Recent Advances in Inverter Controlled, Gas Shielded Arc Welding Power Sources and other Applications

Hideyuki Yamamoto

This report summarizes trends of arc welding processes and power sources, especially, recent advances of inverter controlled power sources with various kinds of new current wave control method for gas shielded metal arc welding process.

The features of inverter controlled machine are not only compact and lightweight design but also various improvement of weldability and control of arc welding phenomena such as metal transfer arc plasma characteristics, bead formations etc. and features will contribute to much more automization of arc welding.

INTRODUCTION

The most outstanding features of advances made in the field of arc welding in the last few years may be characterized by rapid developments in automation, robotization and systematization of welding process and further spread and applicational expansion of gas shielded arc welding process in concert with the former, and new technical developments have been made in all aspects such as related welding materials, welding equipment and welding process. Especially, the improvement over function and performance of a gas shielded arc welding equipment based on the introduction of transistor inverter control technology started from 1982 is particularly remarkable, and a part it played in automation of welding is very great.

Here, the position and trend of gas shielded arc welding in the field of arc welding in the last ten years are surveyed to begin with and a historical transition of the welding power source which contributed to that development as well as a role in recent inverterization are described together with a try to feel out subjects for future.

Spread and advance in automation rate of gas shielded arc welding process in Japan

In the event of surveying the application ratio of welding processes to occupy within the entire arc welding, it is general to look into the MITI's (Ministry of International Trade and Industry's) statistics on national production of the respective welding materials (electrodes and wires). In the case of (iron and) steel, the production of welding materials of arc welding on the whole was changing nearly within the level of 300,000 to 400,000 tons from 1975 and on corresponding to business fluctuations although there had been ups and downs in the meantime.

However, in view of various welding processes, unlike the covered electrode which was continuing to decrease nearly monotonously in the past ten years, welding wires for gas shielded arc welding have been increasing on the whole and outstripped the covered electrode for the first time in 1978.

Fig. 1 Itemizes ratios of weights actually deposited on weldment by various welding processes on the assumption estimation of the efficiency of deposition shown in the figure as based on the aforementioned production statistics. As can be understood from the figure, application ratio of gas shielded arc welding is now completely reversed that of covered electrode welding. Besides, a so-called automation rate (including the semi-automation rate of gas shielded arc welding) inclusive of submerged arc welding has reached 75% in 1988.

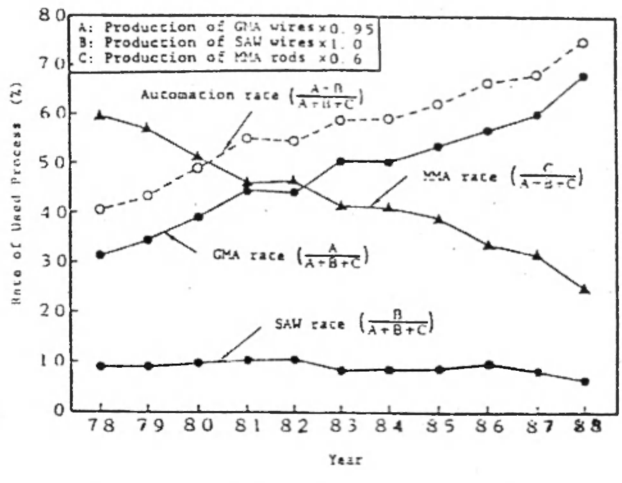


Fig. 1 : Deposit Weight Ratio of Various Welding Processes

Fig. 2 compare the transition in productions by materials for gas shielded arc welding wire. The growth of steel wires centered about wires for CO_2 gas/MAG welding slowed down from the begining of 1980 and tended to be saturated but increased rapidly in 1988 due to a sharp expansion in domestic demand. In the case of stainless steel, spread of cored wire from 1983 and on was particularly remarkable. Furthermore, MIG wire for aluminium alloy and TIG arc welding electrode feature that they are increasing steadily without hardly influenced by economical trends.

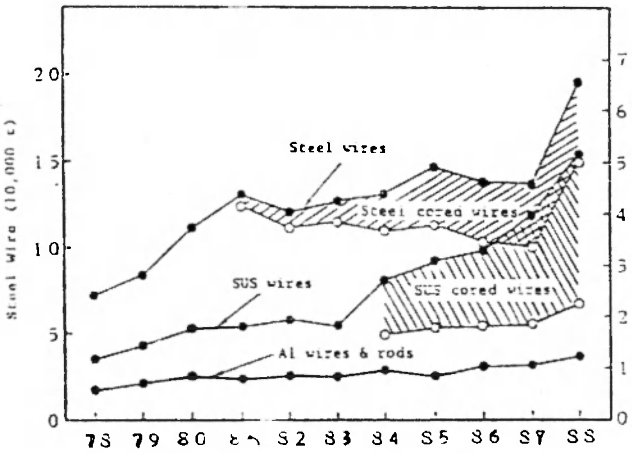


Fig. 2 : Transition in Annual Production of GMA Wires

In this way, the application ratio of gas shielded arc welding process is still in an increasing trend, its applications to such as high-class steel and nonferrous metal are expected to expand particularly, and moreover its role as a leading welding process for future drive to automation.

