KAWASAKI STEEL TECHNICAL REPORT
No.15 (October 1986)

Development of Pipe Marking Robot

Kazuyuki Sakurada, Yutaka Funyu, Kazuhiko Miura

Synopsis :
For the precise tracking of pipe, a robot which automatically imprints code figures on the interior of the pipe end has been developed and applied at Chita Works medium-diameter seamless pipe mill. A compact dot-spray painter attached to the robot's wrist permits the high-speed imprinting of the identification code, without touching the pipe, on the inner surface of pipe 150 mm or larger in inner diameter. The robot is also equipped with a sensor that enables it to locate the exact spot on the pipe rim to be marked. Robot marking is automatic from start to finish, through a link-up with a process computer which informs the robot of outer diameter and wall thickness of incoming pipe, and of code numbers and characters to be imprinted. With software changes, robot automation of other marking operations is possible.

The body can be viewed from the next page.

KAWASAKI STEEL TECHNICAL REPORT No. 15 October 1986

Development of Pipe Marking Robot*



Kazuyuki Sakurada
Staff Assistant
Manager, Equipment & Engineering Sec., Chita Works

Yutaka Funyu
Staff Assistant
General Manager, Equipment & Engineering Sec., Chita Works

Kazuhiko Miura
Manager,
Pipe Sec., Hot Rolling Dept., Chiba Works

Synopsis:

For the precise tracking of pipe, a robot which automatically imprints code figures on the interior of the pipe end has been developed and applied at Chita Works medium-diameter seamless pipe mill. A compact dot-spray painter attached to the robot's wrist permits the high-speed imprinting of the identification code, without touching the pipe, on the inner surface of pipe 150 mm or larger in inner diameter. The robot is also equipped with a sensor that enables it to locate the exact spot on the pipe rim to be marked. Robot marking is automatic from start to finish, through a link-up with a process computer which informs the robot of outer diameter and wall thickness of incoming pipe, and of code numbers and characters to be imprinted. With software changes, robot automation of other marking operations is possible.

1 Introduction

The automation of manufacturing processes in iron- and steelmaking has proceeded more rapidly than in other industries. On the other hand, the steel industry has been slow in adopting low-priced, general purpose commercial robots, because positioning and handling tasks in the steel industry involve large scale, massive objects. In recent years, however, with progress in utilization and control techniques for industrial robots,[1] the range of application has expanded considerably.

Various types of marking equipment have already been put into practical use in both the steel and other industries, but all these marking devices are classified as variable-sequence robots, with a restricted range of objects. The marking robot newly developed by Kawasaki Steel is the first general-purpose robot in the field of marking, and can imprint letters and symbols on curved surfaces such as those of steel pipe.

The No. 1 marking robot was installed in the medium-diameter seamless pipe mill at the Chita Works for the purpose of imprinting code figures on the inner surface of pipe and has been operating smoothly since December 1984. The functions and features of this device are described in this paper.

* Originally published in *Kawasaki Steel Giho*, 17(1985)4, pp. 378-384

2 Significance of Newly Developed Marking Robot

2.1 Medium-Diameter Seamless Pipe Manufacturing Process

The manufacturing process at the Chita medium-diameter seamless pipe mill is broadly divided into the hot rolling line, heat treatment line, inspection and cutting line, and finishing line. Hot rolling is conducted using a Mannesmann plug mill.[2] The semi-finished product after hot rolling is temporaily held in automatic storage and is fed to the heat treatment line, inspection and cutting line, or the finishing line depending on application. The process from the hot rolling line to the heat treatment line and inspection and cutting line has been made continuous, and pipe is automatically tracked piece by piece using process computers. Process computers control the reheating furnaces and rolling mill,[3] and also control for optimization of material flow[4] and optimal pipe cutting[5]. At the same time, these process computers transmit actual result data in real time to the central compuer at the Chita Works. The central computer side includes a production control system; operation and quality control, covering the entire process within the Works, are conducted on the basis of results of data transmission between the central

