KAWASAKI STEEL TECHNICAL REPORT
No.31 (November 1994)
Special Issue on 'Stainless Steel 'and
' Engineering and Construction'

Automatic-Controlled Circumferential MAG Welding System for Pipeline Construction

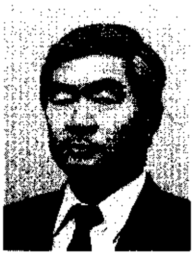
Tomoya Fujimoto, Noboru Fukuhara

Synopsis :
An automatic-controlled MAG welding system which incorporates expert programs simulating professional skills and know-how has been developed and applied to field welding. The principal results work were: (1) Joining efficiency was nearly double that with conventional SMAW, (2) the quality of welded joints was excellent with few variations, and (3) further labor savings associated with a higher arc time rate are desired. The new system also holds considerable promise for alleviating dirty, dangerous, and hard work conditions in pipeline construction.

The body can be viewed from the next page.

Automatic-Controlled Circumferential MAG Welding System for Pipeline Construction*

Tomoya Fujimoto
Staff Assistant General Manager, Pipeline Engineering Sec., Pipeline Engineering Dept., Engineering & Construction Div.



Noboru Fukuhara
Senior Researcher, Construction Engineering Lab., Structure Res. Labs., Engineering & Construction Div.

Synopsis:

An automatic-controlled MAG welding system which incorporates expert programs simulating professional skills and know-how has been developed and applied to field welding. The principal results work were: (1) Joining efficiency was nearly double that with conventional SMAW, (2) the quality of welded joints was excellent with few variations, and (3) further labor savings associated with a higher arc time rate are desired. The new system also holds considerable promise for alleviating dirty, dangerous, and hard work conditions in pipeline construction.

1 Introduction

As the 21st century approaches, large-scale introduction of natural gas is planned as a means of satisfying the rising demand for basic national energy sources such as electricity and city gas and improving the global environment. In line with this, plans for the construction of major gas pipelines crisscrossing the Japanese archipelago and the concept of an Asia Pipeline have become subjects of keen interest.

Pipeline construction basically involves the successive welding of segments of steel pipe in a narrow trench at the site. However, a high level of skill and ample experience in the requisite techniques are required. In addition to the fact that a great deal of time is needed to acquire these skills, these techniques are not easily transmitted to others. The advanced age of welders with a high level of skill and the generally inadequate number of persons with such skills must not be underestimated. Likewise, the automation of circumferential welding is also an urgent task from the viewpoint of eliminating dirty, dangerous, and hard conditions in welding work.

A large amount of research work has been done on the automation of circumferential welding of fixed pipe.[1-3] As the state of the art, computer control has been applied to this task,[4] but such technology has not yet reached general practical application. The main unsolved problems are to incorporate the skill and know-how of rich experienced welders in automation, develop a small, lightweight, easy-to-handle circumferential welder, and maintain groove accuracy and expand the tolerance range.

In the present work, an automatic-controlled circumferential MAG welding system equipped with an intelligent function was developed by incorporating the skills and know-how of expert welders in a computer. The new system was applied in field welding, satisfactorily confirming its practical capabilities. The configuration, development, and application of the system are described below.

2 Automatic-Controlled Welding System

2.1 Configuration

The configuratin of the system is shown in **Fig. 1**; the main specifications of the various units of hardware are given in **Table 1**. An off-line computer is used to prepare and revise the data on conditions for circumferential welding and to output values for execution. During welding, the welding head performs automatic welding while travelling on a rail secured to the outer circumference of the pipe, operating in accordance with present data input at the controller using a floppy disk. Naturally, the data varies widely, depending on the material properties, diameter, and wall thickness of the pipe

