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# Failure Prediction of Helical Gear Using Wear Debris Analysis

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**ABSTRACT**

Modern high speed and power machinery components like gears, bearings, pumps, hydraulics, and motor normally reach the end of their useful operating life due to a gradual or sudden failure (M.J.Neale, 19731). The gradual occurrence of a failure is maintainable and acceptable as it is steadily developed with time [2]. On the other hand, a sudden failure is not desirable, as it may involves in human life and interruption of machine operation(M.J.Neale, 19731; S.Mahalungkar and M.Ingram, 2004 ). Wear debris analysis (WDA) has been proven useful in providing supporting evidence on gear status as it also provides valuable information on the wear mechanism involved. It is vital to analyze the basic features of wear debris for determination of component health. In this paper, a back to back gear test rig was used to study the effect of abnormal loading conditions against life span. From this research, the estimated helical gear life as shown by the particle count graph is very close to the theoretical value calculated by using the BS ISO 6336-2.



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## INTRODUCTION

In the study of helicopter system failures, it shows that 32 percent of helicopter accidents due to fatigue failures were caused by damaged engine and transmission components (D. G. Astridge, 20004). In 1999, from total of 192 turbine helicopter accidents, 28 were directly to mechanical failures with the most common in the drive train of the gearboxes (D.Learnmont, 2000). To avoid sudden failures and their possible consequences, it is very important to determine the failure causing events from the machine in near real time (J. Lin and M. J Zuo, 2003.; W.Wilson, 2008). Among the monitoring methods, wear debris analysis (WDA) is considered as an accurate and effective approach due its capability of being able to reveal wear condition of the machinery through the analysis of oil properties and wear particles (C.Q.Yuan,Z.Peng,X.C.Zhou and X.P. Yan, 2005). WDA can provide the actual details of these events (wear mode, wear severity, surface degradation rate and component source or location) by analyzing the debris that contain the direct information of the surface of a components[9]. This has motivated researcher to study the effect of loading on gears related to the generation of wear debris. Beforehand, a back to back shaft test rig was developed using a torsional misalignment device to study the effect of loading conditions against the gear life span. In this paper, the first case of loading condition was used to validate the helical gear life estimation by using the test rig. The gear life was estimated by using mathematical model based on BS-ISO 6336-2. Result from the experiment then will be compared with the mathematical estimation to validate reliability of the test rig.

### *2. Methodology:*

### *Life Estimation by using BS-ISO 6336-2:*

Refer to BS ISO 6336-2, the calculation of helical gear pitting is based on the contact stress, at the pitch point of the meshing gears, or at the inner point of single pair tooth contact. Contact stress shall be less than it permissible for preventing failure and vice versa.The formula of contact stress for the pinion gear :

$$\sigma_H = Z_{B.} \bullet \sigma_{HO} \bullet \sqrt{K_A \bullet K_V \bullet K_{H\beta} \bullet K}_{H\alpha} \quad (1)$$

Solving the equation,start time of the onset failure or the useful life of the gears will be **46 hours.**

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***Life Estimation by Experimental Investigation:***

A developed test rig is constructed of drive and driven gears, main shaft, shaft connector, torsional misalignment device and DC motor which serves as drive unit, brake unit and adjustment device for gear assembly condition as shown in Fig.1.

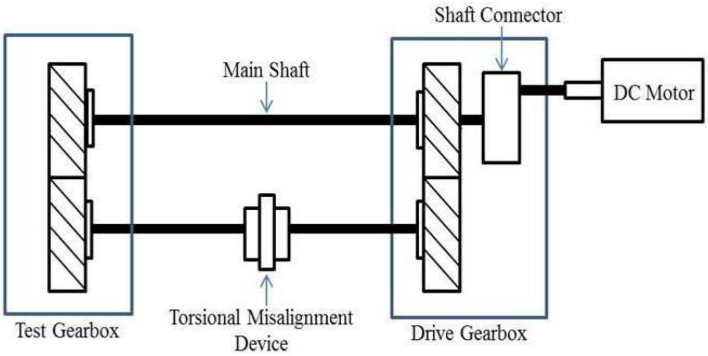


**Fig. 1:** Major component schematic of test rig

The drive gearbox contains one pair of helical gear that serves as the drive side. The drive power is from a variable speed DC motor to the belt drive. The drive speed is **1000rpm**. The basic principle of loading is twisting one shaft relative to its mating shaft and locking it in position. To twist the shaft, a load hanger as shown in Fig. 2 is used. At the end of the hanger, loading is applied according to the required torsional loading. When the load was applied, four lock screws are used to lock the both shaft. Then the load will be released and the shafts will have remaining torsional load. The remaining torsional load will give pre-loading to the test gear.