The change in output control system of arc welding power source and application conditions of an inverter controlled welding power source

Fig. 3 arrange the change in and spread conditions of output control system of welding power sources being used in gas shielded arc welding in Japan as well as the development time of main welding power sources. Fig 3(a) is related to the consumable electrode (GMA) type. Around 1970, the thyristor was adopted in a DC power source for the first time as an output control device in place of an electromagnetic amplifier which was used up to that time, and thus the function of the welding power source was improved. After that, MIG pulsed arc welding source and making capacity larger were pushed forward and have been much used as a popular CO2/MAG welding power source even day. Early in 1980, a power transistor of a large capacity capable of controlling in higher speed than the thyristor appeared, and the secondary side chopper controlled, pulsed arc welding power source which uses the former device was developed. And then, in 1982, a CO_2 arc welding power source of transistor inverter control capable of further high-speed controlling was developed for the first time, and its application has also advanced to such as a pulsed/MAG welding power source, AC CO_2/MAG welding power source recently. Also for non-consumable electrode gas shielded tungesten arc (GTA) welding power sources shown in Fig. 3(b), the course of the change from thyristor control to transistor chopper control and then to inverter control was nearly the same as for the consumable electrode (GMA) type even if their development times differed between these two types. And types of applicable welding power sources also have expanded from a DC welding power source in the beginning to pulsed TIG arc welding power source and then AC TIG or plasma arc welding power source.

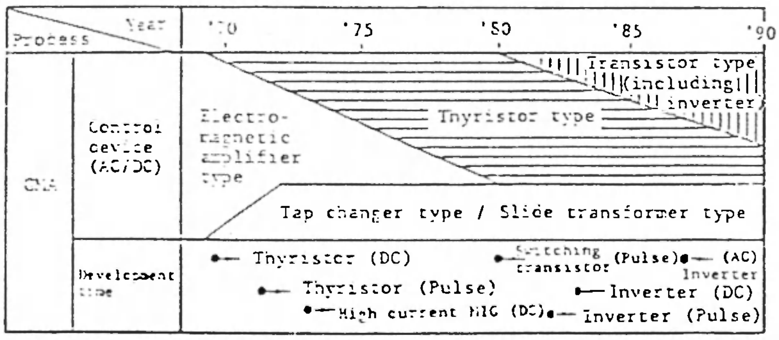


Fig. 3(a) : Change in Output Control System of GMA Welding Power Source

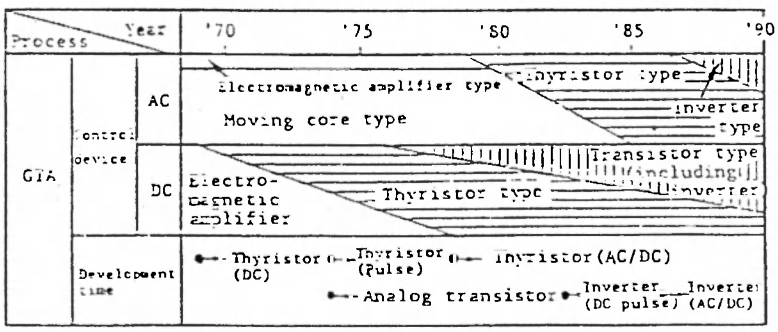


Fig. 3(b) : Change in Output Control System of GTA Welding Power Source

Fig. 4 compares relations between the control device of control system of welding power sources and their output control frequency and proves that the change in control system shown in Fig.3 has a very close relation with transition in speedup of control frequency of a control device as described later.

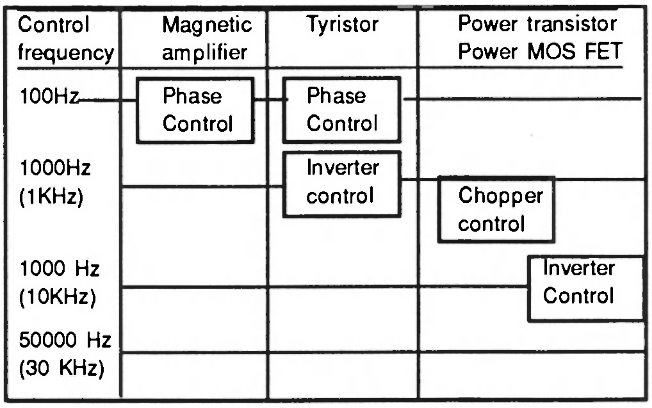


Fig. 4 : Control Devices and Control Frequency of Welding Power Source

Present conditions and features of an inverter controlled welding power source

In the thyristor controlled type which is used to be the mainstream of arc welding power sources, the input voltage is first stepped down by a transformer directly connected to the commercial frequency power source to a voltage suitable for welding, and this output is than regulated by controlling the firing phase angle of the thyristor in synchronism with the commercial frequency and finally supplied to the arc through a smoothing DC reactor.

