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Behavior of Slip Force in Continuous Flat plate Casting

Si-Young KIM*

An equation was derived which describes the slip force that occurs at the casting of initial state due to unequilibrium with support bar weight, liquid metal, casting velocity, thickness, control roller, hydraulic motor and etc.

The slip force equations are solved on the basis of velocity, gravity and thickness in casting ingot. In this paper the auther assumed that the other mechanisms are normal.

The behaviour of slip force in many characteristics is calculated as a function of velocity, gravity and thickness with variation. The conclusion with this phenomena is reached that the present theory realistically predicts the growth of slip force in a flat plate ingot continuous casting machine.

Introduction

In drawing of wires, tubes casting irons and other applications where high power, guide roller and pinch roller are used, the slip force (Alexander, 1963 : Kim, 1981) can often not be neglected. In the equations for the slip forces system, it is necessary to consider the unequilibrium force(Backfen, 1972) concerning with the various components in the system.

A few of ingot shape (Backen, 1973) are frequently made in iron industry for casting. The slip is so important that flat plate ingot continuous casting are made in initial state.

The analysis of slip force in the casting machine may be considered as a result of dynamic equilibrium in the behaviour of fluid mechanism, supportbar, pneumatic control system, gravity, velocity, thickness and others in the casting ingot.

In these problems the influence of gravity, velocity, and of rhe state can be especially important if the others mechanism are normal. The present investigation of slip force behaviour is directed toward developing a formulation of the state which concerns with all of a flat plate ingot continuous mechanism and of two dimensional form for inital state of casting.

The problems studied are gravity of melting metal velocity, and thickness of the state.

By the Fig. 1 of the problem, In the initial state it is improtant to consider supporting bar load and hence the assumptions of uniformal solidification state in accordance with the solidification factor, k, are needed. By means of the pinch roller, the flat plate ingot is sustained toward the guide and control roller. In the unequilibrium state, it may be equated and the other phenomena are investigated.

These tendencies will be used to calculate the suitable pressure with pinch roller casting, and are similar to that used other type of material.

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*釜山水産大學; National Fisheries University of Busan.

Basic equations

1. Perpendicular force of suport bar.

The physical problm is depicted in Fig. 1. The support bar is interposited between the both molds. The initial solidification state and it's length are l_v, l_m respectively.

The state of the casting and support bar is described by the equation.

$$F_1=q(l_m+l_v) \quad \cdots\cdots(1)$$

Where q is gravity, the weight of element at the guide roller is an arbitary function of angle given by

$$dw=(R-\frac{b}{2})\,d\varphi \quad \cdots\cdots(2)$$

and the equation of state in tangential force gives,

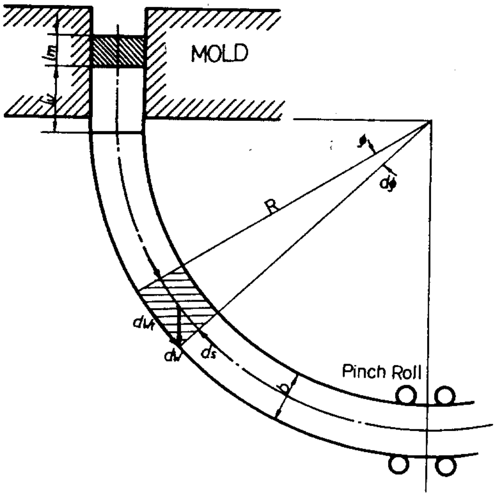

Fig. 1 Schematic diagram of mold and support bar.

$$dw_t=q\,(R-\frac{b}{2})\,\sin\varphi d\varphi \quad \cdots\cdots(3)$$

The force for the guide axisymetric roller is

$$dF=q(R-\frac{b}{2})\,\cos\varphi d\varphi\cdot\mu \quad \cdots\cdots(4)$$

where μ represents the factor of friction in the roller. The result is,

$$dF_{s_1}=dw_t-dF=q(R-\frac{b}{2})\cdot(\sin\varphi-\mu\cos\varphi)d\varphi \quad \cdots\cdots(5)$$

Integration of the equation (5) φ between $\varphi=\pi$ and $\varphi=\frac{3}{2}\pi$ gives,

$$F_2=\int_{\pi}^{\frac{3}{2}\pi} q\,(R-\frac{b}{2})(\sin\varphi-\mu\cos\varphi)d\varphi$$

$$=q\,(R-\frac{b}{2})(1-\mu) \quad \cdots\cdots(6)$$

Where $\mu=\mu_o\,(\frac{D_i}{D_a})$ and μ_o is the friction factor of bearing.

