NUMERICAL MODEL OF INDUCTION PUMPS ON ROTATING PERMANENT MAGNETS

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Abstract: A disks type electromagnetic induction pump based on permanent rotating magnets is studied numerically. The theoretical analysis of such pumps is cumbersome since the magnetic field and, hence, the induced electromagnetic forces are distributed non-uniformly in both radial and transverse directions. In this work, the 3D numerical model of a liquid metal flow in a semi-circular duct between two rotating disks is being developed. A finite element analysis is performed using ANSYS software.

1. Introduction

Electromagnetic (EM) pumping technology is being extensively used nowadays in a variety of industrial and research applications, including liquid metal flow control in cooling circuits. Different types of EM pumps are being designed to generate the molten metal movement. In EM induction pumps on permanent magnets (PMP) [1] an alternating travelling magnetic field which induces electromagnetic driving forces in liquid metal is generated by the system of rotating magnetic poles of alternating polarity. Theoretical analysis and experimental tests demonstrated the significant advantages of PMPs in comparison with traditional EM pumps based on 3-phase linear inductors, such as: simpler construction due to the absence of windings, smaller dimensions and size, and much higher efficiency [2-4].

One of the possible modifications of the PMP is the disk-type design concept shown in fig. 1. The active magnetic system consists of two solid ferrous disks with permanent magnets fastened on them in the radial direction. The flat bent channel of the pump with liquid metal, having a rectangular cross-section, is located between the disks. The main parameters defining the efficiency of the disk-type PMP is the magnetic field strength and its distribution in the liquid metal layer in the pump channel.

The design of reliable and more powerful EM pumps requires increasing their efficiency and improving the output parameters (developed pressure and flowrate). However, the experimental investigations of EM induction pumps and the disks-type PMPs in particular, are associated with technical and economical difficulties. The theoretical prediction of disk-type PMP parameters is also complicated since the problem is highly three-dimensional, and the magnetic field, and consequently the electromagnetic forces are non-uniformly distributed both in radial direction and also across liquid metal layer in the channel of the pump and in electrically conducting walls of the channel. In this regard, the numerical simulations of the problem seem to be an appealing alternative from both practical and financial point of view.

In this work, the numerical model of the disk-type induction pump based on rotating permanent magnets is developed. ANSYS software is used to conduct the EM simulations of the pump performance.

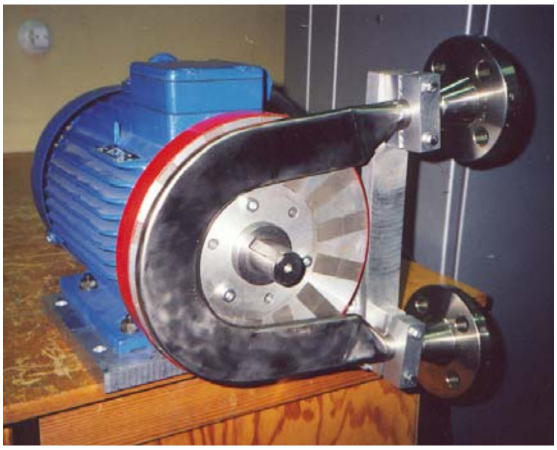

Figure 1: Photo of a typical disk-type the EM induction pump with permanent magnets (the second disk is removed).

2. Disk-type PMP design

The disk-type PMP 3D model created in ANSYS is illustrated in fig. 2. The pump consists of two basic parts: rotor (two rotating disks with installed permanent magnets) and stator (C-shape stainless steel channel carrying liquid metal).

The outer radius of magnetic system is 230 mm. The solid ferrous yoke has a thickness of 12 mm. The permanent magnets are located in the radial direction around the disk and fastened on the aluminium base. Each magnet has a rectangular form (60x30x20 mm^3) and the residual magnetization of Br = 1.1 T. The total of 16 magnets with sequentially altering polarities is placed on each disk with poles facing the channel side walls (i.e. the magnetic polarities are oriented along the rotation axis).

