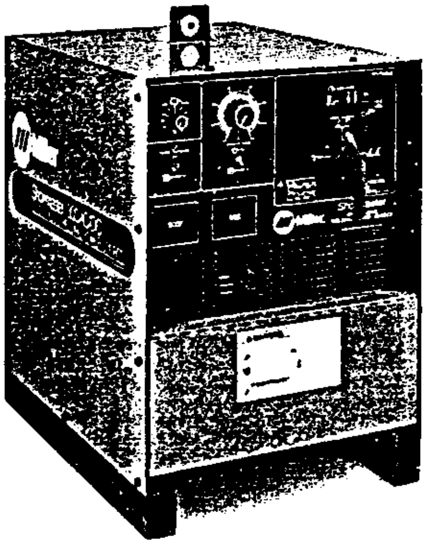
Lecture 6.

Shopmaster™

Ask for Literature No. AD/2.3

Industrial — CC/CV — AC/DC — 1 Phase

Stock Number	Mode	Rated Output	Welding Amperage Range	Max. Open-Circuit Voltage	Amps Input at Rated Output, 60Hz 200 V	230 V	460 V	575 V	KVA	KW	Dimensions	Net Weight
(#903 126) 200/230/460 V	DC/CV	300 A at 32 VDC, 50% Duty Cycle	12–32 V	40 VDC	103.5	90	45	36	20.7	13.6	H: 33½ in (851 mm) W: 19¼ in (489 mm) D: 27 in (686 mm)	370 lb (168 kg)
(#903 127) 230/460/575 V	DC/CC	300 A at 32 VDC, 50% Duty Cycle	20–330 A	68 VDC	105	91.2	45.6	36.4	20.9	13.7		
	AC	200 A at 28 VAC, 40% Duty Cycle	20–300 A	75 VAC	85	73.5	36.7	29.3	16.8	8.2		



Processes
- AC/DC Stick (SMAW)
- DC MIG (DC GMAW)
- Flux Cored (DC FCAW)
- AC/DC TIG (GTAW) with HF-251D-1 Arc Starter

When you need one welding machine that can handle just about any task, the Shopmaster™ answers the call. This compact power source features simplified operation, single-phase power requirement and exceptional versatility. And you don't have to sacrifice one feature to get another. The Shopmaster is designed to give you everything you want.

Here's a system that provides outstanding constant voltage (CV) and constant current (CC) arc characteristics for manual and semi-automatic applications. With both AC and DC output, the Shopmaster's high-end performance adapts to light-industrial fabrication and manufacturing. The rugged internal components include a solid-state contactor and controls that yield a long service life, even in high-cycle applications.

The Shopmaster has the range to be at home in a wide variety of situations. With its expansive multiprocess capabilities, it's ready for any general repair or maintenance job. The Shopmaster is a great value for farmers and ranchers who never know what welding tasks will turn up next. It's exceptional scope make it a great machine for technical and vocational training. Plus, the unit's small footprint saves valuable floor space in tight quarters.

Need a machine that can grow to meet your welding needs in the future? Add a HF-251D-1 portable high-frequency arc starter, and the Shopmaster will deliver 200 amps of Square-wave balanced AC output for exceptional TIG performance. Other options allow you to customize the Shopmaster to the specific welding tasks you have.

Features
- Simplified, easy-to-use front panel
- Three input voltage configuration
- Dual output terminals provide easy hook-up and electrical isolation between the welding processes
- Built-in line voltage compensation ensures consistent welding power
- Front-mounted 14-pin receptacle for remote control and wire feeder operation
- Both 24 volt and 115 volt AC power for wire feeder
- Contactor and wire feed control with 10 amp circuit breaker
- 115 volt AC, 15 amp duplex receptacle with circuit breaker protection
- Variable arc control

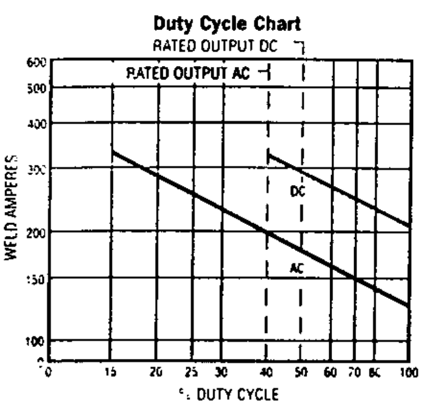
Suggested Wire Feeders

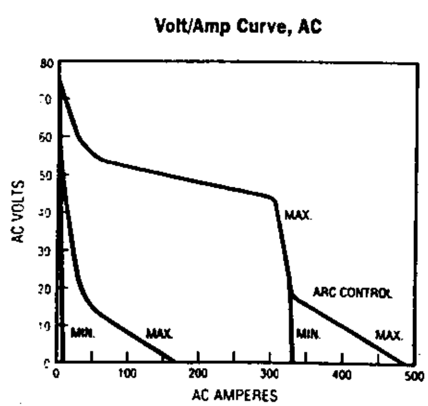
S-22A (pg 53), XR Series (pg 58), Spoolmatic 30A (pg 59)

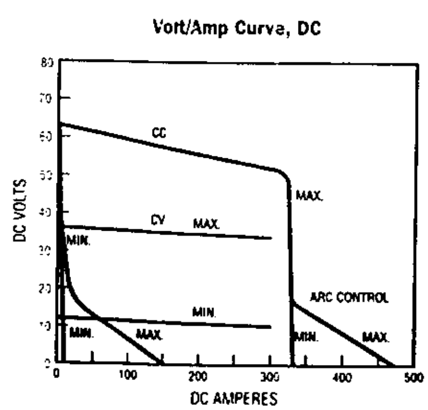
Accessories

Remote Controls: RCC-14, RFC-14, RHC-14 (pgs 75/76); **TIG High-Frequency Arc Starter:** HF-251D-1 (pg 77). See your Miller distributor for information on Voltmeter and Ammeters.

Performance Charts

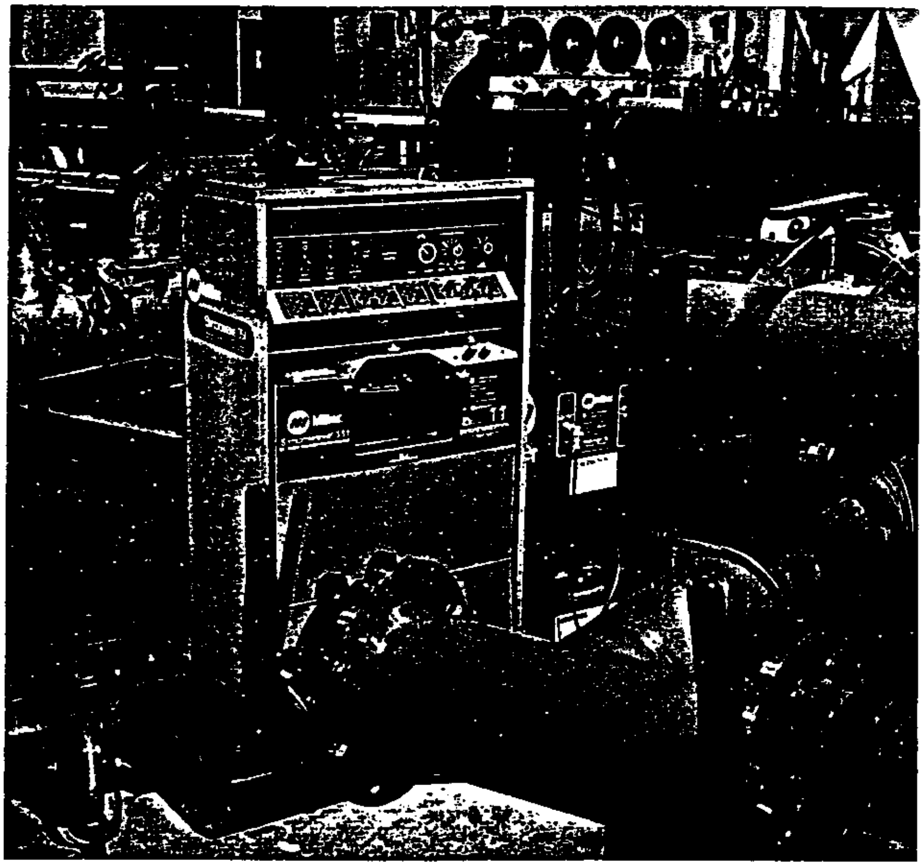






Syncrowave® Series

Welding applications that call for the highest technical skills of a master craftsman require equipment with the precise control equal to the task. Miller meets the needs of this demanding market with the Syncrowave® Series of single-phase, constant current power sources.



