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Development of Diagnosis Techniques for Hot Strip Mills*

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1 Introduction

Never in the history of the steel industry have hot strip mills turned into so sophisticated and complex lines as in recent years. While this unquestionably reflects a fundamental drive of the industry for higher efficiency production, more specific factors include operation rationalization moves such as the synchronization with CC plant, and a series of equipment refurbishments aimed at higher product quality.

A long downtime at the hot strip mill causes serious adverse effects in iron- and steel-making upstream and to the cold strip mill downstream. In addition, nonconformance in hot strip quality causes significant operational instability in the cold strip mill. Therefore, stable operation of the hot strip mill constitutes an indispensable requirement for the sound operation of the entire steelworks.

Against the above-mentioned backdrops, equipment maintenance at the hot strip mill has been carried out with a special emphasis on preventing long downtime, unsatisfactory quality, and securing facility precision and maintaining control levels, all of which are vital for stabilized operations. For this reason, Kawasaki Steel has implemented stepwise developments and developed comprehensive facility diagnosis techniques. In this paper, diagnosis techniques peculiar to the hot strip mill, which have been developed for such equipment as the sizing press (HARP), rolling mill, and coiler, are introduced.

2 Application Condition of Diagnosis Techniques and Their Features

The hot strip mill has been subjected to extensive facility renewal along the entire line ranging from the heating furnace to the coiler; the introduction of the sizing press[1] (with the aim of synchronizing operation), 6-Hi rolling mill (HC—high crown—mill), the tapered work roll shift mill (K-WRS mill),[2] AJC (automatic jumping control) coiler, and walking beam to the heating furnace. These have brought about improvements

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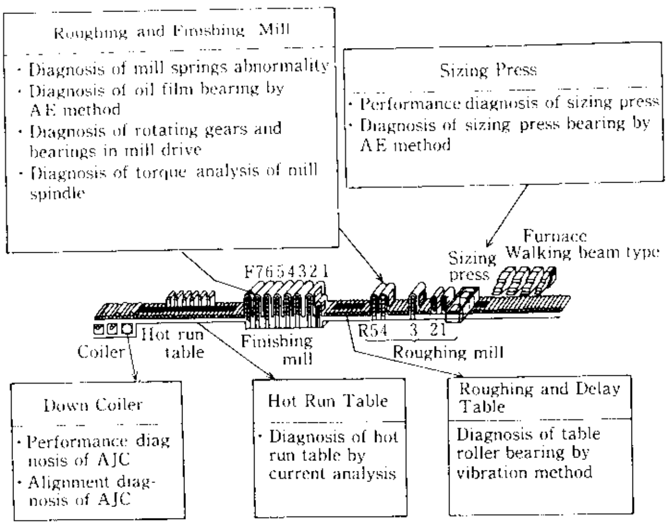


Fig. 1 Layout of hot strip mill and items of main diagnosis technique

in product quality, thereby enhancing both quality and cost competitiveness.

Diagnosis techniques have been developed and applied with the aim of guaranteeing the functions of the renewed facilities, and are broadly divided into (1) those for realizing synchronized operation[3] of production processes at the continuous casting plant and the hot strip mill and (2) those aimed at maintaining high dimensional accuracy in the production lines. **Figure 1** shows itemized typical diagnosis techniques developed and applied at Chiba and Mizushima Works; **Table 1** shows itemized diagnosis techniques, including those which are soon to be introduced, classified by objectives and measuring equipment.

The overall features of facility diagnostic techniques in the hot strip mill are as follows:

(1) The facilities subject to diagnosis techniques include the sizing press, rolling mill, coiler, and table, which have been applied throughout the entire line.

(2) Facility diagnosis techniques include not only the diagnosis of "electrical control" accuracy, but also the diagnosis of "machine alignment" accuracy, thereby forming diagnosis techniques incorporating both machinery and electricity into a single entity.

(3) Measuring equipment, which forms the basis of the diagnosis techniques, uses several types of sensors including the vibration method.

An outline of the features of major diagnosis techniques are explained below.

The sizing press is a slab width reduction equipment of the press type, which was developed by Kawasaki Steel for the first time in the world, and has the following features which significantly increase its reliability:

(1) Within about 1.4 sec, a single cycle of slab width reduction, width adjustment and slab tranfer, is completed. This cycle is repeated about 30 times per slab.

(2) The width reduction mechanism consists of a reciprocal mechanism using an eccentric shaft, and the eccentric bearing is subjected to an excessive load.

Consequently, when various operations fail to synchronize due to trouble with the electric control system or to an increase in frictional force at the mechanical-unit reciprocating mechanism, various units of equipment mechanically interfere with each other and cause abnormal loads, resulting in the breakage of the equipment. On the other hand, it is very important to predict abnormalities of ball bearings which support excessive load by the eccentric bearing. The authors have developed diagnosis techniques which monitor such deterioration based on the response of the electric control system, frictional force of mechanical units and metallic fatigue of ball bearings, in orde to make early predictions of abnormalities. **Figure 2** shows the configuration of the sizing-press performance diagnostic system.

The company introduced its K-WRS mill and HC-mill[4] to the rolling mill and used them to renew the crown control mill. In the crown control mill, the strip crown (thickness difference between the strip-width center and plate edges in the sectional area) is aimed at producing "dead flat" strip (crown "0"), but consequently, steering of the rolled material is more liable to occur than when the strip crown is larger. Further, compared with conventional rolling mills, the current rolling mill is also equipped with intricate devices which are liable to produce adverse effects on the roll cross, roll off-center and mill spring's modulus, and therefore require high-grade operation techniques. As a result, the authors have developed a rolling mill regidity abnormality diagnosis technique to analyze a portion of accuracy deterioration by monitoring the difference of mill constants between the rolling mill operation side (OP side) and the driving side (DR side), whose difference occurs mainly by a lowering of rigidity of pressing unit.

