

Profile and Flatness Set Up System for Rolling Mill

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IHI has developed the Profile and Flatness Set Up System (PFSU) in order to improve crown and flatness control in hot rolling mills. This system provides high controllability and accuracy when used with the CNP[®] (Combined Numerical Profile) Mill developed by IHI in hot rolling operations, and shape quality is also improved significantly. These improvements have satisfied customer requirements. The latest IHI technique for shape control in hot strip mill and reversing finishing mill is described below

1. Introduction

The improvement of dimensional quality in the hot rolling process began with improvement of thickness accuracy in the 1960s, and shifted to improvement of width accuracy, and then to improvement of thickness distribution in the width direction (crown). Recently, high-variety low-volume production has become the mainstream in the hot rolling process, and there have been many trials of the rolling of hard materials, such as ultra thin strips and high-tension steels. Accordingly, it has become necessary to secure and further improve the shape (crown and flatness) when rolling such hard materials.

Conventional shape control techniques have focused on developing a “crown control mill”, which has highly capabilities with regard to the free setting of crown and flatness. In addition, recent technical innovations in computer control have made it possible to accurately predict crown and flatness along the full length and optimally control the actuators.

IHI has developed the PFSU (Profile and Flatness Set Up System) in order to improve the accuracy of crown and flatness control. PFSU has high controllability and accuracy performance when used with the CNP[®] (Combined Numerical Profile) Mill in actual hot rolling operations. As a result, product quality has been successfully improved.

This paper introduces the profile and flatness set up system (PFSU) for finishing mill in hot strip mill and reversing finishing mill in plate mill.

2. Basic concept of profile and flatness control

Crown and flatness, shown in **Fig.1**, are used⁽¹⁾ as indexes to evaluate the shape of a strip and plate. Crown (**Fig.1-(a)**) represents variations of thickness in the width direction, and is defined by the difference in thickness between the width center and the predetermined edge position (25 to 100 mm).

Flatness (**Fig. 1-(b)**) is defined by the difference in longitudinal elongation of each position in the width direction, and is broadly classified into “edge wave,” a state in which the edge elongates more than the center, and “center buckle,” a state in which the center elongates more than the edge.

Changes of flatness result mainly from changes of crown ratio (obtained by dividing crown by thickness at the center). Crown change factors are classified into rolling conditions such as steel grade, rolling sizes, and rolling loads; and operating conditions such as roll materials, initial crown, and thermal/wear crown. There

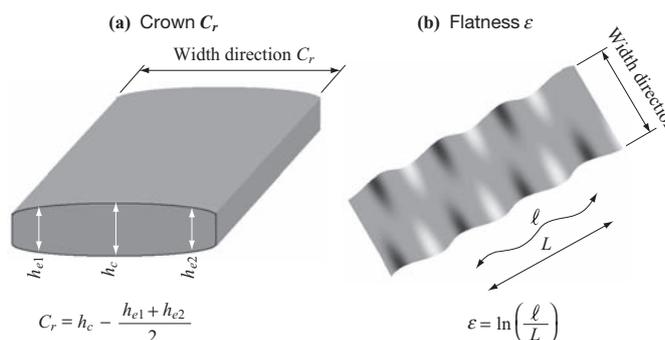


Fig. 1 Definition of crown and flatness

are a variety of factors which intricately influence each other, causing crown and flatness to change during rolling.

A conventional rolling mill is equipped with a work roll bending system⁽²⁾ to correct changes of crown and flatness and in order to achieve the target indexes IHI has developed the CNP[®] Mill, which has high crown and flatness controllability.

CNP[®] Mill can control crown and flatness by shifting work rolls with a special curved roll profile along the work roll barrel. For further information, refer to "IHI Shape Control Equipment for Strip and Plate Rolling Mill," a paper appearing in the IHI Engineering Review.

PFSU predicts crown and flatness based on these conditions, and determines actuator setting values, such as CNP[®] roll shift positions and work roll bending forces, for achieving the target crown and flatness with consideration given to the permissible limit of flatness change.

