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MAGNETIC FLUID SEALS FOR BEARING ASSEMBLIES OF MINE MAIN VENTILATION FANS

The conditions of the work of main ventilation fans and their impact on the reliability of the seal bearing fan assemblies are analyzed. The application of magnetic fluid seal complexes instead of regular seals is proved.

Computer simulation of nonlinear magnetic processes in the core of magnetic fluid seal (MFS) numerical finite element method using the software package Comsol by varying the gap in the range of 0.1...1.0 mm was carried out. The technique is described in detail.

The calculation was performed in two stages. In the first stage distribution was calculated in static magnetic field (MF) in the active zone of the seal considering the nonlinear characteristics of magnetic circuit and the magnetic fluid in the magnetic saturation assuming $M = Ms$. It identifies the position of the MF boundary limited by isobars $p = Ms \cdot B = \mathrm{const}$, where $B = |B|$ – magnetic induction vector module. In the second stage hydrodynamic processes in MF while the shaft rotates under the assumption that the magnetic fluid boundaries coincide with boundaries of liquid in static conditions were calculated. At the same time we take into account the empirical nonlinear dependence of the viscosity MF on the magnetic field and the nonlinear properties of the Navier-Stokes equations. Thus, the problem in two stages regarded as loosely coupled, which allowed to perform consistent solution.

The developed mathematical model of magnetic and hydrodynamic processes occurring in the seal gap allowed to design and implement optimized design of magnetic fluid sealing complex (MFSC) for two main ventilation fans of various types considering the increasing gaps in the work area of seal.

Analysis of operating experience MFSC proves the prospects of their application in the main ventilation fans (MVF).

The research results are confirmed by experimental-industrial exploitation of MVF with installed with sealing complexes. MFSC tests were carried out on the mine axial fan ВОД-30М (m. Ternovskaya, Pavlograd) and centrifugal mine fan ВЦ-25 (m. Yubileinaya, Pavlograd).

Key words: *magnetic fluid seal, magnetic fluid, the main ventilation fan.*

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МАГНІТОРІДИННІ ГЕРМЕТИЗАТОРИ ДЛЯ ПІДШИПНИКОВИХ ВУЗЛІВ ШАХТНИХ ВЕНТИЛЯТОРІВ ГОЛОВНОГО ПРОВІТРЮВАННЯ

Проаналізовано умови роботи вентиляторів головного провітрювання та їх вплив на надійність ущільнень підшипникових вузлів вентиляторів. Обґрунтовано застосування магніторідинних герметизуючих комплексів замість штатних ущільнень.

Тому було проведено комп'ютерне моделювання взаємопов'язаних нелінійних магнітних та гідродинамічних процесів в активній зоні магніторідинного герметизатора (МРГ) чисельним методом кінцевих елементів за допомогою пакету програм Comsol при варіюванні зазору в діапазоні 0,1…1,0мм.

Розрахунок виконували у два етапи. На першому етапі розрахували розподіл у статичних умовах магнітного поля в активній зоні герметизатора з урахуванням нелінійних характеристик магнітопроводу та у припущенні насичення магнітної рідини (МР) M = Ms. При цьому визначали положення кордону МР, обмежене ізобарами p = = Ms · B = const, де B = |B| – Модуль вектора магнітної індукції. На другому етапі розраховували гідродинамічні процеси в МЖ при обертанні валу в припущенні, що межі магнітної рідини збігаються з межами рідини в статичних умовах. При цьому враховували нелінійну емпіричну залежність в'язкості МР від величини магнітного поля та нелінійні властивості рівняння Нав'є-Стокса. Таким чином, завдання на двох етапах розглядали як слабко пов'язані, що дозволило виконати їхнє послідовне рішення.

Розроблена математична модель магнітних та гідродинамічних процесів, що відбуваються в зазорі герметизатора, дозволила спроектувати та впровадити оптимізовані конструкції магніторідинного герметизуючого комплексу (МРГК) для двох вентиляторів головного провітрювання різних типів з урахуванням підвищених зазорів у робочій зоні.

Аналіз досвіду експлуатації МРГК доводить перспективність їх застосування у вентиляторах головного провітрювання (ВГП).

Результати досліджень підтверджено дослідно-промисловою експлуатацією вентиляторів головного провітрювання із встановленими герметизуючими комплексами. Були проведені випробування МЖГК на осьовому шахтному вентиляторі ВОД-30М (ш. Тернівська, м. Павлоград) та відцентровому шахтному вентиляторі ВЦ-25 (ш. Ювілейна, м. Павлоград).