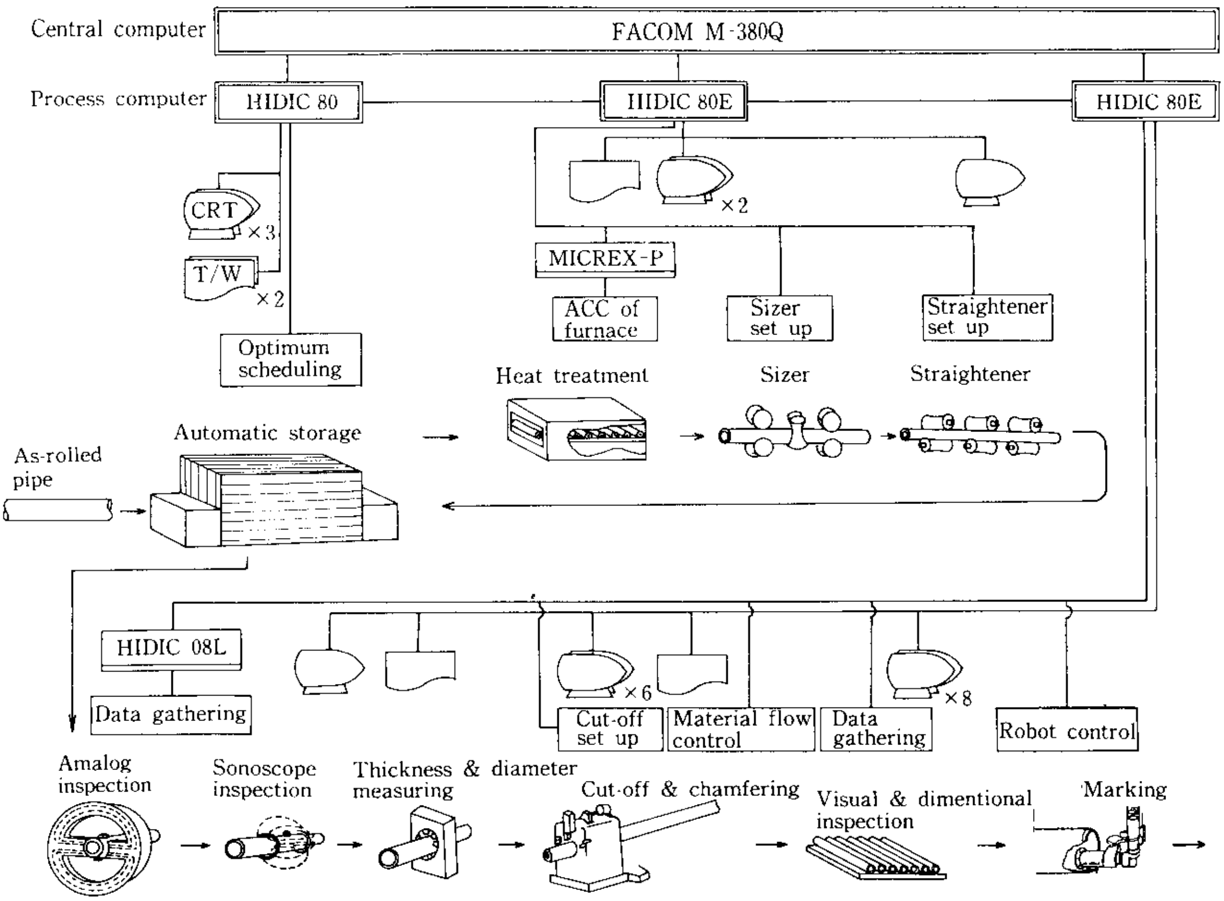

Fig. 1 Control system of pipe finishing process

computer and the process computers and terminals. The computer control system for the automatic storage and downstream processes is shown in **Fig. 1**.

The inspection and cutting line is a continuous process from leakage flux inspection (Amalog and Sonoscope inspection) to visual and dimensional inspection, as shown in Fig. 1. At the end of the inspection and cutting line, pipe is automatically internally marked, piece by piece, with control numbers, using the newly developed marking robot. Pipe is bundled together in several piece lots and stored on off-line racks through use of an overhead traveling crane. Pipe temporarily stored on the off-line racks is transported to the downstream finishing line depending on application and given predetermined inspection and working. The finishing line comprises ultrasonic inspection, magnetic particle inspection, threading, etc.

