LUBRICATION SYSTEMS

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Summary

The fundamental information on structure, operation conditions, technical characteristics, schemes and parameters of OS's of: aircraft GTE's and PE; GTU's of ground application, including GPA with a gas turbine drive and EGPA; lubrication systems of ICE is explained. The methods of estimation of the amount of heat arising as a result of friction in rotor supports, designed with antifriction or plain bearings, and circulation of oil, necessary for heat rejection, are reviewed. Some aspects of analysis of usage of fuel as a cooling agent in a system of oil cooling of fuel-oil heat exchangers, required air consumption in the oil-air heat exchangers and particular aspects of maintenance, provision of necessary level of reliability and diagnostics are considered.

1. Introduction

Lubrication in engines is basically intended for reduction of friction between components moving relative to each other while in contact and their wear and rejection of friction heat. A properly selected lubrication system allows higher specific loads and enhances durability and reliability of elements of friction – bearings, pistons, gear wheels – and an engine as a whole. In this chapter structure and conditions of operation of lubrication systems, used in power plants of aircrafts, marine and locomotive GTE's and ICE's, GPA's, electric power stations etc are considered. Specific features of oil systems, including diagnostics methods of failure arising out of separate units of power plants – details of bearings, gear wheels, torsion shafts etc. on measuring of concentration of wear products of these details in process of their work are discussed.

2. General Information on Friction and Lubrication

Depending on the type of relative movement the friction is subdivided into different categories: sliding friction, rolling friction and mixed, when rolling is accompanied by sliding. In turn three main kinds of sliding friction are distinguished: dry friction between absolutely dry surfaces of solids; fluid (or viscous) friction, when the contact surfaces in the moving bodies are completely separated by a fluid layer; boundary (or semi–fluid) friction between bodies, separated by insufficiently thick oil layer, so alongside the friction in the fluid layer friction between immediate micro profile peaks takes place, separated only by the absorbed film. The law of dry friction is expressed by the formula:

$$F = f\,P,$$

where F – friction force; P – force acting along a normal to the friction surface; f – friction coefficient depending on the condition and material of the friction surfaces, but not on their area. The law of fluid friction is written in the following form:

$$F = \mu \cdot S \cdot V / [h + (\mu / \lambda_1) + (\mu / \lambda_2)], \quad (1)$$

μ – coefficient of internal friction of lubrication fluid called as absolute or dynamic viscosity; S – contact area of moving surfaces; V – relative speed between surfaces; h – thickness of oil layer; λ_1 and λ_2 – coefficients of external friction between particles of lubrication fluid and moving surfaces of solids. Magnitudes of λ_1 and λ_2 for the oils applied for lubrication are many times larger than μ, which allows us to rewrite Eq.(1) in the simpler form:

$$F = \mu \cdot S \cdot V/h \qquad (2)$$

or in the differential form:

$$F = \mu \cdot S \cdot dV/dh \qquad (3)$$

From the last expression it follows, that the absolute viscosity is numerically equal to the friction force per unit area of the surface at a velocity gradient dV/dh, equal to unity. In the CGS (centimetre – gram - second) system the unit of viscosity is : 1 poise = $1\text{dyne}\cdot 1\text{s}\cdot 1\text{cm}^{-2}$.
The ratio of absolute viscosity of oil η to density ρ is called as kinematics viscosity $\nu = \mu/\rho$. The unit of kinematics viscosity in the CGS system is 1stoke (St) = $1\text{cm}^2\cdot 1\text{s}^{-1}$. The kinematics viscosity of oil is usually given in centistokes (cSt), one centistoke is equal to 1/100 stoke. The viscosity is measured by viscometers in terms of the time it takes for a certain amount of oil to pass through a calibrated capillary tube.

Viscosity depends on the type of oil, its temperature and pressure. The decrease of viscosity with temperature rise is approximately proportional to the third power of temperature. The preference is given to that oil, the curve of viscosity of which is more gently sloping. Too high viscosity at low temperature makes engine starting difficult, and low toughness at high temperatures can result in semi-fluid friction. For reduction of oil viscosity at very low temperatures and facilitation of start of PE rarefaction of oil by petrol is used. During the operation of an engine some physical and chemical processes occur, resulting in an increase of viscosity of 15-25 percent over 50 hours of work, if petrol content doesn't exceed 0.8 percent. While operating with rich mixtures and bad fuel evaporation toughness fall can be observed, as a result of augmentation of petrol content. The viscosity increases with pressure. However in the calculation of plain bearings lubrication this dependence is usually neglected, assuming viscosity as a constant, corresponding to the average temperature of oil layer and atmospheric pressure. For a temperature mode of the bearing the large value has heat capacity of oil. The last in a temperature dependence changes linearly for miscellaneous oils on the average from 0.4 $\text{J}\cdot(\text{kg}\cdot\text{K})^{-1}$ at 20°C up to 0.55 $\text{J}\cdot(\text{kg}\cdot\text{K})^{-1}$ at 150°C.

