CONDITION MONITORING OF VARIABLE SPEED WORM GEARBOX LUBRICATED WITH CONTAMINATED GEAR OIL

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ABSTRACT

Vibration and temperature monitoring are the techniques for machinery maintenance and fault diagnosis that could predict the gears and bearings failure. This research focuses on the condition monitoring of worm gearbox lubricated with contaminated gear oil. Worm gearbox consists of a spirally grooved screw moving against a toothed wheel. The main objectives are to characterize vibration behavior of worm gear as function contaminated lubricant viscosity. Experimental test rig with inverter, electric motor and gearbox was developed and employed for this research. New gear oil with ISO VG 100, 460 and 680 had been indentified to serve the sliding friction of both gears as a comparison to contaminated oil. A predetermine speed of electric motor at 900, 1150 and 1400 RPM was introduced to the gearbox and a set of vibration instrumentations with ICP accelerometer model PCB 393B04 was installed as to capture the vibration signal generated. As to enhance the effectiveness of condition monitoring techniques, temperature rising in the gear oil upon the testing period was monitored using PicoLog USB TC-08 Data Logger and later to be analyzed. The experiment had revealed that oil with higher viscosity will contribute to less vibration spectrum. At 900 RPM for ISO VG100, ISO VG460 and ISO VG 680 the vibration reduction percentage within new and contaminated gear oil were 51.02%, 24.66% and 51.30% respectively. The temperature monitoring for ISO VG100, 460 and 680 for new and contaminated oil were observed within 34.97°C, 35.67°C and 39.27°C respectively. The higher viscosity the higher temperature observed.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Industrial operations are much depending on the rotating equipment to ensure continuous plant operation or production performance. The internal mechanical parts which have widely contributed to a major breakdown in rotating equipment are known as gears and bearings. On the other hand, lubricants are another factor to be considered as to ensure the performance of gears and bearings are within optimum operating conditions. Any unscheduled breakdown can easily burst the maintenance cost, lapses in production schedule and even interfere the human casualties. As to minimize the unscheduled breakdown, a proper maintenance practice and monitoring systems are required to detect faults in the early stages and provide alert notification to the operators. The capabilities of Condition Monitoring Systems provided it has been conducted correctly could extend the life span of the rotating equipment. These could also reduce the maintenance cost and avoid catastrophic failure to the gears and bearings.

Vibration and temperature monitoring are the techniques for machinery maintenance and fault diagnosis that could predict the gears and bearings failure. Both techniques have their unique advantages and disadvantages associated with the monitoring and fault diagnosis of machinery. When these techniques are conducted independently, only a portion of machine faults are typically diagnosed. However, practical experience has shown that by integrating these two techniques in a machine condition monitoring program will provides better and more reliable information, bringing significant cost benefits to industry.

1.2 Problem Statement

Gearboxes are classified as the rotating equipments at any industrial applications worldwide and play an important role to the industrial performance. The major internal components of the gearboxes are mainly named as shaft, gear, bearing and seal. The challenge is now to seek further significant improvement in the technology and prolong the life span of the internal component. The issue of wear and tear of the gears and bearing are much related to the lubricant performance. Failures associated with gears typically caused by gradual deterioration and wear. Such deterioration probably could happened when rotating equipment are working within a condition of excessive load, excessive vibration, high temperature, lack of lubrication or contaminated lubricant. Such degradation process can be identify if a proper condition monitoring techniques is used to detect and give sign of early warning.

Vibration and temperature monitoring are the most regularly measured condition parameter in rotating machinery, and it is continuously monitored in many important applications. The commonly monitored vibration parameters are displacement, velocity, and acceleration. Books and references of vibration analysis to gear fault diagnosis are widely available, however in contrast there is limited references and information pertaining to the monitoring of worm gearboxes performance. From the previous study, most of the gear failure are result of bending and surface fatigue (Elforjani *et al.*, 2012).

Worm gearbox normally consist of one step speed reduction mechanism but capable for higher reduction ratio. Worm gearbox could be both slow speed and high speed rotating parts internally. Since the vibration analysis could predict the gear failure effectively, the application need to be extend to the output shaft of worm gearboxes which typically has great speed reduction compared to the input shaft. The limitation of vibration analysis to low speed rotating machine has been described in Condition Monitoring of Worm Gears (Elforjani *et al.*, 2012). Further study still need to be conducted to analyse the correlation between vibration, worm gear speed, lubricant characteristic and temperature.

1.3 Objective

The objective of this experiment is to characterize worm gears vibration behavior tested with contaminated lubricant provided new oil as a baseline value. The analysis to be extended up to the lubricant temperature and seek correlations within mechanical vibration.