2.2 Necessity of Imprinting Control Numbers

Seamless pipe plays a very important role in the exploitation of energy resources such as petroleum and gas, in the machine industry, in various types of industrial plants, and so on; requirements for product quality have recently become increasingly severe. In seamless pipe mills recently constructed by steel pipe manufacturers, therefore, automatic piece tracking by process computers is conducted from the start of the process. Systems that permit piece-by-piece quality control are incorporated.

However, some of the special processes in the inspection and finishing lines cannot be made continuous for such reasons as production capacity, so pipe must be temporarily stored on off-line racks. This company's medium-diameter seamless pipe manufacturing process is not an exception and, as mentioned earlier, pipe is temporarily stored on off-line racks after the inspection and cutting line.

Since pipe that is temporarily brought off the line leaves the automatic piece tracking system, some means of lot identification is necessary for preventing the mixing of dissimilar lots. For this reason, operators have to date marked the outside of pipes with identification codes by hand stenciling with spray paint.

This manual marking method not only poses problems of accuracy and speed, but also of safety of operation, making automatic marking desirable. Furthermore, it is desirable that control numbers be imprinted on the pipe interior near a pipe end, rather than on the outside, for easy reading even when pipe is stacked.

In one identification method, adhesive labels with printed bar codes, letters, and symbols are applied to the inside of pipe. In this method, however, a downstream process is required for label removal, necessitating extra work.

The present marking robot, which imprints code figures on the interior of pipe, was developed to realize fully automatic marking and prevent mixing of dissimilar lots; at the same time, integrated piece control is exercised even in off-line areas through imprinting of individual piece numbers.

3 Outline of System

The marking robot installed in the medium-diameter seamless pipe mill is schematically shown in **Fig. 2**; its system configuration is shown in **Fig. 3**. A small marking head attached to the end of an arm of an articulated type robot is inserted in the object pipe, and a marking is applied to the interior pipe surface.

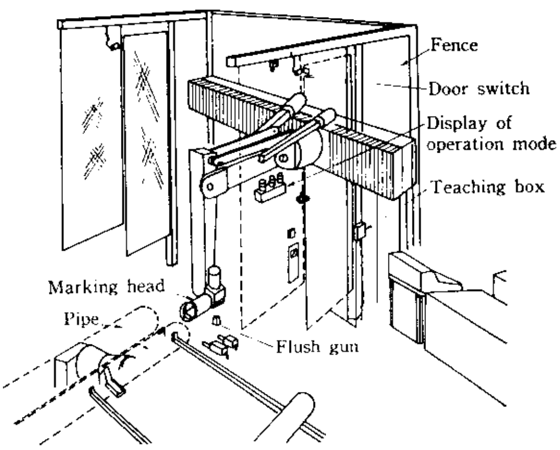

Fig. 2 Illustration of the marking robot

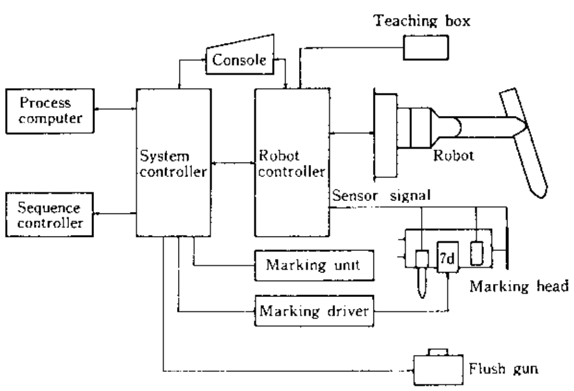

Fig. 3 System configuration of marking robot

One marking consists of a total of 12 figures: 8 lot-number figures and 4 piece-number figures.

Pipe to be marked may be 7 to 17 in. in nominal outside diameter and 150 mm or more in inside diameter.

Marking is conducted in one of the two marking positions described below, depending on the pipe travel route. Pipe that is longitudinally conveyed on the roller table is slowed to a stop within the marking motion range of the marking robot, then forwarded to downstream processes after marking. Pipe that is conveyed traversely on the skid table from upstream processes is stopped by a stopper on the entry side of a roller conveyor, where marking is conducted before the marked pipe is conveyed by roller table to downstream processes. Pieces of pipe conveyed by different routes meet at the marking robot, but marking position on the interior pipe surface differs depending on the travel route. This difference in marking position is necessary to avoid bottlenecks in equipment capacity at the marking robot. However, this equipment restriction does not pose a special problem because a general-purpose robot with versatile software is used as the marking robot.

