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ISSN 0543-5846
METABK 55(4) 593-596 (2016)
UDC – UDK 669.18.002.2:66.065:538.12.001.5:518.1=111

MAGNETIC FIELD DISTRIBUTION IN THE ELECTROMAGNETIC FEEDING RISER OF RECTANGLE STEEL INGOT

Received – Primljeno: 2015-11-25
Accepted – Prihvaćeno: 2016-04-05
Original Scientific Paper – Izvorni znanstveni rad

The electromagnetic feeding method was used to improve solidification quality of steel ingot, and the feeding principle of electromagnetic riser was introduced. The distribution characteristics of magnetic field in electromagnetic riser were investigated before and after pouring steel by the measures of numerical and physical simulation. The results showed that there's a good symmetry of magnetic field distribution in electromagnetic feeding riser before pouring steel, but both symmetry and uniformity of magnetic field distribution are broken after pouring steel into riser, and magnetic induction intensity of the surface is higher than that of the inner of feeding riser.

Key words: steel ingot, solidification, magnetic field distribution, feeding riser, numerical simulation

INTRODUCTION

Steel ingots have been widely applied in not only important industrial field but major construction projects, such as military industry, manufacture of heavy machinery, construction of nuclear-power plants and so on, the development of industry depends on the quality of the ingots. Feeding capacity is so critical to solidification quality and the finished product rate for casting and ingots[1]. In more recent work, improving riser design efficiency and accuracy was studied to ensure the casting quality[2,3]. The characteristics of chemical heating was studied to reduce heat loss and improve the finished product rate of small to medium steel ingots[4,5]. Electroslag hot-top had been tried to ensure high yield of large steel ingots[6].

In the current study, the electromagnetic feeding method was proposed to improve solidification quality of steel ingot, the distribution characteristics of magnetic field in electromagnetic feeding riser before and after pouring steel were mainly investigated by the measures of numerical and physical simulation.

PRINCIPLE OF ELECTROMAGNETIC FEEDING

The traditional structure of ingot mold is shown in Figure 1. The schematic diagram of electromagnetic feeding principle during solidification process of steel ingot is shown in Figure 2. Hat shell and ingot mold are often made by cast iron, which can impede permeating ingot of alternate magnetic flux due to the skin effect, as shown in Figure 1. Consequently, the hat shell of riser is designed to be stainless steel material with palisading

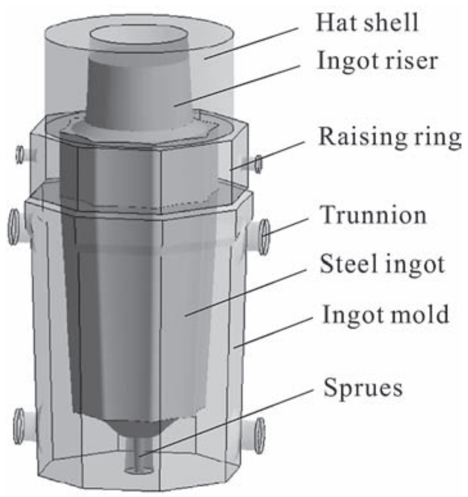

Figure 1 The traditional structure of steel ingot mold

structure, that can be practical useful to the design of weakening magnetic shield. Then the electromagnetic field generator is introduced in the ingot riser, it can generate time-harmonic electromagnetic field, as shown in Figure 2.

The Joule heat, which is generated by inductive current within depth of current penetration, can make steel temperature in riser remain unchanged, heat up, or slow down. Meanwhile the electromagnetic force, which is generated by interacting between the induced current and alternating field, can drive solute elements in the riser to flow with liquid steel. Theoretically, the electromagnetic feeding technology not only can control solidification process of steel, but also reduce extent of elements segregation in the end of ingot solidification.As a consequence,the distribution characteristics of magnetic field in riser is one of the important contents of electromagnetic feeding technology research.