Table 1 Purpose of diagnosis in hot strip mill and its measurement techniques

		Purpose: For failure prediction	Purpose: For performance assurance		Vibration	AE	Torque	Displacement	Load cell	Temperature	Ampere	Others
Furnace			Heat efficient							△		
Sizing press			Press control									◎
		Gear & bearing			○							
		Crank bearing				◎						
Mill	Drive device	Rolling torque					○					
		BUR bearing				○						
		Gear & bearing			○							
		Cross bearing (UJ spindle)										△
	Screw down device		Mill spring	· Screw down · Pressure block					◎			
			Response of Jack	· Servo value · Jack				□				
	Others		Alignment	· WR shirt · Chock				△				
		–	Looper response									□
Table		Bearing		· Roller	○							
			Motor ampere	· Roller level · Coupling							◎	
			Colling efficient	· Nozzle						△		
Down coiler			Response of AJC	· Servo value · Hyd cylinder				◎				
			Alignment									◎
			Coil profile					○				
Utility			Tank level	· Leak				○				
			Hydraulic pressure	· Pump								○

◎ using in KSC (described in this report) ○ using in KSC □ preparing to use △ planning

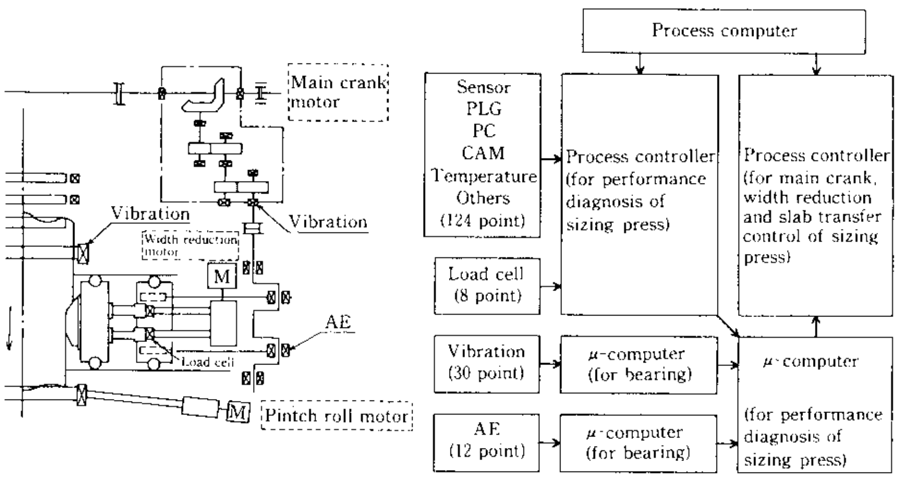


Fig. 2 Concept of sizing press performance diagnosis system

Elsewhere, diagnosis of buck-up roll bearings[5] using acoustic emission (AE) and diagnosis of main drive bearings using the vibration method have also been developed and introduced to the mills. **Figure 3** shows the configuration of the crown controll mill performance diagnosis system.

A cooling facility[6], which controls the material quality of the strip, and hot run table rollers (about 450 roll-

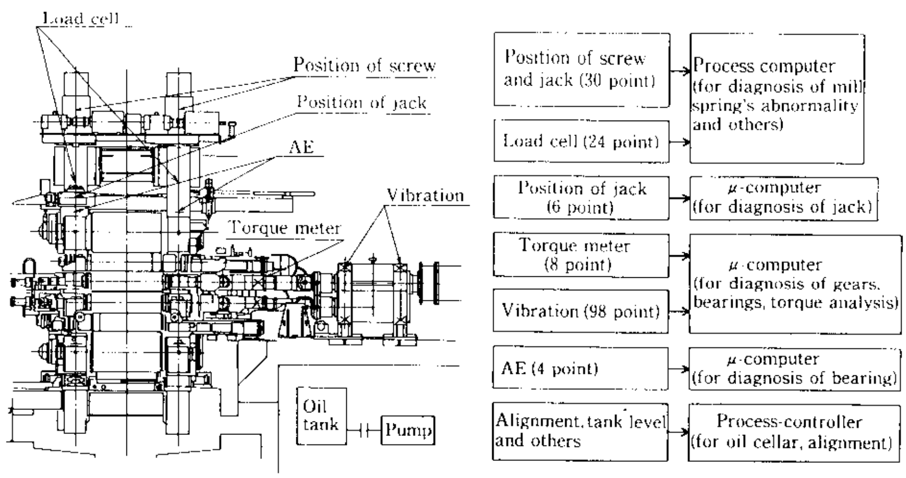


Fig. 3 Concept of crown control mill performance diagnosis system

ers) are installed at the downstream of the finish-rolling mill. In particular, when the strip material is to be threaded, the strip develops a waving phenomenon due to irregular roller levels arising from roller wear, thereby deteriorating the quality of the thin strip during coiling. For this reason, the authors have developed a roller level diagnosis technique which is based on an analysis of the current value of the roller drive motor. On the other hand, bearing diagnosis techniques have been introduced based on the vibration method.

In the coiler, a system for guaranteeing coil quality has been developed and introduced. In order to prevent quality trouble of overlapping defects (top marks) on the strip, a performance diagnostic technique for the blocker roll AJC operation has been developed and introduced so that the blocker roll jumping position may be tracked at high accuracy, and diagnosis is carried out on the basis of the blocker roll jump motion for each coil. Further, a diagnosis is carried out together, to dynamically diagnose response-time and jump-height accuracy, and predict future troubles of sensors and actuators which constitute the basis of such control. On the other hand, for the diagnosis of machinery accuracy which constitutes the AJC operation, the authors have developed diagnosis techniques by the frequency response method. **Figure 4** shows the AJC coiler performance diagnosis system. In the following sections, system outlines of the diagnostic techniques listed below will be reviewed.

