Recent innovations in equipment for GMA welding help enhance productivity & quality

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ABSTRACT

Gas Metal Arc Welding (*GMAW*) has established itself as a high deposition welding process, bringing in tremendous benefits of higher productivity and economics over MMA welding. Full utilisation of these advantages have not been possible in the past, due to limitations in the conventional equipment and controls used for the process. Also, conventional equipment are not compatible for mechanised or automated welding applications.

Recent innovations, particularly transistorised power blocks, special wire drives and controls, have now added a new dimension to the *GMA* welding process, helping to increase productivity and quality, while retaining process economics with these units, it is possible to have total control over the metal transfer mechanism in *GMA* welding. Process variations like Plasma-MIG welding and Synchro-Pulsed-MIG welding, which give much higher productivity and process flexibility are now practically viable with these units. On line mechanisation and automation of the welding cycle become straight forward and simple.

This paper outlines these innovations in equipment and brings out how they have helped *GMA* welding process in steadily replacing *MMA* welding, as the most universal arc welding process.

1.0 Introduction

The rapid growth of welding engineering in recent decades has been made possible not only by the many advantages offered by electric arc welding as opposed to orthodox methods of joining, this growth is also attributable to the many ideas, improvements and new processes which have consolidated the basis of welding engineering and have opened up new possibilities for expansion, on a large scale. Gas Metal Arc Welding (*GMAW*) can undoubtedly be considered as one of the most significant developments, and probably the principal one in welding engineering in the recent decades. Since its inception in 1953, after a discovery made by Dr. P. C. Van der Willigen of Philips Research Laboratories, CO_2/MIG Welding has grown with astounding rapidity, both in extent of application and in variety of techniques and equipments.

Two factors stand out as responsible for the rapid absorption of this process by industry. The first factor is the high productivity that can be attained with the process and the second is the universality of the process and equipments.

In the *GMAW* process, there is a range of interdependent adjustments in the power supply outputs and consumables feed rates, that in the correct combination constitute viable operating conditions for any given material and welding situation. In the initial stages of the development and absorption of the process by industry, conventional equipment based on electromagnetic circuitry and controls was employed. Such circuitry have response times as high as 100 milliseconds, as compared to the metal transfer rate of 5 to 10 milliseconds. This wide mismatch results in lack of penetration, cold laps etc. in the weld, leading to lower productivity and uncertain quality. The operator also faces lot of inconvenience due to uncontrollable parameter variations in the system.

Till 1979, arc voltage was considered to be the controlling parameter in dip transfer mode of *GMA* welding. Hence, flat characteristic (constant voltage) power sources were employed. Now it is established that arc current and not arc voltage is the most critical parameter in dip transfer mode. This calls for true vertical current/voltage characteristics in the power source. On the other hand, for spray transfer mode still true horizontal current/voltage characteristics are preferred since it ensures a constant arc length. To meet the total requirements of *GMA* welding, therefore, we require a power source which can give any volt/amp characteristics from true horizontal to true vertical. The transistorised power block provides the answer.

With the availability of high speed switching transistors, working at high frequencies, reliable systems are now possible with response times of the order of 0.1 to 0.5 milliseconds i.e. 10 times faster than the metal transfer rate. These systems allow the total integration of the electronics with the welding arc to monitor, correct, control and maintain the arc for very high quality and reproducibility in the end product. Mechanisation and automation as aids to increasing productivity are now practicable since on-line adaptation becomes simple and straight forward.

Plasma-MIG welding and Pulsed MIG welding are variations of *GMAW* process which have better flexibility and give much higher productivity. So far the equipment and controls required were very complex. The transistorised power source with its fast response, overcomes this lecune. All position welding with *GMAW* process and its variations is now totally viable for day to day industrial applications.

Two applications are cited which bring out the improved weldability and high production rates made possible by transistorised power blocks and controls.

2.0 Critical Welding Paramaters and their consistency

In *GMA* welding process, there are a number of critical parameters, the correct selection and combination of which only can give reproducible results. The parameters are :

(a) Current/wire feed speed
(b) Open circuit voltage and arc voltage i.e. slope
(c) Inductance

In the conventional units, these parameters are independent. Hence following problems occur.

A. *Incorrect selection of welding parameters*

The choice of critical parameters are left to the welders' judgement. Calls for extensive skill to strike the optimum.

B. *Variation of torch to work distance by the welder cannot be compensated*

With resulting colder arc cr excessive spatter, porosity and cold laps occur. Unfortunately, most welders feel comfortable to work with a cold arc.

C. *Delay in restoring correct heat to work piece*

Reaction time is very slow.

Furthermore, conventional units employ electromagnetic controls. Here the control and consistency of the weld metal are always at the mercy of the associated electrical system. High productivity, reproducibility and quality be realised in the MIG process, only when the power source can respond to the process variations instantaneously. Also the power source characteristics should be such that heat input to the weld can be kept constant. Table 1 gives a comparison of the reaction times of different types of power sources. This clearly brings out the gross inadequacy of the conventional units.

Table 1 Reaction Time

Type of Power Source	Reaction Time in Milliseconds
Electromagnetic Systems (Transductor Control)	±100
Thyristorised Power Source	±50
Switched Mode Transistorised Power Block	±0.5 to 1.0

3.0 Requirements of GMA Welding

3.1 Dip transfer welding : Control of arc energy a prerequisite for weld reliability.

The various phases of the short arc or dip transfer arc is shown in Fig. 1. Each cycle has two distinct parts, the arcing period and short circuit period. The rate of short circuits being 80 to 200 per seconds depending on wire size, gas used and current level.

Till now dip transfer welding has always been done with a constant voltage power source, because this method allows a regular melting of the wire with low arc energy by self regulating principle. This however does not control the arc energy to keep the heat input constant. Weld faults like lack of fusion and cold laps can be avoided only if heat input to the weld is maintained constant.

Detailed study has established that arc current is the critical parameter to be controlled to achieve constant heat input. It can be explained as follows :

Figure 2 shows the various components of a MIG arc.

