NIPPON STEEL & SUMITOMO METAL TECHNICAL REPORT No. 121 MARCH 2019

Technical Report

UDC 621 . 771 . 2 : 681 . 3

Real-time OBserver and Operation Controller with Open PC

Kenji SORAO* Takeo HOSHINO
Yoshifumi YAMANAKA

Abstract

This paper proposes a new real-time control system for steel making processes that has the "high computing ability and superb functionality of personal-computers (PCs)", and the "stability of fixed-cycle operation of the processing cycle and high reliability of programmable-logic-controllers (PLCs)". The new signal processing techniques we developed can realize use of PCs as real-time controllers for the steel rolling process. The proposed new control system can significantly improve problems of the conventional system such as low flexibility in the development and implementation of new control functions. In this paper, we also introduce several application examples in steel making plants.

1. Introduction

The steel production process requires highly advanced and stable control functions due to its large scale, operating conditions under large disturbances, and required accuracy of product quality. Also, the rolling process in the steel production process requires high-speed process control with a sampling time in the order of milliseconds, which differs from the upstream processes including blast furnaces or chemical plants.[1)] To this end, in steel production process control that requires these high performances, an industrial programmable logic controller (PLC) that can achieve operation stability and high-speed processing has been conventionally used for a Level 1 control system that requires high-speed processing. These systems have low flexibility in implementation of the control logic due to limitations of central processing unit (CPU) capability or software development environment.

However, with the advancement in control system specifications exemplified by the network in recent years, the open system computer represented by a general-purpose personal computer (PC) can be directly connected to a Level 1 network that performs real time processing. This reduces the implementation restrictions of the real time control logic that has been a problem in conventional control systems.

However, stability of the sampling time is essential in real time process control and free programming using a general-purpose PC may not be feasible. We have established a method that sophisticatedly combines the advanced value computation capacity of a general-purpose PC and the flexible software development environment with the high reliability and stability of an industrial PLC, and developed a new control system that enables the process observation based on the advanced model computing and the operation control function using the observation results in a real time order of milliseconds.

The following describes the outcome expected from this new control system using the steel rolling field, considered the most effective field for application of the proposed new control system. Then, the signal processing method that enables the new control system is described and application examples of the steel rolling process are introduced.

2. Outcomes from New Control System

2.1 Current status of steel rolling process

In the steel rolling process, while maintaining a comprehensive and good balance of thickness, sheet shape, tension, temperature, etc. of the steel sheet, advance automatic control technology such as automatic gauge control (AGC) has been used to produce steel sheets at the transfer speed of nearly 100 km/h in a stable manner. However, the production volume of high tensile steel sheets that have both thinness and strength has increased recently. The characteristics of these steels vary significantly due to the fluctuation of tension or temperature during rolling. Therefore, according to the conventional control regulations, non-satisfactory performance is increasing. In addition, the rolling phenomenon of these highly functional products is not yet clarified in many parts. A flexible control system that supports the ever-improving operation technology in a timely manner is highly expected.

In addition, there has been a reduction in the number of skilled

* Senior Manager, Head of Dept., Systems & Control Technology Dept., Systems & Control Engineering Div., Plant Engineering and Facility Management Center
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

operators who have advanced operation expertise and can perform the techniques that cannot be covered by automatic control alone. Such reduction in the number of skilled operators is also similarly found in the equipment maintenance departments. This reduction of on-site skills is a concern because optimum operating conditions must be maintained at all times, which requires recognizing subtle changes in the overall process including equipment and taking the necessary measures at an early stage.

For the future rolling control system, three important points must be considered: (1) useful for clarification of unknown process phenomenon, (2) timely implementation of solutions for clarified phenomenon, and (3) assisting operation or supplying maintenance information for non-skilled operators.

