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Development of Automatic Charpy Impact Testing System

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Synopsis :
An automatic Charpy impact testing system has been developed for the Mechanical Test Center at Chiba Works, Kawasaki Steel Corporation, and is operating successfully. The new system has various functions such as the rapid control of temperature of specimens, automatic transfer of specimens from cryogenic bath to anvil, self-check function of test values and so on. The features of this system are as follows. (1) Automatic continuous impact testing has been successfully completed. (2) The test result has been fed back promptly to process management by linking the system to a host computer. (3) The SCARA robot provides the rapid transfer and setting of specimens with high accuracy. This report explains the specification and constitution of the automatic Charpy impact testing system, together with the results of the performance test on the specimen-transfer robot to be specially used in many developed apparatus.

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(2) The test result has been fed back promptly to process management by linking the system to a host computer.

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1 Introduction

With steel production increasing and product quality becoming higher, the amount of quality inspection work in the steel industry has recently been increasing extraordinarily. There are already many automatic systems for flaw detection and chemical composition analysis that are directly connected with production lines. Contrarily, however, in inspection equipment used in materials testing for strength and hardness, the progress has been far from remarkable with automation achieved only to a limited extent under the restrictions placed by standards and criteria.

However, to improve productivity and increase the reliability of quality inspection for elimination of human errors, it is absolutely necessary to make inspection work efficient and automate inspection equipment. Against the background of the recent progress in computer technology and electronical mechanism, automatic testing machines have been developed one after another for use in tensile testing[2-5] and hardness testing[2-5].

With respect to impact testing, automation has so far been limited to individual testing machines and the automation of a whole testing system has not been conducted. At Kawasaki Steel, the development of an automatic Charpy impact testing system was started in March 1982 with a view to automating the whole impact testing on the occasion of the construction of a mechanical testing center at its Chiba Works. The automatic Charpy impact testing system was brought into operation at the same time with the opening of the mechanical testing center. This testing system is operating smoothly.

This report presents the specification and structure of this newly developed automatic Charpy impact testing system and gives results of a performance test on a specimen transfer robot, one of the principal units that composes the system.

2 History of Automation of Charpy Impact Testing

The impact testing is conducted to test the fracture toughness of materials. The importance of this testing has been increasing noticeably in connection with the recent progress in materials for oil-country tubular goods, LNG tanks, and materials related to ocean development. There are three methods of impact testing, i.e.,

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Charpy impact test, Izod impact test and dropweight tear test (DWTT). The Charpy impact testing is most frequently employed in Japan and the history of automation of this testing is old. **Table 1** shows the history of automation of Charpy impact testing in the steel industry.

Automation was started in about 1963. Automatic lifting up and releasing of the pendulum was first completed by using motors and clutches. Then, the measurement of the swing angle of the pendulum was automated by installing an angle detector on the pendulum shaft. In 1975, a testing machine provided with a manipulator was developed. The manipulator automatically sets specimens in the fracture position which are manually placed outside the machine. Therefore, it became unnecessary for the operator to put his hand directly over the plane of swing of the pendulum, thereby increasing safety substantially. At the same time, progress was made in instrumentation toward arithmetic processing using personal computers. Personal computers were then used for data processing for testing machines and occupied an important position in automation. The adoption of personal computers came to put data processing unit in desktop consoles and the work efficiency was improved. As a result of these automatization, it has become possible to perform the Charpy impact testing work by one or two operators which required three or four operators before.

Table 1 History of automation of Charpy impact testing

Year	Subject
1963	Automatic lifting up of pendulum Automatic releasing of pendulum
1968	Automatic measuring of swing angle of pendulum Digital indication of swing angle Calculation of absorbed energy by micro-computer
1973	Automatic discharging of specimen out of machine Print out of absorbed energy
1975	Completion of setting device of specimen used of air manipulator Calculation of absorbed energy by personal computer Unit conversion of absorbed energy
1979	Adoption of personal computer with CRT display

Apart from these actual automatization, an overall integrated automatic system for the material testing process was planned by Japan Industrial Robot Association (JIRA) in 1976 and the Charpy impact testing was examined. However, techniques suggested by the Association were nonexistent at that time and its report simply pointed out the need of developing many techniques in order to realize an unmanned system.

3 Problems in Development

When the development was started, the testing machine proper had been considerably automated. However, there were still many problems to be solved in order to realize an unmanned testing work. **Table 2** gives Charpy impact testing items which had already been automated at the beginning of the development and those not automated. This table reveals items to be developed for the testing work automatization.

