MEASUREMENT AND ANALYSIS OF MAGNETIC FIELDS OF ELECTROMAGNETIC CASTING ALUMINUM ALLOYS①

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ABSTRACT Results of magnetic field investigation in a Kaiser type caster show that magnetic induction decays rapidly on moving inward from the outer surface and is almost doubled near corner. In the presence of screening, magnetic field strength is attenuated near periphery, but it isn't influenced within the interior. The resultant electromagnetic pressure balances with static head of liquid column, i.e, the upper magnetic induction is smaller than the lower's. However, the maximum pressure moves downward about 1 cm from half height of inductor.

Key words electromagnetic casting magnetic induction electromganetic pressure

1 INTRODUCTION

Electromagnetic casting is a vertical continuous casting technique without contact with inductor. The process is based on such a fact that the liquid can be constrained by a force resulting from the interaction of magnetic field with eddy current generated at the liquid metal surface. To produce an ingot, the vertical side of levitated liquid metal column must be straight. Thus, the electromagnetic pressure must decrease linearly from the half height of inductor to the top of liquid column. In other words, the electromagnetic pressure must ballance with the static head of liquid column[1]. In this paper, a Kaiser type inductor is adopted. In order to eliminate the round corner of liquid metal column owing to magnetic doubling to get a smooth ingot with accurate dimensions, the structures of inductor and screen as well as their positions need be designed accurately. This can begin with studying the magnetic field of EMC process. For a rectangular inductor, the magnetic field is a complicated three dimensional eddy problem, its numerical analysis haven't been reported so far. Thus, this paper only aims at its experimental measurement.

2 EXPERIMENTAL METHOD

When the inductor is fed with an alternating current at frequencies of middle audio range generating an alternating electromagnetic field. This field, in turn, creates induced potential in a coil posed in inductor. Fig. 1 is a magnetic field measurement probe. From electromagnetic induction theory, the induced potential with magnetic inducion is given as follows[2]:

$$E = 2\pi fNBS/\sqrt{2} \quad (1)$$

that is, $$B = E/(4.44fNS) \quad (2)$$

where E is effective induced potential, N is effective circle number of coil, S is its effective

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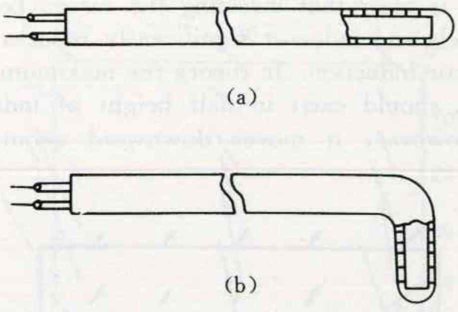

Fig. 1 Magnetic field measurement probe
(a)—vertical component;
(b)—horizontal component

area, f is frequency of magnetic field, B is normal component of magnetic field.

To keep the measurement accurate, the area of coil should be small enough. In this paper, a coil of diameter 2 mm is used. As shown in Fig. 1, it is incorporated with glass tubes and shielded aluminum foil. One end of coil runs through a fine glass tube, another end runs against the glass tube outer wall. At last, the coil is wrapped and fastened by aluminum foil and a big glass sheath. Two shielded lines are connected to the two ends of coil to eliminate the walking line error from the induced potential. A microvoltmeter (Type SX-2173) allows the measurement of induced potential. Nothing that the probe need be cabibrated with test gauge (Type CT-3) first. To begin with, a block is posed into inductor, and an alternating current at frequency of 2 340 Hz is fed until it reaches 4 800 A.

3 RESULTS AND ANALYSIS

For a rectangular cross section inductor, a three dimensional electromagnetic field is generated. Owing to symmetry, only a quarter of its volume is examined. The coordinate system is shown in Fig. 2, which is drawn to scale. The coordinate Z expresses the direction of drawing down. Point O indicates the center of upper surface of liquid column. Coordinates X, Y respectively the length and width directions. The displacement of the probes along coordinates X, Y, Z are also shown in Fig. 2. The intervals of each close points of coordinates X, Y, Z are respectively 50, 30, 10 mm.

