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TECHNICAL ARTICLE—PEER-REVIEWED

Risk Assessment and Intelligent Control of Ladle Pouring Mechanism

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Abstract The constant current casting of molten steel in ladle lifted by special-purpose crane is an important part of metallurgical production line. At the same time, there are risks of failure in the pouring process, so it is necessary to carry out risk assessment on the pouring system. Based on the constant current casting theory, the relationship between velocity and time is deduced by assuming the physical model in the pouring process. And the visual programming software is proposed, and the lifting speed of the auxiliary hook at different moments in different pouring stages is calculated. The lifting speed of the auxiliary hook at different times was input into MATLAB, and the Gaussian curve was fitted in the Notebook environment, to obtain the function and function curve of the lifting speed of the auxiliary hook with respect to time. It can be seen from the comparison of a series of auxiliary hook lifting velocity function curves that the molten steel starts to flow from the ladle until the molten steel is poured. The lifting speed changes smoothly and does not cause huge fluctuations and splashes of molten steel. This study not only prevents the failure of ladle crane, but also realizes the intelligent automatic control of the casting process of ladle crane. It is of great significance to the intelligent development of ladle crane.

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Introduction

Ladle crane is an important equipment for steel ladle lifting and pouring of molten steel on the metallurgical production line, which enables the high-temperature molten steel in the ladle to be poured at a constant flow rate. Steady pouring of ladle is a prerequisite for safe production. Once the failure of the ladle of the crane, crane hook occurs; it will bring great losses to the production process. Therefore, the realization of intelligent constant current pouring is of great significance to the metallurgical industry. In the stable pouring process, the change of the molten steel mass and the tilting angle always needs to be matched with the change of the lifting speed of the ladle crane's auxiliary hook. To calculate accurately, the relationship between pouring time and volume is obtained through the hypothesis analysis of the physical models at different stages in the pouring process. At the same time, the velocity matching formula of each stage is derived to realize constant current pouring of ladle.

The failure of ladle of crane in early stage increases significantly, which brings danger to industrial production, and the manual intervention control of ladle of crane increases significantly. In 2004, Vernon observed excessive middle tread damage; metallurgical failure analysis was performed on a set of carbon steel gantry crane wheels [1]. In 2005, Yano K proposed an advanced control method and proposed an automatic control robot, motor inverse system design and flow model feedforward controller to control the liquid pouring of the ladle and complete automatic pouring, effectively preventing the ladle failure [2]. In 2006, Noda Y proposed a new modeling and control method for the automatic pouring process of tilting ladle. The pouring control system is established by using the inverse dynamics feedforward control of the proposed model to prevent failure of auxiliary hook in the pouring process, the system can be applied to tipping ladle automatic pouring, and the actual flow from the ladle out of the liquid can be accurately close to the desired flow [3]. In 2007, the position control of molten steel from the ladle was proposed. The mathematical model of the drop position was deduced from the shape of the ladle and the pouring conditions. The automatic pouring was completed by controlling the motor [4]. In 2008, Noda Y introduced a method for pouring flow in an automatic pouring system for the foundry industry. The flow was measured by using extended Kalman filtering and sensor dynamics, and the flow of liquid from the ladle was precisely controlled and poured into the mold to complete the automatic pouring [5]. In 2009, it was proposed to control the weight of the pouring molten steel at the target weight to achieve accurate control of the weight of the pouring molten steel. During pouring, molten steel can be accurately and quickly poured into molds, increasing productivity, and saving energy [6]. In 2010, an advanced control system for tipping ladle automatic pouring robots for the metal foundry industry was proposed. The mathematical model of the drop position was deduced from the shape of the ladle and the pouring conditions, adopting the proposed mathematical model of falling position to establish the position control by means of feedforward control [7]. A method for controlling automatic pouring of molten steel through tipping ladle is provided. By installing a computer that controls the pouring process program, controlling the servomotor corresponding to the desired flow pattern of the molten steel enables molten steel to be poured into the mold [8]. In 2012, Ito A and Noda Y presented a novel falling position control of the outflow liquid which makes the pouring mouth set as low as possible while avoiding clash between the ladle and the mold [9].

In recent years, intelligent control has been widely used in metallurgical industry to prevent ladle crane and crane hook failure. In 2015, Yano K and Kaneko M proposed the supervisory control of the automatic pouring process. First, a series of mathematical models of the pouring process were established. Then, the monitoring system used model predictive control to reasonably switch from forward-inclined motion to backward-inclined motion to achieve accurate pour volume and avoid failure of crane ladle [10]. In 2017, Qin and Xie introduced the boundary interpolated reproducing kernel particle method (BIRKPM) to analyze the mechanical property of a crane hook. It is deduced by combining the interpolated reproducing kernel particle (IRKP) method with the boundary integral equation (BIE) method which aims to solve elastic mechanics plane stress [11]. Qin and Li proposed a new vibration analysis and control method on the nuclear power crane to improve its stability, which is based on magneto-rheological fluid damper (MRFD) and switch algorithm control strategy. It is proved that MRFD should be taken into consideration in the vibration control of nuclear power crane [12]. In 2018, Alam and Hassan presented metallurgical failure analysis method to find the root cause of a mobile crane turret bolts failure [13]. In 2020, Kishore used a multidisciplinary approach, including field observer perspectives, metallurgical surveys and finite element analysis, to analyze the failure of a 24-ton hook [14]. In 2020, Ho Duc Tho and Akihiro Kaneshige proposed a simple motion planning method for the vibration-free transfer process of an overhead crane using S-curve commands. Based on a position baseline S-curve, which is generated from a bang-off-bang acceleration profile, two approaches are proposed to build the vibration suppression capability to reduce the possibility of ladle failure [15].

