High Response Control System and Diagnosis System for Servo Valve

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25 sets of new high response control systems developed for the hydraulic roll gap control systems of rolling mills in the end of 2000 were delivered up to the end of 2007. These have features of easy programming, expansibility, and multipurpose use compared with the conventional response control systems developed in 1993. Subsequently, the servo valve diagnosis system was commercialized using its high-speed data processing capacity. The versatile adaptability of the new high response control system permits applying to other controlling units besides the roll gap control. Its technical description and applications are described.

1. Introduction

In 1968, we commercialized the world's first hydraulic mill equipped with hydraulic roll gap control system using position sensors and electro-hydraulic servo valves. (1) Since then, our hydraulic roll gap control system has had its adaptability expanded to cold rolling mills, hot rolling mills, plate rolling mills and seamless tube mills, with the dramatic improvements in the high responsiveness of the hydraulic roll gap control system and the thickness accuracy achieved by the control unit for variable mill modulus control that was adopted together with the hydraulic roll gap control system. During that time, we have achieved many improvements and developments regarding the hydraulic roll gap control system.

Examples are 1) applying digital position sensors in 1972 (2), 2) developing direct-drive servo valves and direct-mounting them to hydraulic cylinders in 1982 (3), 3) switching from hard wire logic that used IC components to a software sequence using general-purpose programmable logic controllers (PLC), 4) replacing the circuit, which is composed of a combination of single-function ICs for addition, subtraction and other functions and operating amplifiers, by a program running on a CPU for the calculation for position control that requires high response in 1994 (4). This adoption of a CPU for calculating the mill's position control improved its adjustment and maintenance abilities compared with the conventional method.

However, this resulted in restriction on interfaces with external equipment, and thereby raised demands for improvement and refinement. For example, 1) the control system cannot be used as a control system for other functions, 2) high response is required for sections other than the position control calculation section (for example, calculation for variable mill modulus control), 3) the assembler program requires special software engineers for software modification, and 4) the data collection system for equipment diagnosis should be mounted as standard equipment to improve the added value.

To meet those demands, we developed a next-generation general-purpose high response control system and practically applied it to the hydraulic roll gap control system. Since the first practical application of the unit in December 2000, we have further improved and refined the control system, and have delivered a total of 25 sets by the end of December 2007. All of them are still working steadily.

This paper outlines the high response control system, VMPC (V type Multi Purpose Controller), developed and practically applied against this background, as well as the servo valve diagnosis system using a data collection technique in a high response control system and that has been delivered to a company in Brazil.

2. Configuration and features of the hydraulic roll gap control system using the high response control system (VMPC)

The configuration of the hydraulic roll gap control system for a rolling mill is shown in **Fig. 1**. The servo

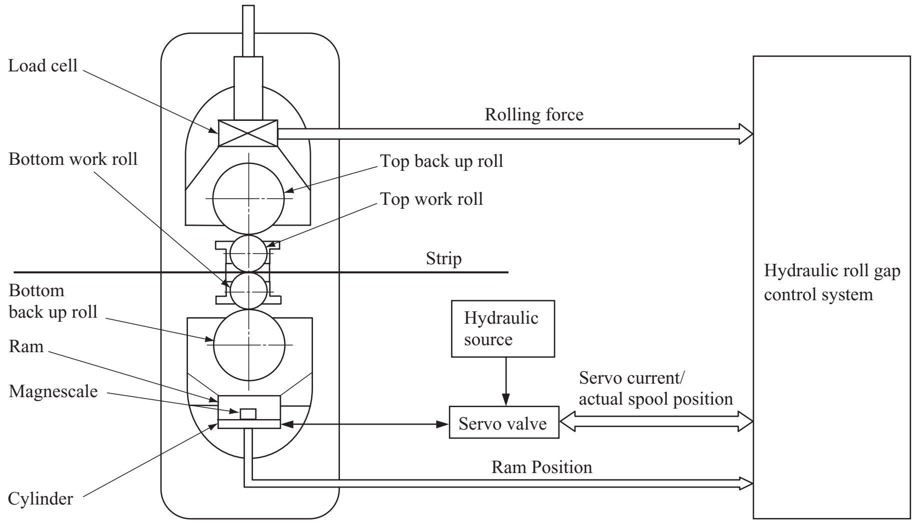


Fig. 1 Configuration of hydraulic roll gap control system

valve controls the volume of hydraulic oil flowing out of and flowing into the hydraulic cylinder and thereby moves the ram up and down to control the gap between the top and bottom work rolls. The position sensor (magnescale) installed in the cylinder detects the ram position to indirectly control the gap between the top and bottom work rolls.