(1) Performance diagnosis techniques for the sizing-press
(2) Performance diagnosis techniques for the crown control mill
(3) Performance diagnosis techniques for the AJC coiler

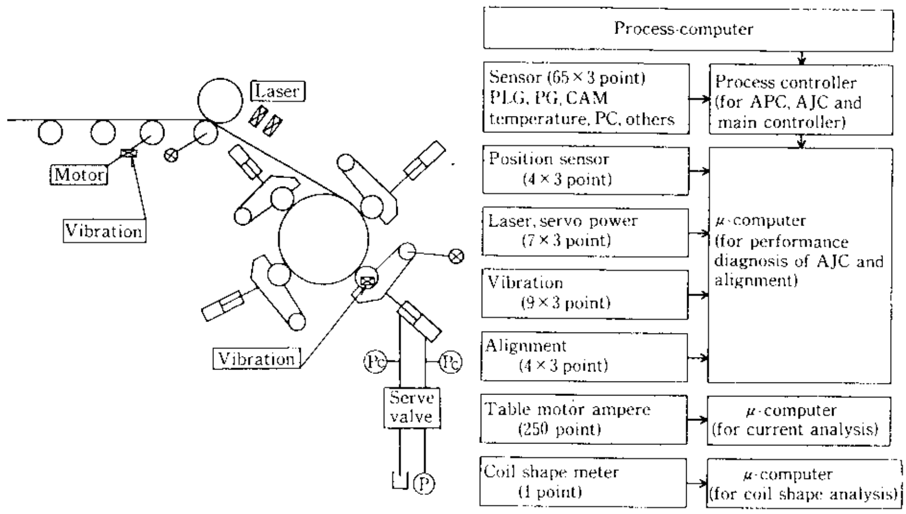


Fig. 4 Concept of AJC coiler performance diagnosis system

3 Performance Diagnosis Techniques for the Sizing-Press

3.1 Features of Sizing-Press Control[6)]

In the sizing press, a hot slab is fed between a pair of anvils which make crank motions, and slab width reduction carried out. These motions of the sizing press are divided into the following two phases:

(1) Leading-and-tailing ends pre-forming press

(2) Constant reduction press

Figure 5 shows a conceptual diagram of the width reduction cycle. In both cases, it is necessary that while the slab width is reduced, parts other than the main crank motion mechanism (namely, width reduction mechanism and slab transfer mechanisms) are stopped. Otherwise (this condition is called the "Collision between the slab and anvil"), the flank of the slab would be scratched or undue force would be applied to the machinery.

To reduce width along the total length of the slab, it is necessary to repeat the width reduction cycle about 30 times. Further, in order to prevent the sizing press process causing bottleneck in the line, it is necessary to reduce the width reduction time of a single slab to 60 s or under, and to reduce the period of the crank motion of the anvil to 1.4 s or under. On the basis of these conditions, the time (T_{max}) allowed for constant transfer of the slab is 0.87 s or under as determined by Eq. (1).

$$1.4 - 1.4\{(180 - 45.6)/360\} = T_{max} \cdots\cdots (1)$$

During slab transfer, the transfer driving force to the slab is conveyed by the friction between the pinch roll and the slab, and therefore, the acceleration force should be kept below the friction force which is determined by the pinching pressure of the pinch roll. Under the design conditions of the present machine, acceleration allowable for ordinary slabs is 4.5 m/s^2 or under, and therefore, even assuming a transfer more efficient than this figure, the transfer time (T_{max}) required will be 0.572 s according to Eq. (2).

$$4.5 \times \frac{T_{min}}{2} \times T_{min} \times 2 = \text{Transfer quantity} \cdots (2)$$

Thus, even if the delay in the electric control system is not taken into consideration, there is only a time allowance of 300 ms or below. In addition, the anvil speed varies with the press load. The transfer pattern, which satisfies these conditions and permits real-time control using the existing DDC (direct digital controller) system, is very limited.

To solve this problem, the authors have developed a control method (harmonious control) which employs a computer model. It was used in commercial facilities and proved successful in actual control. This computer model consist of (1) total control logic and an interference check block, (2) main crank control block, (3) transfer control block and (4) anvil width reduction control block as shown in **Fig. 6**.

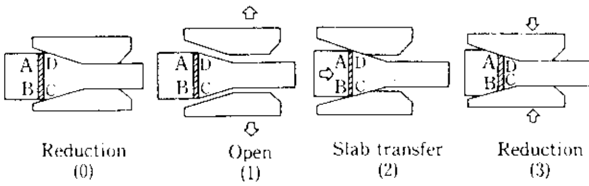


Fig. 5 Width reduction cycle using sizing press

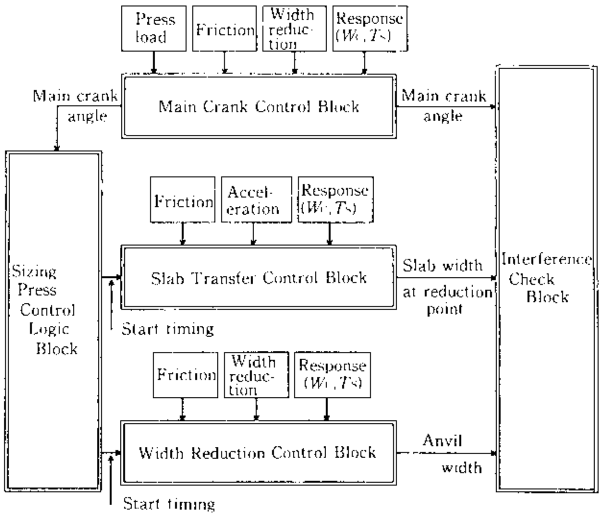


Fig. 6 Configuration of sizing press simulation model

The above mentioned (2), (3) and (4) are composed of ASR and APC blocks which have incorporated both the physical model (which has taken into consideration press load, the inertia moment of the mechanical system, and friction force) and the electric-system control model, (which has taken into consideration the control response of motors and DDC). By substituting various parameters into the sizing simulation model, each block has been simulated. **Figure 7** shows, as an example, a block diagram of the main crank control. The (1) component of the simulation model draws a graph and executes an interference check by designating the starting times of the transfer and width reduction system.

