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Present Status and Future of Equipment and Process Diagnosis Technologies

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Abstract:

Twenty years have already passed since Nippon Steel started developing the equipment and process diagnosis technologies and putting them to practical use. So far, the technologies have produced many desired application results in all the aspects of equipment, quality and operation, and are firmly fixed on the operating site. On the other hand, requirements for an effective operation and maintenance by a select few which fulfill equipment functions to the maximum are now increasing with a view to coping with an intensified cost competitiveness. It is considered, therefore, that the equipment and process diagnosis technologies will play an increasingly important role hereafter. In this paper, described are the contents of development on an off-line/on-line diagnosis system and some examples of diagnostic results made clear by the equipment and process diagnosis technologies, together with the direction these technologies should follow in the future.

1. Introduction

Recent tendencies of equipment use toward higher speeds, greater automation and nonstop operation has made people's abilities of supervision and judgement closer to their limits. As existing equipment becomes older, and as technological levels become lower because of decreasing number of people who are able to operate and maintain such sophisticated equipment, there has been growing concern about increases in total cost of production and maintenance.

Nippon Steel has developed equipment and process diagnosis technologies, and enhanced equipment capability in order to solve such problems and achieve maintenance modernization including improvement in equipment reliability and reduction of service costs. Also, Nippon Steel has greatly stabilized crucial production factors, such as quality and yield improvement, by combining equipment deterioration diagnosis with "process diagnosis technology", thus allowing ongoing evaluations of quality and production.

Fig. 1 shows Nippon Steel's transition from development to practical use of equipment and process diagnosis technologies.

Twenty years have passed since Nippon Steel began developing equipment and process diagnosis technologies. These two decades can be roughly broken down into two time periods.[1)]

The first period involved both basic and applications research as well as development of off-line diagnosis systems, which began in the first half of the 1970s.

In this initial period, we conducted experiments to corroborate

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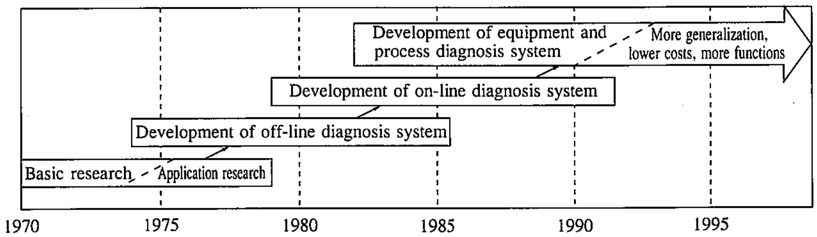

Fig. 1 Nippon Steel's transition of equipment and process diagnosis technologies

the symptoms of deterioration and the cause-and-effect relationship between detection parameters by equipment element; we also established equipment diagnostic logic as well as testing prototypes of diagnostic devices. During this phase, almost all diagnostic hardware and software were of the batch processing type, which of necessity, required continual operator intervention.

In the latter period, we popularized and expanded the software and hardware developed in the first part, and also gradually advanced the development of automatic diagnostic procedures.

The second period, which began in 1980, was the time during which we pursued enhancements in systems and process diagnosis. This period can be also classified into two halves: In the first half, we developed on-line diagnosis systems equipped with traditional simple, precise diagnostic functions, as well as automatic diagnosis technologies. Also, given the widespread use of personal computers, we enhanced the functions of our off-line diagnosis systems such as our batch-type equipment diagnosis data management systems which provided for efficient management of measurement data.

In the second half up until the present time, we have integrated the technologies established in the first half, adding to their sophistication as well as promoting their transferability. We offer diagnostic expert systems and early-troubleshooting guidance systems, in addition to developing inexpensive general-purpose diagnostic systems for further marketing and promotion.

We have previously reported on the first period.[2] In this paper, we outline the progress of equipment and process diagnosis technologies established after 1980 at the second period, and describe future directions in technological development.

2. Details of Development of Equipment and Process Diagnosis Technologies

2.1 Development of off-line diagnosis systems

We developed the basic algorithms and systems for equipment diagnosis by 1980. We then refined our algorithms (to improve accuracy and usability) in addition to developing equipment diagnosis systems suitable for either individual simple diagnoses or precise diagnoses. Typical examples are given below.