The configuration of the hydraulic roll gap control system with VMPC is shown in **Fig. 2**, and the internal arrangement of hydraulic roll gap control system is shown in **Fig. 3**. This control system consists of a VMPC that performs the calculation for position control for two axes, the calculation for variable mill modulus control and the data collection for equipment diagnosis; a sequence control section with PLC ; a human machine interface (HMI) section with a touch operation display ; and a personal computer for operating the equipment diagnosis function and for editing and storing data. The features of VMPC are described below.

2.1 Configuration of VMPC system

Up to four control sections with VMPC can be configured, by allocating 5 slots to each controller from among 20 slots of the dedicated rack. Each control section consists of one CPU board and up to four I/O boards. I/O boards with various kinds of interfaces are available, enabling interfacing with external equipment in various ways. In addition, desired I/O boards can be selected depending on the required functions. This way, the system has great versatility.

Figure 4 shows the configuration of VMPC system. Users perform programming by selecting I/O boards suitable for the functions to be realized in individual control sections. **Table 1** shows the relations between the individual control sections shown in **Fig. 4** and the functions shown in **Fig. 2** for a hydraulic roll gap control system with standard functions. I/O boards are used for interfaces between each controller and external equipment, while Dual Port RAM, Ethernet and an I/O boards are used for interfaces between control sections.

2.2 High response achieved by VMPC

When CPU was adopted for the position control calculation section in 1994, three control systems (calculation cycle of 1 ms) based on the assembler programs were used (two for calculation of position control and one for calculation for variable mill modulus control). By adoption of VMPC, those control systems were replaced by one control section with one CPU, which realized the calculation cycle of 0.8 ms.

The control cycle of each control section with VMPC can be set in a range of 0.5 to 1 000 ms in 0.1 ms units. Note that the settable control cycle is restricted by the volume of calculations by the program and thus the control cycle must be set to be longer than the program processing time. For your reference, the position and load calculation section shown in **Fig. 2** has the load factor (the ratio of the actual program processing time to the set control cycle) of about 80% when the control cycle is set to 0.8 ms. This means that about 0.64 ms is actually required for program processing.

This processing speed is high enough for VMPC to perform functions that require high response and were conventionally operated by board computers other than the position control calculation section (such as the calculation for variable mill modulus control, the calculation for roll gap and the detection of timing for impact drop compensation). This has already been practically applied to and demonstrated on several machines.

2.3 VMPC programming

When a CPU was adopted in 1994, assembler language programs were used and thus only special software engineers could build the software. On the contrary, VMPC uses the dedicated language Visual Module Designer (VMD) for programming. VMD consists of combinations of visualized modules (instructions)

