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CONDITION MONITORING ON TEXTILE MACHINE GEARBOX USING OIL DEBRIS ANALYSIS

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ABSTRACT

Condition monitoring is the process of monitoring some parameters from the machinery, such that a significant change in the parameter can give information about the machinery health. Transmission failure prediction could be done by gaining the information based on wear debris analysis. Failure of transmission gearbox is unpredictable and regular maintenance of it would totally depend on mileage or duration time of the system had been used. This research would focus on the industrial gearbox located at Mechanics of Machine Laboratory and also towards having the wear particle trends of passenger car transmission gearbox. The industrial gearbox are exposed to different speed and vibration condition within a predetermined running hours. The contaminated oil collected was sent to 3rd party to express the wear element presence inside the oil samples. The same approached was applied to the automotive transmission gearbox while moving towards condition monitoring. Spectroscopy method and Ferrography method are the two main approached at the test laboratory. The experiment had reveal that greater vibration with high speed of rotation will contribute to shorter gearbox life span. While in the automotive gearbox the presence of Iron, aluminium and silicon had shown a significant trend of wear debris.

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CHAPTER 4 RESULT AND DATA ANALYSIS

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Since development of the world getting progressively, there is growing involvement in studies of wear of sliding components. Greater machineries in industries are growing faster than their operator. In this situation, we could say that condition of lubricant plays an important role on the working condition of the machine significantly. The chemical and physical properties of a lubricant have a direct effect on a lubrication situation. This means, lubricant provides secondary information about the condition of the machine itself.

Maintenance has developed via scheduled maintenance to predictive and even improving maintenance. Repairing maintenance means that machines were repaired after their breakage. Instead of that, changes of oil and replacement of certain machine elements or part were carried out after certain period of time or number of working hours of the machine without ensuring if it is necessary or not. This kind of maintenance is justifiable if the machines elements are cheap and changed oil volume are very small. This is due to the small costing and time taken on production did not causing delays. However, it would be a big problem if it involving a big element on the machine. This could cause downtime and significant production losses.

Condition monitoring could assist in overcoming this matter. It could be carried out using oil analysis, vibration monitoring or process parameter monitoring. In this research, condition monitoring had been choose as a method in analyzing wear on the industrial transmission gearbox. There are many types of techniques in condition monitoring. In this research, Atomic Emission Spectroscopy (AES) and Ferrography Direct Reading (DR) had been chosen as the techniques in accomplishing the research significantly.

1.2 Statement of Problem

Failure of a transmission gearbox is unpredictable and regular maintenance of it would totally depend on mileage or duration time of the system had been used. Lack information of this situation would cause several problems, such as shown below:-

i. Failure of transmission gearbox on unnecessarily time.
ii. Inefficient in use of money and time by running regularly maintenance of gearbox.

In that case, this research may solve these problems by running wear debris analysis in transmission gearbox through condition monitoring methods. This analysis would let us know how the debris could affect the failure or lifetime of transmission gearbox.

In addition, as to increase the understanding of wear particles trend in the gearbox, the experiment had been extended to an automotive application to analyse the presence of wear element in the transmission gearbox.

1.3 Significance of Study

Significances of this study consist of following aspects:

i. Manufacturer of industry

The manufacturer could be able to improve their production and reducing cost on maintenance of their machinery as they could predict perfect time when the machine needs run for a maintenance before it breakdown. Production of the industry would increase since downtime could be eliminated significantly. Economy of our country would also increase progressively indirectly.

ii. Entrepreneur of workshop

This study would be useful for entrepreneur of workshop due to acknowledgement that they would gain in determining the appropriate time for vehicle run maintenance. Instead of that, they could estimate life cycle of the vehicles. On the other hand, consumption of less energy could be reach while handling a properly working system rather than a faulty one.

iii. User of vehicle

Nowadays, most of user of vehicle totally put on their trustworthy on technicians or mechanics in handling any defects or problem that occur on their own vehicles. Sending the vehicle to the workshop is one of the best initiatives in order to repair the vehicle. However, it is better if the users itself have base knowledge on how to overcome the problem and why does it happened. Through this research, any user of vehicles might gain a new knowledge in improving maintenance of their car, instead of waiting for their vehicle tends to breakdown and send them to the workshop.

1.4 Objective

Main objective of this research is to predict failure on transmission gearbox by gaining information from wear debris analysis.

1.5 Scope of Study

This research consists of following study:

i. Running four transmission gearboxes existed in laboratory of Mechanics of Machine with several of speed and different experience of vibration condition.
ii. To get the automotive transmission gearbox contaminated oil sample within a predetermine running milage.
iii. To gain the contaminated oil from four of the gearboxes and sent them to Metalux Oil Analysis to obtain the related data of the debris.
iv. Make a research and analyse all the data obtained and relate them to the condition of gearboxes.

1.6 Expected result

There are several expected results that would be considered in order to accomplish this study, which could be seen as follow:-

i. Life of transmission gearbox could be estimated
ii. Reasons on why transmission gearbox easily tends to fail could be indicated
iii. The possible automotive gearbox wear element could be identify.

1.7 Problem face

These are several problems that might be occurred in accomplishing this study, which could be seen as follow:-

i. Meet the appropriate time to run the transmission gearbox in the laboratory of mechanics of machine. This is due to noise that would be developed by vibration from the running gearbox. This situation might significantly interrupt lecturers and students while experiencing their laboratory lecture session.

ii. Length of time needed to run the gearbox in order to get the contaminant oil. This research would run the gearbox five times with increment of 48 hours of time. However, the experiment could not be able to run the gearbox for two days directly. This is due to the limited time in using the laboratory where the machine is located. In that case, the gearbox would be run from 9.00 a.m to 5.00 p.m until it reaches 48 hours.

iii. The highest accumulated milage is the better to conlcude the wear patern of automotive gearbox. The time constraint to be take into consideration and yet only at 1000 km interval the contaminated oil samples to be collected.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Unscheduled downtime is the number one enemy of an organization or industry. In an environment where equipment is expected to run 24 hours a day under extreme operating conditions, equipment failure could quickly brings production to a halt. The number one cause of failure that occurs in mechanical application is due to contamination in gearbox. The gearbox plays an important role in mechanical system that could determine the system run smoothly without tends to fail. Wearing in gearbox might cause significant expenses to industry. Fortunately, the development of condition monitoring process might increase the machine performance in order to avoid catastrophic failure. The condition monitoring could assist us to acknowledge condition of the lubricant and equipment without experiencing downtime. Detection on failures and trace the root cause could be provided with sufficient lead time to schedule corrective maintenance before catastrophic failure occurs, with minimal disruption of the operations time. Consequently, effective use of condition monitoring might assists the industry in cost saving by reducing scheduled maintenance and increasing productivity of the system.