In contrast to the former, in a new inverter controlled type, the alternating current of the commercial power source is converted to the direct current once, it is normally converted again to a high-frequency alternating current of about 10 to 50 kHz, then the voltage is stepped down by a high-frequency transformer, and finally the direct current is supplied after being rectified and smoothed again. For power devices of the thyristor to control this output, a module bipolar transistor and a module or discrete power MOS FET are being run in parallel at the operating frequency of under and above 20 kHz, respectively, and are used in combination with various inverter types as shown in Table 1.

TABLE 1 : MAIN CIRCUIT SYSTEM AND POWER DEVICES OF INVERTER CONTROLLED WELDING POWER SOURCE

Device	Bipolar transistor	MOS FET
Operating frequency	7 - 16 KHz	20 - 50 KHz
Inverter types	Full-bridge Half-Bridge Forward converter	Full-bridge Forward converter
Maximum ratings of device	150A 500V Darlington 200A 500V Single	50A 450V Operation in parallel 10A 500V Operation in parallel

The main circuit composition of an inverter controlled AC arc welding power source which is lately attracting attention of the field is as shown in Fig. 5, and components and functions up to the DC reactor on the secondary side of the transformer are the same as a corresponding DC arc welding power source, but the secondary inverter is also provided in the subsequent step to the DC reactor in this circuit to convert the output to the alternating current again. The secondary inverter is lower in frequency than the primary inverter and normally about 100 Hz, but it features a fast response speed in inversion and thus offering the square wave alternating current.

In the case of the inverter controlled type as described so far, its basic features are that the frequency of an alternating current impressed to the transformer is a few 100 times that of the conventional thyristor controlled type, and for that account, the transformer which is a major component part of the welding power source and the smoothing reactor to follow the rectification on the secondary side of transformer can be extensively miniaturized and made lighter in weight and can quicken the response speed of output current.

Fig. 6 compare the weight against the rated secondary current of various inverter controlled arc welding power sources (inverter types) which have been put on the market up to now with that of thyristor controlled welding power sources (thyristor types). For a small capacity of below 100 A, a handy type of approximately 10 Kg. has been also materialized lately.

At the beginning of development for inverter types, their technical development advanced as centered about such a functional aspect as miniaturization and making themselves lighter in weight in comparison with the conventional type, and they have been in fierce competition for speedup in the operating frequency. After that, however, much efforts have

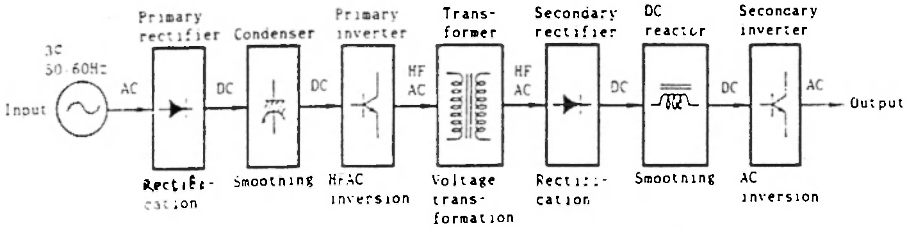


Fig. 5 : Main Circuit Composition of Inverter Controlled AC Arc Welding Power Source

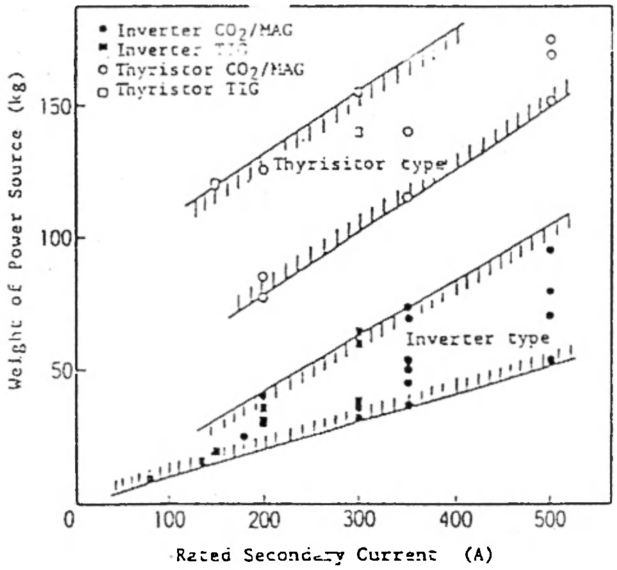


Fig. 6 : Weight Comparison of Various GMA Welding Power Sources

been focused on improvements of weldability or workability fitted to various kinds of welding processes and on their reliability. Especially recently, various wave form control systems to control directly the arc welding phenomena themselves have been proposed by making good use of a high-speed responsibility of their output, and these control algorithm has been incorporated in almost all the welding power sources.