2.2 Problem of conventional rolling control system

Figure 1 shows the conventional typical steel rolling control system. The process computer (hereinafter referred to as P/C) positioned in Level 2 is connected to the business computer positioned at a higher level and manages the production of the overall plant. Specifically, setting computations for PLC or distributed control systems (DCS) in Level 1 are performed and operation information is collected, analyzed and learned for next setting computation. Thus, a highly advanced computing model is installed. In the era before the development of current PLC or DCS, the P/C performed real time control called supervisory computer control (SCC) or digital direct control (DDC). Currently, the scale of the P/C has been further downsized and control at the level of seconds with a general-purpose PC using UNIX®[*1] or Linux®[*2] for the operating system (OS) is now widespread. In contrast, real time control at the level of ms is performed by PLC or DCS in which excellent high-speed processing is available.

Complicated model computing is performed by P/C and high-speed real time sequence control and loop control is performed by PLC or DCS. Meanwhile, devices including PLC have undergone significant improvements recently. Furthermore, with the spread of the IEC 61131-3 standard language, freedom of programming has increased in the real time system. However, since malfunction of a PLC directly connected to a Level 0 sensor or actuator cannot be tolerated, the program must be developed by certified operators. Another problem is the use of an older version of CPU, which lacks the capability for advanced computing such as matrix or convergence computing.

It is also difficult to perform simultaneous on-line verification (parallel running) of the new function due to the low computing capability of the PLC or other restrictions. Therefore, off-line verification is sufficiently performed using architecture or programming language that differs from that of the PLC, which is used for actual process control in the same way as a general-purpose PC. Therefore, the developed function was re-installed on the online PLC after re-coding and sufficient trials including debugging of the online coded software were performed. However, immediate practical use of the new function was problematic.

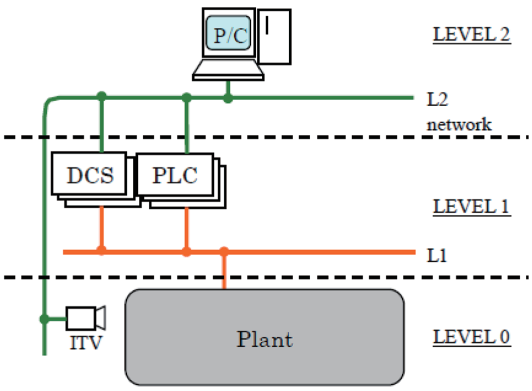


Fig. 1 Typical conventional system

2.3 Expectation for new control system

Figure 2 shows the configuration of the new control system. In recent years, the developed open network has been applied both in Level 1 and Level 2. In addition, by coordinating the industrial PLC developed by us with the PC, a general-purpose FA-PC that is open type equipment was introduced in Level 1 of the real time system. The introduced PC can input/output any information on the real time network (L1 network in Fig. 2). It can exchange information with the L2 network in the upper level.

In recent years, the P/C has been positioned at Level 1 in terms of hardware. The prerequisite is that the PC introduced here uses general-purpose OS (Windows®[*3], etc.) that operates the general-purpose application software. This allows advanced model computing, which has been conventionally performed on the P/C in seconds, in real time in the order of milliseconds. Also, the unique model developed on the PC concerned can be used as is for real time monitoring of the process or operation control. Therefore, the time required for conversion to the industrial program and its training are not required.

By using this new control system, the following are expected.

(1) Analysis of operation problems

For example, PC1 in Fig. 2 works as an operation analysis PC. Through the L1 network, real time sensor measurement value or control output is taken and the operations are analyzed successively by the process analysis model configured in PC. Since PC1 is a normal PC, the program language to which you are accustomed can be used to establish the analysis model. For example, a sophisticated process model is configured with a general-purpose tool such as MATLAB, etc. and online process simulation that works in real time can be performed.