Although the location of pipe ends which are to be marked is controlled to almost uniform position by a sequence controller that regulates travel, small variations, within ± 100 mm in most cases, may occur. However, if great variations occur, an overrun detection sensor installed on the conveyance equipment notes the pipe and abnormality and gives a warning so that the robot will not collide with the pipe.

When variations in pipe end position are within specified limits, a position control sensor attached to the marking head automatically detects the actual pipe end position and applies the specified marking to the pipe interior at a specified distance inside the pipe end.

All pieces of pipe which are automatically transported are also automatically tracked piece by piece by a process computer. Dimensions such as outside diameter and wall thickness of the pipe, along with marking data necessary for robot motions, are transmitted for each piece from the process computer to the marking robot.

When the pipe reaches the marking position, where it stops, a marking-motion-request signal is given by the sequence controller to a system controller. At this point, marking position, pipe dimensions, and marking data have already been transmitted from the process computer to the system controller. The system controller selects the specified robot motion program code to match the given marking position and pipe dimensions, and transmits the program code and start command to the robot controller. Since the distance between the system controller and the robot controller is about 150 m in this system, data transmission between the two con-

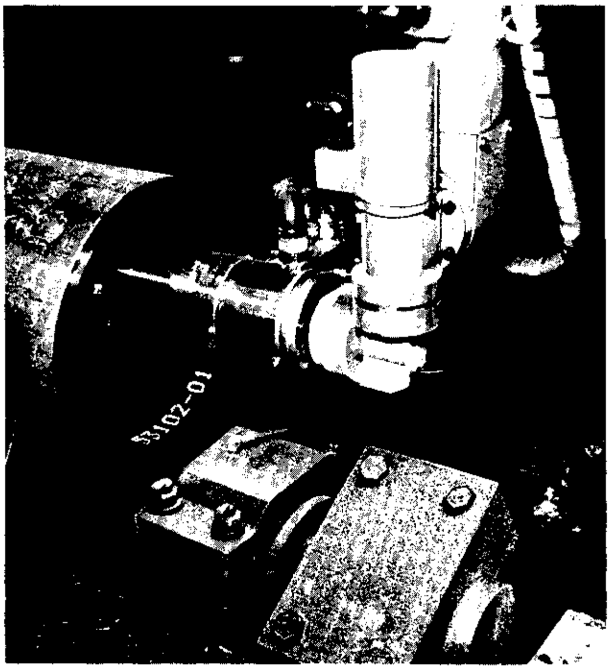

Photo 1 Marking robot

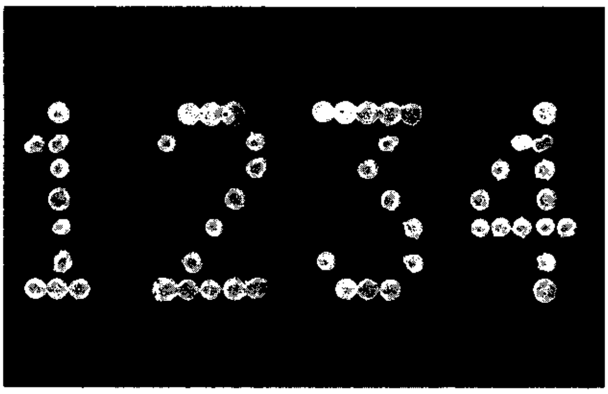

Photo 2 Full-sized marking example

trollers is performed via RS422 line, which possesses excellent anti-noise characteristics.

When the robot starts its motions and the marking head enters the pipe, the sensor incorporated in the marking head detects the pipe end position and the robot automatically starts an arc movement. The arc movement follows the pipe interior maintaining a constant distance between the marking nozzle and the inner surface of the pipe. When the arc movement reaches a prescribed speed, the robot controller gives a marking start command to the system controller. A dot spray pattern suited to the desired marking character pattern is transmitted to the seven solenoid valves incorporated in the marking head via a marking driver, and marking is conducted. The marking robot in the process of marking is shown in **Photo 1**; an example of marking figures is shown in **Photo 2**.