ARC welding phenomena and a role of an inverter controlled welding power source (inverter type)

Since any one of arc strike, electrode consumption, metal transfer, molten (weld) pool formation and other phenomena is a high-speed and intricate phenomena, it had been taken for granted that to control directly them by output regulation of a welding power source is difficult to do. However, since the advent of inverter controlled welding power sources, output control of by far higher speed than before has become possible, and attaining the proper output current and voltage waveform meeting the purpose has become comparatively easier.

In consequence of this, not only many improvements on the functional aspect as described before but also remarkable improvements were promoted on aspect of welding performance, and thus, new performances not seen before are beginning to be brought forth.

Table 2 arranges the physical operation time (time constant) or the natural frequency of leading phenomena related to performances of arc welding and the controllable frequency of major output control devices of a welding power source as well as of the control system against the former in contrast to each other. With speedup in the output control by inverterization of a welding power source, that a high-speed control becomes possible at a speed suited to various phenomena and the objects of control are expanding on the high-speed side can be understood.

If the latest concrete objects of control in gas shielded arc welding and their effects are mentioned, there are :

1. High-speed stabilization of arc through making the output current and voltage of higher accuracy,
2. Improvement on arc startability (strikeability) based on improvement about the transient characteristic in start (arc strike) and end and making conditions of crater treatment (crater filler) proper,
3. Reduction in spatter by various kinds of current waveform controls in short-circuit transfer welding,
4. Stabilization of metal transfer and control on the bead shape by pulse current control on arbitrary frequency and arbitrary waveform,
5. Control on penetration of base metal and excess weld metal based on arbitrary setting of the proper current at each electrode and electrode negative/electrode positive (EN/EP) ratio control of AC waveform, etc.

Table 2 : RELATION BETWEEN OPERATING FREQUENCY OF ARC WELDING PHENOMENA AND CONTROL FREQUENCY OF VARIOUS KINDS OF POWER SOURCES

