UDC 621 . 791 . 753 . 9 - 52 : 621 . 644

Automatic Control Technology of Welding Machine MAG-II for Onshore Pipelines

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Abstract

The authors developed a new, automatic narrow groove welding system MAG-II for onshore gas pipelines. It has a through-the-arc sensor (arc sensor) and a vision-based sensor. The vision-based sensor is used for controlling the traveling speed and oscillation width for the root pass. The arc sensor is used for controlling the torch position and torch oscillation width for hot and filler passes. MAG-II equipped with these sensors enables high quality girth welding at field.

1. Introduction

For gas pipeline construction in Japan, the introduction of automatic welding machines began to be considered for welding large- and medium-diameter steel pipes in the 1970s, and the automatic welding of pipes for high-pressure gas pipelines was rather firmly established in the 1990s. Since the mid 1990s, Nippon Steel has been developing a welding system MAG-I to assure weld quality and for higher-speed welding performance, NSC has developed and introduced in site work an automatic welding system MAG-II. This paper mainly describes technical aspects of the MAG-II automatic control.

2. Characteristics of MAG-II

2.1 System configuration

Fig. 1 and **Table 1** show the system configuration and the specification of MAG-II. MAG-II consists of: (1) a welding head; (2) a controller; (3) pendant box; (4) guide rail; (5) an internal clamping machine; (6) a power supply; and (7) shield gas.

By the combination of the pinion gear of the welding head and the rack formed on a guide rail suited for a steel pipe size between 12”O.D. and 36”O.D., this system performs high-speed welding with one or two heads, while providing high-precision speed control. **Photo 1** illustrates MAG-II performing two-head welding.

2.2 Welding process

The welding method is a narrow-grooved gas metal arc welding (GMAW), with the torch oscillated at a high frequency (75 Hz, max.) in a groove of bevel angle 9.5˚. The welding progresses downward semi-circularly from top (0˚) to bottom (180˚) of a steel pipe on one side and on the other side alternately. The system uses a solid wire, having an outside diameter of 1.2mm, and a shield gas of a mixed gas consisting of Ar by 70% and CO_2 by 30%, determined to assure good welded joint quality and welding performance. **Fig. 2** shows a typical groove for MAG-II.

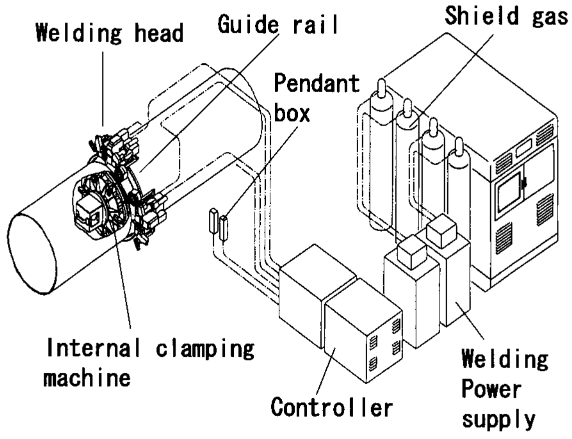

Fig. 1 Welding system

2.3 Automatic control technology

In GMAW, generally, welding wire oscillation center position

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Table 1 Specifications of MAG-II

Dimensions (mm) / Weight of welding head (kg)	255 height × 525 length × 360 width / 17
Traveling speed (cm/min)	300 (max)
Oscillation frequency (Hz)	75 (max)
Welding process	Metal active gas welding, down hill
Diameter of welding wire (mm)	1.2
Welding power supply (A)	DC 500A
Control unit	Industrial PC, DSP, ADC, DAC, Serial IF, Ethernet IF
Feedback control system	
Seam tracking	Arc sensor
Oscillation width control	Vision-based sensor (root pass), arc sensor (filler passes)
Traveling velocity control	Vision-based sensor (root pass)
Internal clamping machine	Hydraulic / pneumatic clamp with a copper backing ring