The previous research results of this research team used BIRKPM to analyze the mechanical properties of crane hooks and proposed a new vibration analysis and control method to improve the stability of nuclear-powered cranes and prevented the failure of hooks, which provided a certain theoretical and technical basis for this study.

According to the previous studies, the difficulty of this study is to control the casting speed and hook speed, to prevent the failure and tilting of ladle. The previous research did not make a hypothesis analysis on the complex model in the pouring process. According to the principle of constant current pouring molten steel, the assumption analysis of the three stages in the pouring process is easy to calculate, and the relationship between the speed of the auxiliary hook and the time is deduced. A new method for calculating the lifting speed of the auxiliary hook is presented, and the corresponding visualization program is programmed. On the one hand, the program can analyze and calculate the lifting speed of the auxiliary hook at different moments in different pouring stages. On the other hand, the corresponding lifting speeds of the auxiliary hook lifting points at multiple moments are fitted in MATLAB, and the corresponding speed function and graphs are obtained through the designed parameterization program. Based on this, auxiliary hook lifting speed function is used to obtain the frequency regulation function and curve of the auxiliary hook drive motor. It can be seen from the comparison of a series of auxiliary hook lifting velocity function curves that the molten steel begins to flow from the ladle until the pouring of the molten steel is complete, and the motor frequency changes smoothly within a certain range. Avoiding failure of ladle pouring, this can guarantee the service life of the motor. The automatic pouring control program can be developed rapidly for different tonnage of pouring crane, which has good safety application value.

The rest of the paper is organized as follows. The mathematical description model of pouring and the relevant formulas are stated in "Physical Mathematical Model of Ladle Casting" section. The intelligent control law of constant current pouring drive and the results of numerical simulation experiments are described in "Intelligent Control Law of Constant Current Pouring Drive of Molten Steel" section. Finally, some concluding remarks wrap up this work in "Conclusion" section.

Physical Mathematical Model of Ladle Casting

Aiming at the shortcomings of the existing domestic and foreign technologies, the research method for lifting speed of auxiliary hooks of ladle cranes with a constant flow volume is proposed. This research method is based on the principle of pouring molten steel at a constant flow volume. With the volume change of molten steel as a variable, according to the original size of the ladle, the ladle rotates 0.5 degrees around the rotation center to reach the next position to calculate the lifting speed of the ladle crane's auxiliary hook until the provided pouring time ends.

According to the ladle structure size shown in Fig. 1, the diameter d of the molten steel surface can be deduced.

According to the size ratio of ladle, there is

$$\frac{mD}{D} = \frac{x}{0.075D} \tag{Eq 1}$$

which is

$$x = \frac{m(D - 0.85D)}{2} = 0.075mD \tag{Eq 2}$$

So the available steel surface diameter d is

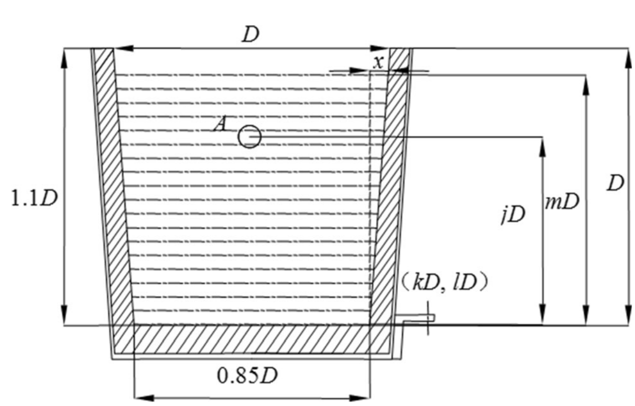


Fig. 1 Ladle outline dimension

$$d = 0.85D + 2x = 0.85D + 0.15mD \tag{Eq 3}$$

The liquid volume formula is

$$V_1 = \frac{1}{3}\pi D(R^2 + r^2 + Rr) \tag{Eq 4}$$

The total time of the ladle dumping process is the time when the auxiliary hook begins to increase to the end of the pouring of molten steel.

$$T = T_1 + \Delta T \tag{Eq 5}$$

where T is the time when the auxiliary hook starts to lift until the molten steel is completely poured, T1 is the time for the molten steel to be poured, and ΔT is the time for the auxiliary hook to start lifting to the outflow of molten steel.

The constant pouring flow of molten steel is

$$q = \frac{V_1}{T} \tag{Eq 6}$$

Then, the principle of constant flow pouring, the establishment of the molten steel volume function.