An example of the simulation is shown in **Fig. 8**. It applies to cases of constant reduction, and indicates the control method for stable slab transfer in all the operation modes ranging from a press load of 0 to 2 500 t. As can be seen from the figure, the time allowance, when the press load, friction force and the control response are taken into consideration, will only be 75 ms which is shorter than the aforementioned 300 ms.

In the lead-and-tail-end pre-forming, control is required to be in a very little allowance in time. This means an easy occurrence of collision between the anvil

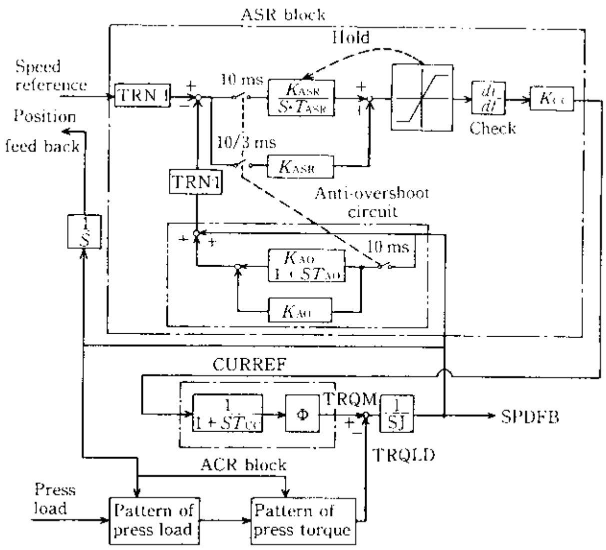


Fig. 7 Block diagram of main crank control

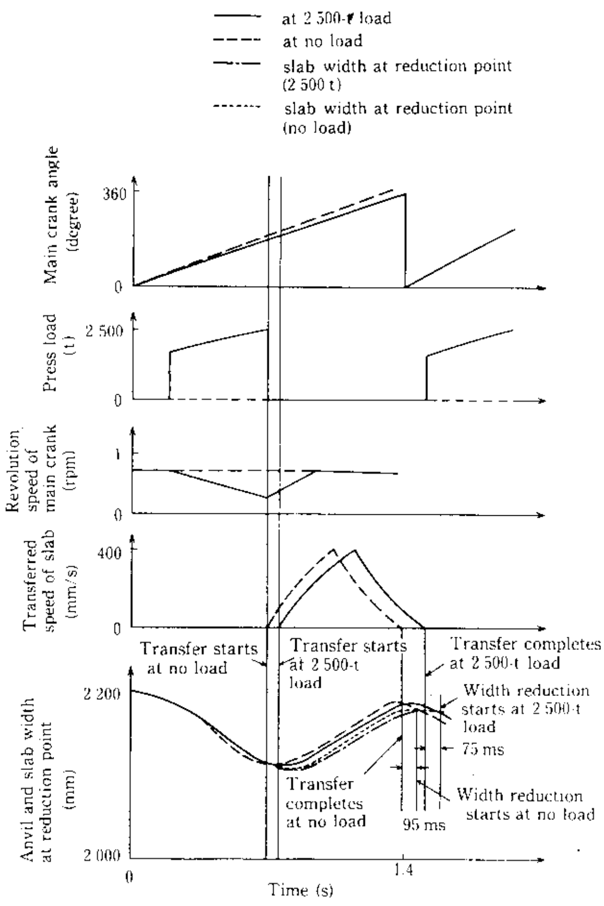


Fig. 8 Results of simulation at constant reduction

and slab, in the case of changes to slab friction coefficient, or a mechanical and electrical deterioration, both in any degrees exceeding anticipation. In view of this, the authors have developed sizing press control diagnosis techniques to guarantee more stabilized operations.

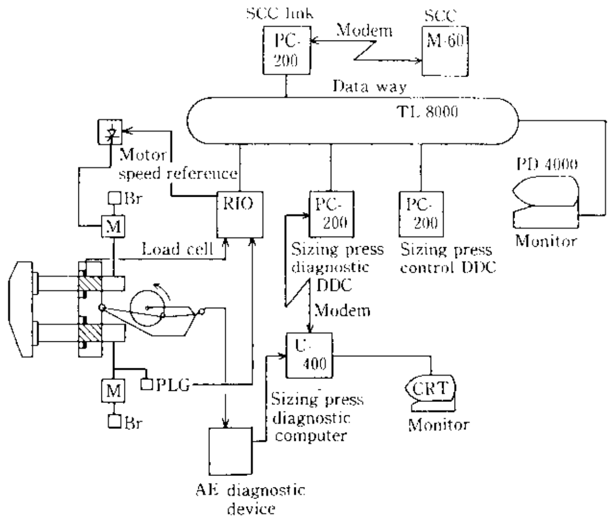


Fig. 9 Configuration of performance diagnosis of sizing press

3.2 Sizing Press Control Diagnostic Techniques

The configuration of the performance diagnosis system of the sizing press is shown in **Fig. 9**. This system consists of a equipment diagnosis DDC connected to a sizing press control DDC and a remote I/O unit through a high-speed data way, a data preserving and analyzing computer connected to the DDC through modems, and HARP bearing diagnostic system. The sizing press diagnostic DDC gathers such data as rolling load, motor current, speed and sensor signals in the same sampling time as for the DDC for controlling. The collected data is arranged for each slab, and sent to the data preserving and analyzing computer. This method has made it possible to collect data at high speeds and preserve large quantities of data.

The functions of these sizing press diagnosis techniques are shown below.

