DEVELOPMENT OF INVERTER WELDING POWER SOURCES

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INTRODUCTION

Inverter circuitry has been used for quite sometime in drive systems, battery chargers, aircraft industries, controls and recreation vehicles. With the advent of Solid State Electronics, the high power, reliable, cost effective switching devices were made available which also make the technology adoptable for welding power sources.

What is an Inverter?

An "inverter" welding power source changes the primary power line 415/220 Volt, 1 Ph or 3 Ph, 50/60 Hz into direct current (DC) power usable for welding. However, the inverter produces a unique set of advantages not attainable from conventional units. Fig. 1 shows a simplified diagram of the major components of both a conventional and inverter power source and the change in the electrical power by each component. In the conventional closed-loop-welding power source, primary power goes directly to a transformer which lowers the line voltage without changing the phase (Ph) or frequency (Hz). The next step is a rectifier assembly that changes the AC (alternating current) to DC (direct current). This goes through a filter and becomes the DC output. Sensing circuits monitor the output and compare the output to input control signals (power source settings). These circuits control the output by adjusting the output of the rectifier assembly.

In inverter the primary power goes immediately to a rectifier that changes the AC to DC. The DC then goes into the high power, very fast switching devices that convert the DC back to AC, but at a very high frequency (20 KHz). The high frequency AC then goes through a transformer to lower the voltage. The lower voltage high frequency AC goes to a second rectifier and is changed to DC. This goes through a filter and becomes the DC output. Sensing and control circuits monitor the unit output, compare the output to input commands, and cause the output to match the input by controlling the inverter.

In early' '80s, high power thyristors

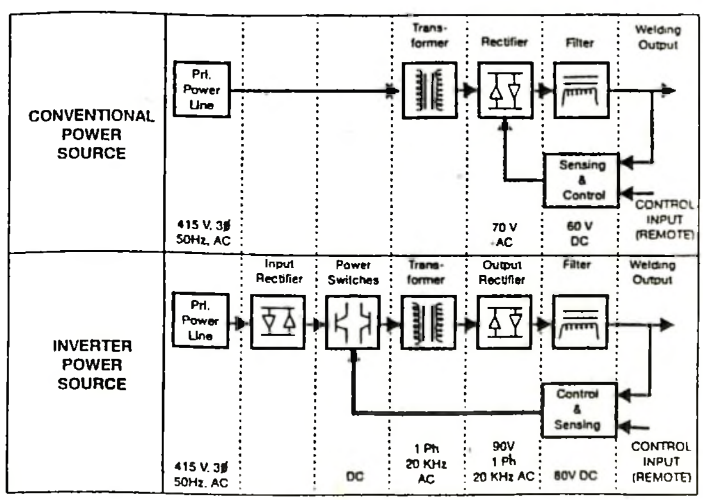
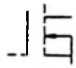
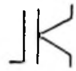


Fig.1: Comparison of components conventional and inverter power sources

POWER DEVICE	THYRISTOR	BJT	MOSFET	IGBT
CIRCUIT SYMBOL				
CURRENT CAPABILITY	400A B	600A B	100A C	600A B
VOLTAGE CAPABILITY	2500 V B	1200 V B	500 V C	1200 V B
SWITCHING SPEED	20 μS C	5 μS B	0.3 μS A	1 μS A
EASY DRIVE	FORCED COMULATION C	CURRENT DRIVE B	VOLTAGE DRIVE A	VOLTAGE DRIVE A

A : EXCELLENT B : GOOD C : FAIR

Fig.2: Characteristics of Power devices commonly used for manufacturing of inverter power sources

IGBT

In the case of welding power sources the high switching frequency is necessary so that, apart from the noise consideration, the volume of the passive components can be kept as low as possible. This can be done with new power semiconductor devices called IGBT modules, which are notable for both their switching performance and their high current-carrying capacity.