2. Moving energy inter position support bar.

2.1 Compoment force of semi-melting iron in molds.

Considering the force of semimelting iron in molds by the support to length, h, In Fig. 2,

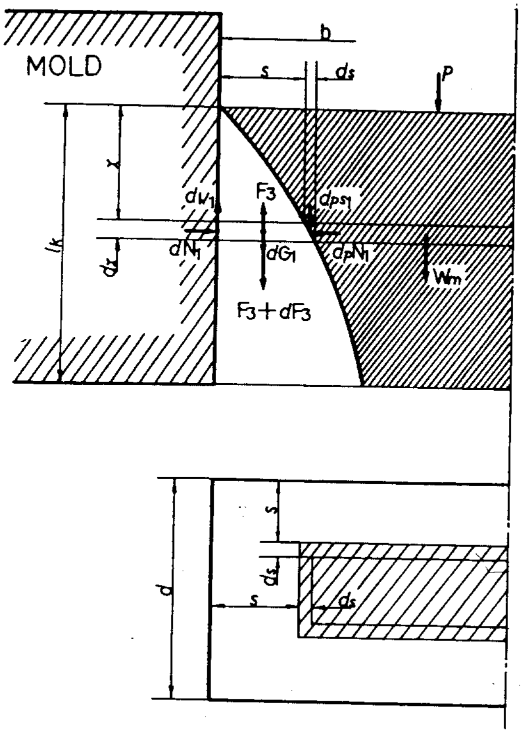

Fig. 2 Initial state of casting plate.

the values gives

$$Wm=\gamma Ahx=\gamma x(b-2S)(d-2S)+P \quad \cdots\cdots\cdots(7)$$

where $S=k\sqrt{x/v}$ and k is solidification factor.

2.2 Force of solidification layer

This force deals with the metal through two molds as shown Fig. 2 and the equilibrium force diagram are revealed in Fig. 3.

Force consumption over molds, melting metal and solidification layer becomes,

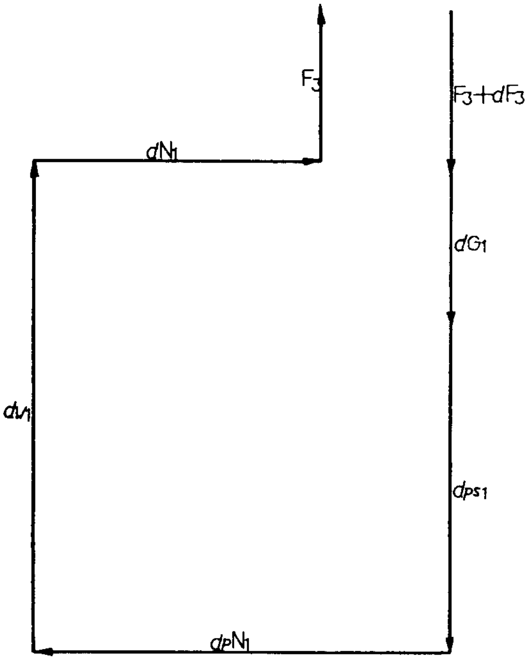

Fig. 3 Equbililium of Force state.

$$F_3+dF_3+dG_1+dp_{s1}-dN'_1-F_3=0 \quad \cdots\cdots\cdots\cdots(8)$$

$$dN_1-dpN_1=0$$

$$dN'_1=\mu_k dN_1=0$$

Where μ_k is the friction factor of metal. The solution of the force gives respectively.