3. Basic configuration of PFSU

PFSU consists of the following three types of functions:

- (1) Functions to predict crown and flatness, and set CNP[®] roll shift positions and work roll bending forces
- (2) Learning function for the strip crown and flatness model
- (3) Function to predict thermal crown and wear crown

3.1 Setup models

3.1.1 Setup model for finishing mill in hot strip mill

Figure 2 shows the PFSU calculation flow for a hot strip mill. When a rough bar rolled by the roughing mill has reached the entry side of the finishing mill, the final finishing mill setup begins. At this time, the CNP[®] roll shift positions and work roll bending forces necessary to achieve the target crown and flatness will be finally determined.

The target strip crown and flatness are transmitted from the host computer. The rolling conditions, such as strip thickness at the delivery side of each stand of the finishing mill and predicted rolling loads, and the operating conditions, such as work roll/back-up roll diameter, are provided as input data. In the setup calculation, the strip crown and flatness at the delivery side of each stand are predicted based on the provided data, and the CNP[®] roll shift positions and work roll bending forces to achieve the target crown and flatness are finally determined, with consideration given to the permissible flatness range.

3.1.2 Setup model for reversing finishing mill

Figure 3 shows the PFSU set up calculation flow for a reversing finishing mill. Although the calculation flow is basically the same as that for finishing mill in the hot strip mill described in **3.1.1**, the setup calculation

is executed before each pass. The crown and flatness at passes that have completed rolling are calculated using actual values, and CNP[®] roll shift positions and work roll bending forces for passes that have not completed rolling are modified in order to achieve the target crown and flatness.

3.2 Learning model

The PFSU setup model predicts strip crown and flatness based on the rolling conditions and operating conditions using a theoretical model. However, the theoretical model has quite a few errors, the predictions calculated by other models are used as input data, and the input data, even if they are the measured values, includes measurement errors; therefore, the crown and flatness predicted by PFSU includes quite a few errors.

To prevent such errors, PFSU is equipped with a learning function to compare the model-predicted values with the measured values and automatically correct errors if needed. The PFSU learning model starts calculations when rolling is started at the final stand/final pass, and the measured crown and flatness data are collected. The crown and flatness are re-calculated based on the rolling results, and the calculated and measured values are compared. If there are some errors between the re-calculated and measured values, PFSU corrects the influence coefficients for the crown model and flatness model to match the re-calculated values to the measured values.

3.3 Thermal crown/wear crown prediction model

In the actual rolling process, due to the transfer of heat from the rolled materials, rolls expand thermally, and a thermal crown is formed. The thermal crown grows as the rolling progresses, and causes the crown to change from a convex shape to a concave shape.

Roll wear, which depends greatly on the rolling length, causes the crown to change to a convex shape as the rolled length increases. Highly accurate prediction of thermal crown and wear crown is essential to accurately predict the crown and flatness.

Both models are left-right (width direction) asymmetric, top-bottom symmetric and half-size, and the temperature distribution inside the roll and wear distribution is calculated based on the measured data. The temperature distribution inside the roll is numerically calculated based on the finite difference method. Because the roll heat input conditions change constantly, calculations are performed at short intervals in order to respond to rapid changes in internal temperature during rolling and enable accurate prediction.

Roll wear distribution along the roll barrel is calculated based on the rolling force distribution at each stand/pass in the roll width direction and rolling length in accordance with the pass schedule after rolling is completed.