Ключові слова: *магнітнорідинний герметизатор, магнітна рідина, вентилятор головного провітрювання.*

Formulation of the Problem

Any modern mine has a large high-performance ventilation systems to pump the air out of the mine. Themselves fans can be both centrifugal and axial. As a conventional sealing the bearing assemblies are commonly used seal, consisting of several elements – the centrifugal drop ring mounted on the surface of the shaft, groove seal, formed the central part of the bearing unit lid and placed in the groove cover rubber reinforced lip seal with spring. The protective sleeve is installed on shaft that protects the shaft from abrasion by sealing lip.

At first glance, the lip seal is in optimal conditions (rich lubricating of sealing lips, high, but not outrageous speed, high quality surface of the protective sleeves, roller bearings, etc.) and seal bearing unit will work well for a long time. The main factor that greatly complicates the lip seal and seal on the whole, are the working conditions in the mine [1].

Main ventilation fans, when working on the absorption, moves mine air, different from the atmospheric because of presence in it of various gases, vapors, acids, significant number of small coal, dust and water. The large amount of solids in the pumped air to the bearing assemblies of axial fans is a major factor adversely affecting the work of bearings units. Intensively getting of particles under lip of lip seal wear the shaft surface and reduce seal sealing ability, expressed s an increase in oil leakage and ingress of solid particles in the lubricating oil in the bearings, which can lead to very negative consequences. Moisture and corrosive gases also penetrate into the bearing assembly, contributing to reduced reliability and performance as the bearing assembly and the fan in general.

It is possible to eliminate the negative impact on the mine atmosphere on sealing lips by installing a hermetic seal in front of the lip seal, guaranteed detaining abrasives particles, moisture, and corrosive gases. Really as such seal may only be used magnetic fluid seal, which is really almost airtight seal. By and large, the magnetic fluid seal has only one drawback – when sealing fluids, in MFS is possible the hydrodynamic mixing of sealed medium and magnetic fluid, which will lead to a malfunction of MFS (problems arise at high linear velocities in the gap and/or held high pressure drop) [2, 3].

In this case, when MFS is installed outside of lip seal, these two types of seals reinforce strengths and compensate for each other's shortcomings – the MFS unit protects against ingress of solid particles on the outside, pushing them out of the working gap filled with magnetic fluid cuff, the lip seal, working in plentiful greasing prevents leakage of lubricating oil from the bearing assembly and oil from entering the working gap of MFS.

The best solution is to combine the two sealing elements – the lip seal and the MFS – in one design as a combined seal or MFSC [4].

Research Methodology

The function of the sealing element in MFS performs magnetic fluid, retained in the gap between the shaft and pole pieces of MFS by magnetic field of permanent magnets. The gap is typically of 0.2–0.25 mm mainly due to the technical and technological capabilities provide running clearance for the bearing unit or the mechanism as a whole.

However, working gap for MVF in MFS has to be increased up to 0.4–0.7 mm, and even up to 1 mm. This is due primarily to the significant size of shafts and bearings, for which the own radial gaps will increase; to the operating conditions when wet dust adheres of on the fan impeller blades and causes its imbalance and the appearance of the mechanism vibration; and with a significant aging of MVF (about 80 % of the fans are operated with exceed of the the resource established by enterprises – manufacturers today) and the poor quality of repair work.

With an increase in the working gap will be a sharp weakening of the magnetic field and, as a consequence, the deterioration of the sealing properties of MFS. However, questions of exploitation of MFS with the gaps of more than 0.3 mm are almost not discussed in the literature.

In addition, the diameters of shafts and linear velocities in the gap, typical for MVF, become a tangible negative effect of the centrifugal forces acting on the magnetic fluid in the working gap [5].

Therefore, for a clear understanding of the behavior of the magnetic fluid in the gap of mine fans MFS must take into account the high speed and the effect of centrifugal force, and the possible weakening of the magnetic field, and the uneven flow in the gap caused by the radial runout of the shaft, as well as other factors.

It is particularly important to know the distribution of the magnetic field in the gap of MFS. This question is not studied because of sharply inhomogeneous magnetic field in the gap, complex geometry because of teeth on pole pieces, non-linear characteristics of permanent magnets, pole pieces and magnetic fluid. Even the use of numerical methods for the calculation did not give significant results due to the high complexity of the calculations. Only in recent years, the development of computer technology has allowed to solve such problems. However, work on the distribution of the magnetic field at the gaps in excess of 0.2 mm, to date, does not exist.

