Design on Optimization of Argon Bottom Blowing of Molten Steel ladle

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Abstract

The cause of controlling argon blowing on steel-making process is analyzed. The strategy of controlling argon stirring energy is proposed, and the scheme controlling flow rate and fixing the pressure is achieved. The argon blowing of molten steel ladle is controlled automatically and properly, which is based on fuzzy control theory and Pulse Code Modulation. The intelligent control system has worked well in several steel plants.

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1. Introduction

Argon plays an important role in the steelmaking process: stirring the molten steel, washing and preventing the oxidizing of molten steel. Obviously, it will result in the oxidizing and splashing of molten steel and inclusions increase if control of argon blowing is unreasonable. Therefore, the control precision of argon bottom blowing makes a direct impact on the purity and quality of steel, mixing time of molten steel and amount of argon. At present, the argon flow rate is controlled by the experience of manual operation, which is easily affected by the operators’ proficiency subjectively and system environment impersonally such as the pressure, temperature, gas leaking of pipe and so on. In order to meet the needs of argon blowing process in the steel industry with bad conditions and high demands for control of argon flow rate, the difficulty of control of argon blowing is analyzed, and then the optimized control scheme is proposed. Finally, the scheme is adopted successfully in several steel plants.

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2. Difficulty of Controlling Argon Bottom Blowing

According to the classical control theory, the mathematic model of controlled object is established firstly, and then the parameters of correction are designed to meet the needs of static and active indicators of the system. The stirring course of argon bottom blowing, however, is gas-liquid two-phase flow which is involved with the transmission of mass and momentum between gas and high temperature liquid; in fact, it is a MIMO, nonlinear and strong-coupling object. The classic control theory is obviously helpless for it. Therefore, many authors have reported control of argon bottom blowing with a great Varity of intelligent control techniques, which rang from fuzzy control to neural control. However all of these techniques employ operator’ experience and common sense as inference rules which are decided by personal proficiency in the process of controlled object.

3. Control Strategy

Role and effectiveness of argon blowing are achieved by certain argon pressure and flow rate. According to the views of entire buoyancy model, energy driving the molten steel is provided with work applied by buoyancy of the air bubble which is generated by hot argon with certain pressure and flow rate after it enters into the ladle. The essence of controlling argon bottom blowing is to control the argon stirring energy. According to the feedback control theory, negative feedback of the controlled physical quantity should be introduced, so a certain stirring energy sensor is prerequisite. However, the senor is not existent for high temperature ladle. The stirring energy can be estimated with the following expression [4]:

\[
\varepsilon = (Q \times 0.74/G) \times T \times \ln(1 + H / 148P)
\]

(1)

Where Q is flow rate of argon, G, T and H are weight, temperature and depth of molten steel respectively and P is the surface pressure of molten steel on the environment. From the Eq.(1) T is same before stirring in general, G, H and P, however, have direct and indirect requirements of argon pressure, therefore, the two main factors affecting the stirring energy are flow rate and pressure of argon. Therefore, the stirring energy is the product of pressure and flow rate for fluid argon entering the ladle; it is controlled indirectly if the flow rate and pressure can be controlled. For a given ladle, the stirring energy it needs is certain; the flow rate can decrease if pressure is high, and vice versa. From the theory and practice, the minimum for argon pressure can not be achieved, which results in low stirring energy and difficulty in bubble forming if the pressure is too low[2].

However, bubble gathered dispersion and utilization rate of argon will decline if the pressure is too high, furthermore too severe stirring causes second oxidation of molten steel and considerable temperature drop. In practice, we find that exorbitant pressure of argon blowing at the start is unsuitable, as the temperature pressure and cubage of argon rises sharply when the argon via pipeline and vent brick in normal condition enters ladle.