The total power of the work piece P_{wo} is the sum of

(i) Power coming from the wire $= P_{wi}$

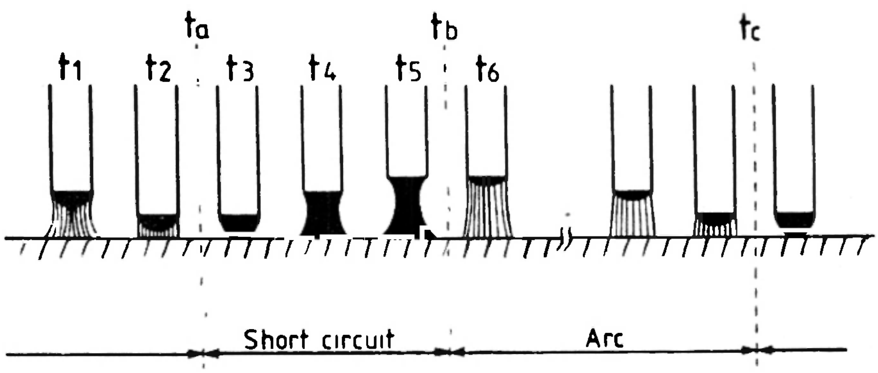


Fig. 1. Various phases of the short arc.

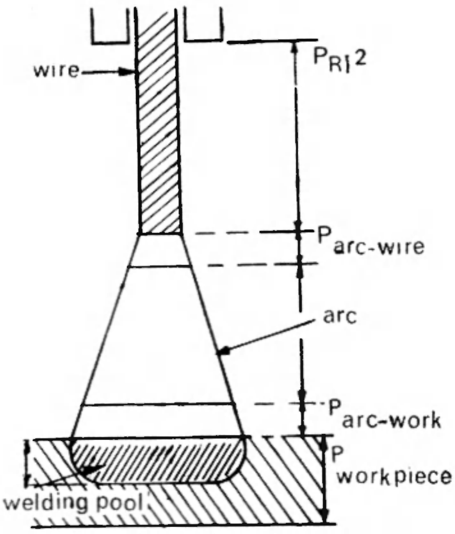


Fig. 2. Various Components of MIG arc.

(ii) Power coming from the arc into the work piece=P_{arc-wo}

So, we can write :

$P_{wo}=P_{wi}+P_{arc-wo}$ (1)

The power in the wire P_{wi} is the sum of :

(i) Power provided by the resistance heating of the wire i.e. I^2R effect=P_{I^2R}

(ii) Power coming from the arc into the wire=P_{arc-wi}

So, we can write :

$P_{wi}=P_{I^2R}+P_{arc-wi}$ (2)

P_{wi} is constant when :
—Wire speed is constant
—melt-off rate is constant
—P_{arc-wi} is constant

P_{wo} is constant when :
—P_{wi} is constant
—P_{arc-wo} is constant

—The wire speed is continuously controlled and kept constant.

—Melt off rate is kept constant by voltage regulation so that I_{arc} is kept constant for any change in P_{I^2R}

—$P_{arc-wi}=n_1\times V_{ano}\times I_{arc}$
$\simeq K_1\times I_{arc}$ (3)

$P_{arc-wo}=n_2\times V_{cat}\times I_{arc}$
$\simeq K_2\times I_{arc}$ (4)

i.e. P_{arc-wi} and P_{arc-wo} are constant when arc is constant.

Combining the equations
$P_{wo}=P_{I^2R}+K_1\ I_{arc}+K_2\ I_{arc}$

$\therefore\ P_{wo}=f(I_{arc})$

Hence P_{wo} the power to the work piece can be kept constant by keeping I_{arc} constant.

I_{arc} is distinct from the $I_{short\ ckt}$ This is clear from the Figure 3.

Arc Current is the mean value of the current when the arc is *on* when compared to the total cycle current (I_{arc}).

Short circuit current is the mean current when the arc is *not on* in comparison with the total cycle ($I_{short\ ckt}$).

Welding current is the mean value of the current in a total cycle (I_w).

So in dip transfer $I_w=I_{arc}+I_{short\ ckt}$ in spray transfer $I_w=I_{arc}$

From the above analysis it is apparent that dip transfer welding calls for a constant current power source. Table 2 gives a comparison of the two types of current regulation.

3.2 Spray Transfer Welding

From the previous analysis, it is clear that in the case of spray transfer, welding current (I_W) is the same as arc current (I_{arc}). To achieve good reliability in spray transfer, it is essential to keep the arc length constant, so that arc force remains unchanged. This means, small

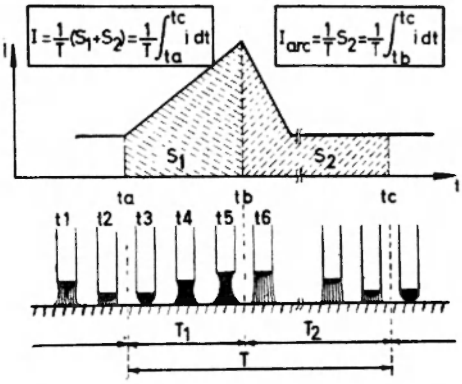


Fig. 3. Arc current and short circuit current.

variations in arc voltage must be compensated fast to bring the system to normal state. This calls for a true horizontal volt/amp characteristics with the self regulating mechanism.

To realise the best benefits from the *GMA* process therefore requires a power source and control system which can provide either true vertical characteristics for dip transfer or true horizontal characteristics for spray transfer. The system should also be capable of reaching fast, to match with the metal transfer rate. These two requirements can be fully met only by a transistorised power block which is described below.

4.0 Transistorised Power Sources

As seen from Table 1 transistorised power blocks give a reaction time of 0.5 to 1.0 milliseconds. Dip transfer welding involves around 80 to 200 short circuits per second. So every 50 milliseconds, a complete arcing cycle and short circuit cycle takes place. It is clear that only a transistorised power source can react fast enough to control the total operation. The transistorised system brings in tremendous advantages :

(i) Any characteristics from the true vertical to true horizontal can be generated.

