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TITLE

PULSED GMAW PARAMETERS IN HY WELDMENTS

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Pulsed GMAW Parameters in HY Weldments

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ABSTRACT

The Parameters in Synergic Pulsed GMAW welding are a direct result of the logic programmed into each specific welding machine and are dependent on the shielding gas, weld wire composition and wire size. In many systems, the pulsing parameters cannot be varied from manufacturer's pre-programmed settings.

This project evaluated the electrical output characteristics of the following three welding systems to determine the pulsing parameters of each of the power sources;

1) Fronius T.I.M.E. 450 Synergic
2) Fronius T.I.M.E. 540 coupled with a TR-19 synergic pulsing unit, and
3) Linde 650

These machines had been utilized to produce weldments for evaluation on previous DREA projects. Lincoln LA 100 welding wire and T.I.M.E. gas were used on each machine but C-5 gas was also evaluated on the T.I.M.E. 540. Pulsing parameters were determined at wire feed speeds ranging from 100 to 500 IPM, various synergic settings, and for welding procedures conducted in previous projects.

Pulsed gas metal arc welding is the superior process for all positional welding of HY steels, however, it is essential that pulsing parameters be recorded during welding procedures qualification in order to establish calibration criteria for production welds.

1.0 INTRODUCTION

Synergic Pulsed GMAW shows promise as the welding process of choice for joining HY steels. However, pulsing parameters are pre-programmed into the equipment and therefore not only varies from manufacturer to manufacturer, but are also dependent on the shielding gas, weld wire composition and wire size. In order to fully characterise a welding procedure, it is essential to understand the synergic logic programmed into each machine. Therefore, the purpose of this project was to evaluate Welding Procedures from selected previous DREA projects to determine the pulsing parameters of each welding machine.

2.0 SCOPE OF THE PROJECT

This project involved the evaluation of the following three welding machines;

a) T.I.M.E. 450 Synergic,
b) T.I.M.E. 540, and
c) LINDE 650.

The latter two machines had been used on previous DREA projects and weldments from optimised procedures were evaluated. T.I.M.E. gas was used as the shielding medium for all three machines but a 95 % Ar, 5 % CO_2 (C-5) gas mixture was also reviewed using the T.I.M.E. 540 system.

3.0 BACKGROUND

3.1 Pulse Welding with T.I.M.E.™ Process

The Transferred Ionized Molten Energy (T.I.M.E.) Process is a modification of the gas metal arc welding (GMAW) technique consisting of a four component shielding gas and new types of welding equipment. The Patented T.I.M.E. gas is a mixture of argon, helium, carbon dioxide and oxygen. The gas creates a unique arc plasma that provides stability at wire feed speeds up to 2000 IPM with 0.045" diameter wire. This compares to less than 800 IPM for conventional GMAW welding processes. The result is a process capable of depositing weld metal with high quality (i.e. higher toughness, no spatter, no undercut) at a very high deposition rate and welding speed (up to 8 times faster than SMAW).

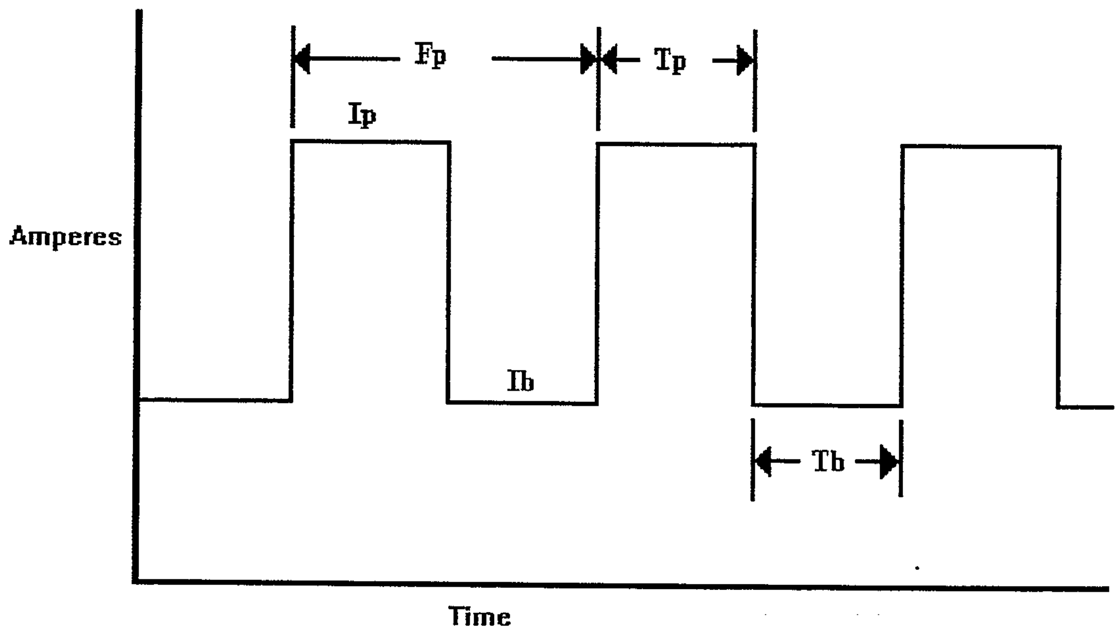
The pulsed gas metal arc welding(P-GMAW) process is a technique developed over 15 years ago to bridge the gap between short circuit and spray mass transfer of weld metal. In this process a pulsating current is superimposed over the steady DC-GMAW causing brief inputs of energy. These current pulses produce a controlled droplet transfer which corresponds to the rhythm of the pulse frequency. The background current ensures that the tip of the electrode and the welding pool are kept molten. With each rise in current, a droplet is transferred to the workpiece due to the "pinch effect". In sophisticated pulsing systems, the size of the droplet can be controlled and adjustable to provide one droplet per pulse.