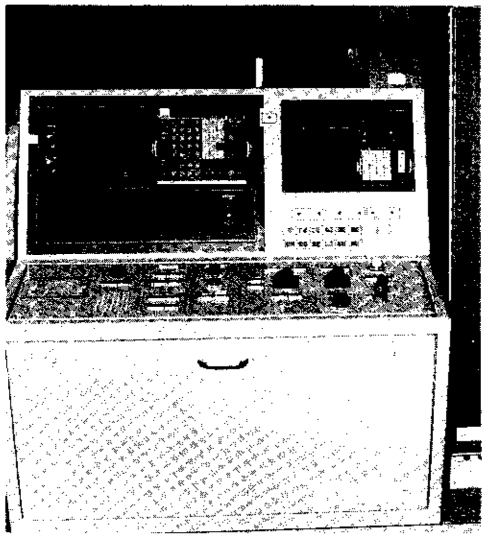

Photo 3 Operation console

When marking is completed, the marking head is withdrawn from the pipe and returns to the standby position for the next marking operation. In the standby position, the marking nozzle is flushed for about 0.3 second with a flushing liquid (principal component: 1,1,1-trichloroethane) jetted from a flush gun. The marking sequence described above is completed within 7 seconds, inclusive of robot motion time.

The operational condition of the robot and marking information are displayed on an operation console installed at the site to facilitate checking of the operating condition of the system. From the operation console, it is possible for the operator to manually operate the marking robot with the signal circuit between the process computer and the marking robot disconnected. Since the marking robot is usually operates fully automatically, the operation console is used only at the start and end of operation, in case of abnormalities, or during adjustments. A view of the operation console is shown in **Photo 3**.

4 Robot Proper

The Fanuc Ltd. S-MODEL 1 (Y-axis travel type, 6-axis type, total weight 650 kg) shown in **Fig. 4** is used as the robot proper. The U-, W-, and Y-axes are used for positioning the marking head at points in space; the α-, β-, and γ-axes, for controlling the posture (direction) of the marking head. The total output of the servo-motor that controls each axis is 1 410 W. The main specifications of the robot proper are shown in **Table 1**.