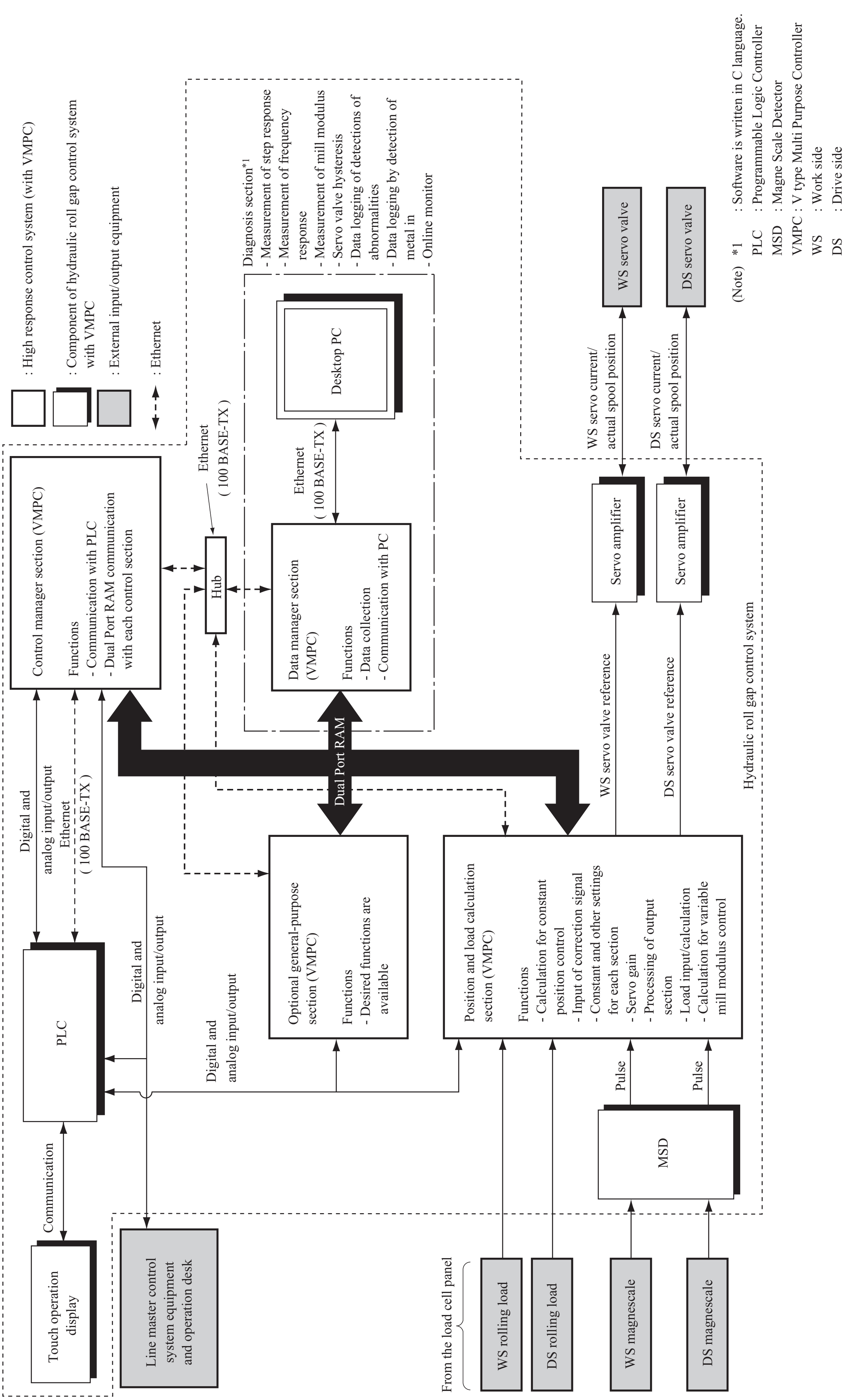


Fig. 2 Configuration of hydraulic roll gap control system with VMPC

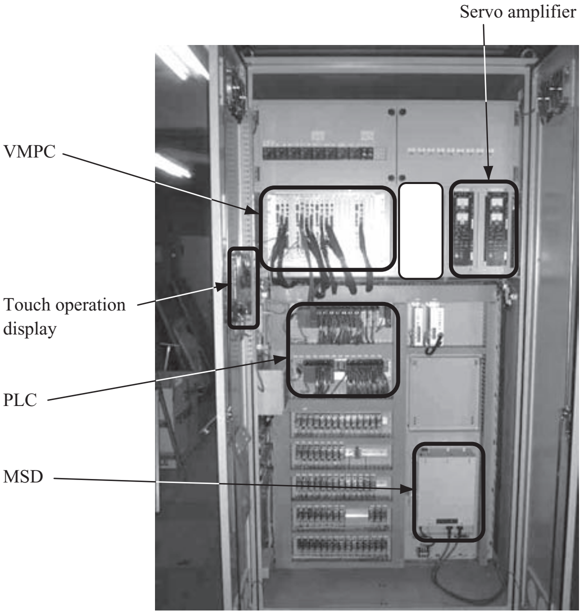
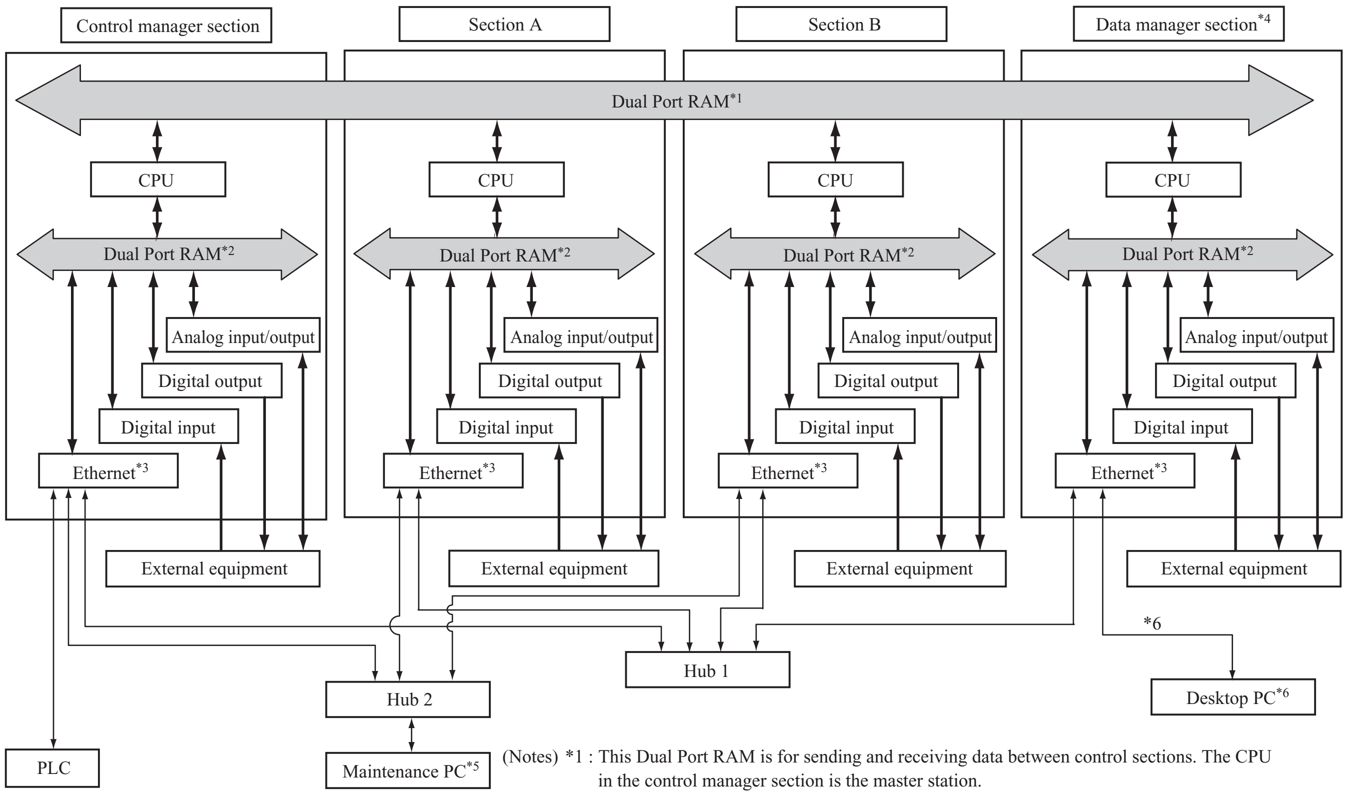


Fig. 3 Internal arrangement of hydraulic roll gap control system

Table 1 Functions of VMPC control section for hydraulic roll gap control system

Control section in configuration of VMPC system shown in **Fig. 4**	Function of hydraulic roll gap control system shown in **Fig. 2**
Control manager section	Control manager section - Communication with PLC - Dual Port RAM communication with each control section and calculation section
Section A	Position and load calculation section Functions - Calculation for constant position control - Input of correction signal - Constant and other settings for each section - Servo gain - Processing of output section - Load input/calculation - Calculation for variable mill modulus control
Section B	Optional general-purpose section*1
Data manager section	Data manager section*2 - Data collection - Communication with PC

(Note) *1 : This option is not used for a hydraulic roll gap control system with standard functions.
*2 : The CPU for diagnosis function is mounted for a hydraulic roll gap control system with standard functions.



