Designation: F2161 – 01

Standard Guide for
Instrument and Precision Bearing Lubricants—Part 1 Oils[1]

This standard is issued under the fixed designation F2161; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide is a tool to aid in the choice of an oil for precision rolling element bearing applications. There are two areas where this guide should have the greatest impact: (*1*) when a lubricant is being chosen for a new bearing application and (*2*) when a lubricant for a bearing has to be replaced because the original lubricant specified for the bearing can no longer be obtained. The Report (Section 5) contains a series of tests performed by the same laboratory on a wide variety of oils commonly used in bearing applications to allow comparisons of those properties of the oil that the committee thought to be most important when making a choice of lubricant. This guide contains a listing of the properties of oils by chemical type, that is, ester, silicone, and so forth. This organization is necessary since the operational requirements in a particular bearing application may limit the choice of lubricant to a particular chemical type due to its temperature stability, viscosity index or temperature-vapor pressure characteristics, and so forth. The Report includes the results of tests on the oils included in this study. The Report recommends replacement lubricants for those oils tested that are no longer available. The Report also includes a glossary of terms used in describing/discussing the lubrication of precision and instrument bearings. The Report presents a discussion of elastohydrodynamic lubrication as applied to rolling element bearings.

1.2 Although other compendia of lubricant properties have been published, for example, the Barden Product Standard, Lubricants[2] and the *NASA Lubricant Handbook for the Space Industry*[3], none have centered their attention on lubricants commonly used in precision rolling element bearings (PREB). The PREB put a host of unique requirements upon a lubricant. The lubricant must operate at both high and low temperatures. The lubricant must provide lubrication for months, if not years, without replenishment. The lubricant must be able to support high loads but cannot be so viscous that it will interfere with the operation of the bearing at very high speeds or low temperatures, or both. The lubricant must provide boundary lubrication during low-speed or intermittent operation of the bearing. And, in many applications, its vapor pressure must be low enough under operating conditions that evaporative losses do not lead to lubricant depletion or contamination of nearby components. These and other considerations dictated the series of tests that were performed on each lubricant included in this study.

1.3 Another important consideration was encompassed in this study. Almost all of the testing was performed by the same laboratory, The Petroleum Products Research Department of the Southwest Research Institute in San Antonio, Texas, using ASTM procedures. This continuity of testing should form a solid basis for comparing the properties of the multitude of lubricants tested by avoiding some of the variability introduced when lubricants are tested by different laboratories using different or even the "same" procedures.

1.4 It should be noted that no functional tests (that is, bearing tests) were performed. The results of the four-ball wear test give some comparison, "a figure of merit," of the lubrication properties of the oils under the condition of this test. But experience has shown that testing the lubricant in running bearings is the best means of determining lubricant performance.

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D972 Test Method for Evaporation Loss of Lubricating Greases and Oils
D1331 Test Methods for Surface and Interfacial Tension of Solutions of Surface-Active Agents

[1] This guide is under the jurisdiction of ASTM Committee F34 on Rolling Element Bearings and is the direct responsibility of Subcommittee F34.02 on Tribology.

Current edition approved Dec. 10, 2001. Published February 2002. DOI: 10.1520/F2161-01.

[2] "Product Standard, Lubricants," available from The Barden Corp., Danbury, CT.

[3] *NASA Lubricant Handbook for the Space Industry*, Ernest L. McMurtrey, *NASA Technical Memorandum TM-86556* , George C. Marshall Space Flight Center, National Aeronautics and Space Administration, December 1985.

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D2270 Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 and 100°C
D4172 Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method)

2.2 *Government Documents*[5]*:*

MIL-DTL-53131 Lubricating Oil, Precision Rolling Element Bearing, Plolyalphaolefin Based
MIL-L-6085 Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-L-14107 Lubricating Oil, Weapons, Low Temperature
MIL-L-23699 Lubricating Oil, Aircraft Turbine Engines, Synthetic Base
MIL-L-7808 Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-L-81846 Lubricating Oil, Instrument, Ball Bearing, High Flash Point
MIL-S-81087 Silicone, Fluid, Chlorinated Phenyl Methyl Polysiloxane

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *ABEC*, *n*—Annular Bearing Engineer's Committee of the American Bearing Manufacturers Association (ABMA). The ABEC establishes bearing tolerance classes. Precision bearings are ABEC 5P and ABEC-5T and higher.

