УДК 621.318.3

MOTION RESISTANCE OF MAGNETORHEOLOGICAL FLUID SEALS FOR ROTATING SHAFTS

J. Salwiński, M. Potoczny

AGH university of science and technology, Krakow, Poland

The problem of using the magnetorheological fluids in seals are considered in the paper. The paper is concentrates in the determination of the essential parameter of the sealing, which is the motion resistance. The results of the friction torque (T_f) of seals with the magnetorheological fluid at the rotational movement under the conditions of over pressing for various numbers of sealing stages.

Key words: *motion resistance, magnetorheological fluid seals, rotating shafts*

Seals with magnetic fluid operate due to a formation of a liquid barrier in between sealed zones, which guarantee their high tightness, mainly in gaseous environments. Such seals are contact-less ones and eliminate friction between cooperating surfaces, turning it into the internal friction in liquids.

A magnetic fluid is administered into a single gap or into several small ring sealing gaps closing the magnetic circuit formed by the shaft, magnets and pole pieces. A magnetic field keeps the magnetic fluid inside gaps and concentrates it in zones of a high magnetic field (Fig.1) [6, 7, 8].

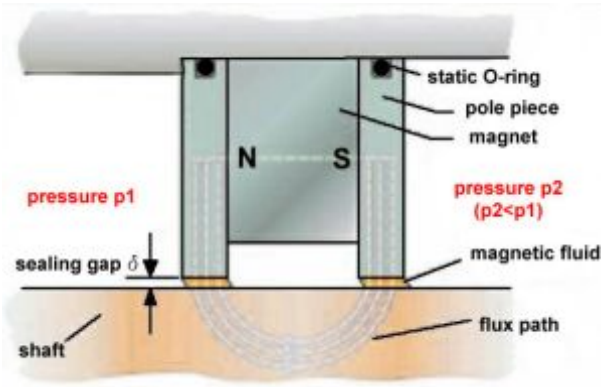


Fig.1. **Model of the seal with the magnetic fluid**

Formulation of the problem

Currently mainly ferrofluids – FF [5, 6] are applied in seals with magnetic fluids. They are characterised by a small friction torque and a high tightness, also under vacuum conditions. One of the most important factors influencing the functional qualities of such seals is the pressure which can be maintained by them. A weakness of magnetic fluid seals

constitutes the possibility of sealing only small pressures of the sealing agent, which results to a large extend, from a low saturation magnetization values of these liquids.

It is quite different in the case of magnetorheological fluids (MR fluids), which are characterised by significantly higher saturation magnetization values. A high saturation magnetization became the grounds on which the application trials of using magnetorheological fluids in the sealing technique, started. High critical pressures obtained in such seals were confirmed in separate research carried out in the world [1, 2, 3] and in Poland [5, 6]. Research concerning sealing with magnetorheological fluids are carried out, among others, in the AGH University of Science and Technology in Krakow.

Objects and methods of investigation

One of the research domains constituted the determination of the friction torque generated in seals with the MR fluid. Especially it concerns the determination of the seals friction torque moments T_f for various number of sealing stages at the steady rotational speed.

Research were performed with the use of the specially designed and built research stand intended for the determination of limiting operating conditions of seals with the magnetic fluid (ferrofluids and magnetorheological fluids), in dependence of their construction and exploitation parameters (Fig. 2), [4].

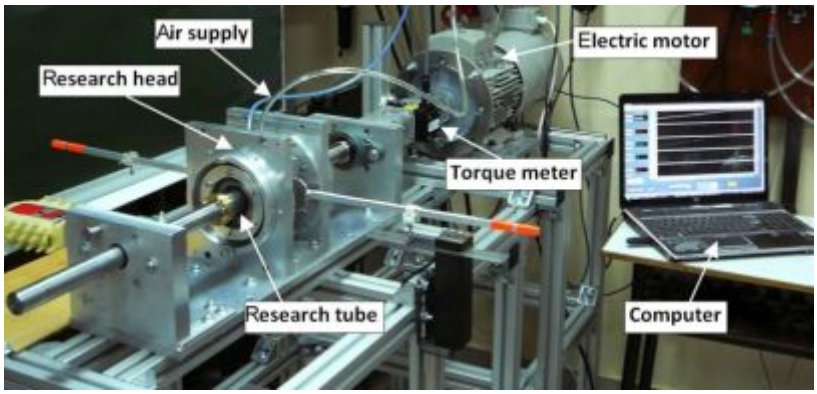


Fig.2. **Research stand**

The stand consists of the research head, driving system, together with the air supply system and computer measuring system. Research tubes with sealing stages constituting - together with the magnetorheological fluid and pole pieces - the sealing node, were assembled in the research head of the stand.

