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Productivity Improvement of Continuous Casting Through Utilization of Caster Speed Using Goal Programming Technique

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Abstract

The steel industry is a traditional heavy industry. Being a commodity product the price is elastic. This makes various players in supply chain “price takers” where the price is set a level that the market will be bearable. Furthermore, the basic nature of the product means that differentiation is difficult to increase. With the price of steel declining over last few years’ margins are tight, making profitability of the basic products low. Therefore, companies are looking to adopt business initiatives in order to stay alive in the new competitive marketplace. This paper first reviews the recent works in continuous casting speed operations and then presents a goal programming model for maximization of speed constraints keeping in par with the designed speed without risks in steel making-continuous casting production process, which is characterized by several constraints: overtime limitations, technological interdependence, minimization of overtime and maximum production with maximum utilization of designing speed of the casters.

Keywords: *Continuous Casting, Casting Speed, Casting Temperature, Cleanliness of Melt, Water Flow Rate*

1. Introduction

The productivity and quality of a continuous casting depend mainly on process parameters, i.e. casting speed, casting temperature, steel composition and cleanliness of the melt, water flow rates in the different cooling zones, etc. The development of optimization models for speed constraints is one of the most useful tools for improving productivity of a large number of manufacturing companies.

Productivity increases with increasing casting speed and increasing cross-section area. The first step in designing a continuous caster is the product end-use dictates the quality, grade, and shape of the cast product (billet, bloom, slab, beam blank, and/or round). Considerations are then made based on desired annual tonnage, liquid steel availability, and anticipated operating hours. Then, the machine design considerations can be made for the number of strands and cast speeds to match the liquid metal supply from the melt shop. In continuous casting of steel a number of parameters have to be set, such as the casting temperature, casting speed and coolant flows, that critically affect the safety, quality and productivity of steel production. In this paper studies have been made concerning the speed analysis and limiting the over-utilization of the casting machines (i.e. caster-I and caster-II) along with overtime considerations using Goal programming whose application in steel industries has been far fewer.

As a part of SAIL Corporate Plan-2012 to enhance the Hot Metal production capacity of RSP from 2 MTPA to 4.5 MTPA, Crude steel production to 4.2 MTPA and Saleable Steel production to 3.9 MTPA by the year 2013, Expansion projects were approved by the SAIL Board on 21st May, 2007 and work is in progress. As the steel industry continues to improve quality and reduce cost, there is growing interest in maximizing the productivity from a single continuous casting machine. Many different processes are currently competing, from conventional thick slab and blooms to thin slabs and strip casting, whose economic feasibility depends on their eventual productivities. Considering the high cost of plant experiments, it is appropriate to apply computational modeling to explore the theoretical limits of continuous casting speed and productivity.

Two casters present in steel melting shop-II (SMS-II) at Rourkela Steel Plant operate simultaneously having similar machine configurations and identical average rate of production. By running 3 shifts, the operational capacity of the plant is 44 hours/day, being a sum of operating capacity of caster-I and caster-II. The production department reported that the speed limit of caster I and II are 1m/min and 1.4m/min respectively. As per statistics the average utilization of casters I and II are 92.1 % and 90.98 %, respectively, i.e., 22.1 hours/day and 21.8 hours/day respectively. The management of the company decided that a stable employment level is a primary goal for the plant. Therefore, whenever there is a demand exceeding normal production capacity, the management simply expands production capacity by providing overtime. However, it was felt that the overtime operation of the plant of more than 2 hours should be avoided because of the accelerating costs.

2. Literature Review

Carlos A. Santos et.al [1] have presented that the productivity and quality of a continuous caster depend mainly on process parameters , i.e. casing speed, casting temperature, steel composition and cleanliness of the melt, water flow rates in the different cooling zones, etc. This work presents the development of an algorithm, which incorporates heuristic search techniques for direct application in metallurgical industries, particularly those using continuous casting process for the production of steel billets and slabs. **C**. Li and B.G. Thomas [2] have reported that with many different processes currently competing, it is appropriate to apply modeling to investigate the theoretical limits of continuous casting speed and productivity. The heat transfer rate during the solidification process drops with time, so the shell thickness at mold exits drops with increasing casting speed. Chunsheng Li et.al [3] have developed a finite element thermal, mechanical model and applied to investigate the maximum casting speed for continuous casting of steel billets with square section sizes and mold lengths, assuming uniform heat flux around the mold parameter and no sub mold support. This model solves 2D finite element equations to predict 3D stress and strain states with the generalized plane strain assumptions in the out of plane direction. K.G. Rackers et. al [4] have reported that nozzle clogging is a serious productivity solution to clogging in continuous casting nozzles. The results of a one dimensional steady state analysis of the heat loss from the molten steel stream through the nozzle wall are discussed. The analysis show that steel may freeze within the clog matrix for a relatively small clog buildup. A.Bellabdaoui et.al [5] have stated that the development of optimization models for planning and scheduling is one of the most useful tools for improving productivity of a large number of manufacturing companies. This paper presents a mixed-integer programming model for scheduling steelmaking-continuous casting production. We first review the recent works in continuous casting planning. The process scheduling is characterized by several constraints: job grouping, technological interdependence, no dead time in the same group of jobs and dynamic processing time of jobs. Lixin Tang et.al [6] have presented a mathematical model, based on the just-in-time (JIT) idea, for solving machine conflicts in steelmaking continuous casting (SCC) production scheduling in the computer integrated manufacturing system (CIMS) environment. The model is developed as a non-linear model based on actual production situations, considering both punctual delivery and production operation continuity. It is then converted into a linear programming model which can be solved using standard software packages.

