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Development of New Model of Mold Oscillator in Continuous Casting

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Abstract

To develop the hydraulic mold oscillator in continuous casting machine, the guiding mechanism of mold was studied. The main topics of this study were to design the guiding mechanism of mold which oscillates to prevent the sticking and to reduce the friction resistant force between the solidified shell and mold on casting. We studied many guiding types to analyze the features of worldwide mold oscillator and developed the new model of hydraulic mold oscillator. On the basis of the mold oscillating experiment, the capability of guiding system was proofed by the position error measuring system. The experiment was carried out up to 50 ~ 500 cpm frequencies and 2~10 mm stroke in the variable waveform and the casting results was analyzed by the oscillation mark of slab surface which was formed unavoidably by oscillation.

Keywords: Continuous cast, Mold, Oscillator, Guiding mechanism, Plate spring, LM guide abstract

1. Introduction

Over the last five years, we have elected pilot caster to develop the high speed casting technology. As we know, the continuous caster is facilities to product slab from molten steel. The quality of slab is affected by components of caster and operating technology. Mold oscillator is main facilities to solidify the molten steel and to decide the dimension of slab.

Its features of product requirement to design the mold oscillator are followings.

- · Slab width: 600 ~ 1,000 mm
- · Slab thickness: 100, 140 mm (Two Types)
- · Copper Length for Low Speed (2.5 mpm): 950 mm
- · Copper Length for High Speed (5 mpm): 1,100 mm

To satisfy these conditions, we developed the mechanism to adjust the centerline of narrow face of 2 types (100, 140 mm N.F) for width adjustment. And for the various technical experiments, we developed the hydraulic mold oscillator that oscillates up to 50 ~ 500 cpm frequencies and 2~10 mm stroke in the variable waveform.

For the various speed range of oscillation to control the powder consumption that function as lubrication between copper plate and solidified shell of molten steel, it needs the light dynamic mechanism to counterbalance the moving weight of mold oscillator (Becker et al., 1997). So, we have adapted the plate spring and linear motion guiding device. For the decision of guiding mechanism, we had tested several guiding device that reviewed the mecha-nism of various mold oscillator in world wide. And we had tested the position error by laser sensor according to various operating conditions of waveforms and asymmetry factor and frequency.

To design the hydraulic power unit and equipment for oscillation, we had calculated the driving force and velocity by dynamic analysis that had been

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needed to operate the oscillator over the limit condition.

To review the performance of mold oscillator, we have analyzed the oscillation mark depth and hook of slab surface produced through various casting speed (Becker et al., 1997).

2. Calculations for basic design

To calculate the technical data for mold oscillator, we had studied the driving force that had been needed to oscillate the moving part of mold oscillator.

2.1 Driving force of mold oscillator

1) Moving mass: 180,000 N
2) Operating load condition
· Dynamic Load = 3g Mass = 529,740 N
· Internal mold friction
= Normal force × Friction factor = 73,804 N

$$\text{Normal Force} = \frac{1}{2}\rho g h^2 \times \text{Peripheral Length}$$

· EMBR viscous damping force (not used here)
3) Driving Force by 2 hydraulic cylinders
.1 Cylinder force = (Load + Friction force)/2
=301,772 N

2.2 Waveform review of mold oscillator

There are 4 types waveform for oscillation like as sinusoidal, non-sinusoidal, triangle, double sinusoidal waveform. Non sinusoidal waveform is modified by asymmetry (Becker et al., 1997 ; Darle et al., 1993)to control the velocity of up and down stroke from the following sinusoidal waveform

1) Sinusoidal waveform review

Displacement :

$$d(t) = h * \sin(\omega t - A * \sin(\omega t + \alpha \sin(\omega t)))$$

Velocity :

$$v(t) = h * \omega * \cos(\omega t - A * \sin(wt + \alpha * \sin(\omega t))) * (1 - A * (1 + \alpha * \cos(\omega t)) * \cos(\omega t + \alpha * \sin(\omega t)))$$

Acceleration :

$$a(t) = h * \omega^2 * (A*\cos(\omega t - A*\sin(\omega t + \alpha*\sin(\omega t))) *(\alpha*\cos(\omega t + \alpha*\sin(\omega t))*\sin(\omega t) + (1 + \alpha*\cos(\omega t))^2 *\sin(\omega t + \alpha*\sin(\omega t))) - (-1 + A*(1 + \alpha*\cos(\omega t))*\cos(\omega t + \alpha*\sin(\omega t)) *\sin(\omega t - A*\sin(\omega t + \alpha*\sin(\omega t))))$$

Here, α and A are asymmetry factor.

2) Velocity comparison of waveform

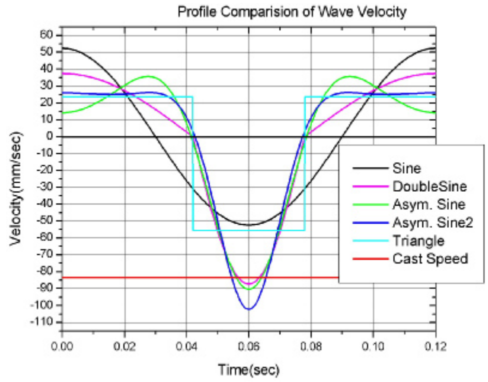

Fig. 1. Profile comparison of waveform velocity.