1.4 Scope of study

Scope of this study is to investigate the correlation between vibration and temperature behavior within different gear oil viscosity characterisation. In order to obtain this, this research will cover the following:

(i) Proposed the proper experimental rig to be set up related to vibrations issues.

(ii) Study the viscosity classification of gear oil and preparing samples of contaminated gear oil.

(iii) To investigate different operating conditions of an experimental rig, consisting of a worm gearbox driven by an inverted electric motor.

(iv) To perform experimental test to obtain both data.

(v) To assess the sampling oil analysis charact

(vi) erisation for the contaminated oil.

(vii) To analyze the data and find the correlations of mechanical vibration and temperature.

1.5 Expected Result

From the experimental rig, the worm gearbox will initially run under normal operating conditions as a comparative test. A series of tests were then conducted corresponding to a different input speed using the same contaminated lube oil. Vibration data will be regularly collected but the temperature will be continuously captured using the PicoLog Data Logger. The data produced by the PicoLog will be compared with the vibration spectra, in order to quantify the effectiveness of the two condition monitoring techniques. The results from this experiment will reveal more understanding on the dependent and independent roles of vibration and temperature in predicting and diagnosing machine faults.

The anticipated key issues will be pointed out in order to produce good condition monitoring practise for worm gearbox. A prediction of gear oil failure and lifespan are much depending on few characterizations. These are:

(i) The correlations of mechanical vibration and temperature will be much depending on operation speed.

(ii) The contaminated gear oil will show an abnormal vibration trending compared to the normal gear oil.

1.6 Potential Contribution

So far, vibration-based condition monitoring of a worm gearboxes has been mostly studied on the wear pattern. An attention to run the gearboxes with contaminated gear oil need to be done to monitor the worm gear vibration behavior. Therefore, the first step in successfully implementing of condition monitoring of worm gear is to establish the base-line behavior of a healthy gear with a suggested gear oil by most industrial practise.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Introduction

Diagnosis and fault detection of gear transmission systems have attracted wide attention in order to reduce breakdown in the industrial rotating machinery. Some researches had been done as to develop the understanding and correlations of contaminated gear oil which generally will contributed to gears failure. Introducing a proper condition monitoring techniques will surely extend the life span of the rotating equipment.

Most of the industrial practice are much rely on the vibration spectral data analysis as a primary tools for assessing machine condition beside to some others predictive tools which available in the market (Yu, 2011). In order to produce proper report of individual machine, a scientific approach need to be considered. All the data gathered by the analyst will be examined along with their deviation comparing to the appropriate baseline values (Watts, 2011). At the end, both parties which are end users and analyst need to understand that the collected data are all facts but the resulting diagnosis and or repair recommendation may be speculation. Some of the predictive tools may need qualified personnel to interpret the data correctly.

2.2 Condition Monitoring Techniques

The condition monitoring techniques philosophy consists of scheduling maintenance activities only when a functional failure is detected. Mechanical and operational conditions are periodically monitored, and when unhealthy trends are detected, the troublesome parts in the machine are identified and scheduled for maintenance. The machine would then be shut down at a time when it is most convenient, and the damaged components would be replaced. If left unattended, these failures could result in costly secondary failures. One of the advantages of this approach is that the maintenance events can be scheduled in an orderly fashion. It allows for some lead-time to purchase parts for the necessary repair work and thus reducing the need for a large inventory of spares. Since maintenance work is only performed when needed, there is also a possible increase in production capacity. A possible disadvantage is that maintenance work may actually increase due to an incorrect assessment of the deterioration of machines. According to (Serrato *et al.*, 2007), 50-80% of bearing components faults are related to deficient lubrication, resulting from inadequate lubricant use, lack or excess of lubricant. To track the unhealthy trends in vibration, temperature or lubrication requires the facility to acquire specialized equipment to monitor these parameters and provide training to personnel (or hire skilled personnel).

Various condition monitoring methods can be used for the diagnosis gearbox and gear failures. The methods are namely classified as vibration analysis, oil sampling analysis, thermograph monitoring, acoustic monitoring and electric motor current monitoring. Figure 1 below shows the summary of types and causes of gear failures. (MTII Troubleshooting Gear Drives, 2008)

SUMMARY OF TYPES & CAUSES OF GEAR FAILURES

Types of Failure, %

Breakage, total		61.2
Fatigue breakage, teeth	32.8	
Fatigue breakage, bore	4.0	
Overload breakage, teeth	19.5	
Overload breakage, bore	0.6	
Chipping, teeth	4.3	
Surface fatigue, total		20.3
Pitting	7.2	
Spalling	6.8	
Pitting and spalling	6.3	
Wear, total		13.2
Abrasive wear	10.3	
Adhesive wear	2.9	
Plastic flow, total		5.3