The background current is adjustable to suit the weld wire material and shielding gas composition. Since the critical level of current necessary to shed the droplets is a function of pulse current, the amount of heat produced is relatively low compared with conventional methods.

There are two features of P-GMAW that are of interest in welding HY80/HY100 steels. First, the critical level of current needed to achieve spray transfer is low enough to allow deposition rates in excess of that which can be easily controlled in normal GMAW for making out-of-position welds hence providing operation economy. Second, it has also been found that pulsing can actually enhance the quality and toughness of the deposited weld metal while maintaining acceptable levels of other mechanical properties.

Pulse welding introduces a number of new variables in addition to the those normally controlled in the T.I.M.E.™ Process (i.e. WFS, tip recess, voltage, travel speed). These are shown in Figure 3.1.

Figure 3.1 Pulse Parameters



I_p	-	pulse current
T_p	-	pulse duration
I_b	-	background current
T_b	-	background current duration
F_p	-	pulse frequency

4.0 EXPERIMENTAL PROCEDURE

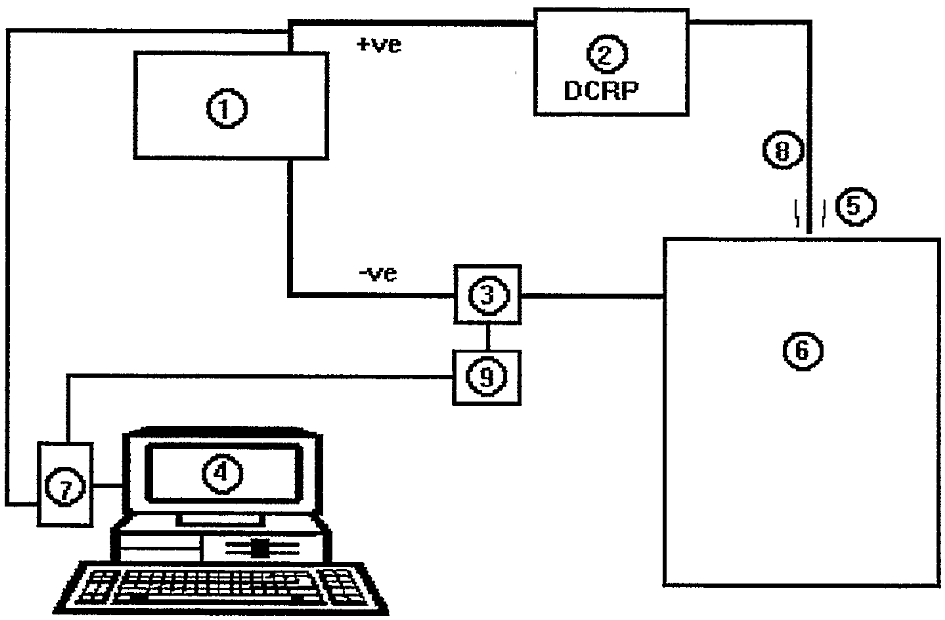
4.1 Consumable Wires and Shielding Gases for the Program

Lincoln LA 100 weld wire (classed by AWS as ER100S-1) was used for all welding. The weld wire was 1.2 mm in diameter. The chemical analysis is given in Table 4-1. T.I.M.E gas was used on all machines. However, 95 %Ar, 5 % CO_2 (C-5) mixture was evaluated on the T.I.M.E. 540 system.

4.2 Arc Voltage and Current Measurements

All arc voltages were measured between the base metal and wire feeder. Welding currents were measured using a LEM shunt Model LT-500-S modified for Fronius welding machines. A low pass 5 kHz filter was used for some readings. A data acquisition card coupled with a 386 computer was used to collect readings and were transformed into data points for statistical and graphical evaluation (See Figure 4.1)

Figure 4.1 Equipment Set-up



1)	**Power Source**	**6)**	**Base Metal**
2)	**Wire feeder Unit**	**7)**	**Data Acquisition card**
3)	**LEM Shunt**	**8)**	**Filler Metal**
4)	**PC**	**9)**	**5 kHz low pass filter (optional)**
5)	**Welding Torch**		

5.0 EXPERIMENTAL RESULTS

There were several tests that were carried out on three different welding machines. Table 5.1 gives the explanation for each experiment.

The first series of experiments was conducted with the T.I.M.E. 450 Synergic welding machine. Although no welding procedure qualification tests had been conducted with this machine in previous D.R.E.A. studies, a series of experiments were conducted to give a comparison of the synergic settings on this machine as compared with the T.I.M.E. 540. The T.I.M.E. 450 Synergic is the latest T.I.M.E. technology available from Fronius and the machine is based upon a much different inverter technology than its predecessor. Therefore the experiments that were conducted with this machine included a series that evaluated changes in the fine tuning controls (Weld 450A), synergic settings varied by the power control alone changing the wire feed speed from 50 to 500 IPM (Weld 450 B), and two welding schedules that were prepared and practised as part of a T.I.M.E. training program held in 1994 (Welds 450 C and 450 D.

