

Calculation & Analysis on Electromagnetic Dam Magnetic Field of Twin-roll Strip Continuous Casting

WEN Hongquan

(Baosteel Technology Center, Shanghai, 201900, China)

Abstract: Electromagnetic dam (EMD) is a newly-developed technology of side-wall dam in the process of the twin-roll strip continuous casting, whose key is the design of electromagnetic apparatus to gain a big enough magnetic field with reasonable distribution on the side-wall of the melting bath. In this paper, effects of various parameters on the EMD's magnetic field are calculated and analyzed based on 2D model, including electric current, coil turns, iron core, roll, rim, and air-gap. The results show that the parameters are listed in an effective order as below: magnetic conductivity of roll rim, coil turn's number, air-gap width, electric current density and iron-core width. Those effects are basically linear except the air-gap width. Therefore, the roll rim design and the number of coil turn and the current density are three important methods to increase the side-confining magnetic field.

Keywords: twin-roll strip continuous casting; electromagnetic dam (EMD); magnetic field calculation

1. Introduction

Electromagnetic edge dam (EMD) is important for the containment of molten steel pool end^[1-4] In twin roll strip continuous casting, the key is the design of the EMD apparatus. In this paper, the effects of various parameters on the magnetic field excited by the EMD was calculated based on the 2-D model, considering the electric current, the electric coil's turns, the iron core, the casting roll's rim, and the air gap between the magnetic poles, on which the improving ways for the EMD design were analyzed, so as to gain a big-enough and reasonably-distributed electromagnetic field for edge damming.

2. Principle of EMD

The EMD in principle uses the force effect of electromagnetic field. The effect is also broadly utilized in the electromagnetic levitation melting, the electromagnetic stirring, etc. When the EMD set beside the steel pool is imposed with alternating current, a magnetic confining force or pressure is formed due to the interaction between the imposed magnetic field and induction electric current in the molten metal. The electromagnetic force F and pressure P is expressed as:

$$\vec{F} = \vec{J} \times \vec{B} \quad (1)$$

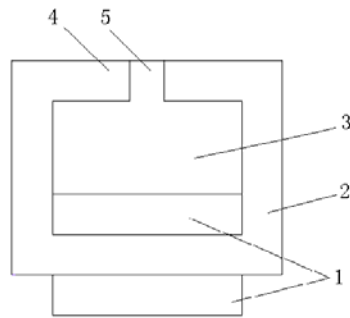
$$P = \frac{B^2}{2\mu_0} \quad (2)$$

where, B is the magnetic field intensity, J is the induction current, μ_0 is the relative magnetic conductivity. In the case of the edge dam, the magnetic pressure must exceed the static and dynamic pressures of molten steel pool between the double casting rolls. The magnetic intensity, especially at

the end of the molten pool must be elevated. Therefore, the design of EMD becomes an effective way to produce a strong enough and reasonably distributed edge-damming magnetic field. There exist various types of actual EMD. This paper pertains only to the “iron core + electric coils” structure.

2. Modelling

2.1 Geometric model



1.electric coil 2.iron core 3.air 4.magnetic pole 5.air gap

Fig.1 Geometric model

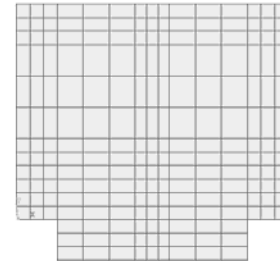


Fig.2 Mesh splitting

The geometric model adopted in the calculation is shown as Fig.1, including the copper coil(s), the C-shape high-magnetic-conductive iron core with the air gap, the iron-core-surrounded air and the air gap between two magnetic poles of the iron core. The width of the magnetic pole is 30mm. The spacing (air gap's width) between the magnetic poles is 25mm. The calculation mesh is split heterogeneously as Fig.2, with total units 125. When the magnetic pole's width or spacing varies, the model needs reconstruction.

2.2 Property of materials

The relative magnetic conductivities of the materials used in the segments of calculation model are 2000 for the iron core, 1/2/10 separately for the roll rim, 1 for the coil and the air. Selecting three different relative magnetic conductivity levels for the rim is to investigate the effect of the rim's material on the magnetic field within the air gap between the magnetic poles.

2.3 Boundary conditions

- (1) The segment “electric coil” is loaded with current density.
- (2) Despite the segment “air gap”, the outer boundaries in the model bear the limit of parallel magnetic lines.

2.4 Scheme of calculation

The B lines of magnetic field are plotted based on the parameter C (the product of location variable R and vector potential A). The density of B lines represents the magnetic field intensity. Therefore, C_{\max} is adopted as a magnetic field index, and the corresponding relationships between C_{\max} and the parameters are analyzed, the characteristic of magnetic field distribution is regarded.

In calculation, the adopted different values of every parameter are:

- (1) Coil turn's number $n=4, 1, 8$;

- (2) Electric current density $\hat{K}=10, 1, 2.5, 5, 7.5\text{A/mm}^2$;
- (3) Magnetic pole's spacing (air gap's width) $d=50, 25, 75, 100\text{mm}$;
- (4) Roll rim's relative magnetic conductivity $\mu_s=1, 2, 10$;
- (5) Magnetic pole's width $W=60, 30\text{mm}$.

