New Technologies for Steel Manufacturing Based upon Plant Engineering

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NKK has successfully developed various new technologies in the field of plant engineering. These have greatly improved the quality of the Company's products and production yield, and extended the life of equipment in the steelworks. This paper introduces typical examples of recent technological accomplishments in the field of plant engineering.

1. Introduction

The iron and steel industry is a gigantic process industry, and its foundation is plant engineering that covers from construction and maintenance of plants to extension of their useful life.

In addition to conventional requirements, plant engineering today must satisfy a wide range of additional requirements such as higher production yield, better product quality, and wider quality assurance of products.

The plant engineering sector of NKK, in collaboration with the Company's research and development sector, has developed various technologies encompassing plant diagnosis, automation, extension of plant life, and instrumentation and control including those required for quality assurance.

This paper introduces typical examples of recent technological accomplishments and discusses the future of plant engineering.

2. Plant diagnosis and automation technology

2.1 Plant diagnostic technology

2.1.1 Overview of plant diagnostic technology

Various maintenance methods are used in iron and steel making plants. In CBM (Condition Based Maintenance), plant diagnostic technologies are used to quantitatively measure the deterioration of facilities, and the minimum required repairs are done at the most appropriate timing based on the diagnostic results. Accordingly, this is the most rational of all maintenance methods.

NKK has actively developed and applied plant diagnostic technology because it is essential for managing equipment based on the CBM method.

The features of NKK's plant diagnostic technology are as follows:

(1) A variety of plants such as iron and steel making plants, hot rolling mills, and cold rolling mills need to be diagnosed. Accordingly, NKK has a variety of plant diagnostic technologies such as vibration diagnostic technology, lubrication diagnostic technology, structure diagnostic technology, and electrical equipment diagnostic technology, combinations of which are used as needed.

(2) Various diagnostic methods were established, each tailored to a specific objective such as routine inspection, checking the conditions of facilities, predicting the life of facilities, identifying the causes of abnormalities, and estimating the degree and extent of damages.

(3) NKK has developed a number of important technologies in-house to suit the actual conditions of facilities and real operation sequences, as well as to make plant diagnosis inexpensive and efficient. Examples include the portable vibration checker, automatic oil analyzer, and compact insulation diagnostic meter.

By rationally combining these plant diagnostic technologies and their particular features, NKK is able to precisely and effectively diagnose plant conditions.

2.1.2 Online monitoring system

NKK has developed a network system covering entire steelworks in order to efficiently and precisely grasp the conditions of facilities. The Fukuyama Works has installed an on-line monitoring and diagnosis system covering 18 major plants in its premises with about 4800 monitoring points. **Fig.1** shows the system configuration. The main features of this system are described below.

(1) The system automatically conducts a precise diagnosis when a plant abnormality has occurred. The system also permits precise diagnosis directly from a given monitoringterminal when necessary. The system incorporates a

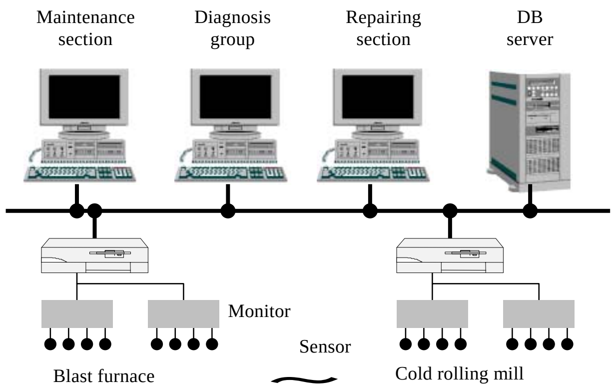


Fig.1 Configuration of on-line monitoring and diagnosis system

newly developed auto-diagnosis function that automatically detects abnormalities of sensors, wire breaks, and failures of monitoring instruments, to improve system reliability.

(2) Inexpensive but durable sensors, microcomputer-controlled monitoring instruments, and monitoring computer software have been developed in-house, more than halving the cost of system installation compared with the older system.

The new system makes it easier to prepare precise maintenance plans and promptly respond to plant abnormalities, thereby improving the stability of operations with fewer maintenance personnel and at lower cost. Not limited to NKK's plants, this system is now being extensively used in various other industries including the electric power, automobile, and chemical industries.