The T.I.M.E. 540 system coupled with the TR-19 synergic controller has been used in its present and modified form in various projects sponsored by D.R.E.A. A series of experiments were developed to evaluate many of the welding procedure parameters developed in those earlier projects (Welds 540 B, 540C, 540D and 540E). Also, in order to evaluate the pulsing characteristics of the machine, a series of experiments were conducted which allowed direct comparison with the T.I.M.E. 450 series. These experiments consisted of varying the synergic settings to achieve WFS's from 50 to 500 IPM (Weld 540A), evaluating changes in the fine tuning controls (Weld 540F). Additional experiments were conducted to evaluate the effect of using a 5 kHz low pass filter in the circuit. These results are given in Weld 540G(no filter) and can be compared to Weld 540A(using a 5 kHz filter).

A final series of experiments were conducted to compare another mixed gas, C-5 (95 % Ar - 5% CO_2) with T.I.M.E. gas, which was used for all other experiments. This experiment used the Ar-CO_2 synergic program provided with the TR-19 controller (Weld 540H) and varied the power control to achieve WFS's of 50 to 500 IPM. This series can be directly compared with the results from Weld 540A

The last series of experiments employed the Linde 650 welding machine and is not designed to allow pulsed synergic output. This series consisted of adjusting the voltage to achieve a stable arc for WFS's from 50 to 500 IPM.

Table 5.1 Description of Experiments

1) T.I.M.E. 450 Synergic

I)	Series 450 A:	WFS constant, change Pv, WF
ii)	Series 450B:	Synergic Settings, WFS 50 - 500 IPM
iii)	Series 450C:	Weld Program #3 (overhead welding)
iv)	Series 450D:	Weld Program #3 (vertical welding)

2) T.I.M.E. 540 c/w TR-19 Synergic Controller

I)	Series 540A:	Synergic Settings, WFS 50 - 500 IPM
ii)	Series 540B:	Flat Procedure from CR/93/436
iii)	Series 540C:	Vertical Procedure from CR/93/436
iv)	Series 540D:	Overhead Procedure from CR/93/436
v)	Series 540E:	L.O.F. Settings from CR/94/436
vi)	Series 540F:	WFS constant, change Pv, WF
vii)	Series 540G:	Synergic Settings but without low pass filter
viii)	Series 540H:	Synergic Settings but with C-5 gas

3) LINDE 650 c/w DigiMig Wire Feeder

I)	Series 650A:	WFS 50 - 500 IPM
ii)	Series 650A:	Horizontal Welding procedure

The following results compare the pulse characteristic of all four major machine set-ups at a wire feed speed of 450 IPM.

Synergic Settings to achieve 450 IPM

	T.I.M.E. 450 *450B*	**T.I.M.E. 540** *540A*	**T.I.M.E. 540 (C-5)** *540H*	**Linde 650** *650A*
I_{avg}	316 amps	300.6 amps	238.5 amps	370.0 amps
V_{avg}	27.5 volts	29.1 volts	24.2 volts	29.9 volts
I_p	543.6 amps	502.5 amps	528.3 amps	421.0 amps
I_b	148.1 amps	91.2 amps	30.2 amps	334.0 amps
T_p	2.84 ms	3.32 ms	4.48 ms	2.08 ms
F_p	227.3 Hz	223 Hz	115.7 Hz	320.5 Hz

6.0 DISCUSSION

Synergic pulsed gas metal arc welding incorporates a number of pulsing features which can be characterised by the electrical characteristics of the machine output. In the synergic relationship, the correct combination of each of the variables is pre-programmed into an EPROM (erasable, programmable, read only memory) and is accessed by changes in the position of the main Power Control on the controller. Different relationships are therefore required for different welding consumable and shielding gas. Also, each manufacturer of equipment may have different views on how the synergic relationship should be constructed in order to maintain a stable arc. In fact this synergic logic was found to be different between the T.I.M.E. 450 Synergic and the T.I.M.E. 540 machines even though each machine is manufactured by Fronius of Austria.

Generally each machine follows the same basic rules when applying the synergic logic. As the wire feed speed is increased in each machine by varying the Power Control, the I_b, T_p and F_p increase accordingly to maintain a stable arc. However, the I_p appears to remain constant throughout the range of wire feed speeds examined.

In comparing the four major combinations of this project, namely Experimental Welds 450B, 540A, 540H, and 650A, in which the synergic relationship at a wire feed speed of 450 IPM was examined (see Figures 6.1 - 6.4), the changes in the pulse characteristics of each machine can be seen graphically. The T.I.M.E. 450 appears to have excellent control over the pulsing parameters and is able to maintain arc stability in a superior manner to the T.I.M.E. 540. The 450 system employs a different synergic relationship and although I_p is common to the 540 system, T_p is smaller while the I_b increases to maintain the same average current for a given wire feed speed. F_p remains the same.

In comparing the T.I.M.E 540 system equipped with T.I.M.E. gas versus C-5 gas, the synergic relationship is entirely different with respect to all pulsing parameters except I_p. It would appear that the synergic logic in both Fronius machines is to keep pulse height at the maximum output of the machine thus varying the other pulse parameters as much as possible on lower settings while approaching a constant voltage/constant current relationship as the wire feed speed continues to increase to a point where the arc current must be over 500 amps to melt the wire in a stable arc condition.

