Some Recent Innovations In TIG Process

BY V. R. RAMESH*

Introduction

The use of greater plate thicknesses in the new aerospace and hydrospace materials has increased the need for new, high speed, high quality welding processes. Conventional methods to weld these materials have serious economic limitations because of low speed. Recent developments, such as plasma arc and electron beam are being utilised to some extent, but conventional tungsten inert gas welding remains the most widely used process where weld quality is very important. Within the last decade, many refinements have been made to increase the speed of welding with TIG process, the most important one being its automation. Along with it have come techniques like magnetic arc GTAW process and hot wire GTA process, which aim at increasing the productivity of GTAW process. The introduction of pulsation techniques have increased the reproducibility and quality of GTA welds. This paper attempts to review the basics of these innovations which have made the GTAW process a highly competitive, economic and productive welding tool.

Magnetic Arc Welding Process

'Arc blow', resulting in the deflection of the arc by the induced magnetic field has been an undesirable phenomenon causing concern to welders. A magnetic field from any source is found to have its own effect on the welding arc which is defined as "a sustained electrical discharge through a high temperature conducting plasma, producing sufficient thermal energy to be useful for the joining of metals by fusion."

A possible explanation as to the cause of magnetic arc-blow has been provided by Jennings and White. The eddy currents caused by the current flowing through the weld plate create a magnetic field on the surface of the weld plate. This surface magnetic field exerts a force on the electrons and ions within the arc, which causes the arc to be deflected away from the normal arc path.

Considerable research work has been carried out in the field of arc magnetics especially towards the use of external magnetic fields for the better utilisation of welding techniques. As a result of the application of an external magnetic field, the arc is found to be displaced either forward or backward depending on the direction of the force acting, as described by the rules of electromagnetism. Application of an optimum magnetic field is found to provide better flexibility of the arc and increased speeds both on magnetic and non-magnetic materials.

Physical Principle

According to the principles of electromagnetism, every current is accompanied by a magnetic field. The lines of force around a circular conductor will be concentric as shown in Fig. (1A). We can consider this circular conductor as a substitute for the arc. If this conductor is located in an external mag-

* The author is with Indian Oxygen Limited. This paper was presented at the Institute's National Seminar 1977 in New Delhi in February 1977.

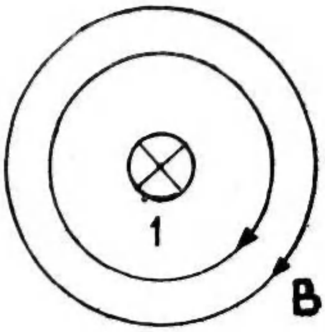


Fig. 1A. Magnetic field of a single conductor

netic field, the various magnetic fields (that due to the arc, external field etc.) get superimposed leading to shortening of the lines of force as shown in Fig. (1B). Hence a force is exerted on the conductor in the direction shown above. This direction is determined with the aid of Fleming's left hand rule.

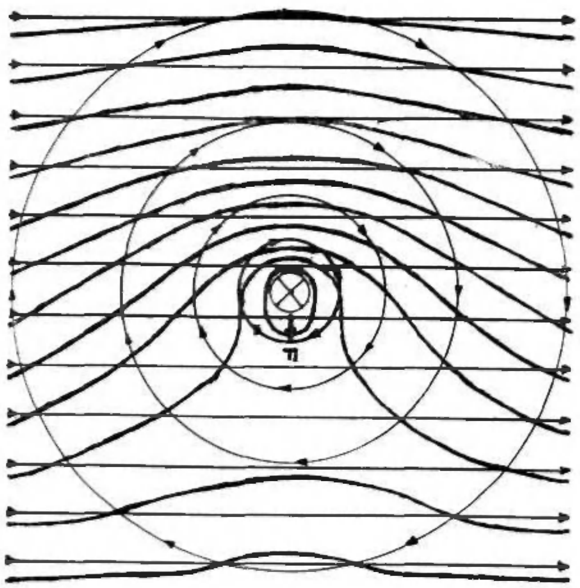


Fig. 1B. Combined field of a conductor and an external magnetic field.

The relation between the vector of force, current density and field density is to be determined in order to arrive at the total force on the conductor. This determination is quite simple in the case of a circular conductor. However, it is quite complex in the case of a welding arc because of the many complex phenomena associated with a welding arc. Some of the conditions which exist within an arc which make the calculations complex are :

(a) Uneven distribution of the charged particles within the electrode regions.

(b) The gas of the plasma which may be singly or multiply ionised.

(c) The potential gradients which exist in the various regions.

Classification of Magnetic fields

In the context of welding applications, magnetic fields are generally classified into three groups.

(a) *Transverse field :* When a magnetic force is imposed upon a welding arc in such a manner that the field is perpendicular to the direction of electrode travel, and to the electrode axis, it is referred to as a transverse field.