Although this robot is usually used as a free-standing

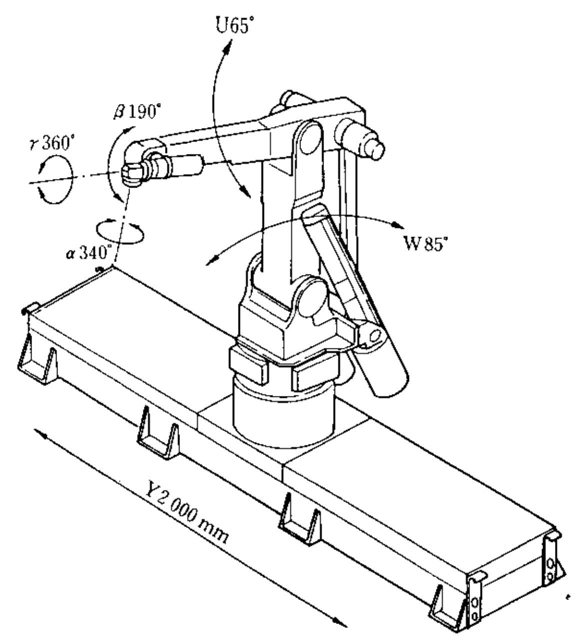

Fig. 4 Main body of robot

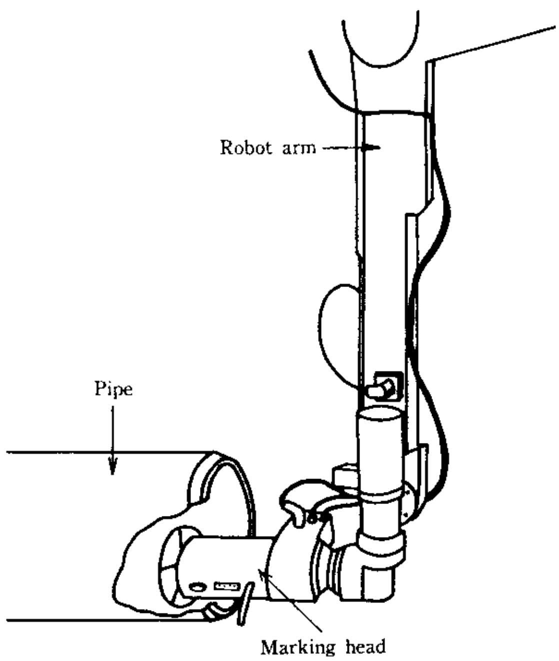

Fig. 5 Robot arm with marking head

Table 1 Specifications of robot

Items		Specifications
Coordinate type		Articulated type
Controlled axis		6 axis (Y, W, U, α, β, γ)
Operation range [max. motion speed]	Y-axis	2 000 mm
	W-axis	85° (90°/s)
	U-axis	65° (90°/s)
	α-axis	340° (120°/s)
	β-axis	190° (120°/s)
	γ-axis	360° (120°/s)
Max. load capacity at wrist		10 kg
Drive method		Electrical servo drive by DC servo motor
Repeatability		±0.2 mm
Positioning		6 axis simultaneous control

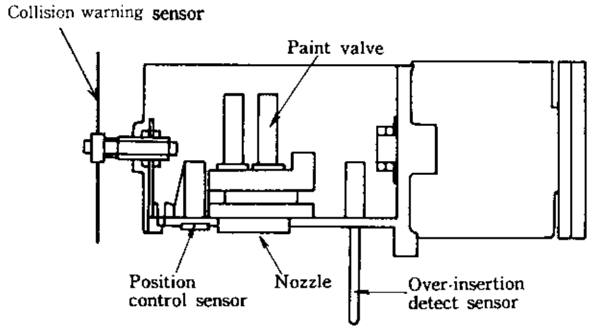

Fig. 6 Construction of marking head

type, it can be used also in a wall-attached position. In the medium-diameter seamless pipe mill, the latter installation method is used due to restrictions in the layout of the surrounding equipment.

5 Marking Head

The marking head, attached to the end of the wrist of the robot as shown in **Fig. 5** and inserted inside the pipes is a small marking device (total weight 8 kg) that imprints the pipe interior while performing turning motions.

The construction of the marking head is shown in **Fig. 6**. The marking head is cylindrical; the portion of largest diameter is the collision warning sensor (diameter 130 mm) attached to the end. This marking head is used for marking pipe with an inside diameter of 150 mm or more.

5.1 Sensors

Various sensors are incorporated in the marking head. Signals from these sensors are sent directly to the robot controller.

As mentioned above, a cylindrical collision warning sensor is attached to the extreme end of the marking head. This sensor detects interference with other objects at a contact resistance 1 kΩ or less or earth capacity of 100 pF or more. When this sensor comes into contact with the pipe or a human body, for example, the robot servo supply is instantaneously cut, stopping the robot.

A position control sensor near the marking nozzle, comprised of a reflection-type photoelectric switch, detects the pipe end while the marking head is being inserted in the pipe in order to allow control of the insertion position of the marking head. Since the position control sensor is near the marking nozzle, the projecting and receiving surfaces of the sensor formerly suffered contamination from the marking paint, leading to incorrect head movement. However, this problem has been solved by making such improvements as, for example, air purging of the projecting-and-receiving surfaces of the sensor.

An over-insertion detection sensor is installed to prevent over-insertion of the marking head into the pipe when the position control sensor is out of order. When the pipe end comes into contact with a sensing lever on the sensor, a microswitch incorporated in the sensor is activated to stop the robot.

The above-mentioned safety devices incorporated in the marking head contribute to stable operation.

5.2 Paint Valves

There are seven small paint valves at the center of the marking head; metallic paint tubes 0.1 or 0.2 mm in inside diameter project from each of these paint valves toward the external surface of the marking head. The construction of the paint valve is shown in **Fig. 7**. The valve case contains a solenoid: when a fixed iron core is magnetized through the activation of the solenoid, a moving iron core is attracted, a gap is generated between a sheet and a spherical plug, and paint is pressure-fed to the paint tube. When activation of the solenoid ceases, the fixed iron core loses its magnetism, and the spherical plug is pressed against the sheet by a spring, stopping the discharge of paint. In this manner, paint is discharged from the nozzle, and the inner surface of the pipe is marked with dots only when the solenoid is energized.

Results of measurement of solenoid current during marking operations are shown in **Fig. 8**. The paint valves, developed by Marktec Corp.[6] have a high response rate of under 1 ms, a principal advantage of this valve.