The purpose of the work

The aim of this work is computer simulation of nonlinear magnetic processes in the core of MFS numerical finite element method as a basis for recommendations to improve the design of MFS and to generalize the use of MFS for the repair and modernization of MVF in mines.

Results and Discussion

Data on the distribution of the magnetic field in the gap is needed to understand the behavior of MF in the MFS gap, as all the main characteristics of the seal are determined by the parameters of the magnetic field. Therefore, computer simulation of nonlinear magnetic processes in the core of MFS numerical finite element method using the software package Comsol by varying the gap in the range of 0.1...1.0 mm was carried out. The technique is described in detail in [6].

The calculation was performed in two stages. In the first stage distribution was calculated in static magnetic field in the active zone of the seal considering the nonlinear characteristics of magnetic circuit and the magnetic fluid in the magnetic saturation assuming $M = Ms$. It identifies the position of the MF boundary limited by isobars $p = Ms \cdot B = \text{const}$, where $B = |B|$ – magnetic induction vector module. In the second stage hydrodynamic processes in MF while the shaft rotates under the assumption that the magnetic fluid boundaries coincide with boundaries of liquid in static conditions were calculated. At the same time we take into account the empirical nonlinear dependence of the viscosity MF on the magnetic field and the nonlinear properties of the Navier-Stokes equations. Thus, the problem in two stages regarded as loosely coupled (classification [7]), which allowed to perform consistent solution.

The examined MFS (Fig. 1) is characterized by the axial symmetry hence the field problem can be solved in two-dimensional formulation in the cylindrical coordinate system in $r0z$ plane. The computational domain for the magnetic field analysis is shown in Fig. 1b and contains the regions with the magnetic materials of three types: the permanent magnets, the magnets that magnetized in the axial direction, the ferromagnetic material of the magnetic system poles, and the rotational shaft, as well as the region occupied by the ferrofluid.

The calculation results are presented in Fig. 2 and 3. The predicted decrease the induction should be noted (Fig. 4).

It is an interesting fact that when δ> 1,0 mm, the highly inhomogeneous field is no longer observed, which reached at the presence of the magnetic flux concentrator. In Fig. 3 clearly shows the absence of the peak areas, which generally indicates a lack of a magnetic field to keep the fluid in the gap.

While solving the hydrodynamic problem of a magnetic fluid flow in the MFS gap the following assumptions were made: the position of free MF borders in dynamics during the rotation of the shaft coincides with the boundary in the static; distribution of the magnetic field in the gap of MFS at the given position of the boundary MF coincides with the calculated field distribution (see. Fig. 2).

Hydrodynamic calculation showed that for typical operating conditions of MVF (speed is less than 1000 rev/min) vortex structures for all values of the gap up to 0.8 mm inclusive, in the magnetic fluid do not arise.

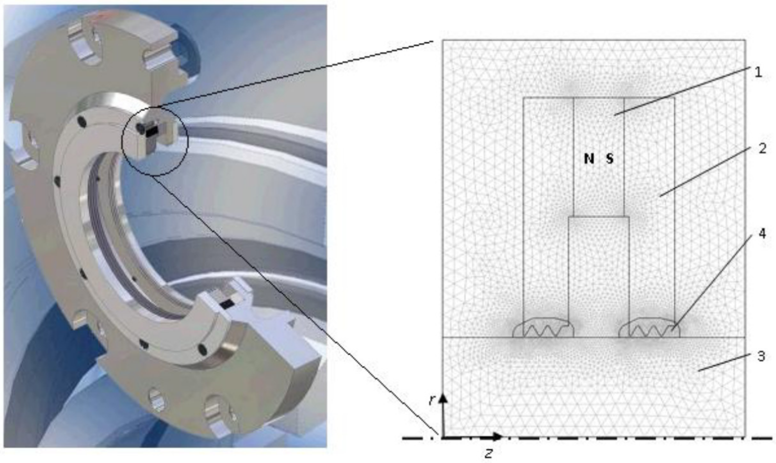
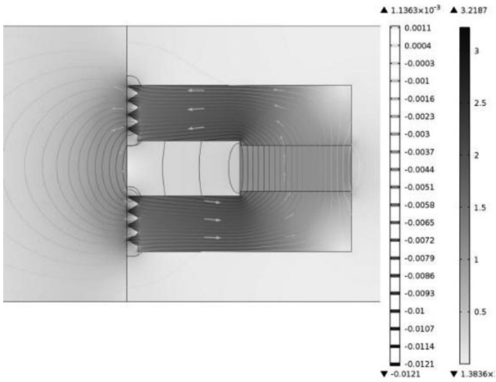