Table 2 Comparison of Constant Voltage with Constant Current Regulation

	Constant Voltage	Constant Current
REGULATION	Arc time, short-circuit time and *Current* adjust themselves so that P_{wi} is kept constant	Arc time, short-circuit time & *Voltage* adjust themselves so that P_{wi} is kept constant
INFLUENCE	P_{I^2R} is kept constant P_{arc-wi} is variating so that $P_{wi}=P_{I^2R}+P_{arc-wi}$ stays constant	I_{arc} is kept constant P_{I^2R} is by any change immediately restored by variating the *Voltage* so that: $P_{wi}=P_{I^2R}+P_{arc-wi}$ stays constant
	Constant Voltage	**Constant Current**
RESULT	I_{arc} is variating $P_{wo}=P_{wi}+K_2\times I_{arc}$ is variating Heat imput is variating High risk of cold laps	I_{arc} is constant $P_{wo}=P_{wi}+K_2-I_{arc}$ is constant Heat input is constant Substantial reduction of cold laps

(ii) Response time is very fast.
(iii) Immunity from line voltage fluctuations.
(iv) Closed loop control is possible ; on line mechanisation is simple.
(v) Remote control/stepless control can be incorporated.
(vi) Output can be pulsed.

4.1 **Switched Mode Power Block**

The principle of a switched mode power block (SMPB) is shown in Fig. 4. It operates at a constant high frequency ($\approx$40 khz) and uses high speed switching transistors as switches. The mean current is then a function of the time for which the transistors are closed (Fig. 5).

The enormous advantage of the fixed frequency is that when we are measuring the welding parameters, we can feedback the data into the power source and act on the time the transistors are open or closed—the complete feed back systems.

The power block essentially consists of four parts (Fig. 6)

—a rectifier part rectifying directly the AC from the Mains
—transistors used as switches (S_1 to S_4)
—Rectifiers (D_{1-2} & D_{3-4}) and smoothing choke (L)
—Transformers working on high frequency (T_1 & T_2)

Every 50 milliseconds, the transis tors S_1 and S_2 are closed simultaneously. The transistors S_3S_4 also close simultaneously but with a delay of 25 milliseconds with respect to S_1 and S_2.

When the transistors are closed for 5 milliseconds, current flows through the primary side of the corresponding transformer, creating a secondary current (i_{1-2} & i_{3-4}).

The secondary currents are rectified again (D_{1-2} & D_{3-4}) and they are shifted by 25 milliseconds. Rectifier D_3 prevents reverse current flow.

Welding parameters I_w and U_w measured and compared with the voltage setting of the control unit e_{in}. If necessary correction is made within 1 millisecond.

By proper choice of e_{in}, any V-I characteristics can be generated.

4.2 **Grip feed drive**

Conventional drive systems suffer from a serious disadvantage viz. very high slippage between the drive mechanism and the filler wire. In this case, the wire feed is not positive and the control loses significance. The slippage observed in conventional systems is shown in Table 3.

Table 3 Slippage

Type of Wire-drive Systems	Slippage %
Single Point/2 Wheel Drive	$\geqslant$ 30
Two Point/4 Wheel Drive	16 to 18
Planetary/Linear Drive	4 to 6
Grip Feed Mechanism	$<$ 2

For ensuring total system reliability, particularly in mechanised applications, a more positive drive system is called for. Grip feed system developed recently provides the solution. The principle of the drive system is clear from the Figure 7.

—The wire is pushed by the trilling action between the two blocks
—A hollow shaft motor—stopper motor or low inertia solid state motors drives the feeder.
—Because of the tapered construction, movement in reverse direction is not possible.

The advantages of the system are :

(a) *Universality* : can be used for all sizes and types of wires without any change of rollers.
Systems now available for use upto 1.6 mm wires
Systems are possible for use upto 2.4 mm wires

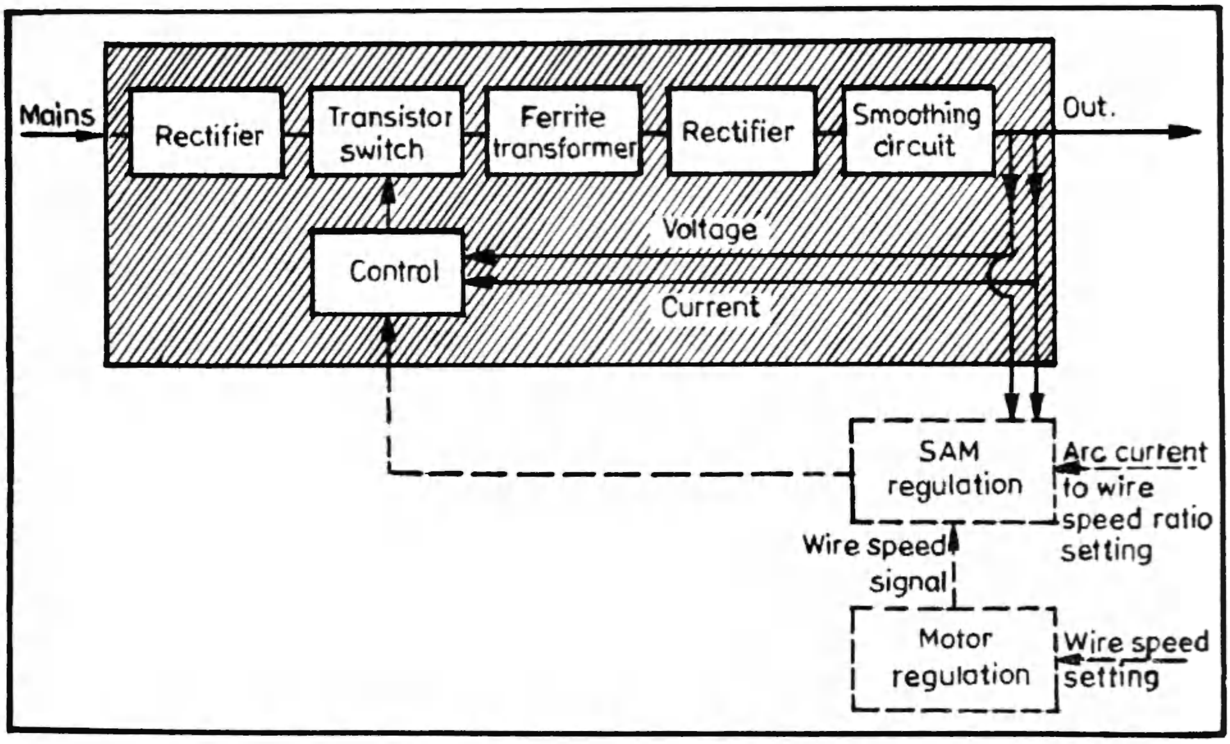


Fig. 4. Switched mode power block.

