Dynamic Performance Analysis of Involute Helical Gear with Significant Defects

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Abstract- **In this paper the study of dynamic performance analysis of Involute helical gear with defects is presented. Analysis is carried out to solve noise and vibration problems. It improves reliability and safety of the gear. This paper proposes study of the common failures of gearbox and vibration analysis related to gearbox defects and its diagnosis, distinct vibration pattern related to gearing defect and noise level of gearbox and its pattern due to defects in gear during its working. For this, we designed and developed small gearbox and experimental setup for study of vibration analysis then analysed the vibration signature of a healthy gearbox. Created different gear defects (Defects selected for this is pitting, tooth breakage in steps from 25% of one tooth breakage up to complete one tooth breakage and scoring.) on gear that normally occurs in a gearbox during power transmission and analysed each defect by vibration signal analysis, compared a faulty vibration signature with healthy gearbox vibration signature and concluded the distinct vibration signature of the defect.**

Index Terms- **Dynamic Performance, Gear tooth defects, Involute helical gear, Vibration Analysis**

I. Introduction

Helical Gears play a vital role in various industrial applications because of their importance in power transmission in any industry. As for any rotating machine, the prime mover runs at constant speed and we require various output speeds and torques for different operations on machines to achieve the objective. Gearbox used to transmit required speeds and torques to an output shaft which is either parallel or inclined at 90^0or at any angle with input shaft. There are different types of gear defects like tooth breakage, scoring and petting because of which vibrations takes place. Because of such vibration the gear box or bearings may damage which leads to economic and production losses vibrations.

Hence in this paper the dynamic analysis of helical gears with significant defects has been carried out to check the vibration levels of gear box. For this purpose the experimental setup with single stage gear box has been developed.

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II. Literature survey

Govind T Sarkar studied the bending and surface stresses of gear tooth are major factor for failure of gear and Stress Analysis of Helical Gear by Finite element Method. This paper investigates finite element model for monitoring the stresses induced of tooth flank, tooth fillet during meshing of gears. [1]

Arvind Yadav has done his work on Different types Failure in gear. By the help of this paper we can know about different types of failure detection and analyzing techniques which is used to reduce these failures from gears. [2]

S. Jyothirmai studied the theoretical basis and performance characteristics of helical gear design, a complete mathematical description of the relationship between the design parameters and the performance matrices is still to be clearly understood because of the great complexity in their interrelationship. [3]

V. S. Panwar gives a case study on various defects found in a gear system. This paper deals with various failures occurred in gears due to design errors, maintenance, manufacturing errors etc. Failures cause loss of time required for production, disturbs machine work and also causes loss of cost. [4]

Prof. A. V. Gaur has done research on design and FEM analysis of helical gear. In this paper solution of failure of gear in speed reduction gearbox at Laxmi Hydraulic Pump pvt ltd, Solapur is given. [5]

Hsiang H Lin gives dynamic analysis of straight and involute tooth form. The effect of load speed on gear tooth form is studied using several finite element models. It is seen that the load speed along the tooth can have a significant effect on the deformation, it induces vibration. [6]

A. Andersson presented a dynamic model to determine vibration in Involute helical gear. The method described in the paper makes it possible to predict the dynamic behavior of the gear set. This method calculated position of the line of contact. [7]

Wenchao Mo has done research on dynamic analysis of helical gears with sliding friction and gear errors. This paper gives a concise and general calculation method to calculate the time-varying meshing line, friction force and friction torque of helical gear system. As the increase of errors, the vibration amplitude of gear increases, but the noise intensity of vibration does not change obviously. [8]

Zhu Linlong studied analysis and simulation of dynamic characteristics of helical gear. The results of experiment show that the fluctuations of time-varying contact wire is an important cause of tooth surface friction and tooth surface friction torque fluctuations. [9]

Amol Patil has done research on design and analysis of helical gear to overcome stucking and scuffing using Finite Element Method. FEM analysis observes the stucking and scuffing area about helical gear. [10]

III. GEAR DEFECTS

Gear defects are occurred due to high-stress condition, insufficient lubrication or manufacturing errors. Some common gear defects tooth breakage, pitting, scoring, tooth wear, surface inaccuracy, misalignment etc.

As localized defects are more critical than distributed defects as they lead to catastrophic failure, so they required to analyze.

Among localized defects, the defects such as pitting, tooth breakage and scoring had yet to be analyzed correctly so defect selected for this research is pitting, tooth Breakage in steps of 25% of one tooth starting from 25% of one tooth breakage to complete one tooth breakage and scoring..

Tooth Breakage Defect:

Among all, tooth breakage is a dangerous type of gear failure as it leads to damage of gear components due to increase in disturbance. The other elements which get damaged due to this defect are shaft, bearing, etc., by broken tooth piece. As shown in Fig.1, tooth breakage occurs due to many reasons such as overload, damage of parts, impacts, dust, fatigue, etc. Mostly, tooth breakage occurs due to initiation of small crack, which then get increasing and leads to tooth breakage defect.