(1) Pencil type machine checker [3]

We developed a monofunction, ultracompact, fully portable pencil-type machine checker. It functions as a simple diagnostic device, designed to detect irregularities in rotating machinery by measuring vibration levels.

Two types of checkers are available: one for Lo range (which is designed to diagnose problems with rotating mechanisms, such as imbalance or misalignment), and the other for the Hi range, which is designed to detect ball bearing troubles.

(2) Portable condition analyzer for rotating machinery [4]

We developed a portable condition analyzer for precisely diagnosing problems with rotating machinery through accurate on-site analysis, combining digital signal analysis with processing of analog data (such as vibrational or acoustical data).

This is an all-in-one type condition analyzer equipped with a computing function for calculating abnormal characteristic frequencies of gears or ball bearings, as well as a field balancing logic function, thus allowing analysis, diagnosis, and repair all by itself.

(3) Diagnostic expert system for rotating machinery [5]

Based on the technologies and know-how which have been so far developed and accumulated, Nippon Steel developed a diagnosis expert system for rotating machinery which occupied the most important position in steelmaking equipment, in order to standardize and make equipment diagnosis more efficient through such an expert system (ES) which possesses expertise and knoe-how in the form of knowledge base, and performs diagnosis procedures without the help of any human expert. **Fig. 2** shows an example display of diagnostic results on the screen.

2.2 Development of on-line diagnosis systems [6]

Off-line diagnosis systems were functionally enhanced, featuring many improvements in equipment, quality and operation. However, on-line diagnosis were still required to avoid problems through early detection of abnormal conditions in either equipment or process. We began development of a hot rolling equipment diagnosis system at the Yawata Works in 1982, and since then have continued to pursue the development and application of such a system. The new cold-strip mill diagnosis system at the Yawata Works (introduced below) is a typical example.

2.2.1 Background of system development

We were concerned about our new cold-strip mill at the Yawata Works (hereafter referred to as the Yawata new cold-strip

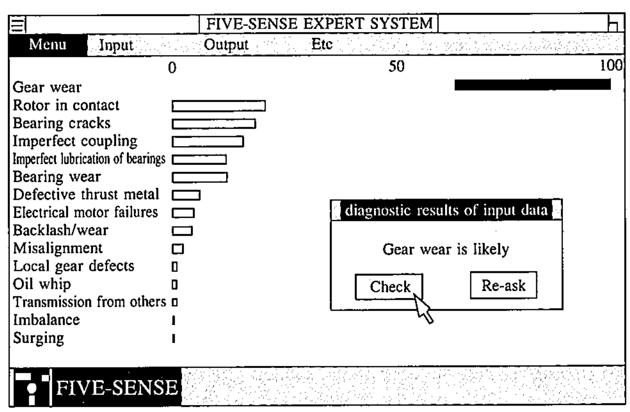

Fig. 2 Screen example of diagnostic expert system for rotating machinery (Diagnostic results display screen)

mill) which began commercial production in August, 1990. This high-performance, highly sophisticated mill is difficult to maintain and control, and the high complexity of its control requirements prevents us from keeping proper track of present situations as well as being able to take proper action in cases of abnormality (non-steady states). For these reasons, we have developed this system, into which we have integrated our equipment and process diagnosis technologies developed over the past twenty years.

2.2.2 System (hardware) and facility (software) configurations

Fig. 3 shows the system hardware configuration.The diagnosis system consists primarily of the process computers as shown above, which facilitate keeping track of production conditions, allowing actions to be taken with reference to a production schedule. Also, using an assortment of EIC (E: Electricity, I: Instrument, C: Computer) shared-network data for diagnostics has allowed not only high-level diagnosis, but has also minimized both the number of diagnostic sensors installed and signal wires connected. Moreover, sharing the CRT display with other functions (e.g., the tracking function) enables us to see diagnostic information and data by switching screens in case of abnormal conditions, thus improving the operating environment.

As can be seen in **Fig.** 4, the system is comprised primarily of the following three functions.

(1) Equipment diagnostics function which monitors deterioration of primary rolling equipment and determines the cause of errors

(2) Process diagnostics function which monitors quality errors, investigates causes of errors and determines actions to be taken

(3) Data analysis support function which supports gathering and analysis of error data

The above three functions are not independent, but rather are closely related to each other. These functions are outlined below.

