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Application of hydrophilic magnetic fluid to oil seal

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Abstract

Bearing and gear are important components in machines. Lubricant for bearing or gear is usually confined in working space by rubber retainer or mechanical seal, and its lifetime which is determined by the friction wear of sealing material is important. In this report, the basic characteristics of magnetic fluid seal applied to lubricant retainer is studied. The fluid used for this purpose is ethyleneglycol-based magnetic fluid in which silica-coated iron particles are dispersed. The lubricant oil seal set consisting of six stages of pole piece and Nd-permanent magnets (4.0 Wb/m^2) in seal housing showed an excellent pressure resistance of 618 kPa under a rotating speed of 1800 rpm. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Oil seal; Lubricant seal; Magnetic fluids

1. Introduction

Magnetic fluid seals have been widely used for keeping vaccum or excluding a working space from dust in the atmosphere. In these applications the resisting pressure per stage of sealing gap is in first-order dependent on the strength of the magnetization of the magnetic fluid and magnetic field distribution around the magnetic tip in the seal. The actual maximum records of resisting pressure are of about 40 kPa per stage, using magnetites-dispersed magnetic fluids. The new type of magnetic fluid which includes silica-coated iron particles, developed by authors, provides magnetic induction 8×10^{-4} Wb m/kg (650 G), higher than the magnetic fluid of the conventional type. This paper describes the experimental result of the application of hydrophilic magnetic fluid containing silica-coated iron particle to an oil seal.

2. Experimental and result

In the magnetic fluid used in this experiment, the size of iron particles coated with amorphous silica is not yet directly determined. The size of magnetite as a raw material of iron particle is of about 10 nm

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in average by TEM observation, before thermal reduction. The magnetites is coated with polymerized hydrous silica compound in aqueous solution, and then is reduced in H_2 gas at 550°C to iron particle coated with amorphous silica. The size of reduced iron particles is dependent on the amount of silica compound used for surface coating, i.e. the larger the amount of silica compound the smaller the size. The iron particles covered with silica (SiO_2/Fe = 0.037 in weight), with the magnetic moment of 1.57×10^{-4} Wb m/kg at 8×10^5 A/m, was stable against oxidation in the air below 150°C. The size of the particles was between 4 and 23 nm by TEM, with mean particle size of 10 nm. The particles are dispersed in ethylene glycol and water, respectively, by using oleate, dodecyl benzene sulfonate and tetramethyl ammonium hydroxide. Fig. 1 shows the change of viscosity in no magnetic field and in 8×10^5 A/m magnetic field, versus the concentration of iron in ethylene glycol as medium. The solid line is the magnetization estimated from iron content in the fluid. The fluid with the iron concentration of 0.7 g/ml is selected for the seal experiment in this study. The viscosity of the fluid is 1.45 Pa s and magnetic induction is 8×10^{-4} Wb m/kg. The water-based magnetic fluid using magnetites as dispersant is also used in the same seal experiments for comparing the results in seal resistance.

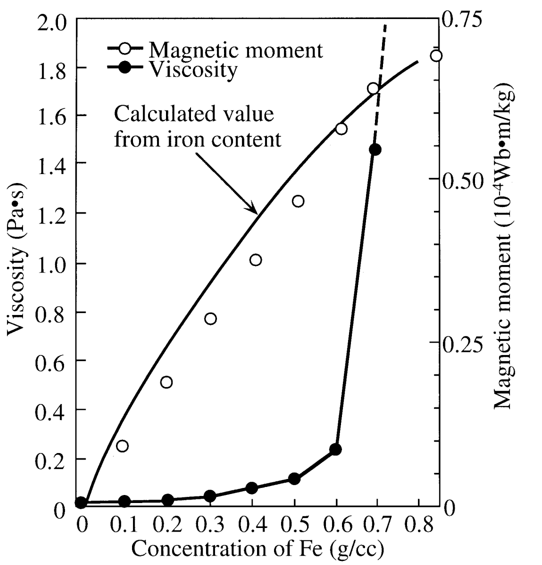

Fig. 1. Viscosity and magnetization of the magnetic fluid as a function of particle concentration.

Fig. 2 shows the arrangement of the magnet and the poles in the seal housing. The diameter of rotation shaft is 23.5 mm, the gap between shaft and pole piece is 0.5 mm, and the dimensions of Nd–B permanent magnet are 48 mm in outer diameter, 33 mm in inner diameter and 7 mm in thickness. Pole piece is made of soft iron, with the thickness of 1 mm with 30° inclination [1] for concentrating magnetic flux (390 kA/m) at the top of the extrusion. The seal housing is made of 18% Cr–8%Ni steel. Magnetic fluid seals of 1–6 stage poles are used for the experiments. The seal is connected to the variable speed motor shaft (0 –1800 rpm), and lubricant oil for diesel engine (CF-4 level in API, Honan Oil Refinery Co.) of 150 ml is filled with bearing part. The lubricant oil is pressurized in the right-hand container with N_2 gas.

