KAWASAKI STEEL TECHNICAL REPORT
No.24 (April 1991)

Progress in Equipment Diagnosis Techniques at Kawasaki Steel Corporation

Akira Ichihara, Satoshi Kasai, Hiromasa Yamamoto, Masafumi Tanaka, Hiroshi Fusegawa, Yushi Miyake

Synopsis :
This paper reports on the development and application of Kawasaki Steel's equipment diagnosis techniques. The equipment control in the iron and steel industry, where production heavily depends on equipment performance, has been changing largely in the form of modernization of equipment with a view to cope with highly sophisticated quality control and multifarious production. In terms of assurance of equipment for desired production, an equipment control technology backed up by engineering has been more strongly demanded. Developed to bring the capacity of equipment into full play are the machinery/equipment diagnosis techniques used as predictive maintenance and process diagnosis techniques for product quality assurance. The above two techniques are being further developed into an equipment control system techniques. Since there are many phases where human judgement is needed, attention has been paid to the role of human support for highly efficient and sophisticated maintenance work in order to establish an equipment diagnosis techniques.

The body can be viewed from the next page.

Progress in Equipment Diagnosis Techniques at Kawasaki Steel Corporation*


Akira Ichihara
Staff Assistant General Manager, Maintenance Technology Sec., Chiba Works


Satoshi Kasai
Staff Manager, Maintenance Technology Sec., Chiba Works


Hiromasa Yamamoto
Staff Manager, Maintenance Technology Sec., Chiba Works


Masafumi Tanaka
General Manager, Maintenance Dept., Chiba Works


Hiroshi Fusegawa
General Manager, Equipment Technology Dept., Chiba Works


Yûshi Miyake
General Manager, Equipment Dept., Mizushima Works

Synopsis:

This paper reports on the development and application of Kawasaki Steel's equipment diagnosis techniques. The equipment control in the iron and steel industry, where production heavily depends on equipment performance, has been changing largely in the form of modernization of equipment with a view to cope with highly sophisticated quality control and multifarious production. In terms of assurance of equipment for desired production, an equipment control technology backed up by engineering has been more strongly demanded. Developed to bring the capacity of equipment into full play are the machinery/equipment diagnosis techniques used as predictive maintenance and process diagnosis techniques for product quality assurance. The above two techniques are being further developed into an equipment control system techniques. Since there are many phases where human judgement is needed, attention has been paid to the role of human support for highly efficient and sophisticated maintenance work in order to establish an equipment diagnosis techniques.

1 Introduction

With its role responsible for sound operation and production, the equipment control in the steel industry has undergone notable changes with the progress of the industry particularly known for its capital-intensiveness. In the recent worldwide fierce competition that came after the high growth period of the industry and the unstable economic periods of the oil crises, requirements for improvement have become increasingly severe in all aspects including quality, cost and delivery.

At Kawasaki Steel, new production facilities have been installed to cope with growing needs of higher grade products including automotive sheets, and furthermore process continuation and synchronization have been made to improve production costs and lead time. Automation and labor-saving techniques for an increase in productivity have had great impact on the equipment control technology for keeping or improving the functions and performance of equipment.

Meanwhile, functional advances made in realizing production diversification have complicated control even further, and this, together with physical distribution requirements, has come to require a guarantee for higher operational stability.

To effectively conduct sophisticated equipment control with a small number of personnel under these conditions, the following are required: (1) accurate monitoring function of equipment, (2) equipment control using scientific and engineering approaches to assured function and performance of equipment, (3) theoretical approach based on failure analysis and equipment control using analytical models of cause-and-effect relationship between equipment condition and product quality, (4) high-level computerization in equipment control that permits information collection, analy-

* Originally published in *Kawasaki Steel Giho*, 22(1990)2, p. 69–73

sis judgment, and evaluation, and (5) education and training of key personnel who can pass high level judgment in equipment control.

This paper describes the development and application of Kawasaki Steel's equipment control systems and equipment diagnosis techniques, and also presents future trends.

2 Concept of Equipment Control and Diagnosis Technology

2.1 Concept of Diagnosis Technology

The concept of equipment diagnosis technology is shown in **Fig. 1**. The equipment control in production has the two main functions. The one is for performing stable operation by early detection or prevention of abnormalities and troubles with equipment, and the other is for producing good products while assuring equipment performance by keeping the accuracy of equipment.

