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열간 사상압연 루퍼장력 측정에의한 열연판폭제어

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HOT STRIP WIDTH CONTROL METHOD BY USING LOOPER TENSION MEASURING SYSTEM IN FINISHING MILL

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Abstract

A high precision hot strip width control method has been developed in this study by applying interstand looper tension measuring system at finishing mill stands. As width deviation of hot rolled steel strip is closely related to abnormal increase in the interstand strip tension, on-line measuring device of looper tension and data analyzing system was developed in this study. To determine dominant factors that will cause local width shortage, the logged data sets of bar width, bar thickness, looper tension, and strip thickness along the strip length were correlated with the data set of strip width change. With the result of the correlation analysis, existing sequence control logic and parameters for looper actuator were modified for strip width quality and the gains of the looper control were refined for the stable operation during the full passage of rolled strip. The on-line tension measurement and tension feedback control for looper system improved strip travelling stability and reduced strip width deviation in the srip top end region.

Keywords: Tension measuring system, Strip tension, Width deviation, Looper control, Hot strip mill

1. Introduction

Recently, there is a strong demand for high dimensional accuracy of hot rolled coils in the worldwide market. Dimensional properties of hot rolled flat steel coil are the thickness profile across width and along length, flatness, width and coiled shape. Among them, accuracy of strip width is considered much important since width deviation needs a larger width tolerance margin to be trimmed along the full length of coil. The width deviation in hot rolled strip has several origins of tapered cast slab width, local temperature deviation due to skid marks in reheating furnace, width shortage in roughing mill operation, local width shortage due to interstand tension jump in the finishing mill stands, and width contraction during coiling process. In this study, however, the width deviation due to finishing mill operation is concerned.

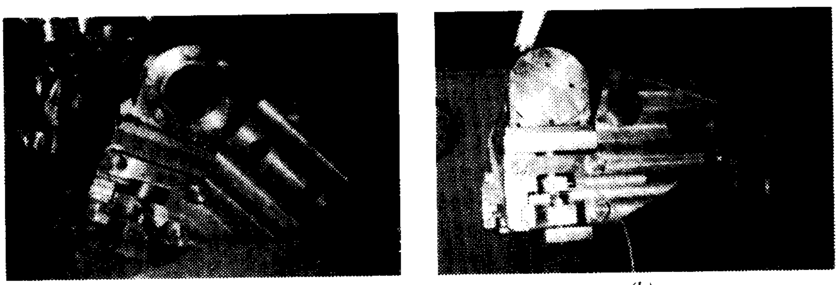
In the finishing mill train, it is thought the strip width deviation occurs due to the excessive interstand strip tension fluctuation. In conventional hot finishing mills, the interstand looper position for compensating mass flow difference between nearby two stands is feedback controlled based on the tension calculated indirectly from the looper motor torque. The interstand tension calculated by the method, however, is not proper to adjust a suitable inertia of looper table. Therefore, we developed a TMD(Tension Measuring Device) to measure the strip tension acting on the looper roll. The TMD is not necessary to consider the effect of mass moment of inertia of looper table, since load is measured at the looper roll shaft. Besides TMD, OLDA(on line data acquisition) and OLA(off line data analysis) system are developed to perform the correlation analysis of the TMD tension and strip width deviation. By correlation analysis with the results from OLDA and OLA, the reasons of the strip width deviation in hot finishing mill operation and the methods to reduce the error was pursued.

2. System Design and Application

To measure the strip tension between stands, TMD was installed under looper roll bearing support. The strip tension was calculated from the TMD measuring load, including the effect of the mass moment of inertia of looper table, looper angle, angular velocity, acceleration, strip weight and so on. To analyze the relationship of the strip tension fluctuation to the strip width deviation, the OLDA and the OLA system were developed and installed at a hot strip mill of Kwangyang Works, POSCO.

2.1 Development of the TMD

It was the design concept of TMD to measure the strip tension between stands without changing existing looper frame. To meet the condition, only the looper roll bearing assembly block to the looper table was modified in this development. Capacity of the load cell was selected by considering the tension set-up values, the dimension of the hot coil and the pass schedule of the hot rolling. In this study, for #1 TMD installed between #1 finishing stand and #2, load cell capacity was 20 ton in each side and #2, #4, #5 TMD were 10 ton in each side of looper roll bearing assembly. Between #3 and #4 finishing stand, #3 TMD was omitted because the space was not available.