Fig. 3 shows the maximum resisting pressure of oil seal under 1800 rpm shaft speed. The magnetic moment of magnetites-dispersed and of the iron-dispersed fluid under external field of 800 kA/m are 2.7×10^{-5} and 6.5×10^{-5} Wb m/kg, respectively. The corresponding pressure resistance of seals are 93 and 618 kPa, showing much larger resistance in iron dispersed magnetic fluid. Two dotted lines in the figure are maximum pressure expected for magnetites dispersed and iron dispersed magnetic fluid from static magnetic potential at pole gaps. The maximum resisting pressure of oil seal using iron particle magnetic fluid is approximately 98 kPa per stage and higher than the value expected from maximum volumetric magnetic energy based on

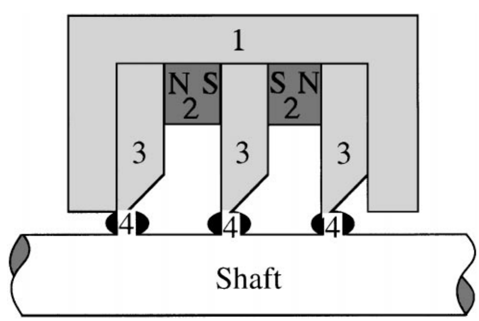

Fig. 2. Cross section of seal with pole piece and Nb–B permanent magnet 1: housing 2: magnet 3:pole 4: MF.

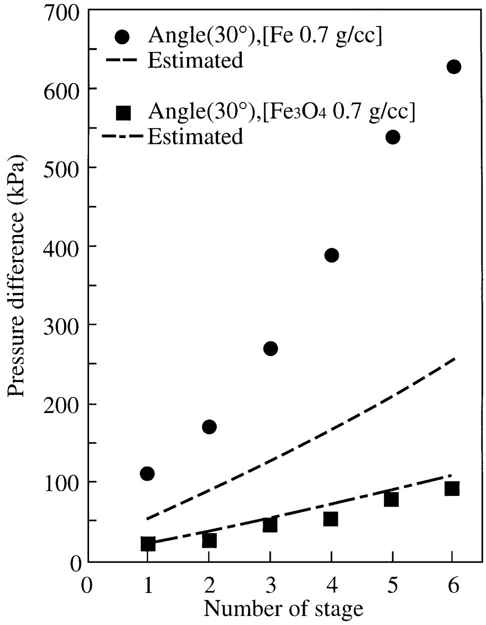

Fig. 3. Pressure resistance of oil seals.

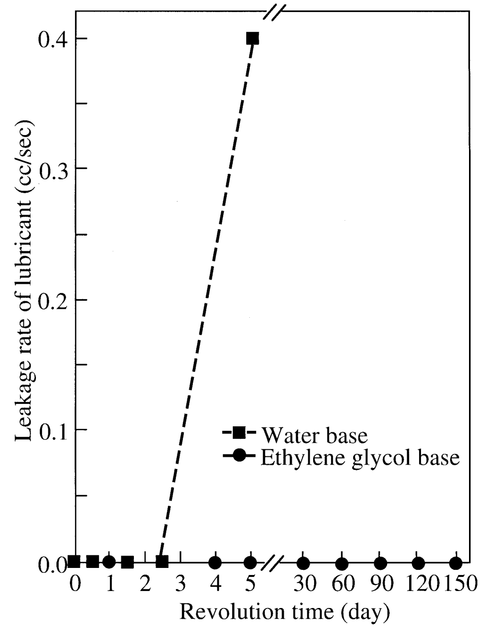

Fig. 4. Lifetime of magnetic fluids in seals.

the magnetization curve of powder, $\Delta P = \int M \, dH$, by more than 2 times. This strong pressure resistance is not explained from a static magnetic energy of homogeneous magnetic fluid model [2]. Presumedly, a strong particle–particle magnetic interaction in the fluid at the pole gap will give an additional contribution to pressure resistance in this system. For example, magnetic particles magnetically interact each other, by keeping some minimum distance between particles by the presence of the surface silica layer without remarkable increase of friction force between them.

Fig. 4 shows the comparison of the leakage of lubricant in the oil seals with ethylene glycole-based magnetic fluid and water-based one. The same iron particles are used as dispersoids for both fluids. The experiments are conducted under the condition of 1800 rpm and 3.7 mPa pressure difference using six stages magnetic seal. The maximum temperature during experiment was less than 50°C in both cases. The seal experiment using ethylene glycol magnetic fluid was continued after 150 days in the figure, for 2 yr except holidays, no leakage was observed. Vapor pressure of ethylene glycol is 0.05 mmHg at 20°C and boiling point is 198°C. These characteristics is thought to be enough to satisfy the practical lifetime of the described oil seal.

3. Conclusion

Magnetic fluid including iron particles coated with silica can be used for long lifetime oil seal, without degeneration of magnetic characteristics of the fluid by oxidation. It is also confirmed in the oil seal experiment that the pressure resistance of the seal can be higher than the theoretical value hitherto expected from a homogeneous magnetic fluid model. From the assumption of the nature of particle–particle interaction, the thickness of the non-magnetic surface film will play an important role for a seal system of this type. Further investigation on the mechanism of seal pressure resistance and rheological properties of magnetic fluid under strong magnetic field is expected.

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