



GEAR DRIVES: Selecting the correct lubricant

Finding a strategy to estimate oil viscosities for a variety of gear types, conditions and lubricants just got easier, thanks to the efforts of two industry organizations.

In the March TLT we introduced selection criteria for a few common types of machine components, including geared components and gear drives. This month we'll more thoroughly discuss the general concepts that appeared in the March article.

Geared components are widely used in manufacturing all types of products and in the operation of many of those products by the end-user. Geared components perform the function of either increasing or decreasing shaft speeds for applied torque/force.

Much like a manual transmission on an automobile or truck, a gear drive

KEY CONCEPTS:

- There are several different gear tooth forms or designs, each with its own strengths and weaknesses that can impose different challenges for the lubrication engineer.
- AGMA and ASM methods for selecting lubricants for gear reducers take into consideration the gear type, speed, operating sump temperature and base oil viscometric properties to finding the most appropriate lubricant.
- Two solutions sets demonstrate that degree of variability can be accepted in the selection of viscosities for gear sets, particularly where there are multiple operating speeds involved.

on a production machine might include several speed adjustments. Machine drives typically reduce speeds from the given input (1,200 rpm is common) to the given output or final shaft speed. A single gearbox may include several sets of gears. Each set includes a pinion and a bull gear or a driving and a driven gear. The number of gear sets required for a particular type of gear drive depends on many factors, but a central criterion is the gap between the input speed and the output speed.

A common industrial drive configuration would include a drive gear (input pinion), one to three intermediate gear sets (each set has a drive/pinion and a driven/bull gear) and a final gear. Each reduction set is supported by two or more bearings, typically element bearings but occasionally plain bearings as well. There are several different and common gear tooth forms or designs.

Each design carries its own strengths and weaknesses and imposes slightly different challenges to the lubrication and reliability engineer. The designs, as noted in Figure 1, from left to right, include a spur, a right-angle spur, a right-angle bevel gear and a worm gear. The degree of sliding force increases as the degree of curvature of the gear tooth increases, with the worm gear presenting complete sliding engagement.



Figure 1 | Common Gear Types and their Frictional Characteristics

A variety of gear/gear drive design parameters influence the final lubricant selection. As one might guess, the parameters for gear design, construction and lubricant selection are interrelated. A change in one parameter often dictates a change in a variety of other parameters as well. Key parameters include:

- Tooth size
- Tooth shape
- Tooth pressure angle
- Gear wheel rotating speed (Pitch line velocity – PLV)
- Gear construction materials (Types of metal)
- Dynamic loading
- Gear tooth finish (Smoothness of the finish).

LUBRICANT SELECTION

Engineering geared wheels is a trip through applied trigonometry and calculus. There are several published documents available through the American Gear Manufacturers Association (www.agma.org) to assist the purist in understanding gear design and construction. Fortunately, the AGMA has provided a fairly advanced set of instructions for the layman. Every lubrication and reliability engineer should have the AGMA 9005-E02 guideline for lubricant selection available and ready within their working papers.

This article will provide advice for selecting lubricants for gear reducers based on both AGMA and ASM (American Society of Materials) methods. Those methods take into consideration the gear type, speed, operating sump temperature and base oil viscometric (i.e., viscosity index) properties to find the lubricant that represents the best fit for the application.

Gear speed is based on the pitch line velocity, not the simple shaft speed. The PLV (see page 26) value indirectly characterizes the contact time between the gear teeth. Generally, high PLV values are associated with high-speeds and low loads, whereas low PLV values are associated with high loads and low-speeds. Following this relationship, lower PLV values tend to require higher operating viscosities and surface-active (AW and EP) additives. Temperature is obviously an observed or measured parameter, and the lubricant viscosity index (VI) is a value that can be calculated but is typically available by simply observing the product data sheet.

There are two different methods shown below to evaluate a typical gear drive lubrication specification. The first solution is based on the use of the AGMA 9005-E02 advice and the AGMA-designated Tables B-1 to B-4 (the tables vary based on viscosity index values from four different lubricant technology types). The second solution follows the method provided by ASM. The viscosity is calculated directly based on the expected operational parameters for the same example gear drive. Lastly, an evaluation for shaft bearing lubricant selection is also provided, along with conclusion for how the information and analysis might be used to make a final selection.