2.2.3 Equipment diagnostic function

The equipment diagnostic function provides primary support to service engineers through the output of maintenance information such as equipment deterioration trend monitoring. This function can be roughly classified into the following subfunctions:

(1) Deterioration trend monitoring function

Optimum monitoring parameters are selected for diagnostics of each equipment. **Table** 1 lists the equipment to be managed, the number of monitoring parameters, and the number of scores.

(2) Failure trace function

This function traces self-diagnostic information of equipment (especially control equipment) in the order of time of occurrence

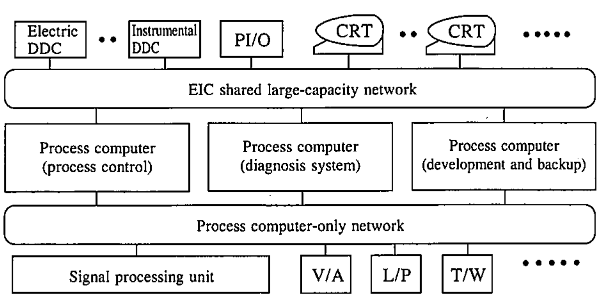

Fig. 3 Hardware configuration of the Yawata New Cold-Strip Mill diagnosis system

to verify when and what error occurred and when equipment was recovered from the error.

(3) On-line performance diagnostic function for control equipment

This function allows measurement of frequency responses from the oil pressure drop control system and the mill motor speed control system during actual rolling.

2.2.4 Process diagnostic function

The process diagnostic function primarily assists operators by suggesting courses of action for them to take. In this case, a gauge diagnosis system was established as a first step. (This gauge measures thickness accuracy at the center of the strip in the lengthwise direction.)

For diagnosis, the system is designed to gather the signals indicating rolling conditions, such as rolling force and tension and 600 kinds of signals indicating equipment status, such as current, at the intervals of 20 millisecond to 1 second. As illustrated in the flow of **Fig.** 5, the system gathers product gauges in a 20-millisecond cycle, providing detailed diagnosis if the upper and lower limits defined by product type are exceeded, and giving the operators guidance on optimum action to be taken.

The time frame, from the detection of an error until diagnostic information/advice is output, is on the order of 1 minute, which is less than the shortest production pitch time for cold rolling coils at the works, thus allowing action to be taken within the production process of an abnormal coil.

2.2.5 Data analysis support function

The data analysis support function supports data gathering and analysis in case of errors.

Previously, we installed charts or recorders, tracking critical signals in case of a certain error, and waited for the error to be repeated before analysis. However, one of the difficulties with

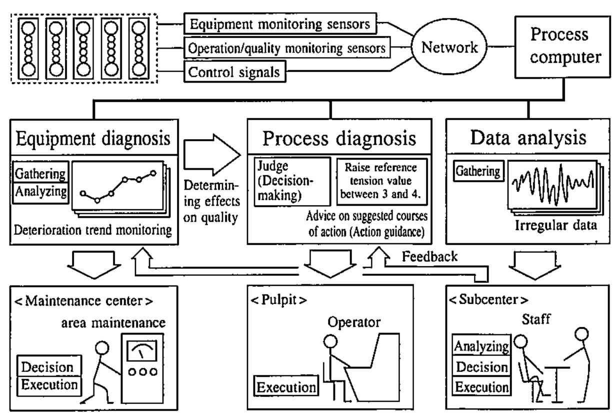

Fig. 4 Facility configuration of the Yawata New Cold-Strip Mill diagnosis system

Table 1 Equipment deterioration trend monitoring items

Equipment	Monitoring parameters	No. of points
Driving equipment	Vibration of rotating machinery Temperature of lubricating oil	71 42
Hydraulic/lubricating equipment	Pressure pulsation of pumps On-load time of pumps Temperature of tanks Null-current of servo-valves	5 5 3 10
Electric/instrumental equipment	Temperature of motors Laser power of strip speed indicators	65 6