Table 2 Development in Charpy impact testing

	Work		Conventional	New
Verification of specimen	1 Management of specimen number 2 Input of specimen specification	× ×	Manual imput at operator's console	Transmission of specimen specification through host computer
Cooling device	1 Setting of test temperature 2 Control of test temperature	× ×	Manual setting Manual operation	Automatic setting by computer Automatic control
Testing machine	1 Lifting up of pendulum 2 Releasing of pendulum 3 Withdrawing and sorting of tested specimen 4 Taking off of flash on anvil	○ ○ △ ×	Discharging by conveyor Manual taking off	Automatically withdrawing and sorting by rotary sorting unit Automatically taking off
Specimen supply	1 Picking up and setting of specimen from bath to anvil 2 Continuous supply of specimen	× ×	Manual supply	Automatically continuous supply by robot
Data processing	1 Measuring of swing angle 2 Calculation of swing angle 3 Judgement of absorbed energy 4 Making up of test report	○ ○ × ×	Manual judgement Manual posting	Judgement by computer software Print out of test report

○: Completed △: Completed partly ×: Incompleted

To fully automate the testing work, it is necessary to develop hardware and software for the following items:
(1) Programmed control of the test temperature and rapid-cooling control
(2) Removing specimens from the cryogenic bath and setting them onto the anvil
(3) Data processing for test results

4 Basic Specification and System Configuration

The basic specification and configuration of the newly developed automatic Charpy impact testing system are described in the following.

4.1 Basic Specification

(1) Applicable standard: JIS B-7722 and ASTM E-23
(2) Capacity: 50 kgf·m
(3) Test temperature: −196°C to +100°C
(4) Specimen size: All sizes specified in JIS Z 2202 and ASTM E-23
(5) Maximum number of specimens of one lot: 150 specimens (50 sets)
(6) Efficiency: Approximately 15 s/specimen

4.2 Configuration and Specification of the System

Figure 1 shows the equipment configuration of this system and signal flows among the units.

(1) Cryogenic bath and specimen stock unit

The cryogenic bath controls the refrigerant temperature by heat exchange using liquid nitrogen. The cryogenic bath is provided with two heat exchange systems, one for forced rapid cooling and the other for temperature control by PID control. Rapid setting control is made possible by a valve changeover. In the cryogenic bath, specimens are arranged on specimen trays of five stages. When a test on specimens on an upper tray has been completed, the specimen stock unit raises the next tray to the position of the upper tray.

(2) Specimen transfer robot

This robot takes a specimen out of the cryogenic bath, transfers it to the anvil of the testing machine and sets it on it. This is a robot with multi-articulated arm that moves horizontally.

(3) Automatic testing machine

The automatic testing machine is of a conventional type. However, it is provided with many malfunction check switches for automatic operation in addition to a device for sorting out ruptured specimens by the set and an automatic flash removing unit.

(4) Data processing computer

The data processing computer connected to a host computer gives control command to each unit of the testing system, i.e., the cryogenic bath, transfer robot and testing machine based on test conditions transmitted before a test, and controls the whole flow of the test. Furthermore, it calculates absorbed energy, checks the friction loss of the testing machine, and judges test results using software.

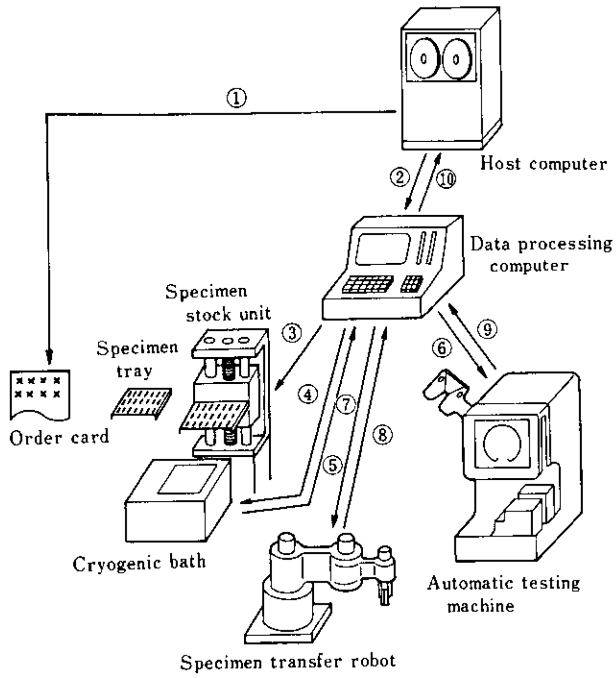

Fig. 1 Automatic Charpy impact testing system

4.3 System Flow Chart

Figure 2 shows the testing flow chart of this automatic Charpy impact testing system. The operator arranges specimens processed in the specimen preparation shop on specimen trays by checking specimen numbers against command cards. All testing procedures are carried out fully automatically after the operator simply gives start instructions. In this system, 150 specimens can be tested in about 40 min.