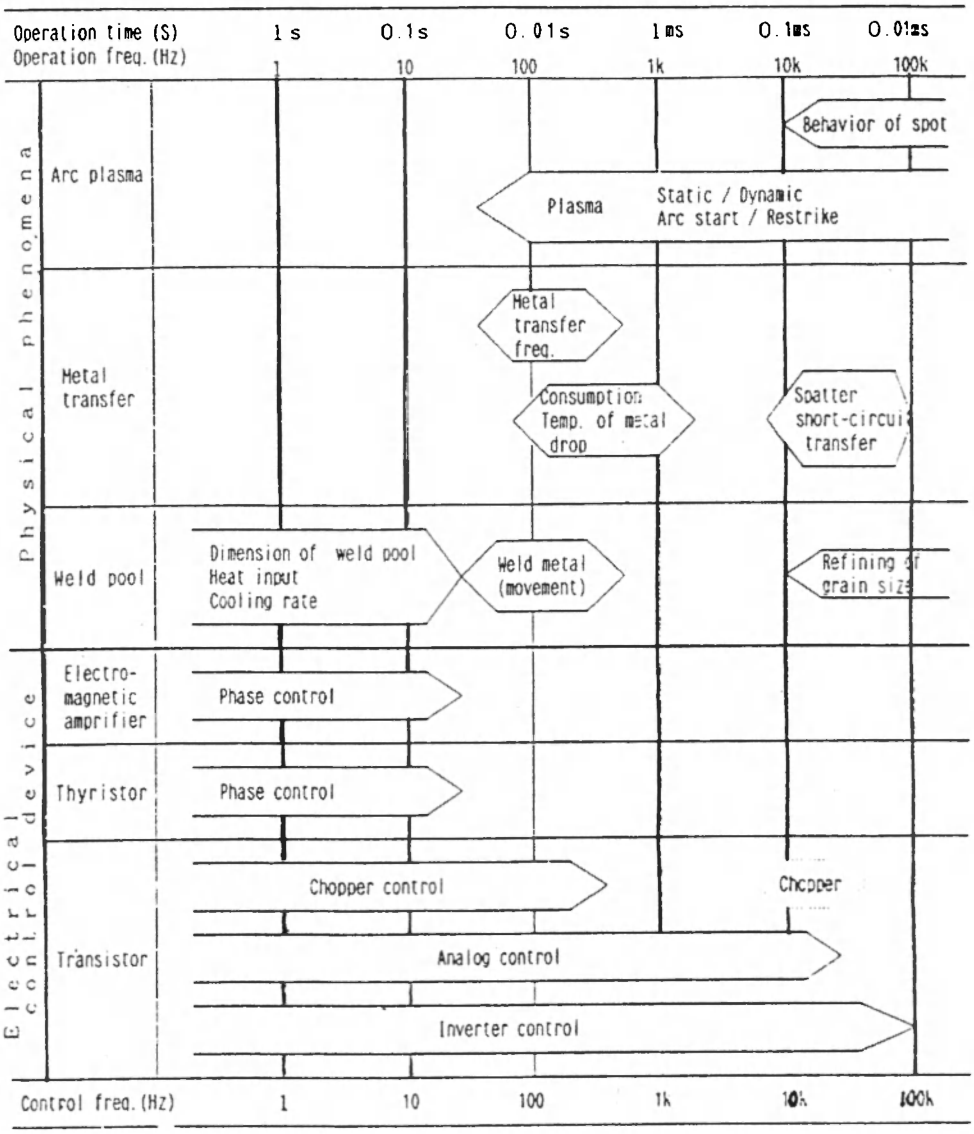


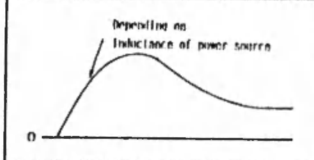
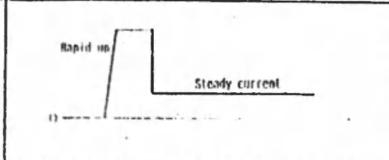
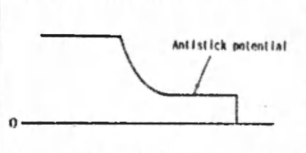
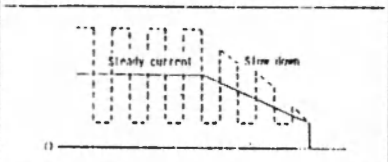
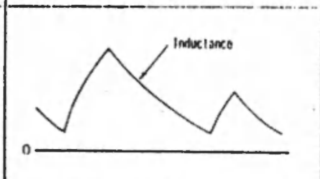
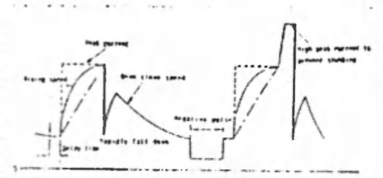
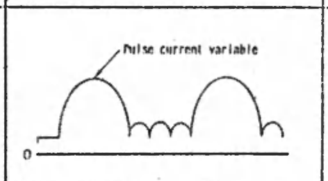
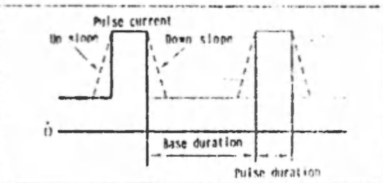
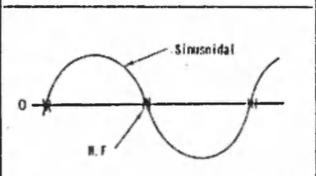
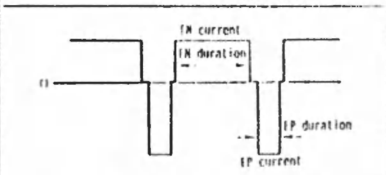
Table 3 arranges the output waveforms of the conventional welding power source and points at issue (problems) for the aforementioned purposes as well as various output waveforms controls of inverter controlled welding power sources proposed and put to practical use up to now as they are corresponded.

Features common to these respective waveform control systems are that controllable parameters are sharply increased over those of the conventional system, and as results of this, precise adaptation control becomes possible, but on the other hand, selection of waveform becomes complicated, and thus the necessity of fitness one-knob control (synergic control) is all the more increasing.

Improvement on welding performance and adaptability towards automation of various arc welding processes

Automation of arc welding progressed with spread of gas shielded arc welding process, and particularly attended with recent general use of arc welding robot, an advance from semi-automatic welding to full automatic welding is remarkable. Here principal accounts centered about those newly presented in the past one or two years regarding a role of an inverter controlled welding power source in the area of welding automation and concrete results are compiled as follows :

