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Automation and Mechanization in Steelmaking Process

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Abstract:

Introduction of a sublance and adoption of an AI system based on aimed and measured operating data have helped automate the LD converter operation resulting in reducing the manpower requirement and tolerating unskilled operators. Automation is pursued in the LD converter, secondary refining, and continuous casting steps with the aim mainly of improving the workplace environment through remote control. Refractories maintenance is mechanized with the introduction of robots in converter bricklaying work and by improving refractories and changing operating patterns, as represented by the use of monolithic refractories and successive operation of hot tundish without requiring preheating. Equipment failures are prevented by introducing diagnostic maintenance, and operating conditions are grasped real time so that corrective actions may be taken automatically and operational instructions be issued timely to operators. As a result of these efforts, steelmaking can now be effected more stably with smaller manpower than in the past.

1. Introduction

The steelmaking plant where hot molten steel is handled is a typical high-temperature, heavy-physical load workplace in the steelworks as it is called a 3D workplace with "D" being a common acronym for dangerous, difficult and dirty. It has acute needs for automation and mechanization of tasks to copy with the heat and physical work load for the operators and workers on the plant floor, as is aptly reflected in the history of steelmaking technology. The switch from the open-hearth furnace (OHF) to the LD convester or basic oxygen furnace (BOF) about 30 years ago and the shift from ingot casting (IC) to continuous casting (CC) about 20 years ago are good examples of innovation through which the workshop environment was dramatically improved and physical work load was sharply lessened. Automation and mechanization continue to be pursued to meet the demand for cost savings and the shortage of skilled labor. Through these steps of innovation, Nippon Steel's labor productivity in the steelmaking area (crude steel production per worker) has increased by about 50% over the past seven years despite the fact that the company's total crude steel production remained

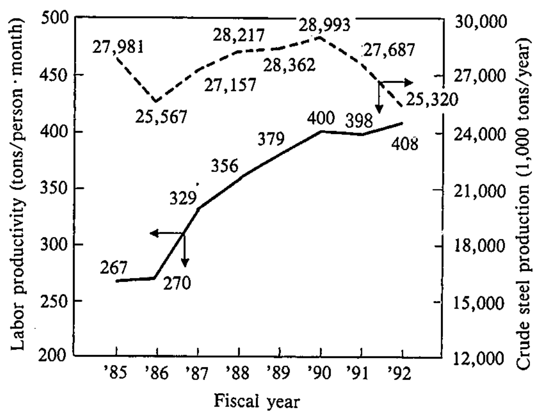

Fig. 1 Change in labor productivity in steelmaking process at Nippon Steel

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practically constant, as shown in **Fig. 1**. The workshop environment has been improved during the same period. Technology development is directed also toward the creation of a more comfortable workplace environment, with various automation and mechanization measures being taken along this line. Described hereunder are representative cases of automation and mechanization in the integrated steelmaking process.

2. Automation and Mechanization in Steelmaking Process

2.1 Automatic control of operation

Since the objects of work are hot and heavy, work in the steelmaking process is performed for the most part by machines, and human workers perform tasks that need advanced skill and judgment and that are difficult to be mechanized.

Automation technology, relying mainly on computers, is inseparable from mechanization. Direct digital control (DDC) has accelerated automation in the steelmaking process with increased speed and capacity of computers, adoption of programmable sequencers in electrical and control systems, and switchover from analog to digital instrumentation that brought a remarkable improvement in control accuracy. These changes are described below taking the BOF plant for example.

Fig. 2[1] shows the progress of automatic control of BOF blowing. Information of the molten steel sampled by the sublance during the blow was added to the static control by the process computer dictating the BOF charge material conditions and turndown target temperature and composition. The dynamic control thus effected significantly improved the accuracy of hitting the set values of turndown composition and temperature. Compared with the conventional sampling method whereby samples were taken only after blowing, the new sampling method using the sublance brought about remarkable improvements in terms of operation results, cost, and work load. The analysis of sublance samples is fully automated lately. This automation measure has reduced the labor requirement for the analytical step, increased the speed of analytical step, enhanced the analytical accuracy, and improved BOF operating indexes[2,3].

