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Control Model of Multifunctional Hot Metal Ladles

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Abstract: For further research on the control model of multifunctional hot metal ladles between the ironmaking and steelmaking interface, the hot metal ladles of K steel plant were taken as the object to analyze the operation process. The factors of blast furnace supply and basic oxygen furnace demand were proposed. According to the principle of supply and demand balance, the control model of hot metal was researched under the following factor conditions: equal to, greater than, and less than 1, respectively. The distribution model of the blast furnace, steelmaking works, and online buffering was proposed. When the supply and demand factor is equal to 1, the turnover number of hot metal ladles equals 16 and the turnover cycle of hot metal ladles equals 512 min. When the factor is greater than 1, the total number of hot metal ladles is equal to the normal turnover number plus the turnover number of the cast iron machine. When the factor is less than 1, the total number of hot metal ladles is equal to the normal turnover number plus the accumulating number. Satisfactory effects were obtained by applying the control model in production. The numbers of turnover ladles and accumulating ladles were reduced.

Key words: ironmaking; steelmaking; interface; multifunctional hot metal ladle; control model; blast furnace; basic oxygen furnace

A multifunctional hot metal ladle is the main transporting tool between the ironmaking and steelmaking interfaces[1,2]. The ladle plays a role in combined matching, coordination-buffering, and ensuring the operational efficiency of the ironmaking and steelmaking interface systems[3,4]. The multifunctional operation[5-8] means that the hot metal ladle possesses functions, such as carrying, transporting, buffering, pretreatment, and tapping. The hot metal ladle transports from the blast furnace (BF) to the basic oxygen furnace (BOF) without the ladle having to change. Compared with the torpedo ladle and the mixer furnace, the multifunctional hot metal ladle has the advantages in turnover efficiency, hot metal matching, and production scheduling. With regard to the universal application, it is important to reasonably control the operation process and turnover number of hot metal ladles.

The multifunctional hot metal ladle has been seldom studied in existing literatures. "One Open Ladle from BF to BOF"[9] has been analyzed by queuing theory and a mathematical model of the queuing system has been built. However, this research just focuses on the queuing problem. All functions of the hot metal ladle have been analyzed and the temperature has been measured[10]. The operation characteristic and effects of multifunctional technology in Sha Steel have been researched[11]. The technology of production arrangement, operation time, and temperature drop of "One Open Ladle from BF to BOF" has been measured[12]. In addition, there are considerable existing researches on the computer control system[13-16] and simulation analysis[17,18] of the hot metal ladle. According to the survey results, the existing methods cannot reasonably guide production. The reason for this is the production plan. Primarily, the operation of the hot metal ladle should fulfill the requirements of the production plan. Subsequently, parameters such as transport quantity, turnover number, and

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turnover ratio need to be determined. However, the production plan has been ignored in the existing researches. The existing researches mainly focus on the ladle itself; therefore, the research results fail to provide useful guidance to the manufacturing process.

In this study, the hot metal ladles of the ironmaking and steelmaking interface in the K steel plant was taken as the research objects. After analyzing the operation process of the hot metal ladles, the factor of blast furnace supply and basic oxygen furnace demand was examined. According to the factor′s span, the calculation model of the turnover number was investigated. After applying the control model in production, satisfactory results were obtained.

1 Operation Analysis of Multifunctional Hot Metal Ladle

The K steel plant comprises one 2500 m^3 blast furnace, one KR desulfurization station, two 120 t basic oxygen furnaces, and one cast-iron machine. The load mass of the multifunctional hot metal ladle is 140 t and the actual load capacity is 120 t. To study the control model, the operation process of the multifunctional hot metal ladle was analyzed, as shown in Fig. 1. Fig. 1 shows that the hot metal ladle has two routes from BF to BOF: BF-KR-BOF and BF-BOF.

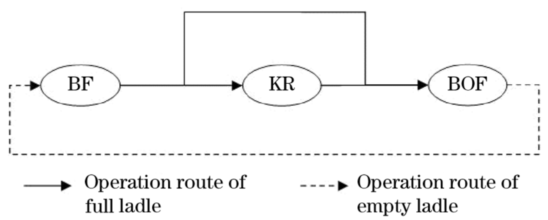

Fig. 1 Operation process of multifunctional hot metal ladle

2 Supply and Demand Factor of Hot Metal

The turnover efficiency of the multifunctional hot metal ladle has an intimate relation with the transport quantity. The higher the transport quantity, the higher the turnover times and number. Therefore, the first priority is to control the transport quantity of the production plan. After that, the ladle′s turnover number can be distributed rationally and the turnover cycle of the ladle will be reasonably arranged. Studies have shown that it is the quantity of BF supply and BOF demand that determines the transport quantity of the hot metal ladle. In other words, the quantity of BF supply means the planned production quantity of qualified hot metal, which is one of the important indicators of the technology level and economic benefits. Similarly, the quantity of BOF demand means the planned smelting quantity of the hot metal. To research the relation between the quantity of BF supply and the quantity of BOF demand, the supply and demand factors of hot metal is put forward. Its expression is shown in Eq. (1):

$$\delta=\frac{Q^{\mathrm{BF}}}{Q^{\mathrm{BOF}}}=\frac{\sum_{i=1}^{N}V_i^{\mathrm{BF}}\times\eta_i}{\sum_{j=1}^{M}O_j^{\mathrm{BOF}}\times P_j^{\mathrm{BOF}}\times\lambda_j} \tag{1}$$

where, δ represents the supply and demand factor of hot metal; Q^{BF} represents the planned production quantity of qualified hot metal in the BF, t/d; Q^{BOF} represents the planned smelting quantity of hot metal in BOF, t/d; N represents the number of BFs; V_i^{BF} represents the effective volume of ith BF, m^3; η_i represents the utilization factor of the effective volume of ith BF, t/(m^3 · d); M represents the number of BOFs; O_j^{BOF} represents the heat number of jth BOF; P_j^{BOF} represents the tapping quantity of single heat of jth BOF, t, and λ_i represents the ratio of hot metal quantity and liquid steel quantity.

Eq. (1) shows that if $\delta>1$, the quantity of BF supply is higher than the quantity of BOF demand. If $\delta<1$, the quantity of BF supply is lower than the quantity of BOF demand. When $\delta=1$, the quantity of BF supply equals the quantity of BOF demand. The transport quantity and turnover number of hot metal ladles vary depending on the supply and demand factors. Therefore, it is necessary to research the control model of the hot metal ladle considering different factors.

3 Control Model of Multifunctional Hot Metal Ladle

3.1 $\delta=1$

When $\delta=1$, BOF can smelt all the hot metal supplied by BFs. At the same time, the turnover number of the ladle should satisfy the transport tasks such as BF tapping and BOF smelting.

With regard to the hot metal ladles, the turnover of the ladles accomplishes the tasks of carrying and transporting hot metal from the BF to the BOF. When the transport quantity equals the quantity of BF supply and BOF demand, the calculation model of the ladle number is proposed under the condition of $\delta=1$.

$$\sum_{j=1}^{M}\frac{24\times60}{T_{\mathrm{ladle}\text{-}j}^{\mathrm{BOF}}}\times n_j^{\mathrm{BOF}}\times Q^{\mathrm{ladle}}=\sum_{i=1}^{N}V_i^{\mathrm{BF}}\times\eta_i=$$

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