Causes of Failure, %

Service-related causes, total		74.7	**75% can be influenced by customer**
Improper assembly	11.2		
Improper lubrication	16.0		
Continual overloading	25.0		
Impact loading	8.9		
Bearing failure	10.7		
Foreign material	1.4		
Operator error	0.3		
Abusive handling	1.2		
Heat treatment, total		16.2	
Excessive core hardness	0.5		
Insufficient core hardness	2.0		
Excessive case depth	1.8		
Insufficient case depth	4.8		
Improper hardening	5.9		
Improper tempering	1.0		
Distortion	0.2		
Design-related causes, total		6.9	**25% cannot be influenced by customer**
Improper design	2.8		
Improper material selection	1.6		
Specification of unsuitable heat treatment	2.5		
Manufacturing-related causes, total		1.4	
Grinding burns	0.7		
Tool marks or notches	0.7		
Material-related causes, total		0.8	
Forging defects	0.1		
Steel defects	0.5		
Mixed steel, wrong composition	0.2		

Figure 1: Summary of types and causes of gear failures, (MTII Troubleshooting Gear Drives, 2008).

2.2.1 Vibration Analysis

Vibration analysis is the most widely used to predict rotating machinery failure in the industrial application. Vibration analysis is often done based on the bearing vibration signal measured by an accelerometer, usually piezoelectric sensor which convert the vibration signal to electrical signal. Since the abnormal vibration of rotary machines is the first sensory effect of rotary component failure, vibration analysis is widely employed in the industry. The fault vibration signal generated by the interaction between a damaged area and a rolling surface occurs regardless of the defect type. Consequently, a vibration analysis can be employed for the diagnosis of all types of faults, either localized or distributed. Furthermore, low-cost sensors, accurate results, simple setups, specific information on the damage location, and comparable rates of damage are other benefits of the vibration measurement method.

2.2.2 Oil Sampling Analysis

The interpretation of oil sampling analysis method is based on the presence of metallic or wear particles in the sampling lubricant collected (Wang, 2008). One of the most common and simplest methods to apply the oil debris monitoring techniques is the magnetic sump plug. The magnetic plug will captured the metallic debris from the lubricant oil path flow. The amount of metallic debris captured will represent the wear trend of the machine provided it has the baseline information. The limitations of wear debris magnetic sump plug method are only on the metallic debris and not extend to the other wear component such as seals and glands. To overcome the situation the oil sampling analysis can be conducted, where the spectrographic analysis of the different metallic elements and other wear components in the lubricant could be extracted and would able to facilitate the location of the fault. The another enhanced method of wear debris monitoring, uses magnets of increasing strength to separate wear particles from the lubricating oil and grades particles by size and magnetic susceptibility on glass slide. However the interpretation of the results is subjective and the ferrographic method cannot be applied for on-line application, (Whittington et al., 1992) and (Roylance, 2005).

2.2.3 Thermograph Monitoring

Another method of condition monitoring is thermograph. Any defects occurred at bearing or gears in the rotating equipment will generate excessive heat that would be easily detected by the thermograph devices. Monitoring the temperature of a bearing housing or lubricant is the simplest method for fault detection in rotary machines.

Taking an example of mineral base gear oil which will begin to oxidize at temperatures that consistently run at 71°C, (MTII Troubleshooting Gear Drives 2008) . A few parameters that will contribute to increase the gear oil temperature are excessive sludge, low lubricant levels, oil contamination, bearing failure or damaged gear teeth. Monitoring temperature differences at multiple gearbox, thermograph devices will display various heat image contour. The most problematic gearbox will have the indication of high temperature which mainly due to lubricant, bearing and gears.

2.2.4 Acoustic Monitoring

The most effective acoustic-based bearing health monitoring is acoustic emission. It is a transient impulse generated by the rapid release of strain energy in solid material under mechanical or thermal stress (Vladimir, 1999). The detection of cracks is the prime application of acoustic emission; therefore, this technique can be used as a tool for condition monitoring of bearing faults and shaft cracks. The measurement of a machine's sound can also be employed for detecting defects in bearings. Typically, the accuracy of these methods depends on sound pressure and sound intensity data.

2.2.5 Electric Motor Current Monitoring

The operating conditions of a machine can be monitored by analyzing the spectrum of the motor current. The changes in the electric background noise are associated with the changes in the mechanical components of the machine; therefore, fault signatures can be detected by motor current signal processing techniques.