(Notes) *1 : This Dual Port RAM is for sending and receiving data between control sections. The CPU in the control manager section is the master station.
*2 : This Dual Port RAM is for sending and receiving data between I/O and the CPU in a control block.
*3 : Ethernet ports of two channels are provided on a CPU board, while Ethernet ports of one channel are provided on a dedicated Ethernet board.
The dedicated Ethernet board can be mounted only in the control manager section and it is dedicated to communication with PLC. Two ports on the CPU board are provided for program maintenance and for broadcast communication between control sections.
*4 : A CPU board for diagnosis can be mounted in the data manager section. The CPU board for diagnosis has two channels of Ethernet ports, which are provided for broadcast communication between control sections and for the PC for operating the diagnosis function.
The program of the CPU for diagnosis cannot be customized by users.
*5 : This PC is for program maintenance in each control section.
*6 : The PC for diagnosis function is connected only when a CPU board with the equipment diagnosis function is mounted.

Fig. 4 Configuration of VMPC system

so that people other than engineers with specialized knowledge can also build arithmetic circuits, unlike the descriptive programming languages.

As an example, **Fig. 5** shows a part of the circuit diagram by VMD for the position and load calculation section shown in **Fig. 2**. A total of 190 modules are used to enable two-axis position control, calculations of the variable mill modulus control and the load scaling function.

2.4 Collection of data for diagnosis

In 1994, the components of the diagnosis system were changed from a conventional combination of a CPU board and an engineering work station (EWS) to a combination of one control section with VMPC and a personal computer. Integration into one control section with VMPC, instead of using a general-purpose CPU board, enabled signals other than analog signals to be collected. (See the configuration of VMPC system in **Fig. 4**.) In the diagnosis system used around 1994, the contents of signals to be collected were limited in advance by hardware and software, but adoption of VMPC enabled the registration and collection of any signals using a personal computer for diagnosis operation.

Compared to the situation in 1994, the flexibility for each function was improved thanks to the improved performance of the CPU board in the data collection section and personal computers. Addition of the online monitor function (including logging by detection of metal in) also eliminated the need to continuously connect and operate separately-installed measuring instruments for signal measurement during rolling. **Table 2** shows the functions of the diagnosis system.

As described above, cost reduction was achieved by adopting the VMPC and a personal computer for collection of data for diagnosis, and the standard installation of the diagnosis system to the hydraulic roll gap control system was enabled by fixing the program thanks to the improved flexibility for signals to be collected.

3. Servo valve diagnosis system

3.1 Background of development of the servo valve diagnosis system

The servo valves used for rolling equipment ① have a performance greatly contributing to product quality, ② are important devices for operating the equipment, and ③ are precision machines containing wear components.

Table 2 Functions of diagnosis system

Item	Function
Offline function	- Measurement of step response at constant position control - Measurement of step response for servo valve - Measurement of frequency response at constant position control - Measurement of frequency response for servo valve - Measurement of hysteresis for servo valve - Measurement of bending step response - Measurement of hysteresis for bending pressure control - Measurement of mill modulus
Online function	- Logging by trigger - Measurement of null bias current of servo valve - List of trigger factor for logging - Logging by detection of metal in - Display of registered data on the online monitor