The viscosity is related to one of the main indexes of lubricating oils, as hydrodynamic regime of lubrication of the components in friction, and mechanical losses due to friction in the engine depend on it. Kinematics viscosity of oil is reckoned at 100°C in $\text{mm}^2\cdot\text{s}^{-1}$. For example, the oil M–10 has kinematics viscosity 10 ($\text{mm}^2\cdot\text{s}^{-1}$) at 100°C. For lubrication of aircraft PE's petroleum oils are used, for example MS-14, MK-22, with toughness of 15-25 $\text{mm}^2\cdot\text{s}^{-1}$ at 100°C. In contrast to PE's, in TJE's oils with small viscosity, such as MK8, MS8P and so on are used, which are stable at temperatures up to 120-140°C. To obtain the required properties oils are subjected to different kinds of processing: chemical – cleaning by sulphuric acid (oils of series MK) and physical – with selective solvents – oils of series MS. The viscosity increases as temperature falls, which causes magnification of friction force in the hydrodynamic regime of lubrication of the components subjected to friction. The greatest friction force arises while starting in cold engines at low ambient temperature, when the viscosity is high and the lubricant is circulated by the pump with difficulty. The slowed down supply of oil to units of friction can increase wear of components and even cause damage to bearings in the starting period of the engine. The increase of viscosity with drop in temperature for miscellaneous oils takes place in different ways and depends on their physicochemical properties. The dependence of viscosity in the above mentioned interval is smaller for oils of low viscosity than for those of high viscosity.

To ensure normal operation of engines in different climatic conditions it is desirable that the viscosity of applied oils is a little bit influenced by temperature. In the estimation of the change of viscosity by its relation to temperature, apart from kinematics viscosity at temperature 100°C, in the technical conditions the kinematics viscosity of oil at 0°C or ratio of kinematic viscosities at 50 and 100°C is employed, so with the help of a special nomogram it is possible to determine its viscosity at any temperature. For this purpose it is necessary to plot two appropriate points on the nomogram and to connect them by straight line, which one will characterize the variation of kinematic viscosity of the given oil with temperature. The usage of the nomogram is illustrated in Figure 1.

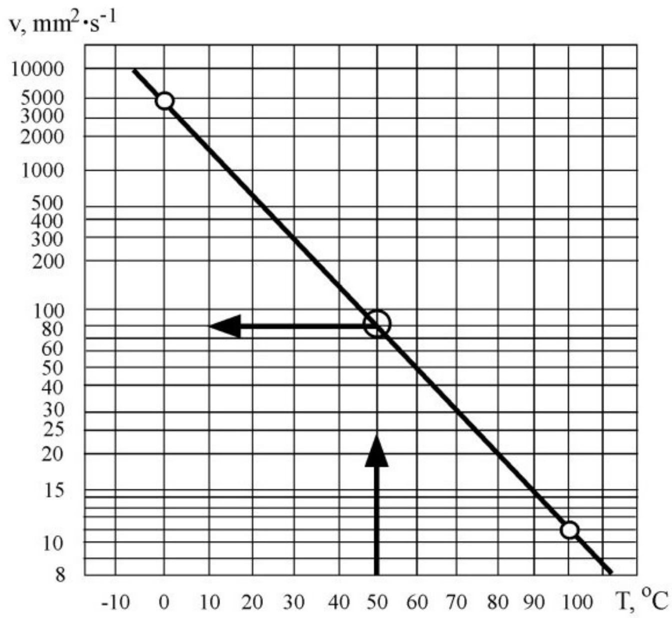

Figure 1. Nomogram for definition of oil viscosity

The viscosity of oils depends also on pressure, increasing with the latter, which has the special importance in lubricating of units of the engine working with large overloads. The dependence of viscosity on pressure can be determined using the formula:

