Pilot Scale Linear Electromagnetic Stirrer Involved in Semisolid Material Processing

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Abstract

The main drive of the current exertion is the progress of a linear electromagnetic stirrer capable of developing adequate force field to break the dendritic structure that normally ensues during solidification. This technique employs travelling magnetic fields to produce strong convection deep inside the molten metal pool close to the solidification front. Usually, low-frequency magnetic fields are used to improve the penetration depth of induced forces in the molten metal pool. This is in contrast to high frequencies employed in induction heating where the force field inside the melt pool is insignificant. In comparison with induction heating, the stirring of liquid metal is a more complex phenomenon involving the interaction of fluid flow and electro-magnetic fields generated in the molten metal. As a preliminary step towards understanding electromagnetic stirring, the present effort focuses on the basic electrical design, fabrication structures and description of a linear electromagnetic stirrer for liquid metals.

Keywords: Design, Development, Pilot Scale, LEMS.

1. Introduction

The mobile and electrically conducting solid or liquid in a magnetic field experiences an electromotive force, which drives a current whose magnitude depends on the resistance of the conducting medium. Alternatively, current may also be induced in a pool of molten metal by imposing a time dependent or a spatially varying magnetic field. Either of these phenomena can result in two consequences as mentioned aside: (a) Induced magnetic field linked with these currents in the melt pool opposes the original magnetic field (b) Electromagnetic force linked with this induced current and the field opposes the original motion. This force is commonly termed as Lorentz force which is calculated from the mathematical equation represented by $\mathbf{F} = \mathbf{J} \times \mathbf{B}$. Where, $\mathbf{J}$ is the current density (A/m^2) and $\mathbf{B}$ represents the magnetic flux density (Wb/m^2).

In particular, if the conducting media is in liquid state then the above forces give rise to stirring of the liquid. Ideally, it can be seen that the fluid velocity field and the Lorentz force field are coupled. This effect of back emf, is often ignored for the applications involving electromagnetic stirring. However, in the present research, it is found that the electromagnetic force in the solid can be significantly different from that in the liquid because of fluid motion. The pertinent interpretations are described consequently in forthcoming sections.

The greatest embryonic application of magneto hydrodynamics (MHD) in metallurgy is in stirring of liquid metals during casting. Depending on the kind of primary excitation field used, electromagnetic stirrer (EMS) may be categorized as linear, rotary or helicoidal electromagnetic stirrer. A linear electromagnetic stirrer (LEMS) utilizes a travelling magnetic field, as in the case of a linear electric motor. In addition, a rotary electromagnetic stirrer deploys a rotating field to produce swirling action in the melt pool.

However, a helicoidal electromagnetic stirrer practices a twisted magnetic field which is a combination of rotary and linear electromagnetic fields.

2. Force Field Analysis in Metal

Although, in the situation of non-metal, it is considered as a non-conducting medium in the annular field space. However, when an electrical conductor such as molten metal is introduced in the field space, the induced currents in the metal oppose the primary excitation current (fig. 1). This alters the magnetic field intensity **H** in the field space. The field analysis is done with the succeeding assumptions: (a) the stirrer is infinitely long in the z direction (i.e L>>R). In such cases, the travelling field is completely axial, (b) the current density **J** in the molten metal is not a function of melt velocity, (c) the end effects and flux leakage due to the presence of air gap between the primary coils and the metal core are ignored, and (d) the entire magnetic flux generated by the primary coils is concentrated in the core of the LEMS where the metal is kept.