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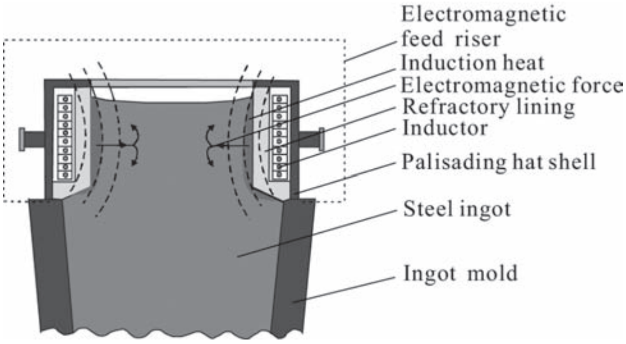

Figure 2 Schematic of electromagnetic feeding principle during solidification process of steel ingot

RESEARCH METHODS

In order to simulate the solidification process of rectangular steel ingot, bakelite is used to make riser, and BiPbSnCd alloy is used to simulate the liquid steel in riser according to the similarity theories. Small coil method is employed to detect magnetic field in riser based on the principle of electromagnetic induction. The length, width and height of ingot riser were 230 mm,100 mm and 300 mm. Magnetic field detecting system is shown in Figure 3. The key physical parameters of simulation material are given in Table 1.

In numerical simulation, ANSYS software, a multi-functional numerical simulation software whose finite element method(FEM) is conducted using numerical discretization, can carry out numerical simulation of the electric field, magnetic field and the flow field, etc. This software is described by the continuity equation, momentum conservation equation and Maxwell's equations, respectively. They are given in Ref.[7,8] in detail. Maxwell's equations are the basis of the theory and calculating the field distribution. Figure 4 gives geometric model of electromagnetic feeding riser.

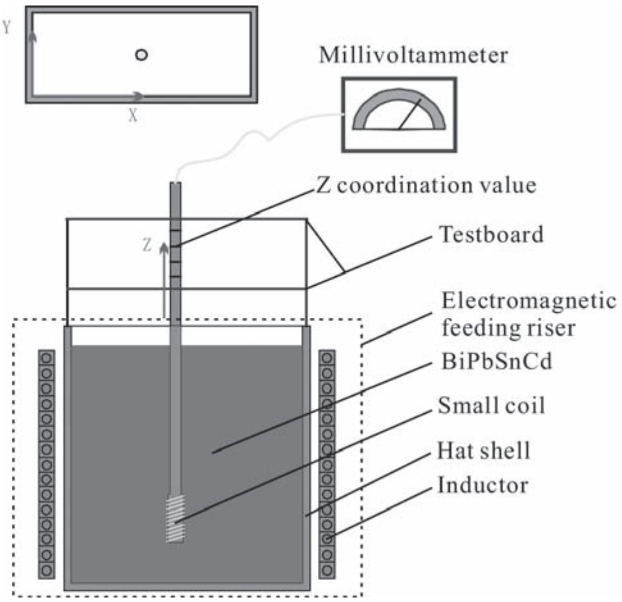

Figure 3 Schematic of the magnetic field detecting system

Table 1 **The key electromagnetic parameters of simulation materials**

Parameters	Values
Relative magnetic permeability (induction coil / ingot mold / steel / BiPbSnCd / air)	1,0 / 1,0 / 1,0 / 1,0 / 1,0
Electric conductivity (induction coil / ingot mold / steel / BiPbSnCd / air) / (Ω m^{-1})	2,78×10^{6} / 7,14×10^{5} / - / 1,82×10^{6} / 8,86×10^{-12}

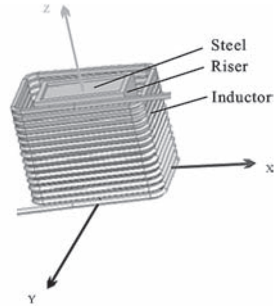

Figure 4 Geometric model of electromagnetic riser

RESULTS AND DISCUSSIONS

Distribution characteristics of magnetic field in riser before pouring steel

It is difficult to apply an alternating current with the high-power before pouring liquid steel into ingot, so the specific electromagnetic parameter(power is 100 W, frequency is 2 000 Hz) is selected to measure the magnetic field in riser. Figure 5 gives the distribution characteristics of magnetic field in riser before pouring steel. Magnetic induction intensity decreases firstly, and then increases along the X and Y direction, displaying a good symmetry, the minimum value(up to ~ 6,69 mT) is near the center of cross section, as shown in Figure 5a and Figure 5b. The magnetic flux density is the most uniform near the center of coil, the study found. But in the Z direction, the changing tendency of magnetic induction intensity is opposite, the maximal value(up to ~ 7,48 mT) of magnetic induction intensity appears at half height of riser, as shown in Figure 5c. The result shows a good agreement with the experimental and computational data.

