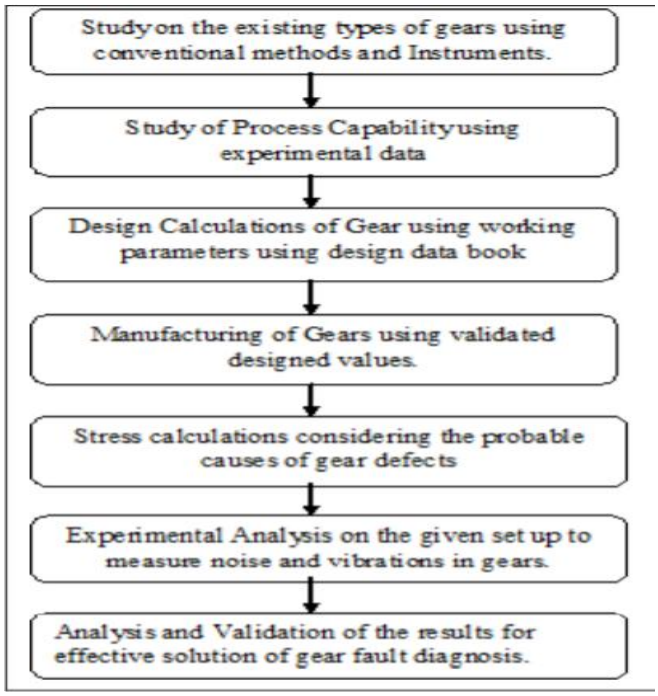
As per demand of design and manufacturing of Spur & Spur gear box for 0.5HP motor, Company needs to set such a system which should check the vibration occurs in the

gearbox, easy inspection to understand by operators, should be as efficient as, and meeting with the quality aspects with improved in design. Therefore for vibration analysis FEA and FFT are used.

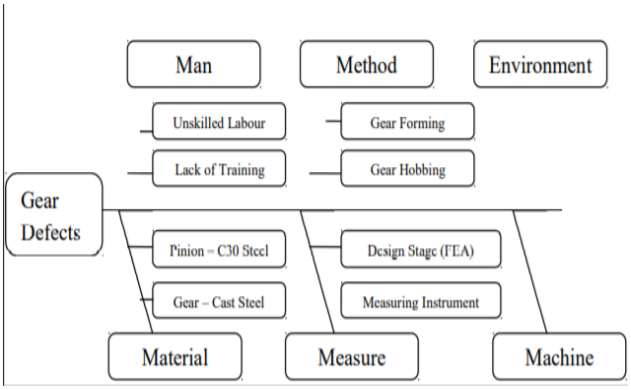
Objective

Inspection of Various types of gears using various metrological instruments like gear tooth vernier caliper (0-150 mm range and least count of 0.2).Calculations of various inspection parameters by considering spur gear using cause and effect diagram, to calculate its process capability.Design and manufacturing of spur gear with given working parameters and finalizing the safe values of gear parameters using various design equations. To evaluate the performance of gear box by inducing various defects at various loading conditions using noise meter. FEA analysis of various possible causes of gear tooth failure and validating the same with results obtained by experimental analysis. FFT analysis at various loading condition for Noise and vibration detection and natural frequencies calculations of possible defects in spur gears to identify the problems in gear at design stages and to find out the remedial measures.

Methodology



Experimental Analysis



Induced defects in gear leading to noise and vibrations

Crack (Gear) Length of crack along the face width of tooth			
	Case 1	Case 2	Case 3
Height	0.322mm	0.322mm	0.322mm
width	1.575 mm	2.745 mm	3.365 mm
Reduction in Tooth Height (Gear)			
	Case 1	Case 2	Case 3
Percentage reduction in tooth height	40%	75%	100%