2.2 Technologies for increasing yield and operating rate, and automating operations

2.2.1 Overview of technologies for increasing yield and operating rate, and for automating operations

Plant engineering plays a key role in rationalization and manpower saving in the operation of steelworks, and will play an increasingly important role, as plants become even more sophisticated. NKK has actively been developing various aspects of plant engineering. Two cases are presented below: the case of raising the operating rate of a BOF (Basic Oxygen Furnace), and the case of developing a technology for automatic operation of a crane.

2.2.2 Side combustion lance for BOF

Oxygen is blown into molten iron charged in a BOF by a water-cooled lance inserted in the furnace from above. The carbon component in the molten iron burns with the oxygen, and the molten iron becomes steel. During this process, the molten iron is vigorously agitated and the splashed metal deposits on the upper part of the furnace wall as scale. In the case of a dephosphorizing BOF, such scale forms easily due to the lower operating temperature of the furnace, seriously affecting the operation of the furnace.

NKK has solved this problem by developing a technology for blowing oxygen from the side nozzles of the lance into the upper zone in the furnace. The blown oxygen promotes side combustion and consequently raises the temperature at the furnace throat, thereby achieving scale-free operation. **Fig.2** shows the newly developed side combustion lance.

This lance incorporates the following newly developed technologies:

(1) A multi-tube structure that prevents thermal deformation of the inner and outer tubes, and

(2) Multi-stage side nozzles that optimize side combustion corresponding to the distance from the furnace wall.

These technologies have successfully achieved almost completely scale-free operation of dephosphorizing BOF, increased the operating rate by about 1%, reduced the maintenance cost and shortened the furnace repair period. Thus, the technologies have contributed greatly to stabilizing the operation of the BOF.

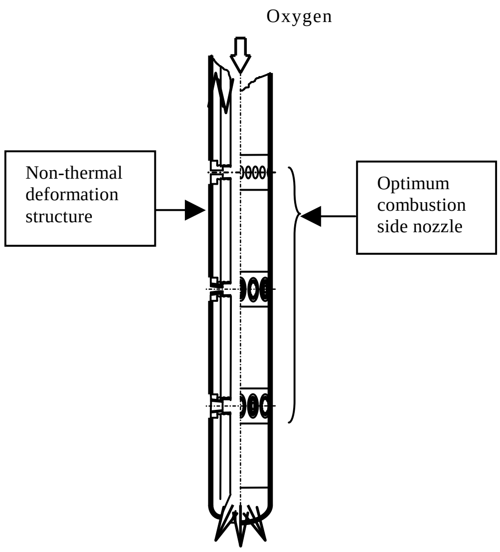


Fig.2 Configuration of side combustion lance

2.2.3 Automatic crane operation technology and advanced swing control

An overhead crane is essential for coil transportation in a rolling mill yard. An automated system for operating the crane needed to be developed to reduce manpower, yet the cost had to be low enough to justify the investment. NKK therefore developed technologies for automatic crane control while minimizing modifications to existing facilities, using low-cost sequencers, and standardizing the system to allow it to be used for other facilities.

The major items newly developed are as follows: NKK-type anti-swing crane control, automatic coil handling by coil position sensors, prevention of collision between consecutive coils by anti-collision coil sensors, high-accuracy crane position detection by laser distance meters, and improvement of coil storage capacity by freely assigning a space. **Fig.3** shows an overview of the newly developed automatic crane control system.

Application of these technologies has reduced capital cost by about 40% compared with crane systems of other makers. NKK automated 14 overhead cranes between 1994 and 2000, with a reduction of 54 operators.

Presently, NKK is developing an automation system for a coil yard, which presents a number of problems difficult to deal with regarding automation, by improving the three-dimensional anti-swing control of travel, traverse, and hoisting movements, and multi-crane control.

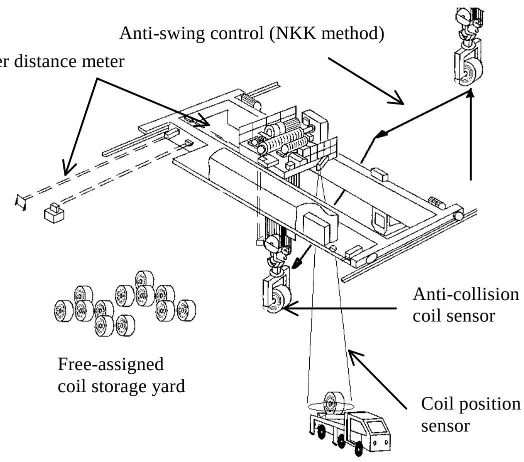


Fig.3 Automatic crane control system

3. Development of technology for extending equipment life, and for replacing obsolete equipment at low cost

3.1 Technology for extending equipment life

3.1.1 Overview of technology for extending equipment life

One of the top priorities of the plant engineering sector is to extend equipment life, which is being studied from various angles.