The concept IGBT represents further advancement of the power MOSFET with the goal of reducing the turn-on resistance. IGBT stands for Isolated Gate Bipolar Transistor

Fig.3

were employed in manufacturing the inverters, but with the improved availabilities of solid state switching devices such as BJT, MOSFET and IGBT, the switching speed increased with the adoptabilities for higher voltage & currents which are essential requirements for Welding Power Sources.

Having the optimal characteristics, use of IGBT as a switching device for inverter circuit has found a new dimension in manufacturing of Welding Power Sources. Fig. 3 & 4 illustrate the details of IGBT.

ADVANTAGES

Size and weight

In conventional power sources, the transformer operating at 50 Hz frequency is the largest, heaviest, most inefficient component. Transformer

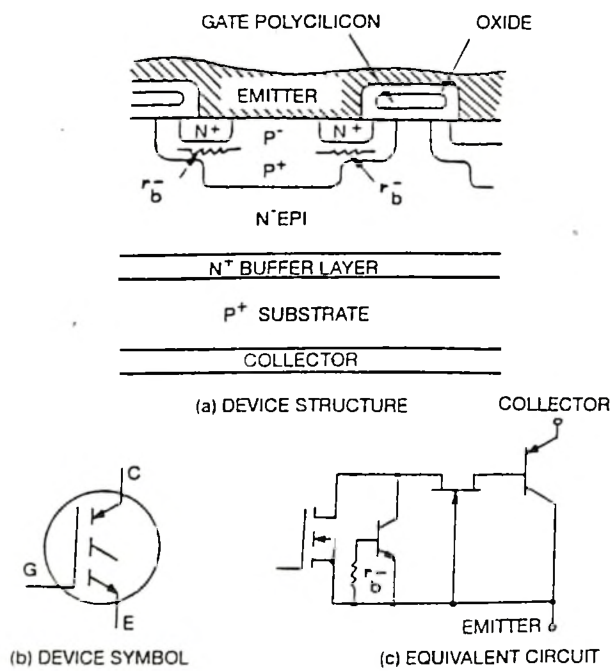


Fig.4: Silicon cross-section of an IGBT with its equivalent circuit and symbol (N-Channel, Enhancement mode). The terminal called Collector is, actually, the emitter of the PNP. In spite of its similarity to the cross-section of a power MOSFET, operation of the two transistors is fundamentally different, the IGBT being a minority carrier device.

size is inversely proportional to operating frequency - the higher the operating frequency, the smaller the transformer. In the inverter, the operating frequency has been changed to 20,000 Hz (from 50 Hz line) or over 400 times higher than the 50 Hz operating frequency of the conventional unit. This allows the inverter transformer (and consequently the total inverter power source) to be much smaller and lighter than the conventional unit. Fig. 5 shows a transformer for a 450 amp 100% duty cycle conventional unit and a transformer for a 500 amp 60% duty cycle inverter unit. The smaller size and lower weight of inverters gives them greater portability - and they use less floor space.