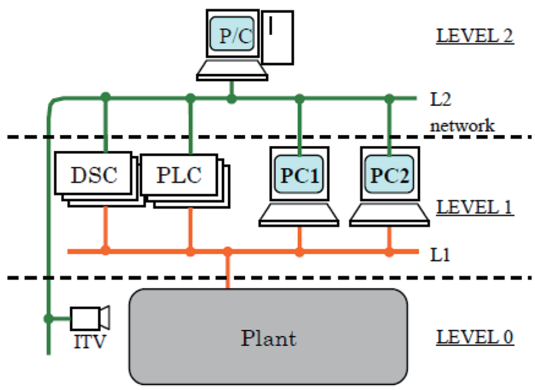


Fig. 2 Real-time observe and operation controlled system

[*1] UNIX is a registered trademark of The Open Group.
[*2] Linux is a registered trademark of Linus Torvalds.
[*3] Windows is a registered trademark of Microsoft Corporation.

(2) Verification and evaluation of new control method

If a new control method is prepared using the problem analysis above, it was conventionally necessary to recode the system for an actual PLC after an offline simulator was established and the new control was verified. In the new control system, PC1 is set to an online simulator in Fig. 2 as in the previous example and the new control idea is installed in PC2. Thus first, exchange of information between PC1 and PC2 can verify parallel running of the control regulations. After verification, the PC2 output can be input in the actual unit process as is. In this way, it is not necessary to implement new coding and debugging.

However, to enter the PC output in the actual unit, a system is required to ensure the signal reliability. This is explained in the following section.

(3) Visualization of operation

Although it is similar to the operation analysis above, preparation of the observer or software sensing function that estimates the process status on PC1 can visualize the physical quantity that cannot be measured or can detect minor changes in the aging of the plant. This function can visualize and quantify the intuition or experience of skilled operators and it can also be used for preventive maintenance. In this way, it can greatly stabilize the operation. An advanced mathematical model is required for this observer. However, in a new control system that allows easy use of a high grade language, this can be easily achieved from the aspect of engineering.

3. Signal Processing Method that Enables New Control System

If a general-purpose PC is used for the Level 1 layer in the new control system described above, improvement of its stability and reliability is essential. In this method, coordination of PLC or DCS that ensures stability and reliability with a general-purpose PC improved the reliability of the overall system. An explanation of the method is provided in the following sections.

3.1 The necessity of stable, fixed-cycle operation and high reliability for the control unit

In the general-purpose process control field that includes steel plants, the following control operation is implemented as one cycle: the process quantity is measured and input in the control system as data; from its measurement value and the target value, the operation quantity of the operation terminal is calculated using the control algorithm such as the Proportional-Integral-Differential (PID) control, etc.; and it is output as a signal to the actuator, etc. of the operation terminal. In this operation, the control algorithm such as PID control generally includes an integral element or differential element. If these are operated with a digital controller providing discrete action, the processing time T of one cycle is included as in Formula (1) or (2). In the process control, time T of this one cycle operation should be constant.

Example of integral processing

$$y[k] = y[k-1] + (u[k-1] + u[k]) \times \frac{2}{T} \tag{1}$$

Example of differential processing

$$y[k] = \frac{(u[k] + u[k-1])}{T} \tag{2}$$

$y[k]$: Differential/integral computing result in sampling k

$u[k]$: Input value in sampling k

The new control system proposed in this paper features an open computer such as a general-purpose FA-PC in Level 1 of the real time process control/monitoring system. In contrast, the PC that is used for the new control system assumes general OS (Windows, etc.) as described in the previous section. In this OS other than so-called real time OS, the time occupying the CPU is not stable. Processing in a regular cycle, therefore, cannot be performed by the single unit itself. Thus, to successfully operate this system as the control unit of the actual process, it is essential to ensure "stability" that is the constant processing cycle time of the overall control system including processing in the PC as described above.

To use a PC that is inferior in reliability as the unit for the industrial PLC for the steel production process requiring high reliability for the control unit, it is necessary to improve the signal reliability that is output from the PC.