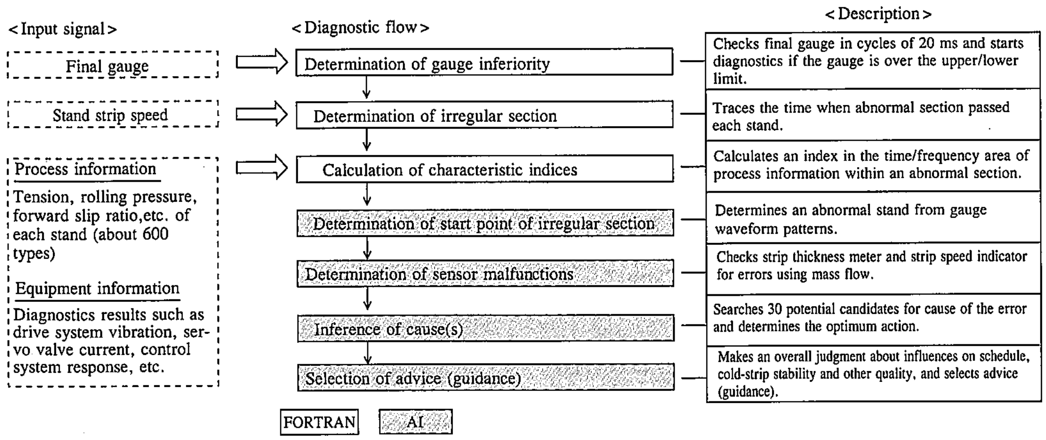

Fig. 5 Yawata New Cold-Strip Mill gauge diagnostic flow

this method is that our engineers must wait for such an error to be repeated, and frequently, sufficient data cannot be obtained even if an error is repeated because the number of signals that the chart/recorder can gather is restricted. The new system allows reliable gathering of error data by storing 600 types of the above-mentioned data in memory within a certain time and saving this data to disk — the data saved is that from two minutes before and two minutes after a preset abnormal triggering event occurs.

We also developed a function which is capable of analyzing the data gathered (both before and after the abnormal triggering event) using a variety of analytical functions through a man-machine interface. **Fig. 6** shows an example of the analysis screen. The analysis functions include: changing the axes of ordinate and abscissa (time axis) of displayed data, four arithmetic operations on the data, relative analysis and frequency analysis, etc.

This diagnosis system is effective at providing gauges with high accuracy and reducing fault times. The concept of a system containing a quality diagnostic function (obtained by expanding conventional equipment diagnostic functions) has shown us a promising future direction in new on-line diagnosis system design.

2.3 Generalization and expansion of on-line diagnosis systems

On-line diagnosis systems have shown great results such as reduction of fault time and stabilization of quality but almost all of the systems currently available are custom-made and thus inflexible and expensive because of the process computer requirements. These factors have hindered the popular acceptance of such systems. In recent years, with personal computers and peripherals having shown remarkable improvement in both signal processing speeds and enhanced storage capacities, they now outperform dedicated process control computers of several years ago. Accordingly, we have promoted downsizing of diagnostic systems equipped with conventional diagnostic functions since 1990. Additionally, we have successfully accomplished the easy construction of flexible, versatile equipment diagnostic systems by grouping the diagnostic features into functional packages (See **Fig. 7**).

The systems are furnished with both the equipment diagnostic and data analysis support functions of the Yawata new cold-strip diagnosis system mentioned above. The system configuration on the same LAN allows information to be seen on the same CRT.

The equipment diagnostic function is expanded/enhanced in sequence and now diversified as listed in **Table 2**. This allows selection of an optimum diagnostic method in consideration of any number of conditions, such as equipment importance, diagnostic accuracy and cost, etc. In particular, most conventional diagnosis systems focus their performance primarily on vibration sensors requiring installation of new sensors. Now, however, the method of effectively utilizing existing signals has expanded, e.g., macro diagnostics of the whole system to be diagnosed, like current diagnostics that use motor current to monitor a mechanical drive system or like an on-load ratio diagnostics that uses the on-load time of a hydraulic pump to monitor a hydraulic system.

Also, providing equipment diagnostic information to another system via a gateway allows analysis on the operational side. In other words, we have succeeded in establishing a foundation for improving the activities of service engineers and operators who can analyze shared information on equipment, quality and operation.

Generalization and expansion in terms of both hardware and software have resulted in a remarkable reduction in cost.