Table 1 Comparison of turndown results

Item \ Operating means	Unskilled operator		Skilled operator		Expert system	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Turndown carbon (10^{-2}%)	15.7	3.4	16.6	3.2	17.2	2.7
Turndown manganese (10^{-2}%)	51.6	7.0	54.3	7.5	57.1	5.8
Simultaneous temperature and carbon hitting rate (%)	Base	—	B+5.0	—	B+7.2	—
Reblow rate (%)	Base	—	B+2.8	—	B−0.2	—

In the 1980s, BOF blowing conditions and interrelated data, such as in-blow waste gas composition and furnace mouth pressure variation were entered into the process computer, and information difficult to express by mathematical equations, such as slopping prediction, was incorporated in artificial intelligence (AI) programs, such as an expert system. These advances made it possible for unskilled operators to operate the BOF process, as shown in **Table 1**[4]. As a result of such technological advance made in the electrical and control systems, controllers were moved from instrument panels to cathode ray tube (CRT) displays to allow operators to monitor and control the BOF process on the same CRT screens. For many BOFs of today, as a consequence, single-operator blowing practice has now been realized, space has been saved, and control pulpits have been integrated with pooled operator manpower. An example of work load by DDC is shown in **Fig. 3**[5]. The operator's judgment and action are now programmed with an evident decrease in his work load.

The BOF operation requires a large crew strength during tapping. To reduce the manpower requirement in the BOF steelmaking process, innovation efforts must be focused on the establishment of advanced tapping technology. Remote control from the BOF control pulpit is under study for a series of tasks from furnace tilting through ferroalloy addition to the judgment of tapping-end-point. A complete one-operator/one-furnace system will be established in due time.