Results and discussion

The measuring gap of the seal

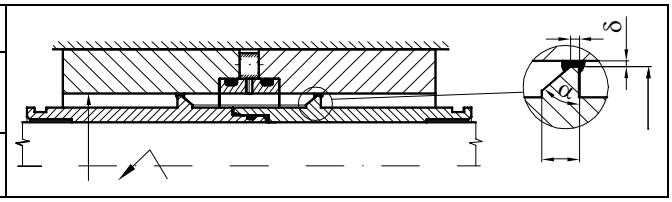
The seal was formed by means of the magnetorheological fluid MRF-122EG of the LORD Company [9] of the saturation magnetization: 270kA/m. Each of the investigated sealing nodes consisted of two research tubes equipped with the same number of stages,

which assembled in pole pieces formed sealing gaps. The liquid volume administered into each gap was determined by the filling factor $\frac{V}{V_n}$. It is the ratio of the liquid volume administered into a gap to the nominal volume $V_n = \pi D \delta t$, resulting from the seal geometry (Table 1).

Table 1

Geometrical parameters of the measuring gap of the seal with the MR Fluid

Geometrical parameters of the measuring gap				
D [mm]	δ [mm]	t [mm]	b [mm]	α [°]
50	0.15	0.6	5	45



Research were performed under conditions of overpressure at the pressure of the working factor being $p = 0{,}5 p_{krd}$ (p_{krd} - critical pressure for sealing in motion). Measurements of the friction torque T_f in multistages seals at the total number of stages: Z_c=2, 4, 6, 8, 10 were carried out. Measurements were done for gaps of a height δ=0.15mm, at a rotational speed n=1000 rpm. Real values of the obtained friction torque were recorded continuously. The diagrams of the friction torque measured for a gap of a height: δ=0.15mm are presented in Fig.3. The higher values of the starting friction torque are seen in diagrams. These values are then decreasing and stabilising and this decrease is more visible when seals contain a higher number of stages.

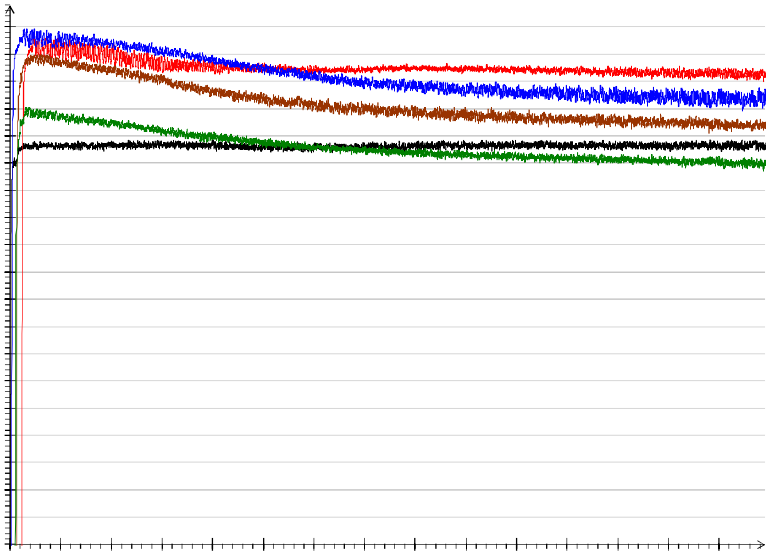


Fig.3. **Actual diagrams of friction torque T_f of a seal at δ=0.15mm for a various number of stages Z_c**

The reading of the friction torque was taken after the preliminary time-history establishing, after approximately 400s. The obtained results for all stages are listed in Table 2. The magnetorheological fluid volume administered into each seal gap is also given in this Table.

Table 2

Friction torque values in seals with the MR fluid

Total number of stages Z_c	Gap height δ[mm]	Filling factor V/V_n	Fluid volume in the gap V [μl]	Total friction torque value T_f [Nm]	Measuring time t_p [s]
2	0.15	10	150	**1.48**	1500
4				**1.74**	
6				**1.80**	
8				**1.60**	
10				**1.50**	

The friction torque values are also presented in the diagram in Fig.4. The measured friction torque values at various number of sealing stages are marked and the trend curve is drawn.

