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Service Life of Magnetic Liquid Vacuum Tribounits

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Abstract

To evaluate the service life of a tribounit with magnetic liquid in a vacuum it is necessary to know the time dependence of dispersed phase growing concentration on the carrier liquid evaporation. According to the molecular-kinetic theory of matter, we determined the evaporation rate and pressure intensity of saturated vapor of single fluid in a vacuum depending on temperature. The solution covers evaporation rate of colloidal systems such as magnetic liquid or magnetic lubricating oil. The obtained equation describes the time dependence of a dispersed phase growing concentration on the carrier liquid evaporation, which allows evaluating magnetic liquid tribounits' service life.

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Keywords: tribounits' service life; magnetic liquid; evaporation rate; magnetic liquid sliding bearing.

Magnetic liquids and magnetic lubricants are becoming more and more popular as a building material for tribotechnical units to increase their quality and extend their rational application area [1-5]. Magnetic liquids are impossible to replace in a number of vacuum sealants due to high reliability and a compact size. Sliding bearings based on magnetic lubricants can work in a hydrodynamic mode friction mode with a low wear rate. Sliding bearings are lubricated with magnetic oil of limited volume that is not retained in them, but goes to a friction zone affected by special heterogeneous thermomagnetic fields. Aerospace equipment designers show more interest in gears that are lubricated with magnetic oil.

A distinctive feature of all mentioned tribounits is that they can operate properly with a small volume of magnetic liquid (oil). Usually, it does not exceed several tens of cubic centimeters. Such volume of a liquid magnetic environment is easily retained by a stationary magnetic field produced by a permanent magnet magnetic system. It is also a mechanism, which is sufficient enough to operate properly for several months or even years.

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If a magnetic liquid friction unit does not work continuously with the boundary lubricating regime (and it is usually the case), then its service life in a vacuum depends on a dispersed environment evaporation rate. Here we assume that the magnetic liquid is good enough and does not lose colloidal stability; destruction processes in a carrier liquid are blocked by special additives.

It is common to use a carrier liquid with low vapor pressure for magnetic liquids in a vacuum. This helps to restrain the phase transition of a liquid into vapor and thereby reduce the evaporation rate. However, it is impossible to neglected dispersed environment mass losses due to low vapor pressure near the surface of the magnetic liquid in a vacuum and its relatively large open surface. The dispersed phase concentration increases in the process of magnetic fluid evaporation. The time to reach its limit (critical) value defines a tribounit’s service life. Mainly, an increase in a solid phase concentration results in an unacceptable increase in viscosity of dispersed environment, and this disturbs the normal operation process of a tribounit.

To estimate a tribounit’s service life in a vacuum it is necessary to know the time dependence of a dispersed phase increase on the carrier liquid evaporation. First, we consider the evaporation process of a single liquid in a vacuum. For this purpose we use the statistical approach proposed by Ya.I. Frenkel [6]. Surface atoms (molecules) of a substance are in random thermal motion. The Maxwell's velocity distribution law implies that there are always atoms that can break the link with neighboring atoms and leave the surface. To be normal to the surface v_z speed should be such that:

$$v_z > \mathrm{v}_{z\,\max} \ge \sqrt{\frac{2\mathrm{L}}{\mathrm{m}}}\,, \tag{1}$$

where m is a molecular mass, L is an evaporation energy of one molecule. It should be noted, that this particular speed corresponds to the most probable atom departure direction. According to Maxwell's law, a relative number of elements with the speed from v_z to $v_z + dv_z$ will be:

$$f(v_z)dv_z = \sqrt{\frac{m}{2\pi kT}}e^{-\frac{mv_z^2}{2kT}}dv_z\,, \tag{2}$$

where T is an absolute temperature, k is a Boltzmann constant. A number of atoms that tend to leave the surface dS for the time dt with the speed from v_z to v_z+dv_z equals to $nf(v_z)dv_z$ where n is the concentration of atoms in a liquid. Then the fluence rate of atoms $I = \frac{dN}{dtdS}$ that cross a potential barrier near the surface is:

$$I = n\int_{v_{z\max}}^{\infty} v_z f(v_z)dv_z = n\sqrt{\frac{m}{2\pi kT}}\cdot\frac{1}{m}\int_{\frac{mv_z^2}{2}}^{\infty} e^{\frac{-mv_z^2}{2kT}}d\left(\frac{mv_z^2}{2}\right). \tag{3}$$

After integrating this equation we have:

$$I = n\sqrt{\frac{kT}{2\pi m}}e^{-\frac{L}{kT}}. \tag{4}$$

Therefore we can determine the evaporation rate, i.e. the mass of the substance that has evaporated from one unit area per unit time $W=I\cdot m$:

$$W = n\sqrt{\frac{mkT}{2\pi}}e^{-\frac{L}{kT}}. \tag{5}$$