The ladle has two special conditions while pouring molten steel. One condition is that when the bottom of the package is not completely covered with molten steel, the entire molten steel forms an oblique cut frustum of a cone body. In another condition, as the tilt angle increases, the molten steel continues to flow from the ladle, and the molten steel in the ladle forms an irregular horseshoe shape. For oblique cut frustum of a cone body and irregular horseshoe shapes, no suitable volume formula calculations can be found. To solve this problem, liquid steel can be conceived as a cylinder with the radius taking the average of the liquid steel level and the bottom radius of the ladle. That is, $R=(1.7D+0.15mD)/4$. In ladle design, the taper is generally small, so this assumption can be established.

To calculate the process speed more accurately, the ladle is rotated by 0.5 degree and the lifting speed of the lifting point is calculated, and the lifting speed of the auxiliary hook is calculated according to the relation of trigonometric function. There are three stages in the pouring of molten steel in the ladle. (1) The ladle has just begun to pour, and the molten steel has not yet flowed out of the ladle. (2) The molten steel begins to flow from the ladle, and the remaining molten steel forms an imaginary oblique cylinder. (3) The molten steel continues to flow from the ladle, and the remaining molten steel forms a horseshoe shape until the molten steel has been poured. Since the molten steel can stably outflow from the ladle, the flow rate of the molten steel is calculated as q.

1. In the first stage, the ladle had just begun to pour, and the molten steel had not flowed out of the ladle, as shown in Fig. 2.

The tangent value of the critical value a1 of ladle dumping angle is

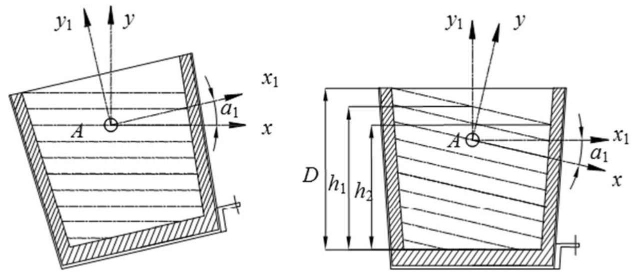


Fig. 2 Ladle tipping a1 angle diagram

$$\tan a_1 = \frac{(1-m)D}{R} \quad \text{(Eq 7)}$$

In the first stage, the ladle dump angle is in the range of

$$\tan a \leq \tan a_1 \quad \text{(Eq 8)}$$

The formula for calculating the flow velocity of molten steel along the wall is

$$q_1 = \frac{(1-m)D}{\Delta T} \quad \text{(Eq 9)}$$

The calculation parameters are shown in Table 1.

The calculation formula of the rotation radius of the lifting point is

$$Y = \sqrt{(kD)^2 + (jD - lD)^2} \quad \text{(Eq 10)}$$

For every 0.5-degree rotation of the ladle, the circular arc calculation formula for the lifting point is

$$S = \sqrt{(jD - lD - Y\sin\gamma)^2 + (kD - Y\cos\gamma)^2} \quad \text{(Eq 11)}$$

The corresponding time calculation formula for each rotation 0.5 degree of the ladle is

$$t_i = \frac{R(\tan a_{1i} - \tan(a_{1i} - \Delta a))}{q_1} \quad \text{(Eq 12)}$$

where Δa is 0.5 degree.

2. In the second stage, molten steel begins to flow from the ladle and the remaining molten steel forms an imaginary slope-truncated cylinder, as shown in Fig. 3.

The tangent value of the critical value a_2 of ladle dumping angle is

$$\tan a_2 = \frac{2D}{R} \quad \text{(Eq 13)}$$

In the second stage, the ladle dump angle is in the range of

$$\tan a_1 \leq \tan a_{2i} \leq \tan a_2 \quad \text{(Eq 14)}$$

The volumetric formula for the formation of an imaginary slope-truncated cylinder for the remaining molten steel is

Table 1 Calculation parameters

Designation	Unit	Implication
D	mm	Diameter of upper surface of ladle
R	mm	The average of the surface radius and the bottom radius of the molten steel
m		Molten steel height coefficient
j		Ladle trunnion height coefficient
k		Lifting point lateral coefficient
l		Lifting point vertical coefficient
V_1	mm^3	Total volume of molten steel
V_2	mm^3	The total volume remaining in the ladle
a_1		The critical angle of pouring when bottom of the ladle begins to flow
a_2		The critical angle of pouring when bottom of the ladle begins to bare
t_1	s	The time for the ladle rotates 0.5 degrees
β		The angle of the liquid surface when the bottom of the ladle is exposed
Y	mm	Ladle rotation radius
S	mm	Ladle rotates 0.5 degrees, distance of lifting point traveled
q	mm^3/s	Flow rate
θ		The angle between the total speed of the lifting point and the horizontal plane
γ		The angle between the rotation radius and the vertical plane of the lifting point
n_d	r/min	The actual rotating speed of the motor
F	Hz	Frequency
S		Slip (3–4%)
R_j	mm	Radius of drum
z_j		The number of gears of the retarder low-speed shaft gear
z_d		The number of gears of the retarder high-speed shaft gear
P		Electromagnetic pole number
n_j	r/min	The actual rotating speed of the drum