* Originally published in *Kawasaki Steel Giho*, **25**(1993)3, 192–195

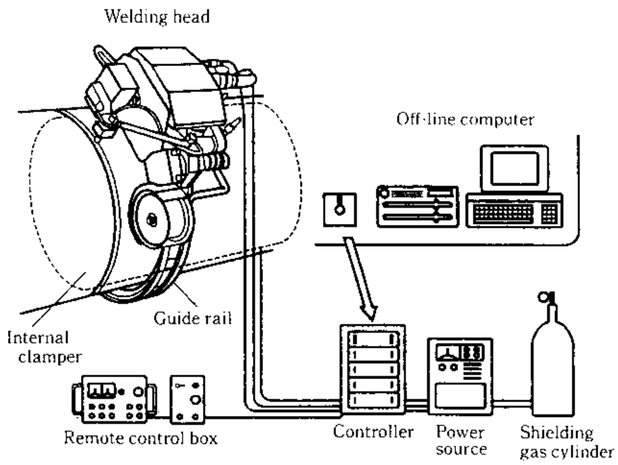


Fig. 1 Computer-controlled circumferential MAG welding system

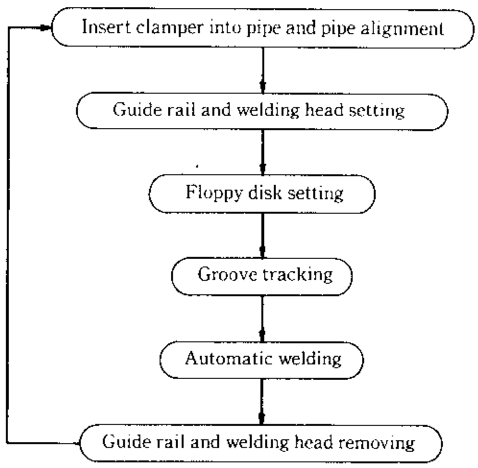


Fig. 2 Sequence of welding operation

Table 1 Specification of system unit

Welding head	
Weaving width (mm)	0—23
Weaving speed (mm/s)	5—35
Dwell time (s)	0—1.4
Travelling speed (mm/min)	0—1 500
Controller	CPU, I/O extended unit, control unit, drive unit, power unit (Weight 150kg)
Power source	DC arc welder (18 KVA, 350 A * 36 V) (Weight 50 kg)
Internal clamper	
Type	Pneumatic force, copper backing attached
Operating pressure (MPa)	0.69
Remote control box	
Control item	Current, voltage, welding speed, weaving condition, etc.
Guide rail	Steel product of two divided type with rack (Weight 7 kg for φ 500)
Shielding gas cylinder	Pre-mixed gas (7 m^3, Ar : CO_2 = 4 : 1)
Off-line computer	PC-9801

being welded, and the pass sequence. A remote control box allows manual intervention to cope with irregular conditions which may arise during welding, and is therefore normally kept near the welded joint.

2.2 Operating Sequence

The welding operation follows the sequence shown in **Fig. 2**. First, the internal clamper is inserted into the pipe to be welded, centered on the groove from inside the pipe by air pressure, and secured. At the same time, a backing copper plate is aligned. Next, the guide rail is attached to the outer circumference of the pipe, and the welding head is mounted on it. Automatic welding begins after three-dimensional measurement of the groove line with a contact sensor. When welding is completed, the welding head and guide rail are detached and moved to the next joint.

2.3 Intelligent Function

When pipe segments have been selected for welding, it is necessary to prepare the data on welding conditions. If it is not desirable to perform welding using the data already recorded in the controller without modification, an expert welder modifies the past welding conditions with appropriate values using the remote control box and gives the necessary instructions for welding. This operation is performed while observing the welding arc and pool. The revised values are recorded at the controller in real time in 1° increments around the circumference of the pipe, and subsequent welding is performed using the newly created data. As this operation is repeated, the data recorded in the controller gradually achieves a level equivalent to that of an expert welder. This function supports the efficient setting of appropriate welding conditions, and makes it possible to quantify, control, and further accumulate the welding skills and know-how of expert welders.

2.4 System Features

The features of this system are as follows:

(1) Automatic Control by Computer

The computer automatically controls 13 preset items in 1° circumferential increments, including the welding current, arc voltage, weaving conditions, vertical and lateral position of the torch, and opening and closing of the welding circuit. These conditions are separately classified according to pipe material, diameter, wall thickness, and the pass sequence, and are incorporated into a data base for effective use as needed.

