NIPPON STEEL TECHNICAL REPORT No. 101 NOVEMBER 2012

UDC 681 . 2 / . 3

Technical Review

Development of System Control Technology

Kenji HASHIZUME*
Shinichiroh SHIMOI
Masato SUGIURA
Hirokazu KOBAYASHI
Jun SASAKI
Nobuo SUMIDA
Isao OHSHITA

1. Introduction

In this age of rigorous competition on a global front, the conditions surrounding steel manufacturing sites have become increasingly severe owing to the rise of China and other newly industrializing economies (NIEs), hikes in the price of raw materials, and the aggravation of global environmental problems, etc. Under that condition, the role that measurement, control and system technology (“system control technology”) should play in supplying high-quality products accurately, meticulously and efficiently has become more important than ever. In this technical review, we describe the advances Nippon Steel Corporation has made in system control technology, together with the latest developmental examples of system control technology.

2. Development of Technology in the Field of Measurements, Controls and Systems

Steelmaking is an exceptionally dynamic and complicated process in which physical, chemical, thermodynamic and metallurgical changes take place while interacting with one another. Besides, the process is subject to high temperatures, high pressures and much dust. Therefore, the system control technology that is applied in the steelmaking process must adapt to all those rigorous environmental conditions.

In order to mass produce tens of thousands of tons of steel per day on a stable basis while maintaining manufacturing accuracies in the order of tens of micrometers (μ m) or ppm for the steel-in-process that undergoes constant changes in phase under an adverse environment, Nippon Steel has long been implementing highly accurate measurements and automatic controls based on the appropriate control theories and physical model calculations (**Fig. 1**).

Looking back over the past three decades, since the 1980s, the steel industry has been required to meet increasingly diverse user needs, save more energy while cutting costs further. In order to meet those needs, Nippon Steel has developed not only new high-precision multidimensional measurement technology, but also “visualization technology” that enables large amounts of measurement information to be displayed at a time. Concerning control technology, the company has upgraded its independent device control to process control aimed at imparting the required quality to the product and to comprehensively optimizing control, while taking both logistics and scheduling into account.

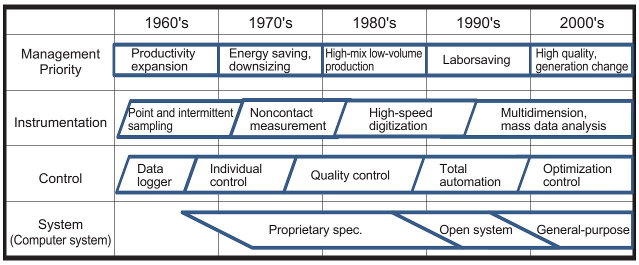

Fig. 1 Trend of system-control technology

In recent years, while searching for more sophisticated theories of measurement and control, the company has been striving to develop and put into practical use new operational supports with emphasis on “humans” to reduce the operators’ burden and enhance the operational efficiency in view of the mass retirement of experienced operators due to age limits.

With respect to system technology, Nippon Steel has built up the technology for in-house software development, and has been proceeding to make its own system architecture after the emergence of open systems in the nineties.

Recently, our system technology has become highly sophisticated and its realm has been extended to such areas as effective implementation of open systems to replace many obsolete systems introduced thirty years ago, and in-house software development for entire process control systems, including electrical control and instrument control.

3. Coke Oven Diagnostic Technology

As an example in which Nippon Steel incorporated measurement technology for high-temperature objects in its commercial production equipment, the coke-oven diagnostic system is introduced below. Many of the coke ovens in the domestic steel industry are becoming aged since they were constructed during the period of rapid economic growth. In order to prolong the life of those coke ovens by reducing such problems as defective pushing of coke cake from the coking chamber, it is a prerequisite to diagnose damage to the walls of the coking chamber. However, the coking chamber is extremely difficult to observe with measuring equipment, since its interior is always kept at 1,000℃ and its width is only 0.4 m as compared to 16 m in

* General Manager, System & Control Engineering Div., Plant Engineering and Facility Management Center
20-1, Shintomi, Futtsu, Chiba 293-8511

