Numerical Approaches to Analyzing of MHD Processes Occuring to Induction Pump

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***Abstract*— The major aim of the work is to show new modern opportunities of numerical simulation of magnetohydroynamic phenomena using open source codes. The work is considered a question of calculating main induction pumps features taken into account process of continuum dynamics. In order to solve the strong coupled problem of electromagnetic and velocity fields it was used a coupler between Elmer and OpenFOAM programs. The coupler called EOF-library serves to properly transfer calculating data between Elmer and OpenFOAM. Electromagnetic filed is described by well-known A-V formulation implemented to finite element program Elmer. And hydrodynamic field is calculated by finite volume method, implemented to OpneFOAM, using modified pimpleFoam solver. The obtained results are compared to date calculated by Comsol Multiphysics software.**

Keywords*— *FVM, FEA, FEM, induction pump, head-capacity curve, instability of flow, EOF, OpenFOAM, Comsol

I. Introduction

Induction pumps as a special case of magnetohydrodynamic pumps are used in many industries, for example, metallurgy, nuclear energy, military, etc. The major purpose of the pump is to pump out a liquid metal having electrical conductivity from one place to other. The opportunity of contactless action on metal is a main advantage among pumps aimed to pumping metal. The main disadvantages are difficult operating conditions of these pumps (high temperatures) and lack of pumps capable of operating in a certain operating range. The problem of difficult operating conditional, as a result of which the windings of pump inductor burn out, have been solved in work [1], and the drawback associated with lack of pump working under certain pressure and mass flow rate have been solve in work [2]. The solutions are shape optimization and design problems, and in the work MHD processes causing instability of flows are neglected. The flows essentially act on performance capability of the pumps. The issue is especially acute in work related to nuclear energy, as in [3, 4], in which opened type of magnetic circuit of inductor (longitudinal edge effect, see Fig. 1), asymmetry of supply currents, finite duct width (transversal edge effect, see Fig. 2), increased gap between duct and inductor cause instability of flow of pumped liquid.

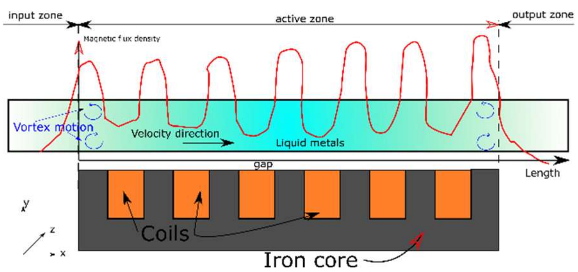

Fig. 1. Longitudinal edge effect

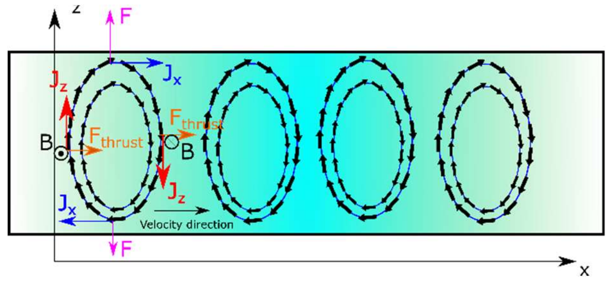

Fig. 2. Transversal edge effect

These effects are often difficult to consider when calculating this type of pump. In [5], a simplified model based on detailed equivalent circuits is used to calculate such installations, and the transverse edge effect is taken into account using the analytical coefficient. The authors of [6, 7, 2] used the commercial ANSYS package in their calculations of MHD pumps, which uses finite volume method to calculate velocity field and magnetic field using finite element method. The main drawback is method of data transfer from FEA model to FVM model and vice versa. This procedure, implemented in these works, significantly increases the calculation time and accuracy. There are a number of works in which MHD completely consider the problem with the help of FEM, for example, in [5]. As is well known, the Navier-Stokes equation is poorly resolved using finite element discretization, which is a drawback of this calculation approach. For this purpose, magnetic problem will be solved using the finite element method implemented to open source Elmer program, and CFD problem will be calculated by the FVM realized to OpenFOAM free software. Data transfer between these problems will be realized by open coupler EOF-library.

The purpose of this work is to combine the unanimous experience of previous work in calculating the related problems of magnetic and field velocity using the example of an induction pump for pumping magnesium. The major advantages of the coupler are several types of data extrapolation and fast and accurate data exchange between the problems. Detailed information of the coupler was published in the article [8].