Similar automatic control technology has been introduced to

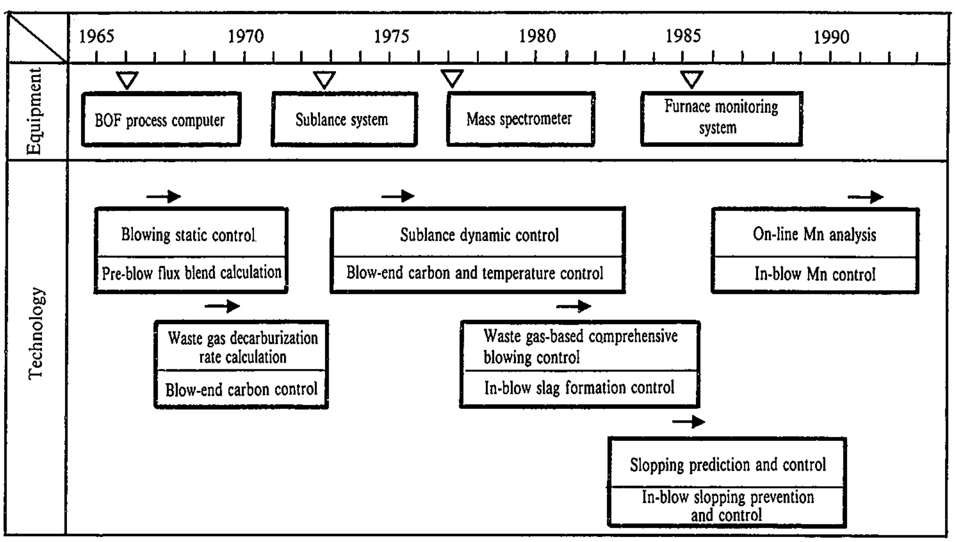

Fig. 2 Progress of BOF blowing control technology

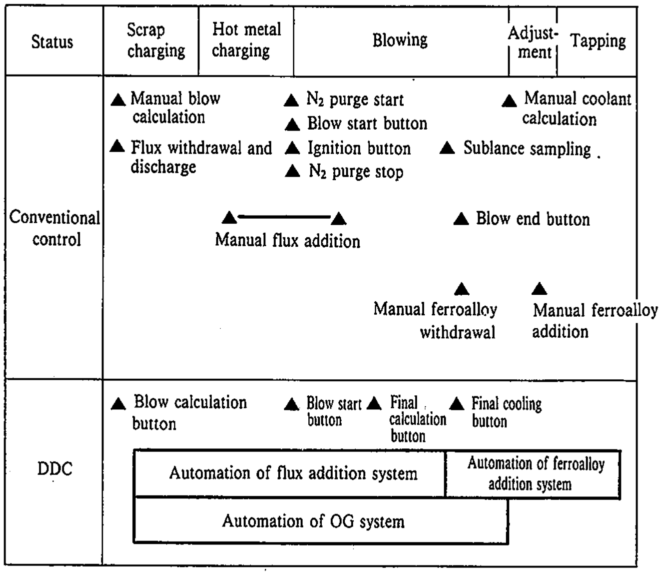

Fig. 3 Automatic blow control by DDC

other processes as well. Oita Works integrated the control pulpits of two RH vacuum degassers and one CAS (composition adjustment by sealed argon bubbling) station, pooled their operating personnel by remote control, converted control panels to DDC, and introduced a CRT system for operational monitoring and control. The two RH vacuum degassers and the CAS station are now operated by three operators per shift. **Photo 1** shows the control pulpit. Complete remote control is accomplished by monitoring through ITV monitor displays and operating through CRT screens. The continuous casting division has a plan to realize four men-a-caster operation through the simplification of preparations, automatic casting start[6] and remote control from the central control pulpit.

2.2 Mechanization

The steelmaking process handles molten steel and other heavy objects and is operated basically by machines, and, in particular, steady-state tasks are mechanized for the most part. Unsteady-state tasks, off-line maintenance, slab flaw detection, and other steps calling for complicated human judgment are left for operators. A typical example is refractories maintenance, including brick laying, brick dismantling, and in-service refractory gunning for vessels to transport and distribute molten iron and steel, such as torpedo cars, ladles and tundishes, and for refining vessels such as BOFs and RH vacuum degassers. These tasks which are performed under harsh and dusty conditions are being gradually mechanized.

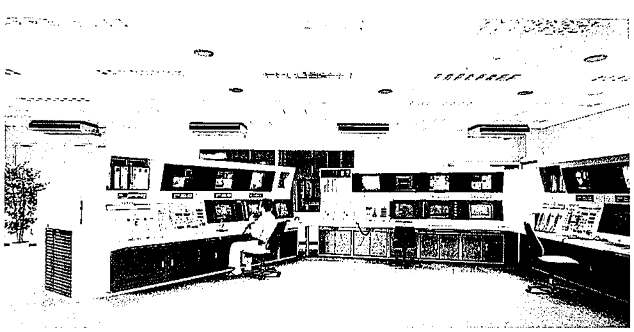

Photo 1 Integrated secondary refining equipment control pulpit

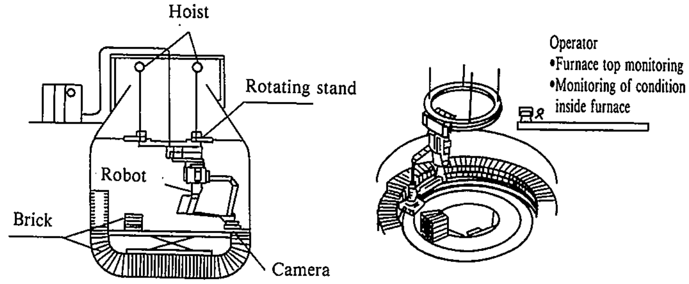

Fig. 4 Schematic illustration of bricklaying robot

Mechanization is facilitated by a shift from brick to monolithic refractories[7], as a result of which flame gunning machines are now at work[8], and brick laying is robotized[9].

Using monolithic refractories, today's technology cannot build BOFs that are exposed to high temperatures of 1,700°C and above. BOFs are now constructed of brick, and at Nagoya Works the brick laying work is robotized[9]. As shown in **Fig. 4**, some ten bricks are stacked in laying order, placed on a pallet, and carried to the place where the robot awaits. The robot processes the brick image, determines the brick position, moves to the position above the brick, and grabs four bricks, each weighing about 50 kg, with vacuum rubber pads. This method of brick position recognition permits the robot to accommodate bricks positioned within a tolerance of ±100 mm. When the robot is first taught the brick laying position, it performs the functions of measuring the actual brick laying position, storing the position data in memory, and calculating the next brick laying position. The robot's arm is equipped with a bearing, air cylinder and other devices, so that it can apply such forces to each brick as done by a skilled bricklayer when he pushes and lays each brick.

The bricklaying robot reduced the man-hour requirement by about 60%. Bricklaying in the furnace is a typical 3D task because of its poor working environment. Elimination of this 3D working environment is another significant benefit of the robot.

