Marcin SZCZĘCH*, Wojciech HORAK**

RESEARCH INTO THE INFLUENCE OF SELECTED PARAMETERS ON CRITICAL SPEED OF THRUST BEARING WITH THE MAGNETORHEOLOGICAL FLUID

BADANIA WPŁYWU WYBRANYCH CZYNNIKÓW NA PRĘDKOŚĆ KRYTYCZNĄ PRACY WZDŁUŻNEGO ŁOŻYSKA ŚLIZGOWEGO Z CIECZĄ MAGNETOREOLOGICZNĄ

Key words: magnetorheological fluid, thrust bearing, critical speed.

Abstract
Magnetic fluids are substances with a complex physicochemical composition. The unique properties of these substances are based on the possibility of reversible, almost immediate, changes in their rheological parameters, as well as changes in the flow direction due to the magnetic field. These properties allow the development of machines and devices with operating parameters that can be changed by the magnetic field. The range of the fluid property changes depends on its composition, magnetic field parameters, operating conditions, and the method of fluid deformation.

The paper presents the results of research into the influence of selected parameters on the critical speed of thrust sliding bearings. These parameters include the magnetic and physical properties of magnetic fluids, the value of the magnetic induction, the fluid volume in the working gap, and the temperature. The results of the conducted research indicate a significant effect of the magnetic field gradient on the critical speed value.

INTRODUCTION

The use of a magnetorheological fluid (MR) in a thrust sliding bearing allows its parameters to be controlled with the magnetic field. This possibility results from the internal structure changes of the fluid. This is because it is a suspension of particles with magnetic properties, such as magnetite or carbonyl iron [L. 1], in a carrier fluid that does not exhibit magnetic properties. These particles are of the size of several dozen microns [L. 2]. In order to reduce sedimentation and agglomeration, the particles are additionally coated with a surface-active substance (surfactant). Dispersing agents, antioxidants, thixotropic additives, or thickeners are also used, e.g., silicon-based agents [L. 3]

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Changes in the rheological parameters of MR fluids are the result of changes in the microstructure of the suspension as a result of the magnetic field influence, which, on the macroscopic scale, is the change in the state of stress in the fluid [L. 4, 5]. Due to the larger particle size, this substance is characterized by a greater range of change in rheological properties than in the case of another type of magnetic fluid – ferrofluid [L. 6]. It is possible to keep the fluid in a specific position by means of magnetic field forces, which may be an important feature, especially in the absence of gravity. These bearings can be characterized by a relatively simple construction, and it is possible to obtain the required rigidity in a much shorter time than is the case in conventional solutions [L. 7]. In addition, pressure is created in the magnetic fluid under the influence of the magnetic field, which is an additional source of bearing capacity and can be used to separate bearing surfaces. The phenomenon of pressure generation results mainly from the creation of molecular chain structures and changes in the internal structure [L. 8, 9, 10].

The research conducted so far on sliding bearings with MR fluid has focused primarily on the determination of basic parameters, such as axial force, friction torque, the modification of the bearing surface, or development of mathematical models describing these systems [L. 11, 13, 14, 15].

In the case of thrust slide bearings with MR fluid, some research was conducted on the determination of the rotation speed at which the fluid is ejected from the working gap, due to the centrifugal force. This rotation speed is defined as the critical speed, and the main functional properties of the bearing are lost if it occurs. The value of critical velocity depends primarily on the density of the MR fluid, the volume percentage of magnetic particles in the carrier fluid, and the geometry of the bearing. The value of this speed can be increased as a result of the modification of the bearing's surface. This can be achieved by creating a magnetic field gradient, which limits the outflow of the MR fluid from the bearing gap. This is called the self-sealing effect [L. 12] and is used, among others, in magnetic fluid seals. In the case of thrust bearings, due to the use of this phenomenon, the supply pump has been eliminated [L. 16].

The aim of this work is to determine the influence of selected properties of the MR fluid and parameters of the thrust bearing on the critical rotational speed of the tested system.

**TEST STAND AND TEST METHOD**

The scheme of the measuring chamber of the thrust bearing with magnetic fluid is shown in Fig. 1. A detailed description of the whole research device is presented in [L. 17]. The measuring chamber consists of a divided housing consisting of the lower (4) and upper parts (5). The electromagnet which contains the winding (7) and core (6) is placed in the bottom part of the housing. The MR fluid (2) is located in the parallel gap between the surface of the rotating element of the bearing (1), made of a material with non-magnetic properties, and the surface of the core of the electromagnet (6). The element (3) is made of a material with non-magnetic properties and limits the excessive ejection of the fluid to the test chamber as a result of the critical speed occurrence. Magnetic field lines (8) have a direction perpendicular to the surface of the electromagnet core.