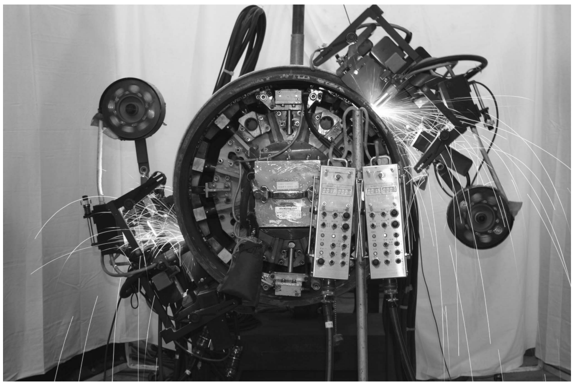


Photo 1 2-head welding

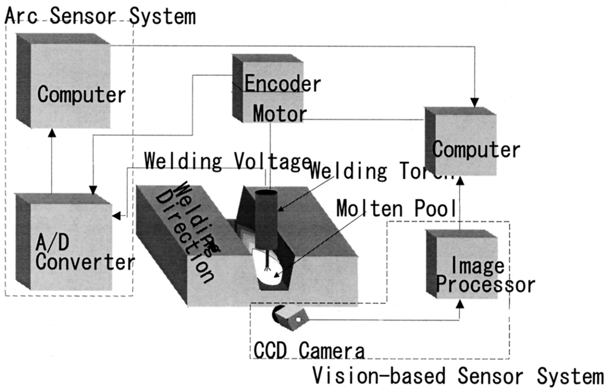


Fig. 3 Outline of sensor system

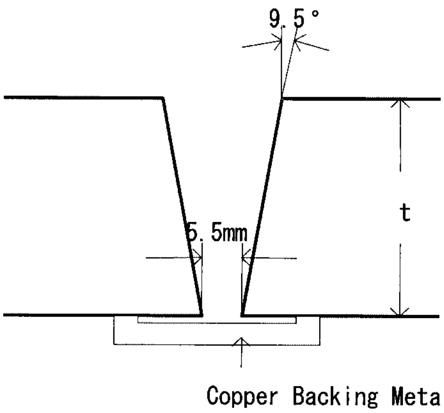


Fig. 2 Normal groove design

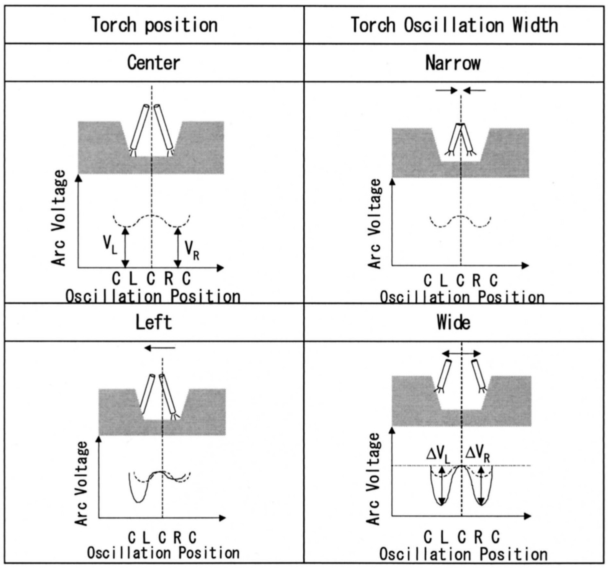


Fig. 4 Principle of arc sensor

and oscillation width relative to the beveled groove to be welded need to be properly controlled to prevent possible occurrence of flaw such as the lack of fusion and incomplete penetration. In gas pipeline welding requiring all types of welding positions, the appropriate formation of back-bead is essential. MAG-II automated these necessary controls by the use of an arc sensor and a vision sensor. **Fig. 3** illustrates a schematic configuration of the sensor system. The subsections below will describe this in further detail.

2.3.1 Arc sensor

The arc sensor technology features determining the relative positions of the groove and the torch by detecting changes in welding current or arc voltage caused by torch oscillation. This is widely used as a groove profiling control technology. **Fig. 4** shows the principle of the arc sensor. If the oscillation center position slides sideways, the arc voltage waveform changes from a dotted-line form to a full-line form, and the amount of the offset from the center can therefore be estimated by the difference between the voltages at left and right oscillation ends, $V_L - V_R$. If the oscillation width increases, the amount of the voltage drop increases from a dotted-line waveform level to full-line waveform levels, and the amount of the oscillation width can therefore be estimated for instance by the deviation from the normal sum of the voltage drop amounts $\Delta V_L + \Delta V_R$.

For narrow grooves, however, sensing technology with greater accuracy is needed to assure welded joint quality. In addition, for welding pipes at horizontally fixed pipelines, various welding conditions were used depending on welding positions, and enhanced sensing accuracy particularly in low current regions was an important requirement because arc voltage fluctuations due to short-circuit transfer in low current regions could degrade the sensing accuracy.

To solve those problems, MAG-II has a high-frequency oscillation mechanism with unique arc sensor design that can freely set up oscillation frequency and oscillation width.