(b) *Parallel field :* Here a magnetic field is applied in such a way that the flux lines are parallel to the direction of electrode travel.

(c) *Longitudinal field :* Longitudinal magnetic fields have their flux lines parallel to the electrode axis.

Effects of magnetic field on a TIG arc

The gas tungsten-arc welding process has been subjected to extensive investigations to determine the effect of an applied magnetic field on the arc. Various forms of magnetic fields have been used for this purpose on a direct current straight polarity arc. Studies have been mainly aimed toward using the negative phenomenon of arc-blow to advantage. This has resulted in both economical and technological advantages in the use of GTAW process. Increased speed of travel at which undercut-free welds can be made, control over arc-blow effects and control over micro-structure are some of the major advantages derived from the application of magnetic fields.

Arc deflection in a Magnetic field

Fig. (3) is a schematic of a normal welding arc (a) and an arc subjected to an external field (b).

L : plasma length.
S : distance from the electrode centre to the leading edge of the flame.
D <L —L <change in plasma length.
D <S —S <change in arc deflection

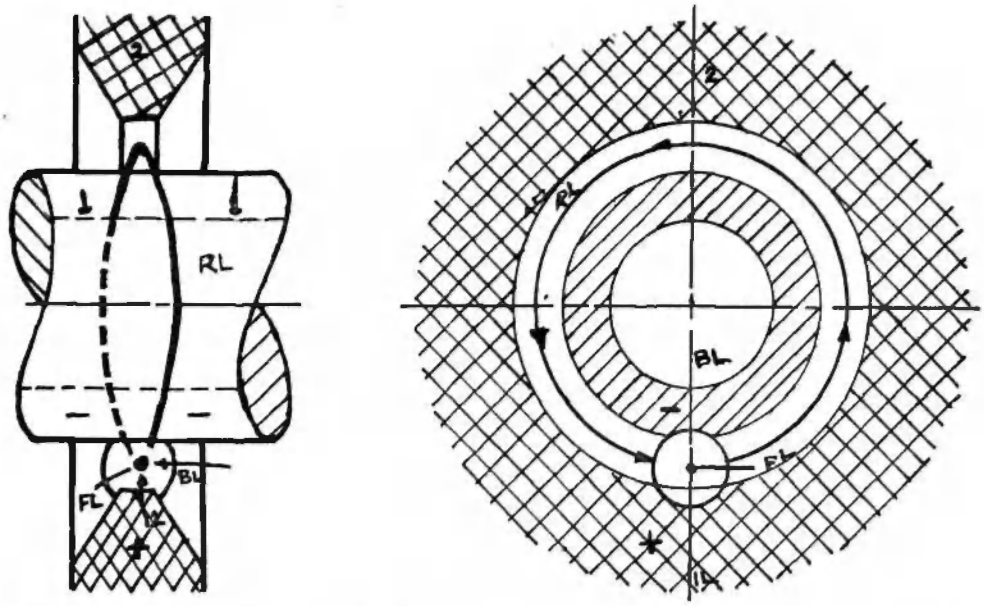
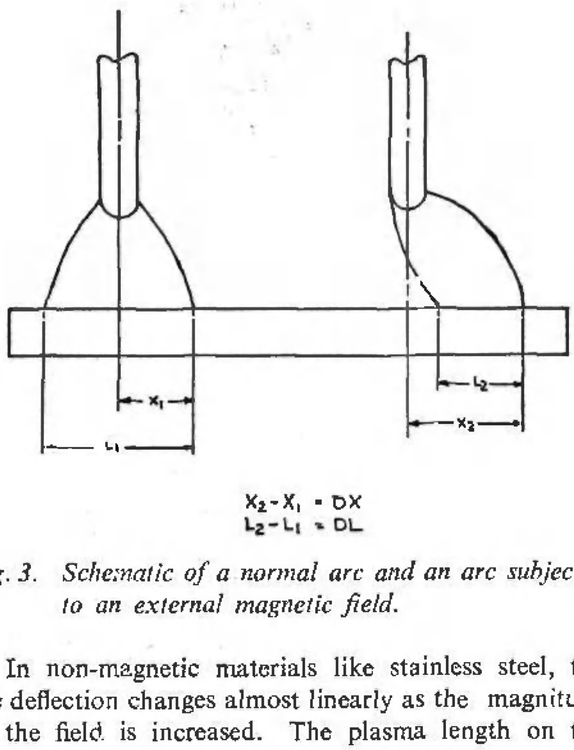


Fig. 2. The resultant direction of force FL due to interaction of arc current and magnetic field.



$X_2 - X_1 = DX$
$L_2 - L_1 = DL$

Fig. 3. Schematic of a normal arc and an arc subjected to an external magnetic field.