3. Goal Programming Method

Goal programming is used to manage a set of conflicting objectives by minimizing deviations between the target values and the realized results. The Goal Programming Method is an improved method for solving multi-objective problems. Goal programming is one of the models which have been developed to deal with the multiple objectives decision-making problems. This model allows taking into account simultaneously many objectives while the decision-making is seeking the best solution from among a set of feasible solutions. The goal programming technique is an analytical framework that a decision maker can use to provide optimal solutions to multiple and conflicting objectives. Goal programming is a special type of technique. This technique uses the simplex method for finding the optimum solution of a single dimensional or multi-dimensional objective function with a given set of constraints which are expressed in linear form. Multiple objectives arise in production companies because of several departments with different functions.

3.1 Assumption using goal programming

- Speed limit differs for different grades based upon the chemistry involved, which has been assumed to be constant irrespective of the grades.
- Average production capacity (in hours) is different for either caster on different days. Only an average value serves the purpose.
- The rate of production for both the casters has been assumed to be same because of the similar configurations.
- The overtime limit has been set to 2 hours.

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3.2 Objectives Formulation

- The 1st goal is to avoid any under-utilization of production capacity (i.e., to maintain stable employment at normal capacity).
- The 2nd goal is to limit the overtime operation of the plant to 2hours.
- The 3rd goal is to limit the respective speeds of caster I and II to 1m/min and 1.4m/min.
- The 4th goal is to minimize the overtime operation of the plant as much as possible.

A goal program is set, formulated and solved to help find the best solution regarding the set considerations.

The average production capacity is limited to 44 hours at present by running 3 shifts. However, since overtime of the plant is allowed to a certain extent, the constraint for production capacity(P1) may be written as Eq (1).

$$X_1 + X_2 + d_1^- - d_1^+ = 44 \qquad \text{Equation(1)}$$

Where,

X1= Speed of caster-I

X2= Speed of caster-II

d1- = Under-utilization of production capacity as set at 44hrs of operation.

d_1^+= Over-utilization of normal production capacity beyond 44hrs of operation.

The analyses of goals indicate that the overtime operation of the plant is to be minimized to 2hrs or less. To solve the problem by goal programming, we need a deviational variable that represents the overtime operation of the plant beyond 2hrs. By minimizing this deviational variable to zero the goal can be achieved.

The overtime operation of the plant d_1^+ should be limited to 2hrs or less. However, it may not be possible to limit the overtime operation to 2hrs or less in order to meet higher order goals. Therefore, d_1^+ can be smaller than, or equal to 2. Constraints regarding overtime (P2) can be expressed as Eq(2).

$$d_1^+ + d_{12}^- - d_{12}^+ = 2 \qquad \text{Equation(2)}$$

Where,

d_{12}^- = negative deviation of overtime operation from 2hrs.

d_{12}^+ = overtime operation beyond 2hrs.

The average maximum speed of caster I and II are 1m/min and 1.4m/min, respectively (60m/hr and 84m/hr respectively). Thus, the constraint for speed (P3) can be represented in Eq (3) and Eq (4).

$$X_1 + d_2^- = 60 \qquad \text{Equation(3)}$$

$$X_2 + d_3^- = 84 \qquad \text{Equation(4)}$$

Where,

d_2^- = under achievement of speed goal of caster-I

d_3^- = under achievement of speed goal of caster-II

The average utilization of caster I and II are 22.1 hr/day and 21.8 hr/day respectively. Since the production rate is same for both the casters, the utilization times per day are in the ratio 22.1: 21.8.

Thus, in this problem the broader objective can be written with respect to all above constraint as Eq (5).

Minimize

$$Z = P_1 d_1^- + P_2 d_{12}^+ + P_3 d_3^- + P_4 d_1^+ \qquad \text{Equation(5)}$$

3.3 Implementation Method

The general goal programming algorithm considered for *n* variables, *m* constraints and *k* pre-emptied priority level.

Min

$$P_1 (W_{i1}^- d_{i1}^- + W_{i1}^+ d_{i1}^+) \text{ for } i = 1,2,\dots m \qquad \text{Equation(6)}$$

……..

Min

$$Pk (W_{ik}^- d_{ik}^- + W_{ik}^+ d_{ik}^+) \text{ for } i = 1,2,\dots m \qquad \text{Equation(7)}$$

Subjected to

$$\sum_{j=1}^{n} a_{ij} x_j + d_i^- - d_i^+ \text{ for } i = 1,2,\dots m \qquad \text{Equation(8)}$$

$$X_j,\ d_i^-,\ d_i^+ \geq 0 \qquad \text{Equation(9)}$$

$$P_1 >> P_2 >> \dots\dots >> P_k \qquad \text{Equation(10)}$$

4. Results and Discussion

After implementing the above method all the prioritized goals have been achieved considering highest productivity for the caster. Some constraints over reducing the overtime is found to be difficult to satisfied but with 12th iteration all the constraints are being satisfied successfully. The major findings for prioritizing goals are found to be speed of caster I and caster II as 0.74m/min and 0.77m/mm. Here the overtime allowed by the plant is 2 hours has been achieved to full extent. The speed constraint of caster-I has been underachieved to an extent of 1m/min and that of caster-II is 0.63m/min as compared to the caster utilization.

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5. Conclusion

As the attainment of each of the goals may not be possible, the goal programming technique used had attempted to minimize the set of deviations from perspective multiple goals set above which are considered simultaneously but weighed according to their relative importance. In this scope of investigation The goal programming implemented for analysis of speed and overtime utilization of the casting machines serves the purpose of finding the under utilization of the above. This gives a prediction of the goals to be set ahead and the extent to which they can be achieved. The results show the casters need to be utilized more on account of their speed constraints. The proposed method can be implemented in various engineering prospects, thus can help to achieve high valued output.

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