$v_p = v_0 \cdot b^p$,

where ν_p and ν_0 – viscosity at pressure p and atmospheric pressures respectively; b – constant, for mineral oils in the range: 1.002–1.004. Viscosity of oil for PE is selected proceeding from the geometry, sizes, and operational regimes of plain bearings of crankshaft, and also from climatic conditions of engine maintenance. For engines working on petrol, oils with viscosity 6; 8; 10; 12 $mm^2 \cdot s^{-1}$, and for diesel engines – oils with viscosity 8; 10; 12; 14; 16; 20 $mm^2 \cdot s^{-1}$ are used. The oils of greater viscosity are applied to more loaded engines or engines working at high ambient temperature (summer conditions, operation in hot southern regions). The viscosity influences its circulation through clearances in the components of friction, and consequently, heat rejection from friction surfaces and cooled components, and expenses of power on the driving of oil pump. The oils with low viscosity with other things being equal scavenge heat better and faster and wash out products of wear of components, taking part in friction.

As a result of pumping action of piston rings the oil comes to thecombustion chamber and burns down there. The oil can also percolate into the combustion chamber through gaps between rods of valves and their guides. The burned oil imparts specific coloring to outlet gases. The amount of burnt oil and consequently, its consumption depends on viscosity. The oils of the greater viscosity burn off in a smaller amount. The consumption of oil owing to burn – up can reach 85 % of common consumption of oil in an engine.

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Bibliography

Kozachenko A.N. (1999). *Maintenance of compressor stations of main gas pipelines*, Moscow: Petroleum and gas. [The technological schemes of compressor stations, regimes of their operation, maintenance and philosophies of checking of GPA with gas turbine and electric types of drive are adduced].

Soloviov V. A., Koulandin A. A., Makarov N. V.; under general edition of V.A. Soloviov etc. (1991). *Device and flight maintenance of power plants*, Moscow: Transport. [Summary arrangements of power plants, gas turbine engines, operation conditions and constructive solutions of details, units and assemblies, device and operation of systems supplying operation of a gas turbine engine are described].

Standard handbook for mechanical engineers, (1997). New York: McGraw-Hill. [Summary information on lubricants and lubrication, gearing and gear lubrication, fluid film bearings, bearings with rolling contact is considered].

Stepanov V.A. (1994). *Method for estimating the antiwear and antiscuffing oil properties on the gearbox rig with the use of ferrography means and wear debris concentration transmitters*, Buenos Aires, TRIBOS-94, International Conference [Characteristics of instrumental methods of investigation of antiwear and antiscoring properties of oils, with using for estimation of wearing intensity of principles of tribodiagnostics, comparison of results of ferrographical and spectral analysis of wear products in the oil etc. are adduced].

Viunov S. A., Gusev J. I., Carpov A. V. and etc.; under general edition of D.V. Chronin (1989). *Construction and designing of aircraft gas turbine engines*, Moscow: Engineering. [Fundamentals of development of constructions of aircraft gas turbine engine, the operation conditions and construction of the basic units of engines and details, and requirements to them, are reviewed].

Biographical Sketch

Valeri G. Nesterenko is an associated professor of Engine Department of the Moscow Aviation Technical University (MAI). He took his Ph.D. degree in 1984 and became senior research assistant specializing in "Heat engines of aircrafts" in 1987; senior lecturer of Moscow Aviation Define (MAI) on chair of construction and design of engines of aircrafts - 1992. In MAI he does teaching work and gives courses of lectures on a number of educational disciplines of specialty "Design of construction of AJE": "Construction and design of AJE", "Power plants of aircraft AJE", "Reliability of AJE" and other. He is the author of more than 70 printed works. Research interests are concerned on energy-machine-building, including aircraft and stationary gas turbine units.

Valeri G. Nesterenko was born in 1939, graduated from Moscow Aviation Institute in 1963. He is the author of more than 70 printed works, including: album "Aircraft modular gas turbine engines"; atlas of schemes and constructions of assemblies of AJE (1991); "Design and calculation of basic supports and shafts of AJE" (1999); "Design and calculation of connections of elements of rotor of GTE" and other. Valeri G. Nesterenko is senior lecturer of Moscow Aviation Institute (MAI) on chair of construction and design of engines of aircrafts with 1992. In MAI he does teaching work and gives courses of lectures on a number of educational disciplines of specialty "Design of construction of AJE": "Construction and design of AJE", "Power plants of aircraft AJE", "Reliability of AJE". In the present he is the technical adviser of Designer Bureau IACI.