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## **A Versatile Experimental Test Rig for GMA Welding Research**

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# A versatile experimental test rig for GMA welding research

Gary Dean, Dominic Cuiuri, John Norrish and Chris Cook

*Welding process research is severely hampered when adequate experimental equipment is not available. With the development of numerous welding processes and the control techniques associated with them, the need now exists for experimental equipment that offers the flexibility to control these processes and to set up parameters associated with the research.*

*At the University of Wollongong an experimental research rig has been developed based on a digital signal processor control system that offers the researcher the facilities to study the various processes associated with GMA welding.*

## Keywords

Experimental test rig, gas metal arc welding, control waveform, digital signal processor, operator interface

## Introduction

The purpose of any experimental equipment is to offer a convenient means to control and monitor an experimental procedure. It should also have facilities to extract relevant data. For the most efficient utilization of equipment some flexibility should exist within the system to provide an adaptable environment for variations in the control procedure. This is particularly important when a field of research may have a number of processes associated with it.

Another issue that confronts the researcher is the way in which the experimental equipment is to be used. Does it need to be compact and transportable or can it remain bulky and stationary? The long-term use of the equipment must be considered in the initial design and be reflected in the final product.

## Description of test rig

The experimental welding test rig described here is being used to develop and test innovative welding control techniques in GMAW. It comprises four main sections.

- 1) Digital signal processor computer based control.
- 2) Operator interface.
- 3) Signal isolation unit.
- 4) Welding equipment and field devices.

The welding power source is controlled via a programmable digital signal processor (DSP) system, which is housed within the host computer. Customised control software, written specifically for the application, is downloaded to the processor on system startup. Control of the welding process is achieved by varying the power source output

through the control reference output signal from the DSP system. Voltage and current feedback signals are input to the DSP system, where process data is extracted for control and monitoring purposes.

The DSP computer based system controls the entire welding process. This includes the implementation of innovative control waveforms, online control algorithms, process state identification and the control of the ancillary equipment associated with the welding process. The process is controlled through analog and digital input/output signals that directly interface to the DSP system.

The operator screen offers the flexibility to change welding parameters used within the control software. Once entered, the parameters are downloaded to the processor and implemented within the control. From the welding parameters the control waveform behavior can be altered to suit the different states that exist within the welding process.

The signal isolation unit provides scaling and electrical isolation between the computer system and the welding field devices for the reference and feedback signals. The field devices comprise the welding power source, wire feed system and any transducers that supply the current or voltage feedback. A simplified diagram of the experimental setup used at the University of Wollongong is shown in Figure 1.

## Software control

### Introduction

The experimental test rig offers a system that is adaptable for different welding processes. The most obvious way of doing this is for the system to be software configurable and maintain compatibility to numerous applications. This is preferable to a hardware configured system with limited flexibility.

The DSP control software and operator interface is designed to control the welding process by varying the welding power source output. The operator interface screen offers a medium through which welding parameters can be modified in the DSP control system, with the aim of altering a welding condition.

To cater for the various welding procedures and control techniques, individual customised software packages have been developed. Loading the relevant software package provides switching between control techniques. This has resulted in relatively short time process changeovers.

### Software Description of Constant Current Dip Transfer

Control algorithms, such as one developed for our current research to provide constant current dip transfer welding, will vary the power source output for the changing states that exist during the process. A function of the control software is to detect the transition states, and adjust the power source output to levels determined by the operator screen setup. Details of the transition states and the operator parameters are shown in Figure 2.

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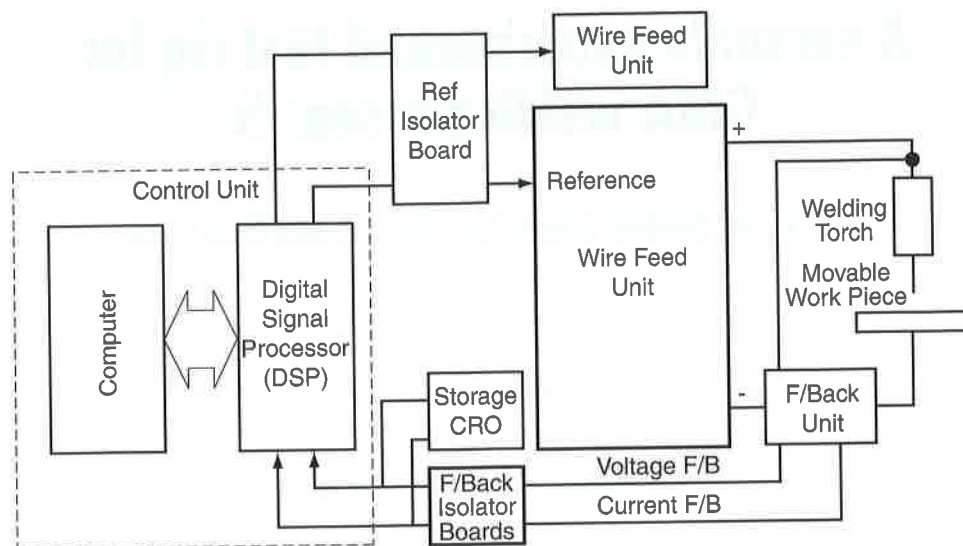


Figure 1. Schematic representation of the experimental setup.