These General-purpose diagnosis systems have been widely employed in the processes ranging from blast furnaces to surface treatment at our works. Also, about 30 such systems have been installed and are being used in domestic and overseas steel companies, and in other industrial fields such as cement and chemical-related companies.

3. Effective Examples of Equipment and Process Diagnosis

As mentioned above, both the off-line and on-line diagnosis systems have been enhanced in performance and have proven effective not only in forecasting equipment irregularities but also helping to take action against quality errors. Effective examples of diagnostics are described below.

3.1 Chatter mark diagnostics for cold-strip mill[7]

Striped non-uniform luster (unmeasurable in thickness) is referred to as a chatter mark, which occurs regularly on the surface of a strip at pitches of several to several tens millimeters in the lengthwise direction in either the whole width or a partial range. Generally, chatter marks are caused by vibration of strip mills. As illustrated in **Fig. 8**, strip mills are complicated structures, and have many sources of vibration, thus causing chatter marks in a variety of forms.

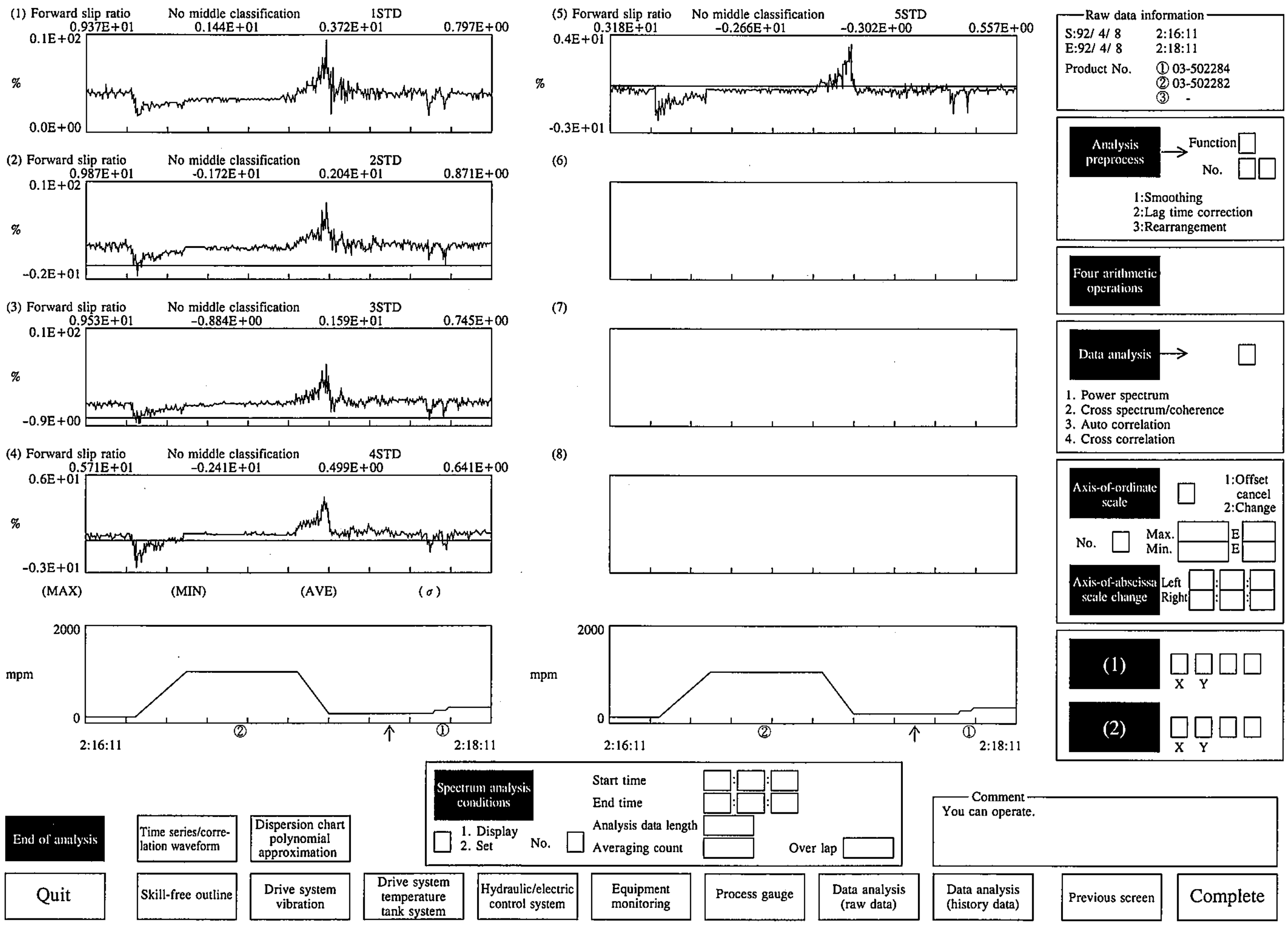

Fig. 6 Display example of data analysis screen

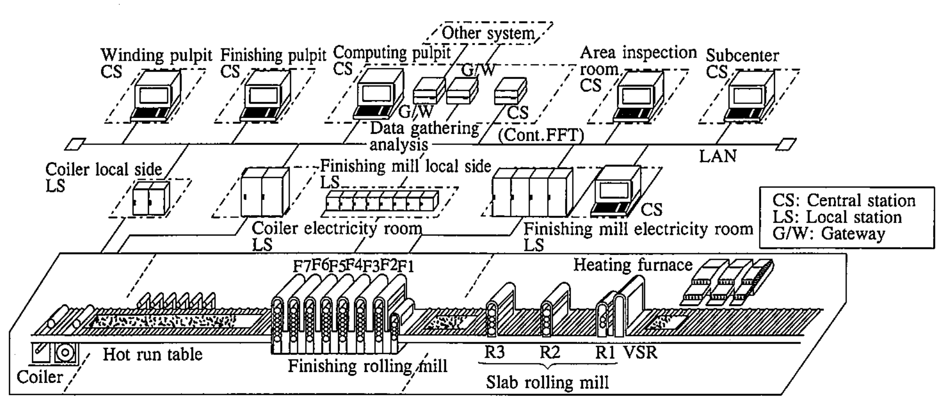

Fig. 7 General-purpose equipment and process diagnosis system configuration (Hot rolling process)

Because of chatter marks with a pitch of 34mm, we tried replacing both the rolls and spindles of the No.3 cold-strip mill at the Nagoya Works of Nippon Steel, but we found no improvement and therefore analyzed the cause of these chatter marks. As a result of measuring the vibration of the work roll bearings, we were able to detect the vibration corresponding to the chatter mark pitch (See **Fig. 9**); however, the vibration frequency did not match the forced vibration frequency of each mill component. Therefore, we considered the possibility that the uneven grinding of rolls could cause such vibration. We measured the vibration when the roll grinder was in actual use, and thus succeeded in detecting the vibration level matching the chatter mark (See **Fig. 10**).

