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Improvement of Rolling Efficiency of Hot Strip Mill

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Abstract:

Rolling efficiency of hot strip mill is being improved in JFE Steel. Although there are hardware remodeling and software modification to improve efficiency, it is necessary to find out the improvement point which greatly hinders the rolling efficiency improvement in order to select the effective means. However, in the hot strip mill which has various equipment on the line and processes several steel materials simultaneously on the line, it is necessary to handle a large amount of data for analysis, and it is time consuming. This paper describes the construction of data analysis system for efficient analysis work.

1. Introduction

To ensure that Japan's aging steel mills remain competitive with state-of-the-art mills in other countries, the rolling efficiency of the hot strip mill at JFE Steel's West Japan Works (Fukuyama District) is being improved with the aims of increasing production and improving production costs. In addition, improved efficiency leads to a reduction in plant idling time at the same production volume, contributing to energy-saving and carbon neutrality as indirect benefits.

The approaches to improvement of rolling efficiency include both hardware remodeling to increase the capacity of production equipment such as heating furnaces and rolling mills, and software modification, for example, to minimize the idling time between slabs by improving the accuracy of slab transfer time predictions, or to improve the slab transfer method [1–3]. Regardless of which measures are implemented, it is necessary to identify the improvement points that hinder rolling efficiency in order to select the most effective means. However, as features of a hot strip mill, the line consists of various types of equipment, and multiple materials are processed simultaneously on the line. Since a large volume of data must be handled for analysis, how to carry out the analysis work efficiently and identify the effective improvement points are important.

In this paper, first, the line layout of the hot strip mill is explained, after which the mill pacing function for slab transfer pitch control and examples of improvement measures are described. Finally, the implementation of a data analysis environment for improvement points, examples of improvements discovered by actually using that environment, and the potential for improvement in each case are discussed.

2. Line Configuration of Hot Strip Mill and Mill Pacing Function

2.1 Line Configuration of Hot Strip Mill

The line layout of the hot strip mill is shown in **Fig. 1**. In this line, rectangular solid materials called slabs, which have been heated in the reheating furnace, are charged into the rolling line, where they are rolled to the specified sheet thickness, width and temperature through the roughing mill and finishing mill, and are then coiled in a coil form. The line also has an idling function which makes it possible to hold the steel strip at a specified position in the line.

The following describes the features of the heating-up time in the reheating furnace and the transfer time in each of these processes. In the heating process, the necessary heating-up time in the reheating furnace is different for each material specification. Therefore, when changing steel grades or other specifications, additional heating-up time is necessary at the timing of changes from slabs with short required heating-up times to longer heating-up times.

In the subsequent roughing mill process, the constraint that only the largest one slab can be transferred

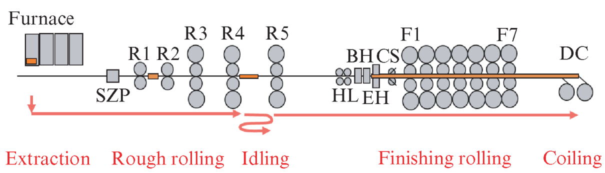

Fig. 1 Layout of hot strip mill plant

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between the roughing mill stands is applied. This means the head end of the subsequent materials can only be advanced after the tail end of the preceding material has cleared the mill. In this line, a multi-pass rolling function is provided at mill stand R2, and a material holding function, that is, an idling function, is provided between stands R4 and R5.

As a distinctive feature of the finishing mill process, the length of the material becomes extremely long due to elongation and thickness reduction of the material after the roughing mill process, and the rolling time increases in proportion to the material length. Since the temperature of the material is a critical factor for the material properties of the product, temperature control also affects the strip transfer speed in the finishing mill process.

In the final coiling process, at the stage when the previously coiled coil has been removed and preparations for coiling have been completed, the subsequent strip is advanced into the coiler and coiled. In reality, many lines employ multiple coilers, and change the coiler used in coiling in order. For example, when a line has two coilers, after the strip being coiled by one coiler is removed, coiling of the subsequent strip by the other coiler is started, and the first coiler is prepared for the next strip, shortening the interval between the materials.

Due to the long material length and extended rolling time in the finishing mill process, this process frequently becomes a bottleneck. However, the other processes also become bottlenecks in some cases due to differences in the specifications of the materials and the combination of the preceding and subsequent strips.

2.2 Mill Pacing Function

To increase the efficiency of the hot strip mill, multiple materials are normally transferred simultaneously on the line. Pitch control of the respective materials is carried out by the mill pacing function. **Figure 2** and **Figure 3** show the content of the collision checks and preparation time checks performed by the mill pacing function, respectively. The collision check is a function that checks whether the time interval from the point when the tail end of a preceding strip A clears the checkpoint until the head end of the subsequent strip B arrives at the checkpoint is at least as long as the set time. If the calculation result is a minus time interval, this means that the subsequent strip B and the preceding strip A will collide. In the subsequent set preparation time check, the mill pacing function checks whether the head end of the subsequent strip B will arrive after the end of the preparation time after the tail end of the preceding strip A clears the checking equipment.

