

# Research on EMD and EMES in Shanghai Baosteel

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**Abstract:** Researches on electromagnetic processing of materials have been conducted in Shanghai Baosteel since the late 1990s. To realize electromagnetic sidewall or edge dam (EMD) in twin-roll strip continuous casting process, an experiment with Sn-15%Pb alloy for the sidewall electromagnetic shaping is carried out and EMD of an 100mm-high molten pool is successfully realized under the alternating magnetic field. Moreover, because the sink roll system in Zinc-pot is one of the main factors influencing the productivity and quality of strip in conventional continuous hot dip galvanizing line, based on the theory of electromagnetic, the principles of electromagnetic enclosed slot (EMES) under the imposition of AC or DC electromagnetic fields are described in the paper, and three methods of hot dip galvanizing technology without sink roll (Traveling Magnetic Enclosed Slot, Alternating Magnetic Enclosed Slot and DC Electromagnetic Enclosed Slot) are introduced and the characteristics are also discussed. Finally, it brings up the possibility of industrial application according to the development of hot dip galvanizing technology with electromagnetic enclosed slot.

**Key Word:** Electromagnetic edge dam; Twin-roll strip continuous casting; Hot Dip Galvanizing; Sink Roll; Electromagnetic Enclosed slot; Electromagnetic field

## 1 Introduction

Since the late 1990s, the researches on electromagnetic processing of material were conducted in Baoshan Iron & Steel Cooperation, Shanghai, China, including the soft-contact electromagnetic continuous casting, the magnetic dispersion feeder for sinter mixture, and the high-magnetic annealing of IF steel and silicon steel, etc. Such researches have gained different progresses in industrial or laboratory scales.

In this paper, the present situations in the electromagnetic dam technology and the electromagnetic enclosed slot technology are introduced

## 2 Electromagnetic dam research

In the steel strip continuous casting, the electromagnetic edge dam (EMD) technology (*figure1*) is developed to confine or dam the steel melt puddle from the side wall, as a substitute for traditional ceramic dam, with great practical value, attracting broad interests of metallurgists and metallurgical enterprises in recent years around the world [1-4]. The carried researches in this case include mathematic analysis, magnetic field calculation and model experiment.

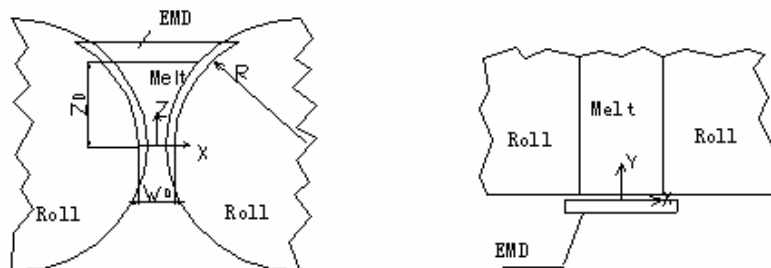


Figure1 Schematic presentation of electromagnetic dam in twin-roll casting

### 2.1 Mathematic model

When steadily damming, not considering the surface tension of molten steel, there exists the balance between the electromagnetic force and the steel static pressure near the EMD:

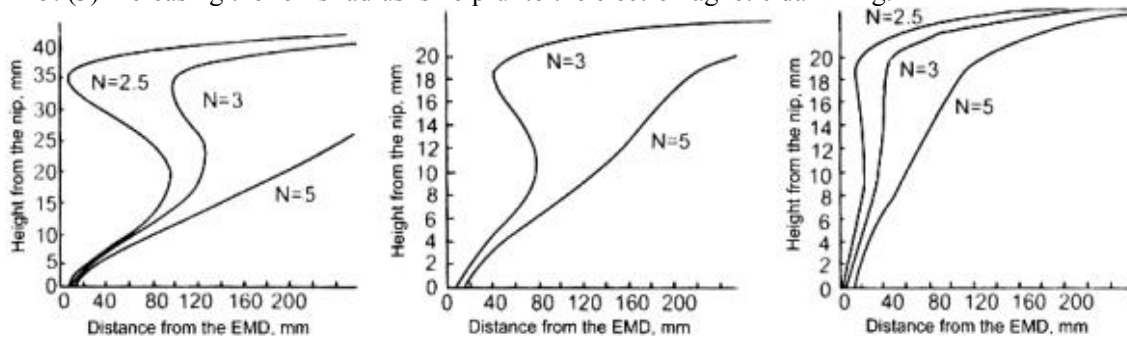
$$P_m = P_s \tag{1}$$

where  $P_m$  is magnetic pressure,  $P_s$  is the static pressure of steel melt. Seen from *figure1*, suppose that the  $\varphi$  is magnetic potential  $\varphi \equiv \varphi_0$  when  $y = 0$ , and  $\partial\varphi/\partial x = 0$  when  $y \geq 0$ , from equation (1) we can get the expression of the melt puddle shape under electromagnetic force in the place  $x = 0$ :

$$y = -2(W_0 + 2(R - z \cdot \cot(\arcsin \frac{z}{R}))) \log_e \left( \frac{8\sqrt{\rho g(Z_0 - z)}}{\pi \mu \varphi_0} (W_0 + 2(R - z \cdot \cot(\arcsin \frac{z}{R}))) \right) \quad (2)$$

where,  $\rho$  is steel melt density,  $g$  is gravitational acceleration,  $Z_0$  is the overall height of the melt,  $z$  is the height from the investigated point to the nip,  $B$  is magnetic density,  $\mu$  is dielectric constant,  $W_0$  is the width in the nip,  $\varphi_0$  is related to the ampere coils( $I, N$ ),  $R$  is the radius of the roll.

Figure2 is the shape curves calculated from equation2 under various parameters. Conclusions can be drawn that: (1) The current density needs to increase sharply with the melt height increase. (2) The proper number for the coils is 2~5. (3) Increasing the roll's radius is helpful to the electromagnetic damming.

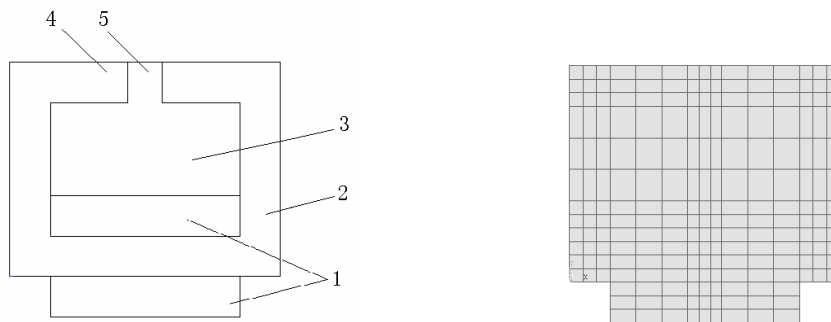


a)  $Z_0=0.38\text{m}, R=0.6\text{m}, I=21\text{kA}, N=2.5, 3, 5$       b)  $Z_0=0.2\text{m}, R=0.25\text{m}, I=10\text{kA}, N=2.5, 5$       c)  $Z_0=0.2\text{m}, R=0.6\text{m}, I=5\text{kA}, N=2.5, 3, 5$

Figure2 Calculated side shape curves for electromagnetic-confined melt puddle

## 2.2 Numerical simulation

Based on the numerical 2-D model (figure3), the effects of various parameters on the EMD's magnetic field are calculated and analyzed including the electric current, the coil's turns, the iron core, the roll rim, and the air-gap.



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

Figure3 Numerical calculation model

The calculated results (figure4) show that the parameters working on magnetic field are the magnetic conductivity of the roll's rim, the number of the coil's turn, the width of the air-gap, the electric current density, the width of the iron-core, etc. in the order of priority, whose effects are basically linear except the width of air-gap. The rim design and the coil turn's number, the current density are three most important methods to strengthen the side-confining magnetic field.