$$dF_3=\mu_k dpN_1-dG_1-dpS_1=0 \quad \cdots\cdots\cdots\cdots\cdots\cdots(9)$$

Where

$$dpN_1=p[b-2S+2(\frac{b}{2}-S)]\ dx$$
$$=P(b+d-4S)dx \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(10)$$

$$dpS_1=p[(b-2S+d-2S)ds-2(ds)^2]$$
$$\simeq P(b+d-4S)ds \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(11)$$

$$dG_1=\gamma[(b+d)s-2S^2]dx$$
$$=\gamma s(b+d-2S)dx \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(12)$$

$$P=\gamma x \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(13)$$

$$ds=\frac{k}{2}(v_x)^{-\frac{1}{2}}dx=\frac{S}{2x}\ dx \quad \cdots\cdots\cdots\cdots\cdots\cdots(14)$$

and substituting equation (10)～(12) into equation (14) gives

$$dpN_1=\gamma x(b+d-4k\sqrt{x/v})dx \quad \cdots\cdots\cdots\cdots\cdots\cdots(15)$$

$$dps_1=\gamma\cdot\frac{k}{2}\sqrt{x/v}\,(b+d-4k\sqrt{x/v})dx \quad \cdots\cdots(16)$$

$$dG_1=\gamma\cdot k\sqrt{x/v}\,(b+d-2k\sqrt{x/v})dx \quad \cdots\cdots(17)$$

Using equation(15)～(17), equation (9) becomes

$$dF_3=\gamma[(\mu_k bk+4kv^2)x-1.5k_v b_k\sqrt{x}$$
$$-4\mu_k k_v x^{\frac{3}{2}}]dx$$

$$F_3=\gamma\cdot x[(\frac{\mu_k b_k}{2}-2k_v^2)x$$
$$-b_k k_v\sqrt{\bar{x}}-1.6\mu_k k_v x^{\frac{3}{2}}] \quad \cdots\cdots\cdots\cdots\cdots\cdots(18)$$

The slip force have solution

$$F_s=Wm-2F_3+S/B(F_1+F_2) \quad \cdots\cdots\cdots\cdots\cdots\cdots(19)$$

3. Force out of exit molds.

This force deals with strained drawing out of both molds as shown Fig. 4.

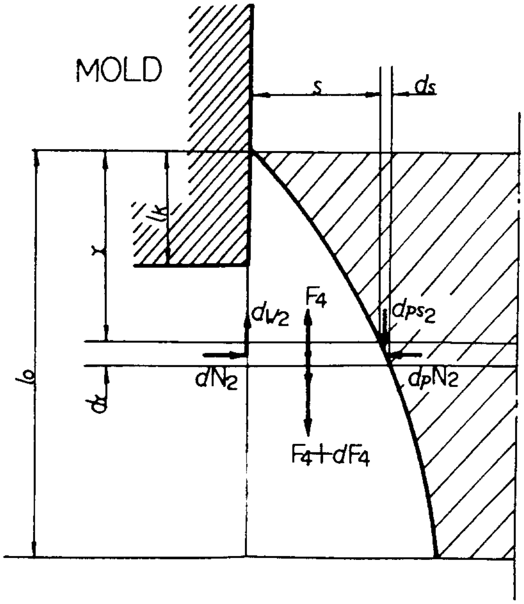

Fig. 4 Mold gate diagram of mold and casting plate.

$$dF_4=\mu dpN_2-dG_2-dpS_2 \quad \cdots\cdots\cdots\cdots(20)$$

and the following equation may be given,

$$dpN_2=\gamma\cdot x(b-2k_v\sqrt{x})dx \quad \cdots\cdots\cdots\cdots(21)$$

$$dpS_2=\frac{1}{2}\gamma k_v\sqrt{x}(b_k-k_v\sqrt{x})dx \quad \cdots\cdots\cdots(22)$$

$$dG_2=\gamma k_v\sqrt{\bar{x}}(b_k-2k_v\sqrt{x})dx \quad \cdots\cdots\cdots\cdots(23)$$

$$dF_4=\gamma[(\mu b+4k_v{}^2)x-\frac{3}{2}b_kk_v\sqrt{x}-2\mu_kk_vx^{\frac{3}{2}}]dx \quad \cdots\cdots\cdots\cdots(24)$$

Calculating the force of drawing from equation (20), we obtains,

$$F_4=\gamma\cdot x[(\frac{1}{2}\mu b+4k_v{}^2)x-\frac{3}{2}b_kk_v\sqrt{\bar{x}}-2\mu_kk_vx^{\frac{3}{2}}]+C \quad \cdots\cdots\cdots\cdots(25)$$

Where

$$x=l_o+(R-\frac{b}{2})\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)$$

Using the boundary condition for $x=l_k$ the values

$S+S_k$ and $F_4=F_3$ may be calculated.