Fig. 1. MFS design scheme
General view of a MFS standard design (*a*) and the core estimation area with the applied finite element mesh (*b*) (1 – permanent magnet, 2 – pole piece, 3 – magnetic fluid 4 – shaft)



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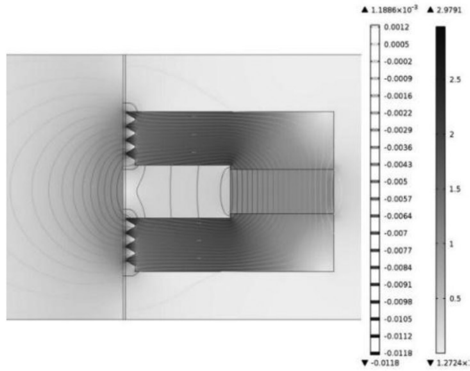

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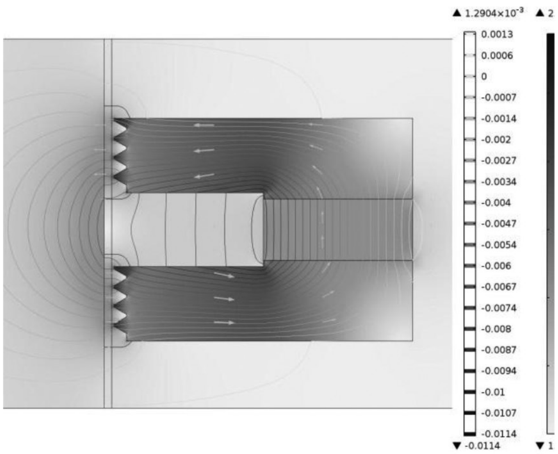

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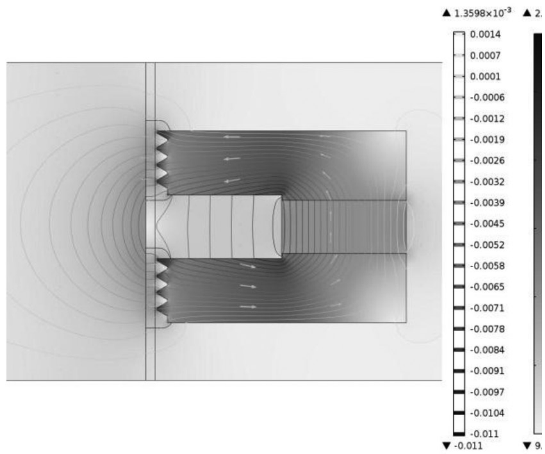

d

Fig. 2. The distribution of the magnetic field lines (isolines $A_{\varphi}r$), as magnetic induction, mm:
***a* – 0.1; *b* – 0.4; *c* – 0.7; *d* – 1**

Fig. 5 shows the structure of the vortex originating in the magnetic fluid and formed by radial and azimuthal velocity components at a gap of 1.0 mm. The structure with the highest speed of the vortex appears in the rightmost field, which is caused by the presence of large size free liquid boundary. There are also vortex structures in other slot regions; however, the maximum velocity therein is several times less intense due to braking of fluid by surrounding magnetic circuit wall.