For control of stirring energy, it is certain that the complexity of controlling will increase if both the pressure and flow rate of argon are controlled at the same time. But if one quality is fixed, and another one is controlled, the controlling will be simplified. Assuming that the flow rate is fixed and pressure is controlled, mass flow rate can be estimated with following expression (in figure 1) when

\[
1 \geq \frac{p_2}{p_0} > 0.528
\]

and gas in pipe is a subsonic flow:
\[ q_m = p_0 A_2 \sqrt{\frac{2\kappa}{\kappa - 1}} \frac{1}{RT_0} \left[ \left( \frac{p_2}{p_0} \right)^{\frac{2}{\kappa}} - \left( \frac{p_2}{p_0} \right)^{\frac{\kappa + 1}{\kappa}} \right] \]  

Where \( K \) is entropy index, \( R \) is gas content, \( P_0 \) is large vessels pressure, \( A_2 \) is exit area of nozzle, \( T_0 \) is general temperature and \( P_2 \) is exit pressure of nozzle. The controlling flow rate deals with the following factors: load size, differential pressure, temperature changes, gas com-credibility, and gas sticky.

Flow rate influenced by pressure cannot be fixed because there is a coupling relationship between the pressure and flow rate. On the other hand, it seems to be easier to control if pressure is fixed and flow rate is changeable. However, the optimum pressure valve is different in several stages of argon blowing. In normal stirring process of argon blowing, the pressure curves are shown in figure 2 roughly for a ladle tested repeatedly.

Where \( P_1 \) is broken top pressure about 1.2-1.4Mpa, \( P_2 \) is normal stirring pressure around 0.5Mpa, \( P_3 \) is the pressure of large discharge argon blowing about 0.8Mpa when carbon iron or other alloy are joined, \( P_4 \) is the pressure around 0.5Mpa when stirring is restored and \( P_5 \) is the soft blowing pressure about 0.35Mpa. Time on every stage is shown roughly in figure 2. The argon flow rate ranges from 0 to 80L/min in normal stirring, 0 to 150L/min with joining carbon iron or other alloy, 0 to 0-40L/min approximately with soft blowing.

From the figure 2, the stirring energy can also be achieved if a certain pressure is adopted, but the time of argon blowing cannot be optimized. Therefore, different stage should adopt different pressure in the process of argon blowing.

4. PCM Technology and Its Improvement

From the above discussion, it seems to be easier to control the stirring energy if pressure is fixed and flow rate is changeable. However, from the Eq.(2), the controlling flow rate deals with the following factors: load size, differential pressure, temperature changes, gas com-credibility, and gas sticky. So
PCM technology is employed in this paper instead of conventional control technology to change the valve of throttle.

Flow control technology with PCM, output control signal in binary to change a group of switch valve (shown in figure 3), adopts hydraulic control pulse coding modulation. The signal adjusts the open area of throttle to $S_0:S_1:S_2:S_3 = 1:2:4:8$, and the comprehensive area is the sum of combination of switch valve. Therefore, argon flow rate which is proportional to the control signal in binary can be achieved when the binary signal changes \[^4\].

![Control principle diagram of throttling type orifice plate](image)

5. **Process Practice**

The system with this control strategy goes through in several company such as Hang Gang and runs reliably. The operating results for three years indicates that This system has advantages of high efficiency and energy saving, compared with the traditional argon blowing control, argon quantity to blow per ton in this system is only two thirds of the former; steel purity and quality are increased effectively; refining time drops 20 percents of traditional argon blowing system. The hardware and software of this system are introduced as follows.

5.1. **System Hardware Introduction**
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1) System Structure Diagram

The system structure can be described with the Figure 4 diagram:

Where F1, F2 and F3 are solenoid valves, M1, M2, M3, M4 and M5 are pressure transducers.