2.3 Industrial Gearboxes

There are variety of gears composition and arrangement as to meet the industrial needs. Engineer has to put their kind attention to select the best gears arrangement either to serve load, speed or direction. Figure 2 shows type of gears and some of the gears composition are discussed below:

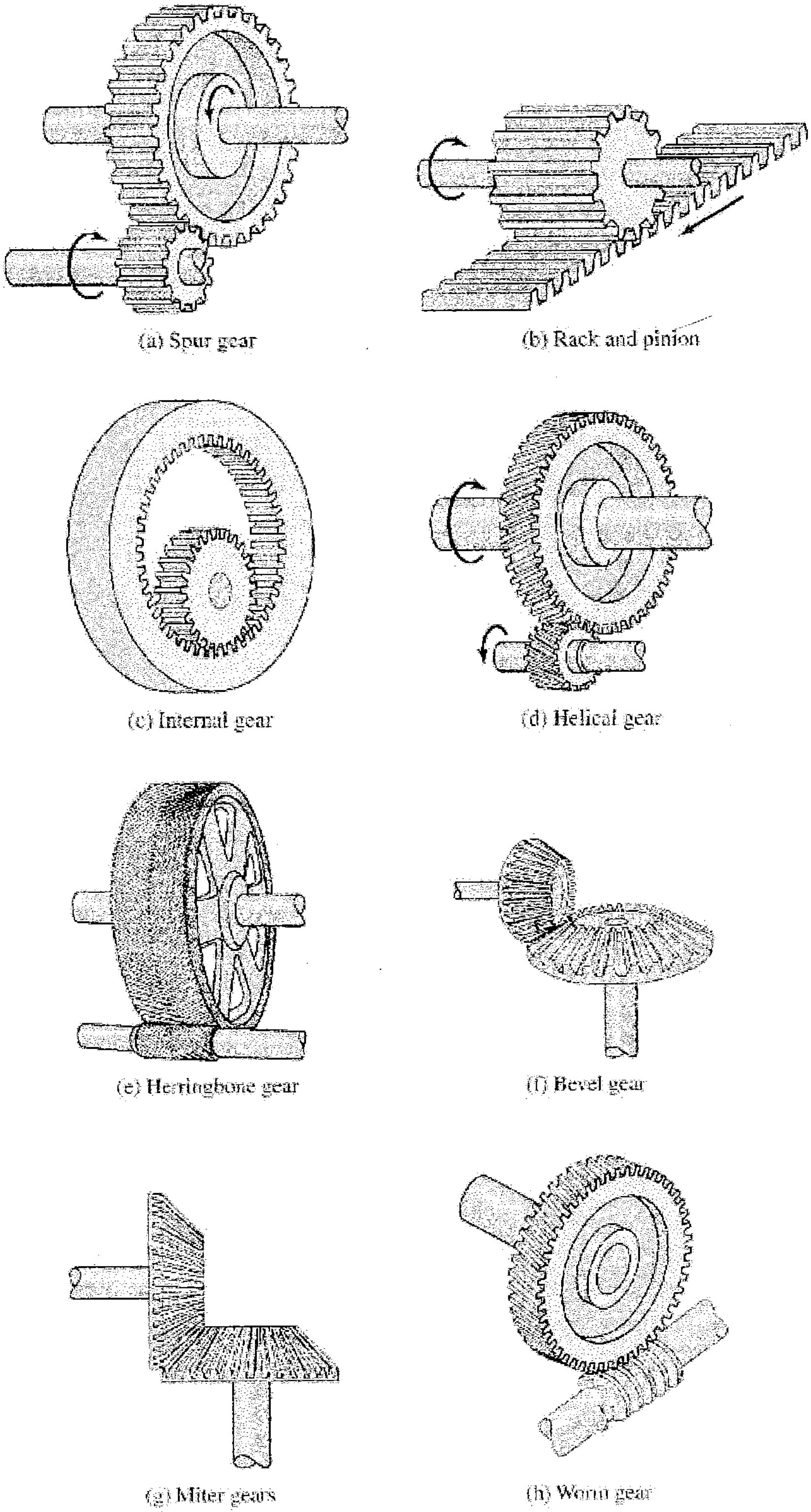

Figure 2: Type of gear, (Myszka, 2012).

2.3.1 Worm gear

A worm gear as shown in figure 3, consists of a spirally grooved screw moving against a toothed wheel. In this gear type, where the load is transmitted across sliding, rather than rolling surfaces, compounded or EP oils are necessary to provide effective lubrication.

Worm gears operate under difficult conditions, presenting unique lubrication demands. Worm gears are used in various industries and machinery applications. They are unique in their ability to achieve large speed reductions in a compact space. They can transmit high loads at high-speed ratios. Ratios of 20:1 up to 60:1 and higher are normally achieved.

There are three major types of worm gears:

(i) **Non-throated** - a helical gear with a straight worm. Tooth contact is a single moving point on the worm drive. This leads to high unit loads and wear

(ii) **Single-throated** - has concave helical teeth which wrap around the worm. This leads to line contact, permitting higher loads without excessive wear.