(2) Actual Execution in Accordance with Skills and Know-how of Expert Welders
Using the learning function, the welding conditions indicated by expert welders are successively incorporated into the computer. Repetition of its operation improves the accuracy and practicality of the conditions, making it possible to consistently achieve automatic welding on a level equivalent to that of expert welders. Accordingly, even non-expert workers are able to obtain satisfactory welded joints, and the property of welded joints does not depend on the skill level of operators.

(3) Real-time Response to Irregular Changes in Conditions
During welding, when the groove is found locally to exceed the tolerance range or when conditions change unexpectedly it is possible to avoid problems in advance by manually intervening to make fine adjustments using the remote control box.

(4) Recording and Instruction of Actually Used Welding Conditions
The finally obtained welding conditions and welding conditions applied after manual intervention can be printed out in 1° increments in the circumferential direction.

(5) High Efficiency Welding, High Quality Joints
In comparison with conventional welded joints, higher efficiency and higher quality can be obtained in joints produced with the new system. With large diameter pipe, a further increase in efficiency can be obtained by simultaneously using multiple welding heads.

(6) Improvement of Dirty, Dangerous, and Hard Working Environment
Because a small lightweight automatic welder is used, it is not necessary for workers to go under the pipe in the narrow area of the trench. This and other improvements significantly alleviate the dirty, dangerous, and hard working environment during welding.

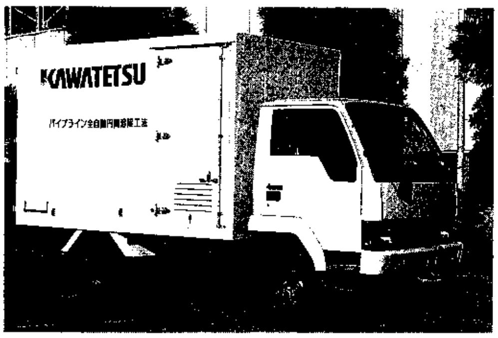


Photo 1 Mobile mount on present system for field service

(7) Outstanding Mobility in Welding Work
The system, including the engine-generator, controller, and other hardware, is mounted on a special purpose vehicle for movement within the work area and quick, easy access to various welding sites. A mobile is shown in **Photo 1**.

3 Welding Test

3.1 Steel Pipe

Welding tests were performed with API 5L X52 and X60 steel pipes, with a diameter of 300–900 mm and a wall thickness of 9–19 mm, which are typically used in electric power and city gas pipelines. Among these materials, the following will discuss a test involving 14 joints of X60 pipe with a diameter of 500 mm, a wall thickness of 11.9 mm, and a unit length of 11 m.

3.2 Execution of Welding

The welding materials are shown in **Table 2**, and the groove geometry in **Fig. 3**. Although various pass sequences are available, as shown in **Fig. 4**, the method used in this case was ③, namely, alternate direction changing in 360° multi-pass welding. This pattern was adopted to avoid wrapping the auxiliary cables (power, controller) around the pipe and ensure the uniformity of the pass thickness. As welding conditions, the welding current ranged from 100 to 150 A, the arc voltage, from 17 to 25 V, and the welding speed, from 100 to 250 mm/min. In spite of this wide range, all settings were possible.

Table 2 Welding material

Pipe grade	Mild and high tensile strength 490 N steel
Wire	Solid type (ϕ 0.9) 5 kg/1 spool
Shielding gas Composition Flow rate (l/min)	 Ar : CO_2 = 4 : 1 15–25