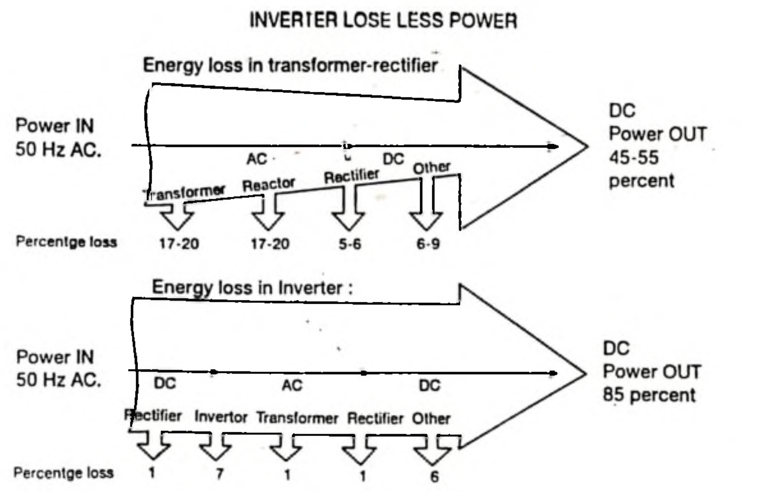


Fig.5

Energy Efficiency

Inverters are more energy efficient than conventional power sources. Fig. 5 shows the energy loss in inverter vis-a-vis conventional rectifier. Much of the reason is related to the difference in transformers. Table 1 shows the input KVA, and efficiency for conventional power sources and an inverter at the same welding output. From 200 amps to 500 amps inverters are much more efficient.

Input KVA determines the amount of primary line current required. The higher the primary line current, the larger size of the line or, for a given line size, the smaller the number of units that can be attached to the line. Here the inverter has a significant

Fig.6 : A multisystem inverter power package

TABLE 1 : ELECTRICAL EFFICIENCY : CONVENTIONAL V/S INVERTER POWER SOURCES

SR NO.	OUTPUT WELDING CURRENT (AMPS)	OUTPUT REQUIRED (KW)	INPUT KVA REQUIRED		EFFICIENCY %		NO LOAD LOSS (WATTS)	
			CONV	INV	CONV	INV	CONV	INV
A	200 A	5.6 KW	15.59	<8.40	75.7%	85%	>200W	<10W
B	300 A	9.6 KW	20.98	<9.90	80.00%	88%	>200W	<10W
C	400 A	14.4 KW	26.00	<14.60	81.4%	88.9%	>200W	<10W
D	500 A	20.00 KW	30.80	<20.20	82.3%	89.3%	>250 W	<10W

TABLE 2 : COMPARISON OF ELECTRICAL POWER REQUIREMENT BETWEEN IGBT INVERTER AND MOTOR GENERATORS

SR. NO.	ELECTRODE DIA IN MM	POWER CONSUMPTION UNITS/HRS.		% SAVING IN POWER CONSUMPTION
		MOTOR GENERATOR SET	IGBT INVERTERS	
1	2.5 MM	6.5	2.5	62%
2.	3.15 MM	8.5	3	65%
3.	4.00 MM	10.5	4	62%
4.	AT NO-LOAD	4.0	NOT MEASURABLE BUT APPROX. 10 WATTS	

TABLE 3 : FUTURE TREND OF INVERTER TECHNOLOGY

SUBJECT \ ITEM	STAGE	CONVENTIONAL TECHNOLOGY	FUTURE TREND
HIGH POWER FACTOR	INPUT	CONDENSER INPUT SMOOTHING	SWITCHING MODE RECTIFIER
LOW EMI	INVERTER	HARD SWITCHING PWM CONVERTER	● SOFT SWITCHING PWM CONVERTER ● RESONANT CONVERTER
	RECTIFIER	FAST RECOVERY DIODE	SOFT RECOVERY DIODE
HIGH SPEED CONTROL SMALLER SIZE	INVERTER	● THYRISTOR ● BJT ● MOSFET	● MOS GATE THYRISTOR ● IGBT

advantage. At 200 amps output the inverter uses approximately one-half the input KVA. This will allow for more units to be placed on an already installed primary line or will allow the use of smaller lines in a new installation.

Use of inverters will decrease the welding energy cost. Table 2 illustrates the electrical power requirement between Inverter and Motor-Generator.

Performance

The major advantage of inverters is a significant increase in arc performance, stability, and control. Note in Fig. 1 that the sensing and control feed back is to the rectifier assembly operating at 50 cycles per second on 3 Ph power for the conventional unit, and to the power switches operating at 20,000 cycles per second for the inverter unit. The control circuitry switches are operating at 20,000 cycles per second for the inverter unit. The control circuitry can change the conventional unit output approximately 360 times per second and the inverter unit 20,000 times per second. The larger transformer of the conventional unit has more built-in inductance (resistance to change) than the smaller inverter transformer. These two conditions allow the inverter power source to give enhanced performance.