5 Performance of Specimen Transfer Robot

Results of development experiments and a performance test on the newly developed specimen transfer robot are described in the following.

The specimen transfer robot must meet the following requirements:
(1) No excessive temperature change shall be given to specimens being transferred. (In consideration of

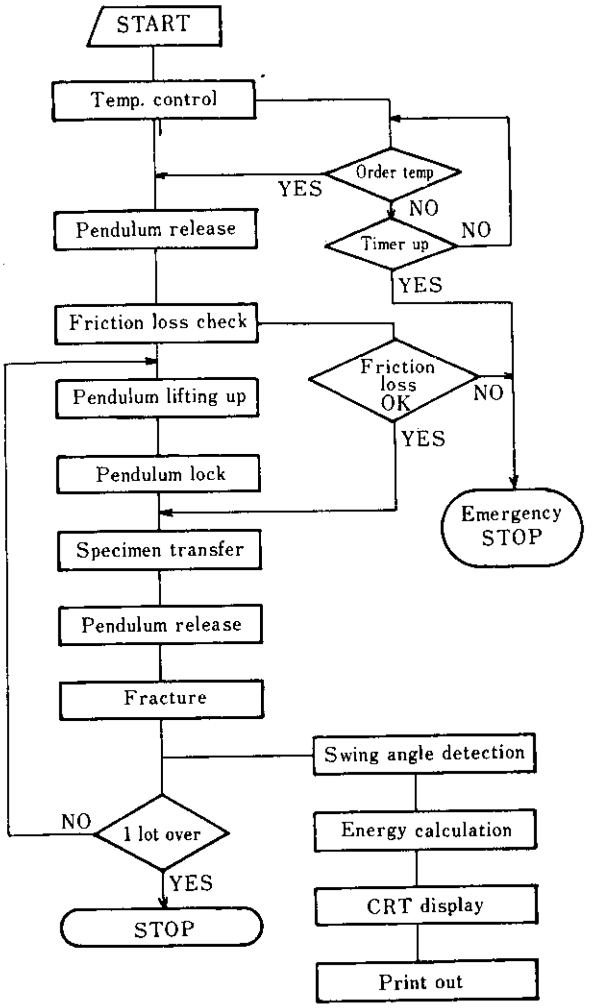

Fig. 2 System flow chart of automatic Charpy impact testing system

the standards, variations in the test temperature are within ±2°C.)

(2) Specimens shall be broken within 5 s after the removal from the cryogenic bath (refer to ASTM E-23.). When the removal of the pendulum, free fall time, etc., are taken into consideration, the transfer time must be about 2.5 s at most in order to break specimens within 5 s. Therefore, the transfer robot must be capable of high-speed operation and provide reproducibility of stop position of the grip with a high degree of accuracy.

In developing this specimen transfer robot, investigations were made on the shape of the grip that seizes specimens, materials for the grip, and the construction of robots suitable for specimen transfer.

5.1 Examination of Specimen Grip

5.1.1 Specimen grip mechanism

The parallel-chuck mechanism was adopted in order to meet changes in the specimen thickness. The parallel-chuck mechanism adopted is of a three-point grip type in which the specimen is seized at the notched portion and at two points opposite to it. In this type, the notched portion of a specimen being seized coincides always with the center of the grip. In this mechanism, the reproducibility of specimen positioning is determined by the reproducibility of stop position of the robot regardless of the arrangement of specimens in the specimen stock unit.

5.1.2 Materials for specimen grip

Specimen grips have so far been made of bamboo or steel. In bamboo grips, the thermal conductivity is very low, with no possibility of temperature effect on specimens. However, there are problems with accuracy and endurance. In steel grips, a high thermal conductivity poses a problem although there is no problem with strength. It has so far been recommended that specimens be constantly immersed in a refrigerant when steel grips are used. Therefore, a material that has a low thermal conductivity and is durable was sought after in developing the specimen transfer robot.