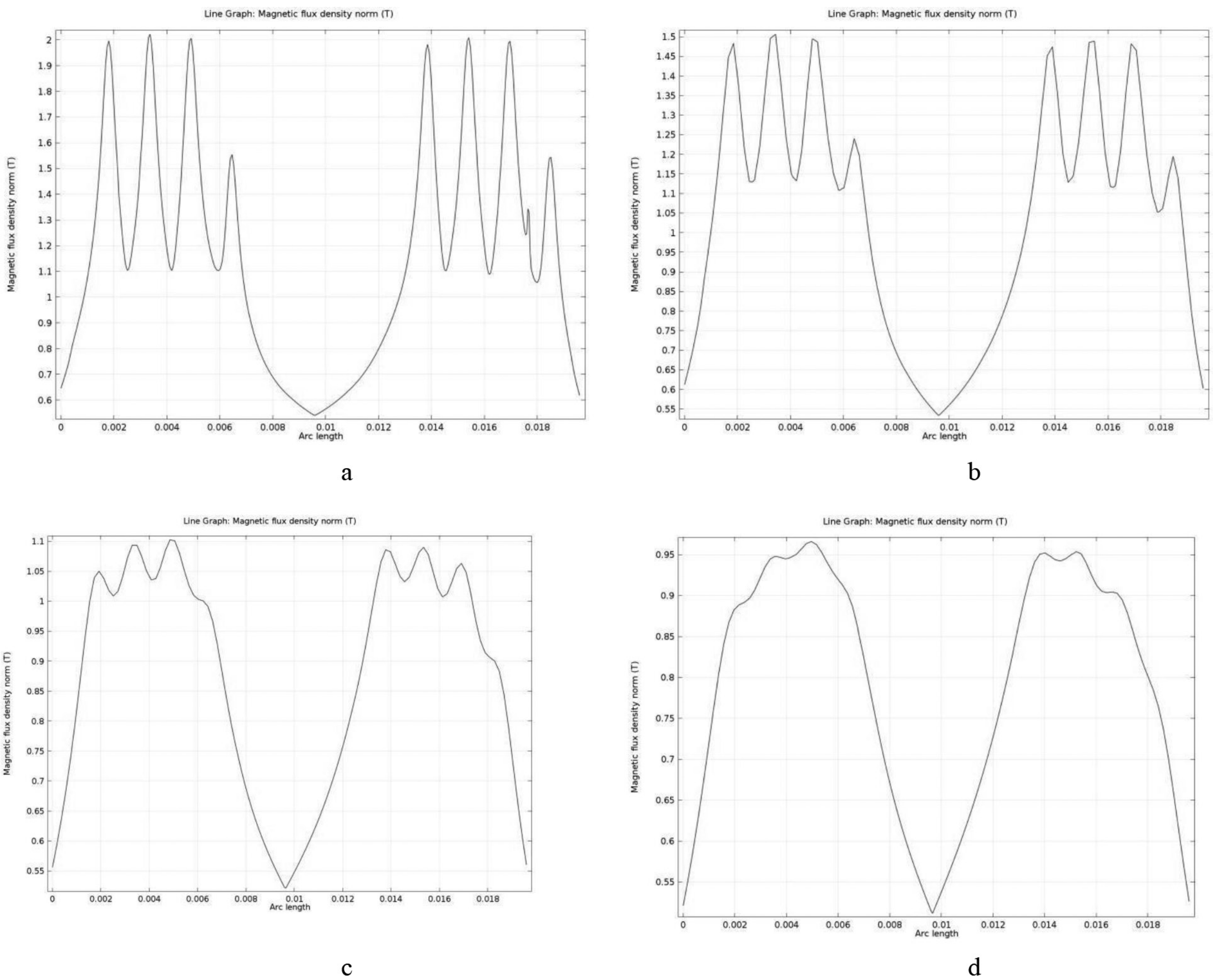

Fig. 3. The distribution of radial component of magnetic induction on the surface of the shaft at the gap, mm:
***a* – 0.1 mm; *b* – 0.4; *c* – 0.7; *d* – 1**