NKK has been developing various technologies for extending equipment life, including a technology for cooling the blast furnace, which is one of the key plants in steelworks, and another concerning repairs of the blast furnace.

3.1.2 Extension of life of cooling stave for blast furnace

The cooling stave ("CS", see **Fig.4**) for cooling the blast furnace has conventionally been the non-coalescent type where the cast iron plate and cooling pipes are not in contact as shown in **Fig.5** (a). Recently, with the increasing heat load on the furnace associated with such factors as massive injection of pulverized coal, deformation of CS now frequently occurs, hindering stable operation of the blast furnace.

The non-coalescent CS has a clearance, or an air gap, between the cast iron plate and cooling pipes to prevent cracks in the CS body from propagating to the cooling pipes. Because of the thermal insulating effect of this air gap, the cooling performance of the CS is reduced. Such measures as installing the cooling pipes close together and back cooling are insufficient to prevent deformation of the CS. NKK therefore developed its proprietary contact type CS as shown in **Fig.5** (b), with a stronger cooling effect.

The contact type CS has no air gap and instead, the cast iron plate and cooling pipes make solid contact via an alloy metal layer. Without the air gap, the cooling effect is markedly improved compared with the non-coalescent type CS. In this structure, when a crack reaches the alloy layer, the fragile alloy metal tears off and thus prevents the crack from propagating to the cooling pipes.

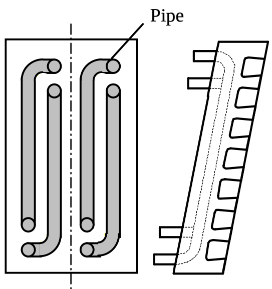


Fig.4 Schematic diagram of the cooling stave (CS)

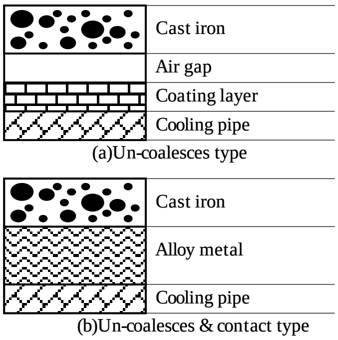


Fig.5 Comparison of the non-coalescent type CS and contact type CS

Fig.6 compares the non-coalescent type CS and contact type CS in terms of temperature, stress and deformation obtained as a result of FEM analysis. The contact type CS has a far greater cooling effect than the non-coalescent CS and so suffers much less deformation. As a result, twice the life, or a life of more than 10 years is expected.

The contact type CS extends the life of the CS; NKK is now expanding the application of the contact type CS to ensure stable operation of blast furnaces.

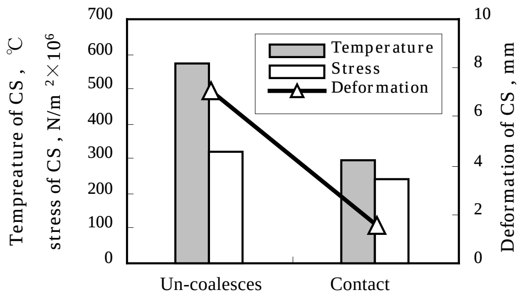


Fig.6 Result of FEM analysis

3.1.3 Blast furnace repair technology by burden-lowering and shutdown

Recent changes in how blast furnaces are operated as represenred by massive injection of pulverized coal have increased the thermal load on the furnace, which has increased the frequency of CS failures, particularly cooling pipe failures in the CS at the bosh of the furnace resulting from failures of the CS bodies. Such failures reduce the cooling effect on the bosh mantle and shorten the life of the furnace. Therefore, a CS unit which has been damaged to more than a certain extent needs to be replaced as a whole.

Traditionally, because of the difficulties of replacing a CS unit as a whole in the bosh portion, round type cooling plates are installed from outside the furnace and refractory grouting is applied, but this method has limited effect.

NKK has developed a technology to quickly replace all CSs around one section of a furnace, as a more permanent measure. **Fig.7** shows the concept of CS replacement, and **Table 1** shows the performance of the new bosh cooling stave replacement method. In the new method, bosh CSs are replaced after lowering the charged burden level in the furnace to the level of the tuyeres and then shutting down the furnace operation. This method enables a large number of CSs to be replaced quickly by applying new technologies as follows: (1) to recover damaged CSs and install new CSs simultaneously at multiple places, (2) to use a CS carrying device specifically designed for installing CSs, and (3) to seal the gaps between the newly installed CSs by refractory grouting.