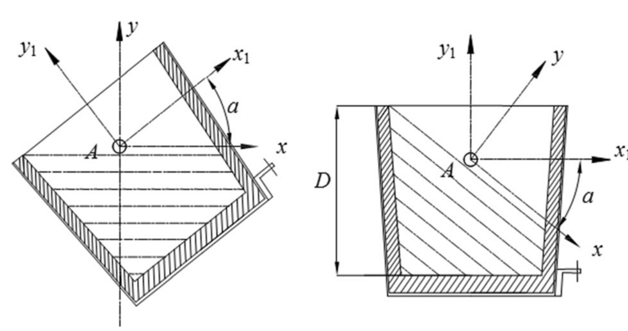


Fig. 3 Outflow of molten steel

$$V_{2i} = \frac{\pi R^2(D + D - 2R\tan a_{2i})}{2} \quad \text{(Eq 15)}$$

The corresponding time calculation formula for each rotation 0.5 degree of the ladle is

$$t_i = \frac{(V_{2i} - V_{2i-1})}{q} \quad \text{(Eq 16)}$$

where V_{2i-1} is the residual molten steel volume corresponding to the previous 0.5 degree.

3. In the third stage, molten steel continues to flow from the ladle and the remaining molten steel forms a horseshoe until the molten steel has been poured, as shown in Fig. 4.

In the third stage, the ladle dump angle is in the range of

$$\tan a_2 \le \tan a_{3i} \quad \text{(Eq 17)}$$

The formula for calculating the volume of residual steel in the ladle is

$$V_2 = R^2 \tan a\left(\sin\beta + (\pi - \beta)\cos\beta - \frac{\sin^3\beta}{3}\right) \quad \text{(Eq 18)}$$

Among them,

$$\cos\beta = \frac{(D\cot a - R)}{R} \quad \text{(Eq 19)}$$

The corresponding time calculation formula for each rotation 0.5 degree of the ladle is

$$t_i = \frac{V_{3i} - V_{3i-1}}{q} \quad \text{(Eq 20)}$$

where V_i represents the volume of the remaining molten steel corresponding to the previous 0.5 degree.

In summary, as shown in Fig. 5, the formula for calculating the lifting speed of the ladle crane's auxiliary hook is

$$\gamma = \theta \quad \text{(Eq 21)}$$

$$v_y = \frac{S\sin\gamma}{t_i} \quad \text{(Eq 22)}$$

Intelligent Control law of Constant Current Pouring Drive of Molten Steel

Auxiliary Hook Lift Speed Intelligent Parameterized Programming

When the ladle crane dumps the ladle using the constant flow pouring method, the lifting speed of the auxiliary hook lifting point at different positions at different times is constantly changing. To make the calculation more reliable, the above hypothetical three-stage calculation process is programmed and calculated according to the flowchart in Fig. 6, and the speed of the auxiliary hook lifting of the ladle crane can be rapidly obtained according to the input parameters. To facilitate analysis, a Gaussian curve is called to fit in the MATLAB Notebook environment, and the polynomial and function curves of the fitting function are obtained. The lifting speed of the auxiliary hook in ladle casting process can be obtained quickly and efficiently by computer programming. Then, use MATLAB's Notebook Toolbox to call MATLAB's Gaussian curve fitting command to get a function of lifting speed and time.

The data of some steel plants are used as input parameters. In the programming software, the parameterized software is compiled according to the flowchart of Fig. 6 and the lifting speed of the auxiliary hook at different times can be obtained, as shown in Fig. 7. The lifting speed of the ladle crane's auxiliary hook at different times is calculated by parametric software. These discrete data are shown in Table 2. The unit of time is min, and the unit of speed is m/min. The ladle auxiliary hook lifting point needs to be fitted to the ascending speed. Therefore, these data are input into MATLAB, and the Gaussian curve is called in the Notebook environment to fitting. The function curve of the lifting speed of the ladle crane's auxiliary hook can be obtained as shown in Fig. 8.