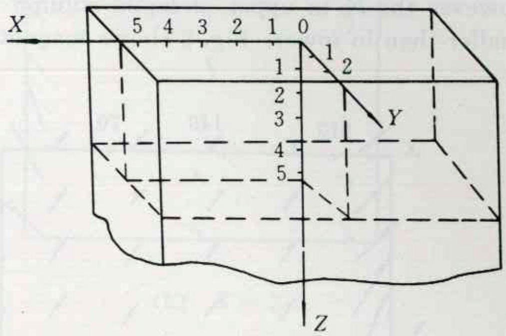

Fig. 2 Measurement point

Fig. 3~5 respectively show the three dimensional electromagnetic fields of no load, screening and no screening. The length expresses its magnitude (maximum value), the arrow head indicates its direction. As shown in Figs, the magnetic induction decays rapidly on moving inward from the outer surface. Only one out of ten is remained in the center of the inductor. The magnetic induction B_z is smaller in upper and bigger in lower. This is beneficial to keep the vertical side of liquid column straight. It is notable that the maximum pressure moves downward about 1 cm from half height of inductor owing to inclination of vertical side of the Kaiser type inductor.

Besides, the horizontal components B_x and B_y are obviously bigger in periphery than in center of inductor, and are almost doubled near corner. However, they are smaller than component B_z. Screen can make vertical component B_z of magnetic field decrease in periphery and increase in center. Moreover, it can be seen that magnetic field lines are marketly sloped toward the vertical symmetry of inductor in periphery. This is true in theory.

4 DISCUSSION

Fig. 6 is the distribution of magnetic induction B_z along periphery of ingot, there exists obvious magnetic doubling phenomenon in corner. Fig. 7 shows the distribution of B_z along the coordinate Y, which decays following exponential law in half height of inductor. However the B_z in upper of liquid column is smaller than in lower. Fig. 8 shows magnetic induction changes of various screen positions. It is clear that inserting the screen between melt and inductor significantly reduces magnetic induction. In theory the maximum value B_z should exist in half height of inductor. However, it moves downward about 1 cm