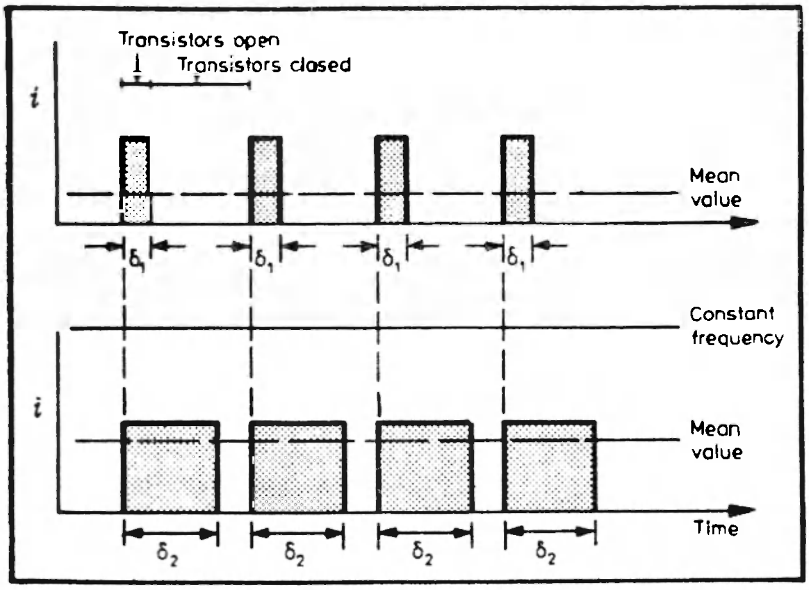


Fig. 5. Principle of switched mode regulation.

(b) *Higher productivity :* nearly 30% higher productivity is possible since the system can deliver the wire much faster. A comparison is shown in Fig. 8.

(c) *Minimum slippage :* this slippage reduces to as low as 2% making it the ideal drive system for mechanised and robotic applications.

(d) *No wire jamming and no flaking:* minimum down time

(e) *No gear mechanism :* very high system efficiency compared to conventional systems.

(f) *Higher pushing power :* longer torch length are possible.

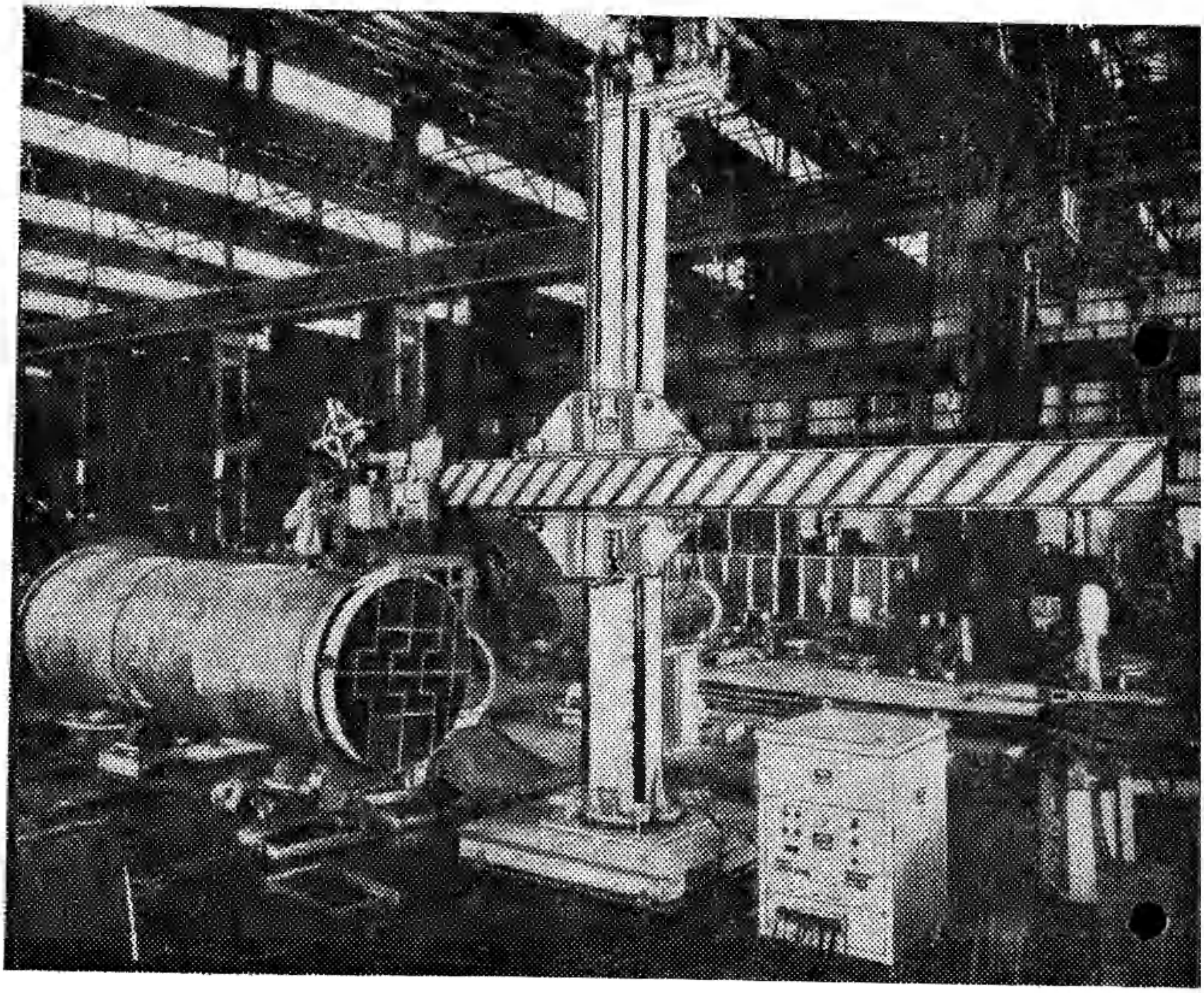
The combination of transistorised power block and a highly efficient wire feed system like "Grip feed" bring in considerable benefits to the *GMA* process and its variations. Some of these are described below.