3.1.2 *absolute viscosity* (η), *n*—(sometimes called dynamic viscosity or just viscosity)—a measure of the tendency of the fluid to resist shear. The elastohydrodynamic theory (EHD) film thickness and torque losses in a ball bearing are very strong functions of η. Since the ratio of absolute viscosity to density, η/ρ, appears frequently in hydrodynamic analyses, it was given its own name, kinematic viscosity, ν. The cgs unit of viscosity is the centipoise (cP). The SI unit of viscosity is the Pascal-s (Pa-s).

Absolute viscosity is defined for a Newtonian fluid as follows. The shear stress at any point in the fluid is proportional to the rate of shear. The proportionality constant is called the absolute viscosity. Viscosity is thus defined by the force, *F*, to move one surface of area, *A*, with respect to another surface separated by a fluid film, *h*, at a speed, *U*, through the following relationship:

$$\eta = (F/A)(h/U)$$

The value of the absolute viscosity changes greatly with temperature, *T*. As the temperature increases viscosity decreases. ASTM International has adopted the following relationship between kinematic viscosity and temperature:

$$\log_{10} \log_{10}(\nu + 0.8) = m \log_{10} T + c$$

where:
m and *c* = constants for each fluid.

ASTM International supplies chart paper with the ordinate proportional to $\log_{10} \log_{10}(\nu + 0.8)$ and with the abscissa proportional to $\log_{10}T$. Thus the values of kinematic viscosity versus temperature can be plotted as a straight line on the paper allowing extrapolation of values intermediate to those that have been measured.

Absolute viscosity is a weak function of the pressure imposed upon the fluid. However, the pressures generated in the ball-race contact zone of a ball bearing can be on the order of 10^3 GPa (10^5 psi) and at these pressures significant increases in viscosity can occur. Experiments have shown that viscosity varies exponentially with pressure and can be expressed as follows:

$$\eta = \eta_0 \exp(\alpha p)$$

where:
η_0 = viscosity at a pressure of one atmosphere,
p = pressure, and
α = pressure-viscosity coefficient.

A table of values of α for some common classes of bearing lubricants can be found after the definition of pressure-viscosity coefficient included in this glossary.

Recent work has shown that the viscosity changes with temperature can also be modeled by an exponential relationship. Thus, viscosity at any pressure and temperature can be expressed as follows:

$$\eta_{T,p} = \eta_0 \exp(\alpha p + \beta(1/T + 1/T_0))$$

where:
β = temperature-viscosity coefficient.

3.1.3 *acid number*, *n*—a measure of the quality of a lubricant. High acid numbers (much higher than the fresh oil) are an indication of lubricant oxidation/degradation. Oils with high acid numbers should not be used. Acid number is measured as milligrams of KOH needed to neutralize one gram of oil.

3.1.4 *additive*, *n*—any chemical compound added to a lubricant to improve or meet special needs necessary for service (formulated lubricants). The most important additives are antioxidants, rust and corrosion inhibitors, and extreme pressure (EP) and antiwear (AW) additives.

3.1.5 *antioxidants* (oxidation inhibitors), *n*—chemical compounds used to improve the oxidation stability and subsequent deterioration of lubricants.

3.1.6 *boundary lubrication*, *n*—a condition of lubrication in which the friction between two surfaces in relative motion is determined by the roughness of the surfaces and by the properties of the lubricant other than viscosity. Antiwear and extreme pressure additives reduce the wear of components operating under this regime.

3.1.7 *centipoise*, *n*—a unit of dynamic viscosity. The unit in the cgs system is one centipoise (cP). The SI unit of dynamic viscosity is 1 Pa-s and equivalent to 10^3 cP.

3.1.8 *centistoke*, *n*—a unit of kinematic viscosity. The unit in the cgs system is one centistoke (cSt). The SI unit of kinematic viscosity is 1 m^2/s and is equivalent to 10^6 cSt.

3.1.9 *compatibility*, *n*—a measure of the ability of a lubricant to be mixed with other lubricants or bearing preservatives (fluids that form films on metal surfaces to prevent corrosion during storage) to form a uniform mixture without causing any resultant reaction or precipitation of material. Compatibility is also a measure of the ability of a lubricant not to cause any detrimental effect to metal, plastic, or elastomer materials.

[5] Available from Document Automation and Production Service, Building 4/D, 700 Robins Ave., Philadelphia, PA 19111–5094.