The first value of above each parameter is made as the standard value. As considering the effect of one parameter, all the other parameters take the standard values. The thickness of the roll's rim $d_s=12.5\text{mm}$. The calculation does not consider the effect of hypothetically existing magnetic saturation phenomenon in the iron core.

3.Results and analyzes

Calculated magnetic fields under various parameters are shown in Fig.3. Generally speaking, the magnetic field lines distribute almost within the iron core. Thus, the iron core gathers the magnetic field, and transfers the magnetic field to near the roll's end, so the electromagnetic confining force is increased in order to realize the electromagnetic damming. Furthermore, shown in Fig.3, the magnetic field lines in the air space surrounded by the iron core are very fewer as a result of the magnetic field congregation of iron core. In other words, the magnetic leakage is little. Therefore, it is reasonable to think that there is no big difference between the strongest magnetic field (C_{\max}) and the magnetic field near the magnetic pole, especially in the end face of the magnetic pole, so the paper uses C_{\max} to present the effect of parameters on the magnetic field.

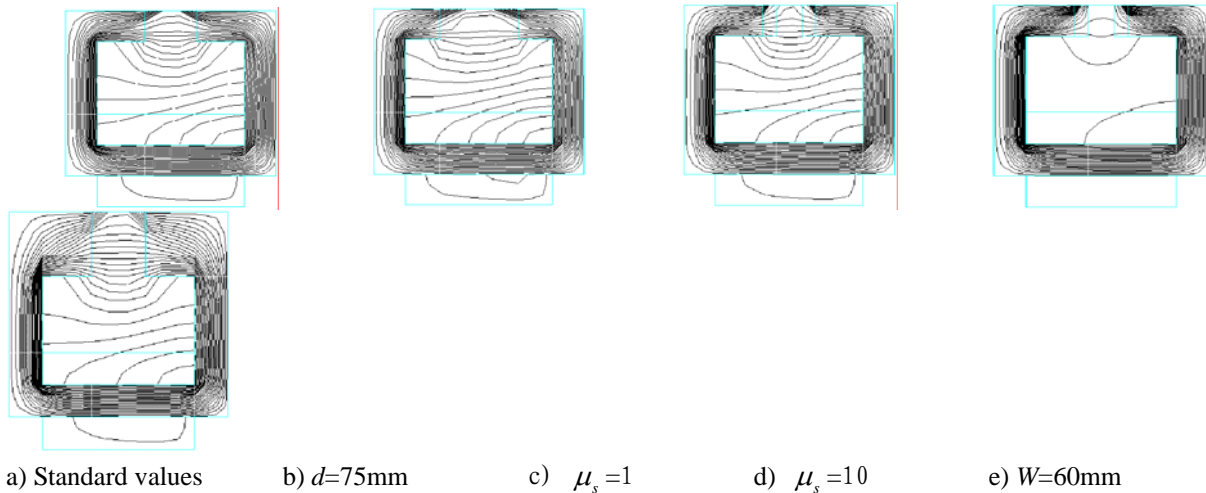


Fig.3 Magnetic field of the electromagnetic dam apparatus with various parameters

3.1 Coil turns

When n increases from 1 to 8, C_{\max} increases from $0.0113\text{T}\cdot\text{m}^2$ to $0.0904\text{T}\cdot\text{m}^2$, i.e., the magnetic field is strengthened almost 8 times while the magnetic field distribution remains almost the same, shown in Fig.3a. Therefore, increasing the coil's turns is very effective to elevate the magnetic field. Multi-coil turns should be adopted if the condition permits. However, with the increase of the turns, the load inductance increases, which is detrimental to the electric current intensity elevation. Such

issue will be more prominent under high frequency, so, the coil turn's number exists an optimum value.

3.2 Electric current intensity

As the electric current intensity or the electric current density \hat{A} increases from $1\text{A}/\text{mm}^2$ to $10\text{A}/\text{mm}^2$, C_{max} increases from $0.0011\text{T}\cdot\text{m}^2$ to $0.0452\text{T}\cdot\text{m}^2$, while the magnetic field form remains unchanged. From above can read the degree of electric current effect on the magnetic field. However, large current greatly raises the need for large electric power. Now, there still exists much difficulty to realize for large power electrical source equipment of middle/high frequency. Thus, the way increasing the current intensity is less effective and convenient than changing the coil turns.

3.3 Width of air gap

When the width of the air gap (d) increases, the parallel magnetic lines within the air gap decrease, and the magnetic lines tend to depart from the pole end, which are detrimental to damming. The magnetic fields with $d=50\text{mm}$, 75mm are shown as Fig3a, Fig3b. When d increases from 25mm to 100mm , C_{max} decreases from $0.0592\text{T}\cdot\text{m}^2$ to $0.0351\text{T}\cdot\text{m}^2$. It can be seen that, even if the effect of the air gap's width on magnetic field is not so distinct as that of the coil turn's number and the current intensity, the harmful effect of the air gap's width on magnetic field in upper melt puddle becomes very prominent if the roll's radius and the strip thickness are fixed.