(iii) **Double-throated** - called a cone or hourglass. It has concave teeth both on the worm and helical gear. This increases from line contact area permitting increased loading and lower wear.

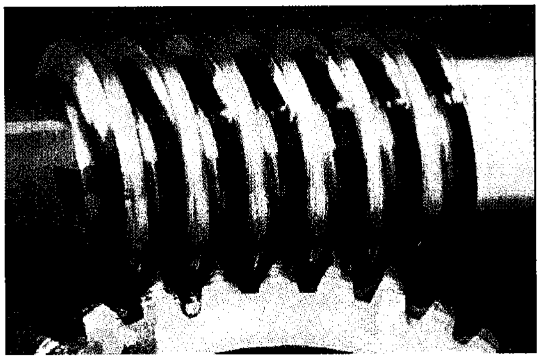

Figure 3: A screw driving a phosphor-bronze worm wheel gear.

Worm gears are commonly use in transmission design where its needs a compact, high reduction and relatively low speed output (Sharif, 2006). Prediction of the wear pattern in worm gears. The normal combination of hard/soft material is necessary as to avoid scuffing since a high degree of sliding between tooth wheel and worm gears are present. The usual configuration is hard steel for worm and a softer material like bronze for wheel, but then the wear rate of bronze gear teeth is much higher than that which might be expected in conventional gearing systems. Anyway, the worn off bronze gear can be replaced with a new one using the process of *"bedding in"*.

2.3.2 Planetary Gear Transmission System

Planetary gearboxes are typically used in applications requiring a large reduction in speed at high loads, such as the final reduction in the main rotor gearbox of a industrial huge stirrer tank. A typical planetary reduction gearbox has three or more planet gears each meshing with a sun and a ring gear. The planetary gears are mounted onto the planetary carrier and contained within an internal toothed ring gear. Drive is provided via the sun gear, the ring gear is stationary and the axes of the planet gears are connected to a carrier which rotates in relation to both the sun gear and ring gear. The planet carrier provides the output of the planetary gear train. A single stage planetary gearset normally will consists of a sun gear, a ring gear, several planets and a carrier.

2.3.3 Parallel Gear Transmission System

The parallel gear system consists of a pinion gear and a driven gear. The pinion gear has a smaller number of teeth than the driven gear. Normally, a gear transmission system is designed to reduce the angular velocity in order to increase the output torque. In such a speed reduction gear transmission system, the pinion is connected with an input shaft, and the driven gear is connected with an output shaft.

2.4 Lubricant

As a general rules, oil temperature of enclosed gear drives should never exceed 89 °C – 93 °C and the best service will be obtained with at temperatures in a range of 50°C – 60°C (MTII Troubleshooting Gear Drives, 2008).

2.4.1 Lubricant Viscosity Classification

Through the years, lubricant users have been treated to a number of ways to designate viscosity grades of the lubricants used in manufacturing. They are:

(i) SAE (Society of Automotive Engineers) grades for gear oils and crankcases (engines)
(ii) AGMA (American Gear Manufacturers Association) grades for gear oils
(iii) SUS (Saybolt Universal Seconds)
(iv) cSt (kinematic viscosity in centistokes), and
(v) absolute viscosity
(vi) ISO VG (International Standards Organization Viscosity Grade)

Viscosity is the measure of the oil's resistance to flow (shear stress) under certain conditions. To simplify, the oil's viscosity represents the measure for which the oil wants to stay put when pushed (sheared) by moving mechanical components. Some of the oil viscosity comparison is shown as in Figure 4.

There are two viewpoints of the resistance to flow that the machine designer is interested in. One is the measure of how the fluid behaves under pressure, such as a pressurized hydraulic line. This property is called absolute viscosity (also known as dynamic viscosity) and is measured in centipoises (cP). The other consideration is how the fluid behaves only under the force of gravity which is called as centistokes. The two are related through the specific gravity of the fluid. To determine the centipoise of a fluid it is necessary to multiply the viscosity of the fluid times the specific gravity of the fluid, or measure it directly using an absolute viscometer. For the practitioner of industrial lubrication, the centistoke is the measure that will occupy most of our attention.