Through further detailed analysis, we determined that cracks in the bearings of the roll rotating portion of the roll grinder were at fault. By replacing the cracked bearings with new ones, the vibration of the roll grinder was reduced and the chatter mark eliminated.

3.2 Blast furnace status diagnosis[8]

The blast furnace has an internal temperature of 1500°C or higher, and can thus be considered as a black box. It is therefore equipped with various sensors to estimate its internal status. An internal phenomenon referred to as hanging which disables material downloading may occur on extremely rare occasions. This phenomenon is one of the reasons which exacerbates the furnace status. However, there is a problem that such a phenomenon cannot be detected directly from the information relayed by the temperature and pressure sensors until a considerable amount of material remains there for a long time.

To solve such a problem, we installed an AE sensor at the outer end of a short sonde for gas analyzing as well as a detecting probe inserted inside the furnace as shown in **Fig. 11**, in order to detect dummy AE produced by the friction between material and the sonde; in this manner we were finally able to know where and how the material remains (See **Fig. 12**).

As another means of stabilizing the furnace status, we also developed a determination method, using the difference in signal arrival time by installing an AE sensor at both ends of a cross sonde to detect where the material drops.

3.3 Pump on-load ratio diagnosis

The above two examples show the effects of precise diagnosis. This section introduces an example of pump on-load ratio diagnosis, as an example of macro diagnosis which we have recently enhanced.