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Condition monitoring consists of several methods that usually chose by researchers in detecting failure of gearbox. There are various methods consists in condition monitoring. Oil analysis, Wear debris analysis, Vibration analysis and Metallurgical analysis were several methods that have been study by many researches in order to diagnose the failure of gearbox. Wear debris analysis has proven useful in providing supporting evidence on the gear status. This method could examine wear particles and contaminants suspended in the fluid including grease and water-based fluids. These particles can reveal abnormal wear, components involved, and the cause of wear.

Wear debris analysis will identify wear related conditions at an early stage and preventing catastrophic equipment failure. Wear debris analysis could gives much more benefits, such as determining start of abnormal wear, evaluate particles contaminating the lubricant sample, predict equipment wear condition and failure potential, qualitatively determine the size, shape, composition and concentration of particles, identify source of wear, determine lubricant life and particle analysis 0-300 microns.

2.2 Condition monitoring

Basically condition monitoring is the process of monitoring some parameters from the machinery, such that a significant change in the parameter can give information about the health of the machinery. It involves the continuous or periodic assessment of the condition of a plant or a machinery component while it is running. Although the main use for condition monitoring is to predict and hence assist in avoiding the unplanned equipment failures. However, there are other means in which condition monitoring can assist in improving maintenance during the Planned Maintenance phase. It helps in minimizing total equipment downtime by taking a holistic view of plant condition, and combining planned maintenance tasks, wherever possible, into a single equipment shutdown. It makes workplace safer by reducing the equipment failure. Information obtained during the condition monitoring also helps in optimizing the equipment performance. A wide range of Condition monitoring techniques is available and some have become standards in many industries. Those standard techniques for the condition monitoring are as follow:-

a) Visual inspection
b) Vibration analysis
c) Acoustics analysis
d) Oil analysis
e) Wear debris analysis
f) Thermography and other Non-destructive testing (NDT) technique

The most basic and cheapest form of condition monitoring is visual inspection by experienced operators and maintainers. Failure modes such as cracking, leaking and corrosion can often be detected by visual inspection before failure is likely. Vibration analysis is used primarily with rotating equipment to find problems such as out-of-balance, looseness, misalignment, gear teeth defects, bearing defects and system resonance. Generally periodic readings are taken and recorded. With acoustics analysis, a machine running in a good condition has a stable noise spectrum. Identification of noise sources and comparing their spectrum with a stable spectrum of a machine in good condition could prove to be an important tool for condition monitoring. Thermography supports maintenance of industries that have high temperature processes. The technique is also used to find electrical components that are hotter than normal.

2.3 Wear debris analysis

Choosing the right lubricant can be an especially tricky task. There are general technical requirements that all lubricants must meet, such as reducing friction and wear, protecting against corrosion, dissipating heat and providing a sealing effect. The lubricant is a powerful source of information on machine condition since if the oil deteriorates, then so does to the machine condition. While when the machine worsens, the oil would suffer. Build up of wear debris in a machine usually originates from interactions between the working faces of mechanical contacts such as bearings, gears and other lubricated components. These are the major causes of mechanical breakdowns (Wright G.J. Neale M.J.1987).

The wear debris found in lubricants has their own characteristics composition, shape, size and concentration which then could be related to the surface damage and assists in determining condition of the component. Wear debris analysis is one of the most used techniques by researchers that could assess the changes of these debris characteristics.

Wear debris analysis is now becoming one of the key techniques used to screen for the presence of abnormal wear in many types of industrial machinery. The industry is required to have a cost effective and efficient wear-particle analysis technique to monitor the condition of a machine reliably. Wear debris analysis has proven useful in providing supporting evidence on the bearing or gear status. Instead of that, it is also provides information on the wear mechanism which is involved.

According to Peng Z., *et al.* (2005), wear debris analysis is fast becoming the most powerful oil analysis strategy for assessing machine condition. In wear debris analysis, there are certain factors that are determined such as quantity of wear debris being generated, size distribution, chemical from debris, morphology and colour of wear debris. There are six main types of wear particles generated from common machinery, corresponding to rubbing, spherical, laminar, cutting, fatigue chunk or severe sliding particles. A representative sample of the lubrication fluid of a machine can provide information on the wear modes, wear sources, and wear phases present in the machine. However, there are limitation in wear debris analysis, which are the technique is very time consuming, requires an expensive laboratory set up and human expert inspection of the wear debris samples.

Based on study by Pekka Vahaoja (2006), increased metal concentrations in oil might tell the maintenance personnel about wearing of machine elements or oil contamination with other oils, process chemicals or airborne dust. Techniques used for wear debris analysis are numerous, for example atomic absorption spectroscopy (AAS), atomic/optical emission spectroscopy (AES/OES), mass spectrometry (MS), X-ray fluorescence spectroscopy (XRF), ferrography and magnetic chip detectors. The underlying principle of wear debris analysis is that the wear debris found in a lubricant will form part of a size distribution that changes progressively as the surface deterioration increases. In addition, information gained from wear debris analysis could assist following aspects:-

i. Detection of abnormal wear that would indicate incipient failure
ii. Diagnosis of the mode, location and mechanism of wear and its severity
iii. Prediction of the future state of the machine
iv. Recommendation of future maintenance action

2.4 Review of wear debris analysis studies

This following section is showing some of the studies that related to the condition monitoring techniques and the expectation that has been conducted by researchers from worldwide.