The pump channel with Wood's metal has a rectangular cross-section (with the liquid metal layer of 11 mm thickness and 70 mm height), and the mean radius of the C-shape part of the channel is 114 mm. The inner and outer steel channel walls are 3 mm thick, and the side walls are 2.5 mm thick. The distance between the magnetic disks ranges from d = 20 mm up to its maximal value d = 48 mm, with the air gap between both sides of the pump channel and a disk surface changing from 2 mm up to 16 mm.

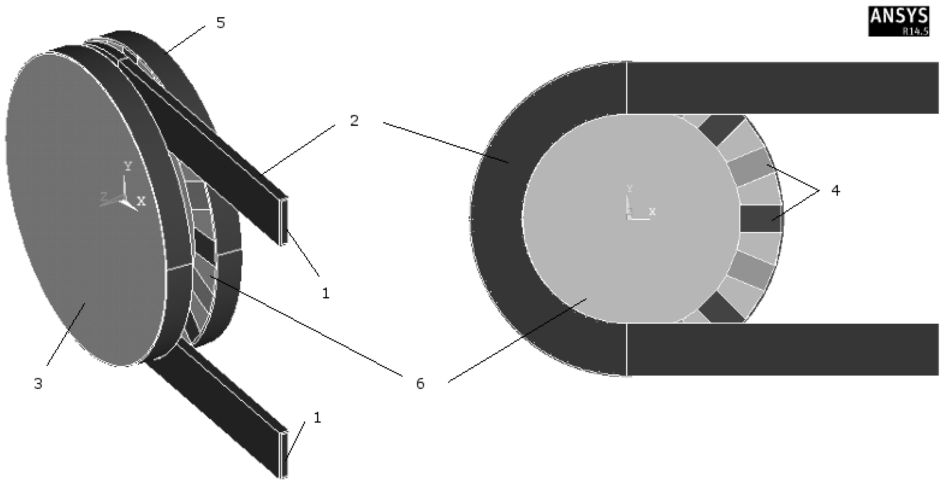

Figure 2: 3D model of disk-type PMP: 1 – liquid metal; 2 – pump channel (steel); 3 – ferrous yoke; 4 – permanent magnets; 5 – steel ring; 6 – aluminium base. The air volume and the second disk (on right image) are not shown.

The two magnetic disks rotate simultaneously with the frequency f (rev/s) generating an altering magnetic field, B, in the volume of the pump channel. The cross product of the current density field, j, induced in the conducting media (both liquid metal and the steel wall), and the magnetic field intensity, B, is a three-dimensional field of electromagnetic volumetric forces distributed along the pump channel, *Fmag*:

$$\vec{F}mag = \vec{j} \times \vec{B} \tag{1}$$

3. Simulation procedure and results

The simulation of an EM pump requires solving both electromagnetic and fluid dynamic equations. In most of industrial processes involving liquid metals (such as pumping) the low magnetic Reynolds number assumption can be used. This means that the electrical current generated by the fluid flow does not significantly affect the magnetic flux, whereas the flow itself is strongly governed by the magnetic field [5]. Since both fields are uncoupled, the numerical analysis and computations are significantly simplified. The Lorenz force (1) resulting from the solution of the electromagnetic problem introduced as a source force for the fluid-dynamic simulations.