Distribution characteristics of magnetic field in riser after pouring steel

After pouring liquid steel, ingot riser is filled with liquid steel. If electromagnetic field is not applied, solidification phenomenon of liquid steel will appear quickly around the inner wall, and move closer to the center gradually because of natural solidification[9]. According to heat balance theory, power and frequency of the alternating current are determined separately as 50 KW and 2 000 Hz.

Notice from Figure 6 how different distribution characteristics of magnetic field are from that of the situation of without liquid steel. Both symmetry and uniformity of magnetic field are much worse, and magnetic induction intensity of the surface is higher than that of the inner of steel on the cross section, the

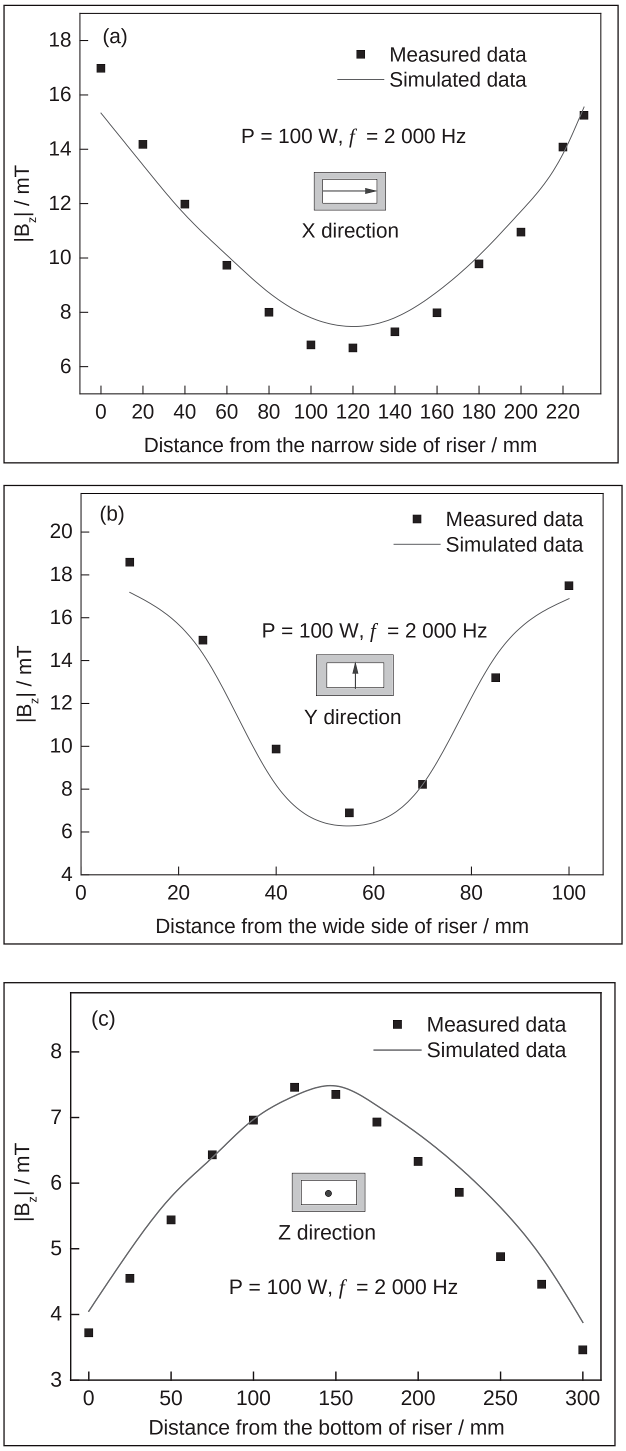

Figure 5 Distribution characteristics of magnetic field in riser before pouring steel:(a) center line along the X direction in half height of riser; (b) center line along the Y direction in half height of riser; (c) central point along the Z direction