2.4.1 Size particle and quantity

Kennedy Space Centre (in P/PM Technology 1991), had stated that ferrography provides early detection of abnormal wear of the lubricated critical component of mechanical system. Analyzes the debris in lubricant could shows the particle size, shape and colour as well as quantity. According to Mark Smith (2008), he says that in mechanical system, when system parts wear abnormally, the particle quantity and size progression in wear severity is from smaller to larger.

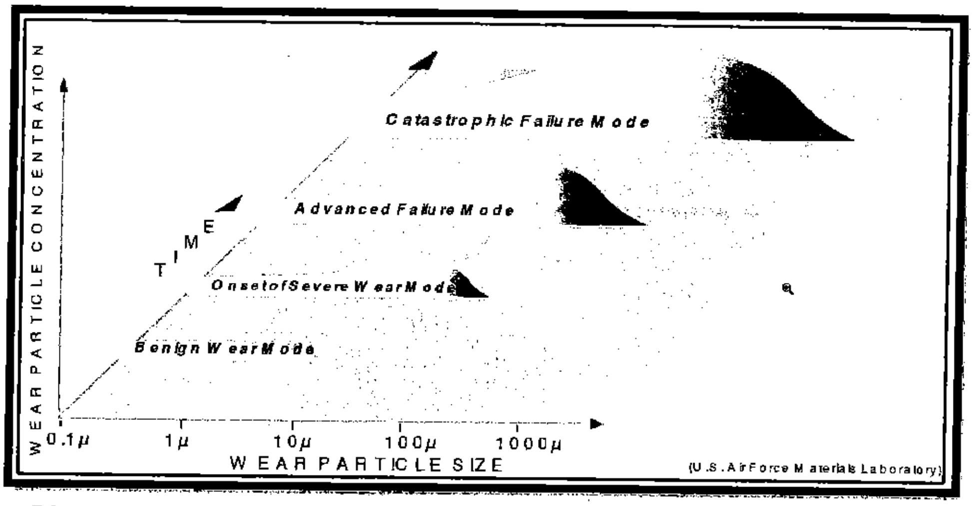


Figure 2.1 Particle size progressions in abnormal wear, (Kennedy Space Centre in P/PM Technology 1991)

Figure 1 above shows the size change is related to stress increase as loaded surfaces depart from their original shapes and clearances, the effect of higher temperatures on lubricant films and alloy structures, and the cascade effect of wear already worn parts release successively larger particles which act to dent and abrade these very same damaged surfaces.

The main point that needs to remember is that, as wear worsens, the average particle size increases, consequently any proactive approach to wear monitoring should detect the size immediately. Figure 2 illustrates some basic information by relating the particles of wear to the real world objects sizes which their sizes approximate. The size ranges chosen are those associated with wear or contamination which has reached a demonstrably serious phase.

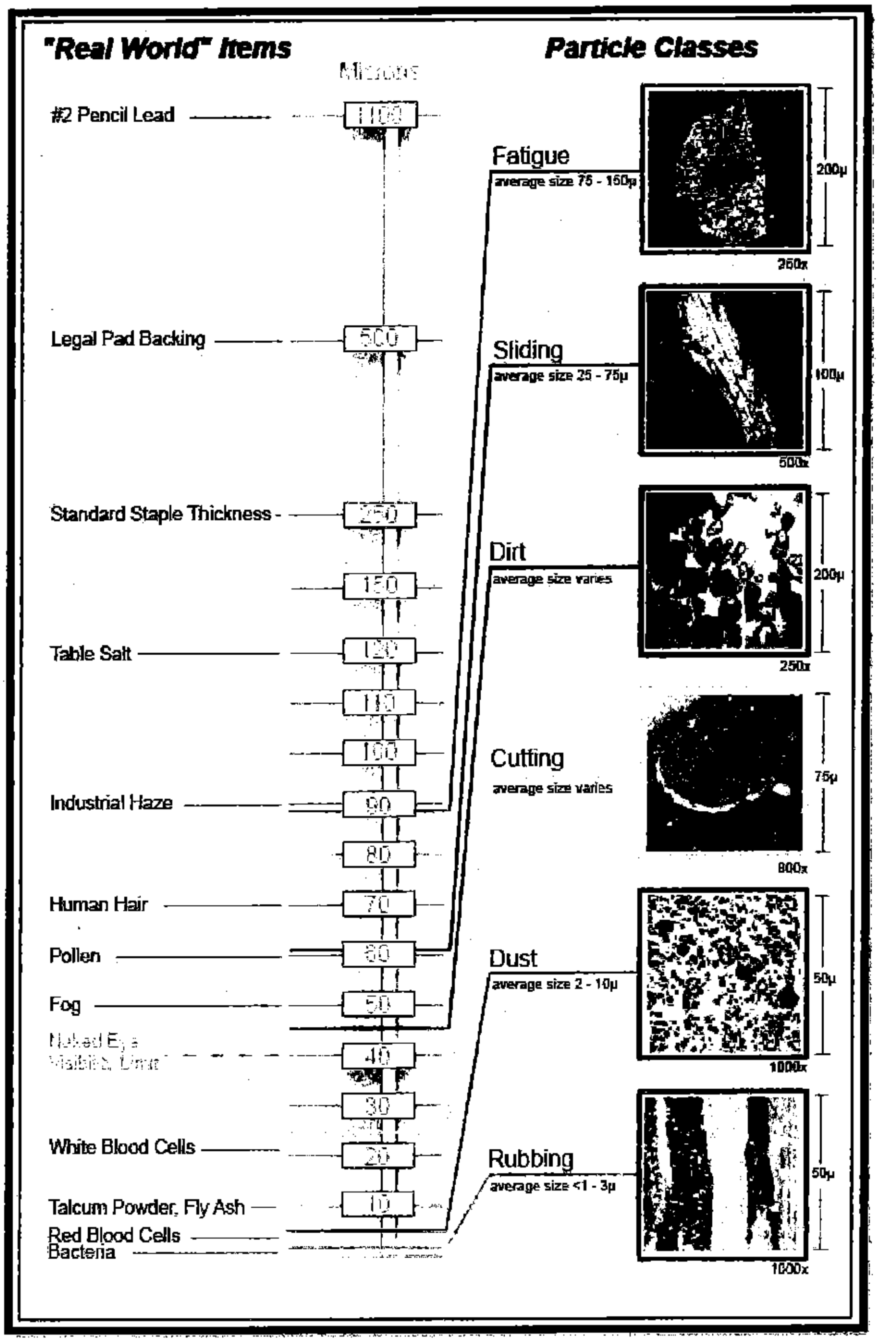


Figure 2.2: Typically encountered particles and their sizes (Mark smith 2008)