In non-magnetic materials like stainless steel, the arc deflection changes almost linearly as the magnitude of the field is increased. The plasma length on the other hand varies linearly upto about 20 gauss and beyond this region, the arc becomes rather unstable. The weld width is found to decrease linearly as a function of applied field. The volume of base metal melted is found to decrease as the magnetic field is increased. Beyond a certain limit however, there is no significant reduction in volume of metal melted. This is due to the fact that, when the magnetic field is sufficient to cause noticeable decrease in the weld width, its tendency to wander decreases and the number of ripples increases. The effect of the field on the arc deflection, weld width and area of metal melted are shown in Fig. (4). An example of a stainless steel weld made with and without a magnetic field is shown in Fig. (5).

Aluminium alloys are also found to behave in a similar fashion but the reduction in melt area is found to be much more than in stainless steel, as is evident from the Fig. (6).

In the case of magnetic materials, the effective magnetic field present during welding is to be determined in order to get the effect of the external field. This is because some of the magnetic field will pass through the magnetic test specimens. In the case of Hy-80 steel for example, there is a difference of nearly 2% in the applied and measured fields as shown in Fig. (7). The weld made without a magnetic field is found to have the same ditch like appearance as in non-magnetic materials. The effect of the external field is felt only when its value is more than 15 or 20 gauss. Under this condition, weld bead has excellent appearance and tendency of wandering is reduced. An example of a weld made of Hy-80 steel with a transverse magnetic field of 50 gauss is shown in Fig. (8).

The change in weld appearance due to the application of a magnetic field is due to a change in the flow pattern of the molten metal. By deflecting the arc

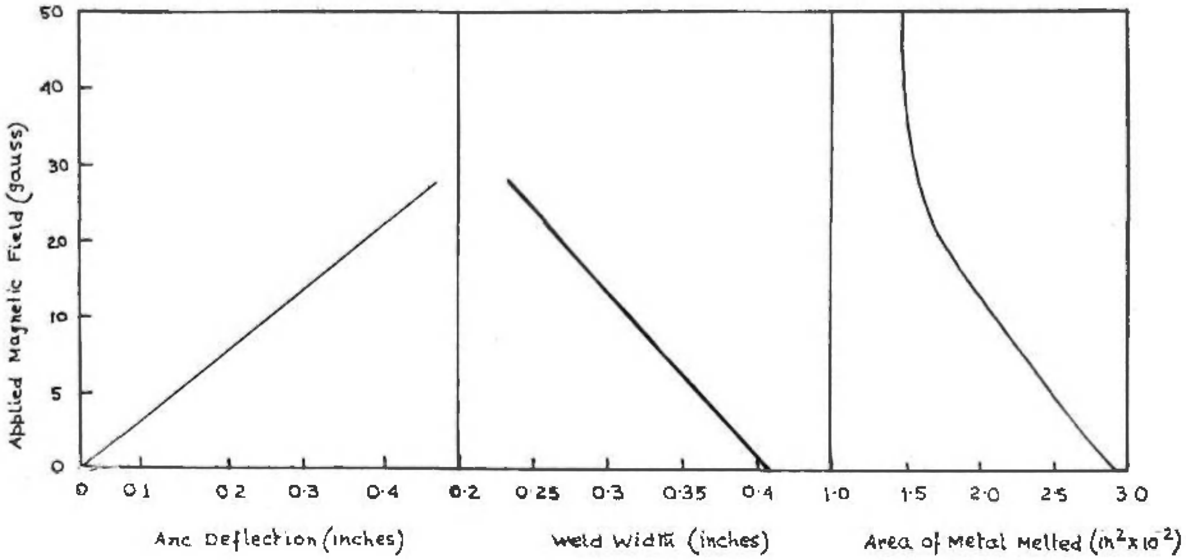


Fig. 4. Effect of magnetic field on arc deflection, weld width and area of metal melted.

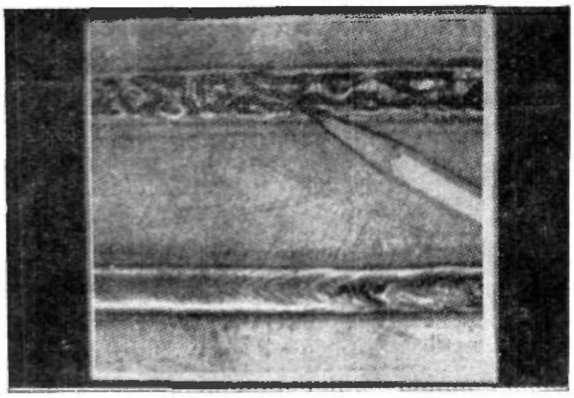


Fig. 5. Appearence of bead of welds on stainless steel without and with a magnetic field.