Multiprocess Capabilities

Power sources of conventional design that could be used for several processes are not usually available. Generally, they were acceptable for each process in a given range but they could not give full range performance for each process. Something had to be compromised for one process to obtain acceptable results for another process. Multiple output connections and special switches settings were required with higher operator understanding. With inverter design, multiple processes are built into a single unit with maximum performance characteristics and full range for each process without compromising any process. A simple switch allows process selection and the same output control sets the output for MMAW, GTAW and GMAW-P. The modular concept enables the users to update the simple inverter, suitable for Pulse Tig or Pulse Mig and synergic Mig Welding Process including air arc gauging as and when required, by addition of function panels for each module. Fig. 6 shows an inverter power source with Pulse Mig wirefeeder and pulse Tig high frequency unit with water circulating unit.

Stick Electrode Welding with Inverter

The very fast response of an inverter with MMAW allows benefits to be incorporated that are of definite advantage to operators. These include built-in hot start and arc force control. The hot start is a very short time high pulse of current when the electrode touches the work. This gives easier starts and restarts. The time involved is so short that it is not noticed by the operator and has no noticeable effect on the work.

Inverter improves the "arc force" feature that is available. Using "arc force", the operator can adjust the arc from "soft with minimal penetration" to "forcible and digging". Fig. 7 shows how the volt-amp curve for MMAW is modified by the arc force control. When the arc force is used, the current from the power source increases as the drop size on the end of the electrode increases. The current is maximum when the droplet is detached. The electomagnetic force causes the drop to travel at a high velocity making the arc very directional and penetrating. This is very helpful for root passes on heavy wall pipe/plate to prevent arcing to the side of the joint.

Tig Welding with Inverter

Along with their much smaller size, inverters used with GTAW give very good low end stability, "lift" start capability, more precise current (heat) control, very stable arc with changes in tungsten-to-work distance, high current pulse rate capability.

Fig. 8 shows the volt-amp relationship for GTAW. At very low currents there is a rapid rise in voltage for a small change in current as compared to higher current settings. The fast response of the inverter allows the contol circuit to operate in this range. It is possible to obtain a hand-held