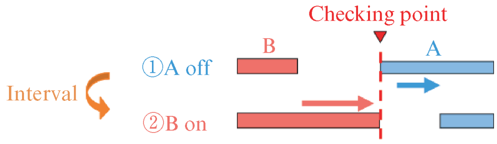

Fig. 2 Collision check

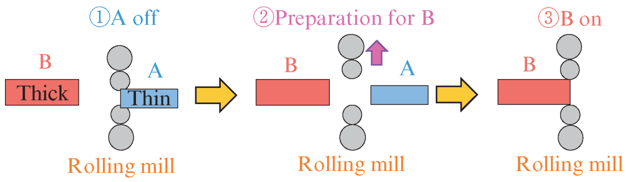

Fig. 3 Preparation time check

By predicting the transfer time of each strip at each position and using the two above-mentioned checking functions, the mill pacing function sets the timing of extraction of slabs from the reheating furnace and decides the transfer speed on the line so as to prevent collisions between the preceding and subsequent strips and secure the necessary equipment preparation time. When there is a risk of a collision between the preceding and subsequent strips due to manual intervention by an operator, or deviation of the transfer time due to error in the transfer time prediction, collision is avoided by holding up the subsequent strip. Considering the possibility of equipment damage if a collision occurs between the preceding and subsequent strips, collisions must be avoided, but an excessive increase in the interval to avoid collisions will result in a corresponding decrease in efficiency. Therefore, the aim of the mill pacing function is to maximize rolling efficiency by transferring the materials at the shortest possible interval while also preventing collisions between the preceding and subsequent materials.

2.3 Example of Improvement and Issues of the Mill Pacing Function

Figure 4 shows an example of an improved mill pacing control. As described above, with most combina-

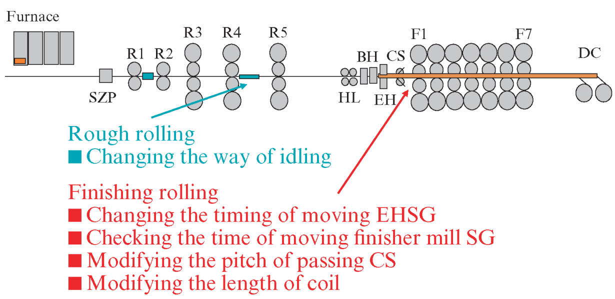

Fig. 4 Example of improved mill pacing control

tions of materials, transfer bottlenecks frequently occur around the finish rolling process. To address this problem, considerable effort has been devoted to the latter half of the rough rolling process and the finish rolling process. However, with this approach, it is possible to implement improvements for actual problems that are recognized by the operator or technical staff, but it is difficult to improve problems that are overlooked, regardless of whether those problems occur before or after the finish rolling process. In fact, a comprehensive check of all the points from upstream to downstream would require checking approximately 700 related data items for each strip. Since it would also be necessary to consider the material data for a total of 6 strips, including not only the 4 strips actually on the line, but also the next slab to be extracted from the reheating furnace and the strip immediately after coiling by the coiler, it would be necessary to handle a total of 4 200 data items in 1 calculation. Moreover, since it is also necessary to make calculations at multiple timings, it is difficult to identify effective improvement points, even by performing a random analysis.

3. Construction of Data Analysis Environment: Visualization of Operation

3.1 Purpose of Constructing Data Analysis Environment

A data analysis environment was constructed to solve the problem described above and efficiently identify effective improvement points in a short time.

First, the items to be checked were selected. In visualizing the improvement points for increasing rolling efficiency, three items were considered necessary, namely, the detailed positions of bottlenecks for each material, error of the predicted delivery time for each material at each point in the process, and the time margin of the interval between the materials (interval margin) at each point. For the detailed positions of bottlenecks, 70 positions on the line were set from the heating-up process to the coiler process, and the positions that become bottlenecks are displayed by the times when the heat end and tail end of each material pass the position in question. Next, the error of the predicted delivery time and the interval margin between the materials are indicated by showing the numerical values at each position on histograms. Statistical data such as the minimum, average, dispersion, etc. can be understood visually at a glance from the histograms.