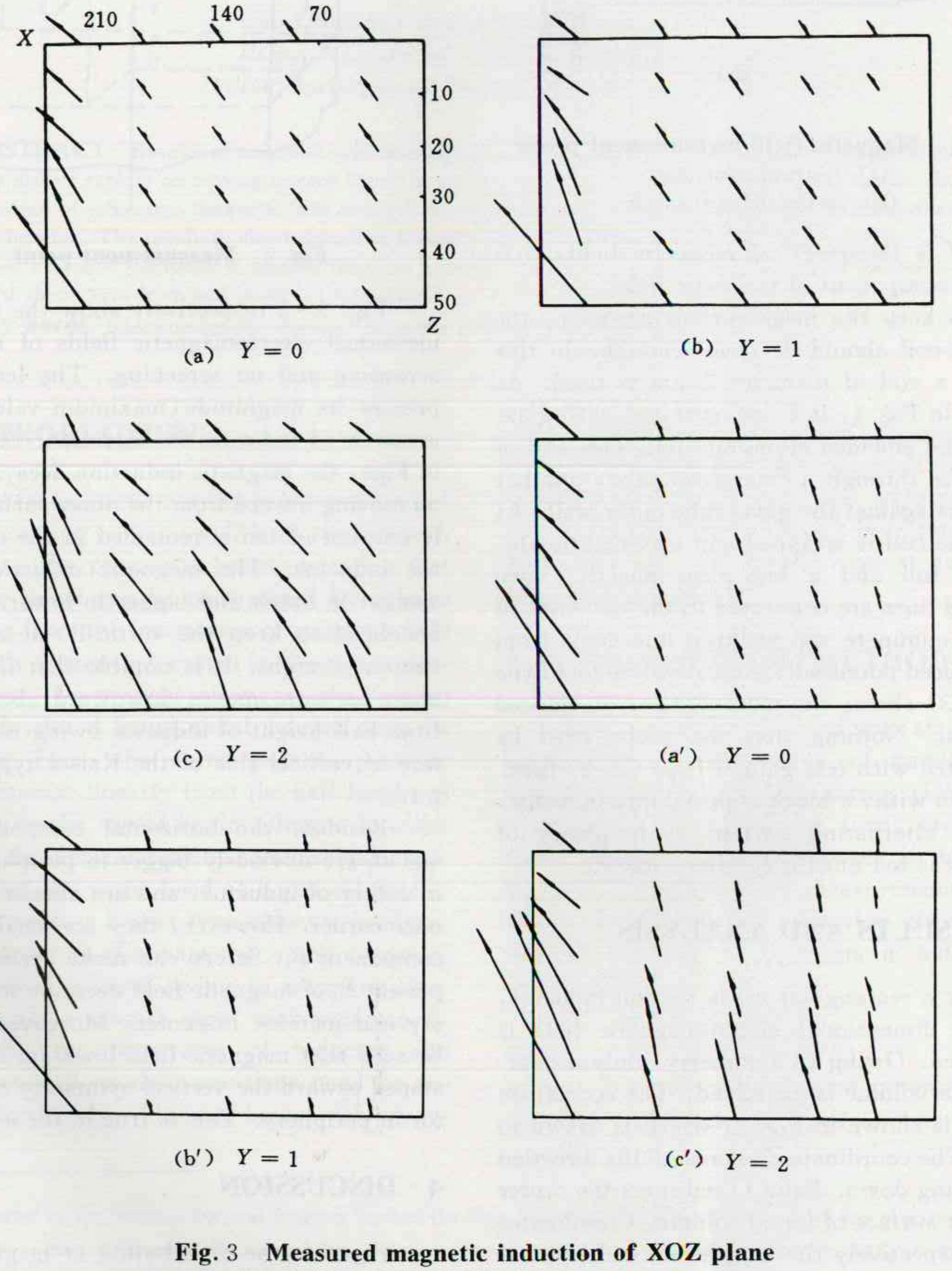

Fig. 3 Measured magnetic induction of XOZ plane
(a-c)—screening; (a′-c′)—no screening