1) Seam tracking system

Fig. 5 shows arc voltage waveforms with the torch oscillation frequency set at 40 Hz.

At a high current level (330A) in a spray transfer mode, shown in the upper chart, the arc voltage continuously varies along with change in oscillation position and shows a decline bottom at left and right (L, R) ends of oscillation. If the center (C) of the torch oscillation width comes off the groove center, the voltage drops at both left and right ends of oscillation vary accordingly, and the amount of the offset can be obtained by the difference in straight accordance with the sensor control concept, justifying the seam tracking system.

The lower chart in Fig. 5 shows an arc voltage waveform at a low current level (180A), featuring short circuit transfer at left and right ends of oscillation. Short-circuit transfer, which is considered to occur usually in a frequency range approximately between 50 Hz and 100 Hz, is repeated independently on the torch oscillation position when the torch oscillation frequency is low and was usually a cause of a decline in deviation detection accuracy. But the findings that the setup of a high oscillation frequency, particularly an oscillation frequency of approx. one half of the short circuit transfer frequency, can confine short-circuiting positions to oscillation ends, and that if the torch oscillation center position deviates from the groove center position, the frequency of occurrence of a short circuit transfer at oscillation ends varies while the short circuit transfer occurrence positions are fixed at the oscillation ends, indicated the possibility of high-accuracy detection of deviations in high-speed welding torch operation even at low current levels as well as the possibility of seam tracking system.

2) Oscillation width control

The sum of the amounts of voltage drops $\Delta V_L + \Delta V_R$ shown in Fig. 4 can serve as an index for estimating oscillation width deviations. But using it as an index could decline the accuracy of deviation estimation because the sum of $\Delta V_L + \Delta V_R$ gives different values depending on short-circuit transfer and oscillation center position deviations. We then used a unique oscillation width deviation control process as delineated in **Table 2**.

(1) The MAG-II system determines voltage drop amounts (ΔV_L, ΔV_R) at both oscillation ends.

(2) The MAG-II system compares the ΔV_L and ΔV_R with the threshold value ΔV_{ref}, and converts them into the two values of ΔU_L and ΔU_R. Here, the ΔV_{ref} is a constant depending on the target oscillation width. We set it so that it was possible to determine the amount of voltage drops in the same way irrespective of short-circuit transfer or spray transfer mode.

(3) The MAG-II system computes oscillation width deviation ΔW and feedback control amount D_w in accordance with a prepared table. If both of the amounts of voltage drops at the oscillation ends are above the threshold value, the MAG-II control determines the oscillation width large; and if they are below the threshold value, it determines the oscillation width small. If the voltage drop amount at one oscillation end only exceeds the threshold value, MAG-II considers that very small profiling deviation from groove center gave rise to short-circuit transfer and determines the oscillation width small.

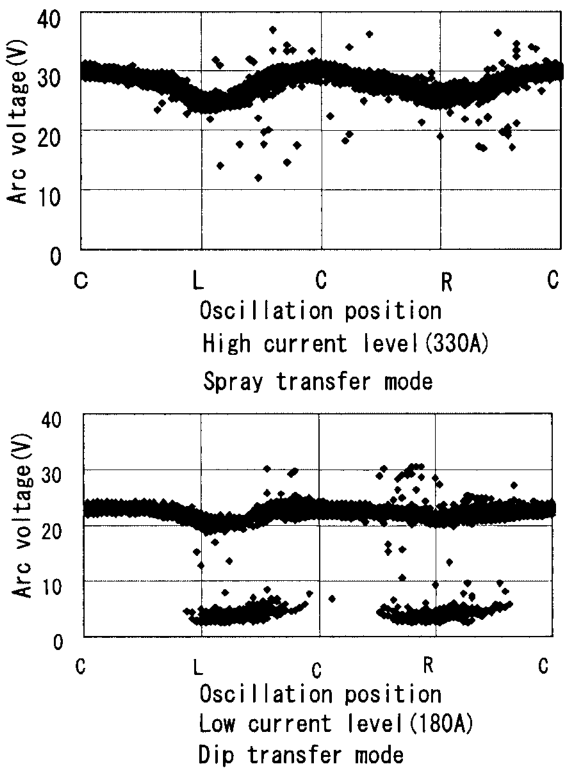
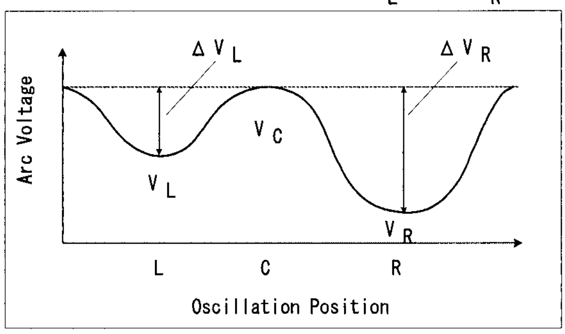