(a) *(b)*

Fig 1. Tension Measuring Device and a looper simulator

Fig 1 shows the TMD for load measurement and a looper simulator for TMD stability testing. As shown in Fig.1. (a), TMD is designed to measure the strip load at arbitrary looper angle by applying four link frame structure and easy to exchange the looper roll assembly by bolt joining method. By the up and down motion of looper, if the TMD is shocked by an impact load of abnormally high, load cell will be out of order in a short period. In order to get rid of the abnormal force, an impact-absorbing device was applied. To test stability of TMD and the measuring accuracy, the TMD was installed at a looper simulator in laboratory before installed at Works. In a looper up and down test, the TMD was fit to the requirements of working conditions.

2.2 The Algorithm of the Tension Calculation

The load value measured at the TMD of the present design consists of strip tension, weight of the strip, looper roll weight, load of strip bending, centrifugal force of strip and looper acceleration force. To calculate the strip tension from the TMD load, assuming that looper acceleration force is zero, we can obtain the following equation (1).

$$T = K_i F_{LC} - (K_j \sin\theta + K_k \cos\theta)(F_1 - F_2) \qquad (1)$$

T	Unit tension (kgf/mm^2),	θ	Looper angle (deg)
F_1	Load of strip bending and weight	F_2	Centrifugal force of strip
K_i	Variable related to looper angle	K_j K_k	Constants related to looper angle

As known in equation (1), the strip tension is described by the load without considering the looper acceleration force. The effect of the looper acceleration force is trivial in the present TMD load and the component was eliminated in the present study to assure the scan time of full sequences of the PLC program in a allocated time by the factory control system. The TMD load interpreted by the equation (1) was interfaced to the existing on-line control system.

2.3 Development of LDPS(Looper Data Processing System)

LDPS was developed to analysis the influence of strip tension to the strip width deviation as shown in Fig 2. It is composed of two sets of system, OLDA(on-line data acquisition system) and OLA(off-line data analysis system). LDPS processes SCC(Supervisory Control Computer) setup data and outputs of looper control PLC. The data is composed of the bar width, bar thickness, looper angles, calculated looper tensions based on motor torque, finishing mill exit coil width, coil thickness and so on.

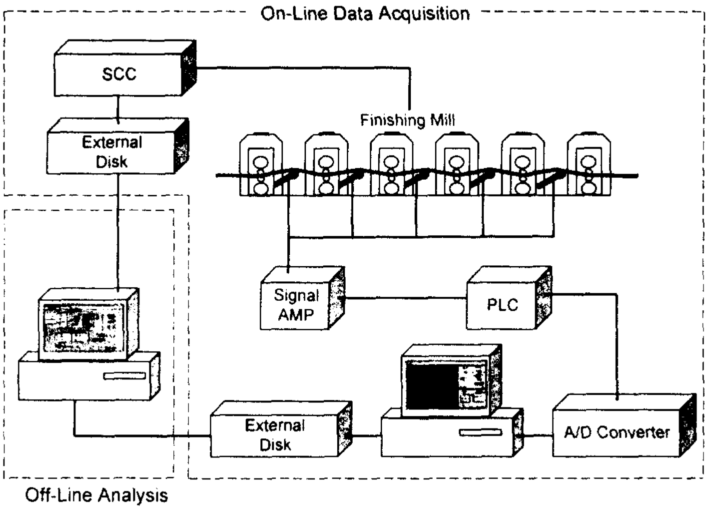


Fig. 2. On line Data Acquisition and Off line Analysis System

All the data gathered by OLDA are saved at an external disk at a 50 samples/sec rate and OLA uses these data sets to analyze and to retrieve the influence of each factor to the strip width deviation. LDPS is installed at an industrial PC with a developed processing S/W using Labview 4.1.

3. Correlation analysis

3.1 The State of the Width Deviation Error

By using the operational data sets gathered by the OLDA system, we were looking forward to finding the causes of strip width deviation. To analyze the reasons of the strip width deviation in detail, we classified the range of the strip width deviation into five levels. We defined the range of goodness to above the level No. 2 and the range of badness to under the level No. 3 as shown in Tab. 1. The set-up data is classified as in Tab. 2

The results of the analysis with the data sets of about 3,579 coils are shown in Tab. 3. The badness rate was about 12 % as mentioned in Tab. 3.

