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INVESTIGATION OF WEAR CONDITION OF GEARBOX USING VARIOUS CONDITION MONITORING TECHNIQUES: A REVIEW

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Abstract- The main objective of this paper to investigate the detection of wear on gears using various techniques. With the help of this paper we can identify various types of debris formation occurs after running a number of load cycles at different speeds and different detection method to identify morphology of gears. The main reasons for wear on gears are the variable loads and speeds. The intention of this paper is reveal detailed description of various detection methods for wear on gears. It also focused on the perspective of future work like detection of wear can be implemented on basis of area of wear on gear, and by weighing the debris particles.

Keywords –: gear wear, area of wear, volume, speed, load, wear debris analysis

I. INTRODUCTION

Spur gears are used for transferring power between two parallel shafts when they engaged with one another. A high gear ratio can be achieved using Spur Gearbox with little effort. Generally multiple no. of gears are required for achieving the required gear ratio.
This type of gear box has an advantage of adjusted within small area, simpler in construction, low backlash, damage tolerance capacity. It does not required high precision during the manufacturing of spur gearbox is used for both enhancement and reduction in speed and torque. It is also used for power transmission in reverse by using an intermediate gears. The spur gearbox has widely used for industrial applications including Rolling, lathe machine, vehicle etc.
The efficiency of spur gear box ranges from 40% to 80% depending on the type of Application. Spur gear generates a great amount of heat. For dissipation of this heat lubricant, fins to gearbox casing or an extra fan are generally provided to keep the operating temperature below 80°C.
As the rolling motion implemented in between two gears therefore it is easily lubricated. The lubricants required are usually very high viscosity (ISO 320 and greater) due to its heavy load condition between meshing points. Bath lubrication can be used for slow speed application of spur gearbox. Splash lubrication is most common in spur gearbox for medium speeds.
For detection of wear in spur gearbox various techniques are available such as Oil Analysis, Vibration analysis, Temperature analysis and Acoustic Emission Analysis. Generally Oil analysis is commonly used as ccompared to other condition monitoring techniques for detecting wear on spur gearbox.

II. LITERATURE REVIEW

Now let us see various literatures available regarding wear detection and various wear condition monitoring techniques applied on different type of gears**.**

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J. Kattelus et al. [1] investigated that the main reason for gear wear is macroscopic pitting. An experimental setup is prepared to collect the data for measuring the progression of pitting on gear. Macropitting is generally measured by two methods, one is photography of pitting portion and second is visual inspections, both method are time laborious and provides very less information of pitting progression. Therefore, in this investigation, macropitting progression measured by using on line particle monitoring from lubricating oil as well as with vibration monitoring and visual inspections. The tests were carried out on gear box under heavy load trials. The result shows that the amount of metallic particles in oil correlate well with the portion of macropitting obtained from the visual inspections. Vibration acceleration descriptors indicating peaked signal correlate also with wear of gear at mashing position.

S. Feng et al. [2] developed a method for predicting wearing of gears based on on-line wear monitoring. In this study, a model is prepared for measuring wear debris concentration that is based on Kragelsky's method with different wear coefficients in respective wear stages. A test setup including motor and gear box with continuously lubricated with oil sprayed for acceleration wear test built and a whole life cycle wear monitoring test was performed by using an online visual ferrograph (OLVF).Wear debris concentration measured by index of particle coverage area (IPCA) and an OLVF ferrogram are obtained by taking sample of used oil for every 2 mins and measurement taken. As demonstrated here, the IPCA curve is consistent for this proposed model, and any irregularity can be easily predicted by warning signs. Additionally, experiment shows that by OLFVF sampling, appropriate time for extraction of particles (usually not less than 30s) found in a critical zone.

S. Ebersbach et al. [3] identified the effectiveness of both vibration analysis and gear debris analysis in an integrated condition monitoring program. For such investigation, a no. of trials conducted on a spur gear box test set up. After conducting of tests under normal conditions, the base line information of the test apparatus examined. Under controlled operated conditions, a number of different machine defects are generated corresponding to (i) constant overload conditions (ii) cyclic load conditions. In this research, the analysis of gear debris particles is done by using numerical approach by using an apparatus named as laser scanning cofocal microscope (LSCM).So that, Prediction of equipment abnormal conditions are found by comparing data collected by wear debris analysis and vibration analysis.