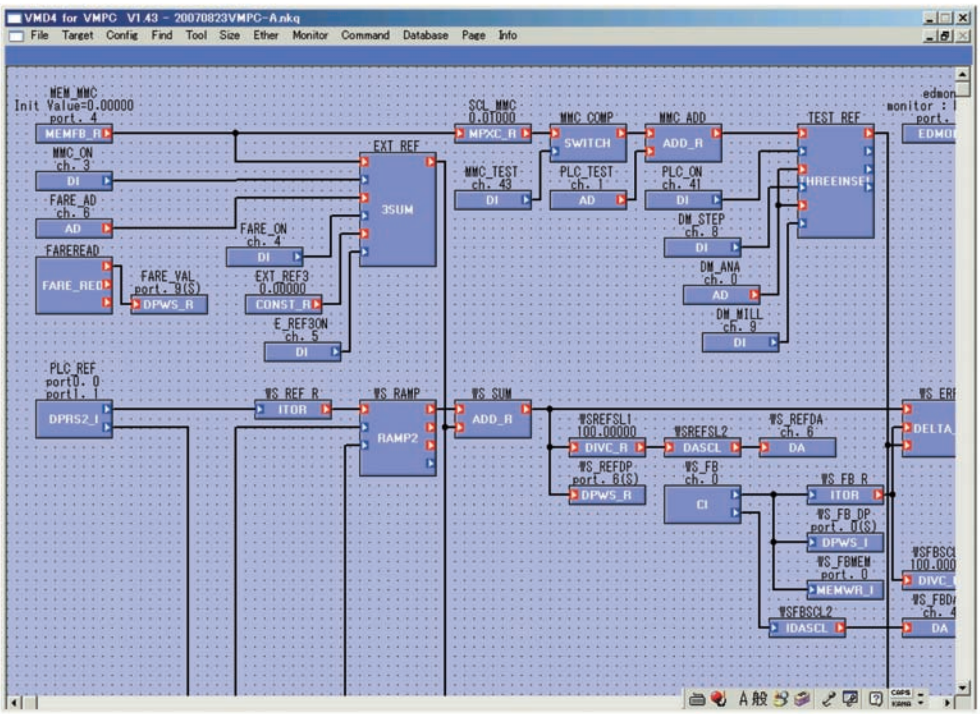


Fig. 5 Circuit diagram by VMD

For these reasons, the servo valves must be periodically overhauled to maintain their performance. In most cases, servo valves are uniformly overhauled after they have been used for a certain period, rather than being overhauled based on specific evaluation of how much they have deteriorated. There are also cases where a servo valve is overhauled only after there has been an abnormality attributable to it.

Therefore, some servo valves that have not yet deteriorated may be overhauled unnecessarily, and other servo valves may deteriorate too fast and generate an abnormality. Especially, for overseas users, servo valves should be overhauled at just the right moment and in the shortest period of time, in consideration of the quantity of spare servo valves and the cost for transporting the servo valves for overhaul.

Against this background, we have developed a servo valves diagnosis system by applying the technology of the diagnosis system for the high response control system.

3.2 Configuration and features of the servo valve diagnosis system

Figure 6 shows the configuration of the servo valve diagnosis system. This system consists of some hydraulic system equipment composed of hydraulic devices and some control system equipment composed of electric control devices. The hydraulic system equipment is shown in **Fig. 7**, and the control system equipment is shown in **Fig. 8**. The function generator with data sampling function for the control system equipment corresponds to the data collection section for equipment diagnosis in the high response control system (VMPC) described in **Chapter 2**.

In this system, the VMPC offline function of collecting data for diagnosis is specialized in measurement of servo valve characteristics. This eliminates the need to prepare measuring instruments depending on the details of characteristic measurement, so that people other than