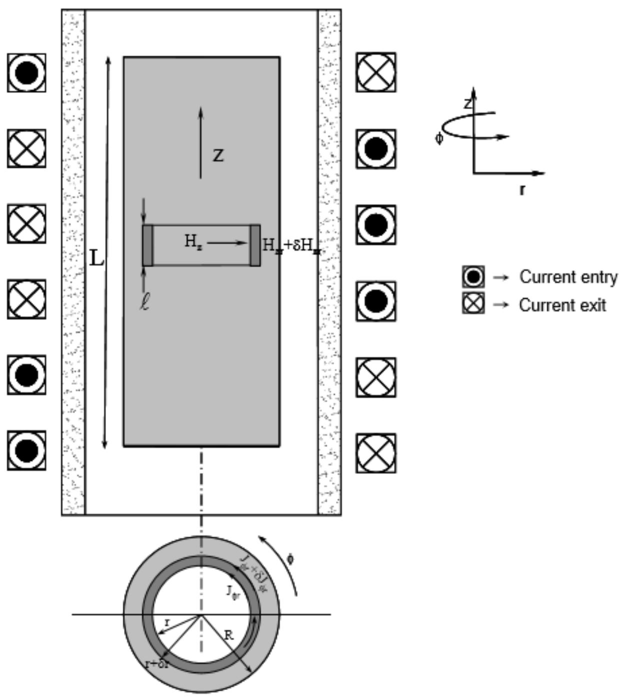


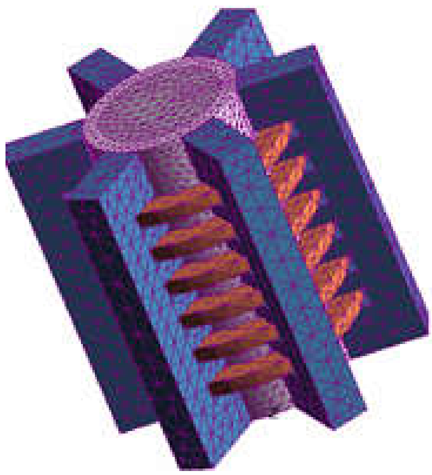
Figure 1. Field formulation for **J** (A/m^2) in metal

Furthermore, the succeeding observations are also noticed: (i) the radial and axial force densities are proportional to the radius and square of the radius, respectively, (ii) the radial force averaged in space and time, is zero, and (iii) the axial force, when averaged in space or time, is in the direction of phase sequence.

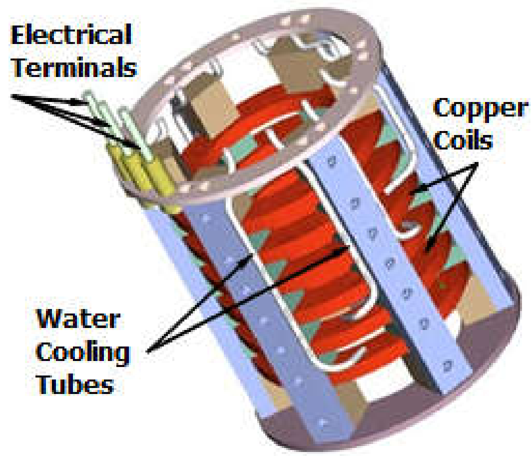
In a LEMS, it is the axial force (F_z) which is responsible for bulk motion in the liquid. As the net average radial force is zero, it does not directly be part of the cause in the fluid motion. The radial force, at most, would generate a pressure field around the melt.