At its initial stage, the role of equipment maintenance was limited to maintaining and, when possible, improving the equipment in performance and function at levels suited to the existing production and operation standards (Fig. 1 "Role of Equipment Management"). Recently, however, its role has seen a great transformation as the industry came to adopt innovative changes in production structures and processes characterized by new equipment and process continuation and synchronization, automation and labor saving (Fig. 1 "Restructuring of Production Process"). All this was to meet growing needs for quality sophistication, and timely delivery spurred by rising product and cost competitiveness, and quality improvement.

These innovations constantly simulate equipment control activities toward higher grade and accuracy as they maintain unmanned or automated equipment at

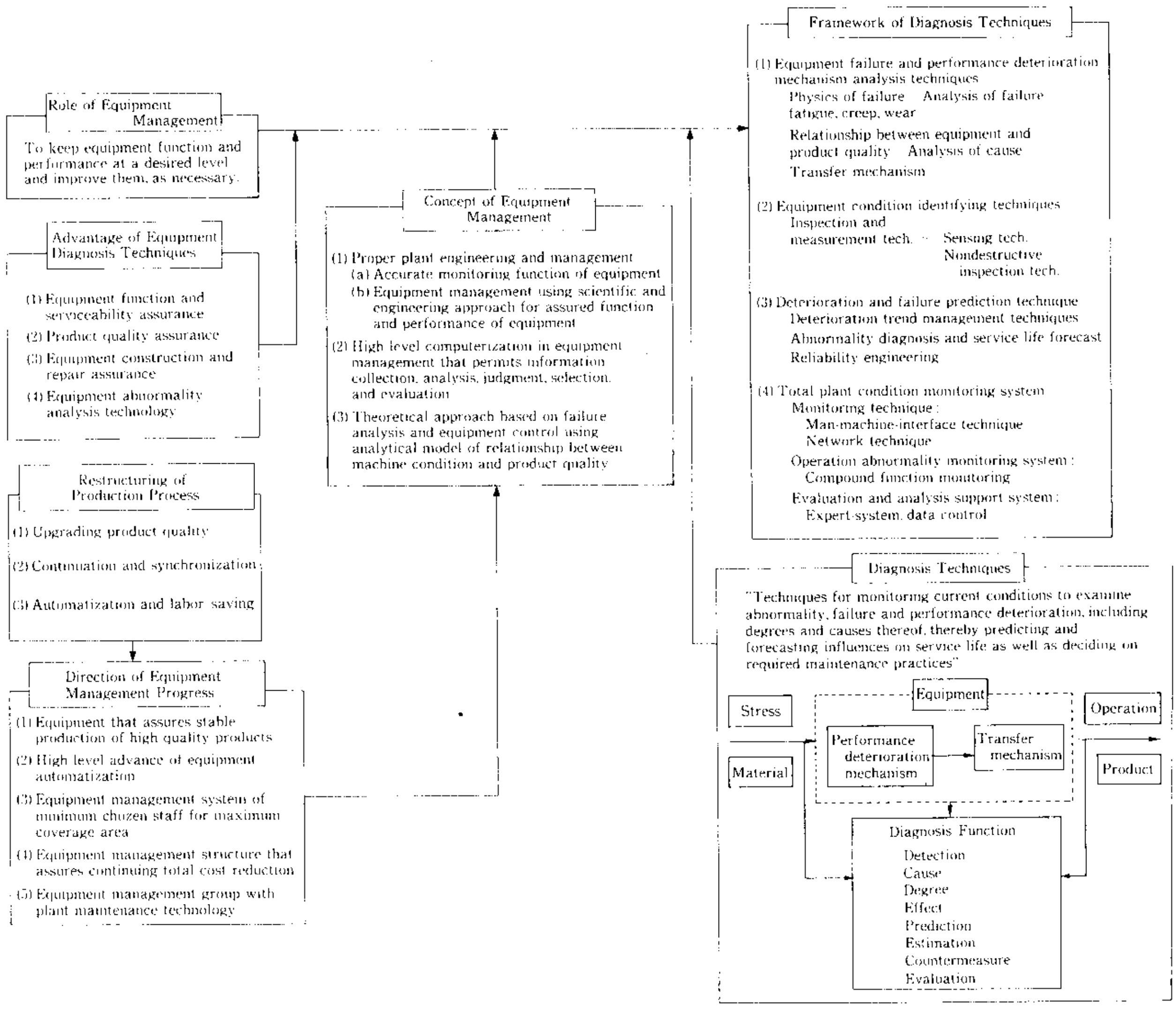

Fig. 1 Concept of diagnosis technology

stable production of high grade products (Fig. 1 "Direction of Equipment Management Progress"). Therefore, equipment control is strongly required to have production equipment control function. These functions include an accurate monitoring of equipment conditions, an assurance of equipment function and performance based on engineering background such as failure analysis, equipment control using cause-and-effect correlation models of quality and equipment, high-level computerization in equipment control that permits information collection, analysis, judgment, selection, and evaluation in equipment control, and structuring of equipment control support system which permits a wide coverage of equipment by a limited number of able personnel (Fig. 1 "Concept of Equipment Management").

In equipment control, equipment diagnosis techniques are defined as "techniques for monitoring quantity of current state of equipment to examine abnormality, failure and performance deterioration, including degrees and causes thereof, thereby predicting and forecasting influences on future service life as well as deciding on required maintenance practices"[1] (Fig. 1 "Diagnosis Techniques"). Therefore, assuming an equipment is regarded as having a function to control production facilities, the concept of equipment control would then have to be reconsidered and equipment diagnosis techniques would have to include the following requirements:

(1) establishment of techniques for assuring equipment function and serviceability, (2) establishment of techniques for assuring product quality, (3) establishment of techniques that will assure execution of work in equipment construction and maintenance, and (4) establishment of techniques for analyzing equipment troubles and abnormalities (Fig. 1 "Advantage of Equipment Diagnosis")

2.2 History of Equipment Control and Diagnosis Techniques

The history of equipment control in Japan and at Kawasaki Steel is given in **Table 1**.

In the history of equipment control in Japan, the 1950s are the age of preventive maintenance introduced from the United States. Productive maintenance took root in the 1960s, and the Japanese style productive maintenance by all members (total productive maintenance: TPM) began in the 1970s. It was in this period that Chiba Works of Kawasaki Steel was commended by the Japan Plant Maintenance Association for its excellent preventive maintenance. However, time-based maintenance continued until the 1970s and the philosophy of predictive maintenance, i.e., condition-based maintenance began to take root in the 1980s. This predictive maintenance has made it indispensable to develop and use equipment diagnosis techniques for diagnosing the condition of equipment.[2]