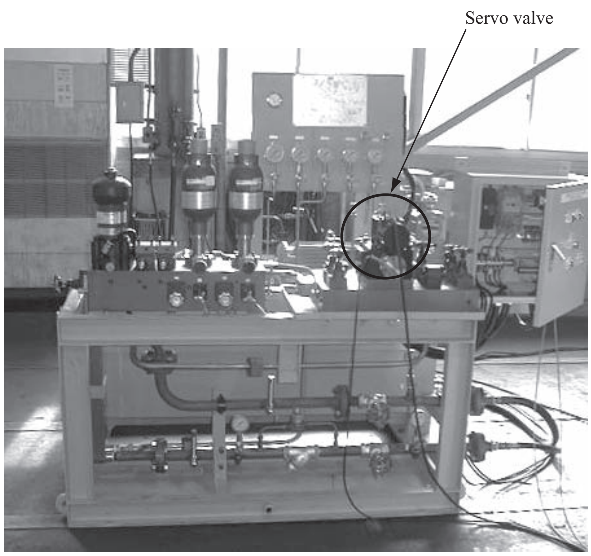


Fig. 7 Hydraulic system equipment

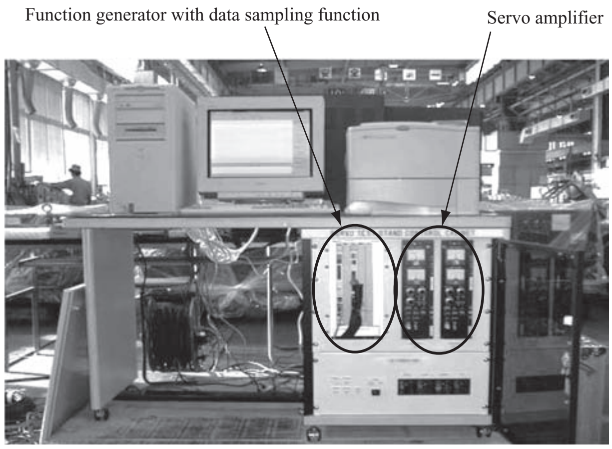


Fig. 8 Control system equipment

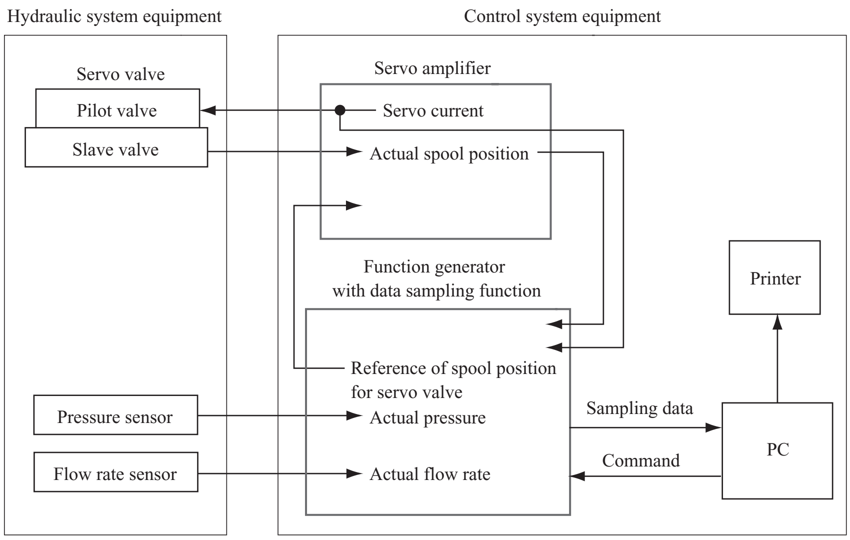


Fig. 6 Configuration of servo valve diagnosis system

special hydraulic engineers can set the measurement conditions and measure and record the characteristics following the measurement condition setting guidance screen (**Fig. 9**).

The measured waveforms obtained from this measurement, and the numerical values to evaluate the characteristics that can be read from the measured waveforms (automatically calculated and displayed with measured waveforms) are compared with the standard waveform and the standard value determined at the time of shipment.

These results can be used to determine the soundness of the servo valve itself and the degree of its deterioration, enabling it to be overhauled at just the right time. In addition, preparations for overhaul (such as setting apparatus up for inspection and procuring replacement parts) can be made before receiving the servo valve, based on the measured waveforms and other results of this measurement. This minimizes the time required for overhaul.

3.3 Measurement items of servo valve characteristics

To enable a comparison of servo valve characteristics with those at the time of shipment, this system is designed to measure the same measurement items as those measured at the time the servo valves are shipped. **Table 3** shows the measurement items of servo valve characteristics. As examples, **Fig. 10** shows a measurement result for characteristics of pressure gain of a pilot valve obtained by using this system, and **Fig. 11** shows a measurement result for characteristics of internal leakage of combined pilot and slave valves. The servo valve used in this example is a two-stage servo valve composed of a pilot valve and a slave valve.