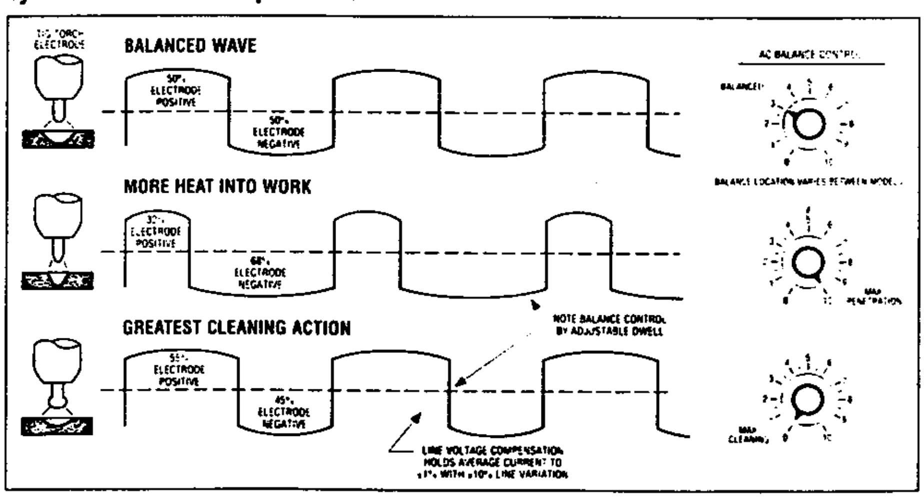
The Syncrowave family features Miller Squarewave™ AC output and manually adjustable balance control for the most demanding aluminum work. This feature also helps eliminate tungsten spitting, and permits the use of smaller diameter tungsten electrodes to operate at higher current levels. Polarity changeover and other process enhancements make it fast and easy to switch to DC TIG or Stick work.

Available in 250, 350 or 500 amp models, the Syncrowave Series offers the operating features and options to assure you of a machine exactly suited for your needs. When the job demands ultimate technical control, the Syncrowave family delivers superior performance and time-tested reliability.

Series Features

- *NEW!* Syncrowave 250 and 351 include Fan-on-Demand™ cooling system — operates only when needed
- Wide amperage range for greater flexibility
- Solid-state contactor permits superior reliability in high-cycle operations
- Automatic line voltage compensation
- Internal high-frequency arc starter and stabilizer provides positive, non-contact arc starting in TIG mode
- Three-position high-frequency switch
- Contactor-activated gas solenoid valve and postflow timer prevents atmospheric contamination of electrode and workpiece
- Polarity changing switch enables quick process changes without changing secondary connections
- 14-pin receptacle for remote control and pulse control
- Choice of foot, hand or torch-mounted fingertip remote control
- Duplex 115 volt AC, 2 kVA receptacle with 15 amp circuit breaker

Syncrowave Balanced Output Control



All Syncrowave models provide Squarewave AC output with manually adjustable balance control. The balance control features adjustable penetration and cleaning action while increasing arc stability on various aluminum alloys (refer to diagram above). This allows the operator to maximize the welding process to suit almost any application. The Squarewave AC output and balance control also help eliminate tungsten spitting and allows the use of smaller diameter tungsten electrodes to operate at higher current levels.

Syncrowave® 250 Ask for Literature No. AD/4.1

Industrial CC AC/DC 1 Phase

Stock Number	Rated Output	Welding Amperage Range	Max. Open-Circuit Voltage	Power Factor Correction	Amps Input at AC Balanced Rated Load, 60 Hz 200 V	230 V	460 V	575 V	KVA	KW	Dimensions	Net Weight
(#903 056) 200/230/460 V	250 A at 30 VAC, 40% Duty Cycle	5–310	80	Without	105.8	92	46	36.8	21.2	11.4	H: 30¾ in (781 mm)	355 lb (161 kg)
				With	76	66	33	26.4	15.2	11.4	W: 19¼ in (489 mm)	
(#903 084) 230/460/575 V	200 A at 28 VAC, 60% Duty Cycle			Without	85	74	37	29.6	17	8.3	D: 27 in (686 mm)	
				With	55.2	48	24	19.2	11	8.3		

The Syncrowave® 250 delivers excellent welding performance, control and versatility. The basic machine includes all the essential features you need for high-precision AC TIG welding, plus the flexibility to handle a wide variety of metals. The Syncrowave 250 offers an effective solution in any light industrial situation that requires constant current Squarewave™ technology.

Efficient and adaptable, the single-phase Syncrowave 250 is a great choice for fabrication shops as well as vocational training facilities. Its low-profile case fits neatly into any industrial location, while its rugged construction ensures reliable operation under constant use. A spectrum of available options allow you to start simple and add features as you need them. This high-performance machine pays off with extraordinary value.

Features

- *NEW!* Fan-on-Demand™
- Single-range current control
- Output range of 5 to 310 amps
- Arc control for Stick
- Crater fill control

Accessories

Running Gear: No. 22 (pg 71); **Coolant System:** Watermate 1A or Cool Runner (pg 72); **Remote Controls:** RFC-14, RCC-14 (pg 75); **TIG Pulsing Control:** PC-300 (pg 77). See your Miller distributor for further information on Voltmeter and Ammeter, Preflow Timer, Spot Weld Timer and Power Factor Correction.

Processes

- TIG (GTAW)
- Stick (SMAW)
- Pulsed TIG (GTAW-P) with optional PC-300

Syncrowave® 351 Ask for Literature No. AD/4.1

Heavy Industrial CC AC/DC 1 Phase

Stock Number	Rated Output	Welding Amperage Range	Max. Open-Circuit Voltage	Power Factor Correction	Amps Input at AC Balanced Rated Load, 60 Hz 200 V	230 V	460 V	575 V	KVA	KW	Dimensions	Net Weight
(#903 219) 200/230/460 V	350 A at 34 VAC, 40% Duty Cycle	2–400	80	Without	151	131	67	52	29.9	17.4	H: 47¼ in (1200 mm)	549 lb (312 kg)
				With	131	102	53	43	22	17.3	W: 24 in (610 mm)	
(#903 220) 230/460/575 V	300 A at 32 VAC, 60% Duty Cycle			Without	130	112	57	46	26.2	13.5	D: 22¾ in (578 mm)	
				With	117	84	45	34	17.9	13.7		

The Syncrowave® 351 is an exceptional single-phase TIG/Stick power source designed for the master welding craftsman. When the work demands the arc control of Squarewave™ technology, premium performance, and the highest levels of efficiency and functionality, the Syncrowave 351 meets the challenge. The three-turn current control with 2 to 400 amp output handles a full scope of AC TIG, DC TIG and Stick applications.