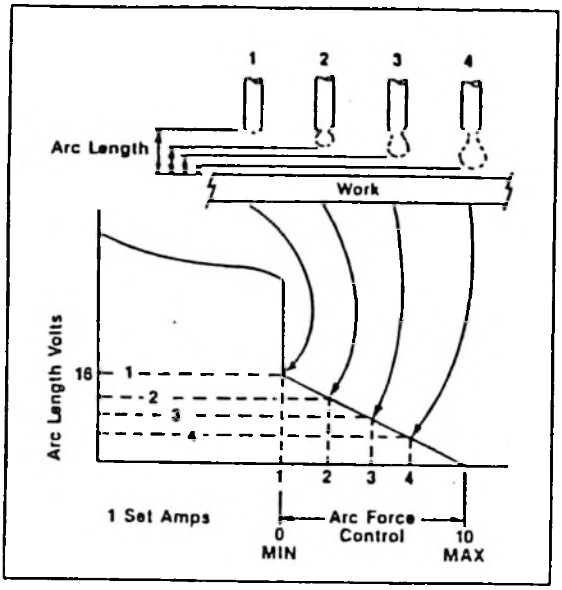


Fig.7 : Arc force control for MMAW

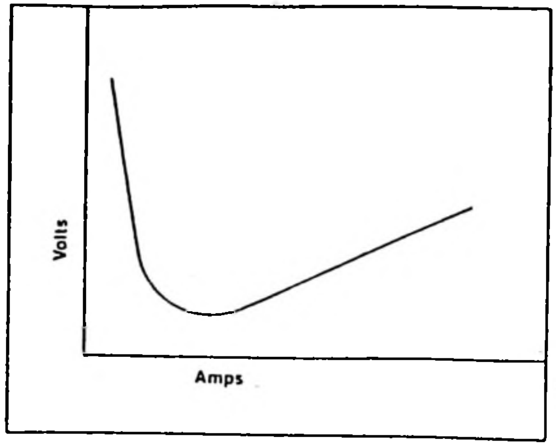


Fig.8 : GTAW volt/ampere characteristics

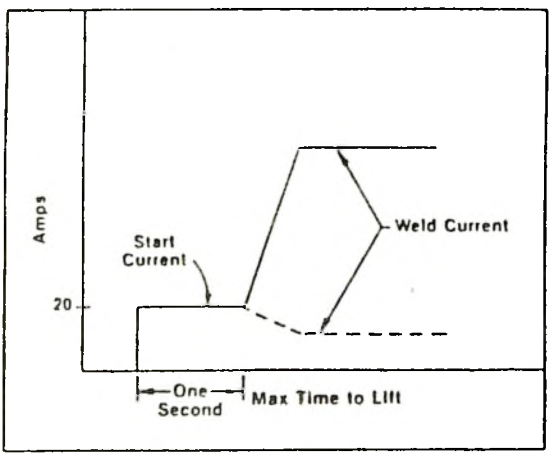


Fig.9 : GTAW "lift start"

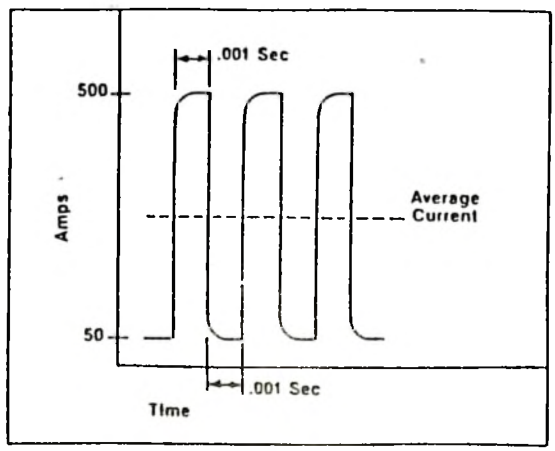


Fig.10 : High pulse rate GTAW wave form

stable arc at approximately one (1) amp. Note : PAW has similar volt-amp characteristics. Inverters with good GTAW characteristics will have good PAW characteristics.

"Lift" start is the ability to start the arc by touching the tungsten to the work and lifting it up. "Lift" start is different from "scratch" start in that (1) the tungsten is touched at one point instead of wiped (scratched) over the work, (2) the current at the start is controlled by the inverter power source and not by the operator, and (3) tungsten will not "spit" across the arc and cause contamination. Fig. 9 shows the amps-time relationship for "lift" start. When the tungsten is toucned to the work (point T), the inverter immediately goes to an internally set start current. The operator has one second to lift the tungsten which establishes the arc. The inverter then goes to weld current as set by a controller or the operator. Since the arc is always started at the start current level, there is no "spitting" of tungsten. If the operator does not lift the tungsten in one second, the inverter shuts itself off and the operator must repeat the cycle. Other major advantages are : complete elimination of high frequency, and ability to start the arc precisely where desired.

For precise welding, inverters can control output changes of less than one amp. Normal arc length changes do not affect inverter output. Both of these features are helpful for thin sections and hard-to-weld materials.

GTAW-Pulse at low pulse rates (less than 30 pulses per second) for operator puddle control have been used for some time. The fast response time of inverters now allows pulse rates of 500 pulses per second with current changes of several hundred amps. Fig. 10 is a schematic which shows change of GTAW current with time. Control of "over shoot" (at high pulse) and "under shoot" (at low pulse) is important. Inverters with proper controls give this wave form. High pulse rates have not shown significant benefits for manual GTAW. However, for automatic welding, speed increases of 25%, improved penetration control, and high quality welds have been observed.