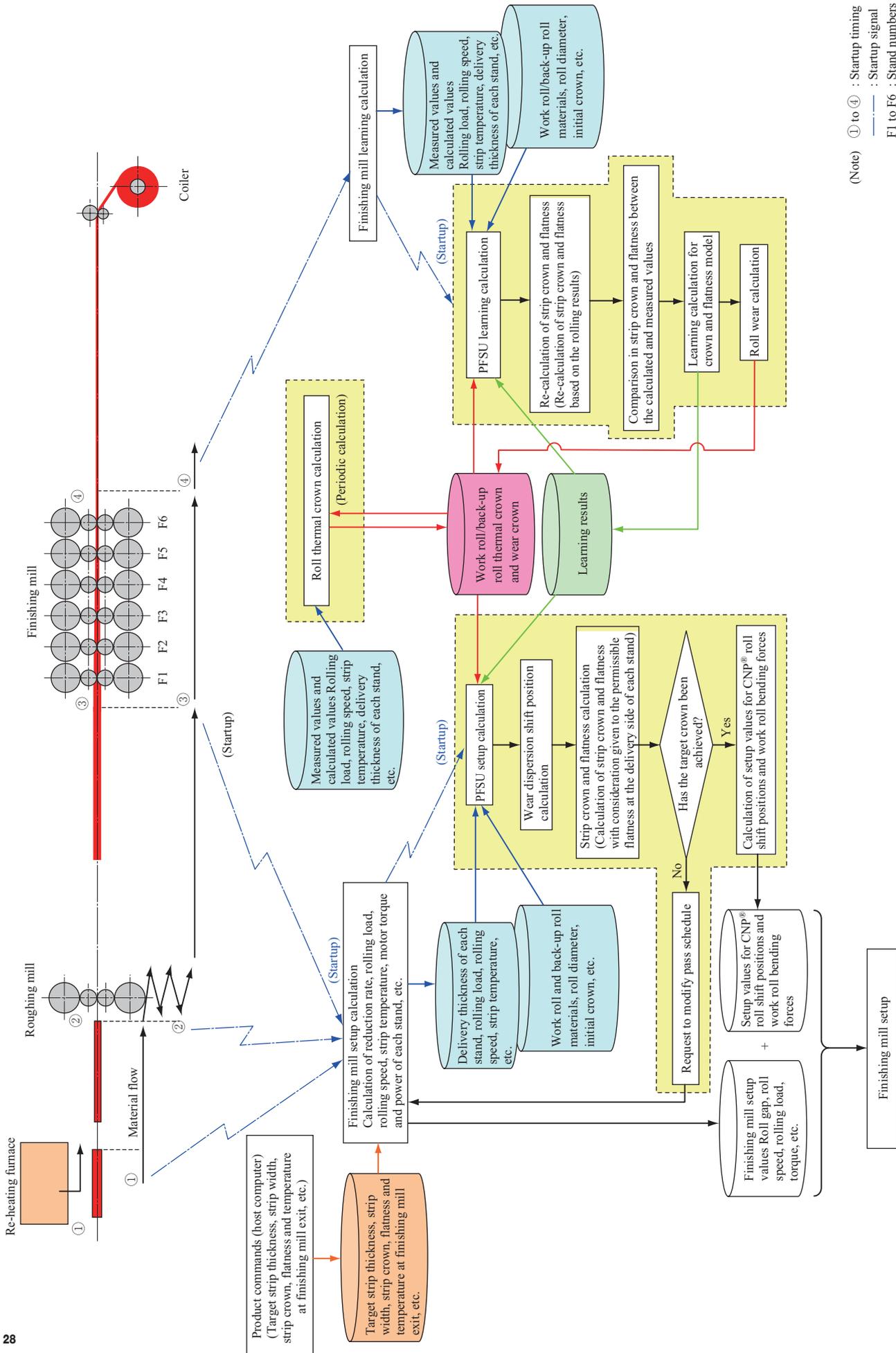


Fig. 2 PFSU calculation flow for hot strip mill

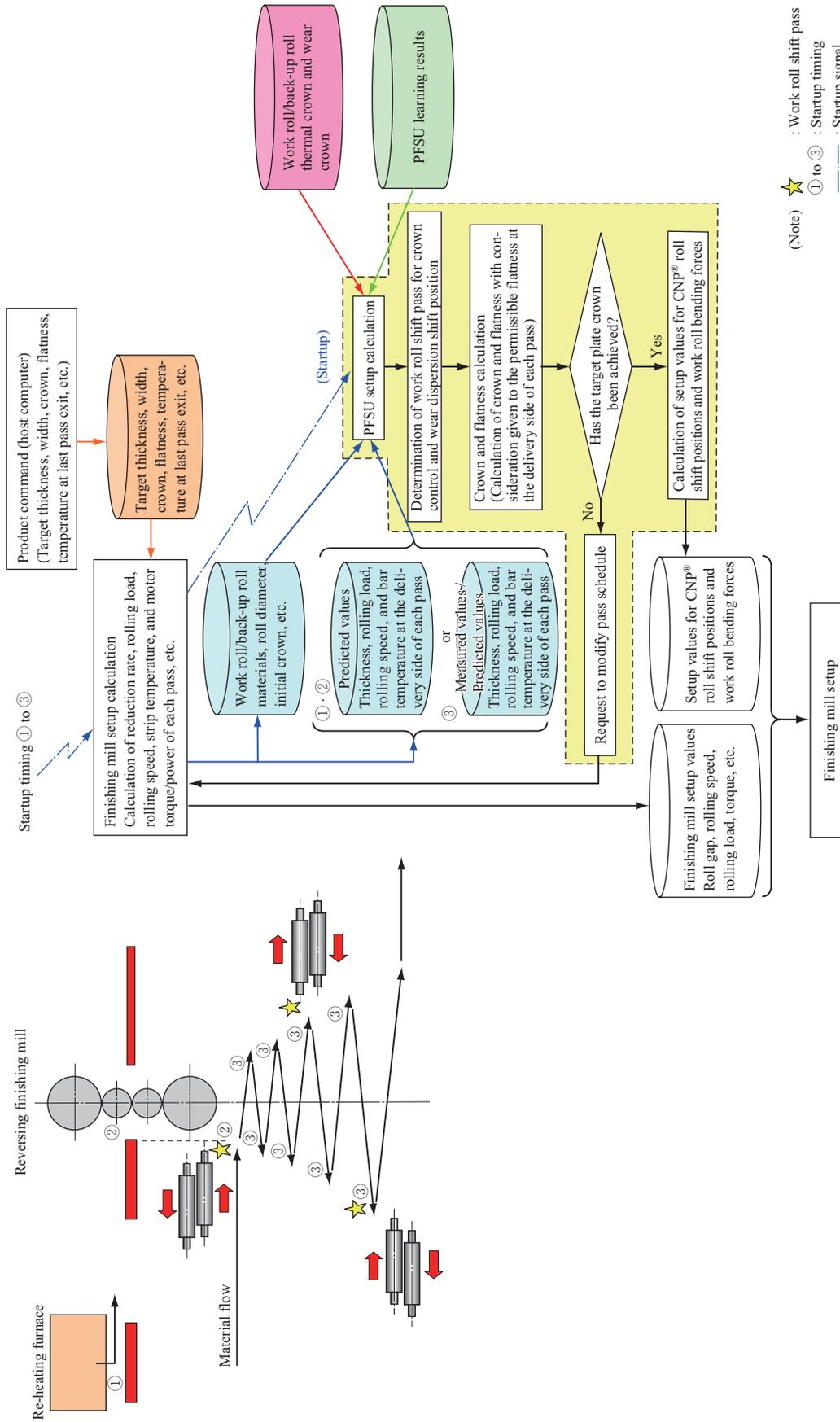


Fig. 3 PFUSU set up calculation flow for reversing finishing mill

Figure 4 shows the result of the calculation by PFSU of the work roll surface temperature distribution(1) with the thermal crown model, and Fig. 5 shows the result of the calculation by PFSU of the work roll wear profile(1) with the roll wear model. The symbols “●” and “▲” are measured values after rolling operation cycle was completed and work rolls were taken out from the mill. Both measured values match well with the calculated values.

The results of calculations by PFSU with the thermal crown model and wear model are stored in the roll profile data table. The PFSU setup model and learning model use the latest thermal profile and wear profile in this data table to predict the crown and flatness.