These technologies for replacing bosh CSs were also used to remove existing CSs and install new CSs in the shaft portion of a blast furnace.

The technologies to replace CSs by burden-lowering and shutdown extend the life of the furnace to more than 20 years, such that the life of a blast furnace is now determined by the hearth only. Technologies to extend the life of the hearth are thus the key issue for extending the life of a blast furnace.

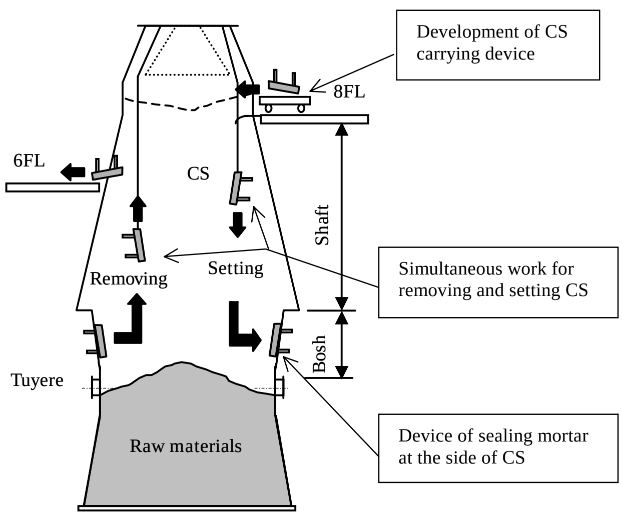


Fig.7 Replacement of bosh staves

Table 1 Results of replacement of bosh staves

Blast furnace	Numbers	Shut down	Execution
Fukuyama No.4	56	86hrs.	Mar. 1999
Fukuyama No.5	64	90hrs.	Mar. 2000

3.2 Technology for replacing obsolete equipment at low cost

3.2.1 Overview of technology for replacing obsolete equipment at low cost

Iron and steel making equipment older than 30 years old is considered to have become obsolete, or reached the end of its useful life depending on the degree of deterioration. Steelworks must reduce the cost of replacing such equipment.

NKK has actively developed technologies for replacing obsolete equipment at low cost while maintaining stable operation of facilities. The following examples are technologies for replacing computer systems and steel structures.

3.2.2 Reduction of cost for replacing obsolete process computers

In a steelworks, as many as 200 process control computers ("process computer") are used, many of which have been in use for 15 to 20 years. The Company expects to replace several of them every year, and so it is important to reduce the cost of replacement. If the option is limited to expensive special-purpose process computers provided by a limited number of manufacturers, or to just downsizing, cost cannot be reduced significantly. NKK has therefore developed an inexpensive open-type process computer system, with a network of general-purpose personal computers that have now become much more powerful thanks to recent advances in information technology.

NKK adopted an open PC system based on the Linux operating system, and developed in-house all the necessary process control software not available in the market. **Fig.8** shows the configuration of the new open-type process control system, and **Table 2** compares the new system with the conventional system, the latter using special-purpose process computers.

This system was first applied in January 2001 to the No.3 continuous hot-dip galvanizing line of NKK Steel Strip & Sheet Corporation situated in the premises of NKK's Keihin Works. Thereafter, the system has been used to replace obsolete process computers in the Keihin Works and Fukuyama Works, slashing the cost by up to 40% compared with the conventional system using special-purpose process computers.

When this new system needs to be replaced in the future, it will be possible to simply replace the personal computers alone, thus reducing both cost and time compared with replacing the entire software and hardware as a package.