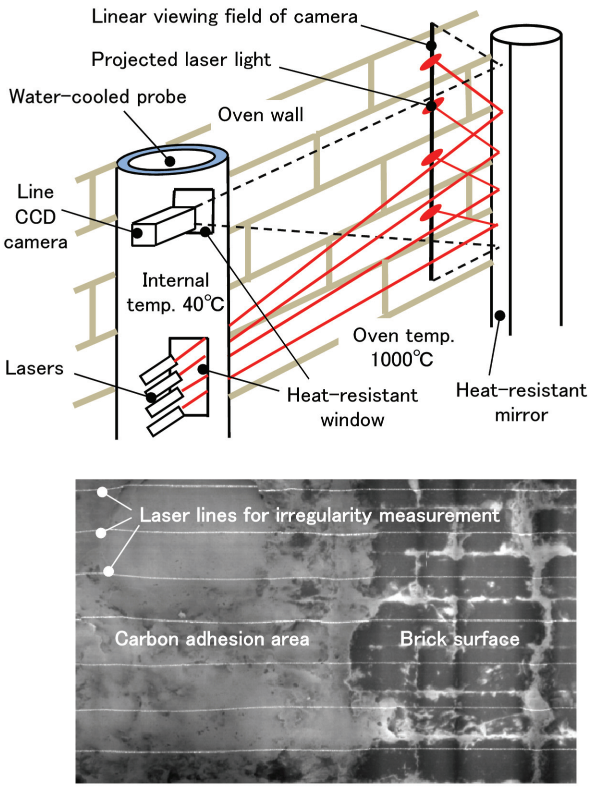

Fig. 2 Schematic structure of the oven-wall diagnosis apparatus (upper) and an example of oven-wall image (lower)

length and 6 m in height.

Nippon Steel has developed and put to practical use a heat-resistant diagnostic system that permits obtaining not only thermal images of the coking chamber walls by inserting a water-cooled probe into the chamber but also three-dimensional profiles of the chamber walls using laser metrology.[1, 2] With the system whose configuration is shown in **Fig. 2**, two-dimensional images of the chamber walls are obtained by moving the line CCD camera longitudinally. The irregularities of any damaged part are measured by projecting laser beams into the linear field of the camera obliquely from below. The laser beams on the images are observed as horizontal lines. If the chamber wall has irregularities, the laser beam fluctuates according to the principle of the light-section method.

The diagnostic system has dramatically improved the level of diagnosis of damage to oven walls that was formerly dependent on visual inspection from the oven opening. The coke-oven maintenance management employing the diagnostic system and a repair system developed at the same time has prolonged the service life of coke ovens. For the above development, Nippon Steel won the 2008 Okochi Memorial Production Prize,[3] as well as the 2010 Invention Prize of the Minister of Education, Culture, Sports, Science and Technology.[4]

4. IT-Based Operational Support Technology

Nippon Steel's technology for automatic control of its steelmaking line is considered among the most advanced in the industrial world. Nevertheless, stable steel production at the company still depends to a large extent on the know-how of experienced operators and maintenance engineers. On the other hand, because of growing need for laborsaving and the mass retirement of experienced personnel (in 2007), people working at the manufacturing sites are continually decreasing in number and relatively inexperienced operators are increasing in proportion. In order to cope with various problems which can arise under those conditions, the company has tackled the development and practical application of new IT-based technology to support the operators and maintenance personnel. A number of examples are given below.[5] Incidentally, the above technology was awarded the Fiscal 2007 Nikkei Monozukuri Grand Prix. (*Monozukuri* means manufacturing goods)

1) IT Field Note System: Examples of the key technologies that underlie this system are shown in **Fig. 3**. They are: (1) mobile noise-proof voice recognition, (2) the addition of a wireless communication function for commercial measuring instruments, and (3) electronic pens. By using one or more of the above technologies according to a specific operation or purpose, it becomes possible to support such operations as dimension measurement, tolerance checks, simultaneous stocktaking, defect recording, and operation logging.

2) Operation Navigation System: The salient characteristic of this system is that it permits skilled operators to register on a database those matters to be heeded and the rules to follow in making decisions as their explicit knowledge under specific manufacturing conditions/circumstances and to reflect them in operational guidance (see **Fig. 4**). During the operation, the system selects a suitable action to take according to specific manufacturing conditions or tracking results