2.3 Operating condition of mold oscillator

Maximum driving force condition is occurred in the stage of upstroke due to gravity. And all dynamic features like as force and velocity and acceleration are affected by the asymmetry of waveform and the oscillating stroke and frequency.

· Asymmetry: 30 ~ 70%
· Stroke: 1~10 mm
· Frequency: 50 ~ 500 cycle/min

From the above basic data, hydraulic specification had been calculated. Hydraulic pressure is calculated by maximum driving force and acceleration. And hydraulic flow rate is calculated by maximum velocity. Then hydraulic cylinder dimension is decided by pressure and force needed and push rod dimension considered by buckling.

3. Guiding mechanism of mold oscillator

Moving part of mold oscillator is constrained to move into up down side, so guiding mechanism is need to support the vertical motion and to prevent the horizontal motion. The performance of guiding mechanism is decided by the horizontal motion error and the abrasion feature and the duration of operation.

3.1 Review of the existing mechanism

We reviewed the 3 types of guiding mechanism on operating and draw out of new guiding mechanism like as the linear motion guide (LM guide).

3.2 Experiment of guiding mechanism

To test guiding mechanism in the above operating condition, we had decided specification of the LM

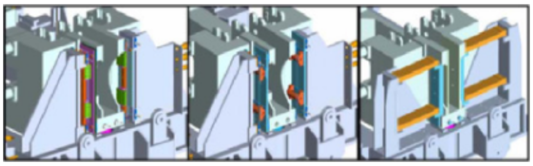

Fig. 2. Guiding mechanism types (LM guide, Roller, Plate Spring)

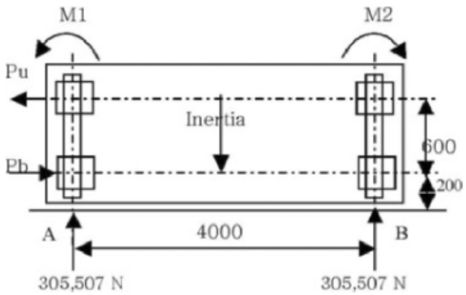

Fig. 3. The schematic diagram of LM guide installation

Fig. 4. Installation status and the dent defect of ball type LM guide.

guide through calculation of the following schematic diagram.

We experiment the LM guide type for 1 year and analyzed the duration of LM guide. First, the ball type LM guide showed the denting defect on surface of guide rail after 2 months. Second, the roller type LM guide had been operated for 1 year and then dismantled to analyze the abrasion status. It showed good performance and we decided to adapt the plate spring that support the counterbalancing weight and resist to structure vibration.

3.3 Case study of guiding mechanism by plate spring

To use the plate spring by the guiding mechanism, we had reviewed the deformation of plate spring.

In the progressing stage of basic design, we decided to study the deformation analysis of plate spring rather than calculation by manual.

To decide the dimension of plate spring, we analyzed the three case combination of plate spring.

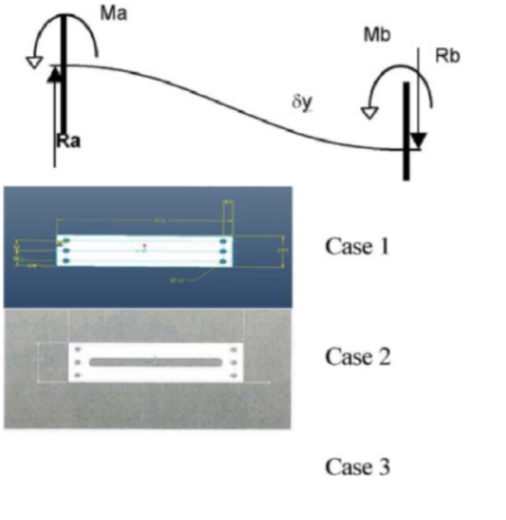

Fig. 5. Case study of plate spring

Table 1. Material property for analysis.

Material	Young's Modulus (kg/mm·s²)	Poisson's Ratio	Density (kg/mm³)	Allowed Strength (kg/mm·s²)
SM400	2.058×10^{8}	0.3	7.85×10^{-6}	2.35×10^{5}
SUP9	7.848×10^{7}	0.275	7.85×10^{-6}	1.57×10^{5}

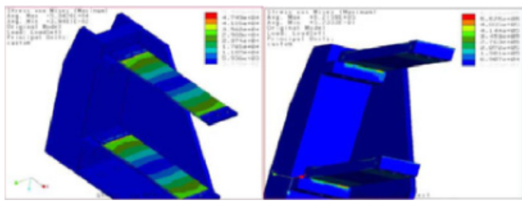

Fig. 6. Stress distribution of case study 1(4 and 5 plates).

