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A Review on Selection of Gear Drive Lubricating Oil

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Abstract

Under fluctuating environmental and operational condition gears failed. The failure modes of the gears are divided in two categories lubricated (pitting, flank wear etc.) and strength based. The failure modes associated to the lubrication can be avoided and minimized by proper selection of the lubricant. In the present work a review of different type of oil used for the gearbox, and additives is presented. Further the selection process based on the AGMA standard AGMA 9005 is discussed.

Keywords: *Base oil, Additives, AGMA 9005*

Introduction

Today's complex systems have greater degrees of reliance among its constituent parts than was previously the case (bearings, gears, cam, shaft etc.). The whole system shuts down if just one component fails. As a result of high load and environmental conditions, a gearbox is susceptible to failure. Failures of gearboxes may be classified as either lubricated (such as pitting or moderate wear) or non-lubricated (such as fracture or bending)[1]. Bearing, lubrication [2–52] and gear failure [53–62] have been documented in the literature. Continuous and changing working circumstances are encountered by the gearbox. It is composed of a number of moving parts including gears, shafts, bearings, and a chassis. The gears continue to deteriorate under the different conditions of use. Failure to discover gear defects early on may result in significant monetary and human life losses [63]. Sliding takes happen in both directions in the gears, with the pitch line acting as a point of contact for both rolling and sliding [1,64,65]. If the sliding contacts are properly lubricated, there is no difficulty. A lack of lubrication causes surface differences to come into direct contact, which results in a rise in temperature, an increase in adhesive bonding under high pressure, and a breakdown of the gear surfaces.

Accordingly, numerous theoretical investigations have been conducted to investigate the mechanism of lubrication and its influence on gear engineering[66–68].

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Research on lubricating properties and gear performance are frequently addressed in numerical studies linked to EHL/Thermal EHL (TEHL), mixed-EHl, and Plasto-EHL, which may be split into statistical and deterministic models [69,70]. In addition to numerical simulations, experiments are necessary to explain the phenomenon. The many researchers conducted the experiment to compare the lubrication properties of different gear oil[8,13,22,43]. In most of the studies the experiments are conducted using standard mineral oils which shows that they are less resistant to the different gear failure modes like scuffing, pitting etc. The use of synthetic oil shows the better performance in terms of the pitting and scuffing resistance of the gears[71]. Further the performance of the lubricant enhanced by the boundary lubricant additives like multi-walled carbon nanotubes (MWCNTs) etc. under extreme pressure conditions. The studies conducted in the past shows the 0.05 wt% to 0.50 wt% concentration of MWCNTs shows reduction in wear rate and friction force under heavily loaded low speed and high-speed applications[7,38].

In the present work a summary of the lubrication, its additives and selection of the lubricant for a gear drive is discussed.

2. Lubrication and lubricant additives

2.1 Base oils

Lubrication minimizes the friction and wear by creating a film on the contacting surfaces. A lubricant performs the various functions like controlling friction, cooling the contact, cleaning of the contact. The lubricant can be found in liquid, semi-solid (grease) and solid phase (graphite)[2,72]. The solid and semi-solid lubricant are used in the application where heat generation and contaminants are not a big issue. Most of the lubricant additives are formed and mixed with the liquid lubricant to enhance the various properties of the lubricants. A lubricant preparation is process of mixing substances. These substances are chosen carefully in accordance with the machine requirements. The base oil and the additives are the two components of the lubricant. The base oils are major part of the lubricant and additives are mixed into base oil to improve their properties. The API categories base oil in different groups API Groups I-III are the mineral based made from the distillation of the crude oils, API Group IV-V are the synthetic oil manufactured by the polymerization process[73]. The mineral oils are composed of hydrocarbons. The kinematic viscosity at 40°C and 100°C is considered for the lubricants. The different groups of the lubricants base oils are listed with their production process in Table 1.

Table 1. API group of base oils [73,74]

	Group I	Group II	Group III	Group IV	Group V
Saturates	< 90%	> 90%	> 90%	X	X
Sulfur	> 0.03%	< 0.03%	< 0.03%	X	X
Viscosity Index	80-120	80-120	> 120	125 -200	>125
Refining process	Solvent-refining	Hydrogenation	High tempera-ture hydrogena-tion	Polymerization	Polymerization
Cost	Low	Medium	Medium	High	High
Source	Mineral oil	Mineral oil	Mineral oil	Synthetic	Synthetic
Examples	Hydro-carbons	Hydro-carbons	Hydro-carbons	Poly alpha olefins (PAO), Synthetic hydro-carbons	Silicone, phosphate ester, polyalkylene glycol (PAG), Biolubes

The Group III oils are produced by the hydrogenation of the Group I oil at high temperature. The viscosity index is the key property of the base oils. It is the dependance of the viscosity on the temperature. The viscosity of the hydrocarbons drops rapidly as increase in the temperature. The concept of molecular design can create molecules with required properties as lubricant system, but cost is the main factor[74].