SOLUTION 1: AGMA GUIDELINE FOR GEAR OIL SELECTION

An example gear set is based on a variable speed gear drive in a wire-drawing line. Since the machine may have a wide variety of actual requirements, it is appropriate to evaluate the high- and low-speed operating conditions and seek to understand the operational limits that the lubricant must meet. So each step as indicated represents a pinion and a bull gear.

Given that AGMA selections are predicated on pitch line velocities, the first stage is to determine PLV values from the gear's dimensions and operating characteristics. This step provides a range of PLVs based on the operational profile for each gear in each set, as follows:

High PLV values are associated with high-speeds and low loads, whereas low PLV values are associated with high loads and low-speeds.

$$PLV = \pi * D * N$$

		Driving	Driven		Driving	Driven
Pinion Pitch Dia – (m)	Pi	3.1415	3.1415		3.1415	3.1415
Pinion Speed – RPM	D	0.08			0.08	
Pinion Speed – RPM	N max	1185		N max		
Crown Pitch Dia (m)	N min			N min	225	
Crown Speed Max			0.3232			0.3232
Crown Speed Min			500			500
Operating (sump) Temp			63			63
PLV, (rev. per minute)-		50°C			50°C	
	Maximum	297.8142	507.6664	Minimum	56.547	63.96597

It is important to remember that shaft speeds are provided in revolutions per minute. The speed increment must be converted to seconds to arrive at a PLV in meters per second.

		Meters/sec		Meters/sec
Pinion PLV	MAX	4.96357	MIN	0.94245
Crown PLV	MAX	8.461107	MIN	1.066099

Viscosity ranges are derived from these values, as follows:

Per the 9005-E02 chart, viscosity is based on **Maximum PLV**.
Recommended ISO Viscosity Grade where: **PLV=2.5 to 5.0 & 5.0 to 10.0**

	35 C	40 C	45 C	50 C
VI = 90 (G1 min oil)	68, 46	68, 46	100, 68	100, 100
VI = 120 (G2 min oil)	68, 46	68, 46	100, 68	100, 100
VI = 160 (G4 PAD)	68, 46	68, 46	100, 68	100, 68
VI = 240 (G5 PAG)	68, 46	68, 46	100, 68	100, 68

Per the 9005-E02 chart, viscosity is based on **Minimum PLV**.
Recommended ISO Viscosity Grade where: **PLV = 1.0 – 2.5**

	35 C	40 C	45 C	50 C
VI = 90 (G1 min oil)	150	150	220	320
VI = 120 (G2 min oil)	150	150	220	320
VI = 160 (G4 PAD)	150	150	220	320
VI = 240 (G5 PAG)	150	150	220	220

When multiple gear sets are involved in the evaluation, it is appropriate to consider the lowest speed mesh and, if

there is any difference, the most critical reduction set. For the parameters provided here, at an operating temperature of 50 C, the selection of the higher viscosity fluid would be preferable (ISO 320 grades dependent on the base oil type). Given that the gears are steel matched to steel, an EP type additive system would be appropriate. This is generally going to be the case with exceptions for very high PLVs and where steel is matched to soft metal gears (bronze) such as with worm gear applications.

A worm gear-specific chart should be used to target the viscosity grade for worm gear applications.

SOLUTION 2: ASM GUIDELINE FOR GEAR OIL SELECTION

The second solution is based on target viscosities derived from gear dimensions and operating profiles with results provided at the lubricants fundamental measurement temperature (ISO VG @ 40 C). Where the gear set operating temperature is appreciably above or below the fundamental (40 C) temperature, the reliability engineer must account for the differences.

The calculations are based on a widely recognized formula found in the ASM handbook, as follows:

	Maximum N	Minimum N	Mean N
$V_{40} = 7000 / V^{0.5}$	223.8518	513.7223	290.2185
$V = .262 * n * d$	977.8563	185.6689	581.7626
n = Driver Speed	1185	225	705
d = Pitch Diameter (in)	3.1496	3.1496	3.1496
Factor	0.262	0.262	0.262
$V^{0.5}$	31.27069	13.62604	24.11976
Factor	7000	7000	7000

Viscosity selection for bearings is driven by element calculation for median speed, commonly referred to as the nDM value.