5.0 **Pulsed MIG Welding**

This process was introduced to overcome the constraints of dip transfer welding with conventional MIG. It achieves :

Improved droplet detachment : Droplet detachment in a free arc analogue to the spray arc process, by way of pulsing the welding current, so that melt off takes place before short circuit.

BOOST WELDING PRODUCTIVITY–DRAMATICALLY



Indarc column and boom being used with Indarc submerged arc welding head for the fabrication of pressure vessels.

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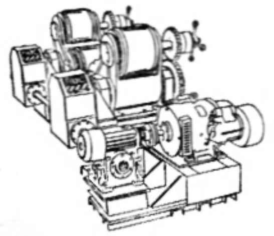
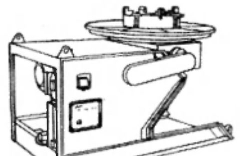
IOL's consultancy services, backed by years of experience and access to the latest technology, can also help your welding engineers to identify problems and to solve them.



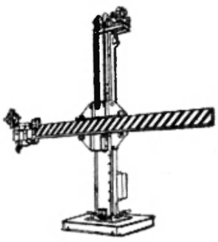
· Beds

- Both conventional and self aligning types. Wide capacity range.
- Thyristor controlled drive.
- Anti-creep and synchronization facility with other roller beds (optional).



Manipulator & Positioner

- Combined tilt and turn facility with thyristor controlled drive. Wide capacity range.
- Robust design — 'all gear' construction to reduce backlash.



Column & Boom

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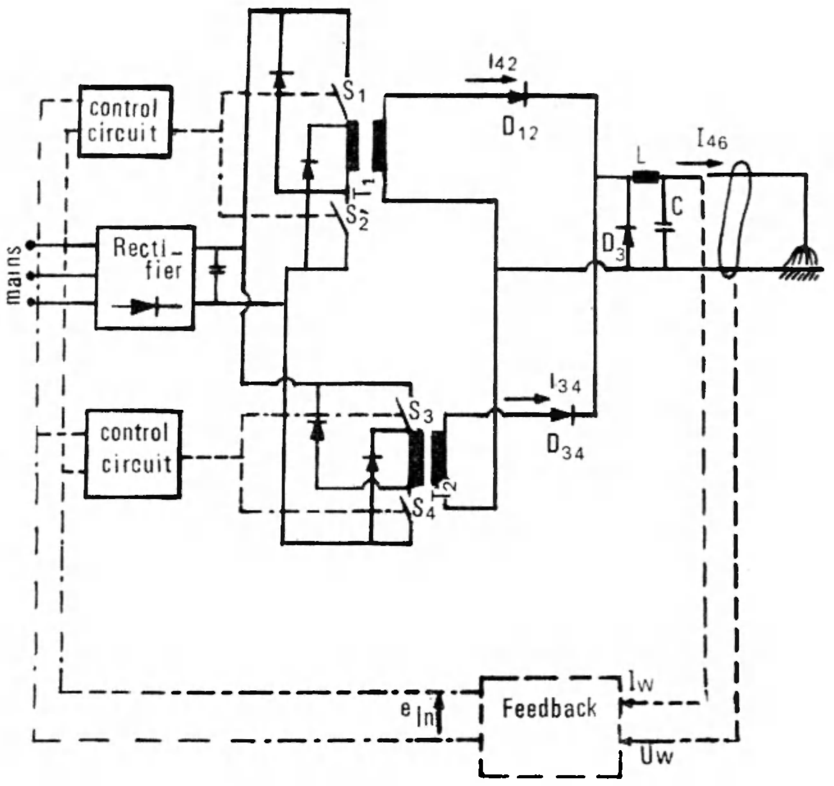

Fig. 6. Switched mode block diagram

ideal conditions for droplet detachment.

Transistorised power sources with fast response times allow pulsed operation to be regulated to far greater degree and help achieve uniform droplet detachment and high quality welds.

Normally pulsing can be synchronised to achieve any of the following:

(a) Uniform droplet size relative to wire dia so that ideal weld pool conditions are met.

(b) Single droplet detachment for each pulse rapidly ejected into weld pool, so no spatter.

(c) frequency of pulsing adjusted to maintain constant arc length to ensure process stability.

Of these, constant arc length by variable frequency regulation of

Sound fusion with lower heat input : Requires lower heat input, so smaller weld pool allows positional welding.

Superior weld pool control : Almost spatter free operation. Use of larger diameters, without high heat input. Advantageous for positional work and thin sheet fabrication.

The basic mechanism of Pulsed MIG is to maintain a stable arc at low current, insufficient for wire melt-off and secure droplet detachment by super imposing pulses of higher current at a frequency so that melt-off rate matches delivery speed. The principle is clear from Fig 9.

The first systems derived pulse frequency from 50 or 60 Hz mains input with pulse height (I_p) and duration (I_b) inter-connected. This meant very little flexibility. Pulsing was in general not coincident with