TABLE 3 : VARIOUS EAVEFORM CONTROL SYSTEMS FOR ARC WELDING POWER SOURCE

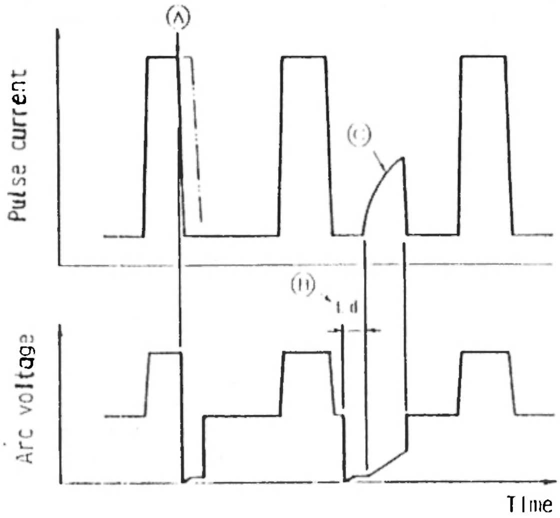
Control system	Conventional		Recent waveform control		
	Waveform	Problem	Waveform	Effect of GTAW	Effect of GMAW
Arc strike		• Unstable of arc strike		• Improvement of arc strike • Reduction of electrode consumption at arc strike	• In an instant arc strike
Crater filler		• Burn back		• Crater filler	• Preventing burn back
Short circuit current control		• Much spatter			• Reduction of spatter • Stable of high speed welding • Stabilization of short circuit
Pulse current control		• Not synchronous • Large droplet • Long arc length		• Penetration bead • Deep penetration • Strong stiffness • Stableness of low current	• One pulse per each pulse • Prevention of blowhole • Reduction of spatter
EN/EP ratio control		• Much consumption of electrode • DC component (not controlled) • H.F. for restrike		• Deep penetration • Without H.F. at restrike • Reduction of electrode consumption	• Increasement of wire melting rate • Control of penetration

CO_2/MAG Arc Welding

The consumable electrode, gas shielded metal arc (GMA) welding centered about carbon dioxide arc welding has many advantages over other welding processes with respect to efficiency and cost workability, but also has much subjects to be improved with respect to repetitive welding which is indispensable in automatic welding and securing of repeatability. As problems peculiar to arc in CO_2 arc welding in particular, (1) much weld spatter and remedy for adhesion to weld zone neighborhood and nozzle needed, (2) reliability of arc start lacking, (3) unsteady arc in a high speed welding, (4) had bead appearance, etc. may be mentioned.

For these problems, various systems to control directly short- circuit transfer phenomena of metal have been presented numerously up to now, as described before. and it becomes possible to control the spatter generating rate considerably. Besides, making the pulse waveform proper in pulsed MAG arc welding to replace CO_2 arc welding is promoted as well as the "Pulse short-circuit system" which makes use of advantages of both the pulse transfer and the short-circuit transfer is developed recently, and the stabilization of arc and a reduction of spatter in a high-speed welding are further advanced.

Fig. 7 shows an instance of new current waveform control system for short-circuit transfer synchronized with pulse.



a) Current control for short circulating during pulse duration
b) Current control for Instantaneous short circulating
c) Electronic reactor control during short circulating

Fig. 7 : Current Waveform Control System in Pulsed MAG Welding

Fig. 8 shows some examples of effect of reduction of spatter between the conventional thyristor controlled welding power source and the lattest inverter controlled CO2/MAG arc welding power source.

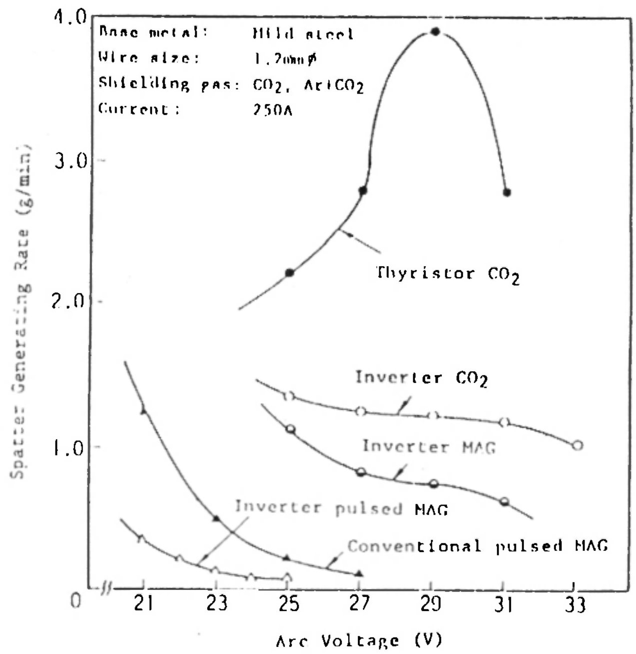


Fig. 8 : Comparison in Spatter Generating rate of Various Arc Welding Processes and Power Sources

Regarding the improvement on arc startability, too, making use of quick response of starting current which is the biggest advantage of inverter control, a technique is developed to grow arc instantaneously by conducting a sharp peak current at a moment the tip of wire short-circuits with the base metal surface, and the instantaneous arc startability is improved to nearly 100%, contributing to improvement on operating efficiency of a welding robot.

Although there are many factors such as groove conditions, shielding gas and wire composition that influence a high-speed welding, weldment of about 1 m/min. in the past has been speeded up to about 2 m/min. by stabilization of arc and arc force control at the introduction of a inverter controlled welding power source.