Fig. 5 Arc voltage waveform in 40Hz oscillation

Table 2 Estimation of oscillation width deviation

1) Measure the voltage drops ΔV_L and ΔV_R



2) Compare ΔV_L and ΔV_R with V_{ref} and calculate ΔU_L and ΔU_R

$\Delta U_L = 1$ (if $\Delta V_L > V_{ref}$), 0 (otherwise)
$\Delta U_R = 1$ (if $\Delta V_R > V_{ref}$), 0 (otherwise)

3) Estimate the width deviation ΔW

		ΔU_R	
		1	0
ΔU_L	1	D_w	$-D_w$
	0	$-D_w$	$-D_w$

By repeating the processing of the steps described above for every oscillation cycle, MAG-II can perform high-precision control of oscillation width[1].

2.3.2 Vision-based sensor[2]

1) System configuration

As shown in Fig. 3, the vision-based sensor system has a CCD camera fitted with an interference filter that is arranged so that the main transmission waveform is in the near infrared region frontward in the welding direction. Images of molten pool are taken into an image processor, where image measurements and control amounts are generated. Oscillation width profiling control and back-bead control are also performed. The following subsections describe the back-bead control in particular.

2) Precedence length measurement and back-bead control

The following is an investigation of molten pool images and back-bead formation in welding.

A CCD camera arranged as shown in **Fig. 6** revealed that the relative positions of the arc point and molten pool end can significantly affect the formation of the back-bead, and that a good bead can be formed there if the distance between the bottom of the molten pool image (the front end of molten pool) and the bottom of the welding wire image (hereinafter referred to as precedence length of molten pool, PL) is within a certain range.

Letting PWY represent Y ordinates for the welding wire end known from a characteristic point in the molten pool image shown in **Fig. 7** and by measurement, and PSY represent Y ordinates for the bottom at the center of the molten pool, the equation below is attained.

$PL = PSY - PWY$

By using a median of data around PL detection and by letting ϕ denote a position angle at the time of detection, we obtain smoothed date $PLmed(\phi)$. If we let $PLstd(\phi)$ be a standard precedence length at the position angle ϕ and enter the difference δPL from $PLmed(\phi)$ into the speed control function graph in **Fig. 8**, the speed increment/decrement value δV (%) is computed and is transmitted as a speed control command to the control panel of the welding system.