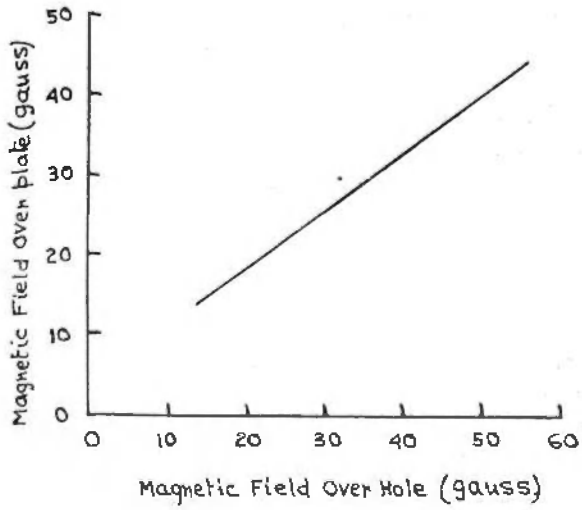


Fig. 7. Relation between measured field and applied field in magnetic materials Hy-80 steel.

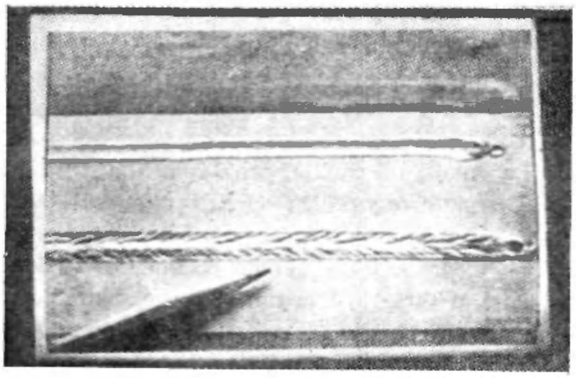


Fig. 6. Appearence of bead of welds on aluminium without and with an external magnetic field.

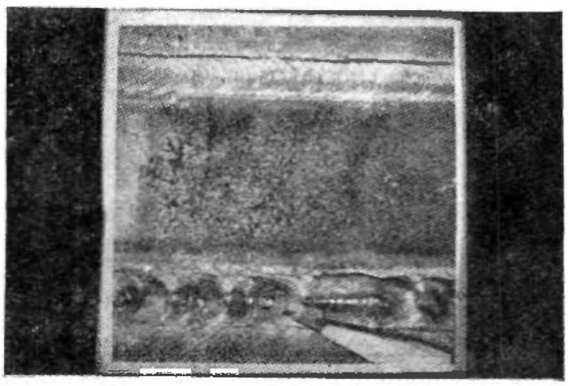


Fig. 8. Weld made with 50 gauss external field on Hy-80 steel

forward, pressure is built up in the leading edge of weld puddle and the magnitude of the pressure is dependent on the current and magnetic field strength. Hence a pressure difference is developed between the leading and trailing edges. The solid metal ahead of the weld puddle prevents the molten metal from flowing away and is forced to come back to maintain equilibrium pressure. This vortex flow pattern is the reason for filling of the craters at the end of the beads when the arc is deflected forward. When the arc is deflected backward, the molten metal behind the arc is driven further away making the bead discontinuous.

Variation of Welding Speed with Application of Magnetic Fields

Since the speed of travel can be increased by deflecting an arc forward, a magnetic field superimposed to deflect an arc suitably can be of advantage. In the absence of a magnetic field, the maximum speed-current relation for getting under-cut free welds is known and is shown in Fig. (9). With the application of a field, the relation is found to change ; the variation of travel speed as a function of external magnetic field is shown in Fig. (10). We see that nearly 50% increase in travel speed is possible with a suitable magnetic field.

Arc Stability

Arc stability is proportional to the arc current and inversely proportional to the arc length. The arc stability at an optimum magnetic field is found to increase with the shield gas flow rate, upto a certain limit.

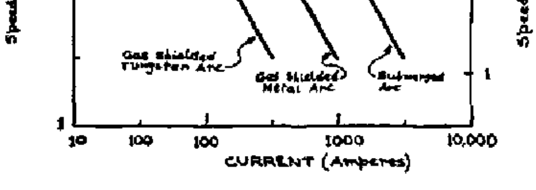


Fig. 9. Max. speed current relationship for undercut free welding without magnetic field.

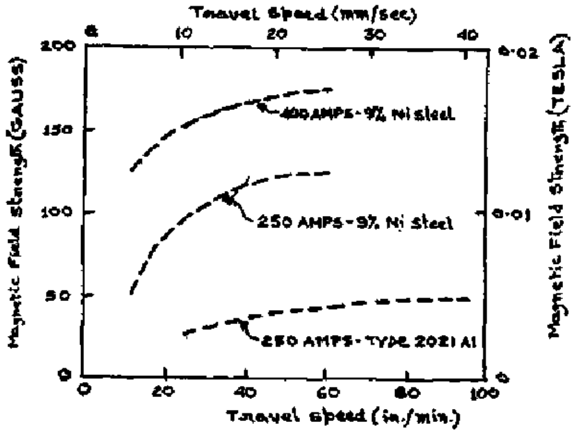


Fig. 10. Max. speed current relationship for undercut free welds with an external magnetic field.

