The Rrsearch of Permanent Magnet Sealing Technology in Vertical Hot Galvanized Pot

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***Abstract*—In order to solve the confinement problem of liquid metal, permanent magnet sealing is discussed in this paper, and its principle is introduced. Based on calculations, some helpful conclusions are made, which are important for research on hot dip galvanizing process without sink roll.**

Keywords- permanent magnet sealing; electromagnetic force; hot dip galvanizing

I. INTRODUCTION

In continuous hot dip coating process, galvanized pot is a key device. Currently using zinc pot, due to the existence of sink roll and stabilizing roll, not only affects the galvanized sheet surface quality, but also increases the amount of maintenance, reduces productivity, brings about a lot of inconvenience to production and operation. So cancelling mechanism immersed in zinc pot, achieving hot dip coating technique without sink roll become the focus of the researchers at home and abroad. And the key of sealing technology is how to use electromagnetic force to make the molten metal stably suspended. In recent years， several types of electromagnetic sealing method have been developed [1-3]. In 1988, Nippon Steel provided an electromagnetic pump sealing technology using traveling wave magnetic field. In 2002 the German SMS DEMAG company also developed a vertical continuous hot dip galvanizing line (CVGL) [4]. But due to the fluid mechanics instability causing by large current [5], and even the emergence of sparks, the electromagnetic technology at present has a leakage problem in the test process and not been found in practical application.

In this paper, a permanent-magnet sealing technology is discussed, introducing its seal flow principle and mathematical analysis of the liquid metal flow model, application of the permanent magnetic sealing technology is discussed.

II. PERMANENT MAGNETIC SEALING TECHNOLOGY

Permanent magnetic sealing technology is a kind of new technology for liquid sealing, based on the basic theory of modern magnetism, achieving magnetic non-contact transmission to the liquid through magnetic force generated by the application of rare earth permanent magnetic materials.

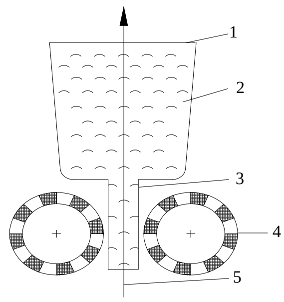


Figure 1. Mechanism diagram of permanent magnetic sealing hot galvanizing pot
1 - zinc pot; 2 - zinc liquid; 3 - PM channel; 4 - PM sensor; 5 - steel belt

Device for realizing this technique is called permanent magnetic sensor, namely PM sensor, its function area is PM channel. See figure 1.

On PM sensor, magnetic field distribution of permanent magnet is placed according to the NS cross; each permanent magnet rotor sets up 8 permanent magnets. The sintered NdFeB permanent magnetic material is selected because of its strong coercive force, largest area of magnetic energy, high working temperature of magnetic materials and high mechanical strength.

Permanent magnetic sealing galvanizing process: liquid zinc from the bottom of the pot enters into the PM channel. When liquid zinc reaches a certain depth (the depth depends on the density of molten metal, the height of liquid level and the current size and other factors), the two permanent magnet rotors (PM sensor) rotate in an opposite direction and synchronous high speed. PM sensor produces external electromagnetic mobile field and forms induced current in zinc liquid, electromagnetic force is produced as a result of the interaction of this current and external magnetic field; electromagnetic force acts on the liquid metal fluid to move upward, avoiding the liquid zinc flows out from the bottom of the pot opening. So when the steel belt from the bottom channel enters into zinc pot, zinc liquid channel is always in a certain height H, achieving the effect of flow sealing.

III. PERMANENT MAGNET SEALING BASIC PRINCIPLES

Figure 2 shows the permanent magnet sealing control principles. As is shown in Figure 2, when magnetic field B_z along the opposite direction of z-axis applies to a metal fluid in the x-axis, magnetic field moves along the positive direction of x-axis, and field direction is along z-axis positive direction next time. According to the formula (1), it will generate the induced current J_y along y-axis direction

$$J_y = \sigma(E + v_B \times B_z) \qquad (1)$$

Considering the metal conductivity σ is very big, the potential E would be zero. So the formula (1) can be rewritten as

$$J_y = \sigma v_B \times B_z = (0,0,-\sigma v_B B_z) \qquad (2)$$

Then The electromagnetic force is given as

$$F_x = J_y \times B_z = (J_y B_z,0,0) = (\sigma v_B B_z{}^2,0,0) \qquad (3)$$

In the formula, σ is the molten metal conductivity, S/m; B is magnetic induction intensity, T; v_B is moving speed, m/s. The electromagnetic force is positive, indicating that the direction of the force is the same with moving direction of magnetic field.