The above example is concerned with mechanization in off-line refractories maintenance. Punishing high temperature adds to the hardships of workers who perform in-service ladle maintenance and repair of RH vacuum degasser snorkel. The Kakogawa Works of Kobe Steel carries out dust collection and heat shielding to lessen work load and improve the work environment in ladle maintenance. Thoroughgoing mechanization is under way to halve the manpower required for ladle maintenance[10].

Refractory wears are repaired by a flame gunning method that sprays molten refractory powder through a nozzle together with fuel gas and oxygen. This assures better refractory serviceability than simple gunning. The flame gunning method is applied to BOFs[8], ladles[11], and RH vacuum degassers[12]. **Fig. 5** schematically illustrates flame gunning equipment as applied to the lower vessel of an RH vacuum degasser. The flame gunning burner lance can freely bend in the high-temperature lower vessel and adequately repair the sidewall that varies in distance from the snorkel center. The flame gunning system succeeded in halving the refractories consumption of the lower vessel of RH vacuum degasser[12].

At present, the flame gunning position and amount are determined from the monitor screen information of a lower vessel monitoring camera. A laser range finder is used to determine the refractory wear and process refractory surface images. These data are combined to judge the necessary amount of flame gunning and to perform automatic flame gunning repair.

An example of extensive automation achieved by improving the operating practice is the hot turnaround of tundish in the continuous casting process[13,14]. A key point in hot tundish turnaround is the removal of residual melt and slag from the tundish as soon as the cast is completed. An example is shown in **Fig. 6**[14]. Within 2 min after the end of the cast, residual molten steel is removed from the bottom of the tundish. The submerged entry nozzle (SEN) used in the cast is pushed out by the same stopper used in the cast and is recovered into the SEN exchange device. The nozzle well is cleaned by the SEN exchange device. A new preheated SEN is installed to complete the tundish maintenance. The tundish can be immediately used for the next cast without being preheated. Tundish maintenance labor, refractories consumption, and energy consumption are thus drastically reduced compared with the conventional method that takes the tundish out of service after each cast and maintains it off-line.