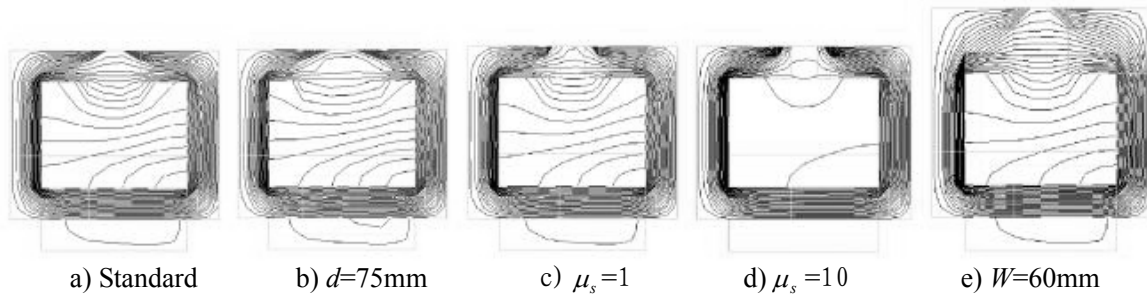
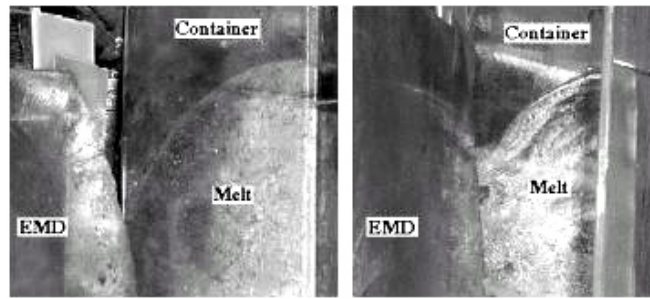


Figure 4 2-D magnetic field distributions of the electromagnetic dam

### 2.3 Experimental

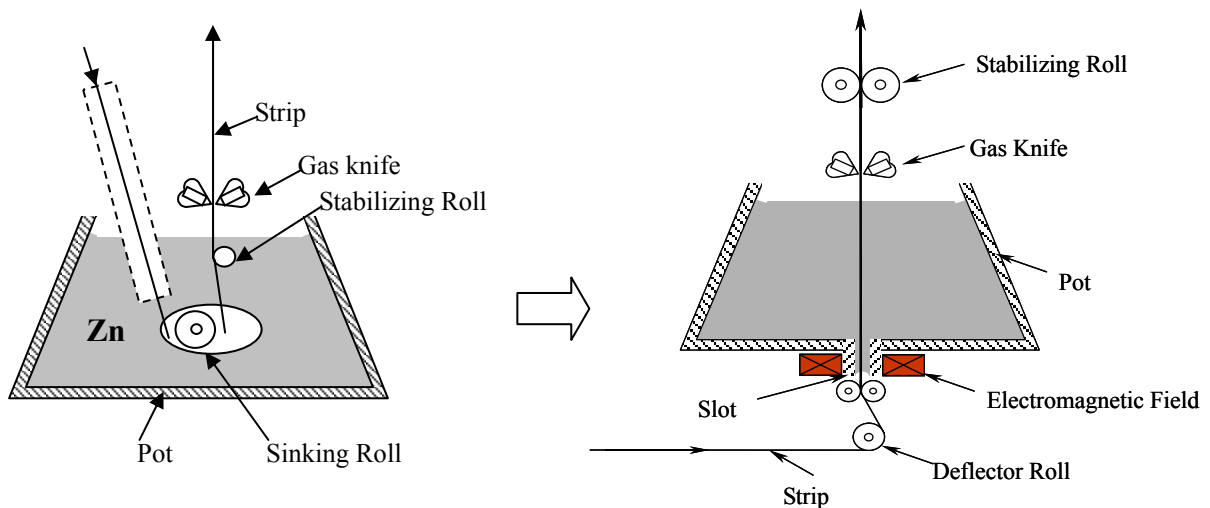
The experiment is done with Sn-15%Pb alloy under the alternating current electric power source. *Figure5* shows that about 100mm-high melt puddle can be dammed from the side direction. The result basically meets the damming need of twin-roll strip continuous casting with the rolls of diameter  $\phi 500\text{mm}$ .



a) Rectangular shape      b) Double-arc shape  
Figure5 Electromagnetic damming of the melt puddle