Based on the study by Peng Z. (2002), three dimensional wear debris analysis techniques have been applied to study wear debris present in oil sample. It consists of counting particles in a specific sample volume of oil, measuring particle sizes and size distributions, examining particle colours and compositions and analyzing individual particle morphologies. There are a number of techniques that could be used to obtain surface topographical information. In the research, technique of laser scanning confocal microscopy (LSCM) has been used. The basic working mechanism of this technique is

i. A high resolution laser beam reaches a tiny region of a specimen
ii. Only light returning from an exact plane of focus is permitted to pass through a small aperture before reaching an electronic detector or photomultiplier tube (PMT)
iii. The PMT converts the light into a digital image displayed on a computer monitor

Based on the study, the advantages of LSCM over other microscopic systems is that the minimum requirement of sample preparations is required, which is no coating is needed. Instead of that, LSCM also might be able to acquire the images of a group of particles in a shorter period of time. LSCM is generally easy to modify a standard system according to the requirements of different applications. LSCM is a suitable system to provide an appropriate image of a wear particle, especially when the size is >5micronmeter. After the three dimensional images acquired from the LSCM, automatic wear particle analysis system could open the image, separating particles from their background, counting particles and analysing particle morphologies. Example of two dimensional of wear particle obtained from LSCM could be seen in the following figure.

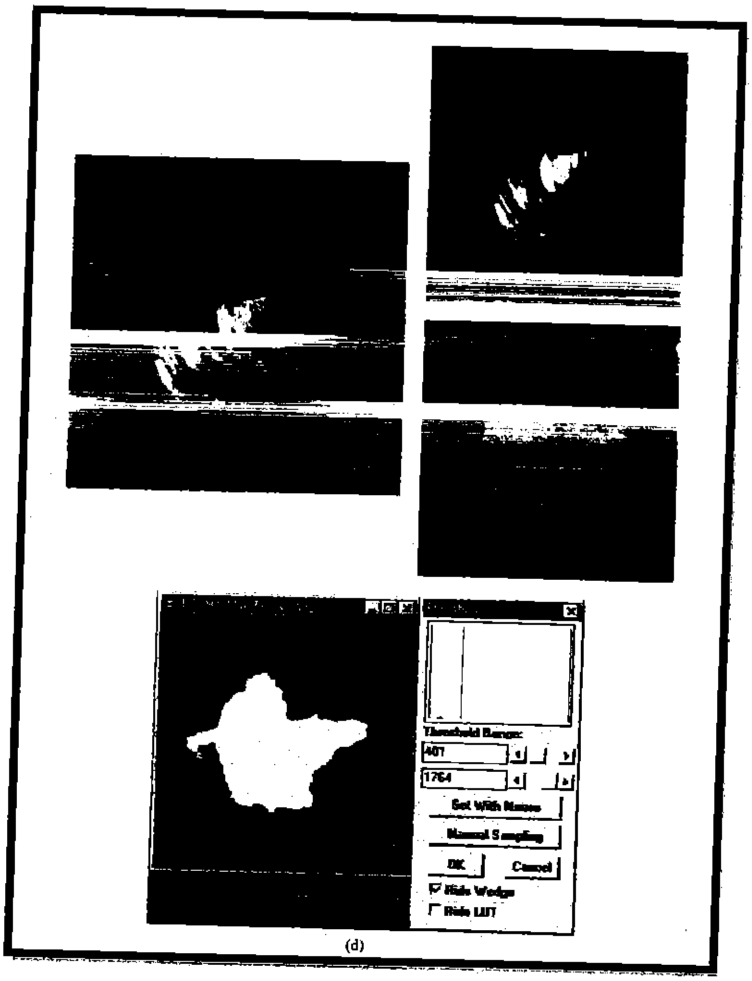
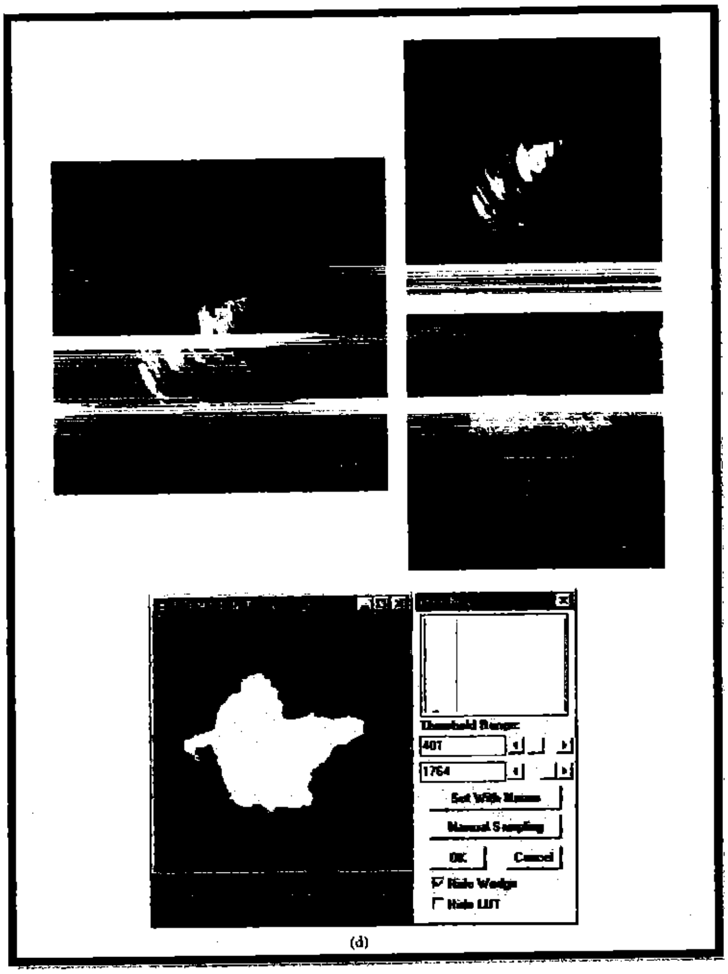