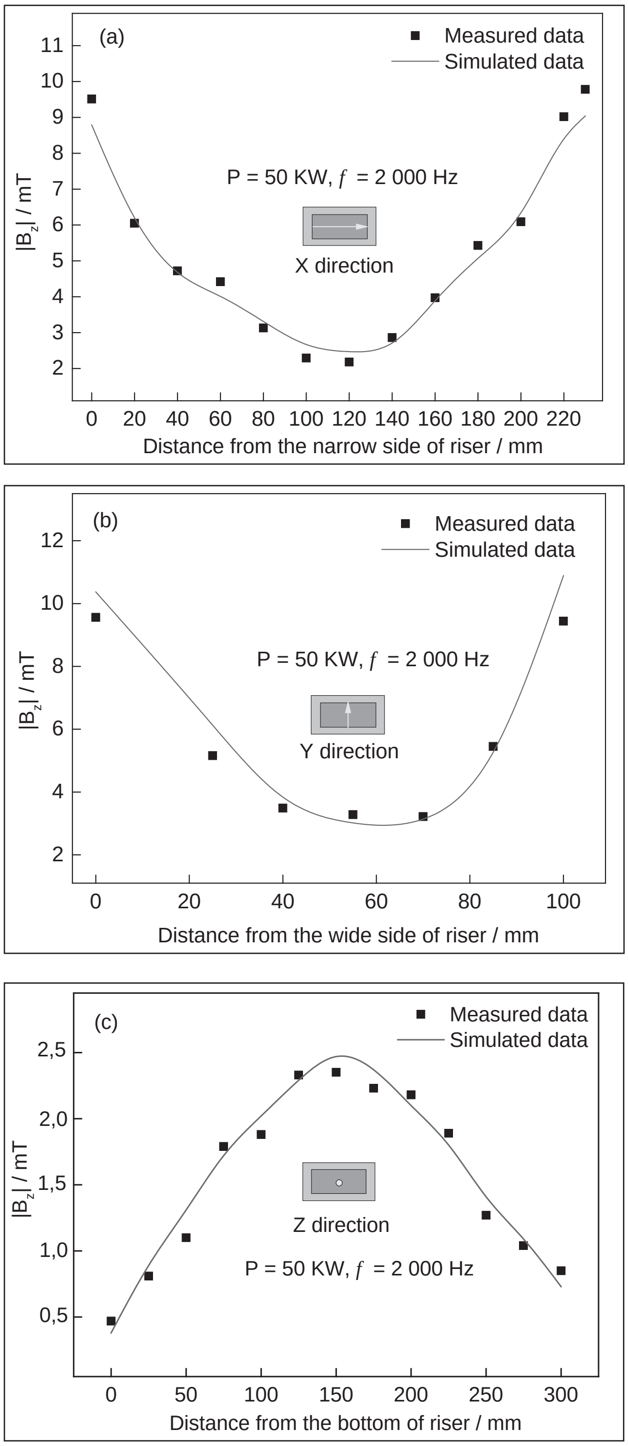

Figure 6 Magnetic field distribution in riser after pouring steel:(a) center line along the X direction in half height of riser;(b) center line along the Y direction in half height of riser; (c) central point along the Z direction

former reaches a peak at 10,37 mT, and the latter to the former is only about 21%, as shown in Figure 6a and Figure 6b. So the magnetic induction intensity in vertical direction become smaller, the minimum value (up to ~ 0,38 mT) appears near the top surface of molten steel, as shown in Figure 6c. This fact also proves that electromagnetic field has its effect on induction heating and electromagnetic stirring in solidification process of electromagnetic feeding.

CONCLUSIONS

Research results have shown that distribution characteristics of magnetic field after pouring liquid steel into electromagnetic feeding riser significantly different compared to the same riser before pouring steel due to the skin effect, eddy current effect, *etc*.

Before pouring steel into electromagnetic feeding riser, magnetic flux density decreases firstly and then increases along the X and Y direction, which possesses good symmetry. But the changing tendency of magnetic induction intensity is opposite along the Z direction, the maximal value appears at half height of riser, where magnetic flux density is the most uniform. After pouring steel, both symmetry and uniformity of magnetic field distribution in riser are broken, and magnetic induction intensity of the surface is higher than that of the inner of feeding riser, which is beneficial for heat preservation function of electromagnetic feeding riser.

Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (Grant No. 51474125, 51504130) and Henan Province Key S&T Special Projects. Partial support was also provided by Anshan city and Liaoning University of Science and Technology for top-level science-technology talents (No. 20140545, 2014RC07).

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Note: The responsible translator for English language is X.T. Yin - University of Science and Technology Liaoning, China