In developing this robot, attention was given to the fact that the thermal conductivity of ceramics is very low and an attempt was made to apply a ceramic coating to stainless steel to obtain strength.

Table 3 and **4** give the chemical composition and physical properties of the ceramic applied, respectively. The thermal conductivity of steel (pure iron) is 0.18 cal/cm · s · °C. The thermal conductivity of the ceramic is about 1/30 that of steel.

To investigate temperature changes during transfer, a thermocouple was embedded in the specimen. Temperature changes during transfer were measured in this

Table 3 Chemical composition of ceramics coating used for specimen grips (wt%)

Cr_2O_3	SiO_2	Al_2O_3	MgO	CaO
82.94	8.39	3.16	2.96	Trifling

Table 4 Physical properties of ceramics coated

Structure of crystals	Hexagonal
Hardness (Hv)	1 600
Melting temperature (°C)	1 650
Coefficient of thermal expansion ($\times 10^{-6}$°C)	6.0
Thermal conductivity (cal/cm·s·°C)	0.006 2
Compressive strength (kg/cm^2)	7 400

manner. As shown in **Fig. 3**, a hole 2 mm in diameter and 27.5 mm in depth was made in the specimen from one end to just below the notch, a thermocouple was inserted and the hole was sealed so that the refrigerant did not come into direct contact with the tip of the thermocouple.

Figure 4 shows the relationship between the lapse of transfer time and the increase in specimen temperature for various materials for grip. The increase in the specimen temperature in 2.5 s, i.e., the time from the grip of specimen in the cryogenic bath, its removal, its transfer to the testing machine and to its release is about 0.3°C in the ceramic coated material. This increase is about half that of the stainless steel SUS 304.

This temperature increase is small enough when compared with the allowable temperature variation of the specimen temperature. Therefore, it may safely be said that the ceramic coated material sufficiently meets the requirements of the standards as the material for specimen grips. In actual specimen transfer robots, a 0.2 mm ceramic coating is applied to the stainless steel SUS 304.

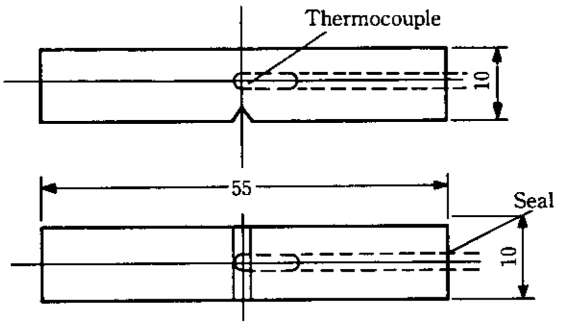

Fig. 3 Location of thermocouple in specimen

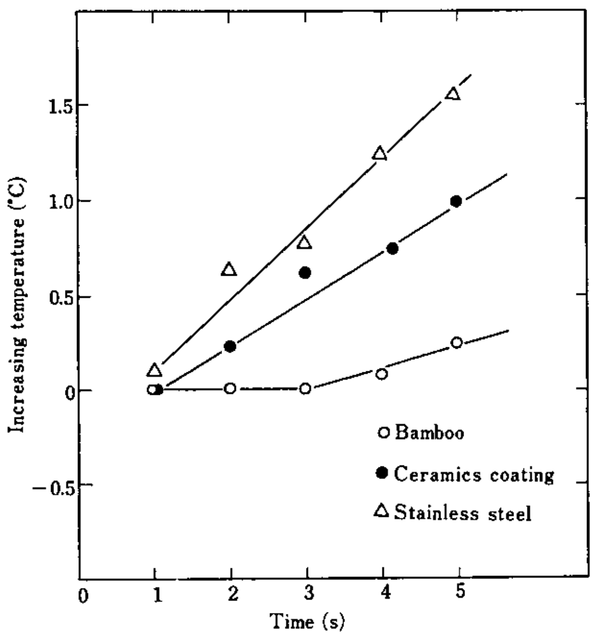

Fig. 4 Increase in temperature during the transference of specimen

5.2 Examination of Construction of Robot

Among many types of robots presented for transference of small parts, a robot with multi-articulated arm that moves horizontally, SCARA (selective compliance assembly robot arm), was adopted because of a wide range of motions and the excellent flexibility of motion programs. This robot was modified in some details so that it became suitable for specimen transfer in the impact testing.