Tab. 1 Classification range of the strip width deviation in strip head

	No. 1	No. 2	No. 3	No. 4	No. 5
Range of the width deviation (mm)	Above the marginal coil width value	From target coil width to the marginal width value	From −12.5 to 0 (target coil width)	From −25.0 To −12.5	Under -25

Tab. 2 Classification ranges of strip width, steel grade, strip thickness

Classification No.	Strip Width (mm)	Steel Grade	Strip Thickness(mm)
1	0 < W <= 900	Low carbon steel	0.00 <= H < 1.40
2	900 < W <= 1100	Commercial Steel	1.40 <= H < 1.60
3	1100 < W <= 1350	Middle carbon steel (40 kgf/mm^2)	1.60 <= H < 1.80
4	1350 < W	Middle carbon steel (50 kgf/mm^2)	1.80 <= H < 2.00
5		Nb-added steel	2.00 <= H < 2.30
6		Cu-added steel	2.30 <= H < 2.60
7		Ti-added steel	2.60 <= H < 2.90
8			2.90 <= H < 3.20
9			3.20 <= H < 3.60
10			3.60 <= H < 4.00

Tab. 3 Rate of strip width deviation by level No.

	No. 1	No. 2	No. 3	No. 4	No. 5	Total
Rate (No. of coil)	45.74 % (1,637)	42.27 % (1,513)	8.89 % (318)	2.24 % (80)	0.87 % (31)	100 % (3,579)

3.2 Analysis of the Cause to Width Deviation Error

In order to perform the correlation analysis on the strip width deviation according to the operational variables such as looper angle, calculated tension, TMD measured tension, the parallel representation of those data sets were depicted as in Fig. 3.
As shown in Fig. 3, in horizontal axis one grid interval represents 1 sec for interstand looper tension variations and 5 seconds for strip width deviation. In vertical axis one grid interval represents 10^0 of angle and 1.0 kgf/mm^2 of tension, and 25mm of width deviation, respectively. The calculated tension by motor torque is depicted by the dashed line, the TMD measured tension by the light solid line, the looper angle by the heavy solid line in Fig. 3(a), (b), (c), (d) and the width deviation by the solid line in Fig. 3 (e).

As displayed in Fig. 3, the tension control usually has errors even in the steady state and is especially not good in the transient region. In the transient stage, both the calculated tension and the TMD measured tension show the peak value but interestingly the calculated tension value and the TMD measured one displayed in a conversed manner of transition until the looper angle to be stabilized. This is understood by the phenomena that the calculated tension value based on motor torque does not account the mass moment of inertia of looper table. The reason of large width deviation at strip head end was not determined by a special parameter but by the parameters like late response performance of the control system, phenomena of the tension peak in initial stage, steady state error and so on.

4. Results of the application to the mill

4.1 Adjustment of the tension set-up value

In equation (2), a mathematical model to set the strip tension between finishing stands is described.

$$T = (K_1 + K_2/H) * \{1 - (K_3 * W)/10{,}000\}. \quad (2)$$

T	Unit tension (kgf/mm^2)	W	Strip width (mm)
H	Strip thickness (mm)	K_1	Constant
K_2	Constant related to thickness	K_3	Constant related to width

By the above equation, when strip thickness is thin strip tension is set to a high value. That is, to reduce the strip width deviation, constants related to the strip thickness should be adjusted.