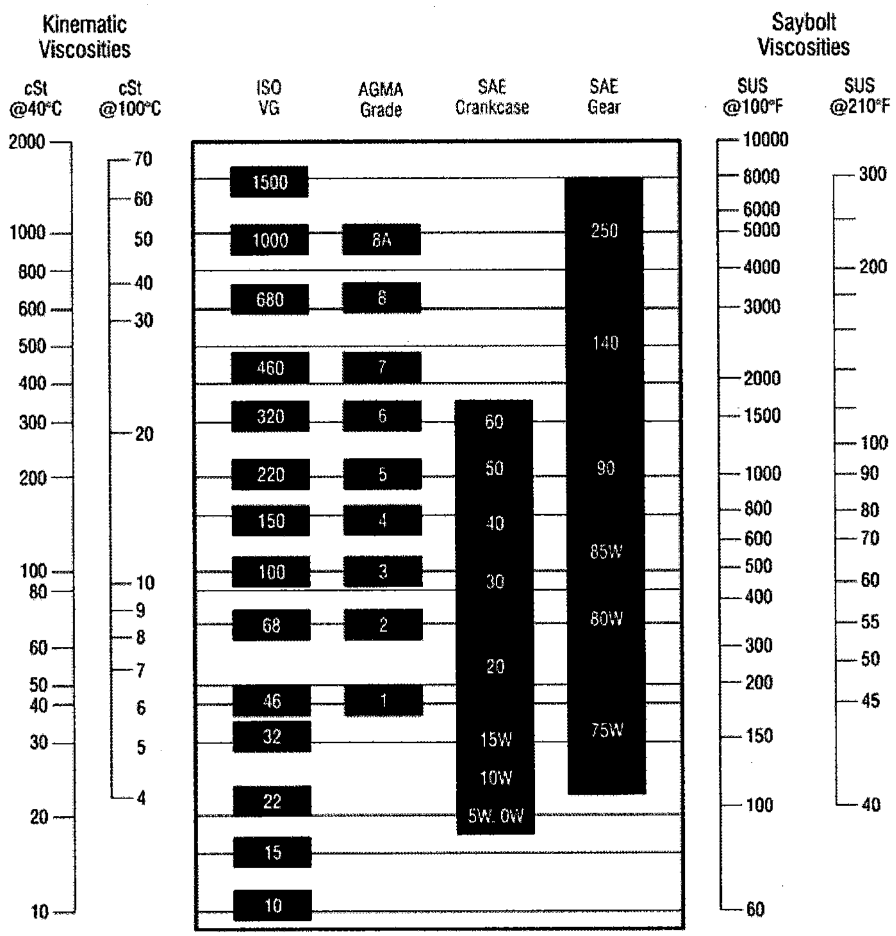

Figure 4: Comparative Viscosity Classification

(http://www.machinerylubrication.com/Read/28681/gear-oil-life).

2.4.2 The Impact of lubricant on mechanical vibration

The thicker the oil thickness causes the level of vibration decrease. Author (Serrato, (2007), focus on three different viscosity grade (ISO 10, 32 and 68). Different ISO grade viscosity or temperature variation changes the vibration of the roller bearing. Previous study shows that oil temperature is proportional to the viscosity degree. High friction force (high viscosity) is related high loss of energy resulting in high heat generation. The low viscosity lubricants cause high vibration level.

Faults on roller bearing found because of 50-80% related to deficient lubrication, inadequate lubricant use, lack of lubricant, lubricant aging and presence of solid or liquid contaminant. The vibration energy of a bearing depends on surface irregularities, external loading, running speeds and lubricant viscosity. Lubricant viscosity causes reduction in vibration energy.

The vibration level is smaller as oil viscosity degree becomes higher, in contrast to the effect of temperature on oil viscosity. The testing time is major factor for gradual decrease in film thickness. Oil film thickness becomes smaller when the viscosity grade is changed to smaller values. Higher bearing vibration causes of smaller film thickness which related to lower oil viscosity.

According to author (Sharma *et al.*, 2008), the oil temperatures are maintained within the recommended range. When the particles come in contact with high-temperature zones these lead to formation of hard and abrasive particles. These on contact with the components cause generation of wear particles causing further reduced system performance. Therefore, to control wear and for increased performance, viscosity and contaminants are the contributing performance parameters.

2.4.3 Contamination Effect

Oil and wear debris analysis have proven in many instances to be a leading indicator compared to vibration analysis to identify wear mechanisms and wear modes present in a machine (Roylance, 1999). There are numerous types of wear mechanisms such as adhesion, abrasion, fatigue, corrosion, erosion, and fretting. Common examples of failure modes include contamination, lubricant degradation, oxidation, load, and speed. Wear debris analysis is the study of the chemical composition, colour, concentration, size distribution and morphologies of wear particles. A particular wear mechanism typically generates one or several types of wear debris, which can be identified by their characteristics (Kannan, 2003). There are six common particle types that are typically found within machinery, corresponding to rubbing, cutting, laminar, fatigue, severe sliding and spherical particles. For each particle type, there may be variations in size, concentration, surface texture and colour depending on the severity, the rate of wear and material source. Both vibration analysis and wear debris analysis have their unique advantages and disadvantages associated with the monitoring and fault diagnosis of machinery (Peng, 2010). For instance, vibration analysis is very adept at detecting resonance. However, it is difficult to apply vibration analysis to monitor low speed machinery (less than 5 rpm).

