Calculation Fluid Dynamic of Induction Pump Using Open Source Software

1st Evgeniy Shmakov
Department of Electrical Engineering
and Electrotehnlogy Systems
Ural Federal University
Ekaterinburg, Russia
shmakov.evgeny@urfu.ru

2nd Ivan Smolyanov
Department of Electrical Engineering
and Electrotehnlogy Systems
Ural Federal University
Ekaterinburg, Russia
i.a.smolianov@urfu.ru

3rd Juris Vencels
EOF Consulting
Riga, Latvia
vencels@eof-consulting.com

***Abstract*—In the paper, when simulation of an induction pump being used two approaches, executing recalculation of electromagnetic problem per a time step and without one. Simulation is carried out by means of open source software packages Elmer and OpenFoam with EOF-library. In the simulation, a three-dimensional model of a laboratory induction pump is used. Ultimately, $p-Q$ characteristics and velocity distributions in the duct is presented, as well as conclusions on the obtained results.**

***Index Terms*—induction pump, EOF, p-Q characteristic, numerical simulation, CFD**

I. INTRODUCTION

Modern industry solves a wide range of tasks that arise during technological operations. One of the problems is the non-contact impact on liquid metals, which can occur, for example, in cooling circuits or during operational process at metallurgical enterprises. One solution of this problem is electromagnetic pumps. Non-contact impact can be provided by pumps with rotating permanent magnets [1] as well as induction pumps [2].

In this article the simulation of an induction pump with a three-phase power system is considered. The advantage of such devices is the ability to develop high flow rate compared to other electromagnetic pumps [2].

Today, numerical simulation application is the most promising in this area, since it is possible to take into account most of the effects of such pumps. But the main problem is coupled calculation of the electromagnetic and fluid dynamic problems. Such problem can be solved by means of commercial software packages such as Ansis or Comsol Multiphysics, or by open source softwares, namely, Elmer and OpenFoam with EOF-library [3]. In this work open source softwares are used.

II. POBLEM STATEMENT

A laboratory induction pump is used as an object of study. The main installation parameters of the pump are given in the tab. I.

Liquid aluminum is used as the pumped metal with the following properties: the electrical conductivity equals to $3.85 \cdot 10^6 \frac{Sm}{m}$, the kinematic viscosity equals to $10^{-6} \frac{m^2}{s}$, the density equals to $2380 \frac{kg}{m^3}$.

TABLE I
IDUCTION PUMP SPECIFICATIONS

Parameter	Value
Power supply frequency, Hz	50
Inductor length, m	0.295
Inductor yoke width, m	0.077
Back iron height, m	0.0116
Back iron width, m	0.06
Air gap, m	0.001
Slot width, m	0.02
Slot height, m	0.04
Tooth width, m	0.0115
Number of turns in the slot	136
Number of slots	9
Duct thickness, m	0.0082
Duct width, m	0.077

As mentioned earlier, the calculation is performed by Elmer and OpenFoam. The calculation of the electromagnetic problem is carried out using the finite element method in Elmer, and the calculation of fluid dynamic is performed using the finite volume method in the OpenFoam.

Since velocity in the duct is significant, the magnetic Reynolds number will be more than 1, consequently taking into account the velocity in the duct is required. This article compares two approaches to account for melt velocity:

1) For electromagnetic problem, velocity is set uniform throughout the duct and the electromagnetic problem is not recalculated;
2) Velocity in the duct is calculated using eq. (4) and electromagnetic problem is recalculated when the velocity changing its value.

III. MATHEMETICAL DESCRIPTION

In this paper, magnetic field is calculated based on the Maxwell's equations in AV-formulation:

$$\Delta \mathbf{A} - \mu\sigma\nabla V - j\mu\sigma\omega\mathbf{A} + \mu\sigma[v \times rot\mathbf{A}] = -\mu\mathbf{j}_{ext}, \quad (1)$$

where $\mathbf{A}$ is the value of the magnetic vector potential, σ is the electrical conductivity of the material, μ is the magnetic permeability of the material, $\mathbf{j}_{ext}$ is the current density vector, v is the velocity, V is the electric scalar potential.