2) Main Part Introduction

In this design, S7-300 PLC\[3\] is used to receive the orders from PC and transmit the industrial field conditions (flow rate, pressure, time to blow and cumulative flow etc) to PC. On the other hand, S7-300 PLC can accept the commands of touch screen and operation box before furnace, collect field working information and issue orders properly according to the program control thought to control switch state of group valve. Operators can deal with matters in control room by touch screen and get present flow rate and time of argon blowing, cumulative flow and argon pressure in actuators. Alarm information will appear on the touch screen in event of jam, low argon pressure and leakage, which is important for operators to deal with the trouble as soon as quickly. At the same time, device state and history curve can be achieved from the touch screen. Manostat after secondary relief valves can control the pressure, cushion the impact and interference of external environment and provide smooth pressure for group valves. PCM flow adjuster composed of group valves is actuator of pressure control system which control and adjust the argon flow rate with PCM technology. Pressure-reducing valve 1, 2 keep pressure constant directly and stabilize flow indirectly. Solenoid valve F3 provides more pressure to blow the clogged plug at the beginning of argon blowing in order to start argon blowing successfully. Solenoid valve F2 switches to response state according to flow deviation in the process of argon blowing to ensure production in normal. Transducer consists of pressure transducer and flow transducer, which provide the valves of pressure and flow for PLC controller, touch screen and PC.

5.2. Control Scheme

According to the characteristics of the controlled objects, the system adopts the control scheme based on fuzzy control theory. In automatic control mode, Referring to the experience of skilled operators, control algorithm and control strategy are modulated in different stages according to the measured valve of pressure and flow rate. The control principle is that pressure is adjusted according to different work conditions: high-pressure branch starts up at the beginning of operation, and system switches to normal...
curve after broken blowing automatically; argon with high pressure blows repeatedly in the event of jam and alarm system will work again if jam is not catabolic in 30 minutes. In accordance with specific work conditions, flow rate of argon is increased or decreased properly to remove inclusion and harmful gas.

Fig. 5. Flow control scheme diagram

In the mode of touch screen and operation box before furnace, PCM flow adjuster can adjust the flow rate of argon precisely and quickly, track the set point of flow rate automatically. The scheme of controlling flow rate of argon is shown in figure 5.

5.3. Software Flow

The system software flow is shown in the figure 6.

Fig. 6. Software flow chart
6. Conclusion

In accordance with the thought of controlling stirring energy, the system utilizes PLC as the controller, the strategy fixing pressure and controlling flow rate is proposed, PCM technology and fuzzy control theory are adopted to control the flow rate of argon bottom blowing automatically. Actual operation results show that the system is characteristic of high reliability, strong anti-interference, short refining time, high steel purity and intelligence; At the same time, man-machine interface and operation before furnace are adopted simultaneously, which is simple and flexible; Alarm functions of jam, leakage and low argon pressure are also provided.

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References

[1] SMC(China)Co.,LTD. Modern practical pneumatic technology[M]. Beijing: china machine press, 2003
[2] ZHANG Dong-sheng. Practice on Process of Bottom Blowing Argon[J]. TIANJING METALLURGY, 2003,(4).
[3] LIAO Chang-chu. Large and medium-sized PLC application tutorial[M]. Beijing: china machine press, 2005
[4] HANG Yong-dong, ZEN Chao-hua, WEI Guo-fang. Modelling, analysis of argon bottom-blowing system and intelligent control[J]. HEBEI METALLURGY, 2002,(5)
[5] YANG Fang, SHEN Qiao-zhen, PENG Qi. Study on Optimization of Bottom Blowing Argon Processing in a 100 t LF[J]. The Chinese Journal of Process Engineering, 2010,(10)
[6] HU Guang-hao, MAO Zhi-zhong. The FUZZY-PID Control System for Blowing Argon at Bottom and Its Simulation[J]. Computer Simulation, 2008,(4)
[7] DING Li-hua, ZHANG Xiao-guang, JIA Li-di. Influence of Bottom Blowing Process on Mixing Time and Deslagging Area for Molten Steel in Ladle[J]. ANGANG TECHNOLOGY, 2010,(3)
[8] MA Jun, SHEN Qiao-zhen, YANG Fang. Numerical simulation of 3-dimensional flow field of the bottom argon blowing ladle[J]. Journal of Wuhan University of Science and Technology, 2010,(2)
[9] LI You-qing, YU Hua-cai, KOU Zhi-qi. Study on Optimization of LF Argon Blowing at Ladle Bottom by Hydraulic Model[J]. IRON STEEL-VANADIUM TITANIUM, 2010,(1)