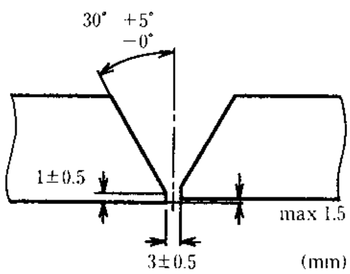


Fig. 3 Groove geometry

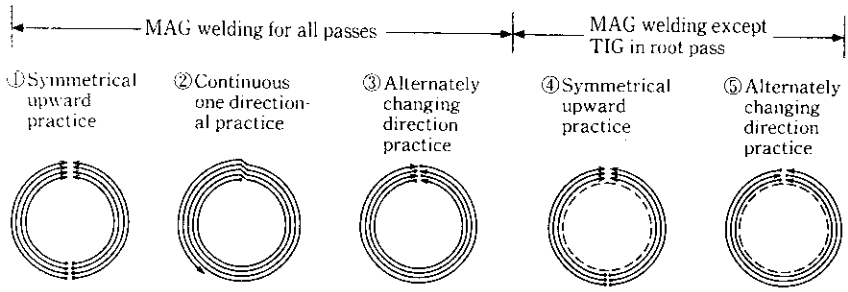


Fig. 4 Pass sequence

3.3 Joint Performance

As mechanical properties, the tensile strength, bending, Charpy values, and hardness of the joints were investigated. The results, as shown respectively in **Photos 2 and 3**, **Table 3**, and **Fig. 5**, were satisfactory and met all relevant industry standards.

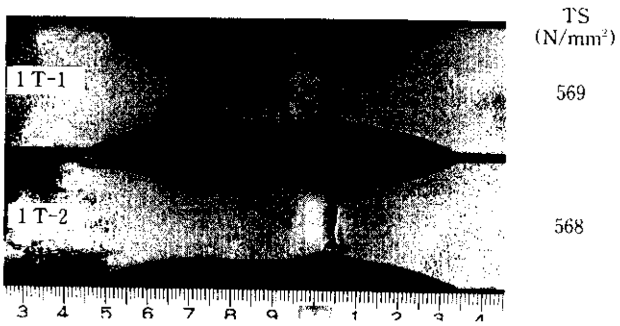
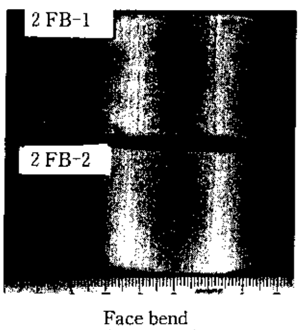


Photo 2 Tensile test results of welded joint (Location of rupture: pipe body)



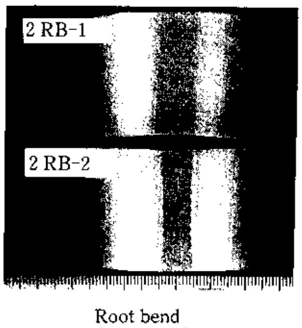


Photo 3 Bend test results of welded joint

Table 3 Charpy impact test results of welded joint

Energy absorbed at −10°C (J)	
WM	HAZ
144	218
159	203
148	259

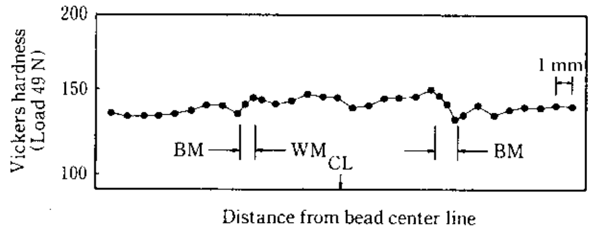


Fig. 5 Hardness value of welded joint

3.4 Results of Field Welding

A summary of the results of field tests, including a comparison of conventional manual welding presented in **Table 4**. The main points are as follows:

(1) The total time required for one cycle, including the actual welding and associated work before and after welding, is 2 h with automatic welding and 4 h with manual welding; thus, automatic welding increases the rate of efficiency by two times over than with manual welding.

(2) Actual welding requires 1.5 h/cycle with automatic welding and 3 h/cycle with manual welding, showing the same tendency as in (1) above.

(3) In terms of man-hours, the automatic and manual methods show no difference, both requiring 3 man-h/joining.

(4) Arc time is 1 h in automatic welding, or only 40% of the 2.5 h required in manual welding.