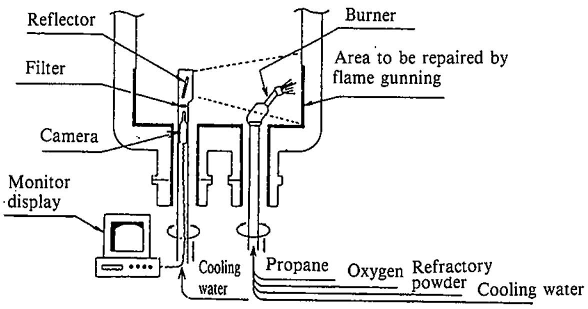

Fig. 5 Flame gunning equipment for lower vessel of RH vacuum degasser

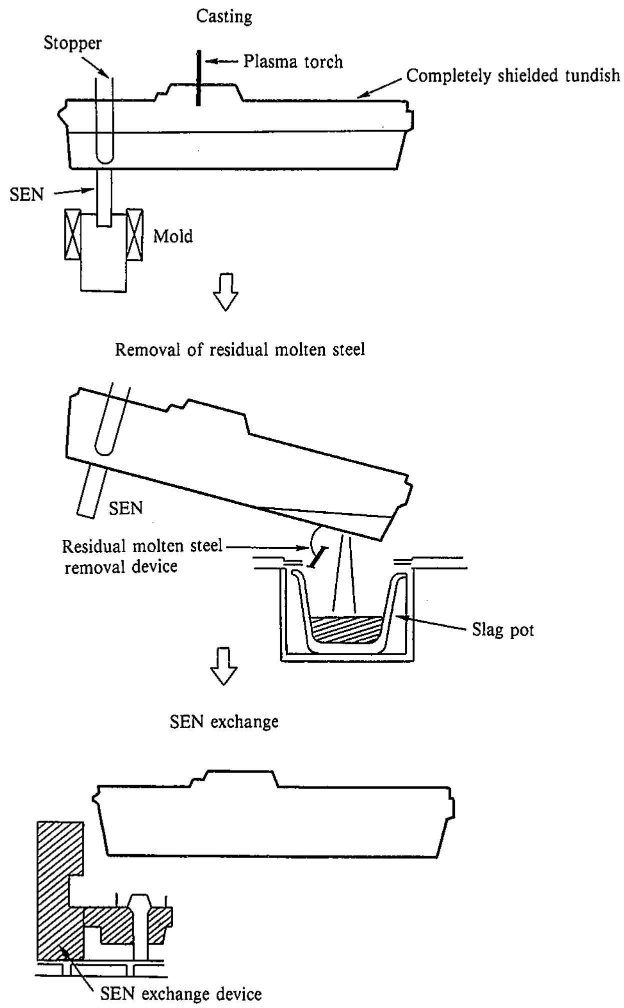

Fig. 6 Flow for hot tundish turnaround

2.3 Operation and equipment control

A system of controlling operation, quality, and equipment that utilizes high-storage capacity computers and various latest instruments permits paper-less operational instructions — a large labor saving.

2.3.1 Operation and quality control systems

The quality of slabs or other products from the steelmaking process is sometimes judged from measured data such as sulfur printing and ultrasonic testing data, but mostly is estimated from operation data. Slab manufacturing standards are determined from the correlation between operation data and quality data of end products fed back from the downstream processes. Accept/reject judgment and disposal of slabs according to production results are all automatically done by computer. Formerly, whether to accept or reject slabs was judged by personnel in the quality control department by observing field operations. A new quality control system was introduced to replace operators in order to meet the needs for a finer control mesh, more rapid response and diversifying standards, and to enter necessary data directly into the computer.

Operational guidance is given through CRT screens. An example is the "mold visualization technology"[15] realized at Nagoya Works. **Fig. 7** shows the system configuration of this technology. Various quality indexes (in-process steel quality indexes) are calculated real time by a simplified model from tundish and mold data. The computed results are sent to the upper-level computer. Quality ratings of the steel being cast are visually displayed on the CRT screen. Guidelines for actions, such as application of electromagnetic braking, to be taken to control each index within the optimum range and their results can be confirmed accordingly.

2.3.2 Material flow control system

Important tasks at the steelmaking plant are matching between BOF steelmaking, secondary refining and continuous casting, and matching continuous casting with the following hot rolling under direct rolling (DR) and hot charge rolling (HCR). In the past, the production control department made necessary adjustments through telephone communication with each plant or control pulpit concerned. Now that the material flow is controlled by computer, finer adjustments can be made.

Slab yard control is a part of material flow control. Stray slabs can be prevented also by checking their weight and dimensions on crane terminals.