3.4 Roll's rim

As described in section3.3, the space between the magnetic pole's ends concerns not only to casting machine specification, but also to the roll's rim which is set on the end of casting roll and between the magnetic pole's end and the melt puddle in order to lay the puddle in stronger magnetic field. Thus, the magnetic lines emitting from magnetic pole must penetrate the rim and then enter the molten puddle. With bigger magnetic poles spacing, the magnetic conductance of the rim has undoubted important effect on the magnetic field. The calculated results show that, when μ_s increases from 1 to 10, C_{max} increases correspondingly from $0.0482\text{T}\cdot\text{m}^2$ to $0.2152\text{T}\cdot\text{m}^2$. Moreover, the leaking magnetic lines in the other position of iron core are obviously decreased, which means extending the high-magnetic-conductance iron core to near the molten puddle position. However, the magnetic field between the magnetic poles is weakened, due to the shielding effect of roll rim, seen from comparing Fig.3(c), Fig.3(d) and Fig.3(a). Therefore, the rim's design is rather important. In fact, the rim is often made of low magnetic conductivity material, and has many narrow slits on it, to improve the rim's magnetic conductance and decrease the rim's magnetic shielding effect. Furthermore, comparing Fig.3(a) with Fig.3(c), the magnetic field distributions in Fig.3(a) and Fig.3(c) are different although both the rim's relative magnetic conductivity are 1, this difference is mainly relevant to the rim's electric conductivity.

3.5 Iron core

When the magnetic pole's width (W) increases from 30mm to 60mm, C_{\max} increases from 0.04521T·m² to 0.0544T·m², the parallel magnetic lines within the air gap are increased. However, the end area of the magnetic pole increases with the increase of W . The B-lines density within the air gap is decreased in fact (Fig.3(e), Fig.3(a)), which is detrimental to damming. This revealed that the effect of changing the iron core width is restricted.

The above calculation results collectively indicate that the varieties of C_{\max} are basically linear with the increase of the coil turn's number, the electric current density, the magnetic conductivity of the roll's rim, etc. When the magnetic pole's spacing increases, C_{\max} decreases nonlinearly, however, its curvature is not big, shown as Fig.4.

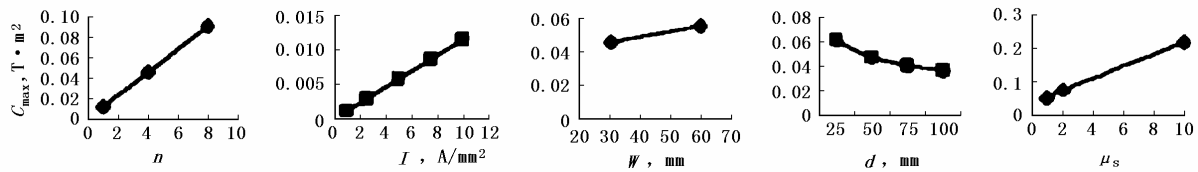


Fig.4 Effect of the various parameters on the maximum $R * A$

The quasi-linear equations of above relations are as following:

$$C_{\max} = 0.0113n - 1E(-07) \quad (3)$$

$$C_{\max} = 0.0011I + 6E(-07) \quad (4)$$

$$C_{\max} = -0.0078d + 0.0642 \quad (5)$$

$$C_{\max} = 0.0183\mu_s + 0.0324 \quad (6)$$

$$C_{\max} = 0.0003W + 0.036 \quad (7)$$

It can be seen that, the parameters in an effective order are the rim's magnetic conductivity, the coil turn's number, the air gap's spacing, the electric current density, and the iron core's width. Therefore, increasing the coil turns and intensifying the electric current are the main ways to strengthen the edge-damming electromagnetic field as the dammed object is determined. However, the roll rim's magnetic conductivity affects the magnetic field more severely, while the effect of the magnetic pole's width is the smallest.

4. Conclusions

The calculation on electromagnetic dam magnetic field of twin roll strip continuous casting was made. The result show that the parameters affecting the damming electromagnetic field in an effective order are the roll rim's magnetic conductivity, the coil turn's number, the air gap's width, the electric current density, and the iron core's width, whose effects are basically linear despite that of air gap's width. The roll rim's design, the coil turn's number, and the current density are three most important ways to increase the electromagnetic field for electromagnetic edge dam.

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Wen Hongquan Date of Birth: May, 1969

Ph.D., Senior Engineer, graduated from Shanghai University of China on October, 1998, with majority of metallurgy of iron & steel, Post-Doctor fellow of Baosteel Post-Doctorate Workstation in 1998-2000, engaged at present in the researches of solidification structure control, electromagnetic metallurgy, etc., main subjecting to electromagnetic edge dam technology and electric pulsing treatment technology of iron & steel material.

Address: Technology Center of Baoshan Iron & Steel Co. Ltd., Rd. Fujin, Dist. Baoshan, Shanghai, 201900, P.R.China

Tel: 021-56780880-2162

Fax: 021-26645250

E-mail: hqwen@baosteel.com