At Kawasaki Steel also, the productive maintenance system was introduced in the 1960s. In the 1970s, the company came to stress equipment stabilization, higher efficiency, quality assurance and cost reduction, with particular emphasis on its unique maintenance for product quality assurance, i.e., quality maintenance for products was promoted in addition to drastic reformation of the equipment maintenance system for enhancing the equipment maintenance department and increasing the efficiency of this department. Around this time, examinations were made as to the development and introduction of equipment diagnosis techniques and equipment maintenance and management systems. In the 1980s, requirements for product quality became diversified with equipment turning complex. Under these circumstances, the needs for higher product grades and shorter delivery time increased and attention was paid to the assurance of the whole production line, i.e., equipment serviceability and product

Table 1 History of plant management

	~1950	1950's	1960's	1970's	1980's
History of plant management in Japan	Breakdown maintenance	Preventive maintenance	Productive maintenance	Total productive maintenance	Predictive maintenance
Type of maintenance		Time-based maintenance		Condition-based maintenance	
Kawasaki Steel's history		Establishment	Introduction of concept for productive maintenance	Reformation of maintenance organization Development of quality maintenance for product Introduction of diagnosis technique Planning of equipment control system	Development of diagnosis technique and equipment control system Development of total quality maintenance

quality assurance. For the former, efforts were made to clarify the failure mechanism, to predict abnormalities and to develop forecasting techniques. For the latter, the relationship between equipment and product quality was clarified and techniques for early detection of abnormalities and prompt actions against abnormalities were developed. On-line diagnosis and automatic diagnosis were carried out for the principal parts of important equipment. Further, for parts which inevitably require manual operation, the efficiency of inspection and diagnosis operation was increased by developing handy terminals for equipment maintenance control systems and expert systems. In addition, training for raising the technical abilities of maintenance personnel was conducted in parallel with the development of these systems.

3 Framework of Diagnosis Techniques, Development and Application

3.1 Framework of Diagnosis Techniques

Diagnosis techniques are composed of the techniques for analyzing the mechanism leading to the failure of equipment and product quality, those for identifying the quantitative indicator of equipment performance, and those for predicting the process in which the quantitative indicator of equipment performance comes to equipment failure or product deterioration. The systems implementation of these techniques has been aimed at.