(1) Timing monitoring in which key data (speed, load, motor current, pressure, etc.) for the sizing press operation during width reduction is sampled and preserved for each slab, for possible trend control, or (in case of a definite existence of anomaly) for guidance to the operator.
(2) Torque monitoring in which various machines and equipment of the sizing press are operated during the stoppage of rolling, for sampling and preserving non-loading current for possible trend control.
(3) Bearing monitoring for diagnosing bearing abnormality at important locations such as main drive parts.

Table 2 shows the main sampling items described in (1) and (2).

The term "torque monitoring" refers to the trend control of torque by monitoring the non-load current of each piece of equipment, and is aimed at assisting with

Table 2 Output item of performance diagnosis of sizing press

No.	Output item
1	Press load
2	Impact drop value with main moter
3	Value of buckling
4	Pressure of anti-buckling roll
5	Pressure of pintch roll and hydraulic cylinder
6	Ampere of pintch roll motor and table motor
7	Speed of table and pintch roll at start point of press
8	Pressure of air brake by width reduction device
9	Position of width reduction
10	Speed of width reduction at start point of press
11	Value of position error by APC
12	Interlock
13	Condition of sensor
14	Sequence
15	Others

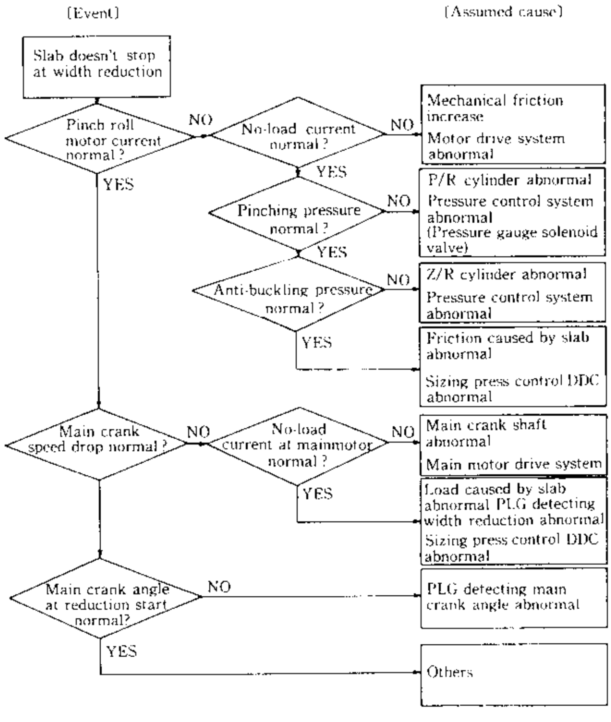


Fig. 10 Example of performance of diagnosis of sizing press

CBM (condition based maintenance) in both mechanical and electric systems. When the rolling operation is stopped for finishing-roll change-over, etc., the non-loading current of the motor driving units can be automatically sampled when the automatic start push-button (PB) is turned ON by the operator.

An example of timing monitoring is shown in **Fig. 10**. Through constant monitoring of the speed reference and feed-back of the transfer system when press load is generated during the operation of the constant press, the collision of the slab and the anvil can be predicted at an early stage. If, at this time, the current of the transfer system is not normal and when the current at the non-load time is on the increasing trend, it can be judged that some abnormality exists in the transfer system. In addition, if the pinch-roll pinching pressure has dropped, even though the current at the non-load time was normal, it is judged as an anomaly of the pinching pressure.

This system has sampled and preserved all data that is considered necessary for abnormality judgment, and it has a system configuration that permits simple additions of data if necessary. Therefore, this system not only detects abnormality generation but can also simultaneously pass judgment as to the causes of the abnormality which is usually not easy.

In this way, the diagnostic system successfully detects abnormalities at an early stage in the sizing press control which is known as the severest in timing limitations, and at the same time can judge the cause of abnormalities, thereby enabling smooth operations and the prevention of long downtime.

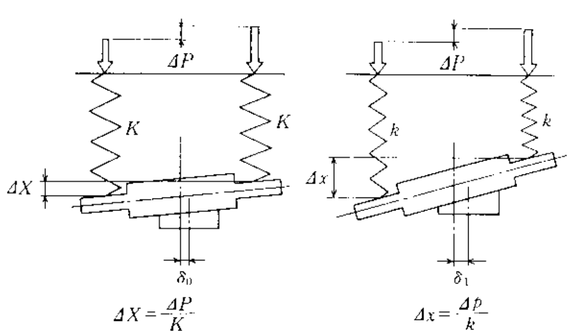
4 Performance Diagnosis Techniques for the Crown Control Mill

4.1 Mill Modulus of Crown Control Mill[7)]

The rolling mill has two kinds of stiffness characteristics, longitudinal stiffness and transverse stiffness. Longitudinal stiffness is represented by a numerical value obtained by dividing the sum loads during simultaneous screw-down operations at the OP side and DR side by the amount of screw reduction, and is ordinarily called the "mill modulus." Transverse stiffness is a numerical value obtained by dividing the differential load at the time of one-side screw down operations at the OP side and the DR side by the one-side screw reduction value, and expresses the unlikeliness of causing strip steering. The crown control mill has a drawback of excessively lowering the transverse stiffness when rolling is carried out, by shifting the intermediate roll in the roll axis direction.

Figure 11 shows relations of steering, mill spring difference, and steering amount with rolling load on the OP and DR sides. This was examined in the case of no shift and the maximum shift on rolls. Both cases assumes a generation of rolling load difference by some factors. The case (a) is where the transverse stiffness is high, the deflection difference small and the housing camber is within permissible values, thus showing a stable rolling condition.

The case (b) is a lower transverse stiffness, a large housing camber difference, and the steering is increas-



(a) Zero shift stroke (b) Max shift stroke

Fig. 11 Relation of steering and mill spring difference value with rolling load (OP side−DR side)

ing proportionately, thereby indicating an unstable rolling condition. This relation clearly indicates that in order to reduce the steering quanity during rolling with a large roll shift, it is important to reduce the rolling load difference which has been generated.