2.4.4 Identifying lubricant Contamination

If contamination is suspected, a sample of oil can be obtained in a translucent glass ware, which is then allowed to sit overnight. When the glass ware is turned over, any contaminant will remain visible on the bottom surface of the glass. Water contamination in the lubricant can also be determined very quickly by placing a few drops of oil on a hot plate. If the oil drops crackle or sizzle, there is water present. In many cases, any water, if excessive, will separate from the oil sample in a glass ware stored overnight. If contamination by dirt, water or wear metals appears to be excessive, laboratory oil analysis should be carried out to identify the wear element.

2.4.5 Lubricant Life Time

According to author (Goncalves *et al.*, 2006), they are research about most important in the maintenance of reducers are vibration analysis and wear particles. Lubricants subdivided into mineral oil, additiveted oil and synthetic oil. Small changes in viscosity will be affect temperature and the lubricant no longer able to provide full performance.

According to author (Goncalves *et al.*, 2006), there are several test to identify viscosity changes such as acid number (AN) and Fourier transform infrared spectroscopy (FTIR) to conform incipient oxidation. Sign of water, soot or glycol ingress identify from contaminant test. Ultracentrifuge test or gas chromatography (CG), to identify a change in base oil chemistry. There are three types of data reading from graph.

(i) The pick to pick value. It is measured the maximum amplitude of the fundamental wave that is useful.
(ii) Crest value (or pick value). It is measured short duration.
(iii) Effective value. The evaluation of the value of harmonic components directly related to the vibration energy content

According to (Goncalves *et al.*, 2006), fresh oil (ISO 320) was work for more 504 hour. When the previous oil replaced by ISO 150 was put to work 672 more hour and vibration measures and oil samples were collected weekly. The result shows inappropriate viscosity will cause problem in parts where vibration need more preparation.

Based on (Brouwer *et al.*, 2012), the density of lubricants continuously changes due to changes particle contain and temperature. Dynamics viscosity is true indicator of oil quality. The film thickness of lubricants in an engine is governed by the oil viscosity. Over the lifespan of the engine oil, the viscosity of the lubricant changes due to excessive heat, soot, engine debris, and fluids such as antifreeze and fuel.

The analysis by (Amarnath *et al.*, 2007) has concluded that film thickness between lubricated contacts is very complex. It involves two rough surfaces in relative motion separated by a lubricant film. This film, when subjected to high contact pressure and sliding, due to difference in surface velocities and increase in temperature, undergoes a change in its physical properties. Under typical operating conditions, the lubricant film separating the contacts is very thin, usually of the same order of magnitude as the surface roughness, which may cause breakdown of the lubricant film. This drastic fall in lubricant film thickness is responsible for gear failure modes, micro- pitting, macro-pitting, gear staining, scuffing and mild wear.

2.4.6 Oxidation in Lubricant

It is often difficult to determine if a gear lubricant is becoming discolored because gear lubricants are normally very dark in color after some time in service. However if discoloration is obvious, particularly if the gear drive has been running at high temperatures, oxidation may be occurring and laboratory testing is recommended.

2.4.7 Oil Analysis

Although there are many and varied analysis tests available, the tests necessary to determine gear lubricant condition must include viscosity and acid number. Generally, an increase of 10% or more in viscosity is an indication that the lubricant has reached the end of its useful life. The general rule for acid number result is if the acid number has doubled that of new oil, the lubricant has reached the end of its useful life. Increases in viscosity and acid levels are definite indicators of oxidation, which suggest that sludge and varnish will develop and flow will be reduced.

2.4.8 Wear particle analysis for machine condition

The most common technique for wear particle analysis is spectroscopic analysis which is used to indicate the levels of ultra-fine particles in the 5–7 micrometer range. (Figure 5.) Usually reported in parts-per-million (ppm), these particles include, among others, iron, copper, aluminum or chromium, which indicate the metallurgical makeup of gear or bearing components in a gear drive. This analysis also indicates the various levels of metallic additives, such as phosphorus and zinc, which indicate typical extreme pressure and anti-wear additives which may be present in the lubricant. Another element reported may be silicon, which is an indicator of ingested dirt. It is important for operators of gear drives to understand that these levels of wear metals are the result of wear, not necessarily the cause of wear. These ultra-fine particles will reach certain levels in every lubricated machine and unless there is a dramatic increase in one or more of the elements, or a sudden change in overall wear rates, no action is deemed necessary. In other words, the spectroscopic analysis results reported in ppm are not as important as are changes or increases in the reported numbers.