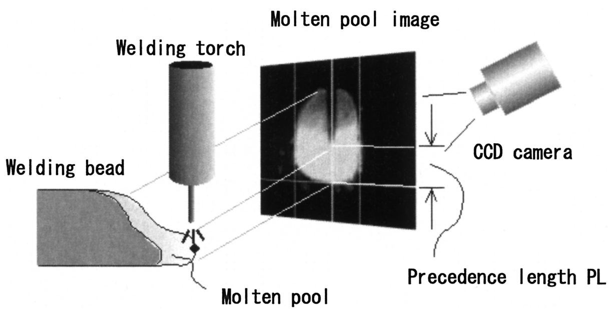


Fig. 6 Precedence length of molten pool

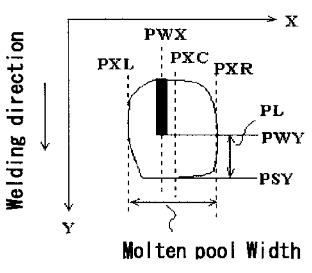


Fig. 7 Measured length

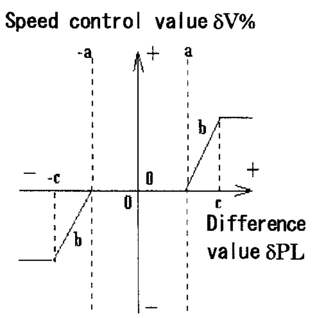


Fig. 8 Function for speed control

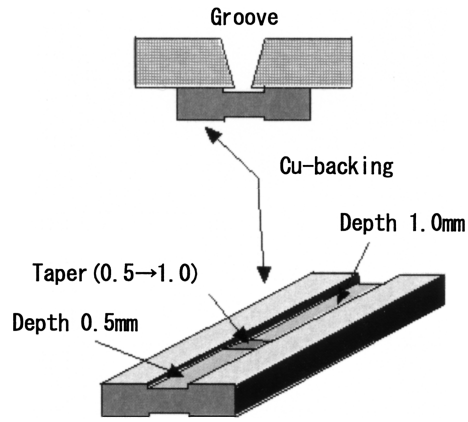


Fig. 9 Test piece

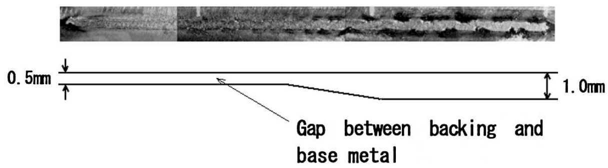


Fig. 10 Appearance of back-bead without control

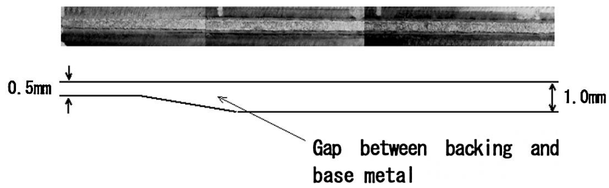


Fig. 11 Appearance of back-bead with control

3) Results of back-bead control experiment using precedence length measurement

Using joint welding specimens of narrow single V groove, each with a root gap of 4.9 mm and a bevel angle of 9.5˚, combined with such a copper backing as providing clearances, between it and the underside of the base metal, of 0.5 mm at the start of the welding and 1.0 mm at its end (**Fig. 9**), we welded them in an overhead position with and without back-bead control. The appearance of the bead is shown in **Fig. 10** and **Fig. 11**, respectively. The joint welded without back-bead control (Fig. 10) had a good formation of bead in the clearance zone of 0.5 mm, but the welding was unstable and the formed back-bead was irregular and defective in the tapered zone and the clearance zone of 1.0 mm. By contrast, the joint welded with the back-bead control (Fig. 11) exhibited a good formation of the back-bead and the welding was stable throughout the entire length of the zones. It was thus verified that the back-bead control were quite able to automatically meet even uneven clearances between the root and base metal and to help formation of good bead.

3. Results of Performance Verification

Using MAG-II equipped with an arc sensor and a vision-based sensor as described above, we tested the performance of the automatic control technology by girth-welding specimen steel pipes in downhill welding sequences (0˚ to 180˚), with the arrangements of

(1) A steel pipe whose root gap is preset 1 mm wider at 90˚ positions than at the pipe top (0˚) and the pipe bottom (180˚) positions, and (2) a steel pipe for which the guide rail position is 6 mm pre-shifted at the 90˚ pipe position compared with that at the 0˚ and 180˚ pipe positions.

The test of root pass under the oscillation width control with the arc sensor gave a result of approximately 1 mm wider torch oscillation width at 90˚ corresponding to changes in groove width, to show that the width profiling control is effective for the setup of (1) above.

Also, in the seam tracking system with the arc sensor, the torch position changed with change in the distance between the groove and guide rail. It drew a locus of showing a maximum of 6 mm at 90˚ and returning to the original position at 180˚. It was thus verified that there is a suitable functioning of the center profiling control for the setup of (2) above[3, 4].

In the root pass oscillation width control with the vision-based sensor, the oscillation width changed with change in root gap, showing a width approximately 1 mm wider at 90˚, to verify satisfactory performance of the oscillation width control[3, 4].

At those prearrangements, back-bead reinforcement was formed satisfactorily, and results of our nondestructive testing also verified that the welded joints were lack of fusion, incomplete penetration and other flaw. In addition, the results of our examinations of the mechanical properties of joints welded as above were satisfactory as listed in **Table 3**.

MAG-II having the above-described automatic control capabilities has been practically applied to onshore gas pipelines since 2003.

Table 3 Mechanical test results

Diameter and wall thickness	609mm outer diameter × 15.1mm wall thickness	API 5L X65
Electrode	1.2mmϕ	JIS Z 3312 YGW24
Tensile test	607 - 610 MPa	JIS Z 3121, Z 2241
Bending test	No crack	JIS Z 3122
Hardness test (HV 98N)	Max. 241	JIS Z 2244
Charpy impact test	Weld metal: Min. 90J @-10˚C HAZ: Min. 185J @-10˚C	JIS Z 2202, Z 2242

4. Conclusion

The automatic welding system with an arc sensor and a vision-based sensor, MAG-II, has capabilities to performing real-time seam tracking system, oscillation width profiling, and back-bead formation control in the welding of narrow grooves in any welding position, to produce quality welded joints independent of the skills of welders or welding operators.

References

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