As for the techniques for analyzing the mechanism of equipment failure and performance deterioration, it is important to clarify the physics of failure, such as fatigue, creep and wear that result in equipment troubles, by applying it to actual phenomena. As for deterioration in product quality, it is necessary to analyze various operational phenomena of production equipment into the cause-and-effect relationships between quality producing conditions and equipment performances, and to clarify a transmitting mechanism by which changes in quality characteristics can be shown by the quantitative indicator of equipment performance. Especially, the field related to quality has a close bearing with the clarification of operational know-how as an important area interdependent with the progress of production technology. The techniques for identifying the quantitative indicator of equipment performance are identical to replacing manual inspection information on equipment with the information from sensors. The development of highly reliable sensing techniques and nondestructive inspection techniques that are beyond the five senses of man is the key.

The techniques for predicting failure and deterioration are the combination of the above techniques, and consist of the techniques for controlling the deterioration tendency of the quantitative indicator of equipment performance, those for diagnosing abnormalities, those for predicting service life, and further those for passing judgment based on reliability engineering.

3.2 Development and Application of Diagnosis Techniques

In developing and applying diagnosis techniques, importance has been attached to (1) development of diagnosis techniques for failure prediction, (2) development of diagnosis techniques for performance assurance, (3) installation of on-line diagnosis systems in main equipment, (4) development of diagnosis instruments, and (5) education of human resources and training. The history of diagnosis techniques at Kawasaki Steel is given in **Table 2**.

The diagnosis techniques for failure prediction in mechanical equipment include the study of bearing designed for rotating machines analysis according to the vibration method, followed by the diagnosis of slide bearing according to the AE method, the diagnosis of low-speed rotating machines[3], and the diagnosis of plunger pumps. The diagnosis techniques for failure prediction in electrical equipment include an insulation deterioration diagnosis of BN cables, on-line meggers for DCM, insulation diagnosis of rotating machines, and thyristor checkers.

The diagnosis of leakage and performance efficiency of oil and hydraulic systems has long been conducted as the diagnosis techniques for performance assurance, however recent diagnosis techniques include the mold oscillation performance diagnosis and break-out prediction in continuous casting, performance diagnosis of hydraulic AGC systems in rolling mill, diagnosis of hydraulic automatic jumping control (AJC), diagnosis of sizing press performance in hot rolling, analysis of chatter and gear marks of rolls, and diagnosis of cutting performance during machining in pipe mills, which have a direct influence on production, product quality and yield.

The installation of diagnosis systems in important equipment corresponds to the adoption of continuous and synchronous processes. In continuous and synchronous equipment, an equipment trouble results in a wide range of disturbance in process and quality abnormality in upstream processes cause a large quantity of non-conforming products. To ensure highly stable operation, therefore, the existing diagnosis techniques have been computerized on the occasion of construction and revamping of plants.

At Chiba Works, diagnosis systems were installed first in the No. 3 continuous casting machine[4] and then in the continuous annealing line[5], the tandem cold rolling mill[6], the continuous pickling line and the hot strip mill. The application of these diagnosis systems to the blast furnaces and the sintering plant is being carried out. At Mizushima Works, diagnosis systems were installed first in the continuous annealing line[7], and then in the continuous casting machines, the hot strip

Table 2 Diagnosis techniques at Kawasaki Steel

Items	1970's	1980's	
	2nd half	1st half	2nd half
Development of diagnosis technique for failure prediction	· Diagnosis of roller and motor by vibration method · Crack depth measurement · Stress analysis of structure · Insulation diagnosis of high voltage cable · Diagnosis of grease system	· Diagnosis of low speed rotating machine · Diagnosis of oil film bearing by AE method · Analysis of gas pipe corrosion · Analysis of mill spindle torque · Insulation diagnosis of rotating machine	· Diagnosis of chimney and torpedo car by thermoview · Diagnosis of hydraulic valve by vibration analysis · Diagnosis of hot-run roller by current analysis · Diagnosis of plunger pump
Development of diagnosis technique for performance assurance	· Performance and diagnosis of oil and hydraulic system	· Analysis of reel rolling · Diagnosis of hydrostatic bearing · Diagnosis of hydraulic AGC system · Diagnosis of cutting performance during machining · Measurement of roll load at CC · Strip gage analysis · Detection of nozzle clogging	· Non-touched measurement method for checking alignment · Mold oscillation performance and break-out prediction at CC machine · Performance diagnosis of A.J.C. · Analysis of chatter and gear mark of roll · Performance diagnosis of H.A.R.P. · Performance diagnosis of welder
Development of instrument for diagnosis	· Vibration analyzer · Roll gap sensor for CC	· Portable vibration analyzer · Handy vibrometer · Vibrometer for on-line system	· AE analyzer · Expert system for rotating machine · Local station for LAN system · Handy terminal for maintenance management system · On-line megger for DCM · SCR checker · SCR BO/BD detector
Introduction to main plant of on-line diagnosis system		· Continuous casting machine · Continuous annealing line · Tandem cold rolling mill	· Continuous pickling line · Hot strip mill · Sintering plant · Blast furnace · Electrolytic galvanizing line · Continuous galvanizing line · Wire rod mill
Education and training		· Monthly meeting for introduction and spreading · Established organization	· Education and training for key person · Concentrated diagnosis training by using test machine