As a latest topic, an instance of applying the AC waveform control to the consumable electrode, Gas shielded metal arc (GMA) welding has been presented. Paying attention to a point that the wire melting rate and the base metal melting rate differ as depended on polarity (electrode), this method makes use of a high-speed inversion characteristic of inverter control to secure the AC arc stability which is said to be difficult to attain in the past and at the same time can set the electrode negative/electrode positive (EN/EP) ratio arbitrarily. Fig. 9 shows a relation between this EN/EP ratio and the bead shape. For welding of a thin plate and in the case of a big-gap groove, effects of such of control is recognized, and adaptation control coupled with the future sensor function has become the subject of consideration.

TIG/Plasma Arc Welding Process

TIG and plasma arc welding processes are good with respect to welding performance in particular and effective for automation of welding for nonferrous materials as well as special materials. However, (1) slower welding speed than of the consumable electrode (GMA) type, (2) lacking in repeatability in repetitive or continuous welding due to consumption of an electrode, (3) influence of high- frequency starting (arc strike) on peripheral equipment, etc. have been pointed out.

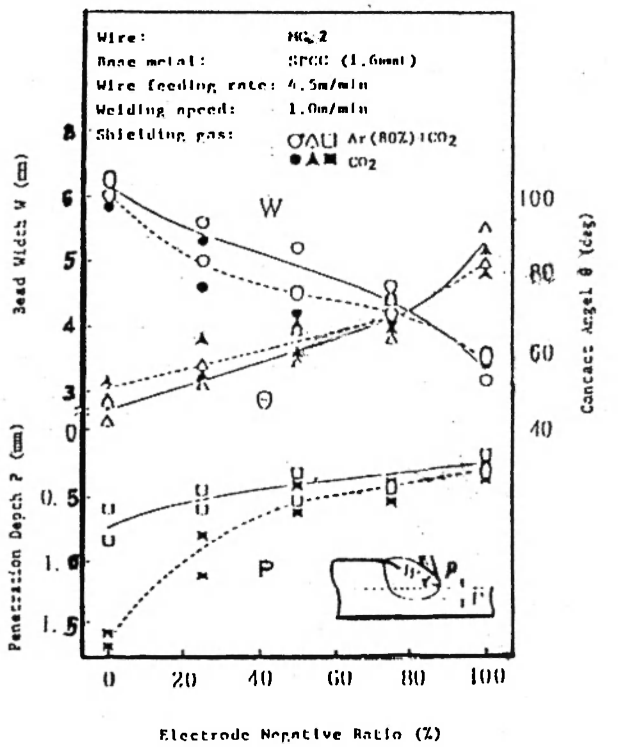


Fig. 9 : Relation between the Bead Shape and the Electrode Negative Ratio in AC CO2/MAG Welding

As an improvement measure for welding efficiency, a method of increasing the arc stiffness based on application of high-frequency pulse is already put to practical use, and a system of controlling the heating current of filler wire which is indispensible to automation in synchronism with the arc current is also developed.

In DC TIG/plasma arc welding for such as aluminium alloy, for example, adaptation of a double inverter controlled welding power source is rapidly advancing, and lately, its effects in combination with ceriated or lanthanited tungsten electrode in place of thoriated tungsten electrode are being considered.

Fig. 10 shows examples of reduction effects on electrode consumption by sinusoidal wave alternating current of the conventional welding power source and by unbalanced square wave direct current of the inverter control type, respectively.

Besides, since high-frequency superposition becomes no longer needed in arc restriking by the square wave direct current of the double inverter control type, there is a big advantage of reducing the radio interference to computer processing and peripheral controlling device.

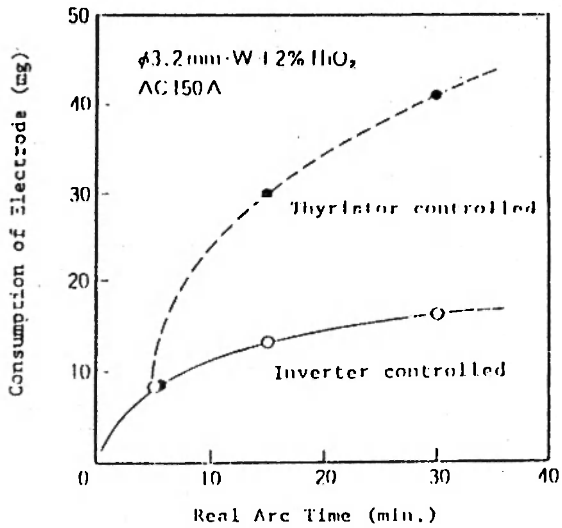


Fig. 10 : Comparison in Electrode Consumption between Thyrostor and Inverter Controlled Power Sources of AC GTA Welding

Future subjects

Attended with inverterization of an arc welding power source, problems in respect of function of performance that had been an obstacle to automation of welding have been substantially improved as described so far, and their adaptability has been expanded.