2.3.3 Equipment diagnosis system

Equipment diagnosis that identifies faulty equipment pieces

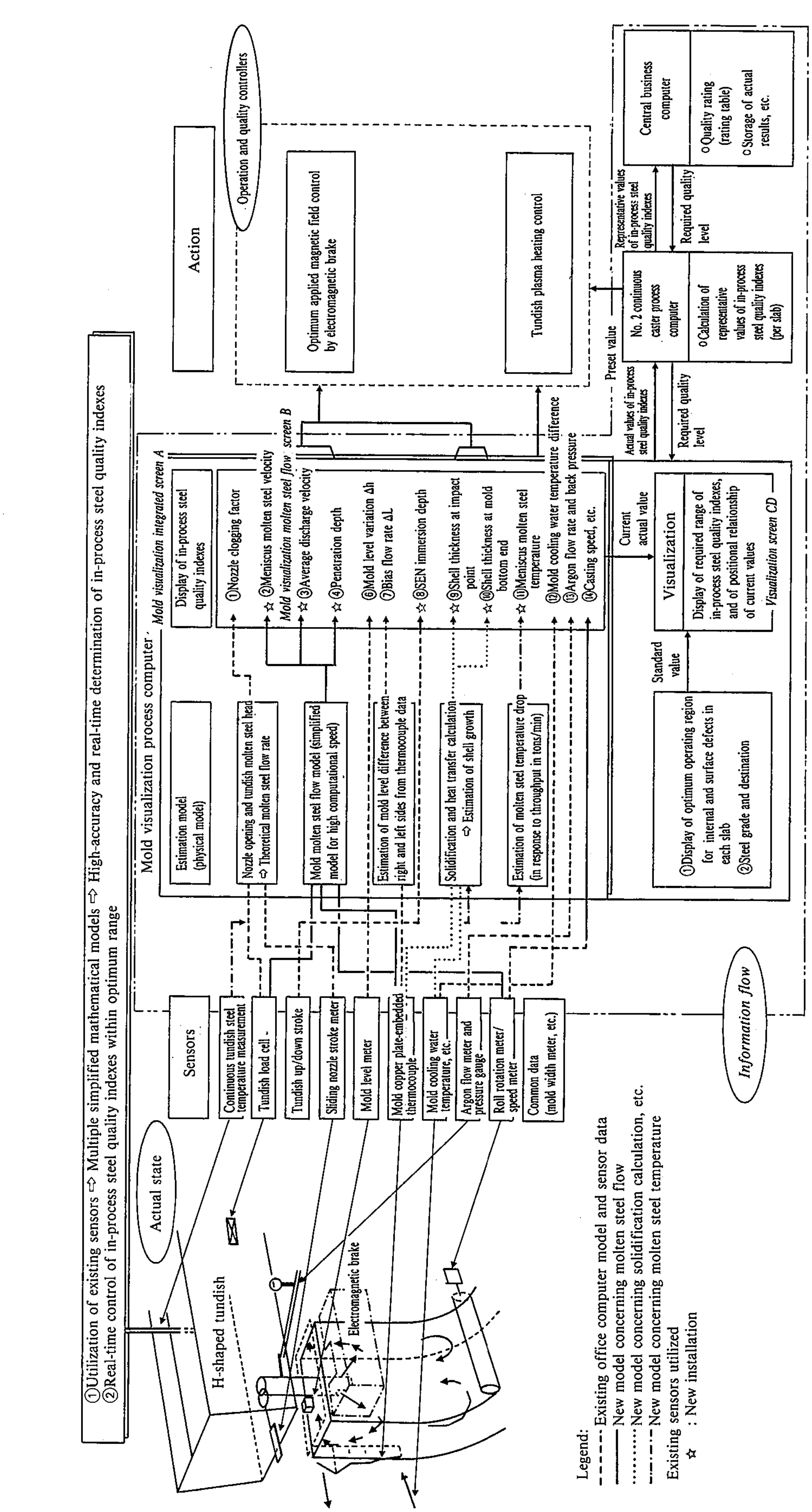

Fig. 7 System configuration of mold visualization technology

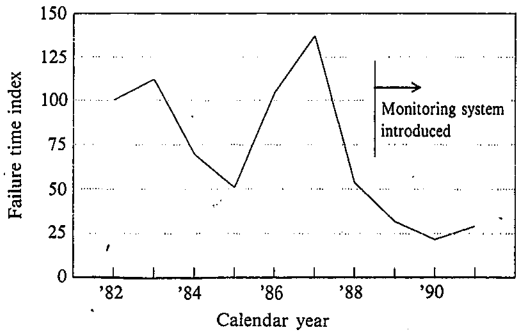

Fig. 8 Failure time transition at No. 4 continuous caster of Oita Works

from their state of operation also comes under the category of automation. Motor current, cooling water temperature, and vibration are measured, and any significant deviation from normal equipment conditions are detected to prevent equipment failures. These tasks were traditionally undertaken by inspectors. Given the sophistication and diversification of skills required and the complexity of phenomena involved, computerized equipment control is now indispensable. **Fig. 8** shows the effectiveness of such a system. In the figure, the failure time of No. 4 continuous catser at Oita Works is shown by index. In 1989, a diagnosis system by inspectors was replaced by an on-line continuous caster monitoring system. As a result, the failure time of the continuous caster was steeply reduced.

3. Conclusions

Automation and mechanization in the steelmaking process have been reviewed above. Automation and mechanization will proceed further, not only to maintain and enhance cost competitiveness by increasing labor productivity, but also to make up for the shortage of skilled workers, to cope with the shunning of manufacturing industries by young people and to develop a comfortable workplace environment as done by steel companies in recent years. Considering the future progress of automation and mechanization, completely unattended operation may be realized even in the steelmaking process where molten steel is handled.

Continuing automation and mechanization call for the following issues to be addressed:

(1) When the operating personnel strength is reduced, it will become extremely difficult to quickly cope with troubles and other abnormal conditions. This calls for the development of technology and equipment to completely ward off such troubles, and to mechanize troubleshooting tasks.

(2) It is imperative to introduce advanced robots and other automation devices, and to standardize design for inter-system compatibility in automation.

(3) Some of the present floor tasks need be modified to adapt to advancing automation and mechanization.

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