Figure 2.3 Image of the particle acquired from LSCM (Peng Z., 2002)

The image (b) is obtained from the reflection channel for surface characterisation, while image (c) is obtained from the transmission channel for boundary analysis and image (d) is the separation of the particle from background using threshold function. There are four groups have been designated for gearboxes, which are <10, 10-20, 20-50 and >50 micrometer corresponding to small, medium, large and abnormally large.

Instead of applying three dimensional wear debris analysis techniques, the researcher also had used a technique that is named as expert system for machine condition monitoring in order to monitor the condition of a machine reliably and efficiently. There are two common ways to assess the change of particle quantities in the expert system. One method is directly through particle counting



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Instead of applying three dimensional wear debris analysis techniques, the researcher also had used a technique that is named as expert system for machine condition monitoring in order to monitor the condition of a machine reliably and efficiently. There are two common ways to assess the change of particle quantities in the expert system. One method is directly through particle counting and the measurement of particle size distribution. The other method is to analyse the concentration of particles in lubricant and changes in concentration, based on the fact that the concentration is dependent on the rate of wear, the rate of particle loss due to filtration, settling, and the system characteristic. In this study, the input data to the expert system is the analyzed results generated from the group and individual analysis of wear debris. The data consists of number of wear particles presented in oil samples, particle sizes and size distribution, types of wear particles presented in oil samples and number of particles percentage of particles of each type. This system using rules <IF-THEN> structure, with <IF> conditions based on particle analysed data and <THEN> for conclusions, where assessed wear rates, wear modes and machine condition. Following figure is one of the results by using expert system from the study.

IF
the machinery is a gearbox;
and particle size range is 3–25 µm;
total particles larger than 15 µm in the oil sample (1 ml) is <30;
80% of particles are rubbing particle.
THEN
the condition of the gearbox is most likely in a normal condition,
suggest to sample the oil at a regular interval.

Figure 2.4 Result by using the expert system (Peng Z., 2002)

From the study, the researcher had conclude that integrated intelligence system is unique that could be use to conduct quantitative analysis at different levels from routine and quick particle analysis to a higher level analysis. This development also could be significantly reduced the human involvement and experience in identification of particle. The whole package is very easy to use with highly computerized level.

2.4.2 Types of wear particle

There are six basics wear types generated through the wear process. These include ferrous and non-ferrous particle comprises, such as follow:-

a) Normal rubbing wear
   This wear is generated as the normal wear in a machine and result from exfoliation of parts.
b) Cutting wear particles
   These wear are generated as a result of one surface penetrating another. Cutting wear particles are abnormal and should be monitored carefully. If a system shows increased quantities of large (50 micrometer long) cutting wear particles, a component failure is potentially imminent.
c) Spherical particles
   These particles are generated in the bearing fatigue cracks. If generated, their presence provides early warning of impending failure. They are also might generate by welding or grinding processes (contamination).
d) Severe sliding
   These wear particles are identified by parallel striations on their surface. The wear sometimes shows evidence of temper colours, which might change the appearance of the particle after heat treatment.
e) Bearing wear particle
   This is due to the fatigue spall particles from the rolling bearing. It occurs when the metal surface had a pit or crack. Laminar particles are also one of the bearing wear particles. It is very thin free metal particles. An increasing quantity of laminar particles in addition to spherical wear is indicative of rolling bearing fatigue micro cracks.

Based on study by Peng Z. et al., (2005), they also use optical microscope and then CLSM technique. Particle type, overall surface characteristics and colour were studied using the optical microscope. The CLSM could determine both the boundary and surface definitions of the particles.

According to Kevan Slater (2004), he had uses Scanning Electron Microscope (SEM) X-ray spectroscopy in order to determine the metallurgy of the wear particle on centrifugal pump. Instead of that, oil analysis and vibration analysis had been use. However, SEM analysis had successfully determined that the wear particles types. Ferrography and Patch tests were not sufficient to determine the source of the particle but had confirmed the presence larger particle types of wear. While vibration analysis could not detect the wear during the short hour run of the system.

Study that has conducted by Raadnui, S. (2005), shows that low cost technique could also useful in determining types of wear particle. Filter debris analysis (FDA) and grease debris analysis could easily indicate the wear types. Characteristics of wear debris before and after were determined from used grease from four-ball sliding and rolling wear tester. The grease collected on labelled glass slides and grease sample bottles. The result analyzed under an optical microscope. For filter debris analysis, the lube oil of earth moving vehicle were collected and consequently contaminants then wear debris were extracted and assessed visually under conventional microscope and some cases using scanning electron microscope (SEM).

Based on the study that has been conducted by researchers from the whole world, we could see that most of the useable techniques in order to determine wear debris are ferrography, atomic emission spectrometric (AES), scanning electron microscope (SEM) and confocal laser scanning microscope (CLSM) in order to indicate types of particle.

2.4.3 Integrated wear debris analysis

Paula J.Dempsey, (2002), both had improve the detection capability of vibration and oil based damage detection features by applying fuzzy logic analysis techniques to gear failure data collected by NASA Glenn Spur Gear Fatigue Rig. The study is trying to provide a simple tool to determine reliably the health of the geared system. Idea of this technique is as collecting vibration data and oil debris data and then would be integrated using fuzzy logic analysis techniques. Fuzzy logic applies fuzzy set theory to data, where it is a theory of classes with unsharp boundaries and the data belongs in a set based on its degree of membership. The theory membership could be between 0 and 1. The advantage of applying fuzzy logic is that it is flexible, making allowances for unanticipated behaviour.