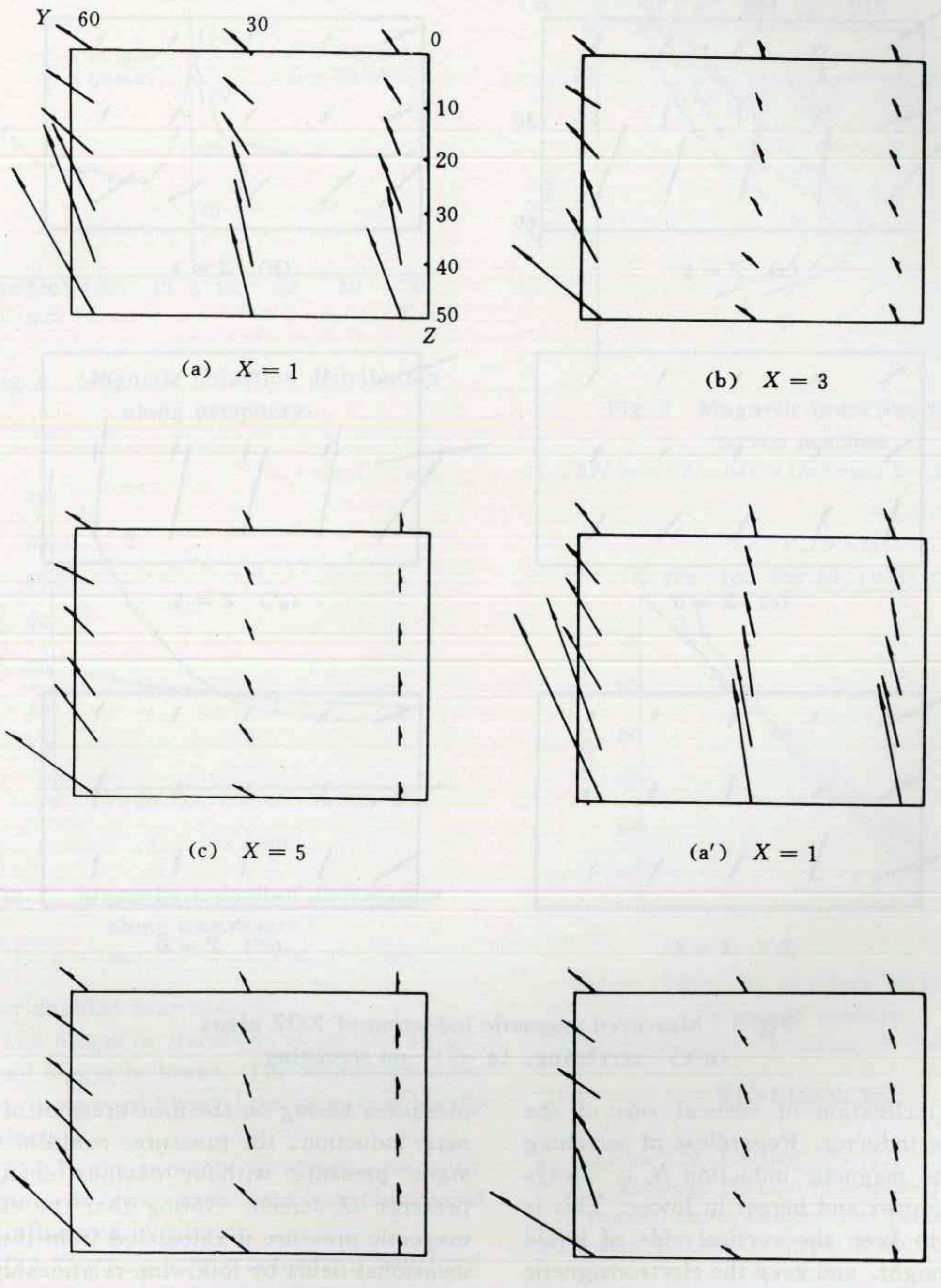

Fig. 4 Measured magnetic induction of XOZ plane
(a-c)—screening ; (a′-c′)—no screening

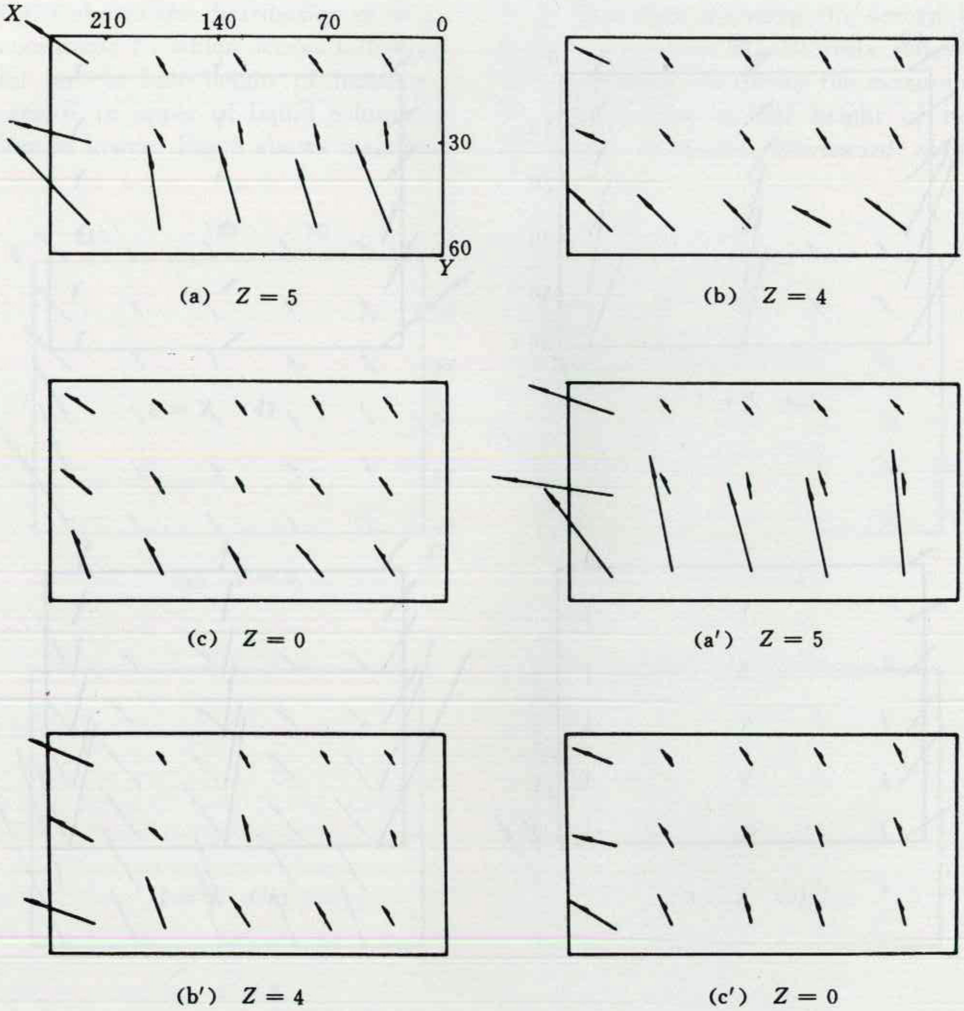

Fig. 5 Measured magnetic induction of XOZ plane
(a-c)—screening; (a′-c′)—no screening

owing to inclination of vertical side of the Kaiser type inductor. Regardless of screening or not, the magnetic induction B_z is always smaller in upper and bigger in lower. This is beneficial to keep the vertical side of liquid column straight. and keep the electromagnetic pressure balance with static pressure. This is also beneficial to raise the control's stability and ingot surface quality. These mean that the Kaiser type inductor can be used to cast qualified ingot.