Arc stability is an important feature that dictates weldment quality and was found to be different between the 450 and 540 systems. Figures 6.5 - 6.8 show the pulse output characteristics over a range of 4000 sample points versus 1500 points used in Figures 6.1 - 6.4. It was found that the 450 system is again superior in maintaining arc stability over time, and this contrast is more prominent in Figure 6.9, the setting used in a previous project for Flat welding. The figure shows that over a time period representing 4000 sample points, the arc goes through zones of arc instability. Extrapolated over 12000 sample points this instability exhibits a cyclic nature but at a much lower frequency to the synergic pulse relationship. During actual welding operations, the welding operator noted changes in arc length (i.e. arc voltage) which is verified by Figure 6.9. The 450 system did not display this arc instability problem and during actual welding operations was noted to have a much more consistent and stable arc than the 540 system.

The Linde 650 machine also exhibits superior arc stability to the 540 system as shown in Figure 6.8. The arc characteristics detected during welding operations with this machine show a smooth, stable arc.

The synergic settings on the 540 system for C-5 gas did not produce a stable arc and made it difficult interpret the experimental results. This arc instability is readily apparent in Figures 6.3 and 6.7. Although the current pulse appears to constant, the corresponding arc voltage is not able to maintain a stable arc and therefore results in an erratic voltage trace.

Another interesting feature that was observed while using the C-5 gas involved the brightness of the arc of the C-5 compared to the T.I.M.E. gas. The stable arc region in gas metal arc welding is very dependent upon the shielding gas mixture. Generally, each shielding gas maintains a stable arc at different arc voltages but due to the presence of helium in the T.I.M.E. gas, the arc voltage and hence arc energy increases. Comparing the experimental results from Figure 6.6 and 6.7, taken from the 540 system, one can see that in order to maintain a stable arc for T.I.M.E. gas (Fig. 6.6), an arc voltage of 29.1 volts is required. However, for the C-5 gas mixture, an arc voltage of only 24.2 volts was required. The difference in arc voltage and hence arc energy results in the T.I.M.E. gas displaying a much greater amount of light emanated from the arc. This problem is easily rectified by changing to a darker lens shade in the welding helmet. No change in the protective clothing was deemed to be necessary.

FIGURE 6.1 T.I.M.E. 450, SYNERGIC SETTING AT 450 IPM, T.I.M.E. GAS

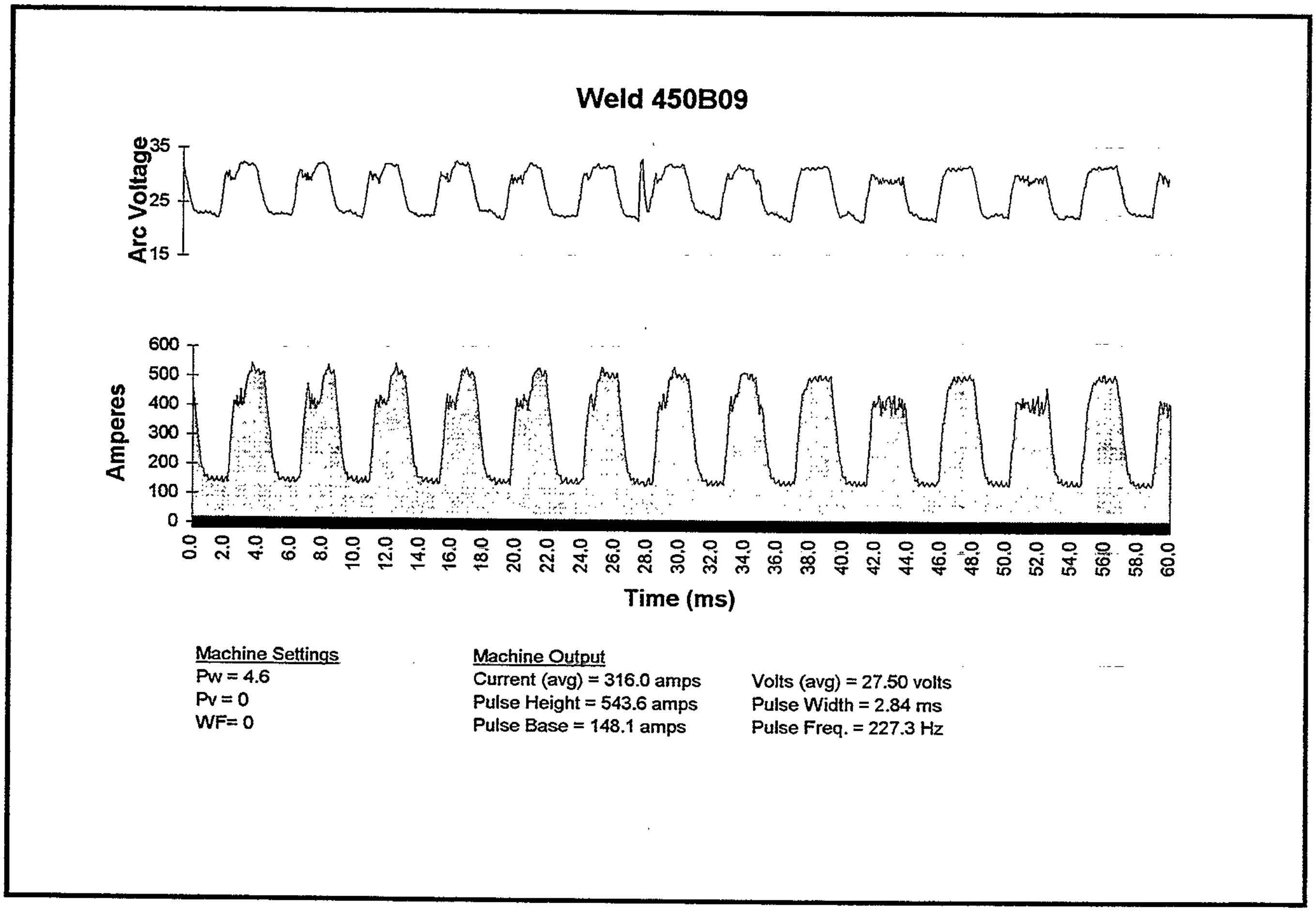
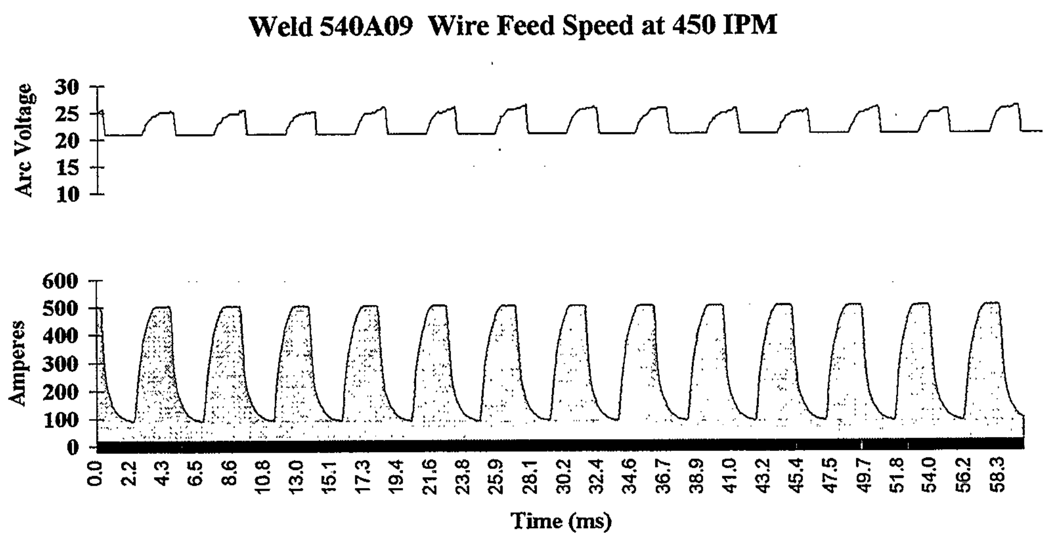