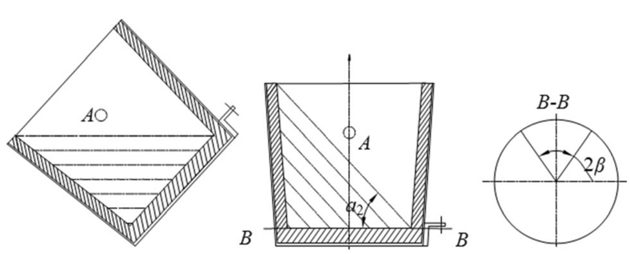


Fig. 4 Ladle tipping a2 angle diagram

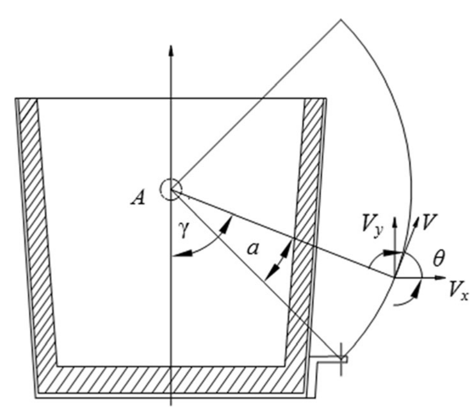
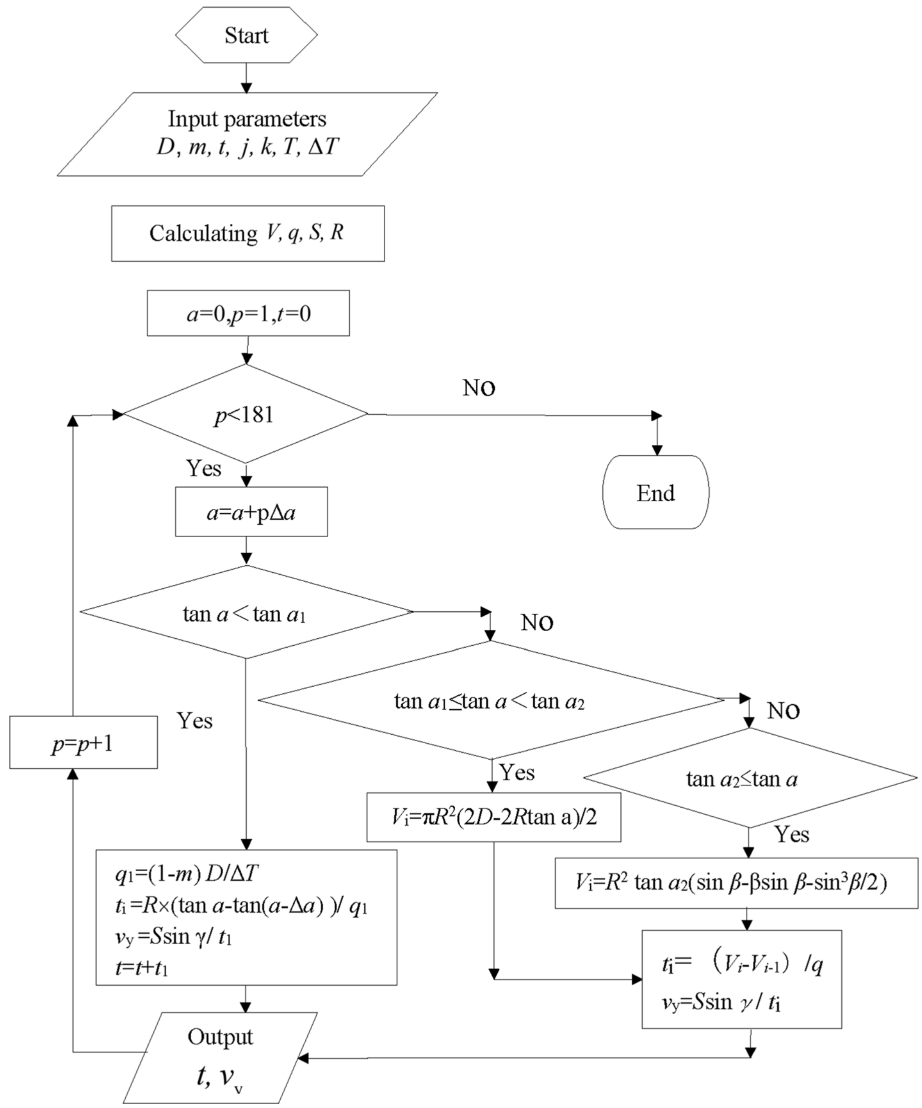


Fig. 5 Auxiliary hook lifting point running track diagram

Fig. 6 Calculation program flowcharts of the auxiliary hook lift speed



Auxiliary Hook Intelligent Drive Motor Frequency

The motor in this paper is induction ac motor, and most of the motors used in industry are of this type. The rotation speed of induction motor is approximately dependent on the number of poles and frequency of the motor. The operating principle of the motor determines that the number of poles of the motor is fixed. In addition, the frequency can be adjusted outside the motor and then supplied to the motor, so that the rotation speed of the motor can be freely controlled. Therefore, the frequency converter is used as the optimal equipment for motor speed control equipment.

Motor speed calculation formula is

$$n_d = \frac{60f(1-s)}{p} \quad \text{(Eq 23)}$$

where n_d is the actual rotating speed of the motor, f is the frequency and its unit is Hz, s is the motor slip ratio, generally 3–4%, and p is the number of poles, a multiple of 2.