Penetration & Dilution with Applied Field

There is a gradual decrease in penetration and dilution with an increase in applied field strength. When the arc gets deflected, the arc length increases. Therefore, loss of heat to the atmosphere increases. This will reduce the heat transferred to the work, thus reducing the nugget area, penetration and dilution.

Conclusion

From the above discussion, it is evident that the application of a suitable magnetic field can bring about considerable increase in the speed of welding, with a TIG torch, at the same time over-coming the disadvantages of arc-blow. Both non-magnetic and magnetic materials can be welded at higher speeds of the order 60-80 ipm. The quality of welding improves with metallurgical advantages. With the increased production and savings in labour cost evident from the experimental studies, we can conclude that time is not far away when magnetically controlled GTAW process will be a commonly used production tool.

Hot-Wire TIG Process

The normal TIG welding with cold filler wire has a deposition rate very much smaller compared to the GMA process or Submerged arc welding process. Although theoretically, it should be possible to deposit filler metal at three to five times the normal cold wire rate, in practice, beyond a certain limit the arc heat is found to divert to the filler wire resulting in lack of penetration. Usage of higher current has off-set this problem to a certain extent but is associated with difficulty in penetration control and puddle shielding.

This drawback has been almost eliminated by introduction of hot-wire system, where the filler material is melted separately, by means of resistance heating, to increase the deposition rate at normal currents.

Essentials of Hot-Wire Welding system

A hot wire welding system consists of a heating device which is usually an arc, and a method of feeding the filler materials. The filler material is heated using a suitable power source. By balancing the power input and filler metal feed rate, the filler metal can be made to melt and deposit itself strictly by the action of resistance heating, without any arc. In this way, any amount of metal can be melted and deposited but is of little practical value. However, metal melted in this manner can be added to a weld puddle developed by another heat source : say a TIG arc. Fig. 11 is a schematic diagram of such a system. A hot wire system shown at the left, is combined with a conventional gas tungsten-arc welding system shown at right.

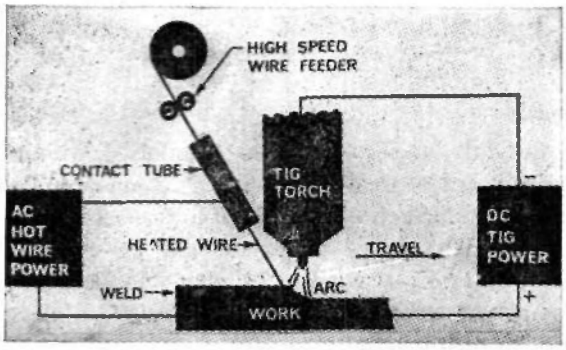


Fig. 11. Schematic of a GTA hot wire system

During welding, the arc leads the filler metal, melting the base metal. The filler metal melted by its own power source, enters the molten puddle behind the arc and forms the weld bead. The filler metal enters the puddle at a steep angle to assure a consistent point of contact and prevent the inertia of the filler metal from pushing the puddle under the arc.

Choice of power source for filler wire melting

Either a d.c. or an a.c. power source can be employed for the purpose. A. C. is usually chosen because of its lower cost. If direct current is used for heating of the filler material, the undesirable feature of arc blow will occur, resulting in the deflection of the arc, either forward or backward. This is prominent when the current used is high. So, a. d. c. source is usually not preferred. If an a. c. system is used, the arc is found to oscillate but, under normal conditions, the amplitude of oscillation has no significant effect on the welding operation.

It is very necessary to match the filler metal melting characteristics with the power supply characteristics. A constant current power source cannot be used for this purpose for two important reasons.

(a) Any increase in feed speed will not be associated with a similar variation in the current. Hence, there will be a "stub out".

(b) Any decrease in feed rate is not associated with a decrease in current and this causes the filler material to melt before reaching the workpiece. The circuit is broken resulting in the full O. C. V. appearing across the gap, and an unwanted arc is initiated.

As shown in Fig. (12), a constant potential power source is found to be satisfactory, because of the small angle between the power supply and filler metal melting characteristics.