3.2 Preparation of Data for Analysis Environment Construction

When constructing an off-line simulator for analysis

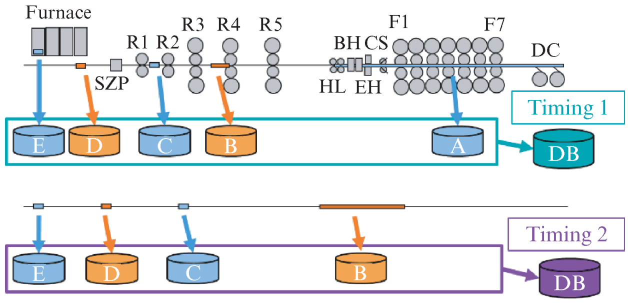

Fig. 5 Database storage

by providing all the input variables, a large volume of relational data is necessary in order to reproduce the data for all materials at all timings, and when the calculation method in the on-line environment is modified, similar modifications are also required in the off-line simulator. These conditions make it difficult to perform maintenance management for the future. To overcome these issues, the calculated data are stored in the analysis database each time that transport-related calculations are performed in the on-line environment. The method of storage in the database is shown in **Fig. 5**. In database storage, this system was constructed so that the data for each material are stored in their entirety, as one set, at the timing of each calculation, and when performing an analysis, only the data necessary for the analysis are extracted from the stored data and used. As advantages of this approach, because all the data for each calculation timing are retained, the condition of the line at the time of the calculation can be reproduced easily, and detailed analysis is possible because all the necessary information is available in case a more detailed analysis is required. This feature also supports analysis of cases when an analysis from a different perspective is desired.

3.3 Visualization of Individual Items

The data analysis environment was constructing using the data stored in the database. As described above, the detailed positions of bottlenecks were calculated, and the error of the predicted delivery time of each material at each position and the interval margin between the materials at each position were visualized.

3.3.1 Transfer Bottleneck Positions

Figure 6 shows the results of the analysis of the transfer bottleneck positions. The results were classified in the four processes of heating, rough rolling, finish rolling and coiler, and the bottleneck positions in each of these processes were further classified into 8 points from A to H. In Fig. 6, blue indicates the finish rolling bottlenecks. For materials with bottlenecks in the finish rolling process, the margin for improvement at each

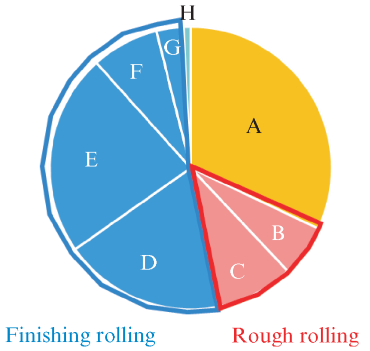

Fig. 6 Bottleneck position

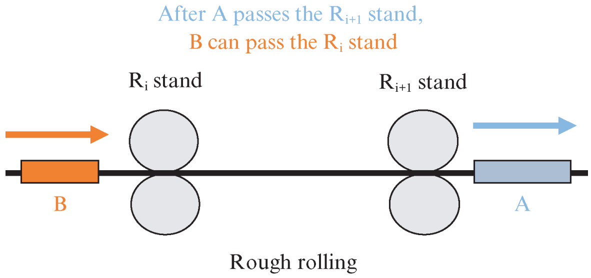

Fig. 8 Constraint of rough rolling

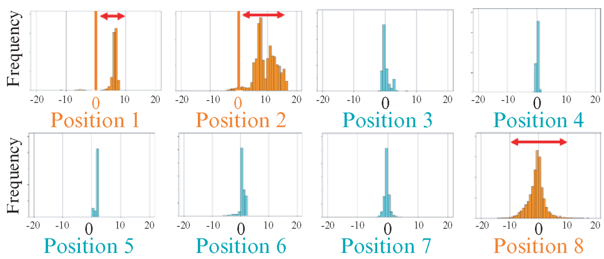

Fig. 7 Error of calculating delivery time

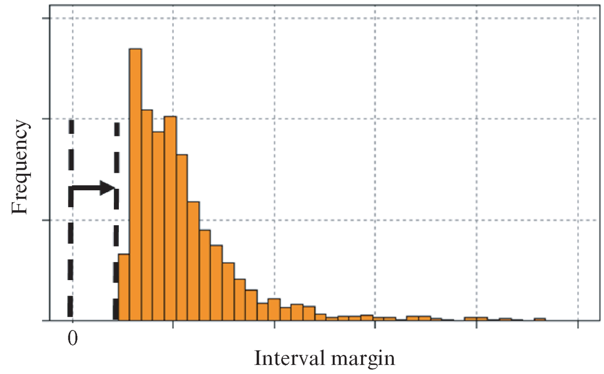

Fig. 9 Interval margin of position C

point can be investigated by comparing the interval between the materials required for the equipment at each of the bottleneck positions D to G and the actual interval margin between the materials. Furthermore, by considering the ratio of materials at each bottleneck position, it is also possible to calculate the approximate merit of improvement at each position. Red shows the bottlenecks in the rough rolling process, which is a part of the rolling process that was not a focus of interest and was overlooked until now. This analysis revealed that there is also a margin for improvement in rough rolling bottlenecks, and among the bottlenecks in the rough rolling process, the detailed bottleneck positions are concentrated at two points.