Because the wire rope is wound from the drum, the lifting speed of the auxiliary hook is the drum's linear speed, so the calculation formula of the drum's actual rotation speed is

$$n_j = \frac{v_y}{2R_j\pi} \quad \text{(Eq 24)}$$

The actual rotating speed of the motor is calculated as

$$n_d = \frac{v_y z_j}{2R_j z_d \pi} \quad \text{(Eq 25)}$$

The formula between the motor frequency and the speed of the auxiliary hook lift is

$$f = \frac{p v_y z_j}{120(1-s)R_j z_d \pi} \quad \text{(Eq 26)}$$

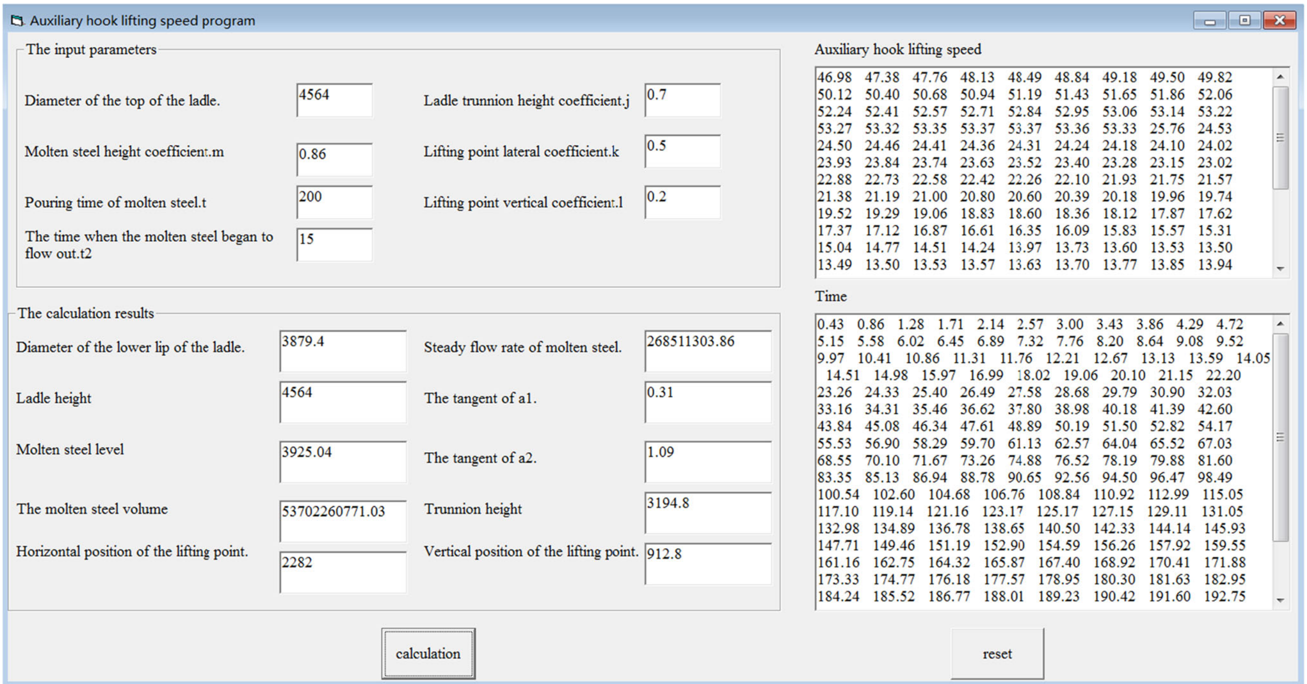


Fig. 7 Auxiliary hook lifting speed calculation

Table 2 Calculation results

Degree /°	Payload capacity													
	50/t		100/t		200/t		250/t		320/t		400/t		500/t	
	Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed
10	0.06	3.23	0.06	2.87	0.09	3.86	0.12	3.12	0.12	3.39	0.14	2.92	0.14	3.14
20	0.13	2.00	0.14	1.34	0.21	1.79	0.27	1.66	0.28	1.57	0.34	1.51	0.35	1.46
30	0.24	1.82	0.29	1.21	0.44	1.63	0.54	1.50	0.58	1.43	0.68	1.37	0.73	1.33
40	0.38	1.47	0.49	1.00	0.72	1.32	0.86	1.22	0.96	1.16	1.10	1.11	1.19	1.07
50	0.57	1.11	0.73	0.74	1.09	0.99	1.29	0.92	1.45	0.87	1.66	0.83	1.81	0.81
60	0.76	1.26	0.98	0.84	1.48	1.13	1.75	1.04	1.97	1.00	2.24	0.95	2.46	0.92
70	0.91	1.53	1.19	1.02	1.79	1.37	2.11	1.26	2.39	1.20	2.70	1.15	2.98	1.11
80	1.04	1.97	1.35	1.32	2.02	1.77	2.38	1.63	2.70	1.55	3.06	1.48	3.37	1.44
90	1.10	11.15	1.43	7.43	2.15	9.98	2.53	9.22	2.87	8.76	3.25	8.39	3.58	8.13

where R_j is the radius of the drum, z_j is the number of gears of the retarder low-speed shaft gear, and z_d is the number of gears of the retarder high-speed shaft gear.

To prevent the occurrence of motor burn accidents, the frequency inverter must change the voltage while changing the frequency, so the voltage must change with the frequency.

Figure 6 shows the flowchart of the calculation program of lifting speed of auxiliary hook; the parameterized software can be compiled according to the above figure.