We have conducted pump on-load ratio diagnosis for the hydraulic equipment of a finishing roll balancing system at the hot rolling mill of the Yawata Works. **Fig. 13** shows an on-load ratio trend management graph in cases of abnormal condition. Our service engineer inspected the oil pressure system because an alarm was indicated. He found that oil was leaking from the sleeve inside the cylinder of the accumulator, and succeeded in repairing it immediately to avoid line shutdown.

4. Future Directions of Equipment and Process Diagnosis Technologies

This paper has described the present situation of equipment and process diagnosis technologies.

Table 2 Functions of general-purpose equipment and process diagnosis system

Diagnostic functions			
Equipment diagnosis	Drive system	Vibration diagnosis	Simple diagnosis
			Precise diagnosis
		Current diagnosis (starting, stable, different current)	
	Hydraulic/pneumatic system	Detection of deterioration of hydraulic equipment (pump on-load ratio)	
		Detection of deterioration of hydraulic unit (pressure pulsation)	
		Diagnosis of cylinder stroke time	
	Control system	Hydraulic servo system diagnosis	
		Diagnosis of null current	
		Diagnosis of vibration of hydraulic piping	
		Diagnosis of drop of oil pole	
	Others	Temperature diagnosis	
		Pressure diagnosis	
Data analysis support		Automatic gathering of fault data	
		General-purpose data analysis	

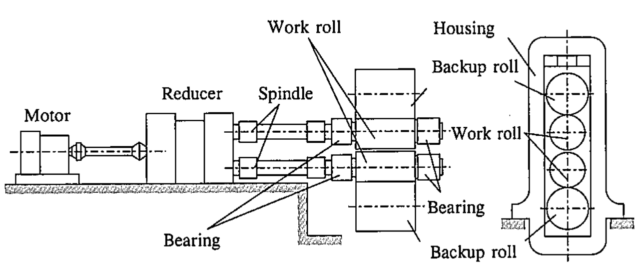

Fig. 8 Structure of cold-strip mill

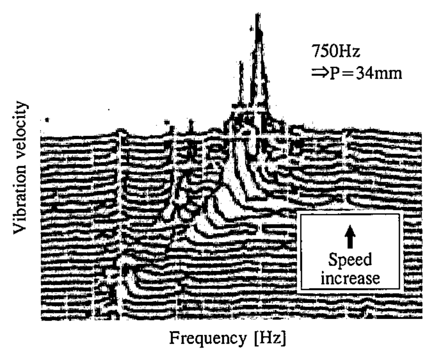

Fig. 9 Vibration of bearings of work roll

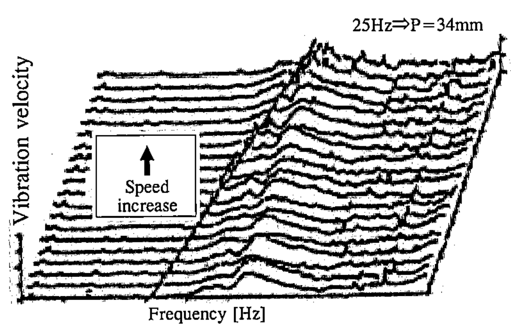

Fig. 10 Vibration of roll grinder in operation

However, there are still many improvements to be made, such as diagnostic accuracy and expansion of the range of target equipment, and thus technological refinement will continue.

Our future directions are described below, including current work in progress.

4.1 Further expansions in process diagnosis

Process diagnosis has been improved lately but some people say that its development is only limited to one of steelmaking processes such as cold rolling. Basically, equipment and process diagnosis have, so far, employed a variety of sensor information to diagnose both equipment failures and operational problems. In addition to the problem of diagnostic accuracy, however, restrictions on where sensors are installed and how many sensors can be installed within given cost limit accurate diagnosis of equipment failures and operational problems. On the other hand, another approach is to try to solve such problems using simulation technology; the disadvantage of this approach, as compared to on-line diagnosis, is that the complexity of analysis models require a long analysis time. To overcome these problems we have been attempting to further expand process diagnosis by providing a fusion of traditional equipment and process diagnosis technologies, with simulation technology (See **Fig. 14**).

4.2 Expansion of application of diagnosis technologies

Existing diagnostic techniques are insufficiently accurate because they are difficult to apply to low-speed rotating machinery, and furthermore, they are not capable of diagnosing cracks on the dedendum of a gear. Basically, these diagnostic technologies are limited to operating states at a constant speed and thus cannot be applied to slab rolling at a hot rolling mill. In other words, the technologies are limited to a narrow equipment range. We have many technological problems to be solved, and so we will expand the application of our diagnosis technologies through continual improvement in future.