Figure 5 is a schematic representation of the specimen transfer robot. This robot is composed of X- and Y-axis drives that provide horizontal motions; No. 1 and No. 2 arms connected to them; a Z-axis drive that gives vertical motions to the grip at the end; and a direction keeping mechanism that keeps the direction of the grip around the Z-axis. Arm positions are detected by encoders of the X- and Y-axis. The grip moves to a specified position through the shortest distance by relative rotations of the X- and Y-axis. Therefore, the condition of the arms in each stop position is as shown in **Fig. 6**.

Main modifications of the robot are summarized in the following.

(1) To increase the transfer speed, the strength of the arms was examined and the capacity of the motors was increased. At the same time, the encoders were converted into the high-speed response type. As a result, it was possible to obtain transfer speeds of more than 1 000 mm/s and shorten the time required for specimen transfer from the cryogenic

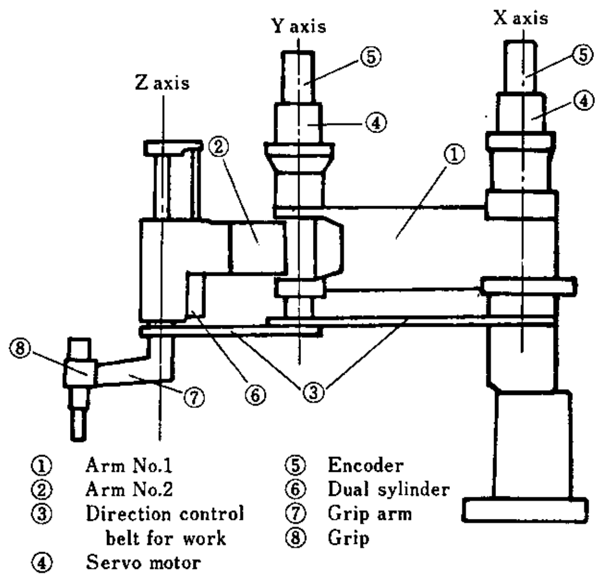

Fig. 5 Schematic view of transfer robot

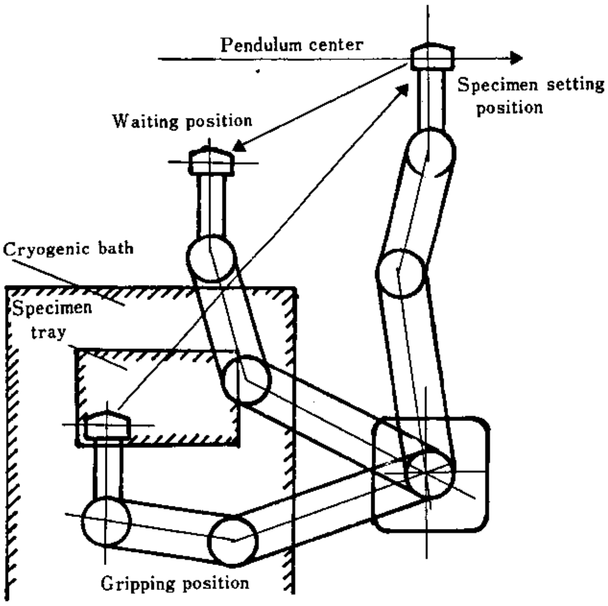

Fig. 6 Motion of transfer robot

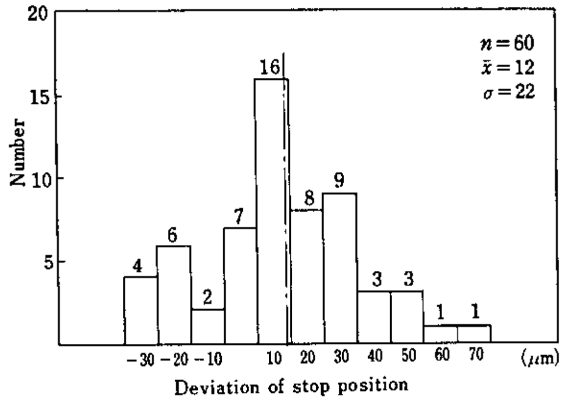

Fig. 7 Reproducibility of stop position of transfer robot grip

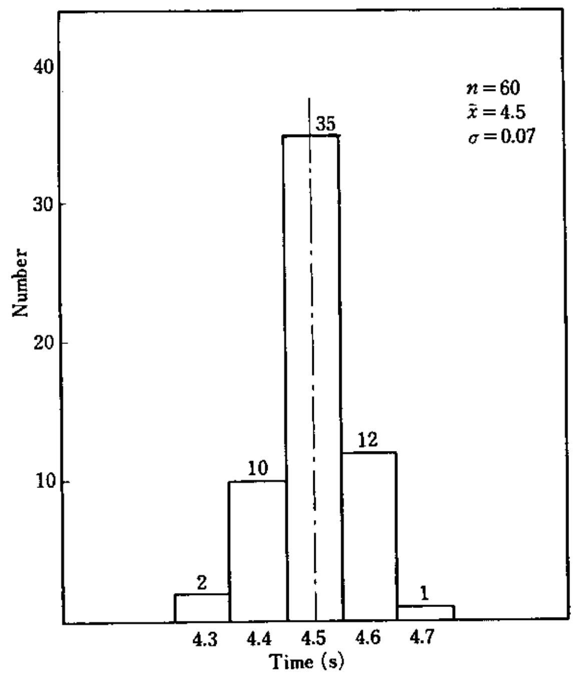

Fig. 8 Distribution of time between pick-up of specimen and its break

bath to the anvil to about 0.6 s.

(2) Three stop positions were provided also in the vertical direction by adopting a dual cylinder for the vertical motion of the Z-axis. As a result, it became possible to set up transfer sequences that permit different motions between going and coming and to shorten the transfer time.

(3) In a stop position, the arms always stop after damping oscillation. Formerly, the motions were regarded as completed at the time when amplitudes of the oscillation became smaller than a certain value. Then, to shorten the time-lag at stop positions, the software that judges the completion of motion was improved. Now, the completion is judged by the number of the occurrence of the amplitude which exceeds a certain value.

(4) The stop accuracy of the grip is governed by the stop accuracy of rotation of the X- and Y-axis and the play of the direction keeping mechanism. The play of the direction keeping mechanism is greatly expanded at the grip. In the present system, the stop accuracy was improved by adopting a silent chain in this direction keeping mechanism.

In addition, various modifications were carried out—for example, increases in the number of inputs and outputs and of setting points, and addition of interlock with the testing machine.