Hence

$$C=F_3-\gamma l_k[(\frac{1}{2}\mu b+2k_v{}^2)l_k-(l_k+0.8\mu l_k)s_k]$$

4. Force of strand out solidification

Consider the case of a out strand solidification at section in Fig.5. The problem may be given the following equations.

$$dpN_3=\gamma\left[l_o+(R-k_v\sqrt{l})\times\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)(b-2k_v\sqrt{l})\times(R-k_v\sqrt{l})\left(\frac{\Delta l}{R-\frac{b}{2}}\right)\right] \quad \cdots\cdots(26)$$

$$dpS_3=\gamma\left[l_o+(R-k_v\sqrt{l})\times\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)(b+d-4k_v\sqrt{l})\times\left(k_v\frac{\Delta l}{2\sqrt{l}}\right)\right] \quad \cdots\cdots\cdots\cdots(27)$$

$$dG_3=\gamma[(b+d-2k_v\sqrt{l})\times k_v\sqrt{l}(R-\frac{b}{2}k_v\sqrt{l})\left(\frac{\Delta l}{R-\frac{b}{2}}\right) \cdots(28)$$

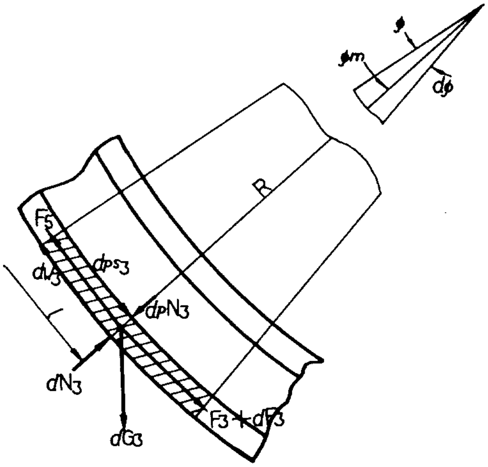

Fig. 5 Outside of casting strand.

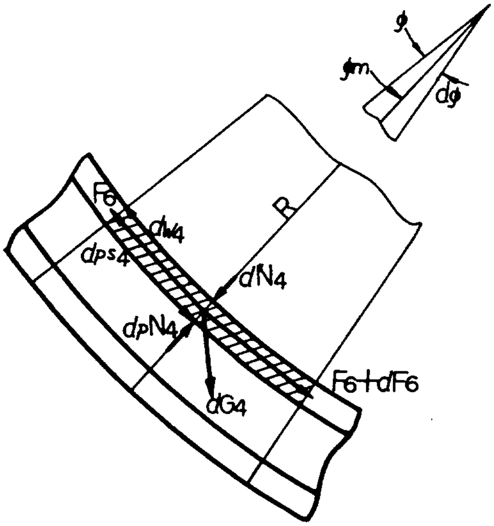

Fig. 6 Inner side casting strand.

Hence we can write

$$F_5(\varphi)=\frac{1}{\cos\left(\frac{\Delta l}{R-\frac{b}{2}}\right)+\mu\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)}\times\left[F_5\left[\cos\left(\frac{\Delta l}{R-\frac{b}{2}}\right)-\mu\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)\right]-dG_3\left[\cos\left(\frac{\Delta l}{R-\frac{b}{2}}\right)-\mu\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)\right]+\mu dpN_3+dpS_3\right. \quad \cdots\cdots\cdots\cdots(29)$$

5. Force of strand inner solidification

By the same method, the following equations may be given

$$dpN_4=\gamma\left[l_o+(R-d+k_v\sqrt{l})\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)\right]$$

$$(b-2k_v\sqrt{l})\cdot(R-d+k_v\sqrt{l}\left(\frac{\Delta l}{R-\frac{b}{2}}\right)\quad\cdots(30)$$

$$dpS_4=\gamma\left[l_o+(R-d+k_v\sqrt{l})\sin\left(\frac{\Delta l}{R-\frac{b}{2}}\right)\right]$$

$$(b+d-4k_v\sqrt{l})\left(k_v\frac{\Delta l}{2\sqrt{l}}\right)\cdots\cdots\cdots\cdots(31)$$