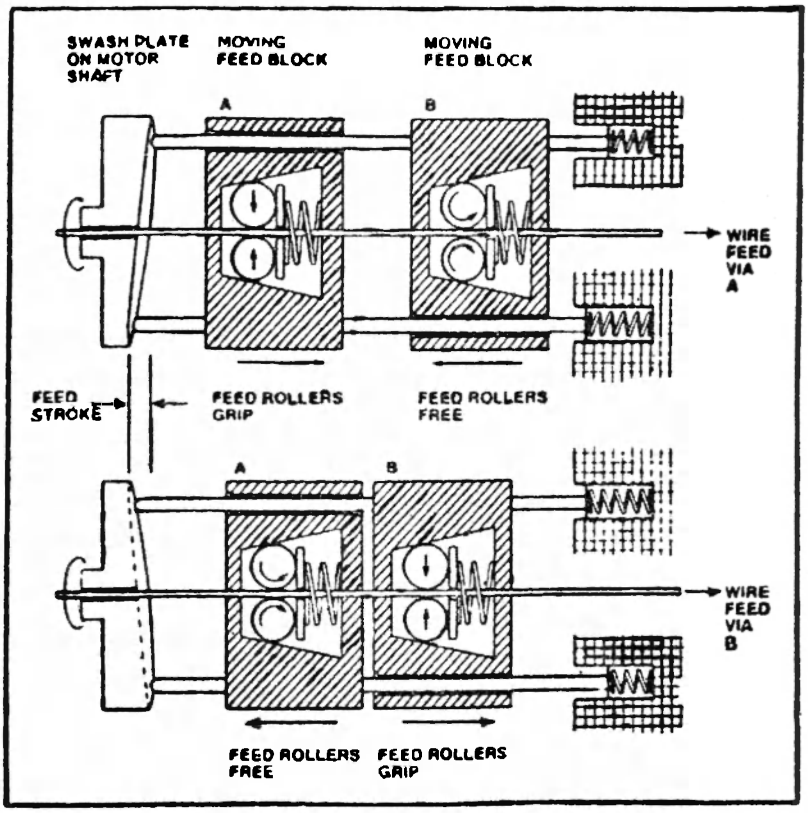

Fig. 7. Grip feed mechanism

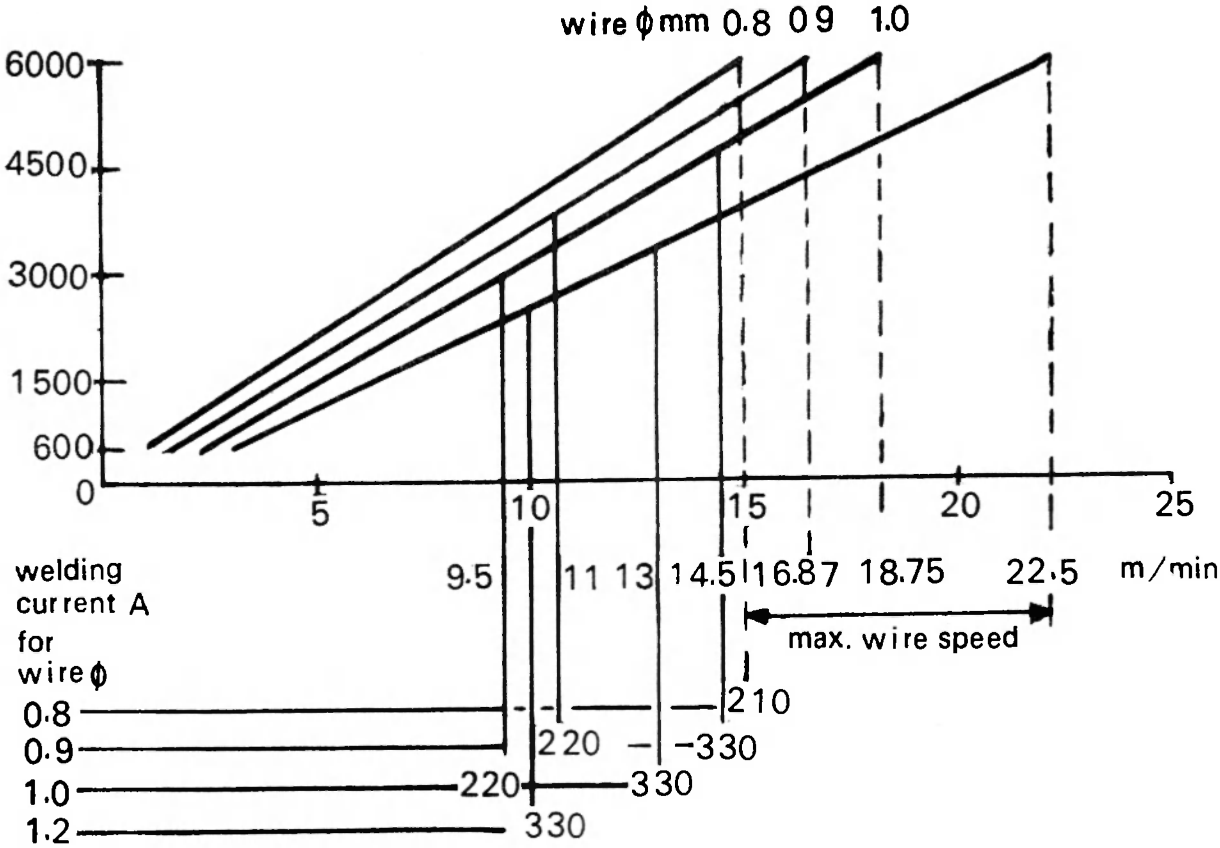

Fig. 8. Higher wire speeds higher deposition rates

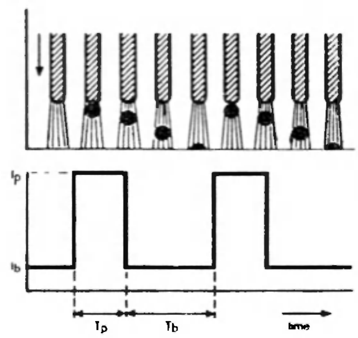

Fig. 9. Pulsed-MIG welding

pulses is commonly used. The Figure 10 shows how the arc length is maintained. Incorrect arc length, hence arc voltage at A will continue for successive pulses B and C at constant interval time T_1, until variation in wire speed etc. discontinue. When the arc voltage at C is measured and compared with the programmed arc voltage (arc length) and the difference used to vary pulse frequence, ideal droplet detachment takes place at D.

Soft start facility and programming to maintain constant arc length are in-built in the electronic regulation circuitry. Since arc voltage is linearly related to wire speed, arc length would always tend to vary. By applying a proportional correcting factor and to the power circuitry, arc length can be kept constant at all wire speeds. The system also allows a personal adjustment for welder (trimming) but always maintaining the same and value as shown in Fig 11.

As seen above, the transistorised power blocks and controls elevate the Pulsed-MIG Welding process to achieve a very consistent droplet detachment process, increase the flexibility and make all position welding with reproducible quality a reality.

Pulsed MIG can replace difficult to run submerged arc welding in stainless steels without loss of productivity. It can also be considered as a direct replacement for hand or automatic TIG welding, thus gaining extra productivity.