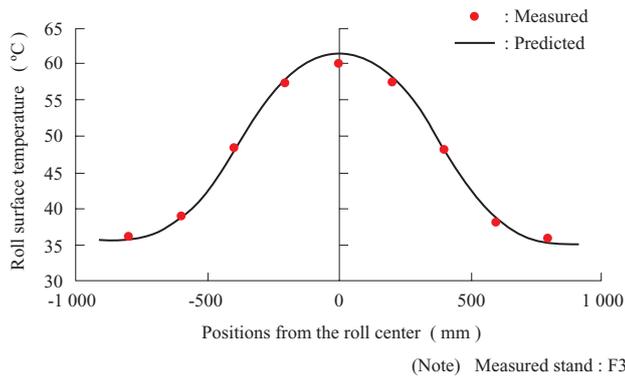


Fig. 4 Temperature distribution predicted by PFSU thermal crown model

4. Operation status with PFSU and CNP[®] mill

Figure 6 shows the strip crown changes for one operation cycle in a hot strip mill. Before the installation of PFSU and CNP[®] Mill (Fig. 6-(a)), it was difficult to maintain the target crown, because the thermal crown grew depending on the heat transfer from the bar, and the strip crown became smaller (changed from a convex shape to a concave shape).

After the installation of PFSU and CNP[®] Mill (Fig. 6-(b)), the difference between the target crown and measured crown (crown deviation) has been reduced throughout the operation cycle, and accurate prediction of strip crown and control to match the target indexes without being effected by rolling conditions and