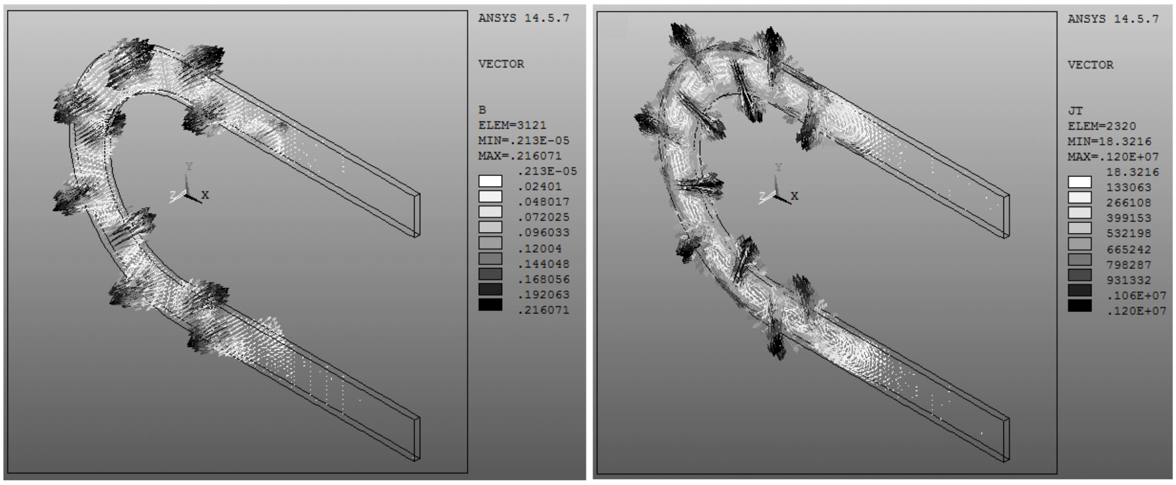

Figure 3: Distribution of (left) magnetic field intensity, B (T), and (right) total current flux density, jt (A/m3), in the liquid metal layer; d = 40 mm, f = 8 rev/s.

This paper presents the work concerning the first step of the numerical analysis - electromagnetic simulations and their experimental validation. The finite element method (FEM) analysis is conducted using ANSYS 14.0 commercial software. The transient dynamic calculations are performed simulating one full cycle (T=1/f) of the 3D magnetic system rotating at the speed of up to f =24 rev/s. The total number of elements exceeds 1.1×10^5, with about 4×10^3 liquid metal elements in the pump channel.

The parameters of interest, provided by the ANSYS solutions, are: the electromagnetic force field, magnetic field, electrical current density both in the liquid metal layer and the steel channel wall, as well as the total Joule heat produced in them.

Fig. 3 and fig. 4 show the vector fields of magnetic intensity, B, and the total current density, jt, both in liquid metal layer and the pump channel wall, respectively. The results are obtained for f=8 rev/s (T=0.125 s) after one full turn of the disks separated by d = 40 mm. The magnetic field distribution corresponds with the experimental data [4].

The operating principal of the disk-type PMP can be seen in fig. 5 where the distribution of the driving electromagnetic force, *Fmag* (N), in the central plane of the liquid metal layer is shown. The disks are rotating counter-clockwise from the view point generating the counter-clockwise motion of the fluid in the C-shape channel.

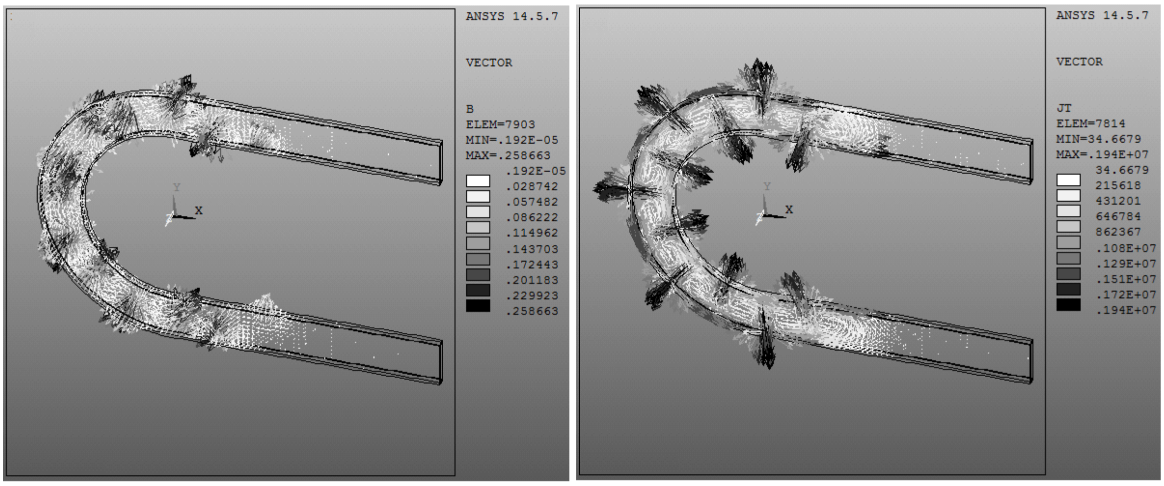

Figure 4: Distribution of (left) magnetic field intensity, *B* (T), and (right) total current flux density, *jt* (A/m3), in the channel steel wall; *d* = 40 mm, *f* = 8 rev/s.

