A Feasibility Study on the 3-Dimensional Flow of the Jet under the Static Electromagnetic Field

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Abstract

A feasibility study on the alternating jet flow under the static electromagnetic field was carried out. When a fluid with electrical conductivity lies in the static electromagnetic field and moves electric current occurs in the fluid. Due to the electromagnetic field and the electric current, lorentz force generates in the fluid, which undergo the "breaking" effect to the fluid. In order to simulate the complex fluid flow in the magnetic field, electromagnetic and fluid flow analysis need to be solved simultaneously. In the present study, a SOLA (SOLution Algorithm) scheme was used in order to calculate electromagnetic and fluid flow field. Jet flow without an electromagnetic field was compared with analytical solution in order to validate the flow analysis scheme. Effect of jet velocity on the flow pattern down the jet was investigated.
Keyword: *Electromagnetic, Jet, SOLA, Lorentz force*

1. Introduction

In the production of continuous casting of steels, control of fluid flow with magnetic field has been widely used. EMBR(Electromagnetic Break) is one of the equipment to control the molten steel flow in a mold of continuous casting process using a transverse static magnetic field. The advantages of using EMBR are : reduce the flow velocity ahead of the jet at the SEN (Submerged Entry Nozzle), stabilization of the melt free surface, and prevention of mold erosion. Recently, a number of research have been tried to design optimum electromagnet by computer simulation. However, generally poisson type equation was used to solve the electromagnetic field. a SOLA (SOLution Algorithm) scheme was used in order to calculate electromagnetic and fluid flow field. Jet flow without an electromagnetic field was compared with analytical solution in order to validate the flow analysis scheme. Effect of jet velocity on the flow pattern down the jet was investigated.

2. Physical Modeling

When a fluid with the electrical conductivity moves(u) in the space with electromagnetic field(B) and u and B lies in the transverse way, induced current (J) generates with perpendicular to u and B. Due to the existence the induced current and electromagnetic field, lorentz force generates. This lorentz force interfere with the fluid flow, the flow pattern alternates.

At this time, F and J can be defined by Ohm's law :

$$\mathbf{F} = \rho_e \mathbf{E} + \mathbf{J} \times \mathbf{B} \quad (1)$$

$$\mathbf{J} = \rho_e \mathbf{u} + \sigma_e (\mathbf{E} + \mathbf{u} \times \mathbf{B}) \quad (2)$$

Where F is lorentz force, E is electrical field, J is current in the mold, B is magnetic flux, u is a velocity of the fluid. ρ_e and σ_e are density and electrical conductivity of the fluid, respectively.
Under the jet flow magnetic Reynolds number which defined by $Re_m = U_0 D \sigma_e \mu_0 = Re \sigma_e \mu_0 \nu << O(1)$ may be negligible, that is, only external magnetic field affect the fluid. Therefore eq. (1) and (2) can be reduced :

$$\mathbf{F} = \mathbf{J} \times \mathbf{B} \quad (3)$$

$$\mathbf{J} = \sigma_e (\mathbf{E} + \mathbf{u} \times \mathbf{B}) \quad (4)$$

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In order to program, Scalar potential(ϕ) concept may be introduced. Rewring Ohm's law :

$$\mathbf{E} = -\nabla \phi_e \tag{5}$$

$$\mathbf{J} = \sigma_e(-\nabla \phi_e + \mathbf{u} \times \mathbf{B}) \tag{6}$$

In order to obtain voltage equation, Maxwell equation can be introduced as follows :

$$\nabla \times \mathbf{H} - \frac{\partial D}{\partial t} = \mathbf{J} \tag{7}$$

In the static electromagnetic field dD/dt term may be eliminated. In the closed fluid region curl of J is equal to 0.

$$\nabla \bullet \mathbf{J} = 0 \tag{8}$$

therefore arranging eq (5)~(7), eq(8) can be obtained.

$$\nabla^2 \phi_e = \nabla \cdot (\mathbf{u} \times \mathbf{B}) \tag{9}$$

In the fluid flow analysis, Navier-Stokes equation with a laminar flow approximation was used. SOLA algorithm by Hirt was used. Lorentz force due to induced current and magnetic force was considered as body force in the fluid flow analysis.

3. Numerical Method

In order to solve the electromagnetic field of the fluid in the container, the poisson-type equation(eq (9)) was used by previous researchers. In the present study, SOLA algorithm was introduced. In order to calculate electromagnetic field, a set of equation may be defined :

$$\nabla \bullet \mathbf{J} = 0 = D \tag{11}$$

$$J^k = \sigma_e(-\nabla \phi^k + \mathbf{u} \times \mathbf{B}) \tag{12}$$

At the first iteration the right side of eq(11) may not be 0. Then the value D can be defined and calculated by using eq(11). When D is related to the following equation (12) :

$$\frac{dD}{d\phi} = \frac{D(\phi + \Delta\phi) - D(\phi)}{\Delta\phi} \tag{13}$$

Then $\Delta\phi$ may be written as follows :

$$\Delta\phi = -\frac{D}{dD/d\phi} \tag{14}$$

The correct scalar potential (ϕ) and current(J) can be calculated by iterating eq(11)~(14). Finally Lorentz force which affect the fluid flow can be calculated by eq(3).

References

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