6.0 **Plasma MIG Welding**

This process was developed to increase the productivity and quality of *GMAW* process, by providing additional heat to the arc using a

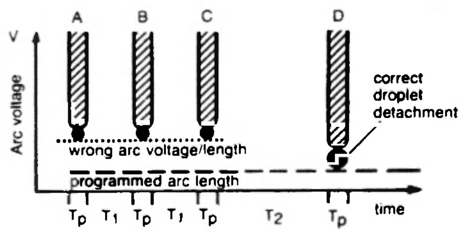

Fig. 10. How constant arc length is maintained

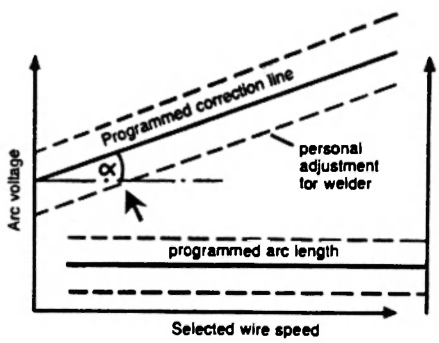

Fig. 11. Programme line.

plasma stream. The basic principle is clear from the figure 12

- The welding wire is fed via the contact tube connected to the MIG Power Source.
- A plasma arc column is created by ionising the plasma gas flowing around the wire using a pilot arc.

The process achieves the following :

- *More control*

Unlike conventional MIG, Plasma MIG has two heat sources (Plasma Arc and MIG Arc) independently adjustable and allow better control and a more flexible process.

- *High deposition rates*

Provides higher welding speeds with lower heat input. Deposition rates can be increased by 30 to 70% over conventional MIG.

- *Surface cleaning*

Welding can be carried out even on unclean plates, particularly aluminium, since the plasma stream helps surface cleaning.

- *Extended current range*

With a given size of wire, welding is possible over a wide current range, with assurance of predictable and easily repeated results.

The first systems of Plasma MIG employed conventional power sources for MIG and used a H.F. system for starting the Pilot arc. This resulted in electrical interference problems and also problem of parameter matching. Soft arc starting was difficult leading to initial spatter.

With the availability of the transistorised power source all these problems are now overcome. The electronically controlled soft-arc improves weld appearance and also aids preheating and precleaing. Synchronising the two heat sources for optimum heat input is achieved via the program console. Semi-automatic arc hand welding is possible since all variations are compensated.

Plasma MIG welding is particularly suited for surfacing application where low dilution and very high deposition rates are possible compared to other processes. Table 4 brings out the comparison. Very high quality aluminium welding with ease is another achievement of this process aided by the transistorised power source.

Table 4 Dilution Levels & Deposition Rates

Processes	Dilution %	Deposition Rate Kg/hr.
SAW Single Wire	15 to 50	6.5
Single Wire+Osci	25 to 40	12.0
GMAW	30 to 50	12-15
FCAW	30	12
Plasma-MIG	5-10	15-20

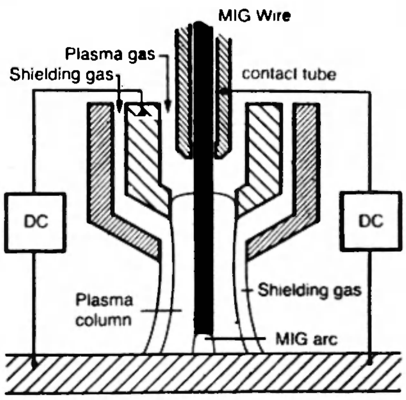

Fig. 12. Plasma-MIG welding.

Choice of horizontal or vertical MIG characteristics provides selection of the exact parameters for a particular application.

7.0 Welding of Cu to SS for Anodes

This is a typical welding application where maintaining low but constant heat input is critical for obtaining high quality welds. Inconel 625—1.2 mm wire with argon shielding gas is used as the filler material. Heat input in excess of a specified joules/cm results immediately in numerous transverse cracks in the weld bead. Too low a heat input causes cold laps.

Welding is preformed in the dip transfer mode and convex beads due to rather reduced heat inputs are produced (Fig 13).

Parameters :

Arc Current	202 A
Welding Current	230—240 A
Welding Voltage	23—24 V
Welding Speed	35 cm/min
Current Rise Level	60 A/ms
Wire Feed Speed	7.3 m/min

With conventional equipment, where heat input control is not possible, this welding would be extremely difficult. The new equipment gives improved weldability and quality. Reject/repair rate of the product made with conventional set was 30%. Now it is zero.

8.0 Dual Schedule Welding for Higher Productivity

As seen earlier (a transistorised power source allows a constant current or constant voltage characteristics to be achieved by the trigger of a switch) constant average arc current welding in the dip transfer mode guarantees constant heat input per unit volume of deposited material. Thus eliminating the lines of cold laps or fusion faults. However, for welding under spray conditions, it is preferable to use constant voltage mode because use of its true horizontal current/voltage characteristics, which guarantees a constant wire tip to work piece distance, i.e. a constant arc length. The transistorised power source allows the welder to choose from the two different schedules, just by activating the trigger switch in the torch handle. Advantage is taken of the high response abilities of the transistorised power source to have a dual schedule welding, which has two parameter settings as follows :

(a) a parameter setting for normal deposition rates with lower welding voltage and welding speeds.

(b) a parameter setting for high deposition rates with high welding voltage and wire feed speed.

Both settings can be selected successively by means of the torch trigger (Fig. 14).

Table 5 gives the typical parameter settings for high deposition welding. From this it is very clear that nearly 2 times the normal deposition rates is achieved with dual schedule mode.

This is particularly useful, when the position of the welding changes due to contours in the work piece when there is a step in the thickness of the plates to be welded, when the gap between the plates varies and when a root pass has to be followed by a filler or capping bead.

The schedule selection is done using the controls shown in the Figure 15.

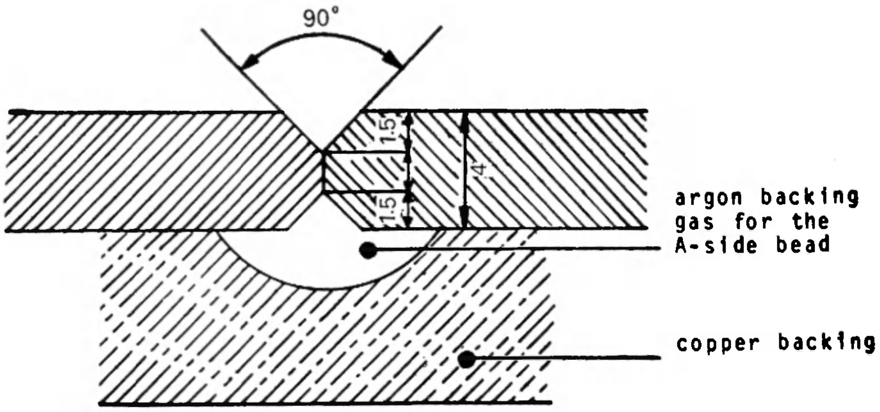

Fig. 13. Weld joint assembly, Cu to SS

Level selection is done with the help of the trigger switch

(i) Rear part of the switch is to be pressed for starting and stopping.