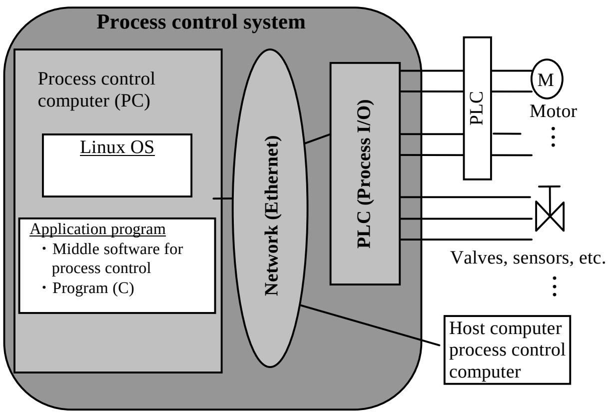


Fig.8 Configuration of new open-type process control system

Table 2 Comparison between conventional and new systems

Items	Specialized computer for process control (Conventional)	Open-type computer for process control (Newly developed)
OS	Developed by manufacturer Functions are not open	Linux All functions are open
Application program	Developed by special language code (upper compatible is not assured)	Middle software for process control is newly developed (upper compatible is assured by adopting C language)
Process I/O connection	・Network (Host Computer, etc.) ・Process I/O are connected directly to computer	・Network (Host computer, etc.) ・Process I/O are connected to PLC(separated from computer)
Main use	Real-time treatment for process control	Ditto
Endurance	24hr continuous run without stop	Ditto
Renewal method	Renewal of both hardware and software → high cost	Renewal of only hardware → low cost

3.2.3 Diagnostic technology for deterioration of conveyor frames

As steel structures in steelworks become obsolete, the cost of replacement tends to increase every year. Of all steel structures, the belt conveyor facilities in the raw material yard, with a total length of more than 100 km, are expensive to replace. Some of the conveyors, the conveyors that supply iron ores and cokes to blast furnaces for example, are so important that their failure may have a serious effect on the production schedule of the entire steelworks. The overwhelming importance of maintaining stable operation rules out simple approaches to reducing the cost of maintenance and replacement.

Generally, a belt conveyor is composed of a truss frame made of channel steel or angle steel, and the movable part consisting of rollers and belts for transporting various materials. The frame of a belt conveyor has to be repaired or replaced when it has corroded such that the strength has fallen almost to the allowable limit.

Traditionally, the necessity of repair or replacement is judged based on inspectors' subjective diagnosis on deterioration by visual observation, as well as by measuring the thickness. Instead, an objective and quantitative diagnostic technology needed to be developed.

NKK has therefore developed a technology for quantitatively assessing deterioration caused by corrosion of the conveyor frame by measuring the natural frequency of a particular vibration mode of conveyor facilities. The development work required repeated on-site measurements, off-site experiments, and numerical analyses (refer to **Fig.9**). NKK has also developed a simple method of measuring the natural frequency on-site for assessing the degree of corrosion. This method has already been put to practical use, and contributes greatly to (1) assurance of safety and steady operation, (2) prevention of loss of opportunity cost due to unexpected major accidents, and (3) stricter definition of the portion of the frame to be replaced and reduction of cost of replacement by extending the usable life through reinforcing particular parts of the conveyor frame.

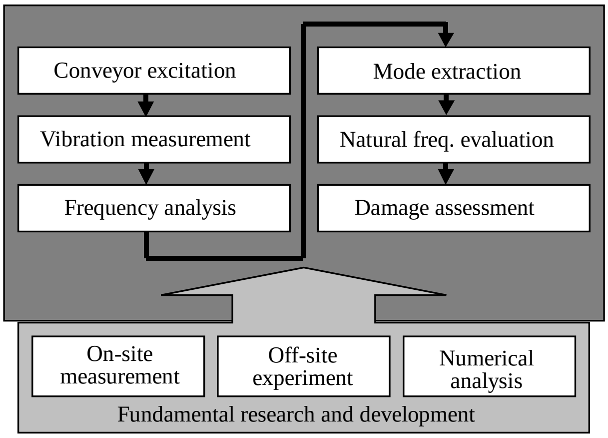


Fig.9 Flow of the damage assessment of conveyor frame

4. Measuring, inspection and controlling technology

4.1 Technology for material property evaluation and quality assurance

4.1.1 Overview of technology for material property evaluation and quality assurance

NKK has actively developed sensors and measuring technologies, as these are the basis of supplying high-quality steel products to customers.

Nevertheless, customers' demands for quality are becoming ever stricter. The steel sheets for automotive exposed panels, for example, are now required to be free from very fine patterned flaws, which are difficult to detect, as well as free from surface roughness defects, which used to be a single most important quality item. The steel sheets for beverage cans are now strictly required to be free from minute inclusions, as they become thinner.

To respond to such quality requirements, NKK has developed new measurement and inspection technologies and introduced them in its production lines.

4.1.2 Fine patterned surface flaw inspection system: Delta-Eye

NKK has developed a highly sensitive and reliable fully automatic on-line surface inspection system named Delta-Eye to fully automate the on-line detection of patterned surface flaws on steel sheets for automotive exposed panels.

Patterned flaws do not have a sharp contrast. Accordingly, if the detection level is set too sensitive, harmless patterns and oil or coating liquids remaining on the steel surface may be recognized as flaws, causing overly-strict inspections and so decreasing the product yield. This inspection system therefore uses polarized light to distinguish detrimental defects from harmless patterns as physical phenomena.