The total Joule heat dissipated in the conducting materials during one period of rotation *T* is calculated by summing up the Joule heats produced in all the elements though all the time steps. In the first approximation (no fluid motion) the value for both the liquid metal layer and the steel channel wall is estimated to be of the order of $3x10^2$ W.

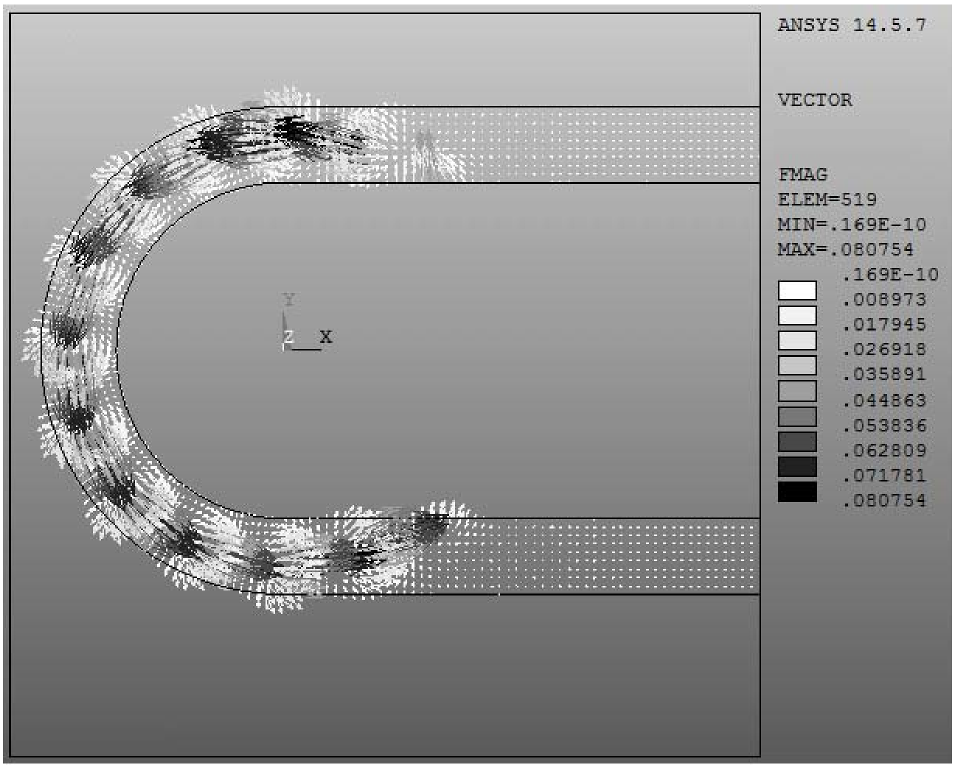

Figure 5: Distribution of magnetic vector force field, *Fmag* (N), in the central plane of the liquid metal layer; *d* = 40 mm, *f* = 8 rev/s.

4. Conclusion

Numerical modelling is an essential and effective tool in electromagnetic induction pump analysis, involving the design of more powerful pumps and optimization of their parameters. In this work, the 3D numerical model of the disk-type pump on rotating permanent magnets is developed. The finite element analysis based on using ANSYS software is employed to simulate the dynamics of the rotating magnetic system and to calculate the induced pumping forces. The results are consistent with the existing experimental data.

Since the problem is highly three-dimensional (due to the disk-type pump design), the simulations are complicated and computationally expensive. Extending the numerical analysis taking into account the fluid dynamic effects of moving liquid metal is the main goal of the future research.

5. Acknowledgements.

The research, which is the contribution of Dr. E.Yu. Koroteeva and Dr. M. Ščepanskis, was financially supported by European Social Fund (project no. 2013/0018/1DP/1.1.1.2.0/13/APIA/VIAA/061).

The authors also acknowledge V.Geža for indispensable technical consultation concerning the performance the simulation using ANSYS software and Dr. K.Kravalis for consultations in design of the pump.

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