Fig.1: Tooth Breakage Defect

This happens due to bending fatigue, which occurs due to repetitive load. As small part of teeth breaks away then remaining teeth had to handle a whole load so due to loss of strength again it starts to breaks, which leads to whole tooth breakdown and catastrophic failure occur.

As mostly a pinion is weaker than gears this defect is created on a pinion. For this, pinion is clamped on bed of vertical milling machine and 25% of one tooth along the width directions cut in taper direction. In similar way 50%, 75% and 100% of one tooth breakage is done.

Pitting Defect:

Pitting is nothing but a small amount of metal particles get to drop off and pits are occurred on the surface of gear. It is a surface fatigue failure of the gear tooth. Whenever contact stresses to get higher than a fatigue tolerance limit then this defect gets to occur due to removal of material from the tooth surface as shown in Fig.2

Fig.2: Pitting Defect

As small material gets removed then remaining portion gets exposed to maximum wear, which accelerates the material removal and pitting defect gets accelerated leads to damage of gear teeth.

For this the defect is created on a pinion with the help of centre punch and hammer and drilling machine. Firstly, pinion is clamped in vice of drilling machine then with the help of centre punch and hammer, very small pits are created on mating surfaces of the pinion teeth. After this drill of 1 mm diameter is made to go towards dent portion so that it gets located in dent and drilling done at this portion.

Scoring Defect:

This defect occurs due to lack of lubrication. Due to many reasons such as overloading, misalignment, dust particles, etc., cause lubricant film to breaks down and allow metal to metal contact who leads to high temperatures and local

Fig.3: Scoring defect welding of gear mating surfaces as shown in Fig.3

The defect is created on a pinion by providing inadequate lubrication along with high tooth load and poor surface finish. High spots are created so that the initial scoring is occurred. And later on by increasing load and speed scoring is spread over large area.

IV. VIBRATION ANALYSIS

The most commonly used method for rotating machine is vibration analysis Measurements can be taken on machine bearing casings with seismic or piezo-electric transducers to measure the casing vibrations and on the critical machines to measure the radial and axial vibration of the shaft Condition monitoring of machine implies, the determination of condition of a machine and its change with time. The condition of the machine may be determined by measuring physical parameters like vibration, noise, temperature, wear debris, oil contamination etc. the change in parameter are called as a signature. The signature indicates the change in condition and health of machine. The analysis of signature helps in predicting and preventing the failure of machine. The above parameters measured or monitored continuously or at regular interval of time, depending upon the application.

V. VIBRATION FREQUENCY SPECTRUM

Machinery vibration consists of various frequency components as shown in figure3.3frequency spectrum of machine showing amplitude Vs frequency plot. The amplitude of each frequency component provides an indication of the condition of particular rotating element within the machine

Vibration signals are transformed to amplitude and frequency plot with the help of FFT analyzer. Nearly all machine defects show frequency component related with operating speed also to show and diagnose the spectrum as a component of frequency is important. The frequency spectrum has a capacity to normalize every vibration element, hence critical machine spectrum gets converted into discrete elements; this feature makes simplicity in diagnosis of mechanical degradation within the rotating machine.

VI. EXPERIMENTAL SET-UP

Fig.4: Experimental set-up

In experimental setup the single stage helical gear box is coupled to the VFD Motor of 3 KW and the load is applied on the output shaft of the gear box with the help of rope brake dynamometer. The experimental setup is mounted on sound foundation with base plate. The load as well as speed varied and the results of vibration analysis are captured with the help of FFT Analyzer.

VII. FFT ANALYZER

The instrument which converts the input signal, with time as an independent variable into frequency spectrum and displays it in a graphical form is called as spectrum analyzer or Fast Fourier Transform (FFT). For diagnostic of all mentioned defects a FFT analyzer and piezoelectric accelerometer is used. The readings obtained from FFT analyzer is processed with spectrum analysis & time domain analysis with its statistical parameters. Multichannel spectrum analyzer, data collector and balancer with software are used.

VIII. EXPERIMENTAL METHODOLOGY

Table 1: Velocity and Acceleration for Helical gear with scoring defect at different loads, speeds and positions of accelerometer.

In an experimental procedure gearbox is allowed to run at its rated power and speed by applying different load conditions. For various load conditions rope brake dynamometer is used. For vibration measurements magnetic base accelerometer is placed on the top just below the location of bearing in axial & radial direction of gearbox.