On the other hand, the screw-down system which governs the transverse stiffness of the rolling mill consists of many parts and bears the rolling load of about 1 500 t on one side. High load will not only generate compressive deformation and friction, but also result in camber deformation. As a result, stiffness drops due to a deterioration of flatness and accuracy, and longitudinal stiffness between the OP side and DR side becomes unbalanced, thereby generating a differential load, even if screw-down is performed at the same quantity. In order to supress such steering generation caused by the rolling load difference, which is generated mainly because of a deterioration in the accuracy of the screw-down system of the crown control mill, it becomes necessary to monitor the fluctuation patterns of the rolling load difference, to enable diagnosis of the deteriorating parts and to restore facility accuracy at an early stage.

4.2 Diagnosis of Crown Controll Mill Spring's Abnormality

The mill housing is generally considered to be a spring model as shown in **Fig. 12**. If the screw-down rate is increased by ΔS, various parts of the mill develop elastic deformation, and the total deformation comes to equal $\Delta S'$. When the mill is assumed to be divided into various parts such as the housing, roll, screw-down system and bottom carriage, their respective spring moduli are denoted by K_H, K_R, K_S, and K_C, respectively, and the increment of the load and the displacement of the screw-down quantity are denoted by ΔP and ΔS, respectively, the mill constant K is expressed as

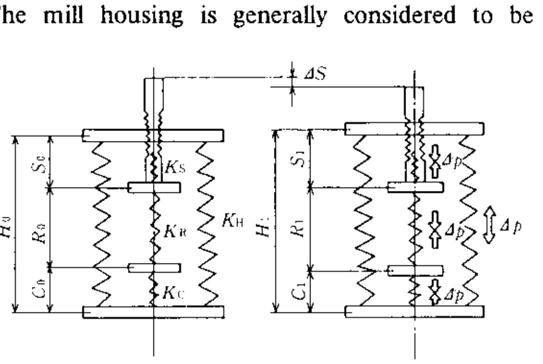


Fig. 12 Model of mill spring with screw down device

$$K = \frac{\Delta P}{\Delta S} = \frac{1}{\frac{1}{K_H} + \frac{1}{K_R} + \frac{1}{K_S} + \frac{1}{K_C}} \quad \cdots\cdots\cdots(3)$$

Ordinarily, the rolling mill has load cells and selsyn meters to measure screw-down quantities at its OP and DR sides, and permits measurement of the mill modulus independently on each side. The rolling mill also receives a differential load from the difference between both sides mill moduli, and can judge the deteriorated part from the fluctuation pattern of the differential load. **Table 3** shows the relation between the typical rolling load difference fluctuation pattern and the facility deterioration part which is foreseen. When rolling load difference is generated as a result of deterioration in flatness and accuracy of the screw-down system at the top and the carriage at the bottom, it is difficult to judge with certainty whether deterioration is at the top or at the bottom. In such cases, spring modulus K_S of the screw-down system will be as follows from the relation of Fig. 12:

$$K_S = \Delta P/[\Delta S - (S_1 - S_0)] \quad \cdots\cdots\cdots\cdots(4)$$

Table 3 Relation between mill spring irregular pattern and damage parts with abnormality of mill spring

Case	Mill spring irregular pattern		Damage parts
1	Rolling load(t) +/− ; Rolling load(t) (OP side + DR side)	Stable	Nothing
2	+ / −	Rolling load (Op side − Dr side) is increasing and decreasing	· Screw down device · Buck up roll carriage · Load cell · Pressure block
3	+ / −	Not stable at low rolling load	· Screw down device · Buck up roll carrige · Pressure block
4	+ / −	Hysteresis at zero rolling load	· Screw Nut · Screw
5	+ / −	Irregular of all zone	· Screw down block · Hydraulic jack · Pressure block

Therefore, the spring modulus of both-side screw-down system can be obtained by measuring the difference between S_1 and S_0. If a difference in spring moduli has occurred, it is judged that the deteriorated part is in the screw-down system at the top, and if no difference in spring moduli has occurred, it is judged that the carriage at the bottom is the deteriorated part.

The authors have developed rolling mill spring abnormality diagnosis techniques which determine whether the deteriorated part is in the top part or the bottom part, by monitoring the fluctuation pattern of rolling load difference from the mill moduli measurements at the OP side and DR side as mentioned above, followed by judging the primary deteriorated part and further by measuring the mill moduli.

An actual example of using the diagnosis techniques is reviewed. **Figure 13** shows an example of a slip outputted by the diagnosis equipment. The figure indicates the relation between the sum of rolling loads (OP side + DR side) at both OP and DR sides and rolling load difference (OP side − DR side) between both sides, and Fig. 13 (a) on the left corresponds to case 1 in Table 3,