4. Conclusion

This paper outlined a high response control system (VMPC) and a servo valves diagnosis system. The high response control system (VMPC) can be used not only for hydraulic roll gap control but also for many other purposes, thanks to its high response, easy program designing using the programming language of VMD, and versatility achieved by combinations of any I/O boards. Being developed as a versatile control system, this system is not limited to certain applications but can be used for any purpose within the capacity of the system at the user's discretion. It can be applied to control and calculation for systems that require high response, and can be a substitute for the functions realized by board computers. When this system is used

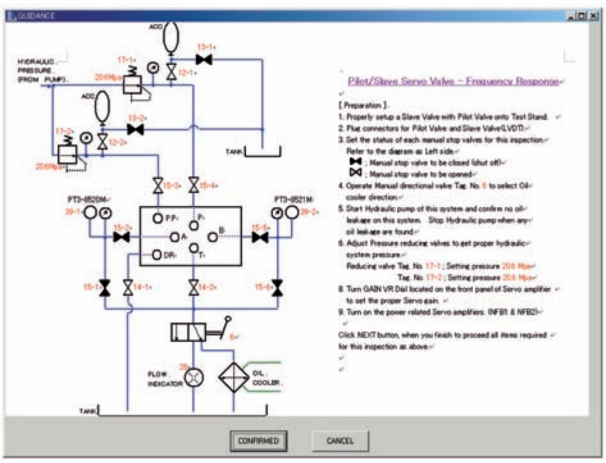


Fig. 9 Operation guidance screen

Table 3 Measurement items of servo valve characteristics

Measurement condition	Measurement item
Single operation of pilot valve	- Measurement of pressure gain - Measurement of threshold and null bias - Measurement of internal leakage
Combined operation of pilot valve and slave valve	- Measurement of pressure gain - Measurement of threshold and null bias - Measurement of internal leakage - Measurement of step response - Measurement of frequency response - Measurement of hysteresis

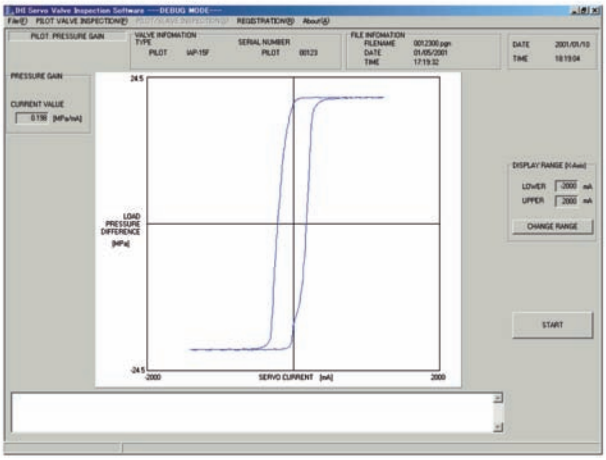


Fig. 10 Characteristics of pressure gain of pilot valve

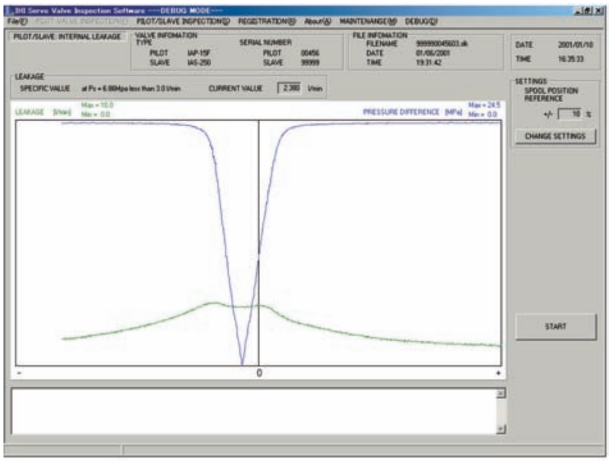


Fig. 11 Characteristics of internal leakage of combined valve

for hydraulic roll gap control, it can be equipped with the equipment diagnosis function that is available in the standard software.

In addition, the servo valve diagnosis system enabled recognition of the degree of deterioration of servo valves by giving specific characteristics data, and this facilitated measurement of characteristics.

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