3.3.2 Error of Predicted Delivery Time

The error of the predicted delivery time at each point was shown by a histogram, as shown in **Fig. 7**. At positions 3 to 7, error was concentrated around 0, indicating that the delivery time can be predicted with good accuracy. In contrast, at positions 1, 2 and 8, deviations were large, and at positions 1 and 2, the average values were shifted to the plus side. From these results, it can be understood at a glance that the points for improvement are around positions 1, 2 and 8. Therefore, we are working to efficiently improve those positions.

3.3.3 Interval Margin Between Materials

The interval margin between materials was also shown in a histogram. **Figure 8** shows the constraint of rough rolling. In the rough rolling process, there is constraint that two or more materials must not enter between the rolling stands. More specifically, the head end of the subsequent material may only advance into stand R_i after the tail end of the preceding material has exited stand R_{i+1}.

Figure 9 shows the interval margin between two materials at position C related to this constraint. From this histogram, it was possible to confirm the degree of margin for transfer of the subsequent material, including the margin for the material with the shortest interval. Since the material ratio when position C becomes a bottleneck in the total process was not particularly high, it was estimated that the entry timing of the subsequent material was not being adjusted to optimize efficiency. To improve this problem, it was possible to shorten the interval margin simply by changing the parameter. As this example suggests, in many cases, improvement points that could not be identified until now can be improved comparatively easily. **Figure 10** shows how the bottlenecks have changed as a result of this improvement at position C. In the present example, after the entry timing of the subsequent material was speeded up by adjusting the parameter, most of the bottlenecks that originally occurred at position C shifted to the next bottleneck position, although some still remained at position C. As demonstrated by this example, simulations to investigate the changes before

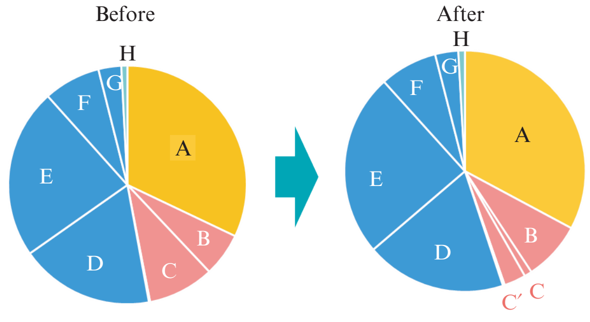

Fig. 10 Change of bottleneck after improvement at position C

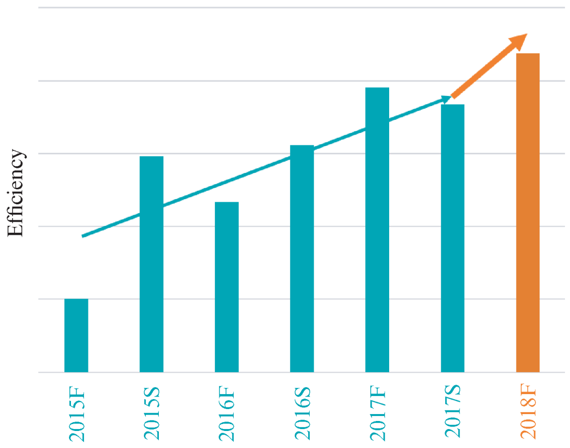

Fig. 11 Trend in rolling efficiency improvement

and after improvements can be performed easily in the data analysis environment constructed in this project.

3.3.4 Improvements Utilizing the Data Analysis Environment

Figure 11 shows the trend in rolling efficiency. Although efficiency improvement measures for four long-standing problems were implemented from FY 2015 through the first half of FY 2017, due to the difficulty of improving some problems, the project required a period of 2.5 years, and the improvement of rolling efficiency was limited to 0.57 %. However, from the second half of FY 2017 to the first half of FY 2018, measures were implemented for two improvement points that were newly discovered using the data analysis environment developed in the paper, and improvements were achieved in 0.5 years. As a result, a 0.81 % improvement in rolling efficiency was achieved.

4. Conclusion

A data analysis environment was constructed with the aim of implementing rolling efficiency improvements efficiently and in a short time period. Although this paper has described examples of improvement at JFE Steel's West Japan Works (Fukuyama District), this method was also deployed at East Japan Works (Chiba District) and actually contributed to improved efficiency. In the future, we will continue to work to identify more effective improvement points and achieve further improvements in rolling efficiency.

References

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This paper reproduces the paper listed as reference 4), which was written by the same lead author, with revisions of some expressions.