(ii) Welding starts in the schedule I (normal welding). Parameter for this are defined by
P_{W1} —Wire Speed Control
P_{S1} —Slop Control
P_{H1} —Heat Regulator

(iii) Depressing the front part of the switch schedule II (High deposition welding) begins. The parameter for this are defined by
P_{W2} —Wire Speed Control
P_{S2} —Slope Control
P_{H2} —Heat Regulator

(iv) Depressing the switch back to neutral position controls the heat of the arc. Brings back Schedule I.

(v) Pressing the switch at the rear stops the welding cycle.

For dual schedule welding, normally thin wire (0.8 mm or 1.0 mm) is used so that good penetration is obtained due to the high current density. Argon with 5% CO_2 or 8% CO_2 is used as the shielding medium. The higher limit for dual schedule welding is set by the transition point beyond which the arc starts rotating due to high electromagnetic forces. With a rotating arc, penetration is shallow. It is very useful for metal spraying applications.

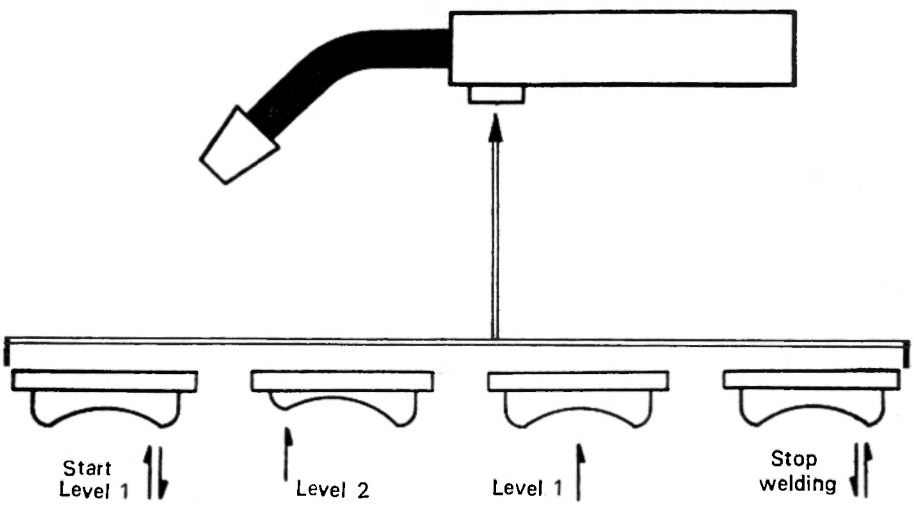

Fig. 14. Torch Trigger

Table 5. Typical Parameter Settings for High Deposition Welding

Type	Current with 0.9mm Wire	Welding Voltage Volt	Wire Speed in m/min	Travel Speed in m/min	Dep Rate in kg/hr.
5mm	300	37	31	0.65	9
6mm	320	38	35	0.65	10
7mm	355	39	40	0.75	12
6-7mm	320	39	35	0.65	10
10-12mm	355	40	40	0.65	12
20mm 1	340	38	38	0.38	11
2	340	38	38	0.45	11
12mm 1	320	37	35	0.4	10
2	320	37	35	0.4	10
5	300	37	31	0.75	9
6	320	39	35	0.75	10

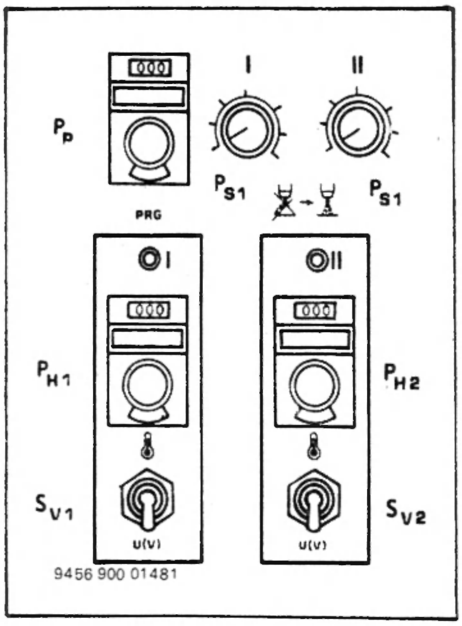

Fig. 15. Controls for schedule selection.

9.0 Automation in GMA Welding

Mechanisation and robots give the opportunity to apply higher consistently reproducible welding speeds to increase productivity. Higher deposition rates require a power source to be exactly tuned to the consumable wire feed speed, joint configuration and shielding gas to give confidence in welding results. Also for efficient application of a robot, the system must have the ability to store both movement and welding parameters as a total program in the control memory.

Realising the best out of automation in *GMA* welding, therefore calls for a highly efficient power source and a suitable control memory. While the transistorised power source described earlier provides the first part, the advent of the microprocessor has completed the rest. The greatest advantage of the transistorised power source is ofcourse the fact that it can be coupled to or interfaced with a microprocessor. The output can be pulsed in any form required and this enables total control of weld bead, shape, size and penetration. The microprocessor enables digital control of the welding parameters and also movement with facility for retrieval.

With these two features, the functions of the system constitutes can be pre-programmed to perform a given welding operation at high speed. This brings in tremendous improvements in productivity.

Conclusions

1. To increase productivity and quality in *GMA* welding more efficient equipment and controls are required.
2. Dip transfer and spray transfer call for different characteristics in the power source.
3. Conventional equipment cannot meet these demands.
4. Transistorised power source with switched mode operation, alongwith improved wire feeders provide the right answers to improve productivity.
5. Pulsed MIG and Plasma MIG operations can be carried out with transistorised power source and give much better flexibility/ quality.
6. Dual deposition welding schedule helps to achieve very high deposition rate.
7. Automation of the process using robot is easier and can be incorporated with microprocessors.

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