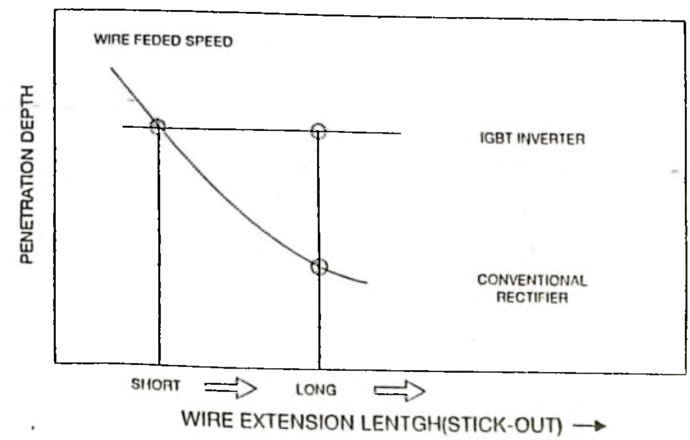


Fig.11 : Effect of IGBT inverter power source on GMA Welding (Depth of penetration)

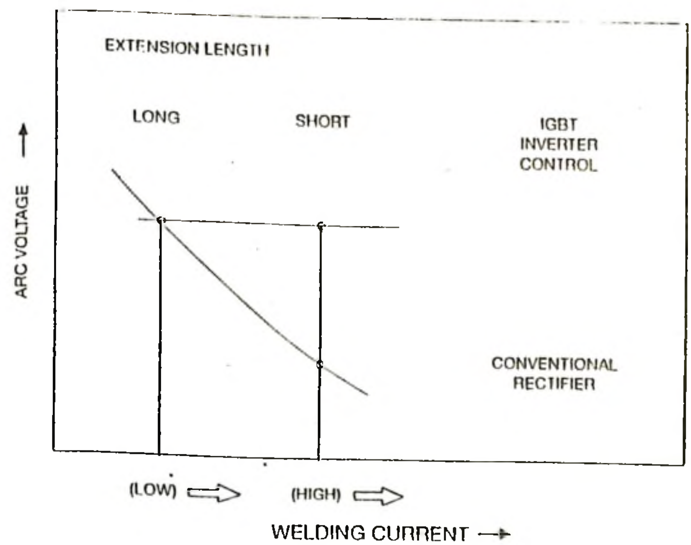


Fig.12 : Effect of IGBT inverter GMA Welding (Arc Suitability)

MIG/MAG Welding with Inverter

The acceptability of short circuit transfer, with its potential for cold lap and undercutting and the amount of spatter, has been debated. Many procedures do not permit short circuit transfer. The process requires a constant voltage (CV) power source. With conventinal power sources design, the rate of rise and fall of the current during the short circuit, and while the arc is extinguishing and the peak amperage is obtained, this is a function of the transformer design and inductance. The fast response of an inverter allows for more control over inductance (rate of rise and fall of current) and the maximum short circuit current. An "inductance" control allows the operator to adjust from a soft, wetting arc to a more penetrating stiffer arc. With an inverter, arc characteristics of GMAW can be designed into the power source and adjusted by the operator. This overcomes many of the perceived disadvantages of short circuit transfer. Fig. 11 & 12 illustrate the stability of the arc and penetration using inverter power sources. Fig. 13 shows the comparison in spatter generation rate using various types of welding power sources.