Figure 7 shows the reproducibility of stop positions of the grip on the anvil. In this transfer robot, $\bar{x} = 0.01$ mm and $\sigma = 0.02$ mm. Therefore, the accuracy is higher compared with the tolerance specified in the standards of ± 0.4 mm.

Figure 8 shows a lapse of time from the removal of specimen out of the cryogenic bath to its breakage. In this robot, $\bar{x} = 4.5$ s and $\sigma = 0.07$ s. Therefore, it is apparent that this robot has sufficient performance in this respect.

6 Effects of the System

At Chiba Works, about 20 000 specimens/month are tested by two automatic Charpy impact testing systems. These two automatic systems are controlled by one operator because the testing work is continuously carried out in a fully automatic manner. As a result, the testing work that has so far required three operators can now be performed by one operator. Furthermore, it has become possible to reduce or omit input operation for test conditions, transfer operation for test results and hostcomputer input operation. Thus, the newly developed automatic Charpy impact testing system is producing great labor-saving effects.

7 Summary

An automatic Charpy impact testing system was developed as part of automation of the mechanical testing center at Chiba Works with an aim of achieving a fully automatic impact testing work. For this purpose, a specimen transfer robot was developed which transfers specimens from the cryogenic bath to the testing machine. In this system, a horizontal multi-articulate type robot was modified so that it became suitable for use in the impact testing. It was completed as a transfer robot having high-speed motions and high positioning accuracy. This testing system passed inspection by Nippon Kaiji Kyokai (NK) and was authorized by the ASTM.

Two systems were introduced in the mechanical testing center. These automatic testing systems, operated by one operator, are generating great labor-saving effects in input and other operations before and after the testing as well as in the impact testing work itself.

References

1) H. Shiraishi: "The Automation of Mechanical Property Testings in Steel Industry", *Tetsu-to-Hagane*, **64**(1978)10, 1625–1637
2) H. Kimura et al.: *Sumitomo Metals*, **28**(1976)4, pp. 508–516
3) S. Saito et al.: *Journal of Material Testing Research Association*, **25**(1980)4, pp. 199–205
4) M. Terasawa: *Metals & Technology (Special Issue)*, (1980) pp. 1–4
5) S. Iwasaki: *Metals & Technology (Special Issue)*, (1980) pp. 5–8