Table 4 Joining efficiency and quality of welded joint

Item \ Welding process		Manual welding	Automatic welding
Efficiency	Cycle time (h)	4	2
	Joining time (h)	3	1.5
	Man-hour	3	3
	Arc time (h)	2.5	1
Quality	Rate of X-ray films superior to JIS Grade 2[a]	101/105=96%	98/98=100%

[a] JIS Z 3104

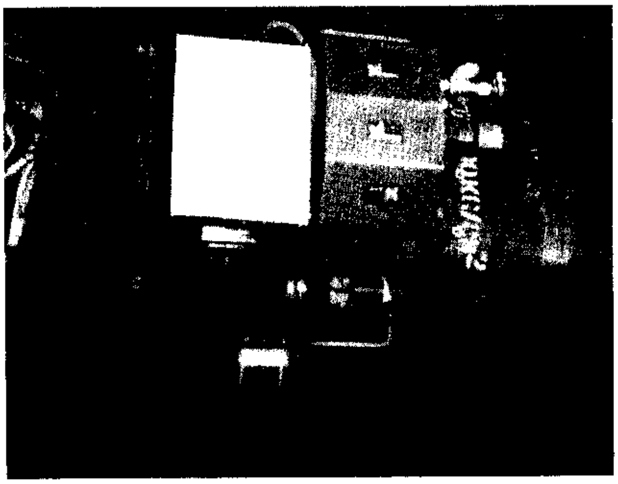


Photo 4 Field view under welding

(5) The arc time ratio in automatic welding shows a lower value (67%) than that in manual welding (83%). It is therefore necessary to increase the arc holding time and rationalize auxiliary tasks in automatic welding.
(6) In X-ray inspections, the rate of acceptance at JIS Grade 2 or above was 96% with manual welding and 100% with automatic welding. In these figures, 96 of 98 X-ray films of automatic welds rated Grade 1.
(7) As weld defects, blowholes (BH) occurred with both manual and automatic welding. Blowholes were found at locations where electrodes were joined in manual welding, and at points where the sputter adhering to the nozzle and/or tip had fallen off in automatic welding.

Photo 4 shows welding in the field with the automatic system. As can be seen from the example presented above, automatic welding offers double the efficiency of manual welding in terms of cycle time, actual welding time, and arc time. However, the two methods show equivalent amounts of man-hours; from this viewpoint, labor saving in automatic welding remains as a task for the future. Moreover, there is also room for improvement in the arc time rate in automatic welding.

On the other hand, joint quality at the JIS Grade 1 level was achieved in virtually all automatic welds. In comparison with manual welding, variations are fewer and it is possible to obtain high quality joints more consistently with automatic welding.

4 Conclusions

With the principal aims of automating fixed pipe welding and improving the dirty, dangerous, and hard working environment typical of pipe joining operations, an automatic-controlled circumferential MAG welding system was developed. The system is equipped with a learning function which incorporates the skills and know-how of expert welders. Field tests were conducted, demonstrating that this system is well-suited to use in practical applications. The results are summarized below.

(1) Joining efficiency was double that in manual welding.
(2) Joint quality was excellent, with few variations, and was stable at a high level.
(3) Labor savings and improvement in the arc time rate are further desired.

In the future, the authors plan to combine remote control operating techniques and high speed welding technology, realize a system with a higher level of automation, and contribute to cost benefits in the construction of large-scale pipelines, and hope to assure further environmental improvements in pipe joining work.

References

1) Y. Nogami, T. Bada, R. Inami, T. Fuseda, and E. Sasaki: Proc. of Technical Commission on Welding Processes, JWS, SW-1343-82
2) H. Imaizumi: *Haikan-to-Sohchi (Piping and Process Equipment)*, (1986)3, 7
3) Y. Sugitani, M. Kobayashi, and M. Murayama: *Haikan-Gijutsu (Piping Engineering)*, (1991)2, 55
4) Sumitomo Metal Ind., Ltd., Sumikin Pipe Construction Corp.: PR sheets "High Speed Automatic MAG Welding System," (1989)