3.2 Ensuring fixed-cycle operation for the new control system

To ensure stability of the control signal in the proposed new control system requires "synchronizing PC computing with the PLC cycle processing time to ensure stability of the processing cycle time of the overall control system." Specifically, time T_s on the PLC side is appropriately set under the conditions shown in Formula (3).

$$T_s > (\text{Computing time in PC} + \text{Transfer delay}) \times \alpha \tag{3}$$

α: Allowance percentage $(1 < \alpha)$

Figure 3 shows the image of each processing time when one cycle operation time interval in the PLC is T_s according to Formula (3). Appropriate selection of the one cycle operation time interval on the PLC side can achieve consistency for the overall process control processing time of "Input of process data to output of operation signal (T_s in Fig. 3)" if there is variation (t_1 to t_3 in Fig. 3) in the PC processing time. In this way, stability in the control system including the PC that cannot maintain consistency of the processing operation can be achieved. Setting the cycle time in Formula (3) applies only to the function that operates the unit using the new control system. We add that any cycle time can be selected as before for normal function, which is processed by the PLC only.

3.3 Ensuring high reliability for the new control system

In addition, to use the general-purpose PC in the control system of the steel production process requiring high reliability, it is also essential to improve reliability of the control signal. Stability of the control cycle can be achieved by the measures described above. However, for cases in which the processing time in the PC increases unexpectedly (freeze of the PC in the worst case scenario), other ac-

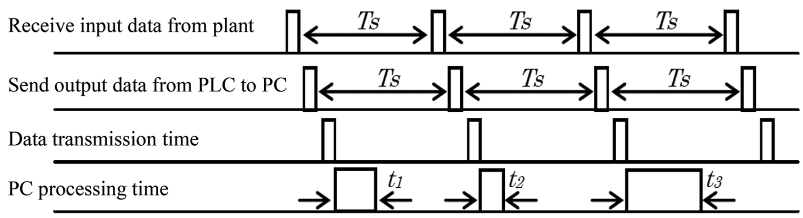


Fig. 3 Constant-cycle time operation with new real-time control system

tions may be required.

In the proposed new control system, reliability of the control signal can be ensured by "checking the signal and stability soundness of the PLC from the PC."

The new control system performs the following functions.

(1) Providing various interlock conditions
Even if the computing in the PC is normal, the PC computing value in question cannot or must not be used depending on the machine/operating conditions, etc. in the plant. Then, so-called interlock processing is performed by the PLC.

(2) Soundness check of PC computing value
Soundness of the PC computing result signal including the upper/lower limit check that determines if the value calculated by the PC is within the upper/lower limit range that is tolerable by the plant is checked by the PLC.

(3) Stability check of control cycle
Synchronized operation status (stable operation status of the PC) of the PC is checked by the PLC.

(4) Processing for lower reliability of the PC
If the above check determines that signal reliability on the PC side cannot be ensured, various preventive actions such as discarding the data in question are taken by the PLC.

4. Application Example of New Control System

Nippon Steel & Sumitomo Metal Corporation is advancing the use of these new control systems with varying degrees of success, some examples of which are presented in the following sections.

4.1 Application example (1)

In the plate leveler,[2)] it was necessary to achieve shape correction control, requiring very high order and complicated computing, at high speeds of 30 ms or less in a constant cycle. However, in the control system configuration of a general steel production system consisting of conventional PLC and P/C, this was difficult to achieve due to limitations of the computing capability and signal transmission.

Therefore, using the new control system concept, the system shown in **Fig. 4** was established and complicated and high order computing processing was performed with a PC with high computing capability. Thus, we achieved high speed and constant cycle operation at 30 ms by using the signal processing method in the previous section, and a new steel shape correction machine was put into practical use (Refer to **Fig. 5**). Also, as the PC in question can operate so-called general-purpose office automation (OA) software or analysis software, evaluation/verification of the new control method can be simultaneously performed with the terminal in question. In this way, more efficient startup adjustments of the control function were also realized.[3)]

4.2 Application example (2)

Along with the change of the control method in the rolling plant, it was necessary to newly search hundreds of the control gain tables which were classified by steel type, thickness and width. With the new control system configured on the rolling plant control system shown in **Fig. 6**, the function that automatically obtains the optimum control gain table for each material category was established.