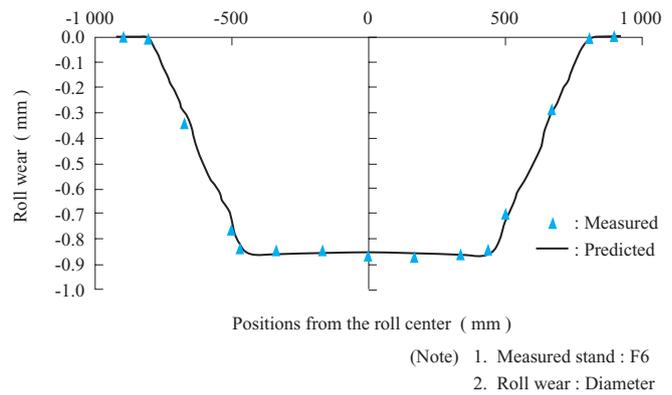


Fig. 5 Wear profile of work roll predicted by PFSU wear crown model

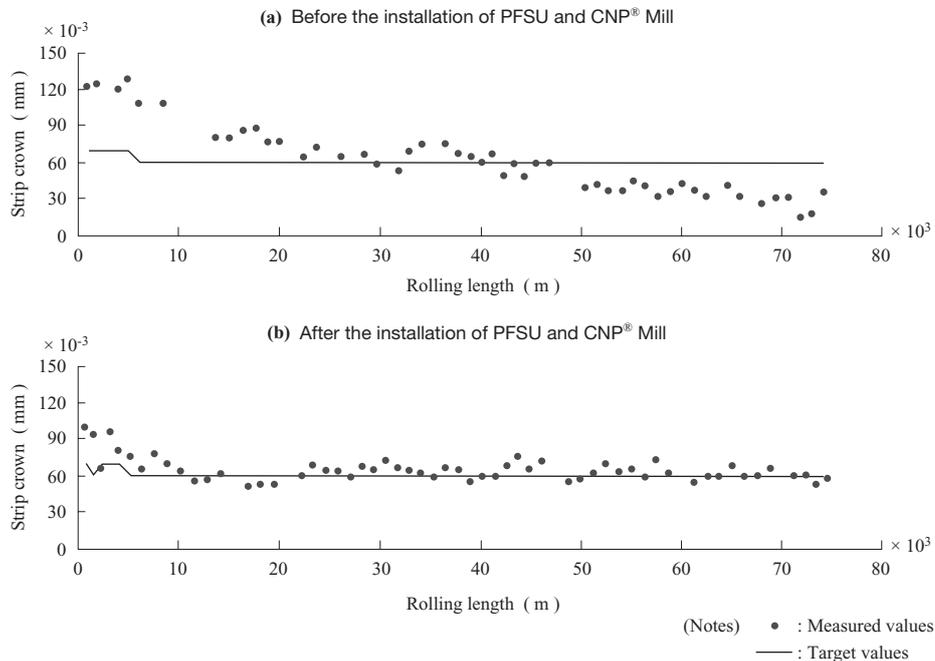
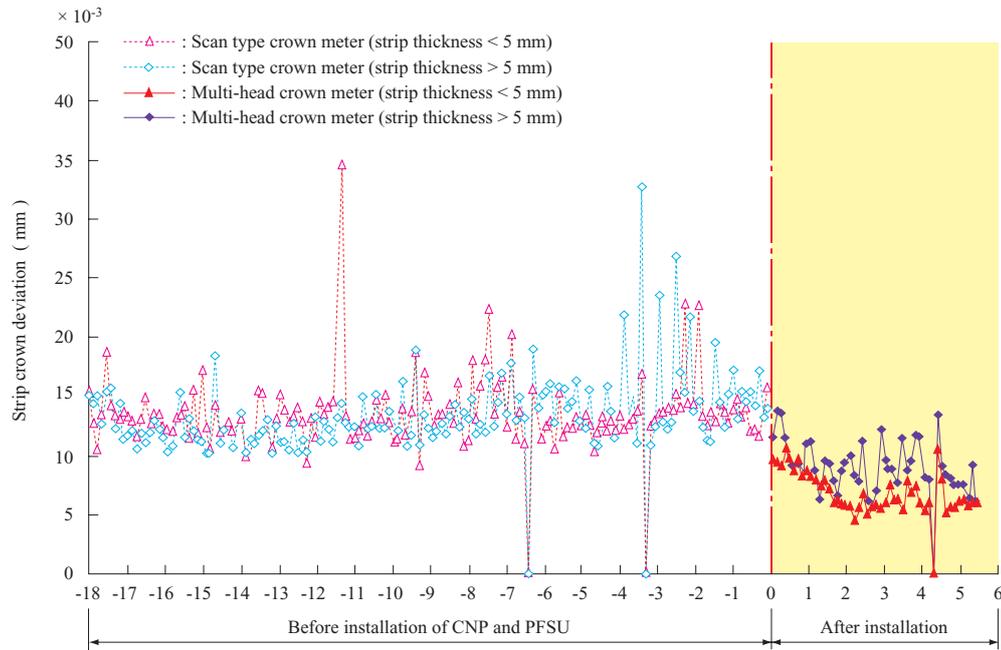


Fig. 6 Strip crown changes in actual rolling



(Note) 1. The vertical axis indicates the standard deviation (measured strip crown - target strip crown)
 2. The horizontal axis indicates the operation period (months).

Fig. 7 Performance of strip crown control

operation conditions, such as thermal crown and wear crown changes, has been achieved.

In particular, the crown deviation at the beginning of operation cycle has been significantly improved compared with that before that installation of PFSU and CNP[®] Mill. It has demonstrated that CNP[®] Mill has high flatness control performance.

Figure 7 shows the performance of strip crown control in a hot strip mill⁽¹⁾. Since PFSU and CNP[®] Mill began operating, the standard deviation (measured strip crown - target value) has been improved and has nearly halved compared with the standard deviation before PFSU and CNP[®] Mill began operating.

5. Conclusion

PFSU has been developed in order to improve the accuracy of crown and flatness control in hot rolling, and when used with CNP[®] Mill in actual rolling operation has showed high performance crown and flatness control. As a result of drastic product quality

improvements, IHI has earned an excellent reputation and has gained customer trust.

IHI intends to develop new techniques to contribute to the further improvement of product quality.

Acknowledgement

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