FIGURE 6.2 T.I.M.E. 540, SYNERGIC SETTING AT 450 IPM, T.I.M.E. GAS

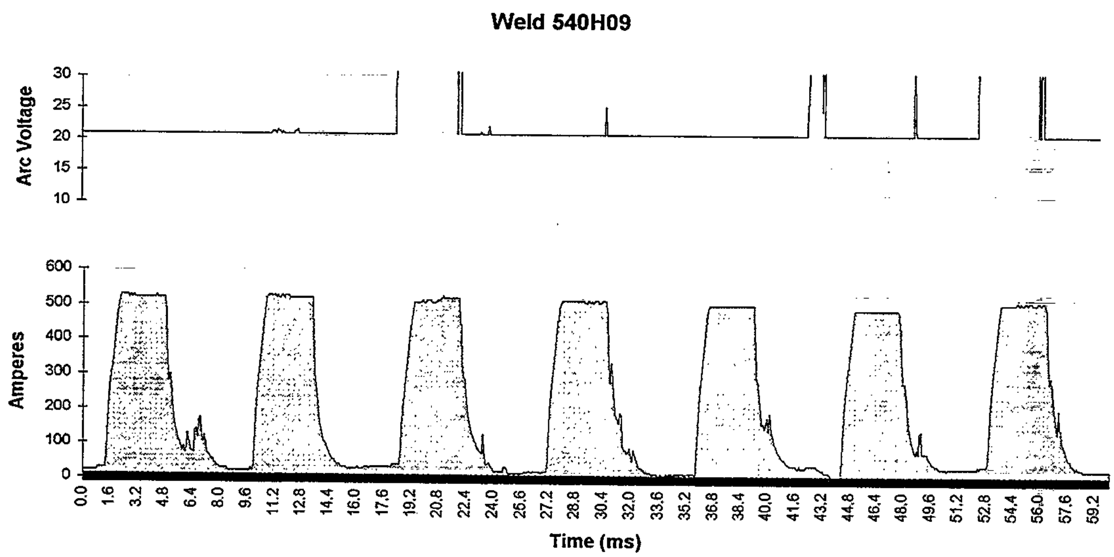


Machine Settings
Pw = 5.75
Pv = 0
WF = 0

Machine Output
Current (avg) = 300.6 amps
Pulse Height = 502.5 amps
Pulse Base = 91.2 amps