The parameterized software to calculate the lifting speed of auxiliary hook is shown in Fig. 7. Input the required parameters to calculate the lifting speed of auxiliary hook, and the lifting speed can be obtained quickly.

In Fig. 8, (a) is 50t auxiliary hook lifting speed and time curve, (b) is100t auxiliary hook lifting speed and time curve, (c) is 200t auxiliary hook lifting speed and time curve, (d) is 250t auxiliary hook lifting speed and time curve, (e) is 320t auxiliary hook lifting speed and time curve, (f) is 400t auxiliary hook lifting speed and time curve, and (g) is 500t auxiliary hook lifting speed and time

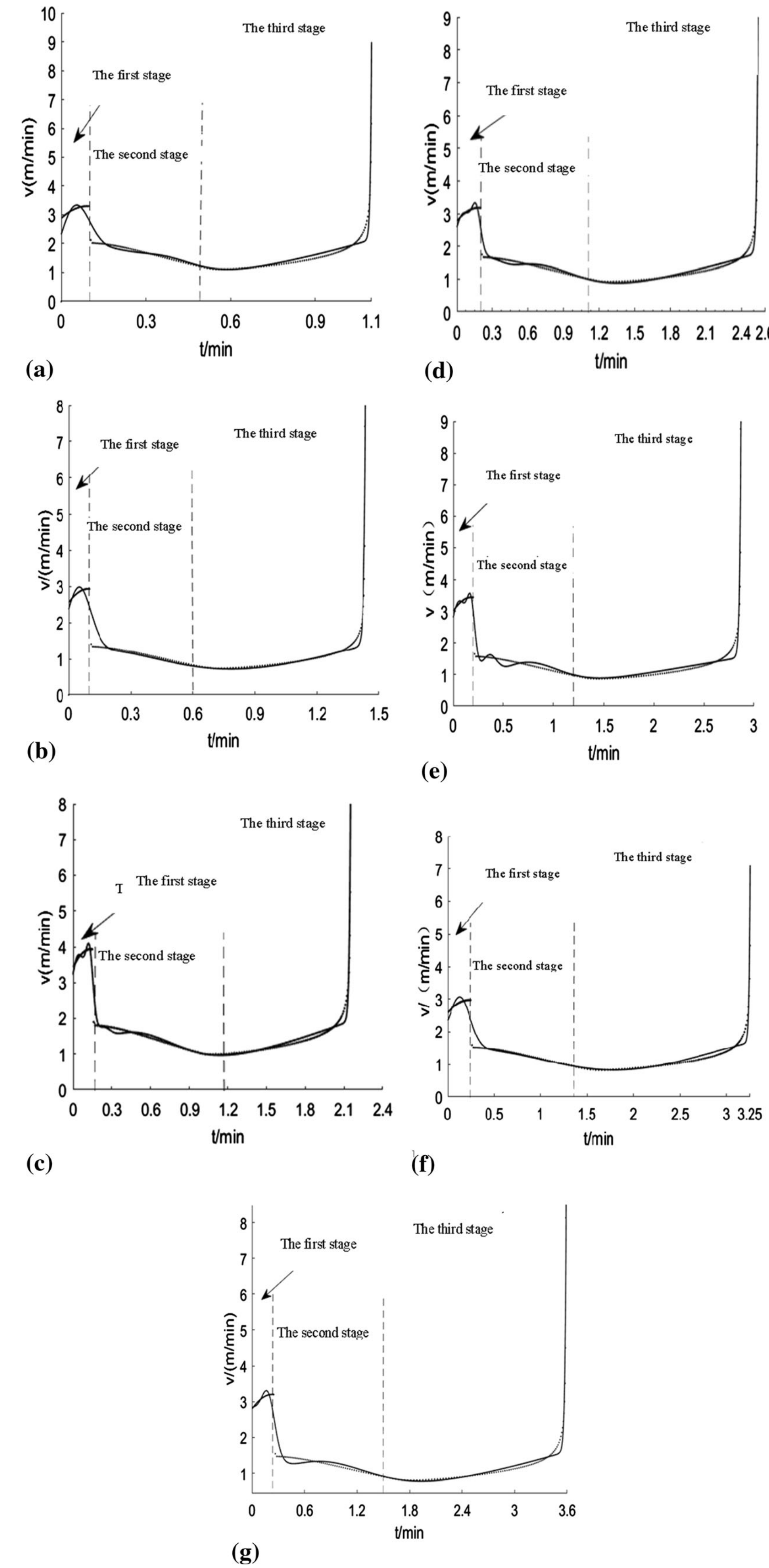


Fig.8 Auxiliary hook lifting speed and time curve

curve. It can be concluded from the above figure that the accurate speed of cranes with different tonnage at different moments is convenient for follow-up research.