In addition, we plan to improve system functions by packaging the diagnostic logic with clear diagnostic items on general-purpose diagnosis systems, such as developed logic or those which have successfully undergone troubleshooting to clarify the cause of an error, as well as to continue to reduce diagnosis system costs.

5. Conclusions

This paper has described both the present status as well as the future of Nippon Steel's equipment and process diagnosis technologies.

It is clear that operation and maintenance specialists will continue to decrease in number in the future. An urgent problem is to preserve the techniques, skills, and sophistication of these specialists.

It is necessary to improve equipment function as well as to allow efficient operation and maintenance with fewer staff by changing from the traditional experimental and qualitative approach to a scientific and quantitative one. The equipment and process diagnosis technologies are becoming increasingly indispensable for achieving this goal.

Consequently, we will improve and enhance our equipment and process diagnosis technologies over those in conventional frameworks.

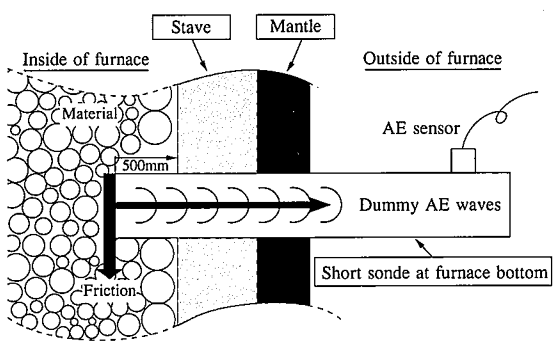

Fig. 11 Basic principles of blast furnace status diagnosis

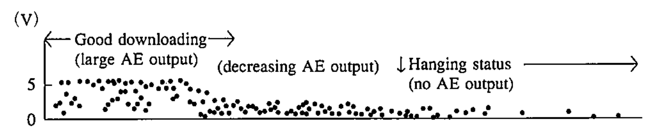

Fig. 12 AE level transition of short sonde

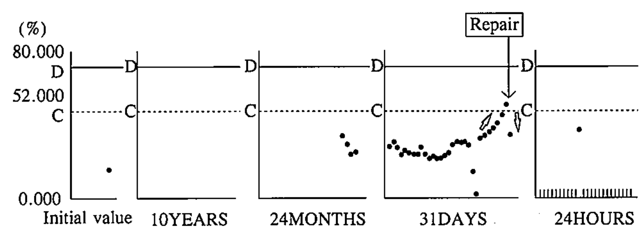

Fig. 13 Pump on-load ratio trend monitoring graph

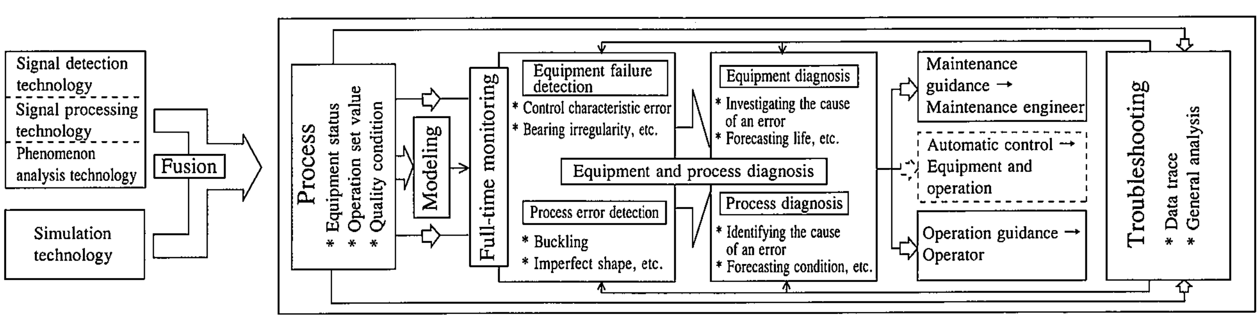

Fig. 14 Fusion of equipment and process diagnosis technologies, and simulation technology

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