Fig. 3 Technology for digitalization of production-memo information

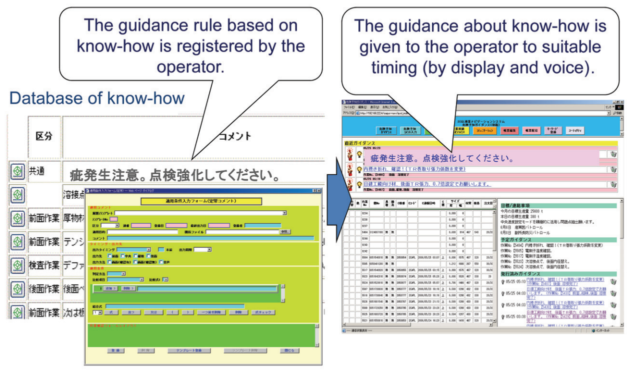

Fig. 4 Outline of the navigation system for plant operation

and gives appropriate instructions to the operator as required via screen display or voice. In order to enable even unskilled programmers to add and revise guidance rules easily, the system provides a screen for registration and permits linking not only text messages but also related electronic files to the system. At each plant that has introduced the system, it is used as a tool to improve routine operations. The system also helps prevent operational errors ascribable to carelessness or miscommunication of instructions.

5. Optimization System for Integrated Raw Materials Logistics

As an example of application of Nippon Steel's optimization technology to actual equipment, the optimization system for integrated raw materials logistics is described below. In the transportation of huge volumes of iron ore and coal Nippon Steel consumes, it is important not only to streamline the logistics of those raw materials but also to make a production plan which allows for a reduction in production cost and the maintenance of product quality. Formerly, production plans were generally made by planners in accordance with established rules based on their experience. Even when some system was developed to optimize production plans, it was intended simply to optimize production plans for the individual production processes.[6] Nippon Steel has developed a system capable of integrated control of information.[7] This manages the raw materials supply and demand from head office to the shipping site, then to the steelworks while optimizing the entire logistics of raw materials by a mathematical programming technique that makes full use of high-performance computers (**Fig. 5**).

Using the example shown in Fig. 5, we explain the ship unload-scheduling system for optimizing vessel allocation plans at unloading sites. When a plan involves both raw materials transported over a comparatively short distance (such as from China) and raw materials transported over long distances (e.g. Brazil), it is necessary not only to plan for the next six months or so, but also to manage the movements of vessels at the unloading berths on an hourly basis. In order to obtain solutions taking into consideration the various conditions mentioned above, the developed system is given a two-level hierarchical structure. At one level, the types, amounts, etc. of raw materials to be unloaded daily are roughly decided over an extended period of time, with due consideration given to appropriate inventory. At the other level, the results of the above decisions as fixed information, including details of the landing berths and times of arrival/departure, are optimized on an hourly basis. In addition, Nippon Steel has developed a technique that divides the planning period by time axes, finalizing the schedules only for the early part

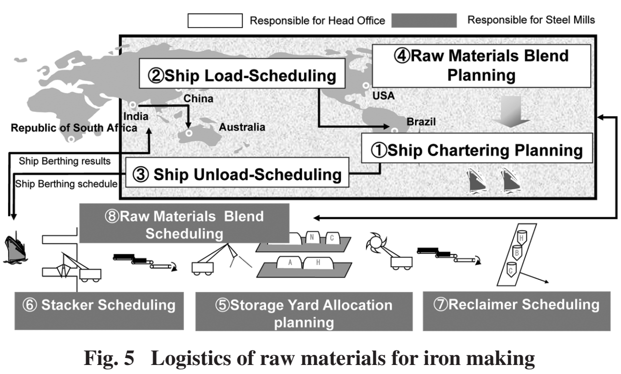

Fig. 5 Logistics of raw materials for iron making

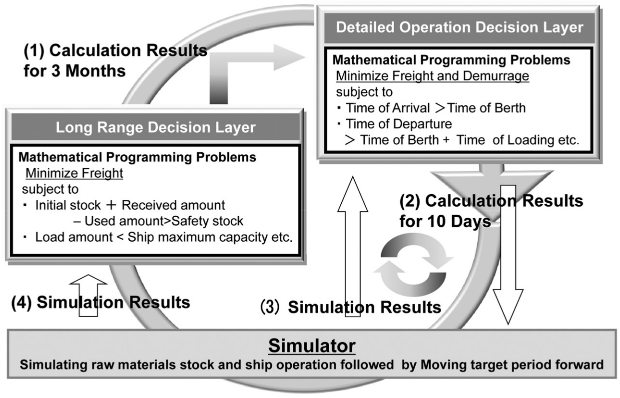

Fig. 6 Concept of time divide and proceed optimization

of that period, and repeating the process using a simulator. With the company's original technique that repeatedly divides a planning period by the combination of a hierarchical mathematical programming technique and a simulator (**Fig. 6**), it has become possible to obtain optimum solutions on a real-time basis during actual equipment operation.[8]