Every detail is addressed, from the rock-solid power output down to the quiet, dual-fan operation that directs air away from the work area. Other top-line professional features further enhance productivity. The basic model easily upgrades with options, including microprocessor control with the factory-installed Intellitig™ MPC. The 351 is a prestigious and productive addition to any shop, and to any welder who takes pride in his work.

Features

- *NEW!* Fan-on-Demand™
- Tall, easy-access case
- Simplified control panel
- Separate, presettable digital voltmeter and ammeter
- Automatic process selector switch
- Arc control for Stick mode operation
- Retractable lifting eye
- Premium arc performance in all ranges and processes
- Quiet, dual-fan operation extends life of machine and internal components

Accessories

Running Gear: No. 17 (pg 71); **Coolant System:** Watermate 1A (pg 72); **Remote Controls:** RFC-14, RCC-14 (pg 75). See your Miller distributor for information on Preflow/Spot Timer, Start Control/Crater Fill, Pulser and Power Factor Correction.

Processes

- TIG (GTAW)
- Stick (SMAW)
- Pulsed TIG (GTAW-P) with optional PC-300

Intelligent Robot Controls Penetration and Bead Height

Lecture 6

System makes adjustments according to variations in the root opening

BY Y. SUGITANI, Y. NISHI AND T. SATO

In order to achieve full automation of arc welding, an intelligent arc welding robot is required that can track the weld joint, detect the shape of the groove and control the gun position and welding parameters.

An intelligent arc welding robot called "Intelliarc" has been developed that has the following special features:

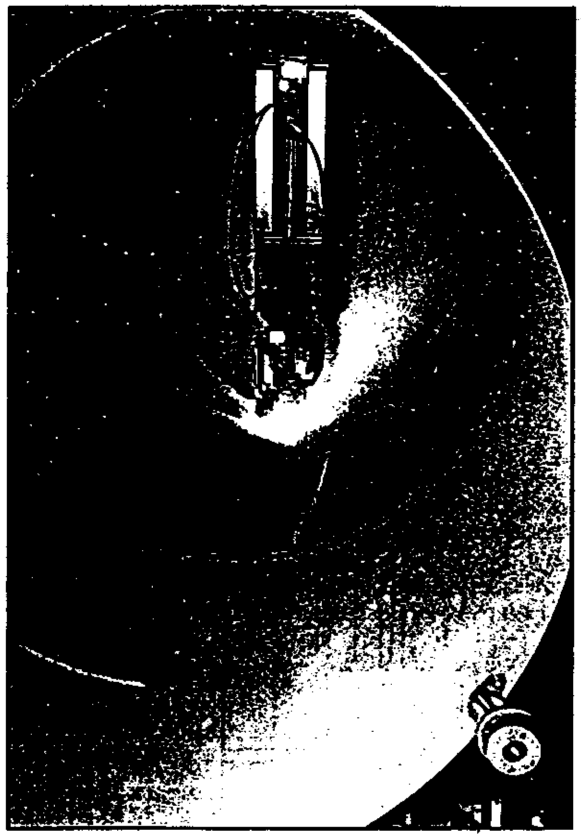
1) A high-speed, rotating arc welding system that provides high-current, high-efficiency welding with improved bead shape, weld penetration and bead height.

2) A camera-based, image-processing system that enables simultaneous control of weld penetration and bead height in variable width root openings.

3) High-accuracy joint tracking based on the combined use of an arc sensor and image-processing sensor.

4) A small welding head that can be easily inserted into closed vessels for safe, unmanned welding.

This paper describes the intelligent welding system and its functions, including the method for simultaneously controlling the penetration depth and bead height with variable root openings.



An intelligent arc welding robot performs a circumferential weld inside a large pressure vessel.

Purpose of Development

The system was developed to weld cylindrical, austenitic, stainless steel pressure vessels with diameters between 1.8 and 4 m (5.9 and 13 ft) and wall thicknesses over 8 mm (0.3 in.). Service requirements mandate back welding and limit bead height.

Two conventional welding methods considered have their problems. The first is submerged arc welding (SAW) with a Y-groove weld preparation. Backgouging is necessary to ensure penetration. The other method is gas metal arc welding (GMAW) with an I-groove. In this method, time-consuming grinding is required after welding due to code restrictions on the welding bead height. Furthermore, both methods require that the final weld is performed inside the closed vessel, endangering the operator.

The intelligent welding system, with its advanced functions, was developed to overcome these problems and offer an improved working environment for operators.

Configuration of the System

The welding system's configuration is shown in Fig. 1. The welding head is mounted on a manipulator—Fig. 2. It can be turned 90 deg to enter the vessel through the 420-mm (16.5 in.) manhole. The robot can be applied to various sizes of vessel with a Y-axis slider. The welding head consists of rotating torch, CCD videocamera, x- and y-axis slide block for joint tracking, R-axis rotation for turning the welding head corresponding to welding direction, and OS-axis movement for changing the offset position for circumferential welding.

Advanced Functions

The main advanced functions of the system are shown in Table 1. Details of these functions are described as follows:

High-Speed Rotating Arc Welding Method

The system uses the high-speed, rotating arc welding method (Ref. 1) developed by NKK. The basis of the process is shown in Fig. 3. The electrode rotates orbitally at a frequency of 20 to 60 Hz. For the work presented in this pa-

Y. SUGITANI and Y. NISHI are with Yasuhiko Nishi Tsu Laboratories, NKK Corp., Japan. T. SATO is with Nippon Sanso KK, Japan.

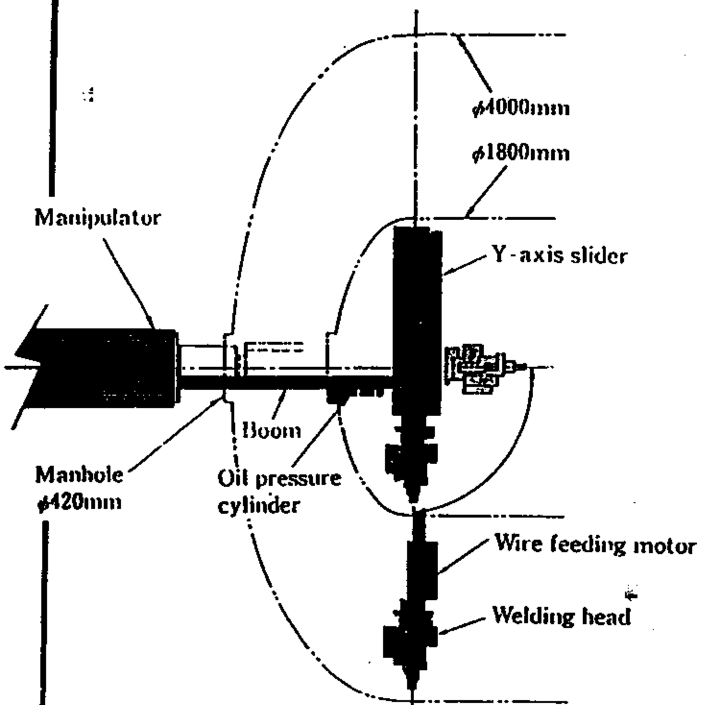


Fig. 1 – Configuration of the system.