J. Sardar et al. [4] designed a thermoplastic composite material and developed a nonmetallic composite spur gear for fabrication purpose. Here, a binding agent , Portland pozzolanic cement (PPC) is used into the polypropylene matrix for fabrication of composite in injection molding technique. However, geometrical structure of the produced outcome depends on some parameters like loading-unloading condition and temperature deflection that severely influence the material performance and the product life shortened. In this work, testing of the composite spur gear material is done for finding out the friction capability and pitting in adhesive and abrasive wear modes. After wear, composite gear weight is determined by measuring directly for specific and variable loads. It is examined that the adhesive rate of wear significantly decreased when the cement filler loading increases. This outcome resulted due to shear strength and surface energy of the composite material changes while toughness and hardness of the material is improved due to strengthening by fillers.

C. Yibo et al. [5] investigated the correlation between gear wear analysis and vibration analysis. This investigation is being made in two parts, which are theoretical analysis and experimental analysis. The theoretical analysis is achieved by analyzing the dynamics equation of a couple of gear. These results of experiments are achieved by investigating eight experiments of simulating gear wear. These experimental gears are different, while the operating conditions are same for all eight simulating tests. These experimental gears are one normal gear, three fault gears for simulating three types of pitting corrosion, three faulty gears for simulating three types of spalling and one fault gear for simulating one tooth break. These experiments are conducted in a test shop for simulating gear wears, the normal gear is initially run as a comparative test. Oil samples and vibration data are collected. Numerical data are compared for both oil analysis and vibration analysis, the experimental results of the correlation of gear wear and vibration analysis are achieved. At the end, from the theoretical analysis and the experimental results, the preliminary results shows that correlation between gear wear and vibration analysis could be achieved, which are as follows: the correlation is not proportioned if the main influencing factor of gear wear to gear vibration is rotation error; the correlation is directly proportioned if the main influencing factor of gear wear to gear vibration is falling-in error.

A. Kumar et al. [6] explained that wear can occur on the gear tooth surface due to excessive load on the gears is the main reason of wear on gear during torque and speed transfer. Some other reasons may be like due to improper operating conditions, friction between the meshed gears, foreign particles like dust particle or by metal debris may inserted in meshing areas. After a number of cycles, gears meshing geometry is not correlate as before due to wearing of outer surface of the spur gear. An actual spur gear tooth profile is different from its corresponding one. The wearing of gear teeth may influenced gear performance parameters like; backlash, center distance, pressure angle etc. Measurement of gears with precision plays a wide role and this may be capable of measuring and inspecting of some spur gear performance parameters with an appropriate accuracy. In the present work, a spur gear is taken for study then it is scanned by using PICZA 3D laser scanner (Roland LPX60) before and after wear. The scanned data is obtained in the form of point cloud data, which is used to remove the scanned noise. The data collected is used to produce the curve geometry of gear tooth profile before and after wear. Then generate the curves of both cases which are used to compare for identification of wear on gear tooth surface. Here, prediction of wear is observed by using reverse engineering approach for measurement of affected parameters due to wearing of gears after a no. of cycles.

F. Gu et al. [7] explained about one of the most common gear failure modes that nonlinear modulation sidebands in the vibration frequency spectrum may be produced by wearing of tooth of gears. In order to accurately monitor gear wear progression, this proposal is approached. He approached a gear wear condition monitoring based on vibration signal analysis using the modulation signal bispectrum-based sideband estimator (MSB-SE) method. The vibration signals are obtained using a run-to-failure test of gearbox under an accelerated test process. In this method vibration signals are analyzed to extract the sideband information. By using a combination of the peak value of MSB-SE and the coherence of MSB-SE, the overall information of gear transmission system can be easily obtained. Based on the amplitude of MSB-SE peaks, Assesment of effects of gear tooth wear is measuring by a dimensionless indicator. The results demonstrated that the proposed indicator can be used for accurate monitoring of gear wear so that wearing of gear may be predicted.

T. Figlus et al. [8] aimed for prediction of wear of gears tooth surface in the gearbox based on measurements of vibration signals and their processing using the wavelet packet transform. Vibration signals found and analyzed in a test bench experiment, during which progression of pitting and spalling of gears teeth is evaluated. The result demonstrates that the processing of vibration signals using the wavelet packet transform allows the detection of fast wear by analyzing data found regarding wavelet decomposition and vibration measurement.

S. Wu et al. [9] analyzed sliding wear of spur gears under gear dynamics and rough-elastohydrodynamic lubrication. Formulas are derived for equivalent wear rate and tooth wear profile along the line of action. Result shows that most of the wear particles materials are detached from both the addendum and dedendum tooth surfaces, and that the highest wear occurs at the beginning of an engagement. This high wear region corresponds to the root of the driving teeth and the tip of the driven teeth. He identified that these analytical results correlate well with the practical data available in AGMA documentation.