6. Open System Technology and Promotion of In-house Software

At Nippon Steel, with the aim of cutting cost drastically, the application of open systems, such as personal computers, was started in the field of process control computers, too, in the 1990s. In order to secure a quick system response in the order of seconds and a high level of reliability to withstand round-the-clock operation, the company developed new middleware for process control (NS Semi System®)[*1] for itself and applied the first model to the No. 5 continuous casting machine at Kimitsu Works in 1997. It also applied a Windows-NT PC Server in the master control of the steelmaking process for the first time in the world.[9] In addition, in 2001, the company applied an advanced Linux and relational database in the relining of the Kimitsu No. 3 blast furnace for the first time in the world.[10] In 2003, an EIC integrated operation control system for blast furnace plants using a large screen was implemented with open systems at reasonable cost. The system won the 2003 Nikkei Digital Engineering System Grand Prix (**Fig. 7**). The HMI (Human Machine Interface) has been built on the Web applying Internet technology. Various display and setting parts to control the steelmaking process have also been developed to allow for remote monitoring of the process.

As of 2011, Nippon Steel has the largest scale of hot rolling process control computer system built with open system components. As shown in **Fig. 8**, open systems account for almost all process control computer systems.[11] At present, there are a total of about 800 process control computers at the company, two-thirds of which are open systems. Many of the proprietary process control computers have become obsolete and increasingly troublesome. On the other hand, problems with open systems have been decreasing since 2006, thanks to the development and practical application of system diagnosis tools mainly for networks and other support functions.[12]

The salient characteristics of application software (AP software) for process control computers are: (1) Large scale (tens to hundreds

[*1] NS SEMI SYSTEM is a registered trademark of Nippon Steel in Japan.

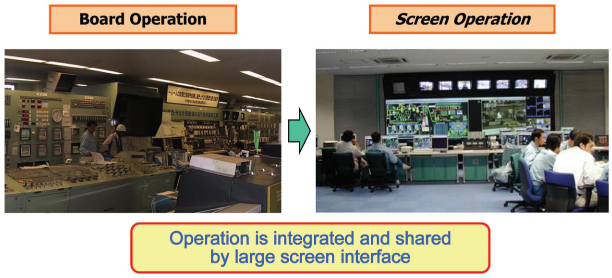

Fig. 7 New IT technology applied to Kimitsu-No. 4 BF

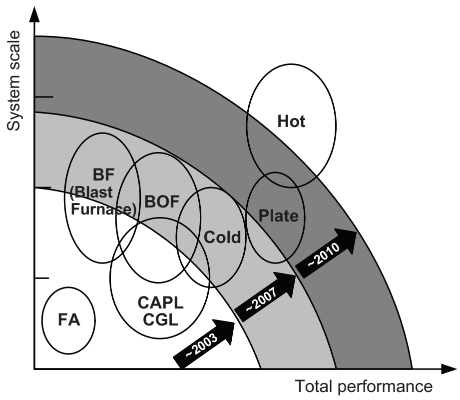

Fig. 8 Expansion of open system applied process

of thousands of steps), (2) Various types of processing (computation/transmission/data editing) to perform, and (3) High reliability/quick response is required. Since the 1980s, the company has been preparing its AP software all by itself in order to: (1) prevent the leak of its know-how of control/operation to other companies, (2) cut the cost of construction projects, and (3) speed up improvements in control/operation.

In 2004, the company developed a program source code converter aimed at minimizing investment in plant and equipment through effective utilization of the asset of AP software that was already in operation. In 2005, the company also developed a parallel-operation test tool to prevent system problems in an aged system renovation project by comparing the operations between the newly developed and existing systems. As a result, even with the existing, large-scale, proprietary process control computer systems and open systems after renovation, productivity improvement and smooth start-up have been achieved.[13]

In view of the improvement in performance of general-purpose programmable logic controllers and the progress of standard language (IEC 61131-3), the company started developing in-house software for electrical instrumentation, too, in the 2000s with the aim of rendering the operational know-how anonymous, implementing low-cost procurement from multiple vendors, and cutting the cost of production by enhancing software productivity. With the electrical instrumentation software design/production support function (E-CASE): (1) the reutilization rate and readability of software were improved through development of software components for steelmaking plants, (2) the correspondence between operation plans and software was clarified by expressing each plan using a combination of the appropriate software components, and (3) the errors and burden in preparing device lists and I/O variables were reduced by developing a device list design support tool.

