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Investigation of gear pitting defect using vibration characteristics in a single-stage gearbox

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Abstract

Gearboxes are the important components in process industries such as cement, food processing and rubber. Pitting is the removal of the material in certain part of gear by the application of repeated stresses. Tooth pitting and surface failure occur due to excessive stress conditions. When a number of pits join together, a larger pit is formed, referred as a spall, which may lead to tooth breakage. The early detection and diagnosis of excessive wear tooth pitting and spalling in gear transmission systems are becoming significant concerns in high-speed, large power applications. The early detection of pitting in gears is important from condition monitoring point of view, which is still to be addressed by an experimental approach. In this study, vibration characteristics of a single-stage spur gearbox with pitting as seeded faults are investigated.

Keywords

Pitting, gear vibration, single-stage gearbox, gear failures

Introduction

Gearboxes are used in many applications such as manufacturing, military, wind turbine, aircraft, etc. Engineers and researchers are monitoring the gear conditions in a timely manner in order to maintain the proper functioning of the plant.[1] As stated, mechanical element such as gears, bearings and shafts are critically

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important for a proper machining operation.[2] The most common failures in industrial machines are those related to power transmission system. Gear faults may get introduced because of unexpected operating conditions or if the service load is higher than the designed service load.[3] If the gear faults are not detected early, then the condition of the machine will continue to degrade causing high economic loss. If the gear failures are predicted at initial stage, then the breakdown of machines they can be reduced or avoided, and this way the machine availability can be improved.[3] Condition monitoring of gearbox is also very important in the context with the modern-day maintenance techniques. In condition monitoring, there is requirement to select the measurable parameter of machine which will change as condition of machine . Condition monitoring is used to conduct preventive maintenance in order to prevent further development of faults.[4]

The reason behind the gear faults are service load beyond the design engineers' limit and operating changes. Pitting is fatigue failure phenomenon. The gear cracks are subjected to alternate stresses during each rotation of the cycle. The tensile stress may open the crack and compressive stresses try to close the crack. Pitting may be of initial pitting type or destructive type. When a number of pits come together, a larger pit is formed, which is also referred as a spall. The inclusion of foreign particles in lubricant may lead to pitting as in the case of lubricated gearboxes. These particles add up to surface stress concentration effect that decreases lubricant film thickness.[5] When pitting is initiated on gear tooth, it alters the gear mesh stiffness so that the vibration characteristics of gears also change as forces generated by gears change. Many researchers had tried to model the crack and determined the effect of this over the gear mesh stiffness.[6] Few researchers also worked on gear tooth pitting modelling. Gearboxes play a vital role in manufacturing as well as in process industries. The failure of the gear leads to the damage of other components and finally results to the failure of whole gearbox unit. If defects occur to one of the gears during operation, the faulty gearbox would result in serious damage. The failure adds to the maintenance cost and there is a decrease in the productivity of the whole plant because in process industry, one machine can stop the working of whole production line. The condition monitoring techniques help in prediction of gearbox defects at very early stages of occurrences. The objective of the study is to establish a standard method for gear fault (pitting) detection by vibration analysis and to prepare a test rig for monitoring the gearbox.

Ozturk et al. studied the effect of pitting by creating the circular pit on one tooth.[7] Also the pitting growth had been modelled by introducing more pits to the same tooth. Hoseini et al. introduced man-made pit on the planet gear in planetary gearbox.[8] Tan et al. studied the growth of pitting in the presence of loading condition. In this study, lubricating oil without anti-wear properties is used to introduce the surface pits in lesser time.[9] Loutridis stated that empirical mode decomposition method can be used for the detection of gear faults.[10] The crack is generated at the root of gear and same has been modelled with theoretical equations. Xihui et al. reviewed the following aspects: mesh stiffness evaluation, gear damage modelling and fault diagnosis techniques, gearbox transmission path modelling and method validations.[11] Kattelus et al. observed that gear flank failure is due to pitting and found pitting life by performing experimentation.[12] Visual inspection and photographic method is used, and as it seems to be time-consuming, the progression of pitting is detected by online lubricating oil particle monitoring method and at the same time vibration monitoring is also done.