Vibration and wear debris analysis are the two main condition monitoring techniques for machinery maintenance and fault diagnose. In practice, these two techniques could only serve about 30-40% of faults when used independently. Based on the study by Peng Z.Kessissoglou N., (2003), they had proves that combining these two techniques provides greater and more reliable information, which resulting effectively maintenance program with large cost benefits to industry. Three tests were conducted on worm gearbox with different situations, which are lack proper lubrication, normal operation and with the presence of contaminant particles added to the lubricating oil. As the result, both wear debris and vibration analysis techniques have been used to assess the condition of the gearbox and diagnose any problems during three tests. For test 1, both methods discovered the lack of lubrication problem between gear surfaces. For test 2, there is no problem indicate by the wear debris analysis, however vibration analysis indicate a developing bearing defect, which has not been identified by a routine wear debris analysis. For test 3, wear debris analysis found a large amount of wear particles. The vibration analysis confirms the wear process due to increase in the peak at the shaft running speed and also an increase in the offset of the frequency spectrum from the baseline. From the study, we could see that more reliable assessment could be made. Wear debris analysis provides further insight on the wear rate and mechanism of the gears. On the other hand, vibration analysis has provided quick and reliable information on the condition of the bearings.

The same integrated techniques were conducted by Peng Z. *et al.* (2005) by using wear debris analysis and vibration analysis in order to distinct the effect of contaminants in lubricant. There are five tests conducted in this study, with Test 1 corresponds to normal lubrication, which is the recommended oil to lubricate the worm gearbox. In Test 2, a special operating condition was created by lacking of lubrication. Test 3 involving the contaminants on the gearbox under normal lubrication conditions. Test 4 also involved adding contaminant to the lubricant, but this time using the recommended lubricant. Finally, Test 5 involves adding iron powder to the gearbox operating under lack of lubrication.

The analysis results of wear debris generated from the five tests

Wear debris analysis	Test 1	Test 2	Test 3	Test 4	Test 5
Particle number	Low	High	Very high	Very high	Very high
Particle size (μm)	Several microns, ~50	Several microns, ~100	Several microns, ~20	Several microns, ~50	Several microns, ~30
Particle types	Rubbing, cutting, and laminar	Rubbing, cutting, laminar, sliding, and fatigue	Rubbing and cutting	Rubbing and laminar	Laminar, rubbing, and chunky particles (small amount)
Surface characteristics visual inspection Ra	Smooth surfaces, 0.06	Rough surfaces, 0.26	Rough surfaces, 0.48	Smooth surfaces, 0.13	Smooth surfaces, 0.18
Overall observations	90–95% ferrous particles, 5–10% bronze particles	20% ferrous particles, 80% bronze particles	30–35% ferrous particles, 65–70% bronze particles	30–35% ferrous particles, 65–70% bronze particles	30–35% ferrous particles, 65–70% bronze particles

Figure 2.5: The analysis results of wear debris generated based on the five tests (Peng Z. Kessissoglou N., 2003)

In terms of vibration analysis, there are also five test had been conducted through the study. In the first test, the gearbox was relatively wear free. The velocity-frequency spectrum of the worm shaft showed two dominant frequencies to the shaft speed (24.8Hz) and twice line frequency (100Hz).

In test 2, it was specifically designed to create an inadequate lubrication condition. The result shows that the peak dramatically increased from 0.005g to 0.03g. a developing bearing defect was consistent with inadequate lubrication, resulting in an increase metal to metal contact and formation of scratches. The result could be seen as following figure.

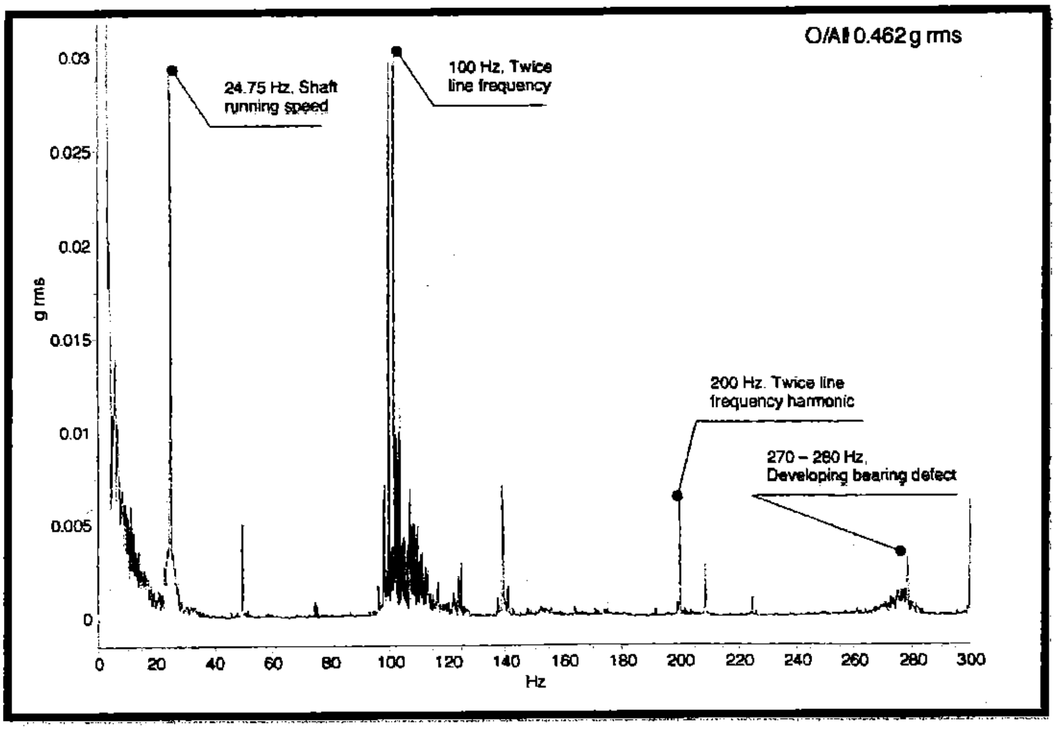

Figure 2.6: Acceleration-frequency spectrum of the crown drive end. (Peng Z. Kessissoglou N., 2003)

The study had shown that both techniques have their own advantages. Wear debris analysis include the detection of rubbing, metal to metal cot and boundary lubrication breakdown. Vibration analysis has provided quick and reliable information on the condition of the bearings. However, results have shown that these two techniques have detected similar wear mechanism associated with the gearbox.