Fig.10 shows the configuration of this inspection system. The following are the major features of this system.

(1) Automatic inspection of the entire steel strip by three channels of polarized light: Four line scanners each housing three line-sensor cameras with different polarization angles are placed above the strip. The signal processing system compensates for the difference in view fields between adjacent line scanners and among three different

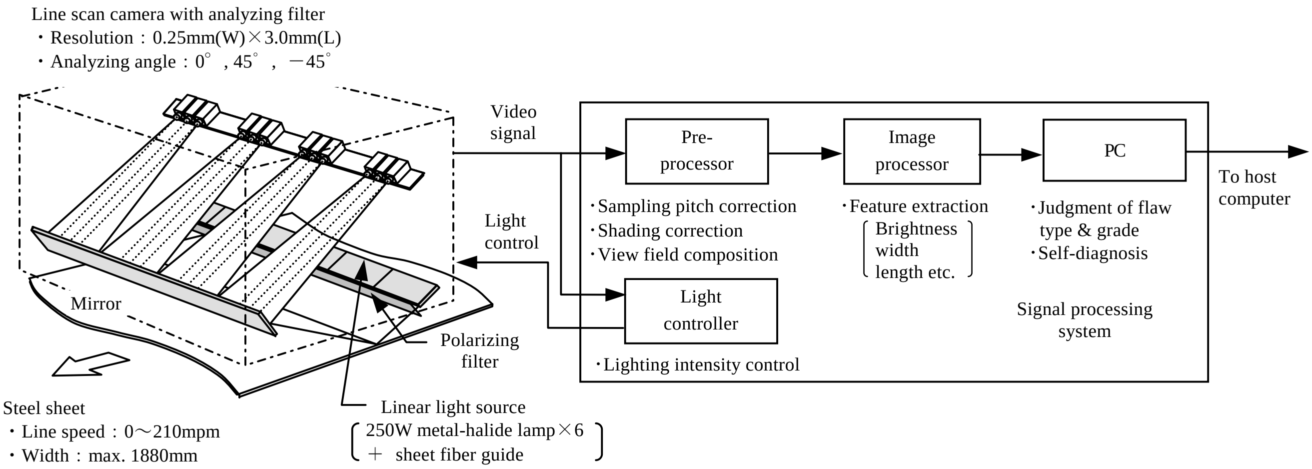


Fig.10 Schematic diagram of the surface flaw inspection system

channels, and synthesizes the view fields, thereby allowing real-time inspection of the entire surface by three channels of polarized light.

(2) Construction of highly reliable system: Based on a general-purpose image processor, a highly reliable and flexible system was constructed by adding a customized pre-processor and light-source control system to compensate for the measurement environment and changes in steel surface conditions such as changes in the line speed, lateral movement of the strip, and unevenness and variation in reflectance.

This inspection system was fully started up in April 1999 on the No.2 continuous hot-dip galvanizing line of the Fukuyama Works. **Photo 1** shows the outside view of the sensor head placed on the line.

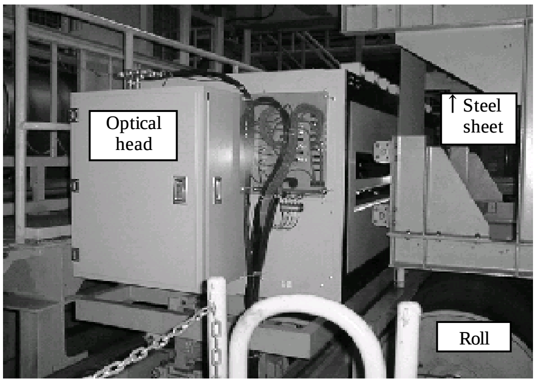


Photo 1 Optical head (Rear surface)

On-line performance tests of this inspection system indicated that its detection ratio of about 800 patterned flaws was 100%, with false-positive detection of less than 1%.

This inspection system has enabled quantitative and objective continuous monitoring of surface patterned flaws for the first time, and the results are being used to assess the effects of actions taken in the upstream processes to reduce defects. Thus, this inspection system has made a great contribution to the production of high-quality steel sheets.

4.1.3 Minute inclusion detector

To improve the internal quality of steel sheets used for making beverage cans, NKK has developed an on-line inspection system capable of detecting minute inclusions thicker than 8 micrometers.