Induced current density depending on the melt velocity is calculated as follows

$$\sigma(\mathbf{E} + \mathbf{U} \times \mathbf{B}) = \mathbf{j}, \tag{2}$$

where $\mathbf{E}$ is the induced electric field strength, $\mathbf{U}$ is the velocity of fluid, $\mathbf{B}$ is the magnetic flux density.

The force acting on the melt, is calculated by the eq. (3):

$$\mathbf{F}_L = \frac{1}{2} Re(\mathbf{j} \times \bar{\mathbf{B}}), \tag{3}$$

where $\mathbf{F}_L$ is the Lorentz force.

The calculation of fluid dynamic is performed by Navier-Stokes equation for an incompressible fluid:

$$\frac{\partial \mathbf{U}}{\partial t} + (\mathbf{U} \cdot \nabla)\mathbf{U} - \nu \nabla^2 \mathbf{U} = g + \frac{\mathbf{F}_L}{\rho}, \tag{4}$$

where ν is the kinematic viscosity, g is the acceleration of gravity, ρ is the fluid density.

IV. RESULTS

The main aim of this research is to consider various approaches to simulation of induction pump. In the folowing paragraps, a comparison of $p - Q$ characteristics and distribution of velocity in the duct is provided.

The calculation is performed at the current density in the slot equals to $2.11 \frac{A}{mm^2}$. Realizeble $k - \varepsilon$ model have been chosen as the turbulence model.

A. Comparesion of $p - Q$ characteristics

The obtained characteristics are presented in fig. 1.

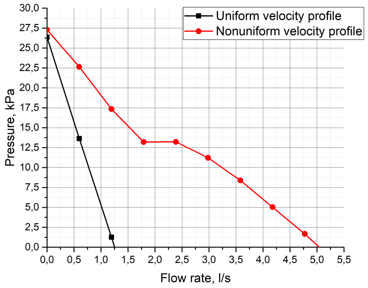

Fig. 1. Comparasion of p-Q characteristics

Based on the obtained dependencies, it can be seen that the first approach provides the result, where the maximum flow rate value of the pump will be smaller, since the nonuniform distribution of velocity in the duct is not taken into account. It is also seen that the characteristics have a significant difference.

B. Distribution of velocity in the duct

In the next part of paper, velocity profile in the duct is shown for various above mentioned simulation approaches. In order to conduct the comparision it have been taken zero values of the flow rate for both approaches and $5 \frac{l}{s}$ for hard coupled approach and $1.25 \frac{l}{s}$ for other one.

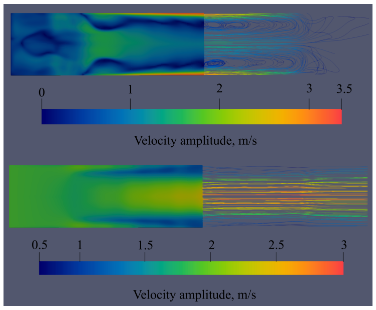

Fig. 2. Distribution of velocity (the fist case)

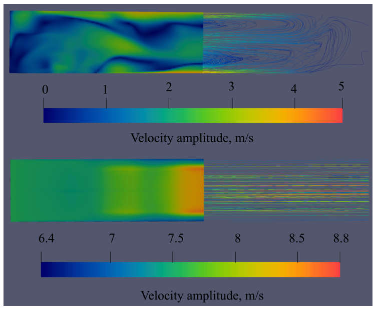

Fig. 3. Distribution of velocity (the second case)

Velocity distibution of the duct for the first and the second cases are presented in fig. 2 and fig. 3.

It can be seen from the figures that the velocity distribution is symmetrical along the duct width in the first case (fig. 2), and the velocity diffrence between the inlet velocity and the maximum velocity is less than for the second case. Also it should be noted that flow is instable (there are lots of vortexes) at initial flow rates, and at higher flow rates it becomes more stable.

V. CONCLUSIONS

Based on the above results, it can be concluded that the results obtained are dramaticly different from each other, which indicates that the approach doing calculation of the electromagnetic problem with the assumption of a uniform distribution of velocity in the duct cannot replace the approach executing recalculation of electromagnetic problem when velocity changes its value. The results also show that significant vortexes occurs only at low flow rates.

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