Fig. 9 is the calculated electromagnetic pressures basing on the measurement of magnetic induction, the pressures conform to the static pressure without obvious change in presence of screen. Noting that the electromagnetic pressure is calculated from three dimensional fields by following relationship[3].

$$P = B^2/(4\mu) \qquad (3)$$

4 CONCLUSIONS

(1) Magnetic induction decays rapidly on moving inward from the outer surface and is

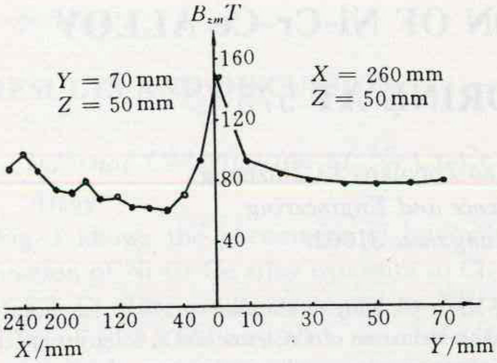

Fig. 6 Magnetic induction distribution along periphery

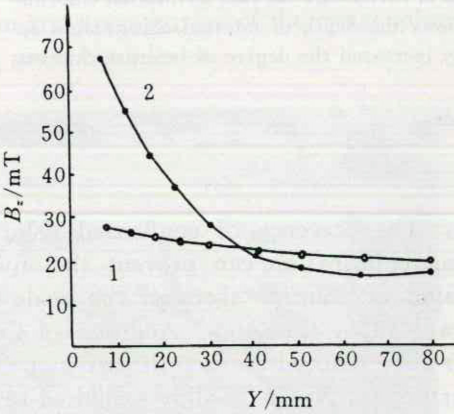

Fig. 7 Magnetic induction distribution along coordinate *Y*

1—$z = 0$ mm; 2—$z = 50$ mm, $x = 0$ mm

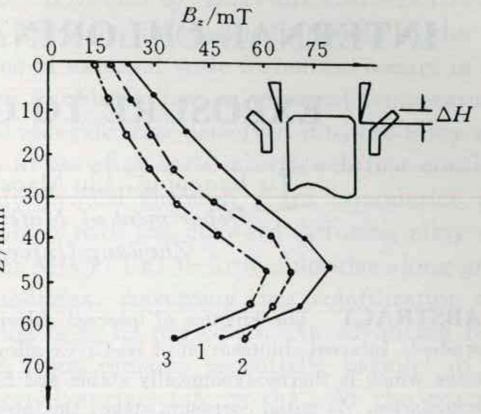

Fig. 8 Magnetic induction versus screen position

1—$\Delta H = \infty$; 2—$\Delta H = 18.5$ mm; 3—$\Delta H = 6.5$ mm

almost doubled near corner.

(2) Magnetic induction is smaller in upper and bigger in lower. The maximum value moves downward about 1 cm from half height of inductor.

(3) In the presence of screen, magnetic induction is attenuated near periphery and isn't influenced in interior.

(4) The Kaiser type inductor is beneficial to keep the vertical side of liquid column straight and to raise control's stability and ingot surface quality.

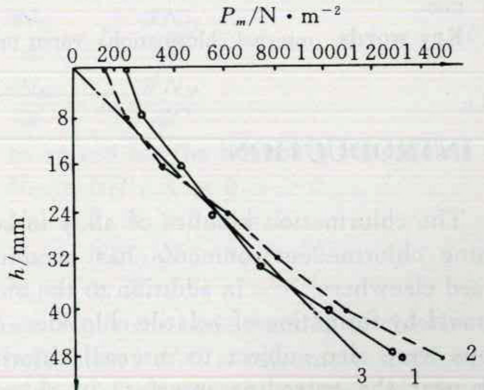

Fig. 9 Magnetic pressure versus height of liquid column

1—No Screening; 2—Screening; 3—Static Pressure

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