According to Tandon N. *et al.*, (2007), they have investigated the effectiveness of vibration, stator current, acoustic emission and shock pulse measurements in detecting the presence of contaminant particles in bearing grease. Silica and ferric oxide particles were used to contaminate the grease. As the result, all of the techniques measurement performed on lubricant contaminated bearings are appreciably increased as contaminant level and contaminant size increases. The contaminant level increase with constant size has shown less increase when compared to particle size increase with constant contaminant level. The comparative techniques show that AE technique is the best technique. It is followed by shock pulse maximum value and carpet value in terms of effectiveness.

2.4.4 Other condition monitoring techniques to diagnose gearbox fault

According to Agoston A. *et al.*, (2005) they had considered various sensor principles for the on-line monitoring of thermal aging of engine oils. The investigation parameter is the viscosity of the lubricating oil, which can be efficiently measured using micro acoustic sensors. The sensors signal should provide information about the actual physical chemical oil quality in order to complete the information needed by the prediction algorithms.

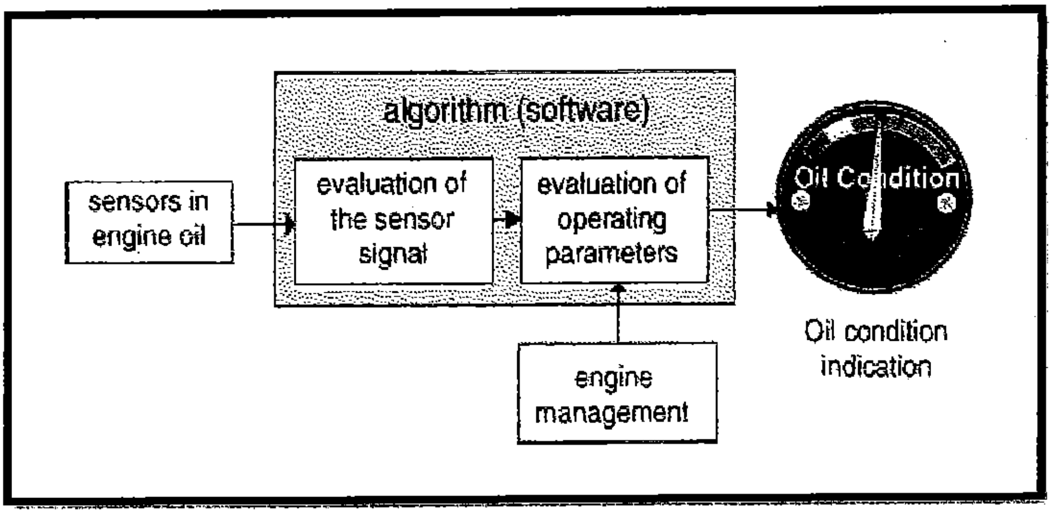

Figure 2.7: Structure of sensor assisted algorithm for a lubrication-monitoring system (Agoston A. *et al.*, 2005)

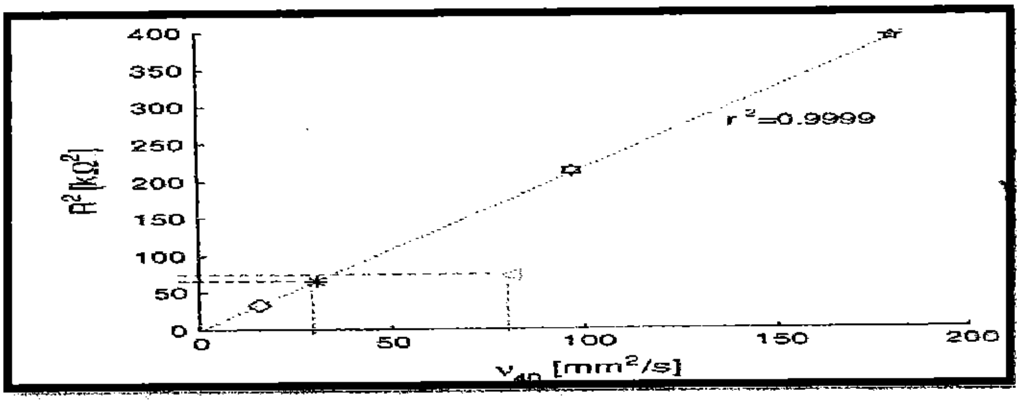

Figure 2.8: Good correlations for base oil (Agoston A. *et al.*, 2005)

The result would produce in a correlation for the oil by using following graph. Based on result of the study, it shows that the viscosity of mineral base oils could be reliably measured by a micro acoustic sensor. The sensor signal correlates with the measured value of the total acid number (TAN) for artificially aged oil. Thus, the sensor is potentially suited for the detection of the oxidation induced viscosity changes caused by thermal deterioration or the oil.

Study by Raja Hamzah R.I, Mba D., (2009), they had run experimentally findings on the influence of speed and load in generating AE for operating helical and spur gears. Acoustic emission (AE) is defined as the range phenomena that results in structure borne propagating waves being generated by the rapid release of energy from localised sources of a material.