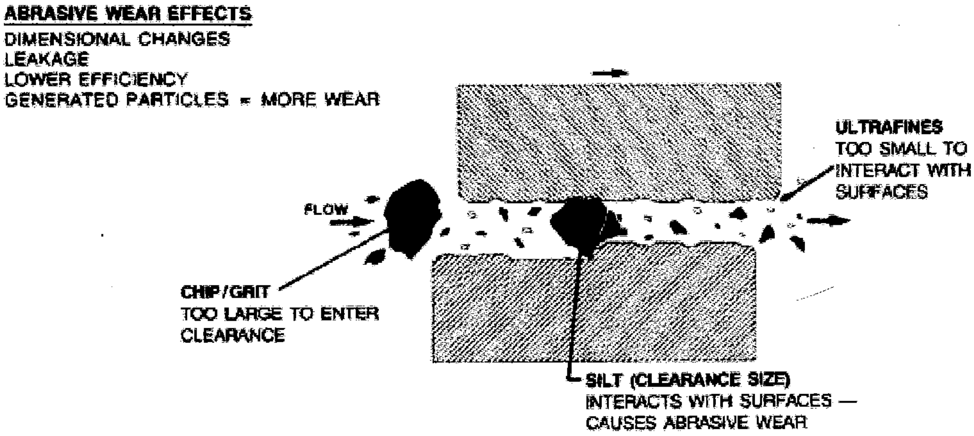

Figure 5: Abrasive wear effects.

2.4.9 Lubrication viscosity

While selecting lubricant for an application there are two aspects to be considered which are, the factors concerning engineering requirements and the factors concerning to the service condition. Engineering requirement is more to the proper selection of viscosity grade while the service conditions factors are more to the selection of proper additive package for the lubricant. The factors concerning to the engineering factors may include load, speed, surface finish of the interacting surface and rise in temperature. According to (Su et. al, 1992) concludes that vibration energy of a bearing depends on surface irregularities, external loadings, running speed and lubricant viscosity. The viscosity of the lubricant at the working temperature, load and the relative velocity of the interacting surface have predominant effect in formation of thick film as to prevent direct contact between the surface. Hence, a minimum viscosity oil grade is required in order to select a proper lubricant to match with working temperature and relative velocity between the interacting surface.

The problem exposed by the service condition of the application is addressed by selecting a suitable additive system and the appropriate base oil for the lubricant.

Different additive combinations are used for providing protection against rusting, oxidation, scuffing and corrosion. The can also facilitate quick separation of water, formation of uniform and stable emulsion as well as facilitate collapse of foams whenever required.

2.5 Theory

2.5.1 Introduction

Vibration analysis in particular has for some time been used as a predictive maintenance procedure and as a support for machinery maintenance decisions as referred to several readings. As a general rule, machines do not break down or fail without some form of warning, which is indicated by an increased vibration level. By measuring and analysing the vibration of a machine, it is possible to determine both the nature and severity of the defect, and hence predict the machine's failure. The over- all vibration signal from a machine is contributed from many components and structures to which it may be coupled. However, mechanical defects produce characteristic vibrations at different frequencies, which can be related to specific machine fault conditions. By analysing the time and frequency spectrums, and using signal processing techniques, both the defect and natural frequencies of the various structural components can be identified.

2.5.2 Detection Defects with Vibration analysis

Gears generate a meshing frequency equal to the number of teeth on the gear, multiplied by the RPM of the shaft on which the gear is mounted. Unlike bearings, for which a bearing frequency will not appear unless a bearing problem exists, gear mesh frequencies will "always" be present even if the gear train is in good condition.

Gear drives with parallel shafts upon which are mounted one gear only will always have only one frequency. Double or multiple gear reduction units which have more than one gear per shaft may have several different gear mesh frequencies and it is for this reason that maintenance personnel should be familiar with the design and construction of the gear drives in service, particularly shaft speeds and the number of teeth on each gear. In order to monitor the rotating equipment, a few information should be gathered which are:

1. A sketch of the gear drive noting the number of shafts, corresponding shaft speeds and the number of teeth on each gear.
2. The bearing types and part numbers for all shaft support bearings.
3. The marked location of all measurement points (axial, radial and vertical) from which vibration data can be obtained at bearing caps and shafts.

Gear drives are designed to maintain a constant velocity ratio between the gears. A good gear combination requires that the normal to the common tangent at the contact point between two gears passes through the pitch point which lies on the center to center line of the two gears. Any variation may cause high vibrations due to poor machining, contact wear, improper gear backlash, or any problem that would cause gear tooth profiles to deviate from their proper geometry.

Gear mesh frequency is often affected by process variables such as changes in loads and/or speeds and this frequency is modulated by sidebands indicating a problem. When sidebands reach ½ the amplitude of the gear mesh frequency, it indicates that the problem may be severe.

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