In addition, in a virtual test operation system, through development of (1) a virtual plant screen and (2) a plant simulator that permits precise confirmation of electromechanical gauged operation while verifying the cycle time and that is capable of highly accurate simulation of physical phenomena, it has become possible to implement such preliminary confirmations as the verification of control logic and the rough adjustment of PI control gain, etc. almost comparable to those in actual equipment test operation. By previously eliminating defects in the software and operation plan which become conspicuous during actual equipment test operation, the company has improved the quality of software, minimized the duration of equipment shutdowns due to on-site test operation, and allowed vertical start-up by trained operators.[14]

7. Conclusion

In order to meet social demands for a reduction in CO_2 emissions and saving resources while developing new steel products that meet the needs of customers around the world, Nippon Steel must further accelerate the sophistication of its system control technology. To that end, it will become necessary not only to upgrade individual techniques but also to build a new system concept that fuses various component technologies together. We consider our IT-based operation support to be part of that new concept.

On the other hand, progress in computer technology that may be said to underlie system control technology has been remarkable. Concerning the CPU performance that was expected to reach a ceiling soon because of the apparent limit to the degree of integration, a new growth trend thanks to the development of multi-core technology can be seen. In the future, therefore, computers will continue to improve in both performance and capacity. It is the mission of engineers and researchers involved in system control technology to make the most effective use of limitless computer resources in the field of measurement, control and system and thereby contribute to improved productivity and quality with reduced costs.

References

1) Sugiura, M., Sakaida, M., Fujikane, Y.: The Society of Instrument and Control Engineers, Proceedings of 26th Sensing Forum. 2009, p. 165
2) Sugiura, M., Irie, K., Sakaida, M., Fujikane, Y.: The Society of Instrument and Control Engineers, Proceedings of 27th Sensing Forum. 2010, p. 343
3) Okochi Memorial Foundation: Reports of Achievements in Industrialization Awarded the Okochi Memorial Prize 2008. 2009, p. 98
4) Japan Institute of Invention and Innovation: National Commendation for Invention Summary of Winning Entries. 2010, p. 10
5) Yamashita, H.: The Iron and Steel Institute of Japan, 59th Shiraishi Memorial Lecture. 2007, p. 95
6) Konishi, M.: Tetsu-to-Hagané, 90 (11), 964 (2004)
7) Kobayashi, H., Saito, G., Yaji, Y., Suzuki, Y.: Bulletin of The Iron and Steel Institute of Japan (Ferrum). 16 (3) 166 (2011)
8) Kobayashi, H., Yaji, Y., Saito, G., Matsuoka, J., Okanishi, K.: Current Advances in Materials and Processes. 20 (5), 957 (2007)
9) Sumida, N., Ueno, T.: Shinnittetsu Giho. (379), 7 (2003)
10) Shimoi, S., Miyazaki, H., Sumida, N.: Shinnittetsu Giho. (379), 14 (2003)
11) Sumida, N.: The Iron and Steel Institute of Japan, Control Technology Sectional Meeting. (137), 2007, p. 1-8
12) Sumida, N.: The Society of Instrument and Control Engineers, Autonomous Distributed System Special Issue. 4 (6), 35 (2005)
13) Suyama, T.: The Iron and Steel Institute of Japan, Control Technology Sectional Meeting. (135), 2006, p. 2-3
14) Tsutsumi, Y.: The Iron and Steel Institute of Japan, Control Technology Sectional Meeting. (138), 2007, p. 1-5


Kenji HASHIZUME
General Manager
System & Control Engineering Div.
Plant Engineering and Facility Management Center
20-1, Shintomi, Futtsu, Chiba 293-8511


Jun SASAKI
General Manager, Dr.Eng.
Instruments & Control R&D Div.
Process Technology Center


Shinichiroh SHIMOI
Department Manager
System & Control Development Dept.
System & Control Engineering Div.
Plant Engineering and Facility Management Center


Nobuo SUMIDA
Manager
System & Control Development Dept.
System & Control Engineering Div.
Plant Engineering and Facility Management Center


Masato SUGIURA
Chief Researcher
Instruments & Control R&D Div.
Process Technology Center


Isao OHSHITA
Manager
System & Control Development Dept.
System & Control Engineering Div.
Plant Engineering and Facility Management Center


Hirokazu KOBAYASHI
Senior Researcher
Instruments & Control R&D Div.
Process Technology Center