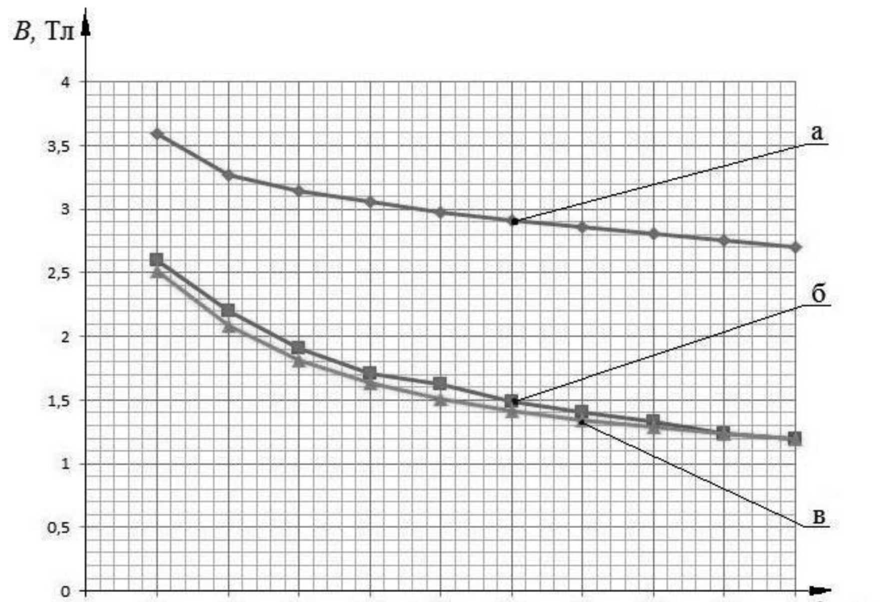

Fig. 4. The distribution of the magnetic field induction of the magnetic flux concentrator to the shaft:
***a* – on a magnetic flux concentrator; *b* – in the middle of the gap; *c* – near the shaft surface**

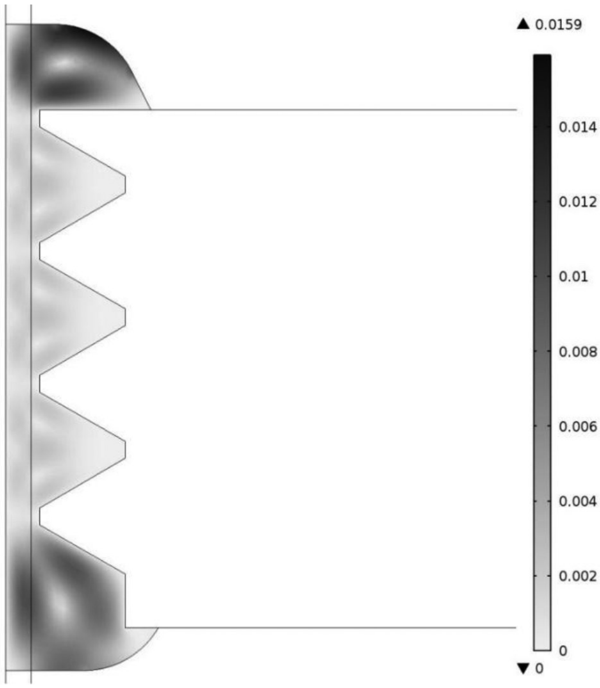

Fig. 5. Vortex structures arising in the magnetic fluid and formed by the radial and azimuthal velocity components

Hydrodynamic calculation results showed that the range of the working gap can be increased to at least up to 0.8 mm.

Tests of MFSC on main ventilation fans

MFSC tests were carried out on the mine axial fan ВОД-30М (m. Ternovskaya, Pavlograd) and centrifugal mine fan ВЦ-25 (m. Yubileinaya, Pavlograd)

Design of MFSC of bearing fan assembly ВЦ-25 is shown in Figure 6 [4].

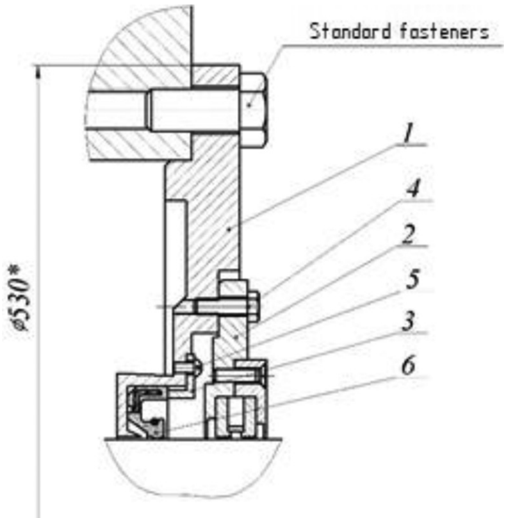

Fig. 6. Magnetic fluid sealing complex of bearing assembly fan ВЦ-25: 1 – intermediate flange; 2 – M10 bolt; 3 – MFS; 4 – bolt M5; 5 – cutting ring 6 – cuff 250 × 290

The complex consists of an intermediate flange 1 and MFS 3. The end face of the intermediate flange has 10 holes M6 for fixing the actual MFS 2 and the annular cavity, which houses the rubber-reinforced cuff 6, which serves as the pre-compression stage.