Volts (avg) = 29.1 volts
Pulse Width = 3.32 ms
Pulse Freq. = 223.0 Hz

FIGURE 6.3 T.I.M.E. 540, SYNERGIC SETTING AT 450 IPM, C-5 GAS

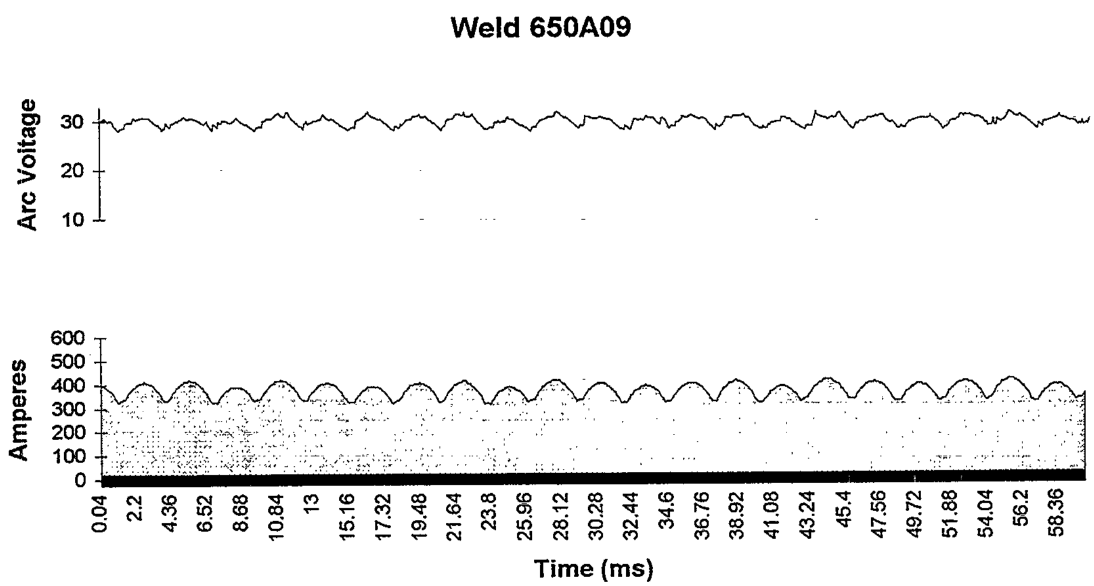


Machine Settings
Pw = +4.5
Pv = 0.0
WF= 0.0

Machine Output
Current (avg) = 238.3 amps
Pulse Height = 528.3 amps
Pulse Base = 30.2 amps

Volts (avg) = 24.2 volts
Pulse Width = 4.48 ms
Pulse Freq. = 115.7 Hz

FIGURE 6.4 LINDE 650, WIRE FEED SETTING AT 450 IPM, T.I.M.E. GAS

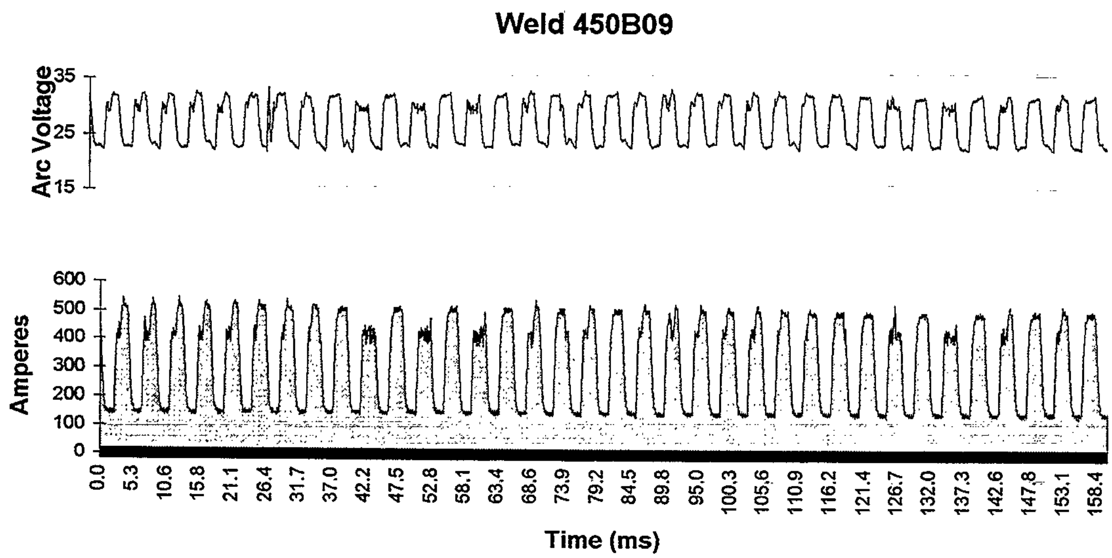


Machine Settings
Pw = N / A
Pv = N /A
WF= N / A

Machine Output
Current (avg) = 370.0 amps
Pulse Height = 421.0 amps
Pulse Base = 334.0 amps