The width of marking characters is determined by the turning angle of the marking head and the intervals of energization of the solenoid; the height of marking characters is mechanically determined by the length of the row of nozzles. To make characters legible by obtaining proper character height, therefore, four of the seven paint tubes were bent, as shown in Fig. 7. The bent tubes have lengths different from the unbent tubes.

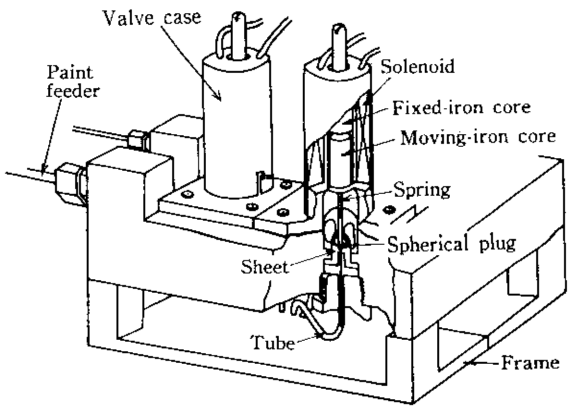

Fig. 7 Construction of paint valve

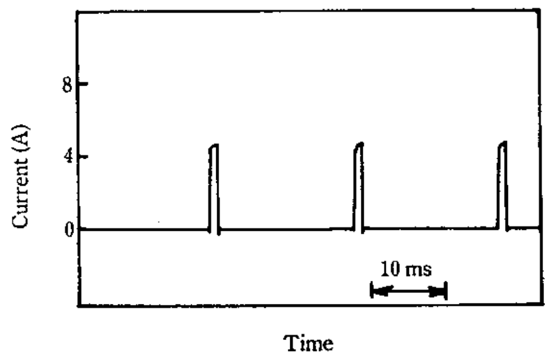

Fig. 8 High-speed response of solenoid

At the beginning of design work, it was expected that the quality of marked characters would not be remarkably affected by the bend shape or the length of the paint tubes. As a result of a preliminary experiment, however, it became clear that variations in the diameter of marking dots and the stability of marking depend on the size and shape of the paint tubes. Moreover, it was clarified that there are optimal values of the inside diameter and end shape of the paint tubes, solenoid energizing time, and spring constant. It became evident that the stability of marking is increased by controlling the paint feed pressure to within a predetermined range. Therefore, these findings have been incorporated in the design of the marking head.

5.3 Paint

The composition of the paint used in the marking robot is shown in **Table 2**. This is a bluish white pigment-based paint. It is possible to select various tints other than this color.

Table 2 Ingredient of the paint

Ingredient		Concentration (%)
1, 1, 1-trichloroethane		80
Stabilizer		6
Cellulosic resin		9
Pigment	Titanium oxide	4
	Prussian blue	1

6 Teaching

Since this marking robot is a general-purpose NC robot, teaching is necessary before use. However, teaching for each change in the size (outside diameter and wall thickness) of the pipe to be marked does not meet the requirements of fully automatic equipment. Therefore, multiple motion programs to cover all sizes of pipe produced in the medium-diameter seamless pipe mill are registered beforehand in the robot controller, and a proper program is automatically selected as required.

Motion routes of the marking robot are basically as shown in **Fig. 9**. The arc motion within the pipe changes relatively in space, depending on changes in the pipe end position. Conventional general-purpose robots cannot change the starting point of arc motion during traveling upon receiving a sensor signal, although motion in an arc, fixed in space, is possible. To ensure stable marking, the function of relative arc movement is indispensable to this marking robot, which must imprint characters on the inner surface of pipe. Development of programs for this function was carried out at Fanuc Ltd.

Combinations of the outside diameter and wall thickness of pipe were divided into 53 groups. Furthermore, two marking positions were taken into consideration and the home position motion was added in developing 107 teaching programs.

Much time is required if a human being directly teaches 107 teaching programs by actually moving the robot arm. Therefore, the simulation of robot motions is carried out using a computer, and space coordinates for teaching are determined beforehand. Numerical values are then keyed into the robot controller without actually moving the robot arm. By adopting this indirect teaching method, all teaching operations were completed in about 1/10 the time required for direct teaching.