Regarding an exclusive welding power source to be used in combination with an arc welding robot, that which builds in the interface with the robot, that which can control the output upon taking various command signals directly from the robot into the power source and that for which consideration had been paid to welding characteristics conformed to arc sensor function, one of sensors needed to expand the adaptability of an arc welding robot, have been developed[16].

Fig. 11 arranges several subjects of improvements in the future on welding equipment, welding power source in particular, in view of pushing on automation and robotization of gas shielded metal arc (GMA) welding.

With respect to performance, developments of new control system based of further elucidation of welding phenomena are expected, and systematic studies of on-line control founded on the feedback of welding results are needed conjointly with development of sensor technology.

Moreover, with respect to function, however, combinability with a rapidly advancing peripheral computer equipment such as for digitalization in waveform control ot the power source and an arc welding robot must be improved.

Furthermore, with respect to welding control, such as a functional improvement that can cope with data basing and artificial intellectualizing (Al'ing) of welding conditions may be mentioned, and further new subjects are much remaining.

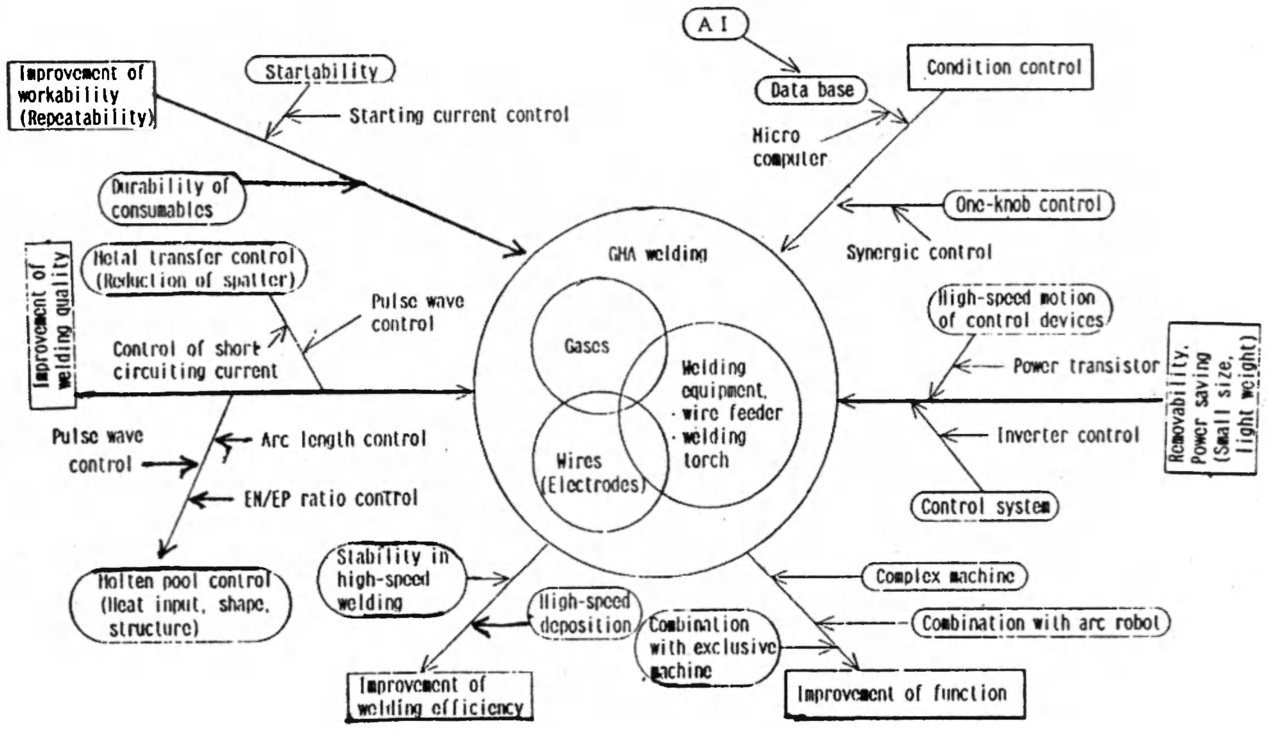


Fig. 11 : Subject for Improvement of GMA welding Equipment

A REQUEST FROM THE EDITOR

Dear Readers,

We are inviting you to send articles on Welding and Allied Technology for publication in the forthcoming issues of the Indian Welding Journal as per guidelines given below ;

Papers should be neatly typed on electric typewriter in double spacing in A4 size paper. All photography shall be of 140X85 mm. Sketches & graphs to be neatly drawn on tracing papers with 25 mm. margin on all sides. Sketches, graphs, photographs shall be serially numbered with appropriate reference in the body of the paper.

Your prompt response on this matter will be appreciated by the Editorial Board-IWJ.

Regards
— Editor