II. Formulation of the Problem

Calculation of magnetic field of induction pump], was executed using well known A-V formulation (1) by Elmer and Comsol, that was discussed to works [1, 5. Both programs is based on FEM, but for the last one scalar electric potential is equal $V = 0$.

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

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

Velocity field was calculated in OpenFOAM working with finite volumes and in Comsol based on finite elements using the well-known Navier-Stokes equation for incompressible liquids (2-3):

$$\frac{\partial \mathbf{u}}{\partial t}+\left(\mathbf{u}\cdot\nabla\right)\mathbf{u}+\nu\Delta\mathbf{u}-\frac{1}{\rho}\nabla p+\mathbf{f} \qquad (2)$$

$$\nabla\cdot\mathbf{u}=0 \qquad (3)$$

$\mathbf{u}$ is the velocity vector, ν is the kinematic viscosity, ρ is the mass density, p is the pressure, $\mathbf{f}$ is the vector of electromagnetic force.

Data exchange during the decision process between OpenFOAM and Elmer is carried out using the EOF coupler [8]. Comsol Multiphysics is a commercial program that allows using the user interface to establish an exchange between tasks for calculating magnetic and field velocities.

III. Results

Head-capacity curve for 2D case were obtained using Comsol and EOF (Fig. 3). It is worth noting that in the Comsol transverse edge effect was taken into account using the Bolton coefficient. These differences are caused by flux instabilities in the magnetic field, which must be correctly resolved in order to obtain accurate results. For this purpose, three-dimensional cases with fine and coarse meshes were solved by EOF. In the main part of the work, the main measures to reduce the instability of flows will be discussed. It is also worth noting that the quality of the mesh in some modes significantly affects the quality of the results (Fig. 4 and Fig 5) with an increase in speed, the influence of the quality of the mesh decreases.

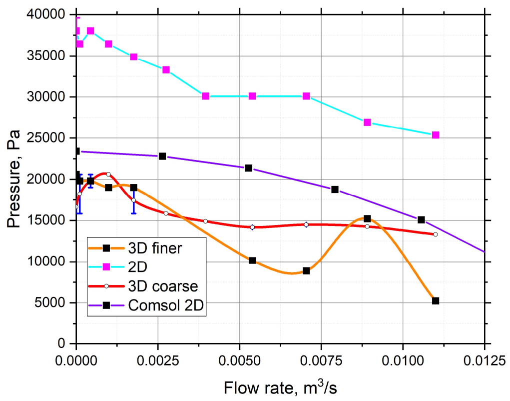

Fig. 3. Head-capacity curve

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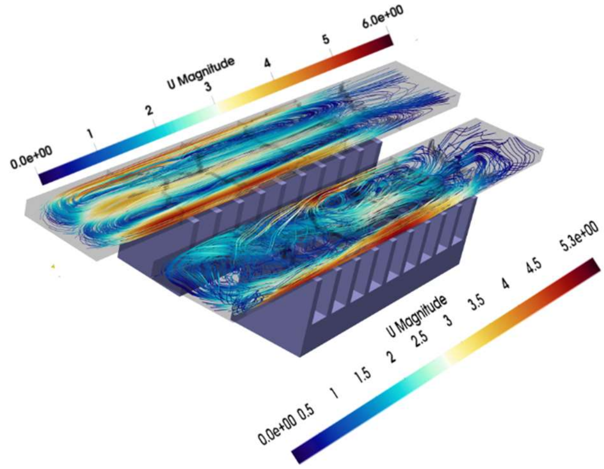

Fig. 4. Velocity profile coarse (up case) and fine (down case) mesh at 0 m/s inlet velocity

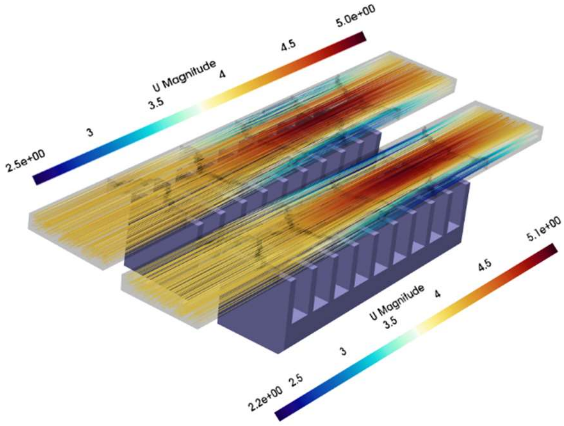

Fig. 5. Velocity profile coarse (up case) and fine (down case) mesh at 81/20 m/s inlet velocity

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