According to Fig. 8, we can see through the comparison of the lifting speed curves of commonly used tonnage ladle cranes. In the first stage, the dumping time is small, the auxiliary hook must reach the state of dumping the molten steel, the lifting speed is relatively fast, and when the critical state reached, the speed drops, and the constant flow pouring begins. In the second stage, the lifting speed of the auxiliary hook slowly decreases. This is because during the pouring of molten steel, the flow rate of molten steel per unit time is constant, the tilt angle per unit time becomes smaller, and the distance to move of the auxiliary hook in unit time decreases. In the third stage, the lifting speed of the auxiliary hook slowly increases. This is because as the volume of molten steel decreases, a constant flow rate is maintained, the tilt angle increases, and the distance of the auxiliary hook per unit time also increases. When the molten steel pouring is about to end, the lifting speed of the auxiliary hook suddenly changes. Since there is little left in the molten steel, it is negligible. Therefore, in the whole process from the start of the auxiliary hook to the completion of steel pouring, the change of lifting speed is stable and easy to control.

Then, use MATLAB's Notebook Toolbox to call MATLAB's Gaussian curve fitting command to get a function of lifting speed and time; Eq. 27 is a Gaussian of the fifth order; from this, we can get the function and function curve of motor frequency and time.

$$f(x) = a_1 e^{-\left(\frac{x-b_1}{c_1}\right)^2} + a_2 e^{-\left(\frac{x-b_2}{c_2}\right)^2} + a_3 e^{-\left(\frac{x-b_3}{c_3}\right)^2} + a_4 e^{-\left(\frac{x-b_4}{c_4}\right)^2} + a_5 e^{-\left(\frac{x-b_5}{c_5}\right)^2} \quad \text{(Eq 27)}$$

where a, b and c are the coefficients of the relation between the lifting speed of the auxiliary hook and the time function, as shown in Table 3.

The lifting speed of the casting crane auxiliary hook at different times is input into MATLAB, and then Gaussian curve was used to fit in the Notebook environment, to obtain the functional curve and relation of the lifting speed of the auxiliary hook with respect to time.

Table 3 Coefficient of the relation between the lifting speed of the auxiliary hook and the time function

$a1$	2.323×1013	$b1$	4.413	$c1$	0.1534
$a2$	1.262	$b2$	0.19	$c2$	0.1026
$a3$	2.122	$b3$	−0.02771	$c3$	0.2599
$a4$	1.031	$b4$	0.69	$c4$	0.8389
$a5$	4.94	$b5$	8.554	$c5$	4.682

According to 500 tons ladle crane vice lifting mechanism parameters, the motor model is YZR 400L1-10, drum radius is 0.5m, the retarder model is QJS-D, and transmission ratio is 40. Substituting these data into Eq. 26, then use the Notebook Toolbox of MATLAB to call the Gaussian curve fitting command of MATLAB to obtain the function of the speed and time improvement, as shown in Table 3. The motor frequency function can be obtained as shown in Fig. 9.

According to Fig. 9, the frequency variation of the motor is like that of the auxiliary hook lifting speed. In the entire process from the start of the auxiliary hook to the completion of the pouring of molten steel, the motor changes smoothly, providing a basis for the automatic control of the automatic casting of the casting crane.

At the same time, the corresponding parameterization program can be developed quickly for cranes of different tonnage, which greatly improves the work efficiency. It is important to realize intelligent automatic control of ladle pouring.

Conclusion

The important research content of metallurgical industry is constant current ladle pouring. In the specified casting time, controlling the lifting speed of the casting crane's auxiliary hook is a necessary condition to prevent ladle failure. In this paper, the three stages in the pouring process are assumed and the relation between the auxiliary hook velocity and time is deduced, and the corresponding visualization program is proposed. The program can analyze and calculate the lifting speed of the auxiliary hook at different moments in different pouring stages. The lifting speed corresponding to the obtained auxiliary hook lifting point is fitted in MATLAB, and the corresponding speed function and curve chart are obtained. From the comparison of the series of auxiliary hook lift speed function

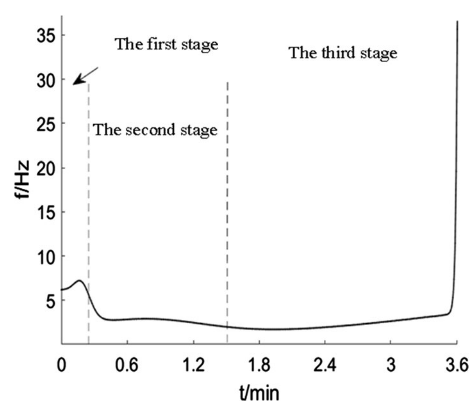


Fig. 9 Motor frequency curve

curves and curve of the corresponding drive motor, the molten steel begins to flow from the ladle until the pouring of the molten steel is completed. The change of lifting speed is stable, which can effectively prevent ladle failure. Safe work for staff and the motor can be guaranteed. The automatic control of ladle crane is realized, which is of great significance to the safe and intelligent development of ladle crane. It is crucial to prevent ladle overturning. And for different tonnage of the pouring crane, the automatic pouring control program can be quickly developed, which has a good engineering application value.

The research results of this paper have been successfully applied to the ladle pouring production line of Taiyuan Heavy Machinery Group in Shanxi Province, China. In the production process of the past 2 years, there was no failure of ladle, and the probability of failure of ladle was significantly lower than that of the past, which brought considerable profit return to the enterprise.

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