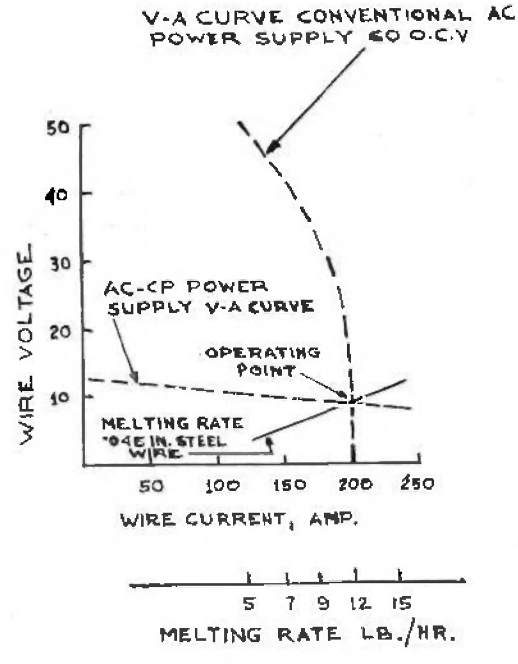


Fig. 12 Comparison of hot-wire filler metal melting and power supply characteristics

The hot wire current should be generally 50 to 60% of the welding current. Under this condition the arc is found to oscillate within 20 to 30 degrees. As the current is increased beyond this range, the amplitude of oscillations also increases. The result is that the heat of the arc is no longer concentrated on the workpiece, and the control of the process is lost. An interference can be totally eliminated by using filler wires of dia 1.2 mm or less because the current needed to melt them is quite small. With this nearly 7 Kg/hr of deposition is possible.

Process Advantages

(1) The hot wire GTAW system enables efficient use of the heat input. Since the filler metal is melted by its own power source, the deposition rate can be controlled independently of the arc over a wide range. By proper selection of parameters, welds can be produced at speeds and deposition rates equal to or greater than GMA process at a lower heat input. A comparison of the deposition rates and heat inputs for the two processes is given in the Table 1. The table also shows that there is nearly 400% increase in the deposition rate compared to the conventional cold wire filler process. The deposition rate as a function of TIG arc energy is shown in Fig. (13).

(2) In addition to increased deposition rates, the next important benefit from the use of hot wire system is the elimination of porosity from weld deposits. The I^2R heating of the filler metal, as it approaches the weld puddle, drives off most of the volatile contamination from the filler metal surface. Also the hydrogen entrapped on the filler metal surface can be removed.

The hot wire TIG system thus has the capability to deposit high quality weld metal at a wide range of deposition rates.

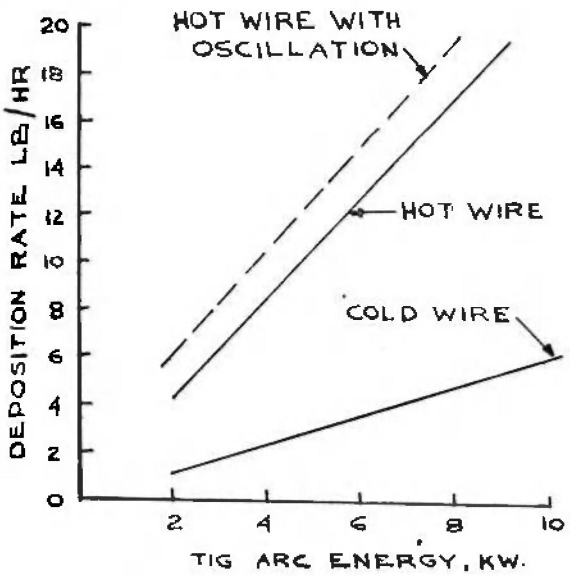


Fig. 13 Deposition rate as a function of TIG arc energy for steel

Applications

The ability of the hot-wire GTAW process to produce excellent controlled penetration root passes has made it commercially useful for welding of pipes for high temperature and or high pressure service, Essentially, the same welding conditions can be used for copper-nickel and nickel-copper (Monel) with the same results. A cross-section of a circumferential weld in 6" diameter schedule ASTM type 106 pipe is shown in Figure 14.

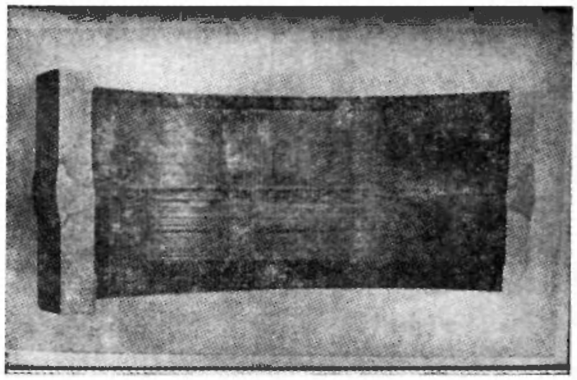


Fig. 14 Weld in 6" dia. schedule 80 ASTM type A—106 pipe

Recently, this process has been used with advantage of speed of welding, on thin sheet metals. Porosity free welds have been produced on sheets as thin as 1/16", which are of importance in jet engine parts, rocket motor cases and similar applications. An example of a production weld on 1/8" stainless steel sheet using hot wire process is shown in Fig. (15). A deposition rate of over 5 lb/hr was used to achieve positive reinforcement at 20 ipm with 3/32" gap.