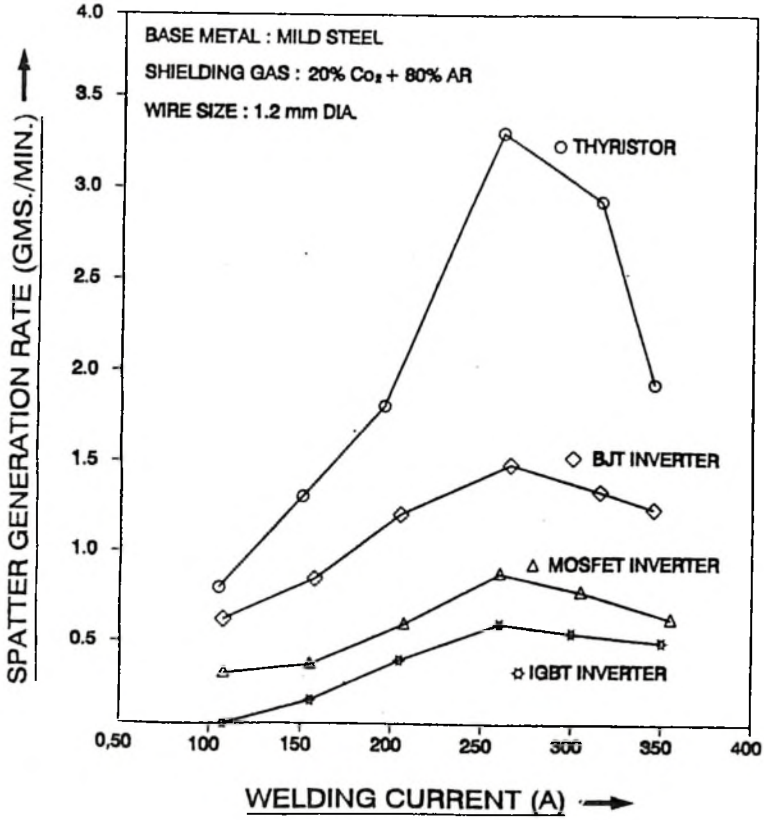


Fig.13 : Comparison in spatter generation rate of various types of welding power sources in GMA welding

Pulse/Mig Welding with Inverter

The development of inverter power sources is one of the main reasons that GMAW-P use continues to grow. The GMAW-P process requires that (1) the power sources pulse up to a current (Ip) in the spray transfer range for the wire being used, (2) remain at this curent for a set time (Tp) to allow the drop to detach from the wire in spray transfer, (3) pulse down to a background level (Iback) sufficient to maintain the arc but not transfer metal, (4) remain at the background (Tback) until the next drop is required, and (5) repeat the process. The average current (Iavg) is the time weighted average of peak and background which can be well within the short curcuiting current range. Fig. 14 shows a schematic representation of the process. Note that the power source can be in the constant current (CC) mode at peak and constant voltage (CV) mode in background. The power source provides the arc energy while the wire

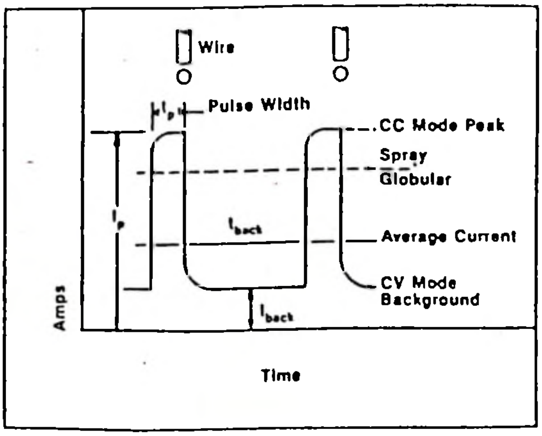


Fig.14 : GMAW - Pulse basic parameters

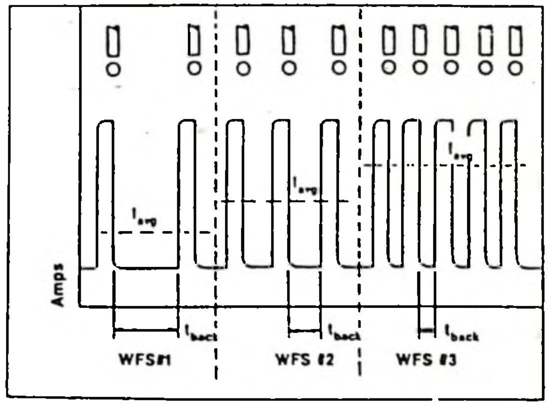


Fig.15 : Wire feed speed and back relationship

feeder supplies the wire. The energy from the power source must be balanced with the wire feed rate. Fig. 15 illustrates how the pulse frequency and average current (Iavg) are changed as wire feed speed is changed. Inverter power sources allow the type of control required for effective GMAW-P welding.