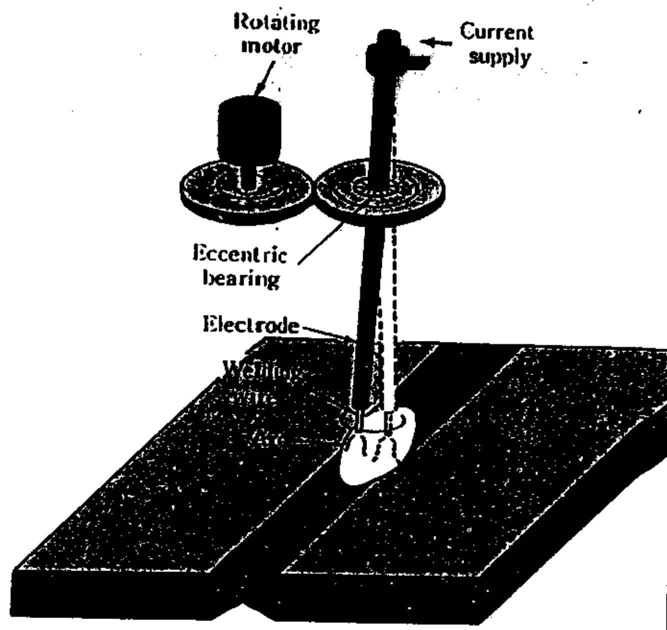
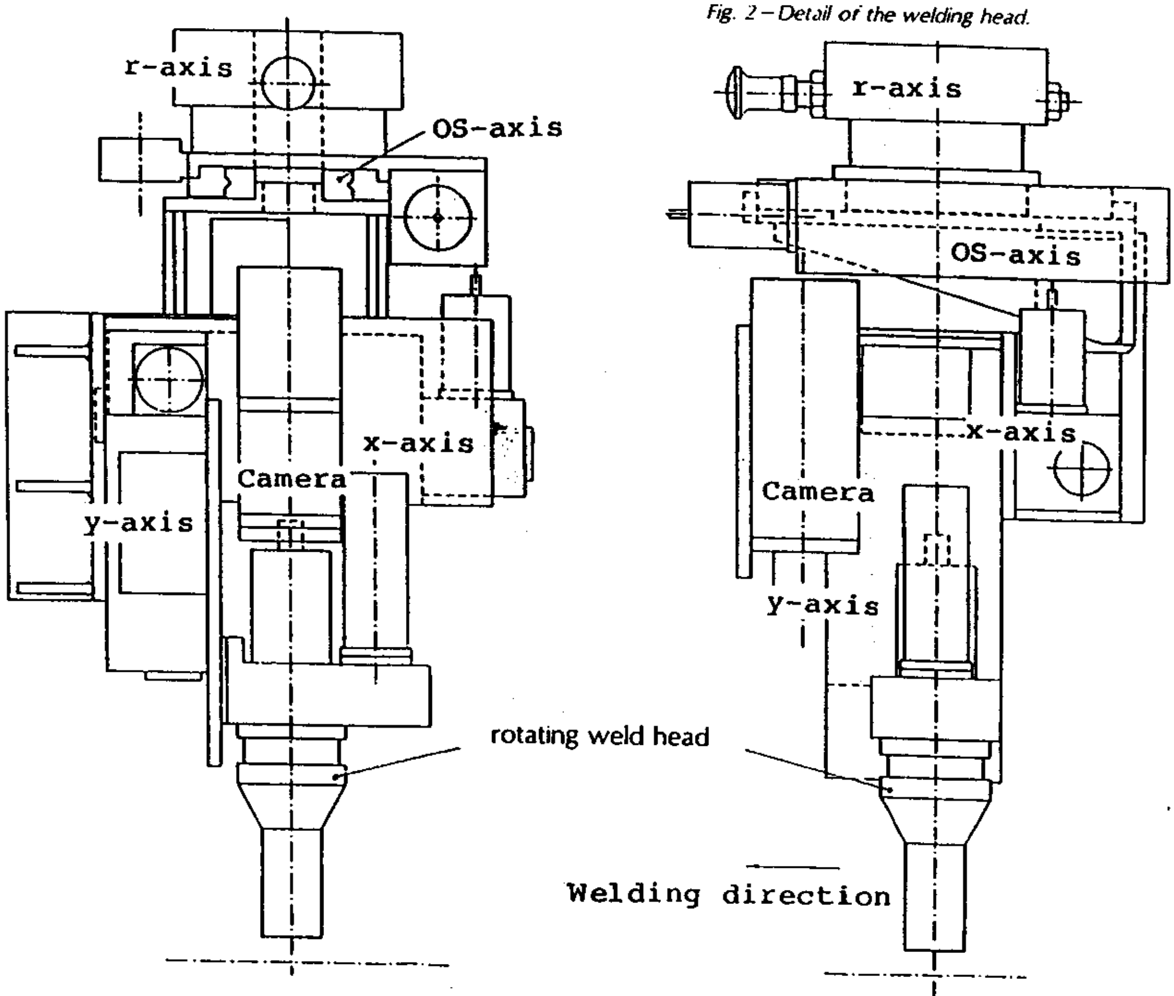


Fig. 3 – The basic principle of high-speed rotating arc welding.

Fig. 2 – Detail of the welding head.



per, a frequency of 50 Hz and a 3-mm (0.12-in.) diameter orbit was used with 1.6-mm (0.06-in.) diameter flux cored wire.

Figure 4 shows the influence of arc rotation on the bead cross-section shape. The high-speed, rotating arc process ensures shallow and stable weld penetration and a smooth, level weld bead. These phenomena appear to be caused by the dispersion of the arc force and heat with arc rotation.

The joint tracking system that utilizes the arc itself as a sensor (arc sensor) has been developed by NKK for use with the rotating arc process. The arc sensor can maintain precise and real-time joint tracking control without being affected by welding wire bends.

The principle of the joint tracking system with arc sensor control is shown in Fig. 5. The arc position (Cf, R, Cr, L) is detected by the rotary encoder. The figure shows the basic waveform of arc voltage to the rotating position of the arc (influence of weld pool is neglected). When the torch is positioned at the root opening ($\Delta X = 0$), arc voltage waveform is shown as a broken line with maximum values at Cf and Cr, and minimum values at R and L. It becomes symmetrical at Cf (center front of rotation). When the weld gun deviates, for example, to the right-side plate ($\Delta X \neq 0$), the waveform changes as shown by the solid line. The phase of waveform advances at point Cf, where it becomes asymmetrical. By dividing the waveform at Cf into left and right, and comparing the integrated values (S_L and S_R) of these two regions, the aiming point of the torch can be detected. In practice, the waveform is liable to be distorted at the Cr side by the influence of the weld pool, so the phase angle of the above integration is set empirically to a value less than 90 deg.

Simultaneous control of penetration depth and bead height is achieved by controlling welding current, wire feed rate, arc voltage and welding speed.

Weld head height control (y axis) is achieved by comparing the average of the welding current waveform with a reference constant value.

Table 1—Main Functions of Intelligent Arc Welding System

Function	Purpose
High-speed rotating arc process	• Smoothing of bead surface • Stabilization of penetration • Control of joint tracking and torch height by arc sensor
Image processing	• Setting the initial gun height • Detecting groove shape (Position and width of root opening) • Detecting the end of joint
Welding parameters control: 1. Welding current control 2. Wire extension length control (wire feed rate control) 3. Arc length control (Arc voltage control) 4. Welding speed control	• Penetration control in variable root opening width • Stabilization of welding arc • High-quality weld • Bead height control • High-efficiency welding

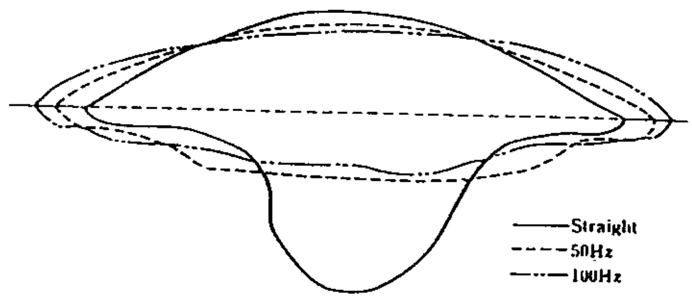


Fig. 4 — The rotating arc's influence on bead shape.