Figure 2.9: AE sensor and thermocouple location on test pinion gear (Raja Hamzah R.I, Mba D., 2009)

Test	Load (N m)	Temperature (°C)	Kinematic viscosity (mm^2/s)	Oil film thickness (μm)	Specific film thickness	Percentage of specific film thickness decrease (%)	AE rms (V)		
							Minimum	Maximum	Mean
Spur									
Test 1	60	50.6	347.62	2.71	0.96	–	0.0062	0.038	0.0085
	120	48.9	384.71	2.66	0.94	2.1	0.0094	0.0344	0.0116
	180	48.8	387.04	2.53	0.90	6.2	0.0098	0.0376	0.0121
	250	49.6	368.88	2.35	0.83	13.5	0.0032	0.0254	0.0166
	370	50.3	353.84	2.17	0.77	19.8	0.0182	0.0376	0.0244
Test 2	60	50.3	353.84	2.74	0.97	–	0.0056	0.0206	0.0073
	120	49.5	371.09	2.59	0.92	5.2	0.009	0.0158	0.0111
	180	49.2	377.83	2.49	0.88	9.3	0.0098	0.0212	0.0120
	250	49.4	373.32	2.37	0.84	13.4	0.0008	0.0626	0.0164
	370	50.8	343.55	2.12	0.75	22.7	0.0186	0.046	0.0244
Test 3	60	50.5	349.68	2.72	0.96	–	0.0056	0.0184	0.0072
	120	49.6	368.88	2.58	0.91	5.2	0.009	0.0224	0.0108
	180	49.0	382.40	2.51	0.89	7.3	0.0098	0.017	0.0116
	250	49.9	362.34	2.31	0.82	14.6	0.0136	0.0456	0.0166
	370	50.4	351.75	2.16	0.76	20.8	0.0174	0.0346	0.0231
Helical									
Test 1	60	47.9	408.79	3.11	1.10	–	0.0974	0.1404	0.1140
	120	47.8	411.29	2.86	1.01	8.2	0.1460	0.1924	0.1690
	180	47.5	418.93	2.75	0.97	11.8	0.1916	0.2546	0.2213
	250	51.0	339.54	2.27	0.80	27.3	0.2500	0.3232	0.2803
	370	53.5	293.90	1.95	0.69	37.3	0.2772	0.3494	0.3060
Test 2	60	48.1	403.83	3.09	1.09	–	0.1018	0.1432	0.1193
	120	47.0	432.04	2.56	1.05	3.7	0.1588	0.1956	0.1764
	180	48.4	396.53	2.64	0.93	14.7	0.1972	0.2548	0.2248
	250	50.6	347.62	2.31	0.82	24.8	0.2546	0.3274	0.2836
	370	54.7	274.68	1.86	0.66	39.4	0.2814	0.3460	0.3111
Test 3	60	44.5	505.56	3.61	1.28	–	0.1006	0.1382	0.1155
	120	46.2	454.06	3.06	1.08	15.6	0.1536	0.1898	0.1707
	180	47.4	421.51	2.75	0.97	24.2	0.1918	0.2532	0.2207
	250	50.6	347.62	2.31	0.82	35.9	0.2486	0.3316	0.2842
	370	54.6	276.22	1.87	0.66	48.4	0.2882	0.3558	0.3201

Figure 2.10: Experimental results on the load variations test for both helical and spur gear sets (Raja Hamzah R.I, Mba D., 2009)

Based on the results of the study, AE is more sensitive to changes in specific film thickness under combination of rolling and sliding on spur gear as compared to pure rolling on helical gear. Instead of that, a numerical relationship between load, speed and AE for both spur and helical gears was established. Finally, the variation in AE levels during helical gear mesh is speculated to be attributed not only the influence of asperity levels but also to the variation in the contact length during meshing.

2.4.5 New development in debris analysis

According to Tandon N., *et al.* (2007), in their study had conducted condition monitoring of electrical motor ball bearing for the detection of grease contaminants. The effectiveness of vibration, stator current, acoustic emission and shock pulse measurements in detecting the presence of contaminants particles in bearing grease has been investigated. In the study, acoustic emission (AE) peak amplitude proved to be the best condition monitoring technique for the detection of grease contaminants in motor bearings.

Based on the study by Raadnui, S. (2005), there have three basics way in performing ways with low costs but usable in several applications, which are Filter debris analysis (FDA), used oil or grease analysis and magnetic chip detector (MCD) ferrous wear particle analysis.

The study has used grease that was carefully collected on labelled glass slides and grease sample bottle. Wear debris from each test was inspected qualitatively and photomicgraphs of representing wear debris. The result could be seen in following figure.

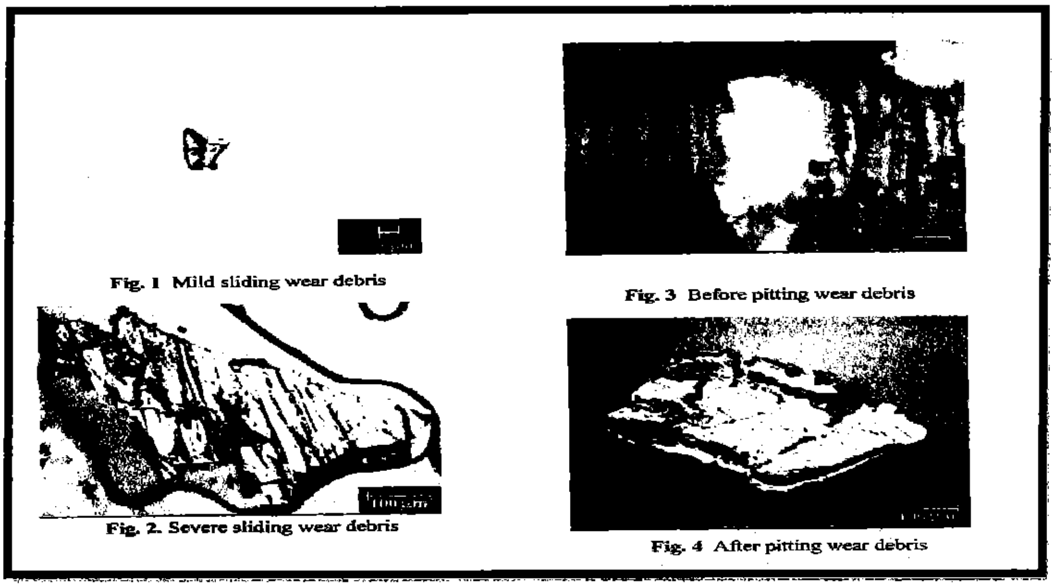

Figure 2.11: Inspected wear debris (Raadnui, S. 2005)

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