Interfacing Inverter with Automated Controls

The fast response characteristics of inverters enhance all automated controls from the very simple through powerful computers and robots. Welding inverters require analog input signals to control output. An "arc established" signal is generated by the power source and sent to the automated control panel. This signal is used to start torch/work motion or energize other controls and changed without breaking the arc.

To take advantage of the inverter, automated controls should have as a minimum :

1. Digital control of output-amps or volts-in one amp increments or one-tenth (0.1) volt increments.
2. Timing functions in real time with at least one-tenth (0.1) second increments.

The following functions are normally built in the Inverter Power Source enabling the usage with automatic controls.

1. Digital control and feed back wire feed rate.
2. Ability to receive or generate arc established signal and to transmit this signal to other controls.
3. Use of multiple wirefeeders with one power source for enhanced utility.
4. Safety shut-down if arc established signal is not received (or generated) within a prescribed time.
5. Safety ground fault sensing circuit with error signal.
6. Safety shut-down if arc goes out with error display. Many other features are available with IGBT inverters for automatic application.

Introduction of Inverters into the Shopfloor

Inverters are "different" from conventional power sources in appearance, sound, and performance. If these differences are not explained and understood, human nature may perceive them as "bad". The following four-step programme can be taken before the introduction which will help to insure success.

Step. 1 Co- ordination with shop floor management : Every new product put on the shop floor must (1) solve a problem that cannot be solved with present product, or (2) reduce costs through greater productivity and/or improved efficiency. The benefits to be achieved upon by shop management.

Step. 2 Weld testing and procedure qualification: Generally the machine settings to obtain the desired goals with an inverter will not be the same as with a conventional power source. New settings and new travel speeds must be tested to comply with requirements for weld quality. Determine a proposed range of settings that give quality welds, meet code requirements, and accomplish the desired goals. Do not just give the machine to the operator and expect him to find the correct settings.

Step. 3 Operator training : First, communicate to the operator why an inverter is being tested. Describe the desired goals. Make the operator a partner in the project. An inverter presents four very new different things to the operator that should be explained before actual welding. The small size can pose a question. "How can this smaller unit give as much power as this big one?". The arc and the machine will have a different sound. The "arc sound" is used as gauge of acceptability. The GMAW-P (pulse) process has a very different sound compared to short circuit. Each control knob should be explained as to function and if it applies to the application. If an operator is not instructed about each control, he will attempt to find out for himself. Since most inverters are multiprocess, operators should know which are to be used, which are not to be used, and why.

Step. 4 Training of maintenance personnel : Inverters should not be described as "a box of circuit boards". Many are designed to protect themselves from primary line spikes, dead shorting, and overheating conditions by turning the unit off before damage can occur. Inverters usually "work" or "don't work". There is nothing in-between. The tendency is to blame the inverter for everything that is not right. Usually, common problems such as poor wire feeding, contaminated tungsten, poor feed rolls, poor electrical connections, etc. will be the real problems. A good house-keeping can sort out all these minor problems.

Inverters generally conform to IP-23 specifications and CE & S marked. Hence these equipment are suitable for outdoor as well as shop floor usage, because of its compact size and light weight.

CONCLUSION

Inverter based welding power source has come to stay in the welding industry throughout the world, due to its higher efficiency, negligible no-load losses and lower power consumption. By using inverter power source, the cost of welding can be easily brought down with significant improvement in Weld Quality.

Table - 3 shows the future trend of welding equipment.

It is a matter of pride that Indian fabrication industries have already started using inverter power sources to uplift the ultimate welding quality with reduced input cost.

ACKNOWLEDGEMENT

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