Pulsed current techniques to improve TIG weld quality

With the ushering in of space age, there has been a

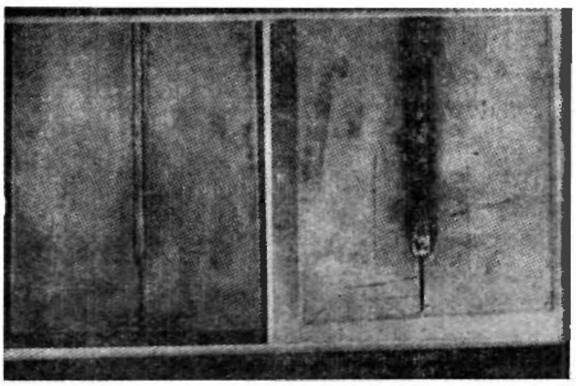


Fig. 15 Production weld in 1/8" stainless steel sheet with hot-wire TIG Process

large expansion in the production of high quality welded structures for use in aerospace and commercial applications. This calls for specialised equipments which possess all controls on the variables that affect the welding process repeatability. The GTAW process with its capability to produce high quality welds has been subjected to extended study to adapt it to take the new challenge. New developments in current and speed regulation accuracy and in welding current pulsation methods, have made possible GTA welds, at required production rates and to a degree of consistency, reliability and accuracy never possible before.

Effect of current control on Weld Quality

The welding current output wave pattern produced by various types of a. c. power supplies reveal a great variety of built-in current ripples or pulses which affect process repeatability and interchangeability of power supplies. The magnitudes of the positive and negative pulses change during welding operation resulting in poor weld quality. Different types of controls of pulsation in a. c. welding have been developed to over come this problem.

Current Pulse Control :

Fig. (16) shows some of the basic welding current output modes which are being presently utilised for GTA welding applications. Of these, square wave pulsation has received wide attention for production applications.

Square wave a.c. pulses (alternate pulses of reverse and positive polarity d.c.) (Fig. 16B) are produced by controls which alternately raise and lower the current throughout the welding cycle according to preset values of high and low current. The duration and amplitude of both high and low currents can be separately adjusted.

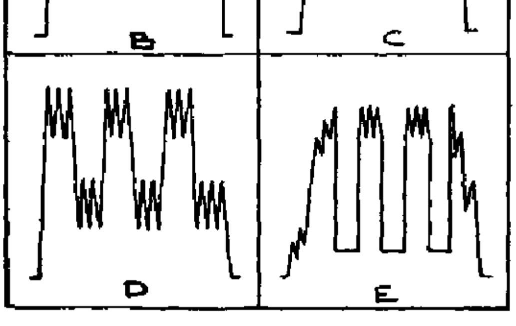


Fig. 16 Basic welding current output modes

In straight polarity, the effect of cathodic etching of the electrode will be mild. In reverse polarity however, the effect of cathodic etching will be prominent resulting in a cleaning of the metal surface. At the same time, the advantages of d.c. s.p. arc in weld penetration, in narrow weld width and in good controllability are retained.

Generally, pulsation rate is adjustable between 1 and 100 cycles/sec. Current pulsation starts at the beginning of upslope time, increases in amplitude of the preset high and low values, continues to pulse during the weld current level and begins to decrease in amplitude at the start of current down slope, diminishing to final current level at the end of down slope time.

The greatest advantage in square wave a.c. welding is the fact that this welding current pulsation introduces vibration in the liquid puddle. A desirable rate of pulsation can be chosen to get consistently good X-ray quality welds with a desired weld penetration.

Fig. (16-C) represents a fast rate current pulsation or modulation in the frequency range 1000 to 20,000 C/S.

More complex pulsation controls like, dual pulsed control mode Fig. (16D & E) featuring simultaneous action of slow square wave and fast rate pulsation modes and dual pulsed mode without the fast rate at the low level have been developed to solve particular problems.

In production welding applications, slight variations in wall thickness, joint fit-up, slight mismatch during tack welding etc. cannot be fully eliminated. This will give rise to slight variations in melt through, weld appearance and penetration. To make sure that 100% penetration occurs in spite of the above variations, an adaptive system which compensates for the variables in the workpiece and process is desirable.

Detailed study of the GTA process variables has revealed that:—

(a) arc length has effect on melt through penetration ; smaller gap produces stable arc and deep penetration.
(b) welding speed is inversely proportional to arc penetration.
(c) welding head position controls the arc voltage.
(d) joint designs and shield gas have lot of bearing on quality.