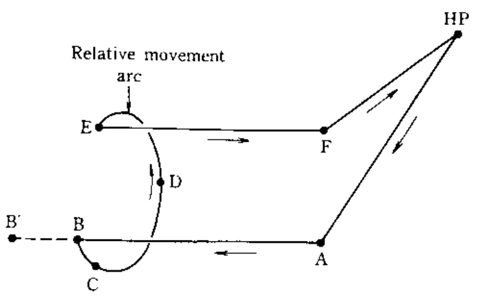

Fig. 9 Approach sequence of marking robot

7 Safety Measures

In June 1983, the Ministry of International Trade and Industry (MITI) promulgated a ministerial ordinance for revising part of the industrial safety and health regulations to secure safety of industrial robot operations. In September of the same year, the Ministry promulgated the technical guideline concerning safety regulations for the use of industrial robots.

To meet these standards, the following safety measures were incorporate in the design and operation of the marking robot:

(1) An steel safety fence is installed around the robot to prevent entry within the movement range of the robot, except through the entrance.
(2) The robot stops automatically if the door of the safety fence should open during automatic operation.
(3) The robot speed is compulsorily lowered during teaching operation.
(4) Indicator lamps are installed so that the operation condition of the robot can easily be determined.
(5) Emergency stop switches are installed inside and outside the safety fence.
(6) The collision warning sensor at the end of the marking head (see Sec. 5.1) works to stop the robot, should a human body come into contact with the sensor.
(7) The card "In Operation" must be used so that the fact that inspection or teaching operations are in progress can be known by third persons.
(8) Standards for inspection and teaching are established and thorough training in operation and maintenance is conducted.

8 Conclusions

Kawasaki Steel developed an articulated-type marking robot with a small marking device at the end of its arm. This robot was put into practical use in the medium-diameter seamless pipe mill at Kawasaki's Chita Works. Curved surfaces of pipe can be marked without difficulty because characters are imprinted in a noncontact manner by the dot spray method.

In the medium-diameter seamless pipe mill, characters are imprinted on the pipe interior for purposes of piece control. Since the robot is fully automatic, labor-savings of three workers were achieved with satisfactory results.

However, the present robot cannot be applied to pipe with inside diameters of 150 mm or less due to the size of the marking head. It will be necessary to decrease the size of the marking head if the robot is to be applied to smaller-diameter pipe.

To apply the robot to large-diameter pipe, a robot for imprinting shipping marks on UOE pipe (outside diameter 20~64 in.) has also been developed. This robot will be put into service in the UOE pipe mill at the Chiba Works. Marking software is very sophisticated: this UOE pipe marking robot can imprint up to 800 characters of different sizes in multiple stages on the inside and outside of pipe. The new robot in the UOE pipe mill, however, has fundamentally the same structure as that of the unit in the medium-diameter seamless pipe mill. Marking of objects of other than tubular form is also possible, provided robot programs are changed.

Much valuable experience and many useful techniques were obtained through the development of these robots. This knowledge will be incorporated in the company's plans to promote factory automation.

The authors would like to extend their sincere thanks to the concerned persons at Marktec Corp. and Fanuc Ltd. for their suggestions and assistance in the development of this marking system.

References

1) K. Inoue, M. Kamioka, T. Tanabe, K. Yamasaki, T. Hirokawa, S. Asanuma, S. Shimizu, H. Ishikawa, and T. Furukawa: *Tetsu-to-Hagané*, **71**(1985)5, S369
2) T. Ando, S. Uesugi, Y. Taguchi, K. Nozawa, T. Maguchi: *Kawasaki Steel Giho*, **11**(1979)2, 228–239
3) Y. Sayama, F. Tomigashi, A. Ejima, H. Abe, Y. Funyu, K. Wada, T. Maguchi, and Y. Taguchi: *Kawasaki Steel Giho*, **13**(1981)1, 1–13
4) Y. Funyu, T. Fujiwara, K. Sakurada, M. Aratama, K. Yamamoto, and Y. Shoji: *Kawasaki Steel Giho*, **15**(1983)4, 288–295
5) K. Iga, K. Sakurada, Y. Funyu, S. Aiyama, K. Nozawa, and H. Kasahara: *Tetsu-to-Hagané*, **71**(1985)5, S309
6) Marktec Corporation: Japanese Utility Model Provisional Publication, Showa 58-128658