IV. MATHEMATICAL ANALYSIS OF PERMANENT MAGNETIC SEALING

The induced current in the time-varying magnetic field, will produce a three-dimensional electromagnetic force. The object model is simplified, see figure 3. After simplification, only consider the effect on the zinc liquid suspension of one permanent magnet on a permanent magnetic rotor.

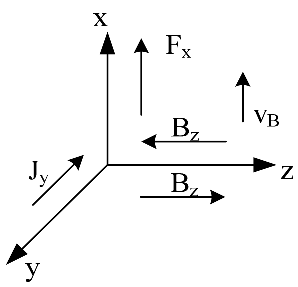
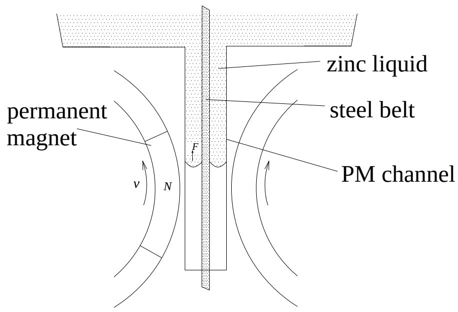
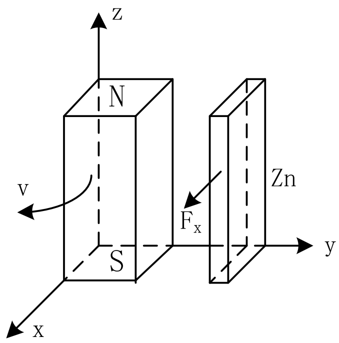


Figure 2. Schematic diagram of permanent magnetic sealing



(a) schematic diagram before simplification



(b)schematic diagram before simplification

Figure 3. Schematic diagram permanent magnetic sealing model simplification

The size of a rectangular permanent magnet is a, b, h, Permanent magnet uniformly magnetized along one direction fully and reached saturation. By literature 6, it is known that the magnetic field in the external is

$$B_x = \int_0^h dB_x = -\frac{K}{2}[\Gamma(a-x,y,z) + \Gamma(a-x,b-y,z) - \Gamma(x,y,z) - \Gamma(x,b-y,z)]\Big|_0^h \qquad (4)$$

$$B_y = \int_0^h dB_y = -\frac{K}{2}[\Gamma(b-y,x,z) + \Gamma(b-y,a-x,z) - \Gamma(y,x,z) - \Gamma(y,a-x,z)]\Big|_0^h \qquad (5)$$

$$B_z = \int_0^h dB_z = -K[\Phi(y,a-x,z) + \Phi(b-y,a-x,z) + \Phi(x,b-y,z) - \Phi(a-x,b-y,z) + \Phi(b-y,x,z) + \Phi(y,x,z) + \Phi(a-x,y,z) + \Phi(x,y,z)]\Big|_0^h \qquad (6)$$

Introducing the function mark:

$$K = \frac{\mu_0 J}{4\pi}$$

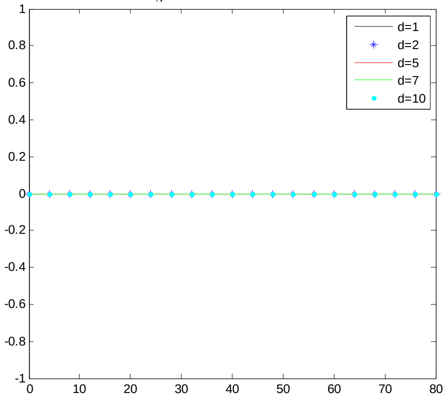
$$\Gamma(\gamma_1,\gamma_2,\gamma_3) = In\frac{\sqrt{\gamma_1^2 + \gamma_2^2 + (\gamma_3 - z_0)^2} - \gamma_2}{\sqrt{\gamma_1^2 + \gamma_2^2 + (\gamma_3 - z_0)^2} + \gamma_2}$$

$$\Phi(\phi_1,\phi_2,\phi_3) = \begin{cases} \arctan\left[\dfrac{\phi_1}{\phi_2}\dfrac{\phi_3 - z_0}{\sqrt{\phi_1^2 + \phi_2^2 + (\phi_3 - z_0)^2}}\right] (y \neq 0) \\ 0 (y = 0) \end{cases}$$

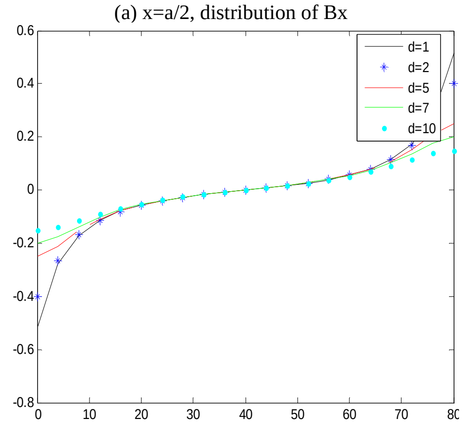
"$[]\Big|_0^h$ "shows the difference of function of the brackets in the Z0 = h and Z0 = 0 of the value. Permeability of vacuum is $\mu_0 = 4\pi \times 10^{-7}$, permanent magnetic surface current density is J. In this way, types (4) ~ (6) which is analytic expression of permanent magnet magnetized in the outer space at any point of the magnetic field generated .