$$dG_4=\gamma(b+d-2k_v\sqrt{l})\,k_v\sqrt{l}\,(R-d+\frac{d}{2}k_v\sqrt{l})$$

$$\times\frac{\Delta l}{R-\frac{b}{2}}\cdots\cdots\cdots\cdots\cdots\cdots(32)$$

and hence

$$F_6(\varphi)=\frac{1}{\cos\frac{\Delta l}{R-\frac{b}{2}}-\mu\sin\frac{\Delta l}{R-\frac{b}{2}}}$$

$$\times\left[F_6\left(\cos\frac{\Delta l}{R-\frac{b}{2}}+\mu\sin\frac{\Delta l}{R-\frac{b}{2}}\right)\right]$$

$$-dG_4\left(\cos\frac{\Delta l}{R-\frac{b}{2}}+\mu\sin\frac{\Delta l}{R-\frac{b}{2}}\right)$$

$$+\mu dpN^4-dps_4\quad\cdots\cdots\cdots\cdots\cdots\cdots(33)$$

Table 1 Position of casting plate along the guide

Metal	Position	Mold	Gate	Strand	Apron Roll
Iron	(m)	9.05	7.85	5	3

Table 2 Value of used constants

d: 1.04m	μ_o: 0.001
R: 10.0m	v: 1.0~4.0m/min
k: 0.023	γ: 6.5~8.0ton/m
μ_k: 0.15	b: 0.1~0.4m

Discussions

To check the phenomena of the present solution, some numerical values of the variable are listed in Table 1. and Table 2.

Fig. 7 Shows the relationships between the slip force and the variation of the flat plate casting velocity. Fig. 7 show that, as velocity increases, the slip force describes a parabola, with their coefficient constant. This may be due to some solidification factor with velocity, some partially developed friction in molds,

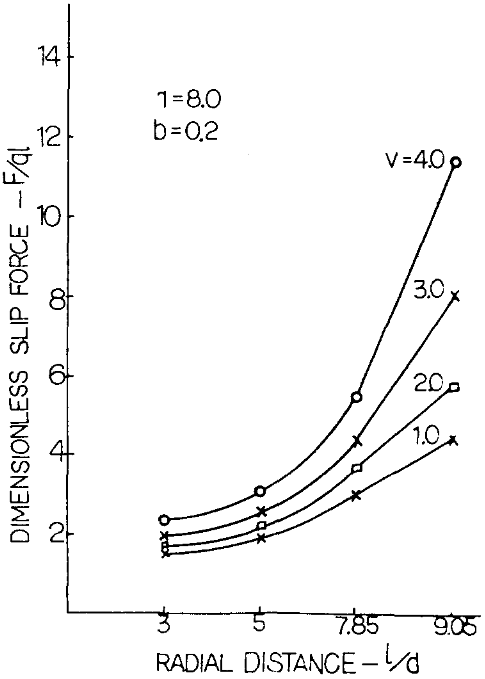

Fig. 7 Dimensionless slip force due to variation of velocity.

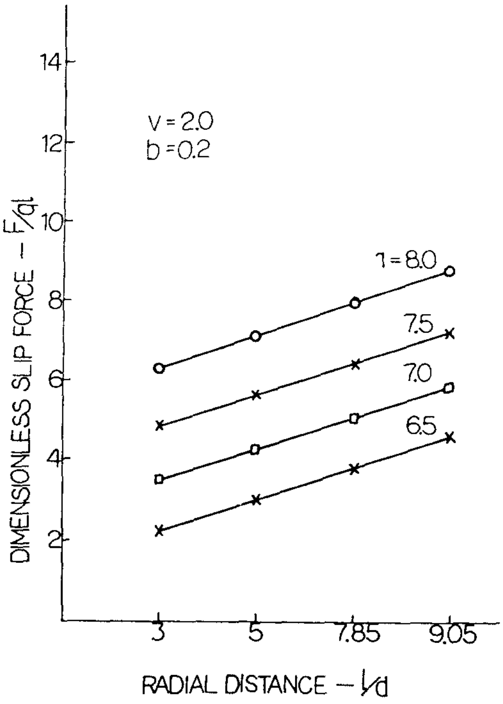

Fig. 8 Dimensionless slip force due to variation of gravity.