Image Processing System

The charge coupled device (CCD) video camera is located about 100 mm (3.93 in.) in front of the welding head, and detects information about the weld groove, including the root opening. Welding parameters are controlled by the detected values to keep weld penetration and bead height constant with changes in root opening. Image processing is also used to set the initial head height before welding and to detect the end of the weld joint.

Method for Measuring Root Opening

The basic procedure of image processing for measuring the root opening is shown in Fig. 6. The CCD camera is placed in front of the head and provides an image of the groove as an overhead view — Fig. 6A. The transverse distribution of light intensity (brightness) along Line A can be obtained — Fig. 6B. The intensity is highest from the reflection of the arc on the bevel surface, while it is lowest in the root opening. This trend can be enhanced by using supplemental illumination. The root opening is obtained by processing these transverse brightness scans. The brightness is integrated to eliminate any noise component — Fig. 6C. Subsequently, distribution is obtained by differential treatment, which has peaks at positions where the intensity changes significantly — Fig. 6D. The root opening is measured as the distance between the two inside peaks, while the groove width is the distance between the two outside peaks.

The root opening can be measured directly in this way for

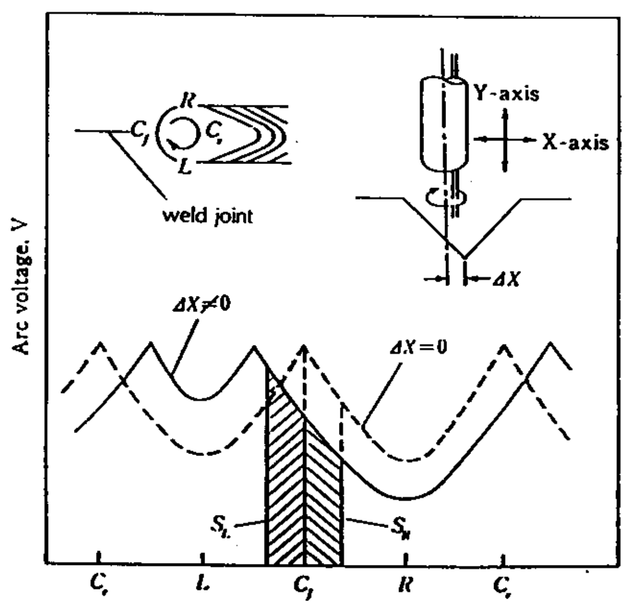


Fig. 5 — Principle of joint tracking performed by an arc sensor.

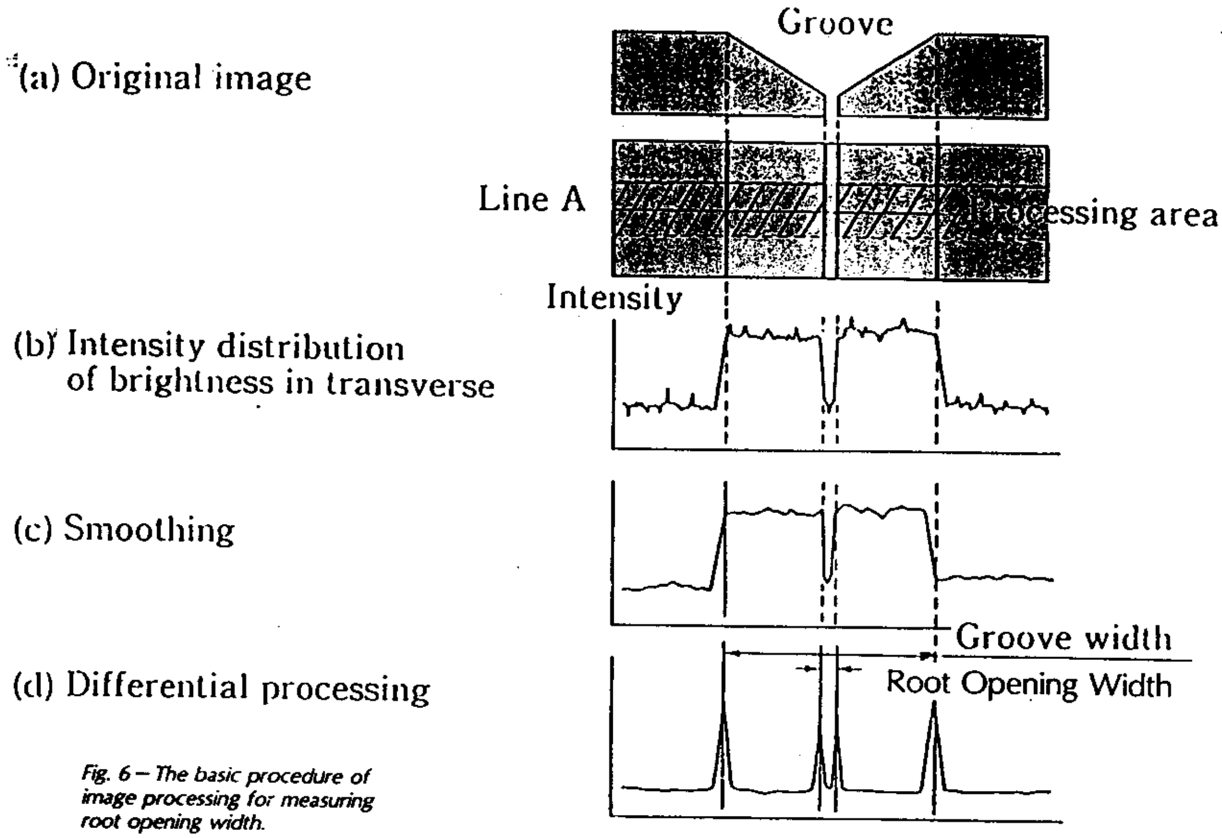


Fig. 6 — The basic procedure of image processing for measuring root opening width.

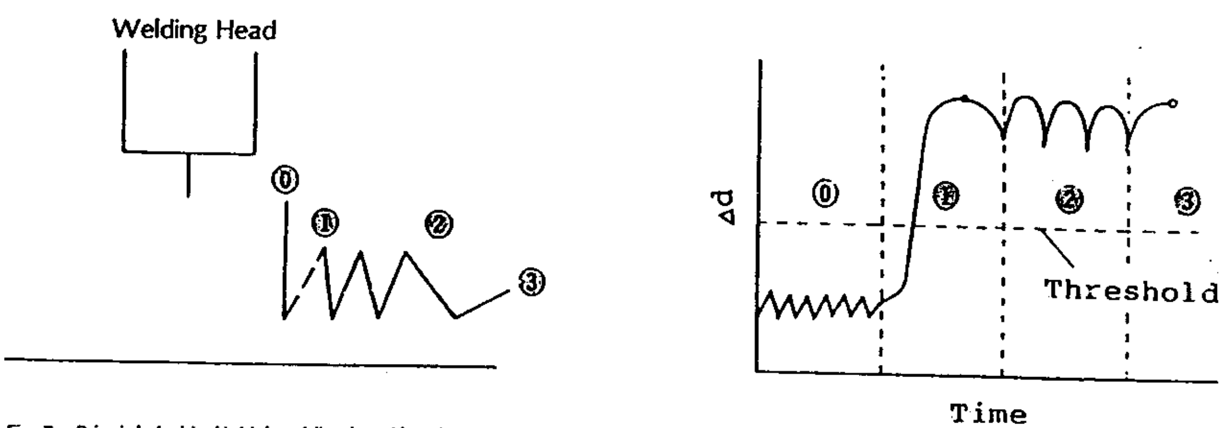


Fig. 7 — Principle behind initial welding head height control (Δd = high-frequency component of brightness intensity): Stage 0 = measure Δd and decide threshold value; Stage 1 — measure Δd during dropping the weld head with a CCD camera, and search for a maximum point of Δd; Stage 2 — raise the welding head and repeat a few times; Stage 3 — position the weld head at a maximum point of Δd.