Volts (avg) = 29.9 volts
Pulse Width = 2.08 ms
Pulse Freq. = 320.5 Hz

FIGURE 6.5 T.I.M.E. 450, SYNERGIC SETTING AT 450 IPM (4000 DATA POINTS), T.I.ME. GAS

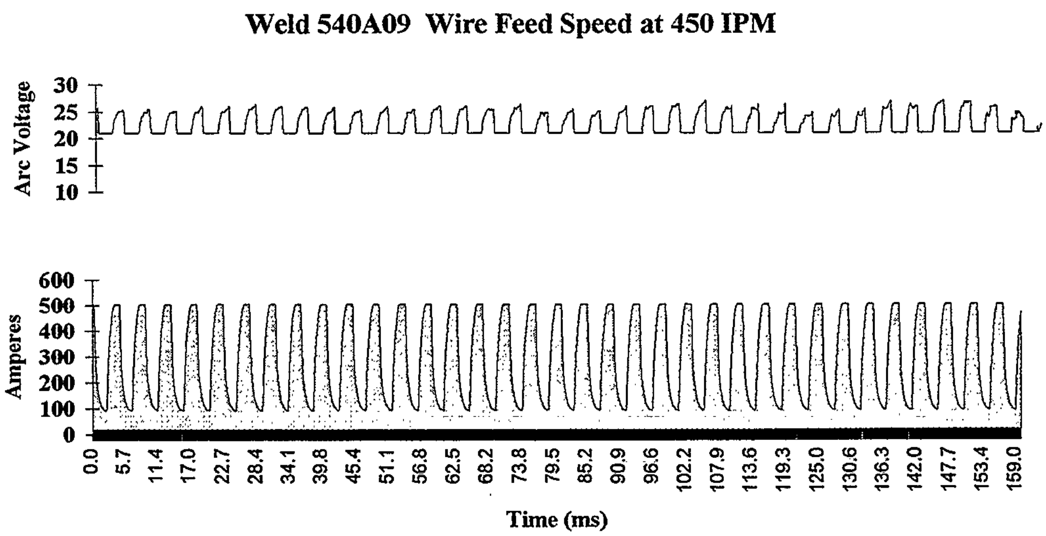


Machine Settings
Pw = 4.6
Pv = 0
WF= 0

Machine Output
Current (avg) = 316.0 amps
Pulse Height = 543.6 amps
Pulse Base = 148.1 amps

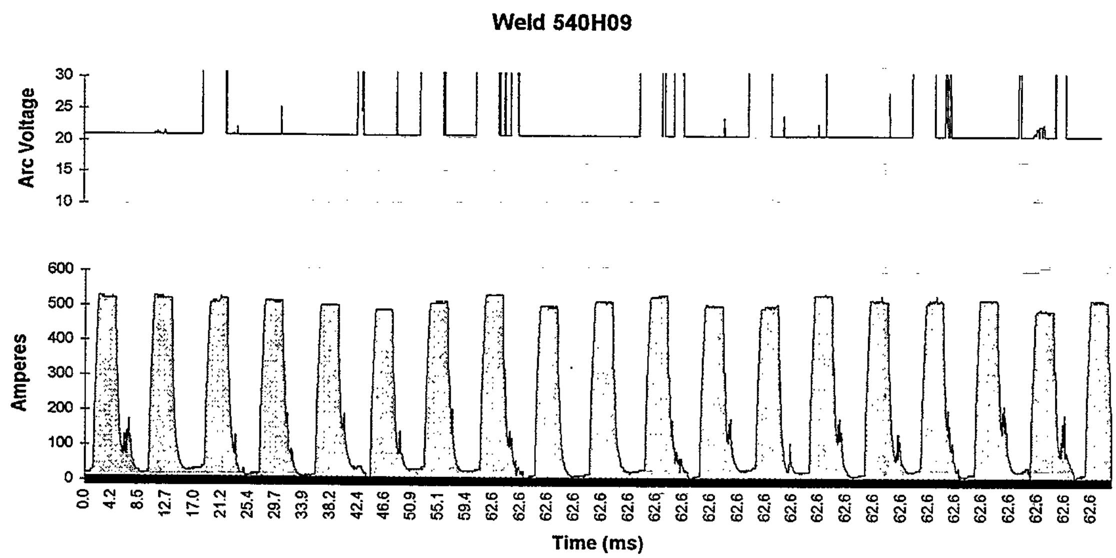
Volts (avg) = 27.50 volts
Pulse Width = 2.84 ms
Pulse Freq. = 227.3 Hz

FIGURE 6.6 T.I.ME. 540, SYNERGIC SETTING AT 450 IPM (4000 DATA POINTS), T.I.ME. GAS



Machine Settings	Machine Output	
Pw = 5.75	Current (avg) = 300.6 amps	Volts (avg) = 29.1 volts
Pv = 0	Pulse Height = 502.5 amps	Pulse Width = 3.32 ms
WF = 0	Pulse Base = 91.2 amps	Pulse Freq. = 223.0 Hz