To detect such minute defects, highly sensitive detection capability is required. In addition, it is necessary to discern between magnetic noises arising from material characteristics and magnetic flux leakage from the defect. The noise flux arising from material characteristics tends to be more spatially dispersed than the magnetic flux leakage from the defect. NKK used this feature to develop a sensor with an E-shaped magnetic core as shown in **Fig.11**, to enhance the detecting sensitivity. This sensor has a ferromagnetic core with three poles, with a coil wound on the center pole only. The noise flux tends to be more dispersed to the outer poles than the flux from a defect, and is less inclined to be converted into an electrical signal, thus reducing the detection of noise signals correspondingly.

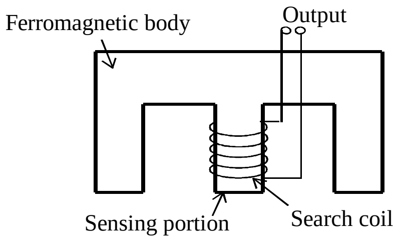
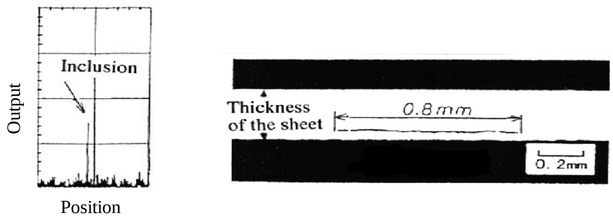


Fig.11 Outline of E-shaped core sensor

Fig.12 shows a result of detecting an inclusion of 10 micrometers thick, 80 micrometers wide and 0.8 mm long. Note that noise was suppressed and the inclusion was detected at a high S/N ratio.

This sensor is now operational on a coil preparation line at the Fukuyama Works. The sensor has enabled the upstream steel making process to be improved and so has greatly helped enhance the quality of canmaking steel sheets.



(a) Output of the E - shaped sensor (b) L - cross section of the inclusion

Fig.12 Off-line detection result of a minute inclusion

4.2 Controlling technology

4.2.1 Overview of controlling technology

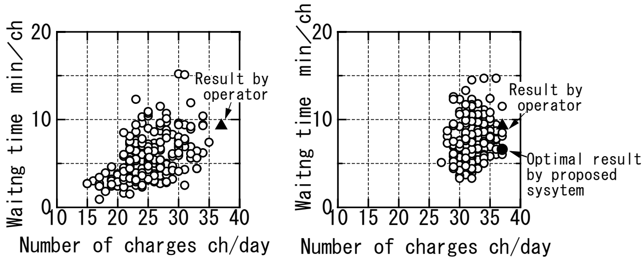
The production processes of steelworks are becoming more complicated to meet the demand for higher grades of more versatile products. Optimization and automation of the production processes are important challenges for plant engineering. Faster development and more precise control models are also required in order to improve productivity and quality, and so control technology is particularly important.

NKK has endeavored to upgrade the whole spectrum of control technology by utilizing the latest information technology. Two examples of recent progress are given below: one is the technology for advanced planning and scheduling of productio, the other for more efficient development of control models.

4.2.2 Advanced planning and scheduling technology

With recent progress in computers, operation research techniques can now be used in practical steel production planning. A search technology called metaheuristics is particularly effective. By using the metaheuristics technique, with proper selection of the search order and search space suited to particular plans, it is possible to prepare better steel production plans faster than when done manually.

Fig.13 shows a daily production schedule diagram prepared by using an advanced version of GA (Genetic Algorithm), one of the metaheuristics techniques. This diagram covers the processes of the Keihin Works from the basic oxygen furnace (LD converter) through the secondary refining to the continuous casters. The display also shows the charge names and charge set names. It used to take one operator about three hours to prepare one day's production plan, but the new system can prepare one week's plan in about 20 minutes. Since this system can visualize one week's plan, the supply and demand in subsequent processes are more accurately balanced. After securing the production volume, this system also enables optimization of operations such as minimization of the process waiting time, and minimization of occurrence of alternative process operations other than standard process operations, thereby reducing the operation cost. **Fig.14** compares the distributions of feasible solutions obtained by the conventional GA and advanced GA, the latter indicating how the search space has been narrowed by introducing restrictions. Note that the proper search method suited to the subject can prepare production plans better than the operator.



(a) GA (b) Advanced GA

Feasible solutions

Fig.14 Comparison of results obtained by conventional GA and advanced GA

4.2.3 Joint development of control model utilizing IT

As NKK's steelworks become more streamlined, the manpower available for developing and improving control models has become limited, and so more efficient development methods are needed. To achieve this, various sectors of NKK have joined forces, through the company's computer network, to facilitate joint development of control models and coordination for it.