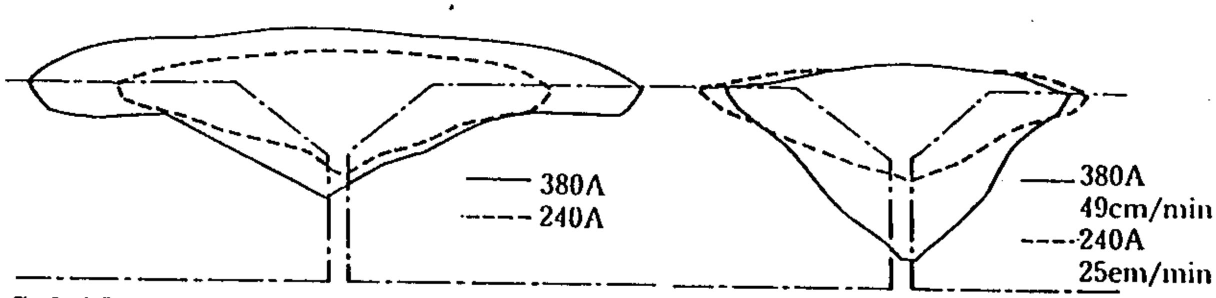


Fig. 8 — Influence of welding current on penetration depth; A — constant welding speed, and B — welding speed control to obtain constant bead height.

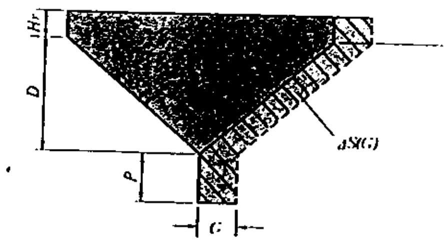


Fig. 9 — Theory behind welding speed control to obtain constant bead height.

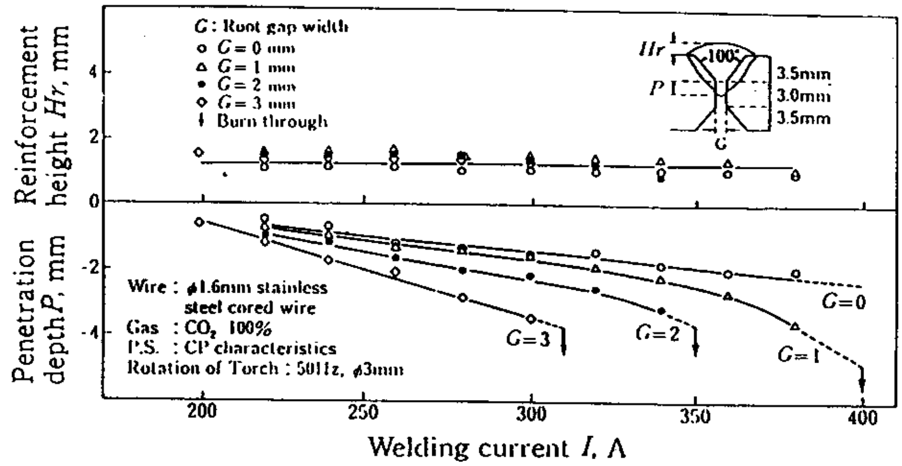


Fig. 10 — Relationship between welding current and penetration depth under constant bead height.

the first side welded. For the second side, however, only the groove width can be measured, since no root opening exists. In either case, a delay is introduced that corresponds to the distance that the camera is ahead of the welding head.

Setting the Initial Weld Head Height

In order to provide unmanned, remote-controlled welding, the head height can be set automatically before welding by image processing. The weld head height is set by the focus of the CCD camera — Fig. 7.

Detecting the End of the Joint

The intelligent welding system can detect the end of the weld joint and stop welding. The end of the workpiece is detected as the end of the weld preparation, or the point where the groove is filled with weld metal.

Welding Parameter Control

Simultaneous control of penetration depth and bead height (Ref. 2) is achieved by controlling four welding parameters: welding current, wire feed rate, arc voltage and welding speed. This is based on changes in the root opening detected by image processing.

Consideration of Simultaneous Control

A comparison of cross-sectional bead shapes with welding current is shown in Fig. 8. With constant welding speed, an increase of welding current primarily causes bead width to increase — Fig. 8A. In the case of welding speed control to keep constant bead height, as shown in Fig. 8B, the depth of penetration changes dramatically due to changes in welding current.

Thus, both welding current and welding speed affect penetration depth. In the system, welding current is controlled to obtain constant penetration, while bead height is kept constant by modifying the welding speed according to changes in the root opening.

Welding Speed Control (Bead Height Control)

The principle of using welding speed control to obtain constant bead height is shown in Fig. 9. The change of deposition area (Δ S(G)) corresponding to a change in the root opening is calculated by Equation 1, as shown by the shadowed portion in Fig. 9. Since So is the optimum deposition area without a root opening, the welding speed, v, which provides the necessary deposition area So + Δ S(G), is determined by Equation 2.

$$\Delta S(G) = (Hr + D + P)\,G \qquad (1)$$

where: Δ S(G) = necessary increment of deposition area due to root gap opening (mm^2); Hr = reinforcement height (mm); D = groove depth (mm); P = penetration depth (mm); and G = root-opening (mm).

$$V = K\,vf/(So + \Delta S(G)) \qquad (2)$$

where: V = welding speed (mm/s); K = cross-sectional area of wire (mm^2); vf = wire feeding rate (mm/s); and So = appropriate deposition area without gap (mm^2).

Welding Current Control (Penetration Depth Control)

The relationship between welding current and penetration depth for various root openings is known from experience — Fig. 10. Figure 11 is obtained by transforming Fig. 10 and shows the welding current required to produce a constant penetration, P, for various root openings. The intelligent welding system has a database of these relationships to determine the most suitable welding current for any root open-

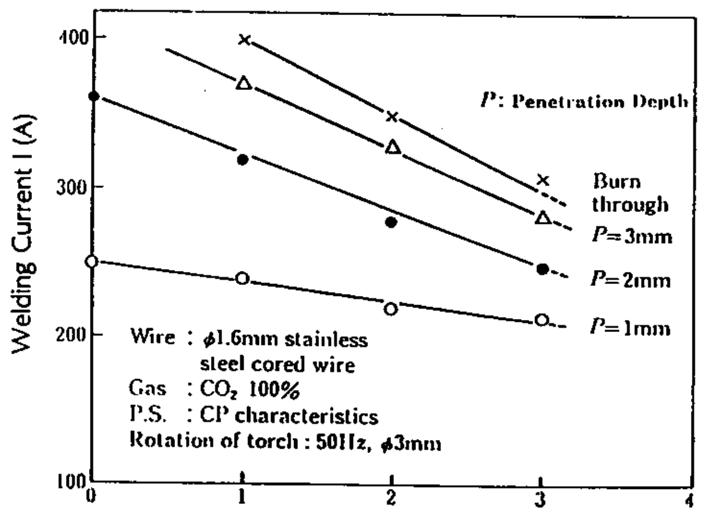


Fig. 11 — Relationship between root opening width and welding current to obtain constant penetration depth.