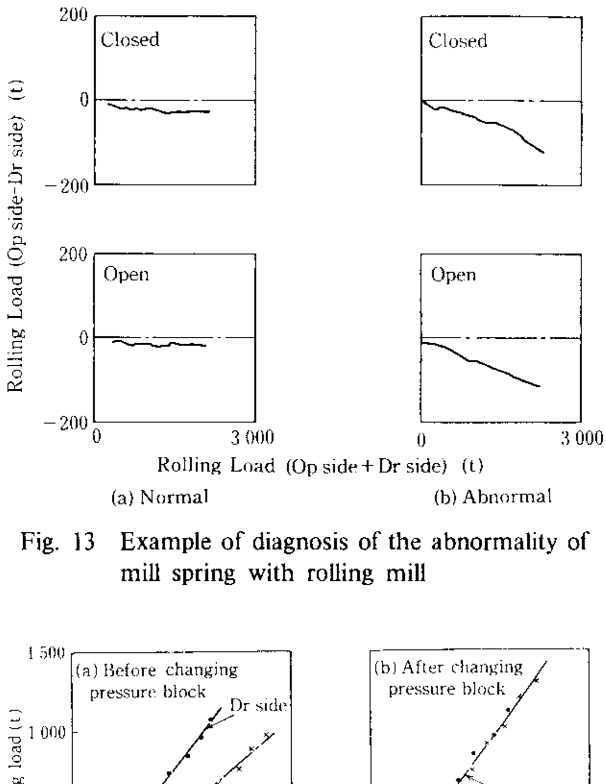


Fig. 13 Example of diagnosis of the abnormality of mill spring with rolling mill

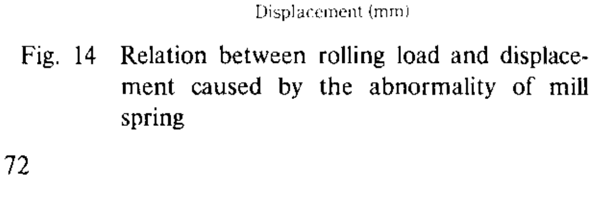


Fig. 14 Relation between rolling load and displacement caused by the abnormality of mill spring

which shows no abnormality. Figure 13 (b) corresponds to case 2, showing that there may be abnormalities. In the latter case, the spring modulus of the screw-down is then measured.

Figure 14 shows an example of a slip, indicating the spring modulus of the screw-down system before and after the occurrence of low stiffness. The figure on the left shows the spring constant at the time low stiffness is generated, indicating that there is an anomaly in the screw-down system. On the basis of the information from the diagnosis equipment, the pressure block of the screw-down system was replaced and the spring moduli difference of the screw-down system disappeared as shown in the figure on the right, showing that the difference was eliminated. On the pressure block, at the time of differential load abnormality, there was a space on the contact surface between the pressure block and the upper back-up roll chock, and it has been clarified that the poor flatness of the contact surface was the cause of the differential load abnormality.

Through daily use of the mill spring's abnormality diagnosis, it has become possible to prevent product quantity from dropping through long and frequent rolling stoppages due to unknown causes of camber. It also prevents excessive spending on repair work and over-maintenance which would otherwise be a necessary precaution to take.

5 Performance Diagnosis Techniques for the AJC Coiler

5.1 Necessity of Diagnosis Techniques

Since the coiler winds steel strip travelling at high speeds from the hot run table, several (3 to 4) blocker rolls (B/R) are provided at the external circumference of the mandrel to catch the leading end of the strip. From the time when the leading end of the steel strip reaches the mandrel till the strip is firmly wound around the mandrel, the blocker rolls push the steel strip against the mandrel as it rotates. While the steel strip is being pushed by the blocker rolls, its leading end is in strong contact with the blocker rolls, and scratches (top marks) occur on the strip every time the mandel completes a full revolution, because of the step which is created in that part of the steel strip. As a result, modification has been made to the blocker rolls so that every time the leading end of the steel strip completes a rotation of the mandrel, the blocker rolls are made to jump up, thereby evading the steel strip's leading end when blocker rolls push the steel strip against the mandrel. This is called automatic jumping control (AJC). In the past, this modification was applied only to very thick strip winding machines, but, in recent years, this modification is also being applied to sheet-strip winding machines, and the company has completed this modification for AJC on all its coilers.

When normal AJC is not carried out at the AJC coiler due to partial wear of the mechanical unit or a slight response delay of the hydraulic servo valve, quality deterioration due to top marks will occur, causing problems in the next process. In addition, since this AJC coiler forms highly-complicated mechatronic unit, it is considered difficult to maintain and control it in a technically normal state using conventional inspection methods. Therefore, the authors have developed the following diagnosis techniques simultaneously with modification for AJC:

(1) AJC diagnosis techniques, which automatically diagnose AJC accuracy on a real-time basis, can judge the winding quality of each coil and carry out real-time diagnosis on the performances of sensors and actuators that could cause faulty accuracy in the AJC.

(2) Machine accuracy diagnosis techniques which can easily diagnose, without special sensors, machine accuracy that will become the basis of AJC.

The above-mentioned two diagnosis techniques are outlined below.

5.2 AJC Diagnosis Techniques

The two main methods include one for detecting the motion of the blocker mill using hydraulic pressure of the blocker-roll (B/R) cylinder and one for using the position of B/R. In the case of very thick strip winding machines, detection by hydraulic pressure is possible, because the inertia of the B/R frame is great. However, the B/R frame of the thin strip winding machine poses difficulties in detection because of the B/R frame's low inertia, and the authors have adopted a method for detecting the position of the B/R.

AJC operates by detecting the leading end of the steel strip by laser, inputting the detection signals of the pinch roll from the pulse generator (PLG) and driving the hydraulic cylinder by way of the servo valve. The height position of the B/R with respect to the outer circumferential surface of the mandrel can be detected by

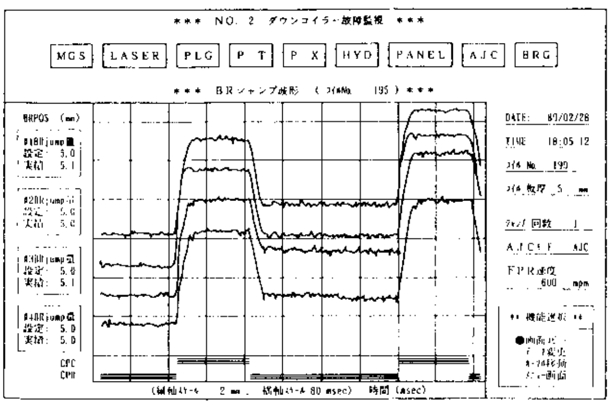


Fig. 15 Example of blocker roll position analysis with performance diagnosis of AJC