CASE-I(CRACK)Normal Gear

Peak sound pressure level dB(A)v/s speed with crack

Motor Speed (Input)	500 RPM	1000 RPM	1500 RPM	2000 RPM	2500 RPM
Test Gear Speed (Output)	180 RPM	360 RPM	540 RPM	725 RPM	900 RPM
Normal Gear	59.1	62.9	68.3	72.0	74.7
Crack (Case 1)	63.2	66.6	71.0	74.7	77.7
Percentage increase in (Case 1)	6.93%	5.58%	3.95%	3.75%	4.01%
Crack (Case 2)	64.4	68.6	72.7	76.7	80.8
Percentage increase in (Case 2)	8.69%	9.06%	6.44%	6.52%	8.16%
Crack (Case 3)	65.4	69.5	73.5	78.4	82.1
Percentage increase in (Case 3)	10.65%	10.49%	7.61%	8.88%	9.90%

Case-II(Decrease in tooth height)

As speed and fault increases it is seen that peak sound level increases. They range is as shown below. **Peak sound level v/s speed with decrease in tooth heightss**

Test gear	180 RPM	360 RPM	540 RPM	725 RPM	900 RPM
Normal	59.1 dB (A)	62.9 dB (A)	68.3 dB (A)	72.0 dB (A)	74.7 dB (A)
40% Tooth	62.5 dB (A)	64.4 dB (A)	70.2 dB (A)	73.9 dB (A)	76.9 dB (A)
Percentage	5.75%	2.38%	2.78%	2.63%	2.94%
75% Tooth	64.2 dB (A)	67.3 dB (A)	71.4 dB (A)	74.9 dB (A)	78.0 dB (A)
Percentage	8.62 %	6.99 %	4.53 %	4.02 %	4.41 %
100%	65.4 dB (A)	68.4 dB (A)	73.0 dB (A)	76.5 dB (A)	81.1 dB (A)
Percentage	10.65	8.74	6.88	6.25	8.56

Literature Survey

G.S. Lamani1, Prashant S.Pawar2,Nikhil G.Ranalkar3,Omkar P.Pawar4,Suyog V.Patil in IOSR Journal of Mechanical and Civil Engineering(2018) in paper entitled, *"Vibration analysis of worm and worm wheel gear box"* Reviewed is made of some current vibration analysis techniques used for condition monitoring in gear fault. Each unit of mechanical equipment has a different signature in the frequency spectrum. The vibration spectrum shows the areas of stress and undue energy. Vibration measurements trend changes at different locations along the units to predict the problems. The key benefits including Monitoring equipment life, increasing equipment uptime, managing and scheduling maintenance work. Vibration analysis can determine misalignment unbalanced, mechanical losses, eccentric shafts, gear wear, broken teeth & bearing wear. [1]

Ganesh Survase1, Suraj Sutar2, Tushar Pawar 3, Akshay Rajmane4 *in* International Journal of Mechanical, Robotics and Production Engineering in paper (2018), "*Study & Vibration analysis of worm and worm wheel gear box by using FFT Analyzer"* Reviewed some of current vibration analysis techniques used for condition monitoring in gear fault. Each unit of mechanical equipment has a different signature in the frequency spectrum. The vibration spectrum shows the areas of stress and undue energy. Vibration analysis can determine misalignment unbalanced, mechanical losses, eccentric shafts, gear wear, broken teeth & bearing wear. Using laser Vibrometer it is possible to get the data that are processed in different methods like FFT Analysis. They found that as load increases there is decrease in acceleration with decrease in value if maximum frequency attainted for corresponding maximum acceleration. As load increase there is initial decrease in acceleration to its minimum and then again starts increasing with same behaviors in trends of corresponding maximum frequency value. As load increase there is initial decrease in acceleration to its minimum and then again starts increasing with same behaviors in trends of corresponding maximum frequency value. [2]

P. Jagadesh, T. Seshaiah, in International Journal of Innovative Research in Science, Engineering and Technology, (2017) in paper entitled, *"Design and analysis of a Gear Box Motor Current"* detect artificially introduced defects in gears of a multistage automotive transmission gearbox at different gear operations using MCSA as a condition monitoring technique. Steady as well as fluctuating load conditions on the gearbox are tested for both vibration and current signatures during different gear operations. This project was concerned to use MCSA to detect defects in Bearings as well as Gearboxes and to measure load fluctuations. It considered a normal operating worm gear drive with introduced gear defects. [3]

