Experimental analysis of the bearing greases lifetime

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Abstract. The purpose of the presented work is to increase the lifetime of space mechanisms bearings. The authors reviewed the studies of the bearings and linear mechanisms operating in air and in vacuum. A testing equipment is developed to assess the lubricity and lifetime of greases in the air. Criteria for the evaluation of relative lifetime are defined. Four types of space greases are tested.

1. Introduction
The increased lifetime demanded of state-of-the-art telecommunications satellites has necessitated the development of new greases for space. Modern lubricants should provide the operation of mechanisms for 15 years. Loads in friction units are increasing constantly. When the pointing mechanism for Ion Thruster Alignment Mechanisms (ITAM) used in the telecommunications satellite ARTEMIS was developed in 1995, thermal vacuum life test performed comprised 15000 movements (= 7500 cycles and 12840 degrees total path) of the spindle over 4 revolutions each, performed around a fixed position on one spindle, and performed at −50°C and +70°C. In 2006 the test was performed in two parts, the first part from 0-37500 cycles with a radial screw load of 9 N and around one fixed point, the second part from 37500-61600 cycles with a radial load of 24 N and 1 mm away from the first spindle point [1]. In table 1 presents the comparative characteristics of greases, which were tested for friction in [2-4]. Most often, as a thickener in the greases production, the polytetrafluoroethylene (PTFE) is used. For the greases preparation the different base oils are used. The perfluoropolyalkylether (PFPE) oils are characterized by an increased density, which gives an advantage in elasto-hydrodynamic lubrication. A considerable amount of work has recently been devoted to the study of greases based on multiple alkylated cyclopentane (MAC). The kinematic viscosity at 100°C of a MAC base oils varies from 2 to 20 cSt, and the viscosity index ranges from 71 to 178.

The purpose of the presented work is to compare the lifetime and lubricity of the greases for space.

2. Materials
Greases considered in this study are based on a PFPE oil and a tetrafluoroethylene, an organosilicon or a lithium soap as a thickener. They were developed at VNII NP (Russia), the characteristics and composition are summarized in table 2.

The greases #1 are used for small rolling bearings (at speeds of up to 30000 rpm) and low-power reduction gears, especially operating under conditions of deep vacuum (up to $1.3 \times 10^{-4}$ Pa) in the temperature range of −80°C...+160°C. The grease #2 was developed for lubrication of parts working in contact with aggressive media in the temperature range −110°C ...+200°C and in conditions of deep vacuum. The greases #2 are recommended for use in aerospace and high vacuum. Low-temperature
antifriction grease #3 is intended for use in antifriction bearings operating in vacuum at temperatures from –120°C to +250°C. The grease #4 was developed for lubrication of parts working in contact with aggressive environments, including carbon dioxide, in the temperature range of 130°C...+250°C, as well as in conditions of deep vacuum. The grease #4 is composed of soluble PFPE metallo-cladding additive.

### Table 1. Properties of the grease for space [2-5].

| Trademark     | Base oil          | Thickener | Oil separation (ASTM D6184) %, by weight | Temperature range, °C |
|---------------|-------------------|-----------|----------------------------------------|------------------------|
| 1 Krytox 240AC| PFPE (Krytox 143AC)| PTFE      | 6 (100°C, 30 h)                        | -34…288                |
| 2 MAPLUB PF100| PFPE (Fomblin Z25) | PTFE      | 2.7 (100°C, 30 h)                      | -60…130                |
| 3 MAPLUB SH050| MAC (NYE 2001A)   | PTFE      | 4.2 (100°C, 30 h)                      | -60…130                |
| 4 Rheolube 2000| MAC (NYE 2001)   | Sodium soap | 3.3 (100°C, 24 h)              | -45…125                |
| 5 Braycote 601EF| PFPE (Castrol Brayco 815Z) | ---      | 10.53 (204°C, 30 h using FTM 321) | ---                    |

### Table 2. Grease composition.

| Base oil          | Thickener          | Viscosity at -40°...-50°C, Pa*s | Evaporation in air at +150...+200°C (1 hour), % |
|-------------------|--------------------|---------------------------------|-----------------------------------------------|
| 1 Silicon liquid  | Lithium soap       | 54                              | N/A                                           |
| 2 PFPE            | Organsilicon       | 210                             | 2.5                                           |
| 3 PFPE            | PTFE               | 79                              | 4                                             |
| 4 PFPE            | Organsilicon       | 100                             | 3                                             |

3. Experimental equipment

The authors developed a test method and equipment for bearing lubricant’s evaluation, figure 1. Technical parameters of the bearing test machine: shaft velocity up to 200 rpm; vertical force on the bearing - up to 16 000 N; temperature of the sample at nominal conditions from –70°C to + 180°C.

The thrust roller bearing is used as a sample for tests. The bearing is loaded with the pneumatic cylinder through the arm. The shaft for load transfer from the arm to bearing is installed inside the housing using two radial bearings. The housing is movable in a vertical direction along the guides. The friction moment is recorded with a strain sensor which fixed to the shaft. A computer data acquisition system (cDAQ-9184 chassis and the modules NI 9219, NI 9217, NI 9203, NI 9269) constantly monitored bearing load, temperature and friction moment. The test terminated when a coefficient of friction exceeds 0.015.

The thrust roller bearing 84104 from NTN Company with inner diameter 20 mm, outer diameter 35 mm, roller diameter 5.5 mm is used (figure 2). All tests are performed using a maximum Hertzian stress of 0.9 GPa, a lower bearing ring rotational speed of 50 RPM. The temperature of the bearings under the nominal conditions is 25…30°C.

For the lifetime tests, the greases are applied only to the lower ring. The small amount of grease deposited on the ring (25 to 30 mg) is determined using the O-Haus Advanture balance with an accuracy of ± 0.1 mg. All bearings are made of AISI 52100 steel.

Relative lifetime is determined by calculating the number of the lower bearing ring revolutions to a sharp increase of friction coefficient per microgram of used lubricant

\[ R = \frac{n}{M}, \]

where \( n \) is the number of lower bearing ring revolutions, and \( M \) is the mass of grease.
4. Results
The results of grease lifetime tests are shown in figure 3. All greases are tested thrice with the bearing test machine. The data, reported in figure 3, clearly show the lifetimes of the grease #3 to be much greater than samples #1, #2 and #4 by 1.4 … 3.9 times. The presence of PTFE in the grease #3 improve its lifetime.

The initial friction coefficient of the greases is shown graphically in figure 4.

Figure 1. Test equipment for lubricant evaluation in air (1 – thrust roller bearing, 2 – pneumatic cylinder, 3 – arm, 4 – housing, 5 – strain sensor).

Figure 2. Sample for lifetime grease test.

Figure 3. Normalized lifetimes of the various greases.

Figure 4. Friction coefficient of the various greases.
5. Discussion
When evaluating the performance characteristics of grease, the most difficult and time-consuming procedure is to determine the resource characteristics of the lubricant. A sharp increase of the friction coefficient is the result of the lubricant degradation in the contact. The surface of the lower bearing ring is shown in figure 5. An important feature of the developed test methodology is the providing of rolling friction in the contact.

![Figure 5. Surface of the lower bearing ring after test with grease #1 (magnification x100).](image)

6. Conclusions
The following conclusions are drawn in relation to the tested greases. These conclusions are specific to greases operating at ambient temperatures.

- The lifetimes of the grease #3 with PTFE outperform another grease.
- The performance of the grease #2 is similar to that of grease #4.
- The friction coefficient of the Silicon liquid base oil grease lower than of PFPE base oil greases.

References
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