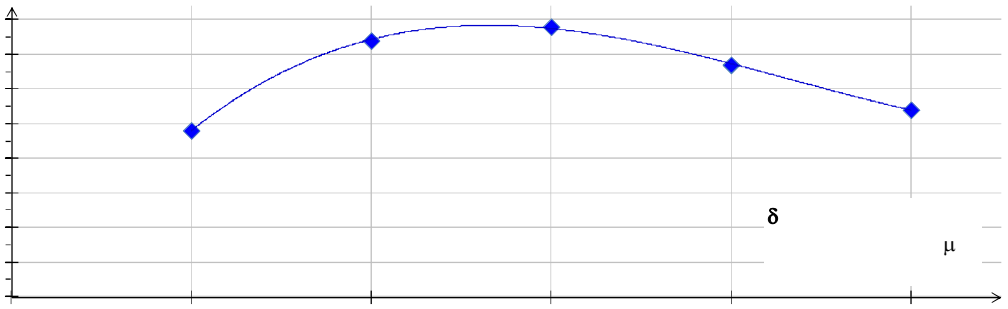


Fig.4. **Friction torque T_f value of seals in dependence of the number of stages Z_c**

In order to determine analytically the friction torque for conditions of sealing under an influence of the magnetic field and under dynamic conditions, the following formula – developed on the bases of the scientific literature and the above presented experimental investigations – was proposed:

$$M_t(B) = 2\pi R^2 t C_t \tau(B)\left(Z_c \frac{V}{V_n}\right)^{1/2}$$

where: $R=D-\delta$ – radius of the turning tube (Table 1 and Fig.5),

t – gap width (Table 1 and Fig.5),

Z_c – number of sealing stages,

$\frac{V}{V_n}$ – filling factor (determining a fluid volume in the gap),

C_t – correcting coefficient, responsible for the friction in the seal, selected empirically,

$\tau(B)$ – shear stress in the magnetorheological fluid:

$$\tau(B) = \eta \frac{\omega R^2}{\left(R^2 - R_2^2(B)\right)}\left(1 + \frac{R_2^2(B)}{R^2}\right)$$

where: $R_2(B) = R + \delta - \delta_0(B)$ – external radius of the gap decreased by the boundary layer thickness δ_0 (Fig.5),

ω – angular speed of the rotating tube,

$\delta_0(B)$ – boundary layer thickness - quasi-solid body, in the magnetic field (Fig.5)

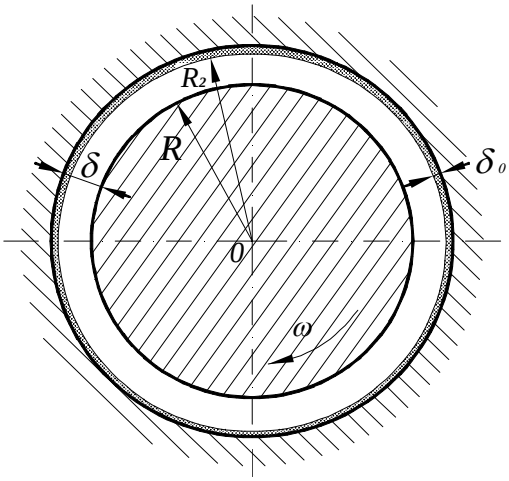


Fig.5. **Ring gap model**

Conclusion

Friction torque values of seals with the magnetorheological fluid for the investigated operating conditions and seals construction are quite significant. These values are decisively higher than in the widely investigated seals with ferrofluids [10, 11]. These is due to large differences of the saturation magnetization values M_s and viscosity η between this kinds of fluids. Owing to higher pressures which can be transferred by seals with the magnetorheological fluids, they can find the technological applications, however the attention should be drawn to the fact that due to significant friction torques their application will be significantly limited.

The results of the friction torque in seals of a various number of sealing stages, indicate that with the increase of their number the friction torque increases, and when their

number exceeds 6 the friction torque begins to decrease. This moment increase corresponds to a larger fluid volume in the seal. Such tendency is maintained up to obtaining the limitation value. The decrease of the friction torque occurring at a larger number of sealing stages is caused by the fact that at a constant magnetic system an increase of the sealing stages number disperses the magnetic field and decreases its concentration in gaps on individual stages. This is the reason that the magnetic field intensity drops below the saturation magnetization of the MR fluid. This leads to the decrease of the dynamic viscosity η of the fluid which influences the shear stresses values in fluids and friction torques in seals.