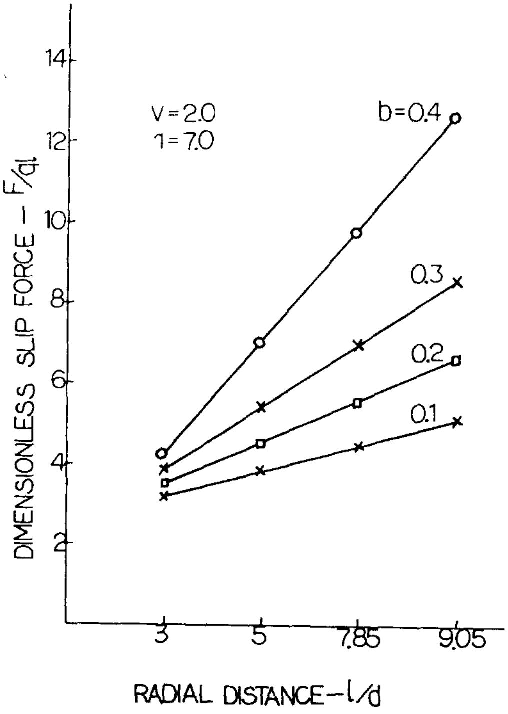

Fig. 9 Dimensionless slip force due to variation of width.

melting metal, or other minor factors. Even with the observed rapid increasing slip force with velocity, the analytical analysis appears to be entirely adequate for the problem of this flat plate casting continuous machine. Especially the values of slip force at initial state are very important problems. It is shown that the solidification factor lag due to the casting velocity are great important. Fig. 8 demonstrates the variation of the slip force due to variation of melting metal gravity.

It becomes very evident that the slip force is not due to only the values. This means that in distance of one strand from the mold, the slip force will have decreased by the factor. For the most engineering case in the production, the values need not to be considered.

The gravity of melting metal is the only factor in slip force increasing. As has been demonstrated above, the inclusion of the value causes with creasing of slip force. But it is not concerned with friction force of solidification cast. The calculations were performed numerically, using procedure similar to that employed in calculating the gravity and velocity as discussed above mention. Generally the slip force appears to be increasing with variation of thickness. The value of Fig. 9 shows that, while there is a considerable effect of the thickness, this is because the results depends heavily upon what thickness of the casting is in relation to the variable values. For the case considered here the thickness was slighly increased. It is important to emphasis that the analysis presented is based on the characteristics of the solidification factor due to the both side of the strand. In reality, the melting metal between the out and inner solidification state effects of the slip force may be resulted in a significant amount of energy being propagated through the strand, partically largely at exit of molds.

Conclusions

The results obtained here may be summarized as follows;

(1) The generalized slip force equation can be applied to many flat plate ingot casting continuous machines for estimating suitable pressure in pinch roller.

(2) The slip force varies parabolic with the variation of the strand drawing velocity.

(3) For the influence of gravity and thickness, the slip force increase popportional to the values. These influences are bigger as the values are greater.

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平板 鋼塊 鑄造用 連鑄機의 Slip Force 擧動에 對하여

金　時　榮

平板 鋼塊를 連續的으로 鑄造할 경우에 初期鑄造 狀態에서 Mold 內部의 Support bar 및 熔鋼自重, 鑄造速度, 熔鋼두께, 이를 支持하는 制御 Roller, 油壓機構, 구동 Motor, 그리고 鑄造組織의 응고等이 熔鋼의 引拔力을 유도하는 Pinch Roller와의 사이에서 動力學的 不平衡을 일으켜 Slip 現象을 招來하므로 本 論文에서는 以上의 諸要因들을 根據로 Slip 現象을 규정하는 式을 誘導하고 鋼塊의 鑄造速度, 比重量, 두께의 變化에 대한 Slip Force 擧動을 규명하였다. 그 結果

1. 本 論文의 解析式에 依하여 平板鋼塊 連續鑄造用 Pinch Roller의 적정압을 設計할 수 있다.
2. 比重量은 순수히 自重만 增加시키는 要因이며 Slip Force는 鑄造速度變化에 對해서 抛物線的으로 增加한다.
3. 鑄造두께 및 比重量의 變化에 對한 Slip Force는 이에 比例하여 增加하나 特히 두께의 값이 小幅보다 大幅에서 그 變化값이 크게 나타났다.