Miss. Radhika Laxman Patil1 Mr. Ravindra D. Patil2 Mr. Sandesh S. Awati3 Mr. Suhas N. Ankalkhope4, (2017) International Journal for Scientific Research & Development in paper entitled "A Review Paper on Design, Optimization and Testing of Special Purpose Worm and Worm Wheel Gearbox for Butterfly Valve Operation" used higher standard output torque gearboxes which are uneconomical, heavy as well as large in size. Also quarter turn worm and worm wheel gearboxes for opening and closing of butterfly valves gives better performance, because butterfly valves rotate only in 90°. This paper represents design, optimization and testing of special purpose worm and worm wheel gearbox for butterfly valve operation.[4]

Ashwani Kumar*, Pravin P. Patil Ashwani Kumar*, Pravin P. Patil, Journal of Engineering Science and Technology Vol. 11, No. 2 (2016) in paper entitled, *"Modal Analysis of Heavy Vehicle Truck Transmission Gearbox Housing Made from Different Materials"* has done weight calculation and modal analysis of gearbox housing. For weight calculation four different materials have been selected, apart from weight calculation the material mechanical properties influence on natural frequency and mode shape of transmission gearbox housing was also simulated using modal analysis. Grey cast iron FG260, Grey cast iron HT200, structural steel and Al alloys are the four materials used for the weight calculation process. Zero displacement constraint based boundary condition was applied for simulation. FEA based numerical simulation method was used to find the natural frequency, mode shapes and weight calculation of housing. The FEA simulation results show that the natural frequency of all materials varies (1669- 4655) Hz. In weight calculation the weight of Al alloys housing is minimum (21.102 kg). The housing weight of Grey cast iron HT200 and FG260 is same, 54.85 kg. The density of structural steel is high, which increases the weight of housing as 59.80 kg. The modal analysis results show the lateral vibration, axial bending vibration, torsional vibration, and axial bending with torsional vibration. The vibration signature patterns for first twenty modes were studied for four different materials. Solid Edge and Pro-E software have good feature suited for complex geometric modeling. FEA based software Ansys 14.5 is used for modal analysis. To get the accurate result the natural frequency range was increased. Finite element analysis offers satisfactory results. The results of this research work will provide reference in design stage of heavy vehicle truck transmission gearbox housing and has theoretical reference value for the dynamics analysis of the gearbox housing. [10]

THEORY AND PROCESS CAPABILITY ANALYSIS:

Failure of gearbox caused losses in terms of money (cost of gear), time (down time during replacement) and production losses. Gearboxes are generally robust and reliable devices. However, problems do occur particularly due to application error. Application errors can be caused due to number of problems, like mounting and installation of gear system, vibration, cooling, lubrication, and maintenance also. Fatigue is the most common failure in gearing. Tooth bending and surface contact fatigue are two of the most common modes of fatigue failure found in gears. E.g. poor design of the gear

set, improper assembly or misalignment of the gears, overloading, inadvertent stress raisers or subsurface defects occurs in critical areas, and the use of inappropriate materials and heat treatments. Vibration analysis has been used as a predictive maintenance procedure and as a support for machinery maintenance decisions. Machines don't breakdown or fail without some form of warning, which is indicated by an increased vibration level. By measuring and analyzing the machine's vibration, it is possible to determine both the nature and severity of the defect, and hence predict the machine's failure.

Permanent Monitoring Does not give long term warning Damage to machine is of prime concern Monitored parameter such as relative shaft vibration & absolute casing vibration Intermittent Monitoring Early warning of incipient fault Loss of production is of prime concern Monitored parameter such as velocity/acceleration of gears/casing Run to Breakdown Maintenance In this method no action takes place until the machine run out completely. Reactive maintenance is depends on the size of job and the number of staff available for service. This method is used when shutdown period is not important. Due to necessity of large number of extra parts and high loss in production rate, it became most costly method. Protective or Preventive Maintenance In this method the machine is repaired / maintained at regular interval of time. In this method replacement of parts are done after some interval of time rather than checking their condition. This method has double cost because of replacement of parts and shutdown period. This method is used to prevent the unfortunate failure of machine.