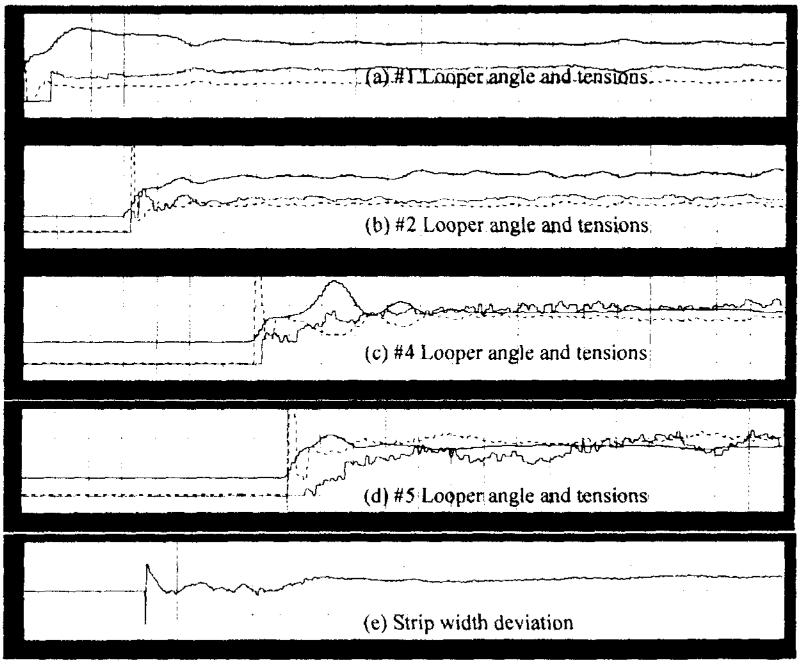


Fig. 3 Results of the Off Line Analysis System

4.2 Adjustment of the Initial Torque for looper driving

After strip is on metal-in state, looper is driven by initial set up torque. If the initial torque is set high, the looper roll impacts the strip abruptly. The excessive impact force shall bring about strip width shrinkage. In the existing looper control system, the initial set up torque is predetermined by 150% to the looper motor rated torque. The initial setup torque was, however, fixed to the same value for all the strips neither considering incoming strip cross section nor steel grades. So the strip width deviation shall be high in the specific strip sizes and in steel grades, naturally. It is necessary therefore to adjust the suitable initial torque by strip dimension to obtain the soft touch between looper roll and strip.

4.3 Adjustment of the looper control gain

In hot strip mill, it is very difficult to control the looper because of the interaction between strip tension and looper angle. To solve this problem, the existing looper control system adopted a non-interactive control technique.

In Fig. 4., block diagram of the non-interactive looper control system is described. We, in this study, adjusted the gains of non-interactive controller to improve the performance of tension control system and those of PI controller to reduce the error of looper angle and strip tension in a steady state.

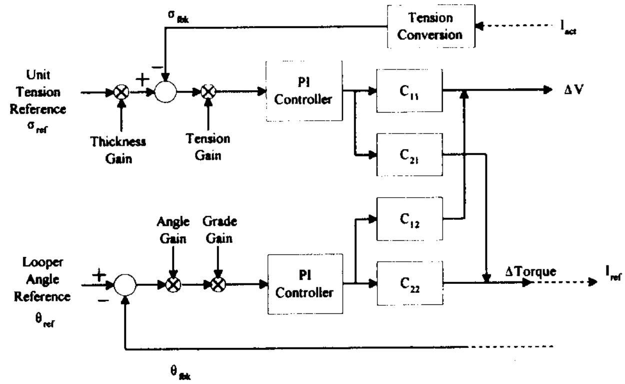


Fig 4. Block Diagram of the Non-interactive Looper Control System

4.4 Results

Refining the tension set up values, initial torque, controller gain and analyzing the data sets of 2,462 coils, we found the decrease of badness rate by 2.5% for the strip width deviation.

Tab. 8 Compare the strip width deviation before and after the parameter refinement

	Total Before the parameter Adjustment	After Tension set-up Adjustment	After Initial torque Adjustment	After Controller gain Adjustment	Total After the parameter Adjustment
Goodness Rate (coils./total coils.)	88.01 % (3150/3579)	90.24 % (684/758)	90.93 % (421/463)	90.46 % (1119/1237)	90.50 % (2228/2462)
Badness Rate (coils./total coils)	**11.99 %** (429/3579)	9.76 % (74/758)	9.07 % (42/463)	9.54 % (118/1237)	**9.50 %** (234/2462)

5. Conclusions

It was performed to decrease the badness rate and to analyze the reason for strip width deviation in this study. The results of this work are summarized as following:

(1) TMD to measure the strip tension between stands was suitable for stable operation.
(2) OLDA, on-line data gathering system and OLA, off-line data analyzing system were developed.
(3) The causes giving strip width deviation were analyzed by using the developed systems and the parameters such as tension set up values, initial torque, control gains in the existing control system were modified and refined.
(4) Badness rate of strip width deviation in the hot coil head end was reduced by 2.5 %.

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