LITERATURE

1. Fujita T. Characterization of magnetorheological suspension of seal / Fujita T., Yoshimura K., Seki Y., Dodbiba G., Miyazaki T. // Journal of Intelligent Materials Systems and Structures – 1999/ – Vol.10. – P. 770-774.
2. Городкин С.Р. Оценка возможности использования магнитореологических суспензий в уплотнительных устройствах / Городкин С.Р., Кордонский В.И., Протасевич Н.А. // Магнитная гидродинамика – 1988. – № 4. – С. 128-131.
3. Kordonsky W.I., Gorodkin S.R.: Magnetorheological fluid-based seal. Proc. of the 5th Int. Conf. on MR and ER fluids, Sheffield, UK, 1995, pp.704-709.
4. Ochoński W., Potoczny M., Zachara B.: Badanie ciśnienia przebicia w uszczelnieniu z cieczą magnetoreologiczną dla wałów obrotowych – [Study of burst pressure in magnetorheological fluid seal for rotating shafts] // Armatura i Rurociągi ; ISSN 1640-9310. – 2010 R. 10 z. 3 s. 35-38.
5. Potoczny M., Zachara B.: Influence of magnetorheological fluid volume onto obtained critical pressures on rotary shaft seals // Key Engineering Materials ; ISSN 1013-9826. – 2012 vol. 490 Spec. topic volume on Fundamentals of machine design / ed. W. Karaszewski p. 119-127 – ISBN-13 978-3-03785-226-2
6. Ochoński W.: Budowa uszczelnień z cieczą magnetyczną, Przegląd Mechaniczny, nr 8, 1989
7. Орлов Д.В. Магнитные жидкости в машиностроении / Орлов Д.В., Подгорков В.В. – М.: Машиностроение, – 1993.
8. Potoczny M., Szydło Z., Salwiński J.: Pomiar rozkładu pola magnetycznego i ciśnienia przebicia uszczelnienia z cieczą magnetyczną wału obrotowego – XXIII Sympozjon PKM – Rzeszów-Przemyśl 2007

9. http://www.lord.com/Products-and-Solutions/Magnetorheological-%28MR%29/MR-Products.xml (04.05.2011)
10. Ochoński W., Szydło Z., Zachara B.: Experimental study of friction torque of a ferromagnetic seal . Balancing leakage, control and performance: 11th International Sealing Conference Dresden : sealing systems for fluid power applications : May, 3-4 1999 in Dresden : Vorträge Workshopbeträge / Institut für Fluidtechnik der TU Dresden; Fachgemeinschaft Fluidtechnik im Verband Deutscher Maschinen- und Aulagenbau e. V.; Dresden Verein zur Förderung der Fluitechnik e. V. – Dresden : Technische Universität, 1999. – S. 230-236.
11. Ochoński W., Szydło Z., Zachara B.: Badanie szczelności i oporów tarcia w uszczelnieniu z cieczą magnetyczną. Uszczelnienia i technika uszczelniania maszyn i urządzeń. IX Międzynarodowa Konferencja. Wrocław–Polanica Zdrój, 2001 / pod red. Marka Gawlińskiego. – Wrocław : SIMP Ośrodek Doskonalenia Kadr, 2001. s. 230-231.

Ю. Салвіньскі, М. Поточни

Опір руху ущільнювачів з магнітореологічною рідиною для валів обертання

У статті розглянуто проблему використання магнітореологічної рідини в ущільнювачах. Метою роботи є визначення ключового параметра ущільнення – опору руху. Представлено результати моменту тертя (Т) ущільнювачів з магнітореологічної рідини.

Ключові слова: *опір рух, ущільнювачі з магнітореологічною рідиною, вали обертання*

Ю. Салвиньски, М. Поточны

Сопротивление движения уплотнителей с магнитореологической жидкостью для валов вращения

В статье рассмотрена проблема использования магнитореологической жидкости в уплотнителях. Целью работы является определение ключевого параметра уплотнения – сопротивления движения. Представлены результаты момента трения (Т) уплотнителей с магнитореологической жидкости.

Ключевые слова*: сопротивление движения, уплотнители с магнитореологической жидкостью, валы вращения*