### 3 Concept of electromagnetic enclosed slot

In conventional continuous hot dip galvanizing process (as shown in *figure6a*), the sink roll is always immersed in the molten zinc as a strip deflector without any power itself, driven by the friction force between the strip and itself. The surface of strip is usually scraped when some surface defect on the sink roll or relative motion between the roll and the strip occur. Usually, the sink roll is made of heat resistant steel and always eroded by molten zinc in the pot. Due to the fact that the strip is easy to be scraped, it is too difficult to keep the surface smooth. Moreover, the speedy rotating bushing and roll will be abraded quickly in the zinc pot because of the eroding. The service period is about from 5 to 20 days. Therefore, the sink roll is required to be maintained or to be replaced frequently, leading to the low productivity, especially in the high capacity operation. Furthermore, a great deal of Fe is dissolved from the sink roll into the molten zinc, influencing the quality of galvanized strip. Therefore, metallurgical engineers in the world always pursue abandoning the sink roll to improve the quality and the productivity of galvanizing strip.



a) Conventional process with sink-roll system

b) EMES without sink-roll system

Figure 6 Schematic view of zinc pot with EMES and without sink-roll system

The electromagnetic enclosed slot (EMES) is good way to solve above problems and realize no-sink-roll galvanizing by the aid of various electromagnetic fields. The schematic view of zinc pot with EMES is shown in *figure6b*. The strip enters the zinc pot through the slot at the bottom. The key is how to prevent the liquid zinc leaking from the slot and to make the strip passing through the slot smoothly, which also is the bottleneck to realize the technology of removing the sink roll.

3.1 Traveling magnetic field [5~7]

In the latest, SMS DEMAG has developed a new continuous vertical galvanizing Line (CVGL), in which the traveling magnetic field has been used to prevent zinc leaking from the slot. It has solved the problem that the strip departs from the center position due to the attraction of magnetic poles. Compared with that in the conventional process, the strip in the CVGL runs more quickly and the productivity can be increased to a large extent. Therefore, the capacity of zinc pot can be decreased by 2/3. The varieties of zinc products can change easily, and the production is more flexible. Furthermore, the defects brought by sink-roll system can be avoided. It was reported [7] that SMS DEMAG has carried out the industrial test at Wuppermann Work in Austria in August, 2002.

3.2 DC electromagnetic field

Seen from *figure6*, a DC magnetic field is set outside the slot, and another DC is connected to the metal, thus the generated electromagnetic force prevents the metal leaking from the slot. The operation is easy, but the waving of the metal and the swaying of strip should be concerned.

3.3 Alternating magnetic field

By alternating magnetic field enclosed slot, the metal in the pot can be levitated by electromagnetic force ( $F$ ) occurred in alternating magnetic field when  $F = \rho gh$ . Compared with the traveling magnetic field or DC magnetic field, the enclosed slot by alternating magnetic field is of high stability, and is easy to control the running of the strip. But the heat generated by eddy-current should be solved by coupling with the hot dip galvanizing process of strip.

As a summary, the hot dip galvanizing technologies without sink roll have many good qualities compared with the traditional galvanizing process. The characteristics of three methods without sink roll are shown in *table 1*.

Table 1 Comparisons of Hot Dip Galvanizing Technology with EMES

Methods Items	AC EMES		DC EMES
	AC Electromagnetic Field	CVGL (Traveling Magnetic Field)	
Principle	Electromagnetic Levitation	Electromagnetic Pump	Electromagnetic Brake
Levitation	Good	Not good	Not good
Swaying	Slight	Severity	Severity
Magnetizing	Slight	Severity	Severity
Heating	Much	A little	None
Operating	Easy	Difficult	Difficult

The swaying of the strip can be solved by application of a reverse magnetic field in the CVGL and the DC electromagnetic field. Regulating the hot dip galvanizing process, especially the speed or annealing process of the strip, can control the heat generated by eddy-current in alternating magnetic field. The electromagnetic force may bring on the waving of the metal surface, which affects the hot dip galvanizing process of strip. It is easy to control the waving of zinc surface in alternating magnetic field, but difficult in CVGL or DC electromagnetic field.

#### 4 Conclusions

The electromagnetic edge dam is an important technique for the twin roll strip casting developing, whose key is how to gain a higher magnetic-dammed height with small electric power through optimizing the design of electromagnetic apparatus. On the base of the research results achieved in laboratory, the further industrial test is being considered.

The EMES or without-sinking-roll technology is a developing direction for hot dip galvanizing process, and also a challenge for the traditional process. In the latest, a laboratory of electromagnetic enclosed slot has been erected at Technology Center of Baosteel, Shanghai, P.R. China, where the hot dip galvanizing technology without sink roll is being studied.

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