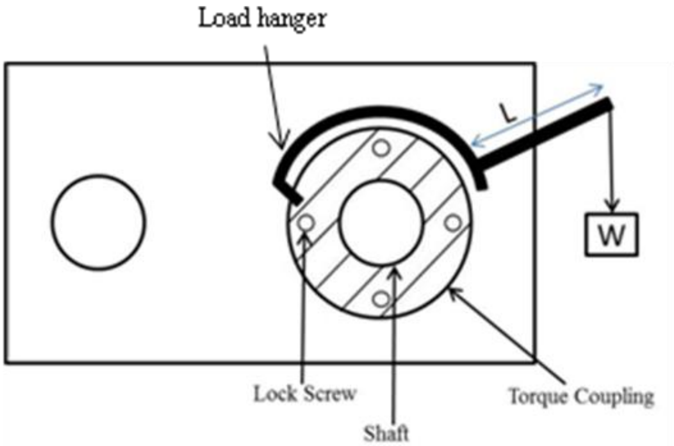


**Fig. 2:** Basic principal of loading

***3. Analysis Method:***

***Debris Size:***

To perform wear debris analysis,oil sampling is taken for every one hour of gear operation. 75ml of oil is taken from each sampling. Before a few drop of oil is taken, oil sample must be shake to get the debris distributed evenly inside oil fluids. A few drops of oil is taken and put on 10cm×7.5cm clean white paper. The drop then is analyzed under microscope to quantify the particle size.

***Visual Inspection Image:***

Visual inspection process starts with checking the condition of gear damage periodically. Visual inspection of the gears is taken for every 3hours and image of the gear tooth is captured and recorded.

***Particle Count:***

70ml of oil is taken from each sampling and process using debris quantitative analyser for analyzing particle count data.

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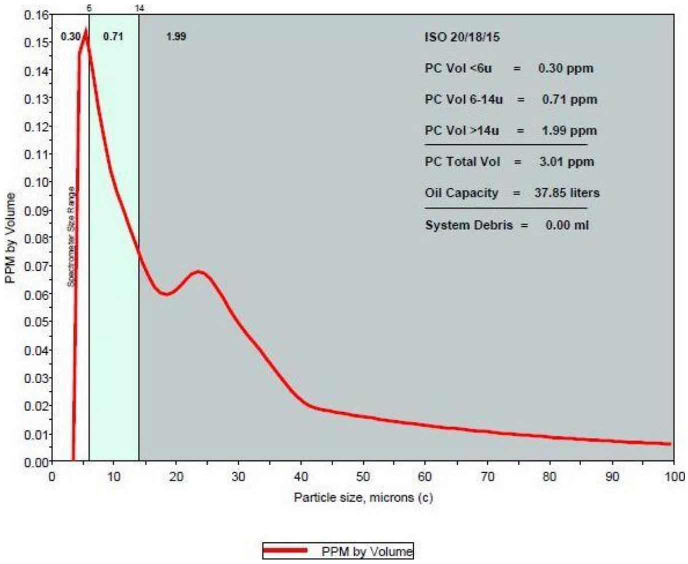
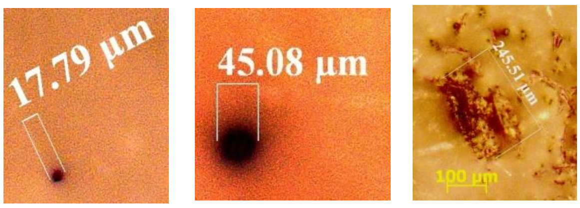



**Fig. 3:** Particle count in PPM by volume from debris quantitative analyser

## RESULT AND DISCUSSION

### *Debris Size:*

From the experiment, size of the debris is gradually increased from 17µm at 3 operation hours to 45µm at 33 operation hours as shown in Fig. 4(a) and 4(b). It is due to improper misalignment or gear tooth surfaces not properly conforming to each other (E.E Shipley, Mechanical Transmission). As gear operations exceed 46 hours, the particle size is abruptly increased indicate high wear rate zone. At 60 operation hours, the particle size is 245µm as shown in Fig. 4(c).