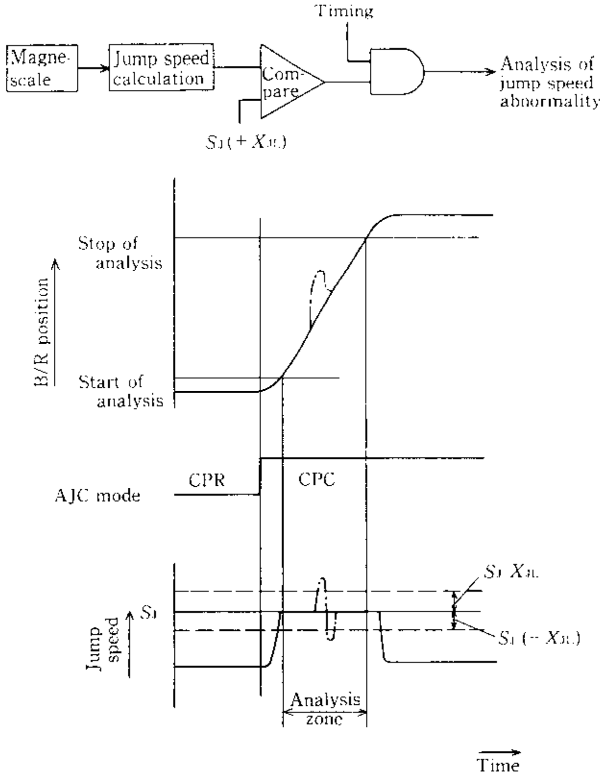


Fig. 16 Example of monitoring flow with jump speed abnormality by performance diagnosis of AJC

rotary magne-scale as the rotation angle of the arm.

Through this diagnosis equipment, jump speed, jump height, sensor performance and cylinder performance are diagnosed in real-time. An example of the display of the diagnostic equipment is shown in **Fig. 15**. For the AJC waveforms at each of the four blocker rolls, the ordinate represents height and the abscissa represents time, permitting determinations as to the quality of jump control at a glance.

On the basis of the concrete example of the diagnosis equipment, the AJC speed diagnosis will be explained below. **Figure 16** shows an example of AJC speed diagnosis logic. B/R position detection signals obtained from the magne-scale are inputted into the speed computation unit, and jump speed S is calculated from the condition of height changing. Abnormality determination is made in such a way that the multiplying speed reference value S_J multiplied by a predetermined allowable speed fluctuation value $\pm X_{JL}$ is set up as the allowable speed range, and this value obtained is compared with the calculated speed.

$$\left.\begin{array}{l} S_J(-X_{JL}) > S \\ \text{or} \\ S_J X_{JL} < S \end{array}\right\} \quad \cdots\cdots (5)$$

When the above-shown condition is generated, it is

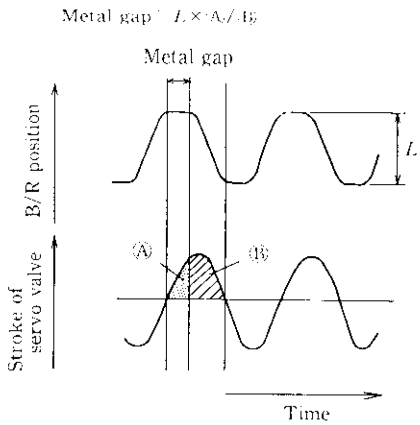


Fig. 17 Detection of metal gap with B/R flame

judged as an AJC abnormality, and the quality anomaly display for the winding coil concerned is outputted.

Since AJC diagnosis is carried out immediately after completion of each winding as mentioned above, the wound-coil with top marks is rejected and does not proceed to the succeeding process.

5.3 Machine Accuracy Diagnosis Techniques

In the AJC hydraulic servo system, the main cause for deterioration of response is wear of the mechanical equipment. To measure this wear, much labor and time was required, and therefore, accuracy diagnosis equipment was necessary to more readily measure wear.

When there is no wear of the mechanism, the opening of the servo valve and the position of the mechanism both change the sinusoidal waveforms, but when there is some wear, changes in the position of the mechanism behave as shown in **Fig. 17**. Namely, since a flat portion appears on the upper and lower parts of the waveform, judgments can be made concerning the existence of wear. Further, from the ratio between the quantity of oil (area A in Fig. 17) which flows into the cylinder during the period when a flat waveform is shown and the quantity of oil (area B in Fig. 17) which is required for moving the full-stroke fraction of the mechanism's position, the wear quantity can be obtained as a product of the area A/area B ratio and the machine position amplitude (L). Further, the oil quantities can be obtained by the integration values of servo valve openings.

Machine accuracy diagnosis using this principle has been applied to commercial steelmaking machinery to enhance efficiency of accuracy control work.

6 Conclusions

Of the diagnosis techniques which have been developed and applied by the authors with beneficial results, techniques used in the sizing press, rolling mill, table and coiler, i.e. the main facilities of the hot strip mill have been reviewed in this paper.

(1) Sizing press performance diagnosis techniques analyze width reduction and transfer control performances which give no time allowances, and also analyze bearings which constitute the foundation of mechanical equipment.

(2) Rolling mill spring abnormality diagnosis techniques monitor the rolling load difference which is generated by the deterioration of screw-down system accuracy at the crown control mill, and analyze deteriorated parts.

(3) Coiler AJC diagnosis techniques diagnose, in real-time, the accuracy and responsiveness of the jumping motion.

Development and application of all these diagnosis techniques have been promoted in line with equipment renewals, but for maintenance work of equipment which are more complicated, we are still largely dependent upon maintenance crew. However, for facilities which are turning into black-box-like entities, the quality of maintenance must be changed by the development of diagnostic techniques. In the future, the diagnosis techniques which have been so far developed and applied will be established securely at production sites. It is a future goal to construct an expert system which will approximate the judgment of skilled and experienced maintenance crews. As renewal to higher-grade facilities continues, the authors intend to develop total facility diagnosis techniques including those for product quality, and process diagnosis techniques having higher reliability.

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