The research is based on a test that includes a linear increase in the rotational speed with an angular acceleration equal to 0.349 rad/s² and on measuring the torque of the bearing. An increase in rotational speed causes an increase in the torque, but, as a result of the influence at some rotational speed of the centrifugal force, the fluid is ejected from the working gap. This phenomenon is observed as a decrease in the friction torque value. The critical speed (nkr) was the value at which the maximum friction torque of the bearing (Mt_max) was measured. The sample measurement result is shown in Fig. 2a.
All tests were carried out for the gap height of \( h = 0.5 \) mm and different values of the electromagnet current in the wire. The diameters of the magnetic elements \( D_1 \) and \( D_2 \) were 45 mm (Fig. 1b). The measuring chamber was thermally stabilized by the flow of the fluid with the appropriate temperature.

The distribution of the magnetic field along the radial direction of the thrust bearing was determined using the finite element method using ANSYS software. A detailed description of the methodology, boundary conditions, and material data adopted for simulation was presented in a previous paper [L. 18]. It should be noted that the simulation results have been verified and are very consistent with measurements. The distribution of magnetic induction for various current values is shown in Fig. 2b, where the length 0 mm corresponds to the axis of the bearing (electromagnet core). As can be seen, the distribution does not have a constant value over the length. The lowest magnetic field value occurs in the axis, and, on the length of 0 to 15 mm, the value increases by about 7%. Then there is a rapid increase and the maximum value occurs on the edge of the electromagnet core (length 22.5 mm).

The most important parameters of the self-sealing phenomenon in the analysed system are \( B_{\text{min}} \) and \( B_{\text{max}} \). Figure 3a presents the dependence of these parameters as a function of the current value in the wire. In the examined range, the \( B_{\text{max}} \) value grows faster than \( B_{\text{min}} \), but the critical speed value depends on the difference between these parameters \( (B_{\text{max}} - B_{\text{min}}) \) [L. 20].

The tests were carried out using four MR fluids; Basonetic 5030, and Basonetic 2040 (manufactured by BASF [L. 21]), and MRF-122EG and MRF-140CG (manufactured by LORD Co. [L. 22]). Each of the tested fluids is characterized by a different value of saturation magnetization, and their density indicates a different percentage of magnetic particles in the carrier fluid. The properties of these MR fluids are presented in Table 1. In turn, magnetization curves as a function of magnetic induction are shown in Fig. 3b.
Table 1. Physical properties of examined MR fluids
Tabela 1. Właściwości fizyczne badanych cieczy MR

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Density</th>
<th>Dynamic viscosity (B = 0 T, ( \dot{\gamma} = 100 \text{s}^{-1} ))</th>
<th>Saturation magnetization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basonetic 5030</td>
<td>4.12</td>
<td>582.9</td>
<td>791</td>
</tr>
<tr>
<td>2</td>
<td>Basonetic 2040</td>
<td>2.47</td>
<td>1075.7</td>
<td>424</td>
</tr>
<tr>
<td>3</td>
<td>MRF-122EG</td>
<td>2.38</td>
<td>203.4</td>
<td>361</td>
</tr>
<tr>
<td>4</td>
<td>MRF-140CG</td>
<td>3.54</td>
<td>1569.1</td>
<td>698</td>
</tr>
</tbody>
</table>

**TEST RESULTS**

Figure 4 presents the results of the critical speed measurements for four MR fluids. In this case, the current in the wire was \( I = 1.5 \text{ A} \), which corresponds to the value \( B_{\text{max}} - B_{\text{min}} = 0.43 \text{ T} \). The volume of the fluid in the bearing gap was 0.8 ml and the temperature was 25°C. It can be seen that, in fluids with higher saturation magnetization and thus higher proportions of particles in the carrier fluid, there is a decreasing trend in the critical speed value. The difference between MRF-122EG and Basonetic 5030 is about 44%. It should be noted that the MRF-122EG fluid is approximately 42% lower in density.

![Fig. 4. Critical velocity for different MR fluids](image1)

**Fig. 4. Critical velocity for different MR fluids**
Rys. 4. Prędkość krytyczna dla różnych cieczy MR

In the next stage of the tests, the influence of the magnetic induction value on the critical speed was considered. For this purpose, two fluids were selected that were characterized by the highest \( n_{kr} \) value obtained in previous studies, i.e. MRF-122EG and Basonetic 2040. The volume of the applied MR fluid was 0.8 ml and the temperature 25°C.