Z. Peng et al. [10] investigated the correlation between vibration analysis and wear debris analysis. This is achieved by investigating different operating conditions of an experimental set up that consists a worm gear box driven by an electric motor. At first, worm gearbox is run under normal operating conditions as a comparative test. A no. of tests are conducted with lack of lubrication, and with different contaminant particles added to the various lubricants. Oil samples and vibration data are obtained after every experiment. Then data obtained by wear debris analysis compared with vibration spectra for evaluating the effectiveness of both condition monitoring techniques. The result provides a major role for predicting and diagnosing machine faults under different conditions of vibration.

G. Wang et al. [11] measured the difficulty found in gear system's diagnosis and tooth failure under complex structural and working conditions and indicate for transmission error detection method used for detecting gear setting error and machining error in precision machinery, a transmission error signal model of two-stage fault gear system is prepared. The effects of incipient gear wear of middle axis and geometrical offset on the transmission error analyzed. Certain experiments are conducted to evaluate the effectiveness of this method. The results show that transmission error signal is of high SNR and the performance of the transmission error detection method is suitable for effective diagnosis of incipient tooth wear under complex structural and working conditions.

L. S. Zong et al. [12] prepared a model which forecasted by iteratively robust least squares support vector machine (IRLSSVM). First, model process robustness assured by increasing weight function iteration times; Second, the IRLSSVM hyper-parameter optimized based on the method combined global optimization method CSA with local optimum method SM; Third, the robust cross validation used as CSA-SM algorithm objective function to improve IRLSSVM model robustness of parameter optimization process; Finally, numerical experiment carried out by using K727840ZW gearbox data. Result shows that the proposed method is working effectively.

H. B. Gao et al. [13] proposed a method based on dynamic backlash for a spur gear box with tooth-wear fault under time-varying backlash caused by tooth-wear, eccentricity and bearing vibration in a gear system. For this, a meshing coupled dynamic model with 6-DOF for a single-stage spur gear box built considering the factors like time-dependent meshing stiffness, dynamic backlash, friction and eccentricity. The simulation methods are presented to analyze the dynamic behaviors of the gear system with uniform tooth-wear fault and eccentric tooth-wear fault. Finally, wearing tests conducted with increase in backlash are performed on a gear box; the tests verified the theoretical analysis results. Results showed that the gear system transmission error, shock status and vibration intensity are in nature for different stages of wear. They provide a theoretical method for monitoring and diagnosing tooth-wear faults of a gear system.

S.R. Wang et al. [14] developed a mathematical model to calculate the friction-fatigue wear-off condition of gear tooth face. The wear rate, teeth slippage during engagement of meshing, rotational speed, time for gearing, number of gear are under meshing process and the coefficients of teeth face modification, lubrication and loading are all suspected for wearing of gears. This model is well versed for calculating such parameters. Results are found to reduce the fatigue wear-off due to meshing of gears under different conditions via the mathematical model describing the physical process of tooth face wear-off. The model is available to provide reference for simulation of wear-off process of gear engagement.

Y. Liu et al. [15] analyzed the wear instance of the gear. They generated an equation with respect to the parameters that generally influencing the wear of the gears teeth like sliding coefficient and contact compressive stress. Simulation is presented with numerical method, the changing laws of relative sliding coefficient and contact compressive stress are found based on the simulation curve. The wear instance of the tooth profile is analyzed on the base. The result will be used to calculate and improve the wear instance of the gear. But they analyzed the wearing of gear on theory basis, no practical results are found.

H. Imrek et al. [16] investigated width modification of a spur gear to fix instantaneous pressure changes along with single meshing area on the gear profile. In this gear, variable pressure distributed by the single and double teeth meshing and the radius of curvature along the active gear profile kept constant by maintaining a constant ratio of applied load to the tooth width (F/b) on every point. Hence, Hertz pressure distribution along the gear profile obtained almost equal. During experiment all other parameters are considered as constant. They prepared a model gear from AISI 4140 steel. Finally, a comparative analysis between the modified and unmodified gears for wearing is being made. The results found that wear depth of modified gear along the meshing area found almost uniform.

III. PERSPECTIVES

After reviewing above detailed literatures it is concluded that most of the analysis for wear detection were based on size and morphology of the debris particles. But no researchers use the following techniques for determination of wear. Main perspectives of future work are considered as following-:

(A) Determination of wear particles can be undertaken by measuring the weight of debris particles in micrograms, which are contaminated in gear box after running a lot of cycles in gear box.

(B) Analysis of the wear on gear can be measured by means of determining the area affected on the gear at micron levels.

(C) Detection of wear particles can be identified by volume basis i.e. by measuring the volume of particular portion which affected during wearing of gear surface.

Hence, it is feasible to predict wear condition of gears by measuring weight of debris particles as well as the measured area of wear exist on gear surface.

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