In the system shown in Fig. 6, the general-purpose analysis software installed in the open-source PC is used and characteristics of the rolling sheets that cannot be measured by sensors are estimated in real time with a cycle of several ms (**Fig. 7**). According to the characteristic parameters obtained, it has become possible to derive the optimum control gain online (**Fig. 8**). Using the system in question, automatic derivation of the control gain table that was previously achieved through trial and error for about two months can be accurately identified in a few days during operation before change of the control method, and the reduction of working time for adjustment of the control system is now possible (**Fig. 9**).

5. Conclusions

We propose a new control system with a sophisticated combination of high computing capability of the open system computing unit represented by a general-purpose PC, high functionality using abundant programming languages and various types of application software, stability of the industrial PLC and high reliability, and introduced examples of this system used for actual steel production processes.

The proposed new control system can significantly improve problems of the control system of the conventional steel production process such as low flexibility and mobility in the development and implementation of new control functions. Furthermore, it can achieve three points that are required for the future steel production process control system: (1) Clarification function for unknown phenomenon in the process, (2) Immediate implementation of solution for clarified phenomenon, (3) Operation support for non-skilled

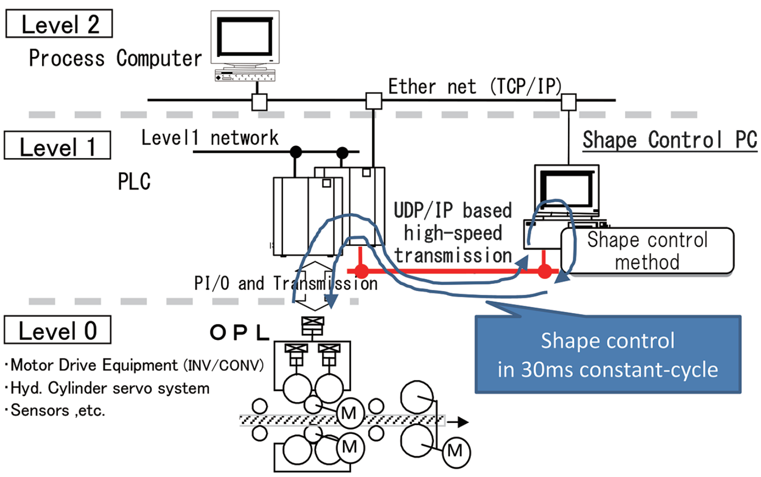


Fig. 4 Example of the application of new real-time control system in plate leveler