So, (4) ~ (6) is analytic expression formula of the magnetic field at any point of the outer space produced by fully magnetized permanent magnet .

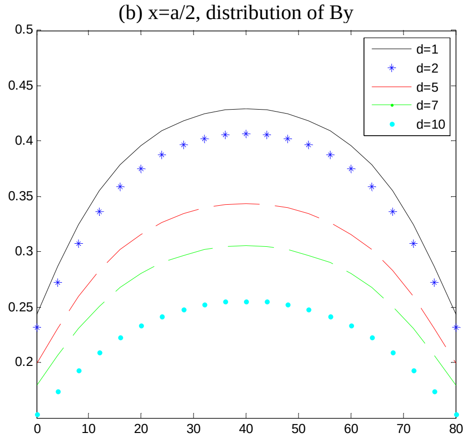
The studied permanent magnet: $a=30\mathrm{mm}; b=40\mathrm{mm}; h=80\mathrm{mm}$, the surface current density was $J=8.55\times10^{5}\,\mathrm{A/m}$. Because liquid zinc is on the right side of permanent magnet, the main research is the permanent magnet external magnetic induction intensity distribution on the positive direction of y- axis.



(a) x=a/2, distribution of Bx



(b) x=a/2, distribution of By



(c) x=a/2, distribution of Bz

Figure 4. Permanent magnet external magnetic induction intensity distribution

The distribution of the magnetic induction intensity shows that on the positive direction of y- axis, Bz is the main magnetic field and magnetic induction intensity does not exist in x- axis direction.

$$B_x = 0 \tag{7}$$

A permanent magnet rotor speed is ω, the distance of permanent magnet rotor center and the liquid zinc center is r , magnet field movement speed of zinc liquid area, namely magnetic field gradient in different directions, can be expressed as

$$v=(v_x,v_y,v_z)=(r\omega\cos\omega t, r\omega\sin\omega t, 0)$$
$$(0\le\omega t\le45^{\circ}) \tag{8}$$

Therefore, induction current J of zinc liquid area can be expressed as

$$\begin{aligned} J &= \begin{bmatrix} i & j & k \\ \dfrac{\partial}{\partial x} & \dfrac{\partial}{\partial y} & \dfrac{\partial}{\partial z} \\ \sigma B_x & \sigma B_y & \sigma B_z \end{bmatrix} \\ &= (\frac{\partial}{\partial y}\sigma B_z - \frac{\partial}{\partial z}\sigma B_y)i + (\frac{\partial}{\partial z}\sigma B_x - \frac{\partial}{\partial x}\sigma B_z)j \\ &+ (\frac{\partial}{\partial x}\sigma B_y - \frac{\partial}{\partial y}\sigma B_x)k \\ &= (\sigma v_y B_z, -\sigma v_x B_z, \sigma v_x B_y - \sigma v_y B_x) \\ &= (\sigma v_y B_z, -\sigma v_x B_z, \sigma v_x B_y) \end{aligned} \tag{9}$$

i, j, k of type (5) are the unit vectors.

the liquid zinc electromagnetic force expression is

$$\begin{aligned} F &= J\times B \\ &= \begin{bmatrix} i & j & k \\ J_x & J_y & J_z \\ B_x & B_y & B_z \end{bmatrix} \\ &= (J_y B_z - J_z B_y)i + (J_z B_x - J_x B_z)j \\ &+ (J_x B_y - J_y B_x)k \end{aligned} \tag{10}$$

V. CONCLUSION

Through the research, the permanent magnetic sealing technology is possible to solve the confinement problem of liquid metal. From the expression of electromagnetic forces, the effective electromagnetic force can be improved by increasing the permanent magnet rotor speed; by balancing of horizontal force on both sides generated by the permanent magnet rotor, strip makes automatic centering. Permanent magnetic sealing technology can solve the problem of sealing flow instability and strip centering that appeared in the AC magnetic field and DC magnetic field sealing, and has the advantages of low cost and equipment maintenance. These conclusions have laid a good theoretical basis to truly achieve no sink roll hot dip galvanizing process.

ACKNOWLEDGMENT

Supported by the National Key Technology Research and Development Program of the Ministry of Science and Technology of China (2012BAF09B00)

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