This approach certainly helps undergraduate electrical engineering students in learning the course electrical installations, maintenance and testing at the third year. The theoretical part of the condition monitoring (advance maintenance technique) will be taught to the electrical engineering students in the aforementioned course, but with this study, they can practically understand this concept with the gearbox as the case study. This study explains the detailed procedure of how to select one of the parameters and how it is to be monitored for the purpose of fault detection at the early stage of defect initiation. Condition monitoring is the process of monitoring certain parameters that indicate the health or condition of machines. Condition monitoring of gearbox is very important, as gearbox plays a critical role in the overall functioning of the manufacturing or process plant. This paper provides a good content for the electrical engineering postgraduates who want to pursue their research in condition monitoring of critical machines. Based on this, a new method for fault detection can be established to increase the effectiveness of maintenance activities. Such techniques can be applied to other components of the plant or system.

Experimental setup

Figure 1 shows the block diagram of the test rig used for gear fault detection. In order to fulfill the objective for condition monitoring of the gearbox, a test rig was designed. The components of design test rig are electric motor, gearbox and dynamometer. The functioning of the component is as discussed below.

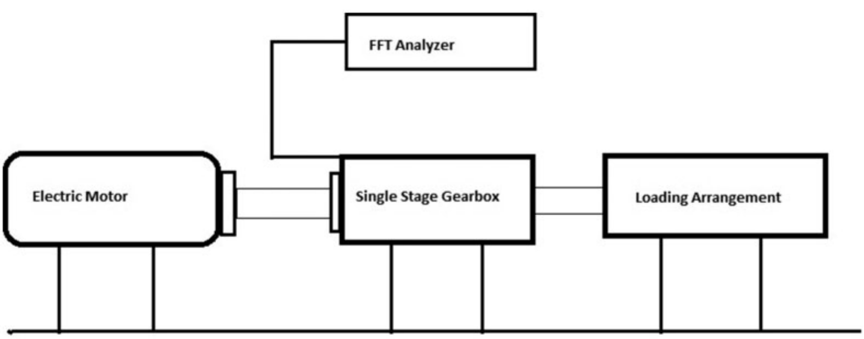

Figure 1. Block diagram of test rig.

Table 1. Specifications of set up.

S. no.	Particulars	Specifications
1	Power	1 HP
2	Input rpm	1440 r/min
3	Input frequency	15 Hz
4	Output rpm	820 r/min
5	No. of stages	1 Stage

It consists of a one HP AC drive motor coupled with gearbox. This motor transmits the power to gearbox unit. The set consists of single-stage spur gearbox, which is selected for condition monitoring of gear fault. To create the loading conditions on the gearbox same as that of in operation, a dynamometer is used. Magnetic base accelerometer is used for the purpose of vibration measurement and is kept in such a way that it will measure vibrations in radial direction. At first, results were obtained for healthy condition and then the healthy gear is replaced with slight, moderate and heavy pitting gear. These data have been stored in FFT analyser. The four-channel Fast Fourier Transform (FFT), analyser is used for vibration signal measurement.

Table 1 shows the specification of set up used for experimentation. A single-stage spur gearbox was used to investigate the pitting effect over the vibration characteristics. All these components are mounted on the base. The motor is coupled to gearbox with the belt drive. The drive pinion had a 32-teeth meshing with a 56-teeth gear.

Experimentation

Figure 2 shows actual condition monitoring test rig. The project deals with design, fabrication and testing of gearbox under the condition of seeded faults in gears. The tests were taken at constant speed and varying load conditions. The condition of gears in the gearbox was altered time to time for getting the desired readings. Only one accelerometer was used during testing. Initially, a vibration response for the healthy gear pair is noted, and then the artificial pitting faults with severity were created on the gears followed by the response measurement for the same.