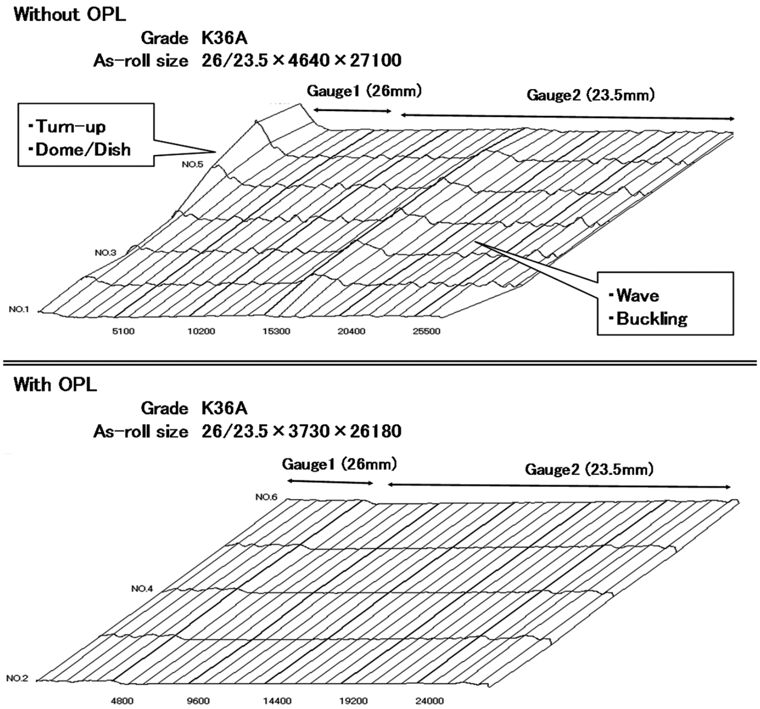


Fig. 5 Result of plate leveling

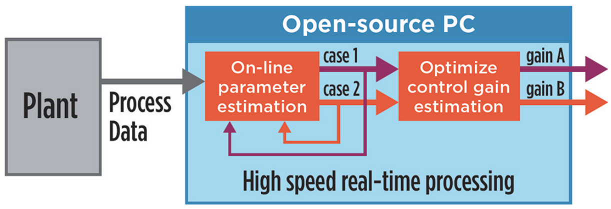
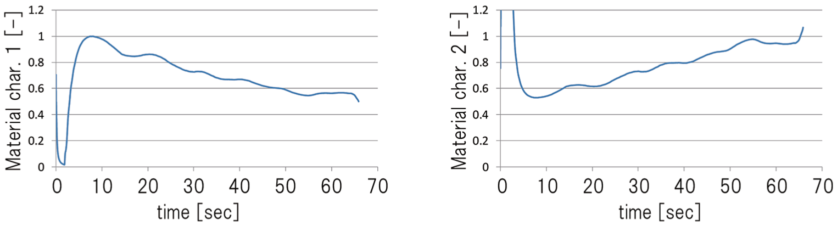
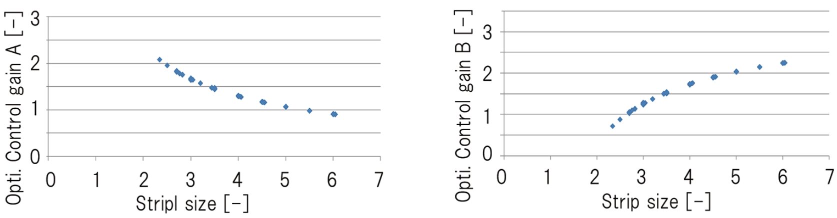


Fig. 6 System configuration diagram



(a) Strip characteristics "1" (b) Strip characteristics "2"

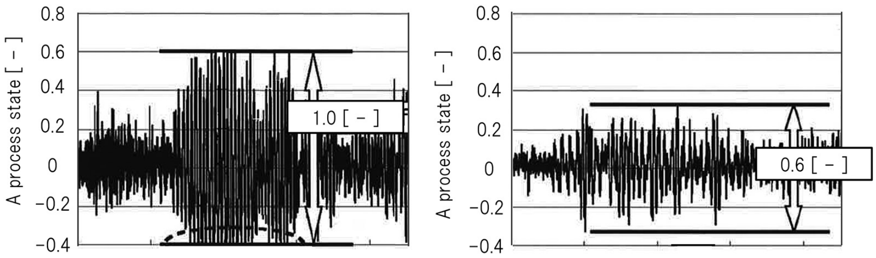
Fig. 7 Result of strip characteristics estimation



(a) Control gain "A" (b) Control gain "B"

Fig. 8 Result of automatic control gain setting

workers or achievement of function that provides maintenance information. Using this system, the AI technology or image processing for which the technology has recently been advanced can be applied to the observation control technology of the steel production process. As future work, we aim to increase the applications of this control system.



(a) Without optimized control gain (b) With optimized control gain

Fig. 9 Result of using optimized control gain

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Kenji SORAO
Senior Manager, Head of Dept.
Systems & Control Technology Dept.
Systems & Control Engineering Div.
Plant Engineering and Facility Management Center
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511


Yoshifumi YAMANAKA
Senior Manager
Systems & Control Engineering Dept. (Rolling)
Equipment Div.
Kimitsu Works


Takeo HOSHINO
General Manager, Head of Div.
Equipment Div.
Muroran Works