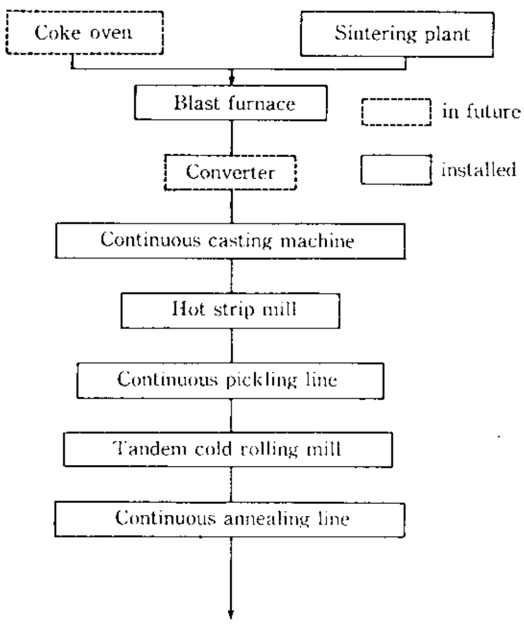

Fig. 2 Main process and introduction of equipment diagnosis system at Chiba Works

mill, the tandem cold rolling mill, the continuous galvanizing line, the electrogalvanizing line, and the wire & rod mill. The on-line equipment diagnosis systems installed at Chiba Works are shown in **Fig. 2**, and main diagnosis items are given in **Table 3**.

The company has developed a portable vibration analyzer, acoustic emission (AE) analyzer and thyristor BO/BD detector as individual analysis apparatus, and local stations for LAN systems and meggering devices for DC machines, an expert system for rotating machine diagnosis, and handy terminals for equipment maintenance and management systems.

The framework of equipment diagnosis techniques requires high-level engineering knowledge and manufacturing know-how, and the practical application of these techniques involves innovations in equipment control. For this reason, it is difficult to put equipment diagnosis techniques into practical use without education or training of the personnel. Therefore, the company has adopted a training system of persons who are expected to play an important role in equipment control. In this system, experts are trained through rotations between

Table 3 Major items in on-line diagnosis systems

Item \ Plant	Sintering Plant	Blast Furnace	Continuous Casting Machine	Hot Strip Mill	Continuous Pickling Line	Tandem Cold Rolling Mill	Continuous Annealing Line
Failure prediction	· Blower, pump · Vibrating screen · Belt conveyer · Lubricant system	· Bell-less device · Conveyor pulley · Hydraulic system · Tuyere · Blower, pump · Break-out prediction	· Lubricant system · Hydraulic oil system level · Grease system	· Mill drive · Pinion stand · Mill motor, pump · Fan · Mill spindle · Hydraulic & Lubricant systems	· Looper separator · Tension device · Fan, blower · Hydraulic oil system	· Mill drive · Mill motor · Pump, reel · Hydraulic & Lubricant systems	· Hearth roll · Fan, blower
Performance assurance	· Drive motor load balance · Gas seal performance of pallet · Pallet movement analysis	· Gas seal of charging device	· Break-out prediction · Roll gap · Roll alignment · Roll load · P/R pressure system · Water spray control system · Valve sequential control system · Slab marker · Mold oscillation system	· Automatic gage control system · Automatic jumping control system · Hot-run rolls load balance	· Welder · Strip position control system	· Strip gage analysis · Chatter analysis · Detection of nozzle clogging	· Tension leveller

the field and the training center. This system enables the level of the whole centralized equipment control to be improved based on the improvement of the skills and techniques of individuals.