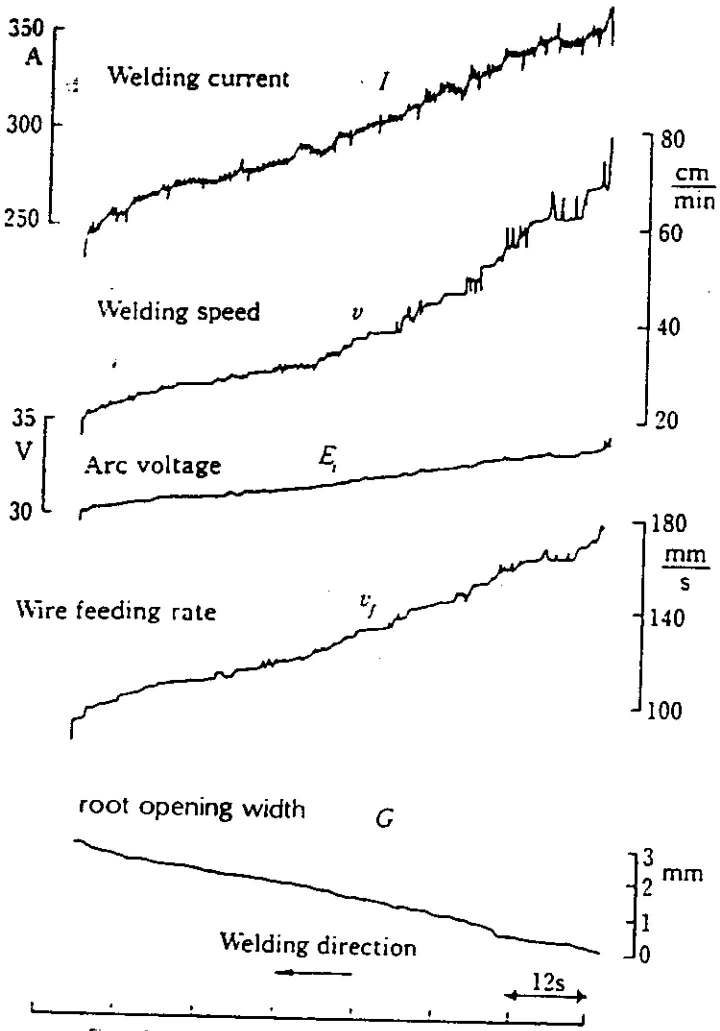


Fig. 12 — Variation of detected root opening width and controlled welding parameters.

ing. For welding the second side, only welding speed control is used with a high constant current, since there is no risk of melt through.

Wire Feeding Rate Control (Wire Extension Length Control)

Wire feeding rate is controlled to maintain a constant electrode extension by using Lesnewich's (Ref. 3) experimental Equation 3.

$$vf = AI + BLI^2 \tag{3}$$

Where: I = welding current (A); L = electrode extension (mm); and A, B = constants.

Arc Voltage Control (Arc Length Control)

The terminal voltage between the welding gun and workpiece, Et, is controlled to maintain a constant arc length. Et is assumed to be the sum of the arc voltage, Va, and the voltage drop in electrode extension, V_L.

$$Et = Va + V_L \tag{4}$$

Where: Et = terminal voltage between welding gun and workpiece (v); Va = arc voltage (V); and V_L = voltage drop in electrode extension (v).

The voltage drop in electrode extension, V_L, can be obtained by Halmøy's (Ref. 4) experimental equation (Ref. 5).

$$V_L = aLI - bvf/I \tag{5}$$

Where: a, b = constants.

Furthermore, the arc voltage can be estimated with Equation 6, which equates Va to the sum of the anode voltage drop, cathode voltage drop and arc column voltage drop. Equation 6 assumes that the sum of anode and cathode voltage drops is equal to the arc voltage just before short circuiting, and that arc column voltage is equal to the product of a constant potential gradient of arc column, X, and arc length.

$$Va = Vo\,(I) + Xla \tag{6}$$

Where: Vo (I) = sum of anode and cathode voltage drops as a function of welding current I (v); X = potential gradient of arc column (v/mm); and la = arc length (mm).

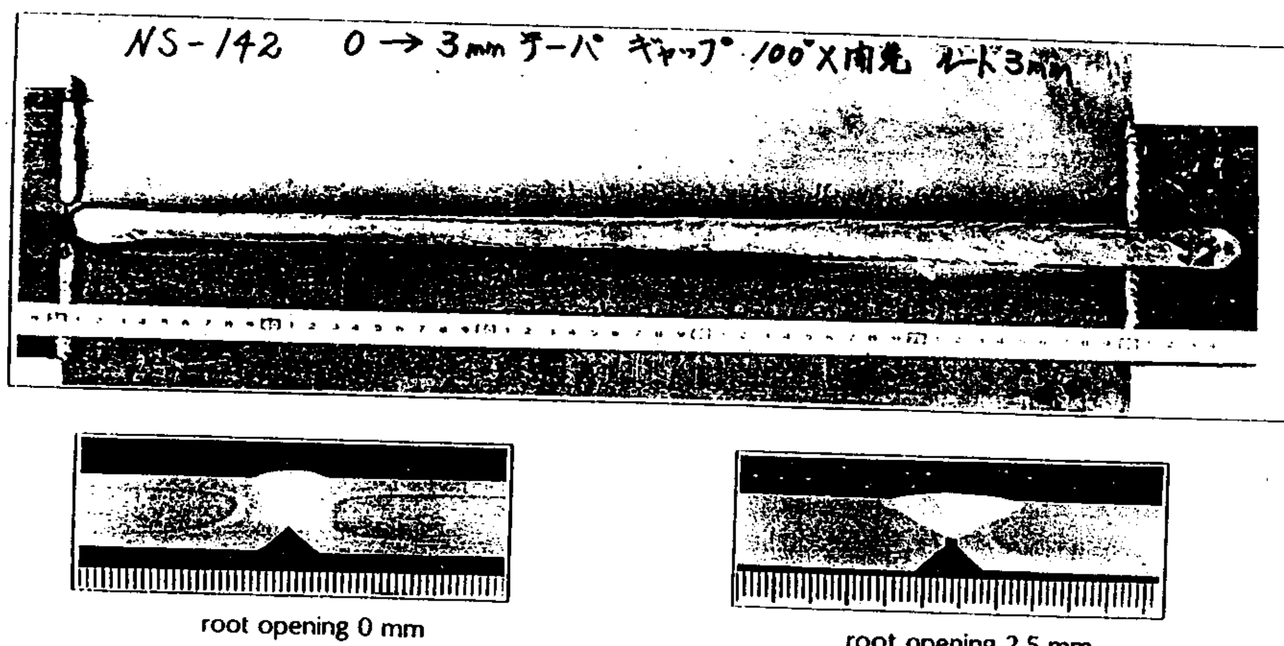
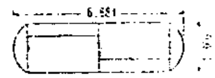


Fig. 13 — Appearance and macrosections of controlled weld bead.

Table 2—Comparison of the Time Efficiency between the Conventional Methods and the Intelligent Arc Welding System

Welding Method	Welding (H)	Backgouging[a] (H)	Grinding (H)	Total (H)
Submerged arc welding (Conventional method)	11	26	1	38
GMAW (Conventional method)	11	0[c]	27	38
GMAW (Intelliarc)	9	0[c]	2[b]	11
Joint length				
Longitudinal welding	6 m			
Circumferential welding	17 m			
Total	23 m			



(a) Including grinding work and penetration test of gouged surface
(b) Grinding for lapped bead and spatter
(c) In the case that backgouging is not required by legal restrictions

Experimental Results

Simultaneous control of penetration depth and bead height was achieved with a double-Y groove, 304 stainless steel test plate with a root opening varying from 0 to 3 mm (0.12 in.). Parameters used were 15 mm (0.59 in.) for electrode extension, L; 3 mm for arc length, la; 2 mm (0.07 in.) for penetration depth; and 1 mm (0.04 in.) for reinforcement height.