FIGURE 6.7 T.I.ME. 540, SYNERGIC SETTING AT 450 IPM (4000 DATA POINTS), C-5 GAS

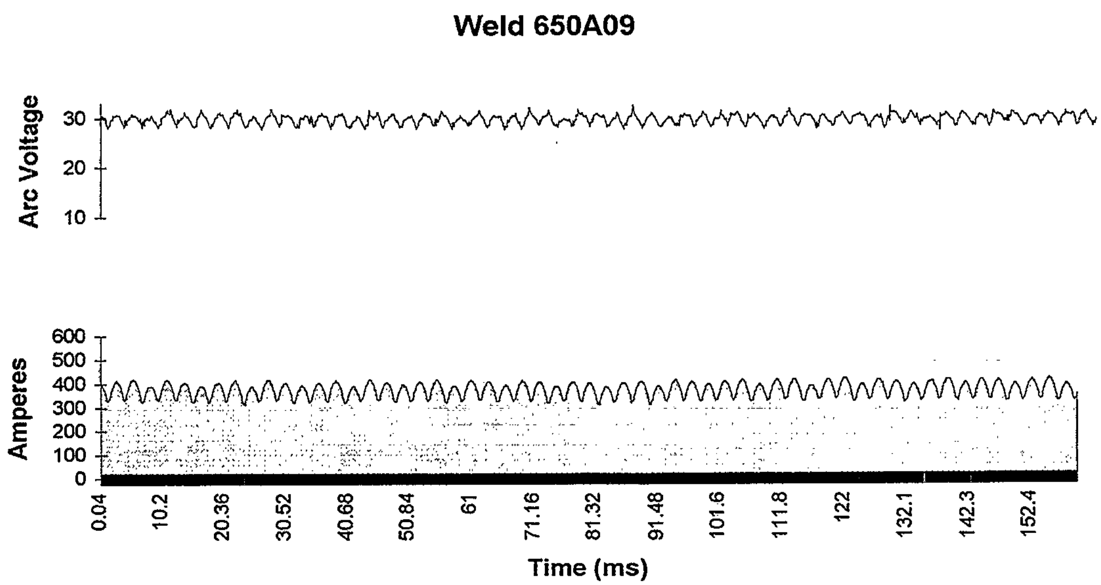


Machine Settings
Pw = +4.5
Pv = 0.0
WF= 0.0

Machine Output
Current (avg) = 238.3 amps
Pulse Height = 528.3 amps
Pulse Base = 30.2 amps

Volts (avg) = 24.2 volts
Pulse Width = 4.48 ms
Pulse Freq. = 115.7 Hz

FIGURE 6.8 LINDE 650, SYNERGIC SETTING AT 450 IPM (4000 DATA POINTS), T.I.M.E. GAS

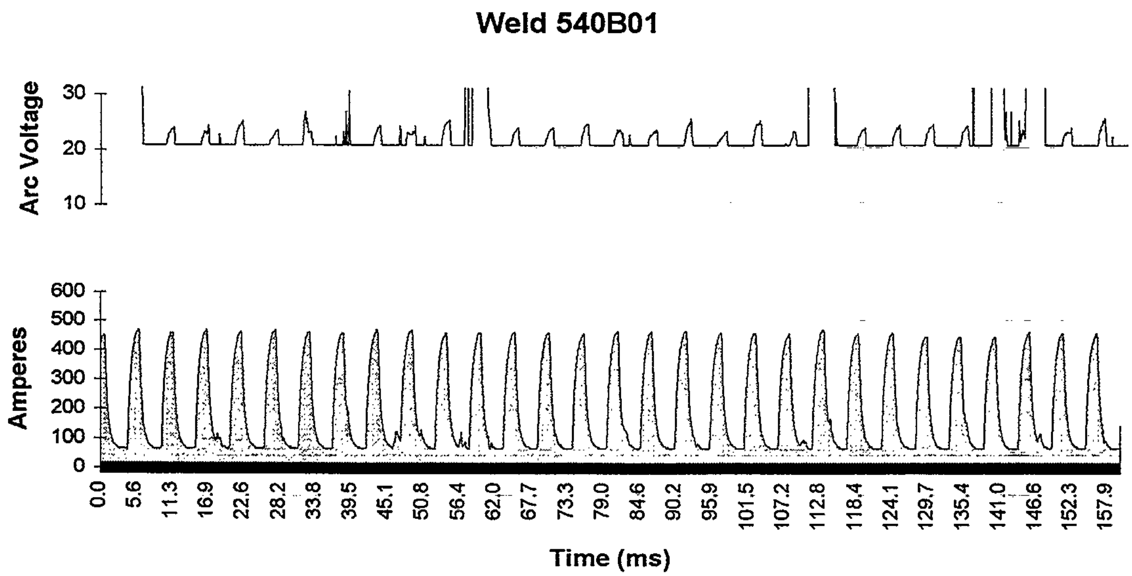


Machine Settings
Pw = N / A
Pv = N /A
WF= N / A

Machine Output
Current (avg) = 370.0 amps
Pulse Height = 421.0 amps
Pulse Base = 334.0 amps

Volts (avg) = 29.9 volts
Pulse Width = 2.08 ms
Pulse Freq. = 320.5 Hz

FIGURE 6.9 T.I.ME. 540, WELDING PROCEDURE FOR FLAT POSITION, T.I.ME. GAS



Machine Settings	Machine Output	
Pw = 5.25	Current (avg) = 204.3 am	Volts (avg) = 25.11 volts
Pv = -3.5	Pulse Height = 452.5 amp	Pulse Width = 2.96 ms
WF= 0	Pulse Base = 70.3 amps	Pulse Freq. = 186.6 Hz

7.0 CONCLUSIONS

1) P-GMAW has superior benefits for welding HY steels and is clearly the process of choice that should be followed for all positional welding.

2) Pulse waveforms must be taken during the qualification of welding procedures to fully calibrate the electrical characteristics of the welding arc and could be used to determine the conditions promoting fusion defects during production welding.

3) The T.I.M.E. 450 Synergic employs a slightly different pulse logic than the T.I.M.E. 540 with the end result being that the T.I.M.E. 450 has much better arc control than the T.I.M.E. 540. The T.I.M.E. 450 Synergic also has much better operational characteristics than the Linde 650.

4) T.I.M.E. process welding causes a much brighter arc than C-5 gas, but a change in lens shade corrects the problem.

5) The Linde 650, although not a pulsed GMAW machine, actually produces a P-GMAW output at lower wire feed speeds.

Acknowledgements

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