2.2 Lubricant additives

To impart certain properties lubricant oil need to be mixed with some compounds (organic or inorganic). These compounds are designated as the lubricant additives. The lubricant additives are classified in three different categories[73,74]: 1. Tribo-improver, 2. Reho-improver 3. Auxiliary function.

Tribo-improver are used to enhance the tribological characteristics of the lubricant compounds. They enhance the antiwear, antifriction and contact condition of the pairs. The detailed list of these compounds is given in Table 2.

Table 2. Function and working mechanisms of different additives [73,75]

Function	Working mechanism	Compounds
Friction modifiers	Chemically	Organic fatty acids, amines, lard oils, high molecular weight organic phosphorous, phosphoric acid esters
Anti-wear	Chemically	ZDDP, organic phosphate, acid phosphate, organic sulfur, chlorine compounds, Sulfurized fats, sulfides and disulfides
Extreme Pressure	Chemically	ZDDP, Chlorinated Paraffins, Sulfurized oils, Phosphate esters, calcium sulfonates, molybdenum base (dialkyl dithiophosphate, dithiocarbamates)
Viscosity Modifiers	Physically	Polymers, copolymers, ploymethacrylates (PMA), butadiene, olefins, alkylated styrenes
Pour point depressant	Physically	Alkyal naphthalene, phenolic polymers, polymethacrylates, ethylene-vinyal acetate copolymer, polyfumarates
Antioxidant	Chemically	ZDDP, sterically hindered phenols, alkylated aromatic amines, sulphurized phenols, derivatives of dialkyl dithiocarbamic acid
Corrosive inhibitors	Chemically	ZDDP, basic metal sulfonates, metal phenolates, fatty acids and amines, etoxylate alcohols, long chain carboxylic acids
Antifoam agents	Physically	Silicon polymers, organic copolymers
Demulsifier	Physically	Aromatic sulfonic acid, copolymer of propylene, ethylene oxide
Dispersants	Physically	Polymeric alkylthiophosphonate, organic complexes containing nitrogen compounds, sulphonates, salicylates, alkylephenolamine, polyisobutylene, succinanhydride (PIBSA)
Auxiliary	Chemical or Physical	Organic phosphates, aromatic, halogenated hydrocarbons, sulphur, amines

Reho-improver are the additives used to enhance the viscosity of the lubricant. They used to modify the viscosity index of the lubricant.

Auxiliaries consist of two categories of the compounds one is for the maintenance and other for the sub-elements of the system. In maintenance the deterioration of the machine element is needed to minimize by the external factors like water vapors, and extreme variation in the temperature of the lubricant. The additives are used are antioxidant, anticorrosive, antifoam and demulsifiers to minimize the effect of water vapor and other lube emulsions. In second category rest of the functions comes.

The additives are polar in nature. They stick to the base metal / lubricant molecules and provide the desired properties.

2.3 Working mechanism of the additives

It is important to understand the working mechanism of the lubricant additives to know the behavior of these additives with change in the working conditions. The working of the lube additives is divided in two categories, first is by chemical reaction and second is by physical action. The first category additives are reacted chemically to the surface and form a compound that protect the base surface. For example, ZDDP additive is the extreme pressure additive react with the tribo-surface and for the secondary layer on the surface called tribo-film that has low shear strength as compared to the base substrate[76]. The antioxidant additives deactivate the tribo-surface and protect it from the corrosion.

In physical action the additive activates after a certain condition of the temperature and pressure and by sticking or entanglement improve the specific property of the lube oil. For example, PMA is the viscosity modifier activate after certain temperature and entangle to enhance the viscosity of the oil.