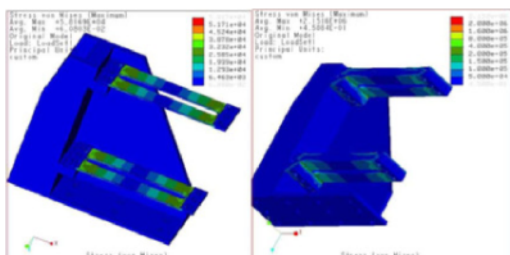

Fig. 7. Stress distribution of case study 2(4 and 5 plates)

The analyzing input condition was 3 mm down stroke in the end of plate and it had been compared each others by maximum stress occurred (Park et al.).

We decided case 1 for safety and counterbalance and adapted the double plates separated by the shim plate between each plate.

3.4 Operating Result of guiding mechanism

From the case study, we had decided the guiding mechanism of pilot caster as following Fig. 9.

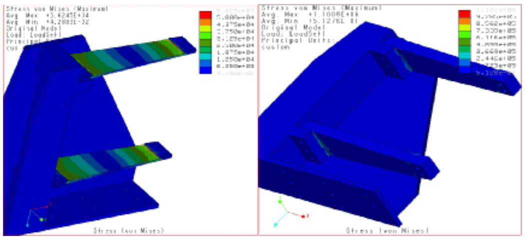

Fig. 8. Stress distribution of case study 3(1 and 5 plates).

Table 2. Results of case study.

Type	Pieces	Maximum Stress (kg/mm·s^2)
1	1	5.34×10^4
1	5	6.22×10^5
2	1	5.82×10^4
2	5	2.15×10^6
3	1	5.62×10^4
3	5	1.10×10^6

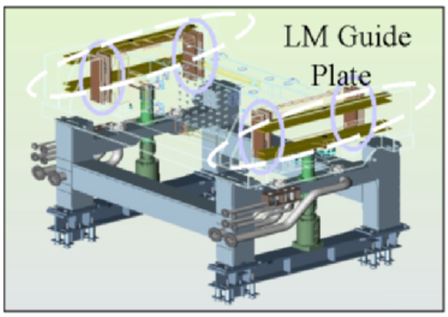

Fig. 9. Configuration of the guiding mechanism.

We had experiment the position error by laser displacement sensor like as following Fig. 10. And position error is tested in the range of operating frequency and stroke (Fig. 11). And we checked the limit condition by the abnormal vibration of structure.

4. Conclusion

To develop the hydraulic mold oscillator in continuous casting machine, the guiding mechanism of

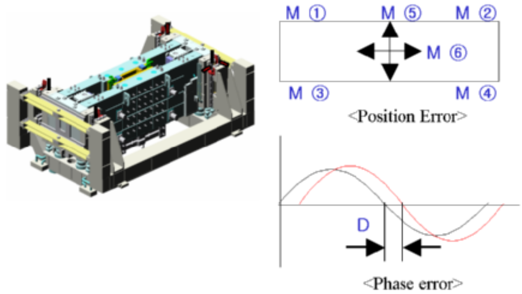

Fig. 10. Measurement configuration of oscillation error.

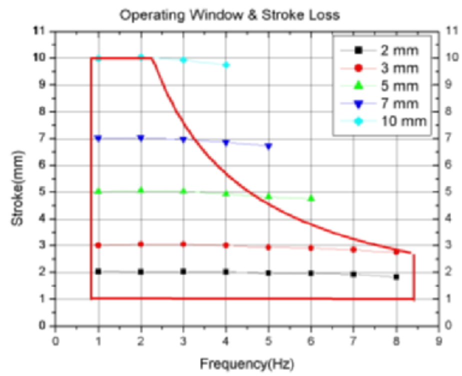

Fig. 11. Measurement results of position error.

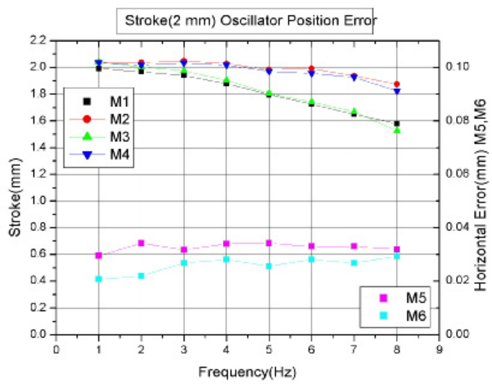

Fig. 12. Measurement results of phase error.

mold and experiments have been performed to reduce the friction resistant force between the solidified shell and mold during continuous casting process.

The guiding performance was improved by the adoption of plate spring and LM guide. In Fig. 11 and Fig. 12, the result of operation shows that position error become worse according to the higher frequency and the bigger stroke. Because the stroke loss defends on the operating condition, to guarantee the position precision, oscillation should be operated in the hydraulic operating range. In the Fig.12, The Vertical position error (0.2 mm) that means phase error makes the horizontal error (0.03 mm) and should be calibrated through the pitch measurement between foot roll and segemnt.

Nomenclature

A: Asymmetry Value
α: Asymmetry factor

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