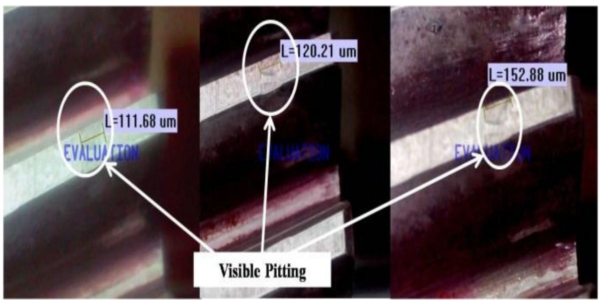



(a) (b) (c)

**Fig. 4:** Images of debris generated after 3hours(a), 33hours(b) and 60hours(c) of operation

### *Visual Inspection Image:*

From visual inspection process, size of the damage on gears abruptly increased when the gear operation exceed the estimated onset failure time which is 46 oprating hours. Pitting fatigue on the top of gear teeth indicates the area of highest contact pressure. Pitting size gradually increased from 110µm at 18hours operation hours to 120µm at 39 operation hours as shown in Fig. 5(a) and 5(b) respectively. At the end of gear operation which is 60 operating hours,the pitting size is 152µm as shown in figure 5(c). With respect to gear operation hours, the pit sizes becoming wider and deeper.




(a) (b) (c)

**Fig. 5:** Validation experiment – gear teeth image after 18hours(a), 33hours(b) and 60 hours(c) of operation

***Particle count:***

Pattern of the particle count against operation hours is plotted as shown in Fig. 6. From the trend line pattern, the particle count is slightly high at the beginning of the operation hours due to initial pitting. This condition is characterized by small pits and occurs at over-stressed areas. It tends to redistribute the load by removing high contact spots (E.E Shipley, Mechanical Transmission). Generally when the load has been redistributed, the pitting stops and the contact surfaces smooth over. This phenomenon explained why the particle counts attenuated. Looking at the trend line, the average of the particle count is high at beginning of gear operation(less than 10hour). The trend then stabilized at 4000 number of debris from 10 to 34 operating hours. After 34 hour, the trend is slightly increased and achieved a peak value of 6000 number of debris at 50 operating hour. This result shows that the gear operation hour is reliable up to 34-50 operating hours. Compare to the debris size and visual inspection image analysis, this result explains that the increasing of pitting size and debris size occurred after the 34 hour.

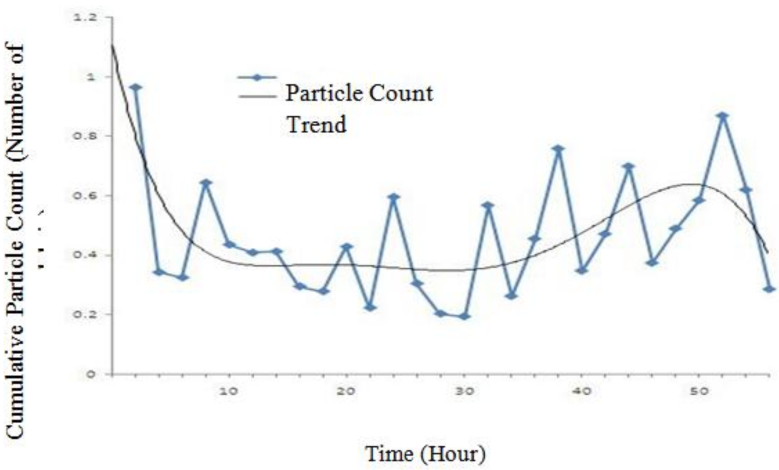



**Fig. 6:** Cumulative particle count against operation hours

***Conclusion:***

As a conclusion,the size of debris generated from experiment and size of pitting on gears is increased with respect to gear operating hours. The estimated gear life as shown by the graph is very close to the theoretical value calculated by using the BS ISO 6336-2. The trend line of particle count is look like to bath tub shape failure rates.

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