Speed (rpm)		750		925		1100		1270		1440	
Different Loads (N) & Positions		Vel. mm/sec (rms)	Acce. (g)	Vel. mm/sec (rms)	Acce. (g)	Vel. mm/sec (rms)	Acce. (g)	Vel. mm/sec (rms)	Acce. (g)	Vel.mm m/s (rms)	Acce. (g)
0	H	0.221	0.033	0.311	0.046	0.37	0.058	0.519	0.061	0.651	0.073
	V	0.43	0.082	0.612	0.123	0.562	0.125	0.463	0.113	0.444	0.138
	A	0.256	0.045	0.258	0.047	0.313	0.066	0.408	0.073	0.664	0.091
10	H	0.406	0.077	0.461	0.089	0.444	0.084	0.568	0.084	0.649	0.093
	V	0.717	0.137	1.04	0.207	0.878	0.191	0.581	0.153	0.583	0.167
	A	0.467	0.84	0.371	0.77	0.317	0.079	0.424	0.086	0.437	0.094
15	H	0.294	0.073	0.351	0.086	0.389	0.099	0.445	0.094	0.535	0.109
	V	0.928	0.169	1.37	0.261	0.845	0.19	0.626	0.166	0.635	0.171
	A	0.492	0.089	0.542	0.11	0.458	0.105	0.391	0.096	0.476	0.107

By making all above arrangements, readings are taken by replace the helical gears with different defects. This data is stored in FFT analyzer for further analysis.

Vibration spectrums are taken for gears having various defects and the data is stored in computer for further analysis. For different condition of defects data is collected at different load and speed conditions.

IX. DISCUSSION OF RESULTS

The basic aim of this project work is to design a test set-up and to carry out experimentation for dynamic analysis of Involute helical gear for different types of defects namely tooth breakage, pitting and scoring. For this analysis the gearbox rotates at loading condition and at variable speed of induction motor. Varying load is applied on the output shaft of the gear box by means of a Rope – Brake Dynamometer. The motor speed is maintained in a range 750 rpm to 1440 rpm by the Variable Frequency Drive (VFD). The vibration response from the gear box is recorded by a FFT analyzer. The response is recorded against frequency scales (FFT).

Readings are taken at different load condition such as 0 N, 10 N and 15 N. Accelerometer is placed on the bearings in horizontal, vertical and axial positions.

Table 1 gives values of velocities and accelerations for load 0 N, 10 N and 15 N at variable speeds 750 rpm, 925 rpm, 1100 rpm, 1270 rpm and 1440 rpm for the helical gear with scoring defect.

Velocity and acceleration spectrums:

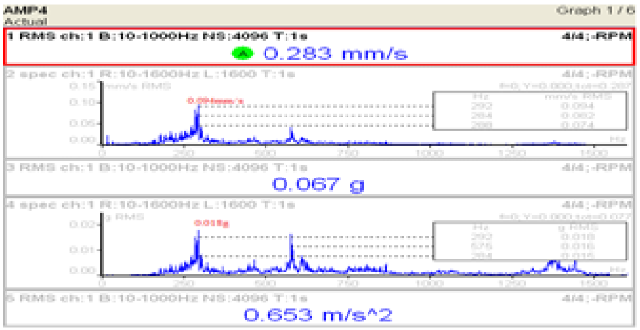

Fig.5: Helical gear with scoring defect with 15 N loads at 925 rpm

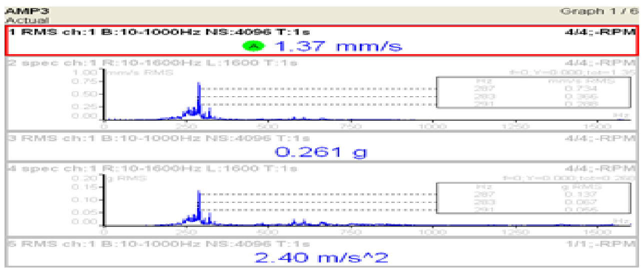

Fig.6: Helical gear with pitting defect with 15 N loads at 925 rpm

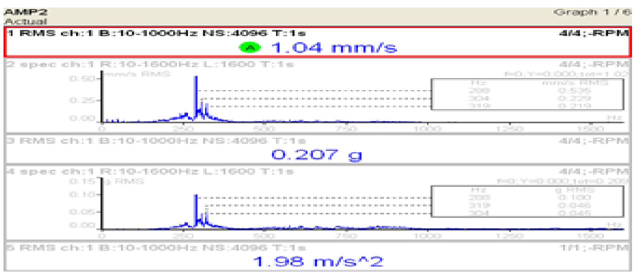

Fig.7: Helical gear with tooth breakage defect with 15 N load at 925 rpm

Fig.5, Fig.6 and Fig.7 gives the velocity and acceleration spectrum of scoring defect, pitting defect and tooth breakage defect for constant load at speed 925 rpm.

X. Conclusion

Experimentation is carried out for dynamic performance analysis of Involute gear with defects. From analysis it is concluded that:

[1] During the analysis it is observed that the vibration level of helical gear with tooth breakage defect is on higher side.

[2] The values of velocity and acceleration are slightly increased by increasing the load and speed.

[3] From the vibration analysis of the helical gears with different defects it is observed that the gear failure and gear defects affect the functioning of the machinery. For this purpose the vibration analysis technique is most powerful tool for preventive maintenance of the machinery.

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