The targeted viscosity grade for the mean is somewhat less than the ISO 320 G1 mineral oil denoted in Solution 1. This VG reference provides for higher viscosity grades for all speed conditions, as can be observed from comparing the two data sets for the highest and lowest operating speeds.

The two solutions sets demonstrate that degree of variability that can be accepted in the selection of viscosities for gear sets, particularly where there are multiple operating speeds involved.

PINION BEARING VISCOSITY REQUIREMENTS

Again, it is necessary to verify that the lubricant viscosities selected are adequate to meet the minimum required viscosity for the specific bearings in use on each shaft. In the August and September TLTs we addressed the method to determine oil viscosity lower limits, though they are resummarized (for element bearings) below.

Viscosity selection for bearings is driven by element calculation for median speed, commonly referred to as the nDM value. This value is calculated from inputs, as follows:

nDM Value	$\frac{((ID + OD) * RPM)}{2}$			
Dimensions	Inches	Millimeters	Pd (in)	Pd (mm)
mm/in		25.4		
OD - in. / mm	5.11811	130	4.035	102.5
ID - in. / mm	2.952756	75		
Width (W)	1.614173	41		
RPM	1785			
nDM	182962.5			

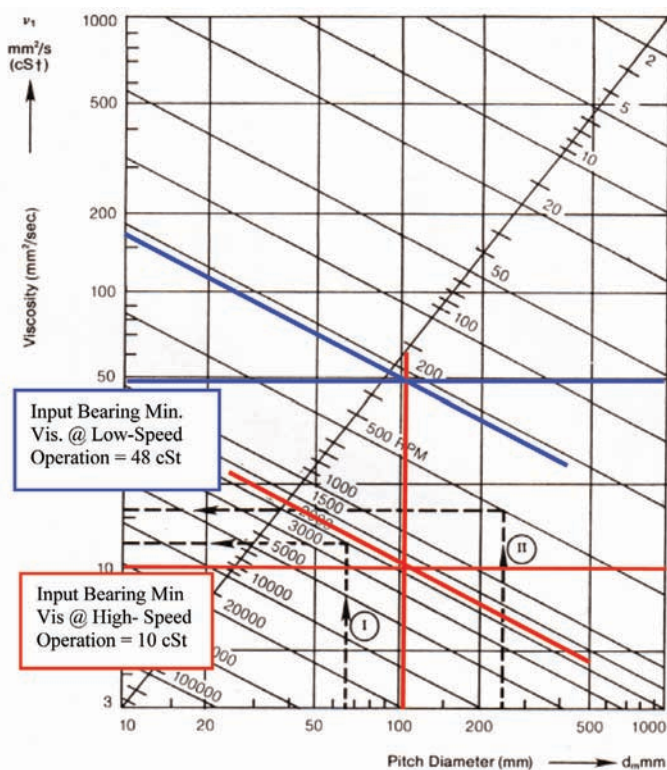
From this value, one may cross-reference to the designated minimum viscosity requirement. Finite calculations may be conducted, but these calculations require significantly



The number of gear sets required for a particular type of gear drive is dependent on many factors.



more data than is typically provided, and the results reflect similar values which are noted below.



In all scenarios, the calculated gear oil viscosity requirements appreciably exceed the minimum viscosity require-

ments imposed by the bearings under low- and high-speed operating conditions.

As long as the bearings are running in a flooded condition, there should be no interruption of oil flow to the element raceway from the elevated viscosity fluids. During particularly cold startup conditions (below 0 C), this would be a point of concern and require consideration of a change in viscosity.

CONCLUSIONS

AGMA and ASM provide documents and methods that are useful to estimate gear oil viscosities for a variety of gear conditions and lubricant types. AGMA methods provide stronger advice where multiple types of lubricant options exist. ASM methods provide more exacting advice for specific operating states but offer little help discerning the benefits of each of the different types of basestocks.

Shaft support is provided by element and plain bearings. After decisions are made for the specific grade of oil and additive complex (EP, with exceptions for high-speeds, worm gears and internal backstop applications) for the gear set, the reliability engineer must verify that this selection doesn't interfere with (fall below) the minimum allowable limits imposed by bearing operating states. This concern is pronounced as the gear sump oil temperatures approach 100 C. **TLT**

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