3. Lubrication selection for the gear drive

The gears design to work under three lubrication mechanisms (Boundary, mixed and hydrodynamic). But under load and pressure the situation become different the hydrodynamic mechanism shift to the mixed and mixed shift to the boundary lubrication. So, it is important to select a proper lubricant for long term effective operation of the gear drive. The selection of the proper lubricant for the gear drives depends on the following points[77]:

Table 3. Lubrication system and application guide to the gear drives

Lubricant	Spur	Helical	Worm	Bevel	Hypoid
Inhibited oils	Normal loads	Normal loads	Light loads and slow speed	Normal loads	Not recommended
Anti-wear/ Anti-scuffing oils	Heavy and shock loading	Heavy and shock loading	Used in most of applications	Heavy and shock loading	Used in most of applications
Compound	Not normally used	Not normally used	Preferred to use	Not normally used	For lightly loaded applications
Synthetic	Heavy and shock loading	Heavy and shock loading	shock loading	Heavy and shock loading	Heavy and shock loading

- Type of gear drive (Open or closed)
- Type of gearing (spur, helical, bevel etc.)
- Type of loading (light load, heavy load)
- Surface finish (rough surface, smooth surface)
- Transmitted power
- Speed of the gear drive
- Material compatibility of the gear drive
- Temperature variation
- Special operating condition of load, contaminants

On the basis of above factors, the lubricant is classified in different categories inhibited, anti-scuff/ anti-wear, compounded, and synthetic according to the AGMA 9005[77]. Inhibited are the rust and oxidation inhibitor lubricants. They are formed of refined petroleum or synthetic oil containing a additive package of anti-oxidant, anti-corrosion and anti-foam. The lubricating oil must work in different environment and temperature conditions. These are suitable for the high pitch line gears. These oil act and deactivate the gear surfaces so that they can't get rusted or oxidized due to water vapor. These are suitable for the lubrication of bearing and gear together.

Anti-scuff/ anti-wear oils are extreme pressure additive packaged oils. They protect against high wear and scuffing. These oils are suitable for the use in high contact stresses. Before using these extreme pressure chemically active oils care must be taken when used for the gear and bearing together. They are the eater of the yellow materials. So, neutralized sulfur and borate are preferred to use. The solid lubricant like graphite and molybdenum disulfide can be mixed in the form of suspension. The filter used should not be fine as the solid lubricant suspension can be removed.

Compounded oils are petroleum blended with the 10% of synthetic fatty acid oils. The operating limit of operating temperature is 82 °C. The splash lubrication is preferred. The viscosity grade should be on higher side for these gears.

Synthetic lubricant are the long chain products. They improve the thermal and oxidation stability, improved viscosity index, reduce friction, reduce energy consumption, and lower volatility. The selection summery is outlined in Table 3 for selection of good grade lubricant oil.

For most of the applications the product manufacturer provides the specification for the lubricant.

3.1 Selection of the lubricant for open gear drive

A lubricant chosen for the open gear drives should be stick to the gears and not flow away. The most suitable lubricants are grease or solid lubricant. In most of the application the grease is used in open gear drives. The different lubrication is required for the gear and other elements. The main problem in this type of system is the low heat dissipation capacity and the trapping of the contaminants. Some of the solid lubricant like graphite and molybdenum disulfide can be used.

3.2 Selection of the lubricant for closed gear drive

The following steps are taken during the selection of proper lubricant for the closed drive.

Step 1: Check the assembly if it is possible to lubricate both gears and bearing simultaneously or not.
Step 2: Chose the proper viscosity of the oil on the basis of operating condition of the drive. The viscosity grade can be determined on the basis of operating temperature range of the system. The viscosity of the oil is defined at 40°C and 100°C of the temperature. The ideal viscosity grade is chosen on the basis of AGMA and ISO standards. The viscosity of the oil can be determined on the basis of pitch line velocity of the oil. The designation of oils is given like 80W90 for the multi grade gear oil. The first number defined the lowest working temperature range and the second number define the viscosity at 100°C. So, chose a proper viscosity according to the operating condition of the geardrive.
Step 3: Select proper lubrication system on the basis of load, speed and variation in operating conditions out of inhibited, anti-scuff/ anti-wear, compounded and synthetic oil lubrication.

4. Conclusions

The above study summaries the type of lubricant base oils, different lubricant additives and their use. Further the study suggested how to select a proper lubricant oil for the gear applications. From the above study the selection of the lubricant is function of the load, temperature range, type of gearing, and unwanted fluctuations. The synthetic oils are the good in performance, but cost is the major issue. The AGMA 9005 standard are used to select and describe the oil lubricant and selection criteria.

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