Conditions that were considered for getting the responses were for healthy gear, slight pitting gear, moderate pitting gear and severe pitting gear. The pitting, scoring and wear tooth defects are the common faults in gears. The pitting defect is generated by Electrical Discharge Machine (EDM) on the tooth.

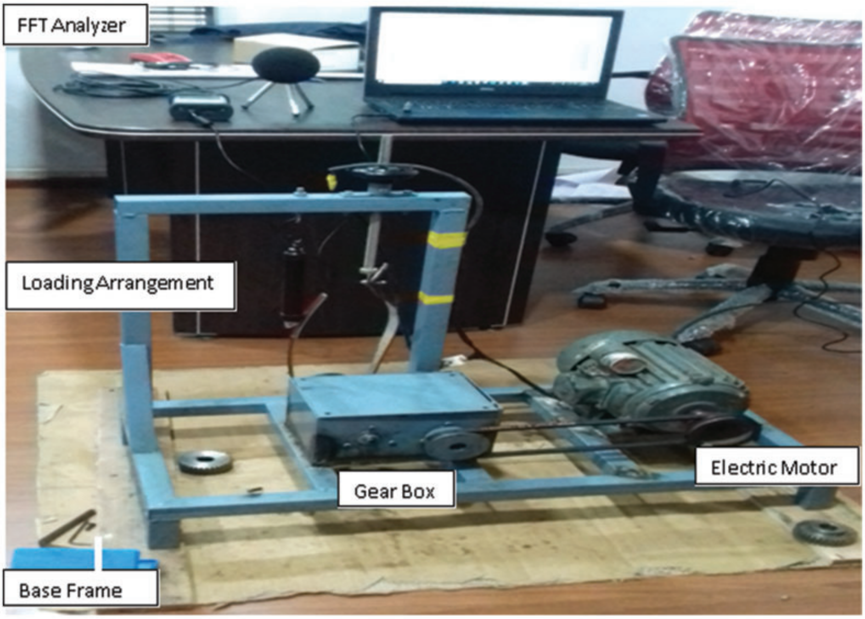

Figure 2. Actual condition monitoring test rig.

Table 2. Acceleration in m/s^2 for different pitting conditions.

Condition of gear	Peak	Peak–peak	Max.	RMS	CRF
Healthy gear	216.272	401.328	19.702	18.113	11.94
6.3% Pitting gear	185.994	355.222	38.815	23.361	7.962
27.8% Pitting gear	253.513	498.884	45.814	28.882	9.795
41.7% Pitting gear	574.116	1041.118	41.4	36.266	15.831

RMS: root mean square; CRF: crest factor.

Results and discussion

Table 2 shows the Root Mean Square (RMS) acceleration values for different pitting conditions of the gears. For healthy gear, RMS acceleration is observed as 18.113 m/s^2 and for gear with 6.3 pitting rate, it increased up to 23.361 m/s^2; when this gear is replaced with gear with 27.8 pitting rate, then RMS acceleration reaches a value of 28.882 m/s^2. The maximum value of RMS acceleration (36.266) has been recorded for a gear with 41.7 pitting rate.

Based on the aforementioned results, the following gear fault (pitting) detection method can be established:

1. Observe the RMS acceleration in terms metre per second square and frequency for this corresponding value for healthy gear condition.

2. State the limit range in terms acceleration for healthy gear condition.
3. If the value of acceleration is greater than the healthy gear acceleration value, then fault is present in the gear.
4. Take the acceleration reading of sample gear and observe the acceleration value and compare with healthy gear acceleration value.
5. Identify the fault in gears on the basis of value of acceleration.

Conclusions

We conclude that as the level of pitting increases from slight to moderate or severe, RMS acceleration also increases. Most of the time gear flank deterioration process start with pitting defect. Therefore, it is possible to predict the gear health condition (for pitting) by measuring its RMS acceleration. As gears are main components of the gearbox, one can easily monitor the health of the gearbox by monitoring the health of gear. It is possible to prevent gearbox failures using this condition monitoring method and further the plant reliability can be ensured by reducing the breakdown time.

Declaration of Conflicting Interests

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