4 Prospects for Equipment Diagnosis Techniques

Started with an initial stage equipment diagnosis activities, the company's equipment diagnosis techniques have upgraded their levels by adding developments and applications of constituent techniques, with assistance from the product quality and performance assurance techniques, not to mention systems implementation of diagnosis techniques. These equipment diagnosis techniques have proved effective in serving the purposes, such as keeping high equipment availability, maintaining high quality and improving productivity.

It is impossible to diagnose and monitor all equipment in assuring their serviceability and performance when they are a complex combination of various functions peculiar to steel plants, equipment composed of various parts, equipment with difficult quality requirements in each process, and equipment with different environmental conditions such as of high temperature, fusion, explosiveness and corrosiveness. It is necessary to build systems in consideration of balance between the purposes and equipment costs and maintenance loads of diagnosis apparatus.

There are many problems to be solved as to develop effective diagnosis techniques, and how to attain overall equipment assurance under some limitation to portions to be dianosed. Further, new problems occur in diagnosis methods of equipment performance because the function and accuracy of equipment as manufacturing conditions change constantly depending on the level of required quality. These are still many unsolved points in the cause-and-effect relations between product quality and equipment. In some fields of diagnosis, such as deterioration diagnosis of components used in control equipment, it is difficult to develop diagnosis apparatus with the existing techniques. To what degree the diagnosis function should be given to equipment and devices to be newly installed will also be an important issue in terms of investment cost and development manpower. Further, the development of robots with an inspection and diagnosis functions and a self-restoration function in dangerous, severe and dirty work environments will become necessary in the future.

Because there is no part of a device which does not require replacement semi-permanently, development is desired of diagnosis techniques with cost and profitability always in mind. Although attempts are made to replace human judgment with computers, there may be basic and fundamental techniques yet to be explored in each engineering field beyond the solution only by the concept of artificial intelligence and robots. Closer cooperation with not only academic circles but also with machine builders must be necessary.

Equipment diagnosis techniques will continue making progress with emphasis laid mainly on:

(1) Development of effective instruments for diagnosis
(2) Development and computerization of diagnosis techniques for unit performance
(3) Combination of diagnosis techniques in each production process and application of diagnosis techniques for unit in each engineering field
(4) Development of total plant condition monitoring and control systems and personnel training

5 Conclusions

The equipment diagnosis techniques at Kawasaki Steel were described. With the environment of the steel industry changing on a worldwide scale under the recent shift in the economic situation, equipment diagnosis techniques have become increasingly important as the support for a productivity increase through the modernization of equipment control. Techniques for predicting equipment troubles and those for assuring product quality have been developed and put into practical use; the two have been developed into equipment control techniques system. These techniques which have proved effective in iron and steel plants are being evaluated as general techniques owing to the technical interchanges for equipment control between different industries. This demonstrates that equipment diagnosis techniques are very serviceable in wide applications. Nevertheless, considering many problems and phenomena yet to be solved, it is important to aim at rationalized equipment diagnosis techniques while clarifying these phenomena. Although the completion of technology may not know its end, the fact remains that incessant efforts accelerate progress. This may be true of equipment diagnosis techniques.

References

1) T. Sada: "Setubi-Sindan-Gizyutu (Diagnostic Technology)", (1978) [JIPM]
2) S. Nakasima, K. Shirase, F. Goto, A. Miyoshi, F. Oota: "Seisan Kakushin no tameno TPM Tenkai Puroguramu (TPM Development Program)", (1986), 6, Japan Institute of Plant Engineering
3) N. Inoue, S. Nishimoto, Y. Fujimoto, S. Harada: *Kawasaki Steel Giho*, **20**(1985)1, 64-68
4) K. Nakamura, H. Onishi, K. Sato, T. Kudo, S. Kakihara, W. Fukuhara: *Kawasaki Steel Giho*, **14**(1982)3, 286-297
5) H. Kishida: Setubi-Kanri-Zenkokutaikai (Symposium of Plant Maintenance), JIPM (1989), C3-1
6) S. Kasai, A. Ichihara, K. Sano, S. Fujimoto, and H. Kobayashi: *CAMP-ISIJ*, **2**(1989)5, S585
7) The Iron and Steel Institute of Japan: Setubi-Shindan (Equipment Diagnosis) Handbook, (1986), 277, [Maruzen]