3. Pilot Scale LEMS for Low Melting Point Alloys

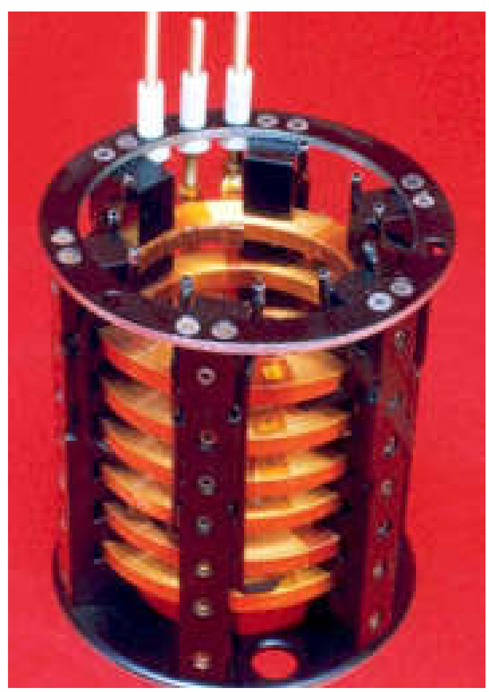
Through an initial stage, the previous analytical exemplary gives us an idea of the forces generated and its spatial distribution for a given excitation current. The induced eddy current is based on the distribution of axial magnetic field intensity (H_z). The influence of the radial magnetic field intensity (H_r) is ignored. However, it is recognized that the radial magnetic field is solely responsible for creation of the axial force field, F_z, in the metal. In practical applications, this radial magnetic field is enhanced by introducing a magnetic return path (MRP) surrounding the primary coils. In such cases, an analytical solution is not possible. Since the problem now is geometry specific, a numerical solution is sought. Accordingly, an FEM model using MagNet software is developed, as shown in figure 2 (a). Based on the detailed numerical analysis, the present electrical design for a two pole pilot scale LEMS is physically constructed, as shown in figure 2 (b) and 2 (c). In this design, the magnetic return paths are provided as shown in the FEM model (fig. 2 (a)). However, the design challenges of the MRP will be described in future for aluminum alloys in the context of the full scale LEMS.



(a)



(b)



(c)

Figure 2. Pilot scale LEMS for low melting point alloys (a) FEM model (b) CAD model (c) physical construction

4. Test Setup of Pilot Scale LEMS

The pilot scale LEMS is built to validate the mathematical formulation and to set up a case for numerical modelling. The pilot scale model also serves to bring out any mechanical/electrical system design issues which cannot be easily predicted theoretically at the design stage. The stirrer coils are designed for handling excitation current up to 200A. As there is high amount of heat generation in the coils (Joule heating), a water cooling arrangement for the coils is provided, as shown in the CAD model in figure 2 (b). The fabricated pilot scale LEMS arrangement is demonstrated in figure 3. In addition, the electromagnetic force on the aluminum cylinders is measured by either suspending the solid cylinders or mould containing the alloy from a weighing balance placed on a test table as shown in figure 3.

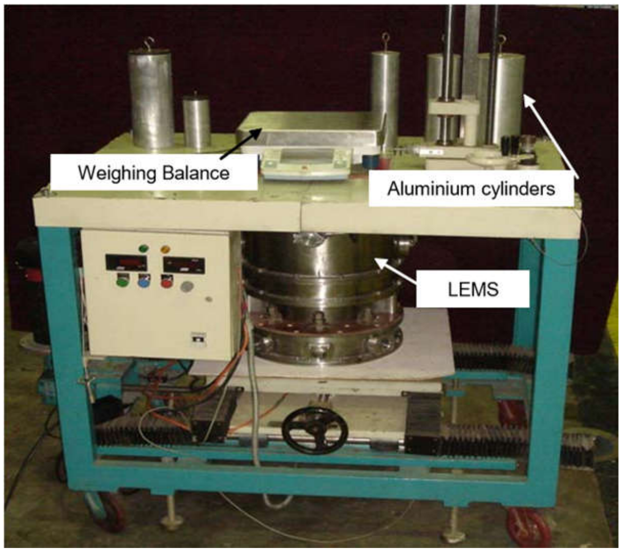


Figure 3. Test table set up for force measurement

A chains of step-down transformers are used to reduce the line voltages. This arrangement enables precise control of input supply current and frequency to the LEMS. The software in the inverter offers flexibility in the form of phase reversal to reverse the direction of axial forces without interrupting the cycle.

5. Conclusion

A complete picture of the potential electro-magnetic field orientation is demonstrated and the resulting convective flow patterns of molten alloys for the present stirrer geometry is exemplified on top. An easy analysis of a linear axisymmetric stirrer for molten alloy solidification process and the related thermal and electrical design challenges are described. A pilot scale model for low melting point alloys is fabricated to set up the cases for detailed experiments. The experimental LEMS procedure also reflects the effects of process variables. The essential safety precautions are also followed in the experimental designs, trials and practices. Furthermore, the comprehensive force measurement experimental facilities are established for the pilot scale LEMS. Nevertheless, the pilot scale LEMS model is very much useful for treatment of molten aluminum alloys.

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