MFS design is shown in Fig. 7. Magnetic fluid sealer includes a non-magnetic body 1 with a flange, of the magnetic system and nonmagnetic outer cover 2. The magnet system consists of magnets of Nd-Fe-B 6 disposed between two pole pieces 4 and a non-magnetic spacer ring 6. At the surface facing the shaft cut surfaces of the annular pole pieces prongs with grooves between them. The front surface of the cover 4 has a hole for threading the magnetic fluid, choked by bolt M5.

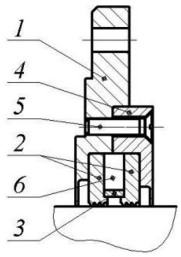

Fig. 7. Magnetic fluid seal fan ВЦ-25: 1 – a non-magnetic body; 2 – a cover; 3 – bolt M6; 4 – pole tip; 5 – magnet Nd-Fe-B; 6 – the spacer ring

Magnetic fluid confined by a magnetic field forms a kind of liquid oil seal that prevents ejection of the oil droplets and vapors from the bearing housing. This oil will be mostly clipped by cuff, and already flying out of its working edge drops and oil mist will be sealed by MFS. Oil stopped by MFS and collected in the cavity between the cuff and MFS, drilling will come back into the cavity of the bearing assembly.

Cuff, which has an outside protection from the penetration of the dust into the working edge, works in almost perfect conditions of abundant lubricant that provides long-term work of assemblywithout the need to replace it.

Construction of MFSC for ВОД-30М fan is shown in Figure 8, 9 [8].

MFSC is made detachable, like the bearing fan assembly cover.

The sealing complex consists of three parts – the big body 1, repeating outer part of the standard cover bearing assembly and MFS mountable with the help of standard bolts 2, mounted on the end of a large body, and the front cover (“boot”) 3. In the cavity between them cuff 4 is located – which serves as the pre-compression stage. MFS 2 is fixed on the face of a large body 1 by bolts 5.

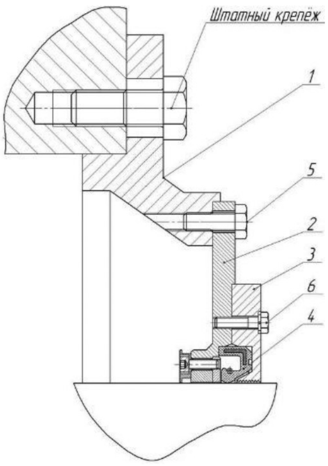

Fig. 8. The seal of the bearing assembly: 1 – the big body, 2 – MFS, 3 – front cover (“boot”), 4 – cuff 300 × 340, 5 – bolt M10, 6 – bolt M6

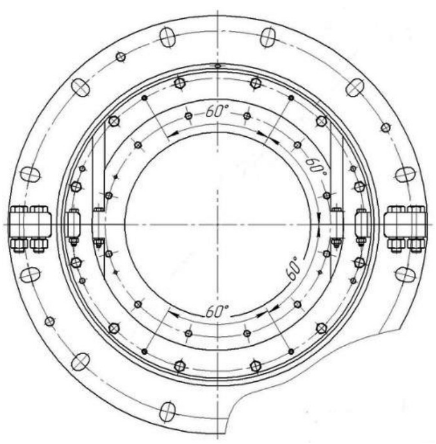

Fig. 9. The seal of the bearing assembly. Front view

Magnetic fluid seal consists of a body with a flange and the magnetic system.

The front cover ("boot") 3 serves as the second pole piece in the MFS, is inserted into the groove on the end face of the flange MFS and clung to it by bolts 6 M6. On the facing surface of the shaft surface of the front cover ("boot") 3 the magnetic flux concentrator are cut – ring prongs with the grooves between them. The outer cylindrical surface of the MFS flange 2 has an opening for filling the magnetic fluid, choked by screw M5.

MFSCs for the centrifugal fan of ВЦ-25 were installed in 2010, and on the axial fan ВОД-30М in 2011. Already at that time the fans had been operated with a significant excess of the resource specified by the manufacturer of this equipment. Maintenance personnel of mines controlled the performance of MFSC every month. Oil emissions were not observed after four years of operation. During 2014–2015 years new main ventilation fans have been installed in the mines.

Conclusions

The developed mathematical model of magnetic and hydrodynamic processes occurring in the seal gap allowed to design and implement optimized design of MFSC for two main ventilation fans of various types considering the increasing gaps in the work area of seal.

Analysis of operating experience MFSC proves the prospects of their application in the MVF.

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