A schematic diagram of an adaptive control system applied to GTA process is shown in Fig. (17). The control is set by first measuring the actual performance and then adjusting current pulse time so as to obtain the best available performance.

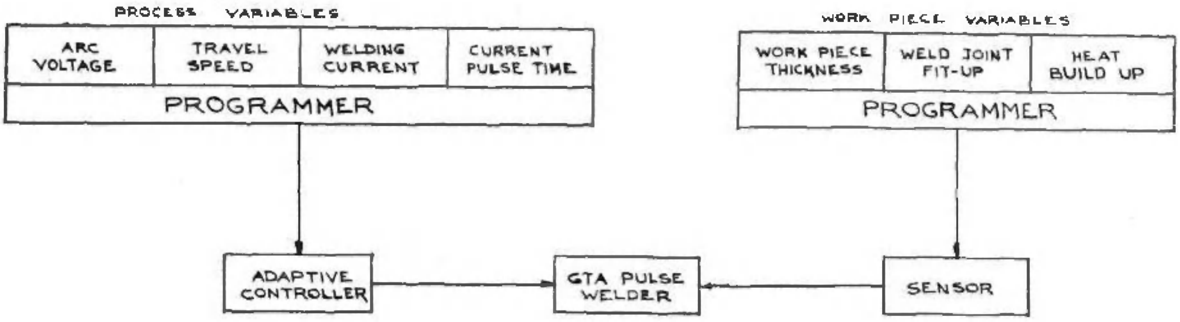


Fig. 17 Schematic of an adaptive control TIG system.

Present-day application of adaptive pulsed current control is essentially in the welding of hydraulic, pressurant and fuel lines in aerospace and aircraft industry. Considerable success has also been achieved in the field of heavy wall tube or pipe welding using adaptive controls.

Advantages of Pulsed Systems

Pulsed current automatic GTAW units possess several advantages over the constant current units :

(a) Increased arc stability particularly at low currents. Arc blow effects are eliminated.

(b) Smaller weld puddle size and much greater uniformity in melt through penetration.

(c) Fast current rate pulsation introduces weld puddle vibration and is useful for aluminium welding.

Table 1 – Welding Heat Input

	Gas metal-arc	Hot wire gas tungsten-arc	Cold wire gas tungsten-arc
Deposition rate, lb/hr	12	12	3
Arc current, amp	350	450	350
Arc power, w	5480	5850	4200
Hot wire power, w	...	1600	...
Total power, w	9480	7450	4200
[illegible] lb of deposited metal	790	620	1400

Conclusions

With the innovations discussed above, the GTAW process can tackle more exacting welding problems encountered in aerospace and commercial industries. While hot-wire TIG welding has already been put into commercial applications with astounding success, the magnetic arc TIG process is in the final stages of entering this area. The square wave a. c. pulsation technique in now being widely used for adaptive control systems for welding of high temperature and/or high pressure fuel lines in aircrafts. Research should now be directed toward combination of a hot wire TIG system with magnetic control. This may improve the productivity of the TIG process still further. With the combination of quality and productivity achieved by the above techniques, TIG process can be expected to reach new heights in serving the welding industry.

Bibliography

(i) Jennings, C. H., and White, A. G., "Magnetic Arc-blow", Welding Journal, 20 (10), Research Suppl., 427-S to 436-S (1041).

(ii) Jaya Rajan T. N. and Jackson C. E. "Magnetic control of Tungsten arc welding process", Welding Journal Vol. 51, No. 8 Research Suppl., 1972.

(iii) Hicken, G. K. and Jackson C. E. "the effect of applied magnetic field on welding arcs". Welding Journal, Vol. 45, No. 11. Research Suppl. 1966 pp 515 S to 525-S.

(iv) Franz-Josef Ganoski, "The magnetarc welding process" Welding and Metal Fabrication, Vol. 42, No. 6 pp 206 to 213.

(v) Perry, R. J. and Paley. Z, "Effects associated with arc-blow" Welding Journal, Vol. 49, No. 9, Research Suppl. 1970 pp. 389 to 394.

(vi) Saenger, J. F. and Manz A. F., "High deposition gas tungsten arc welding", Welding Journal 47 (5). pp. 386 to 393 (1968).

(vii) Wilson J. L., Claussen, G. D. and Jackson C. E. "Effect of I²R heating on electrode melting rate", ibid ; 35 (1), Research Suppl., 1-S to 9-S (1959).

(viii) Saenger J. F. "Gas tungsten-arc Hot wire Welding—A versatile new production tool" Welding Journal Vol. 49, No. 5, pp 363 to 371.

(ix) Vilkas, E.P., "Welding current pulsation methods", Welding Journal 47 (7), pp 649 to 560 (1963).

(x) Vilkas, E. P., "Pulsed current and its applications", Welding Journal 49 (4), 955 to 262 (1970).