*International Journal of Multidisciplinary and Current Research* ISSN: 2321-3124
*Review Article* Available at: http://ijmcr.com

# A Review on Selection of Gear Drive Lubricating Oil

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Received 26 May 2022, Accepted 25 June 2022, Available online 01 July 2022, **Vol.10 (July/Aug 2022 issue)**

***Abstract***

*Under fluctuating environmental and operational conditions, gears failed. The gears' failure modes are divided into two categories: lubricated (pitting, flank wear etc.) and strength-based. The failure modes associated with the lubrication can be avoided and minimized by adequately selecting the lubricant. The present work presents a review of different types of oil used for the gearbox and additives. Further, the selection process based on the AGMA standard AGMA 9005 is discussed.*

***Keywords:*** *Base oil, Additives, AGMA 9005*

## Introduction

Today's complex systems rely more on their 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 [53,54,63–72,55,73–77,56–62] have been documented in the literature. The gearbox encounters continuous and changing working circumstances. It comprises several 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 [78]. Sliding happens in both gears' directions, with the pitch line acting as a point of contact for both rolling and sliding [1,79,80]. 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[81–83]. Research on lubricating properties and gear performance is 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 [84,85]. In addition to numerical simulations, experiments are necessary to explain the phenomenon. Many researchers compared 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 better performance in terms of the pitting and scuffing resistance of the gears[86]. Further, the lubricant's performance is enhanced by the boundary lubricant additives like multi-walled carbon nanotubes (MWCNTs) etc., under extreme pressure conditions. The studies conducted in the past show the 0.05 wt% to 0.50 wt% concentration of MWCNTs shows a 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 the lubricant selection for a gear drive is discussed.

## 2. Lubrication and lubricant additives

### *2.1 Base oils*

Lubrication minimizes friction and wears by creating a film on the contacting surfaces. A lubricant performs various functions like controlling friction, cooling, and cleaning the contact. The lubricant can be found in liquid, semi-solid (grease) and solid phase (graphite)[2,87]. The solid and semi-solid lubricants are used in the application

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DOI: https://doi.org/10.14741/ijmcr/v.10.4.1

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 a process of mixing substances. These substances are chosen carefully as per the machine's requirements. The base oil and the additives are the two components of the lubricant. The base oils are a significant 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 crude oils, and API Group IV-V are the synthetic oil manufactured by the polymerization process[88]. 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 with their production process are in Table 1.

**Table 1.** API group of base oils [88,89]

| | 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-temperature hydrogenation | 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, polyethene glycol (PAG), Biolubes |

The hydrogenation of the Group produces the Group III oils I oil at high temperatures. The viscosity index is the fundamental property of the base oils. It is the dependence of viscosity on temperature. The viscosity of the hydrocarbons drops rapidly as an increase in the temperature. The concept of molecular design can create molecules with required properties as a lubricant system, but the cost is the main factor[89].

*2.2 Lubricant additives*

To impart specific properties, lubricant oil must be mixed with some compounds (organic or inorganic). These compounds are designated as lubricant additives. The lubricant additives are classified into three categories[88,89]: 1. Tribo-improver, 2. Reho-improver 3. Auxiliary function.

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

**Table 2.** Function and working mechanisms of different additives [88,90]

| 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, polymethacrylates (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, sulfurized 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, a 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 is the additives used to enhance the viscosity of the lubricant. They are used to modify the viscosity index of the lubricant.

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

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

### *2.3 Working mechanism of the additives*

It is essential to understand the working mechanism of the lubricant additives to know their behaviour with changes in the working conditions. The working of the lube additives is divided into two categories, the first is by chemical reaction, and the second is by physical action. The first category of additives is reacted chemically to the surface and forms a compound that protects the base surface. For example, the ZDDP additive is the extreme pressure additive that reacts with the tribo-surface and the surface's secondary layer called tribo-film, which has low shear strength compared to the base substrate[91]. The antioxidant additives deactivate the tribo-surface and protect it from corrosion.

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

## 3. Lubrication selection for the gear drive

The gears work under three lubrication mechanisms (Boundary, mixed and hydrodynamic). But under load and pressure, the situation becomes different. The hydrodynamic mechanism shift to the mixed and mixed shift to the boundary lubrication. So, it is essential to select a proper lubricant for the effective long-term operation of the gear drive. The selection of the proper lubricant for the gear drives depends on the following points[92]:

**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 applications | Heavy and shock loading | Used in most 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
- The exceptional operating condition of load, contaminants

Based on the above factors, the lubricant is classified into different categories inhibited, anti-scuff/ anti-wear, compounded, and synthetic, according to the AGMA 9005[92]. Inhibited are the rust and oxidation inhibitor lubricants. They are formed of refined petroleum or synthetic oil containing an additive package of anti-oxidant, anti-corrosion and anti-foam. The lubricating oil must work in different environments and temperature conditions. These are suitable for the high pitch line gears. These oil act and deactivate the gear surfaces so they can't get rusted or oxidized due to water vapour. 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 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 use. Solid lubricants like graphite and molybdenum disulfide can be mixed in the form of suspension. The filter should not be accepted as the solid lubricant suspension can be removed.

Compounded oils are petroleum blended with 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 the higher side for these gears.

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

For most 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 stick to the gears and not flow away. The most suitable lubricants are grease or solid lubricant. In most applications, grease is used in open gear drives. 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 solid lubricants like graphite and molybdenum disulfide can be used.

### *3.2 Selection of the lubricant for closed gear drive*

The following steps are taken while selecting the proper lubricant for the closed drive.

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

## 4. Conclusions

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

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