Figure 12 shows variation of the root opening detected by image processing and the controlled welding parameters. Welding current is adjusted to coincide with changes in the root opening, based on the empirical database. Wire feeding rate is also controlled with Equation 3 to obtain constant electrode extension. Welding travel speed is controlled with Equation 2, while the terminal voltage is controlled with Equations 4–6 in order to obtain constant arc length. The appearance and macrosections of controlled weld beads are shown in Fig. 13. Figure 14 shows the result of measuring of the bead shape. These results indicate that both penetration depth and bead height are controlled virtually constant.

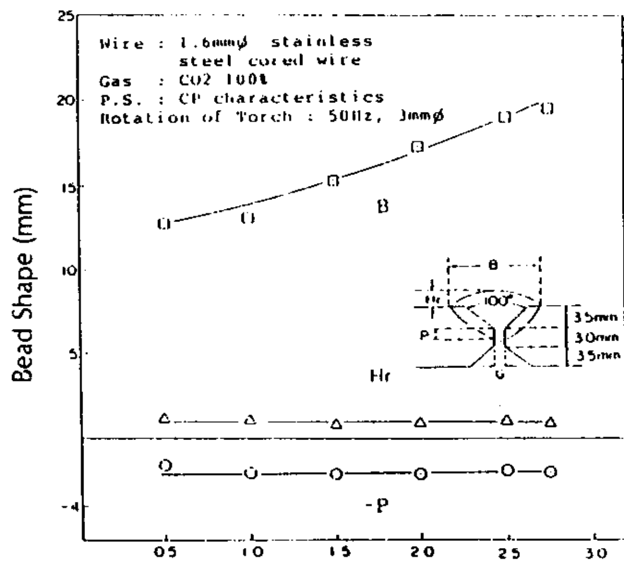


Fig. 14 – Results of bead shape

Practical Application

The intelligent arc welding system has been successfully used to weld a liquefied gas storage tank at Keihin works of

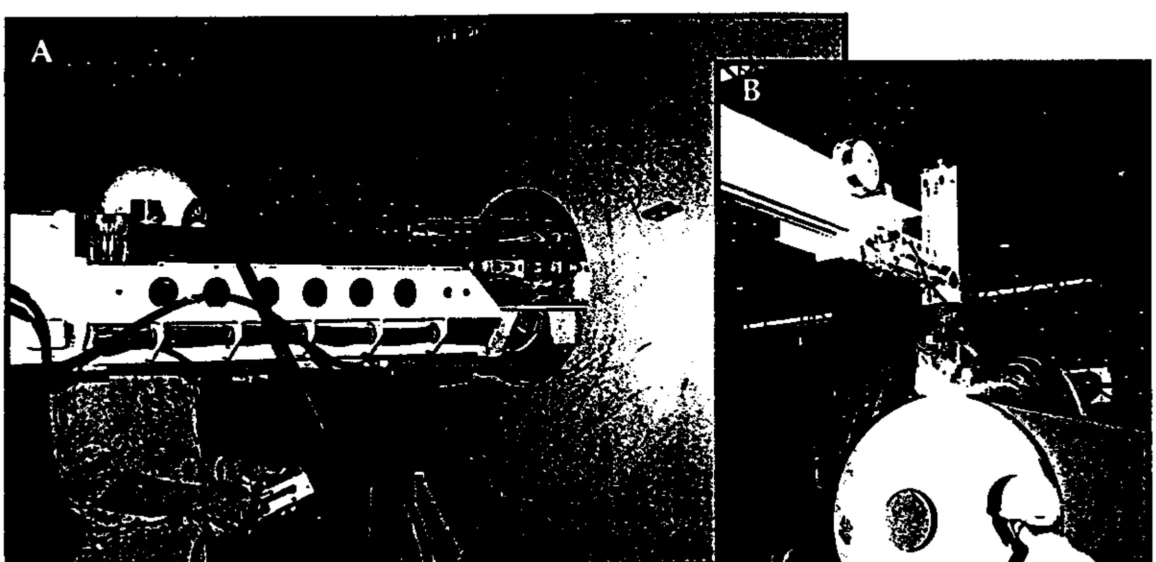


Fig. 15 – A – The welding system is inserted into the vessel through the manhole; B – circumferential welding outside of the vessel.

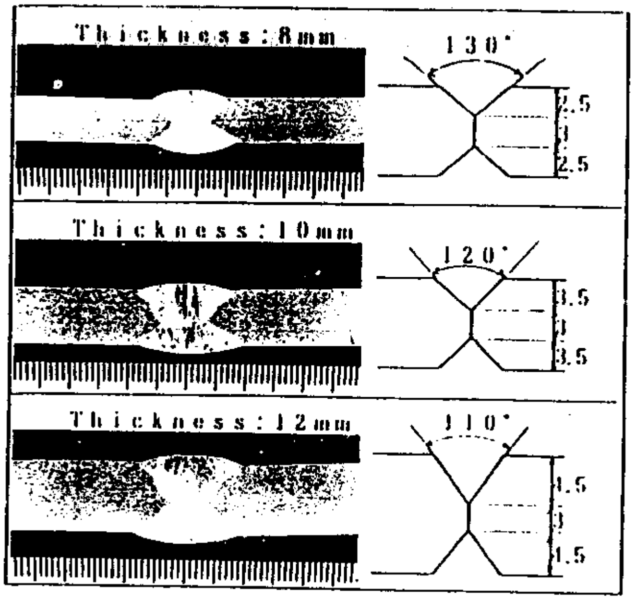


Fig. 16 — Macrosections and groove preparations

Nippon Sanso K.K. Figure 15 shows the welding application for the vessel. The weld head was inserted into the vessel through the 420-mm manhole as shown in Fig. 15A, and carried out unmanned welding inside the vessel. The outside circumferential weld is shown in Fig. 15B.

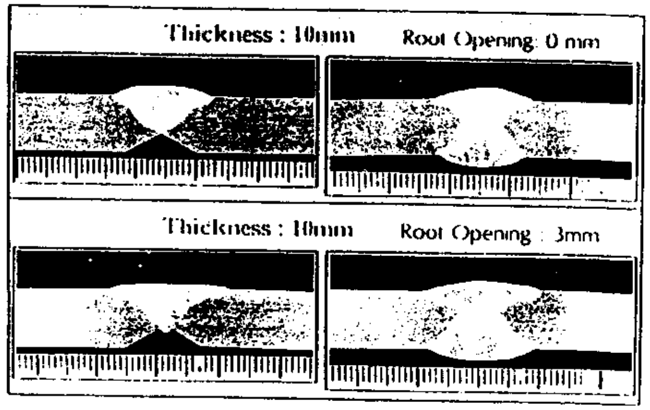


Fig. 17 — Macrosections when root opening width is 0 and 3 mm for longitudinal welding

Figure 16 shows macrosections and groove shape with 8-, 10- and 12-mm-thick 304 stainless steel plate, while Fig. 17 shows macrosections where the root opening is 0 and 3 mm on the longitudinal weld with 10-mm (0.4-in.) thick stainless steel.

Welding current is controlled to obtain constant penetration while bead height is kept constant by modifying the welding speed according to changes in the root opening.

Table 2 compares the time efficiency between the conventional methods and the new method for one CE17 vessel. Using Intelliarc, the time for backgouging and bead grinding can be reduced substantially.

Conclusions

Intelliarc has achieved the simultaneous control of penetration depth and bead height with continuously varying root openings. The welding process is efficient and produces high quality welds, while dramatically increasing operator safety. ♦

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