Fig.15 shows the collaboration network system for joint development of control models. The production data collected by process computers are stored in the database of the personal computer server. This data can be retrieved at laboratories or steelworks at any time via the corporate network. **Table 3** shows representative data which can be retrieved from the database. Development staff can see real-time production data, parameters for control models, or programs on their own computers. With this new environment, each sector in the Company can both work independently and also join forces to collaborate on development projects, utilizing analytical and simulation tools.

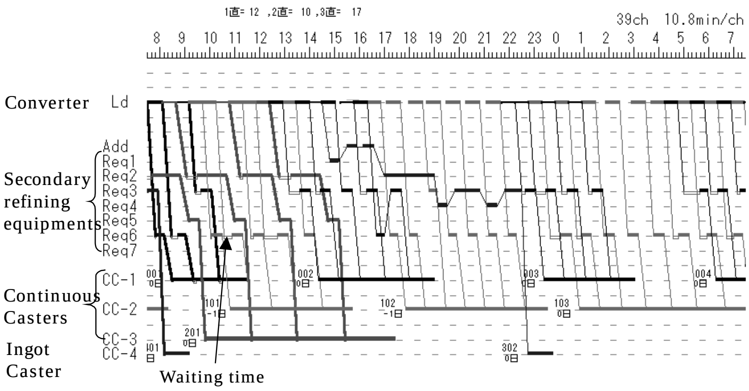


Fig.13 LD-CC diagram scheduled by advanced GA

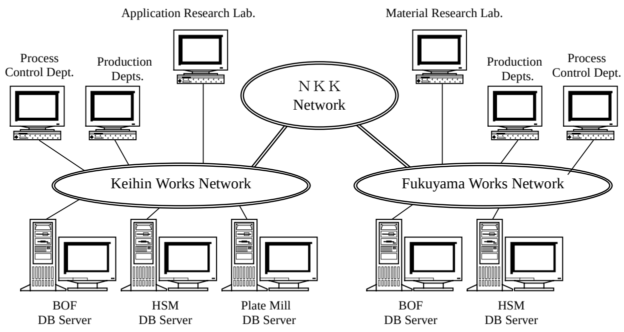


Fig.15 Configuration of collaboration network system

Table 3 Contents of DB

Items \ Process	BOF	HSM	Plate mill
Number of data (Storage period)	10000 heats (6 months)	6 months each coil	1 month each path
Data collection mesh	2 sec.	Top and bottom; 2m Middle; 5m	Top and bottom;0.2m +10ms AI
Data items	3500 items	160 items	100 items
Examples of data items	Oxygen flow rate Waste gas flow rate Sub material addition Bottom gas flow rate ・・・etc	Sheet width Sheet thickness AWC data Temperature ・・・etc	Plate width AWC data Temperature Roll gaps ・・・etc

In the conventional approach, the development of models required much time and manpower for collecting production data, analyzing them, and performing simulations. This new system has cut the development lead time to about one-third, as shown in **Fig.16**, enhanced development efficiency and shortened the time required for achieving productivity improvement. The system has also facilitated the analysis of quality problems and operation troubles, and enabled countermeasures to be taken quickly.

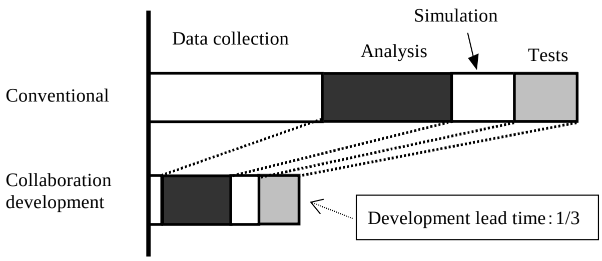


Fig.16 Comparison of lead times

5. Conclusion

This paper introduced some of the recent progress in technological developments by NKK in the field of plant engineering. These technologies have been highly evaluated by industrial organizations, academic societies and other companies, and some have received various awards, including the prestigious Ohkochi Technology Prize and the Information System Award.

The plant engineering sector of NKK does not limit its activity in the fields directly related to plant engineering such as mechanical or electrical control, but adopts a broad vision in its efforts to develop new technologies and improve production processes.

Plant engineering plays a crucial role in iron and steel making. We intend to combine rapidly advancing technologies of other fields with plant engineering, in close collaboration with research institutes and plant makers, to strengthen the foundation of the iron and steel industry.