Predictive Maintenance It is also called condition based maintenance. It is used widely in all the online system maintenance. Its aim is to remove the shutdown period by inspecting the condition of machine, detecting the defects and implementing a correct solution for it to avoid the run out of machine. Fault Detection Overall vibration level measurements in a frequency range 10 Hz to 1 kHz or 10 kHz at certain typical positions. This is compared with available vibration criterion charts. Trend Analysis Vibration level vs. Time plot may indicate deteriorating machine condition. Prediction of shut down for repair is possible. Frequency Analysis A stable vibration spectrum changes when parts wear out or faults are developed. A component in a vibration spectrum corresponds to a specific source in a machine. Each fault occurs at a particular frequency. Therefore frequency domain analysis is useful for fault detection. Reasons for Using Frequency Analysis Frequency analysis is an aid to understanding the vibratory excitation, structural responses, and radiated noise arising from meshing gear pair because If the driving gear shaft is rotating at a constant speed and the force transmitted by each gear mesh is nominally constant, then the vibratory excitation arising from each meshing gear pair and the resulting structural responses and radiated noise all are periodic functions of time. Many harmonics can be present in the excitation and response arising from each meshing gear pair. Nevertheless, as the locations and relative and absolute strengths of these harmonics can be very useful in diagnosing the causes of gear noise and in implementing its reduction. The above-mentioned attenuating effects of simultaneous multiple tooth contact are most easily described and understood in the frequency domain. Structural resonance effects are most easily described and understood in the frequency domain.

CONCLUSION:

Design calculations were safe as per the design criteria on basis of working parameters. Process capability analysis and Fishbone diagram (Cause and effect analysis) shows the manufacturing methods are acceptable and errors are within control limits. Fault of gear box are identified by measuring the gear box noise in sound pressure level. The peak noise level at mid frequencies shows that, as the crack depth increases the sound pressure level increases. Using this method and observing the graphs obtained after the study forecast of defects can be done. As the height of tooth of gear decrease the sound pressure level increases. Sound pressure level also increases as the speed of gear increase. IRJET sample template format, Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

FUTURE SCOPE:

In the present study only two artificial defects (crack and decrease in tooth height) have been consider. Natural pitting, bending and wear can also be considered for further study. Following solutions can be attempted for resolving the issues, FEA analysis can be done for analyzing, Stress and Reduction of a Spur gear by adding different shaped holes to reduce stress concentration. FFT Analysis can be performed for vibration analysis at different frequencies. Gear design can be improved by using improved material, hardening surfaces with heat treatment and carburization, and shot Peening to improve surface finish etc. Few more efforts can be made to improve the durability and strength by altering the pressure angle, using the asymmetric teeth, altering the geometry of root fillet curve and so on. The stress redistribution techniques by introducing the stress relieving features in the stressed zone to the advantage of reduction of root fillet stress in spur Gear. This also ensures interchangeability of existing gear systems. Combination of circular and elliptical stress relieving features are used to obtain better results than using circular stress relieving features. An attempt can be made to use an aero-fin shaped stress relieving feature. In the present study only three parameters speed, crack size and decrease in tooth height have been varied. For further study load variation, lubricating oil and multi hour test running can also be considered. In the present study no further advanced signal processing technique has been used. For the future work FFT

and RMS value can also be considered. Similar work can be performed on different types of other gear and gear boxes for reduction in vibration caused by rotating machinery parts. Observation results obtained by FFT can be validated with mode shape analysis using various Finite element software like ANSYS to get more accurate results. Various metrological methods can be implemented for online inspection of rotating machines on basis of results obtained by above experimental work, for suitability to low skilled workers. This kind of project work proves to best suited method in field of NVH Analysis in various automobile sectors.

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