Figure 5 presents the results of the critical speed measurement as a function of the \( B_{\text{max}} - B_{\text{min}} \) difference. The increases in this parameter to a certain value increase the critical speed. For the MRF-122EG fluid, which has a lower saturation magnetization, the maximum value is obtained at 0.57 T, and for the second fluid at 0.43 T. The upward trend of \( n_{kr} \) is observed only until the fluid is not magnetically saturated, i.e. magnetic induction is below 1 T. The highest magnetic induction value is observed in the region of the electromagnet core edge, so the condition can be expressed as \( B_{\text{max}} < 1 \text{ T} \). As can be seen in Fig. 5, a fast decrease in the \( n_{kr} \) value is observed for the difference of magnetic induction above 0.83 T, which corresponds to \( B_{\text{max}} = 1.35 \text{ T} \).

![Fig. 5. Critical velocity for different values of the magnetic field](image2)

**Fig. 5. Critical velocity for different values of the magnetic field**
Rys. 5. Prędkość krytyczna dla różnych wartości pola magnetycznego

In the next stage of the tests, the influence of the MR fluid volume on the critical speed of the bearing was determined. The volumes of 0.2, 0.3, 0.4, 0.6, and 0.8 ml were chosen, while 0.8 ml represents the total filling of the working gap of the measurement system. The intensity of the current in the electromagnet coil was \( I = 1.5 \text{ A} \), which corresponds to the difference of \( B_{\text{max}} - B_{\text{min}} = 0.43 \text{ T} \). The bearing temperature was 25°C. The results obtained for all four MR fluids are shown in Fig. 6a.

It should be noted that, in the curve trend (Fig. 6a), two ranges of \( n_{kr} \) variation can be distinguished. Reducing the volume of MR fluid from 0.8 ml to 0.4 ml results in an approximately linear increase in critical speed. Further reduction in the applied volume causes an even more intensive increase in the analysed parameter. The higher values of the \( n_{kr} \) speed are observed for the MRF-122EG and Basonetic 2040 fluids, which are characterized by a lower saturation magnetization value than is the case for the other two. In the case of the MRF-122EG and Basonetic 2040 fluids, the results obtained for a volume of 0.2 ml were omitted from the graphs, because, for this value, no critical speed was recorded (for the speed \( n < 700 \text{ rpm} \)). For them, the value...
of the frictional torque after increasing the rotational speed above 500 rpm took a constant value. In addition, during measurement, there was no fluid ejection from the working gap. Such a result may indicate that there was a slippage between the rotating plate and the MR fluid.

In the next stage of the tests, the change in the critical speed was examined as a function of the bearing temperature. In this case, the current in the wire was $I = 1.5$ A. The results of the tests are shown in Fig. 6b. The MRF-122EG and Basonetic 5030 fluids were chosen for the tests because of the smallest and highest saturation magnetization values. An increase in temperature from 25°C to 60°C resulted in an increase in the $n_{kr}$ speed by about 5%. This indicates that the bearing operating temperature has little effect on this parameter, and this small change may be result of the viscosity change in the carrier fluid.

CONCLUSIONS

The value of the $n_{kr}$ speed of the thrust bearing with MR fluid has a significant influence on the functional properties of the system. When the speed is high enough, the MR fluid can be thrown out from the working gap and this is related to the overlapping of several phenomena, i.e. the centrifugal force, which has a crucial effect due to the relatively high density of the MR fluid, and an uneven distribution of magnetic induction inside the working gap. One of the symptoms of this unfavourable phenomenon is the loss of bearing capacity [L. 15].

As research has shown, an important phenomenon that affects the value of $n_{kr}$ is the effect of self-sealing. This is related to the fact that, in the case of a constant value of the magnetic induction, there is no force that would counteract the centrifugal force acting on the MR fluid. The effective use of the self-sealing phenomenon (increase in $n_{kr}$) is associated primarily with the selected fluid, which should be characterized by low density and a low value of saturation magnetization.

The value and spatial distribution of the magnetic induction is the next parameter that has a significant impact on the discussed phenomena. The magnetic induction in the working gap should be lower than the magnetic saturation value of the MR fluid.

The test results indicate that the use of a magnetic field gradient to increase the critical speed is also associated with the appropriate selection of the fluid volume in the working gap. The test results indicate that, along with an increase in the volume, a decrease in the critical speed value is observed.

Due to the multi-criteria influence of the saturation magnetization, magnetic field distribution, and MR fluid volume in the bearing [L. 12, 19], it is to be expected that the choice of these parameters requires optimization analyses.

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