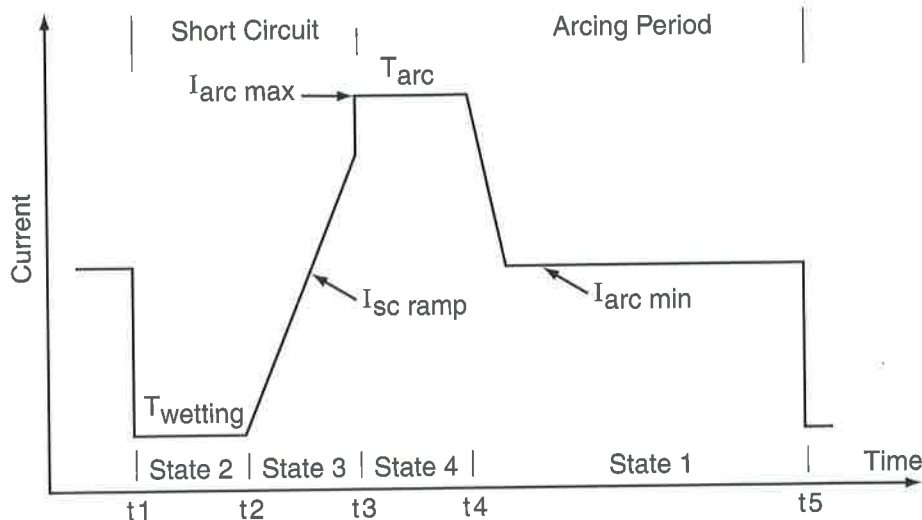


Figure 2. Details of control waveform parameters.

#### State 1 – Minimum arcing current

Once the arcing pulse period has expired, the current is decreased to the minimum arcing current  $I_{arc\ min}$ . The rate at which the current decreases is determined by the  $I_{arc\ ramp}$  setpoint.

#### State 2 – Short circuit droplet wetting

A short circuit between the droplet and weld pool exists. To promote the wetting of the droplet with the weld pool, the current is reduced for the period  $T_{wetting}$ <sup>1,2</sup>.

#### State 3 – Short circuit control

Once the wetting in period has expired, the current is increased at a rate determined by  $I_{sc\ ramp}$  where the current will rise until the molten bridge ruptures.

#### State 4 – Re-establishment of the arc

With the establishment of the arc, a current pulse is applied. The magnitude and time period of the pulse are determined by  $I_{arc\ max}$  and  $T_{arc\ max}$ . The purpose of the pulse is to grow the droplet to an optimum size and to depress the weld pool, and so minimise premature shorting circuiting of the droplet with the weld pool<sup>3,4</sup>.

## Operator screen interface

### Operator screen

As stated earlier, the operator screen offers a medium through which setup data is transferred to the DSP controller, and to display the process data and status. A typical operator screen is shown in Figure 3.

The operator interface screen outlines the various process parameters that are configurable. Parameters can be altered as required by following the screen instructions and entering the appropriate value.

## DSP control system

### DSP computer control

The control system operates in a real time environment. During a welding process, reference and feedback data are continually updated. The applied reference reflects the conditions that exist at that time within the process. This is particularly important in processes such as dip transfer GMAW where the feedback data offer an accurate indication of the process status and can

Program Name: Pmsrcn10		Mode: Weld Stopped		
Digital I/O I/O (hex) xxxx	Current F/B (Amps) xxxx	Voltage F/B (volts) xxxx	Ain B1 (bits) xxxx	Sem. xxxx
1:Isc max (Amps) xxxx	2:Isc ramp (A/ms) xxxx	3:Iarc max (Amps) xxxx	4:Iarc min (Amps) xxxx	
7:Twetting (msec) xxxx	8:Tarc max (msec) xxxx	9:WFR nom (m/min) xxxx	a:WFR crp (m/min) xxxx	
d:Vsc thrsh (volts) xxxx	e:Varc thrsh (volts) xxxx	f:Iarc ramp (A/ms) xxxx		
ERROR				
MESSAGES				
KEY COMMANDS	1-9,a-n as shown above. Q:Quit/Exit		R:Run weld S:Stop weld	

Figure 3. Operator screen layout.

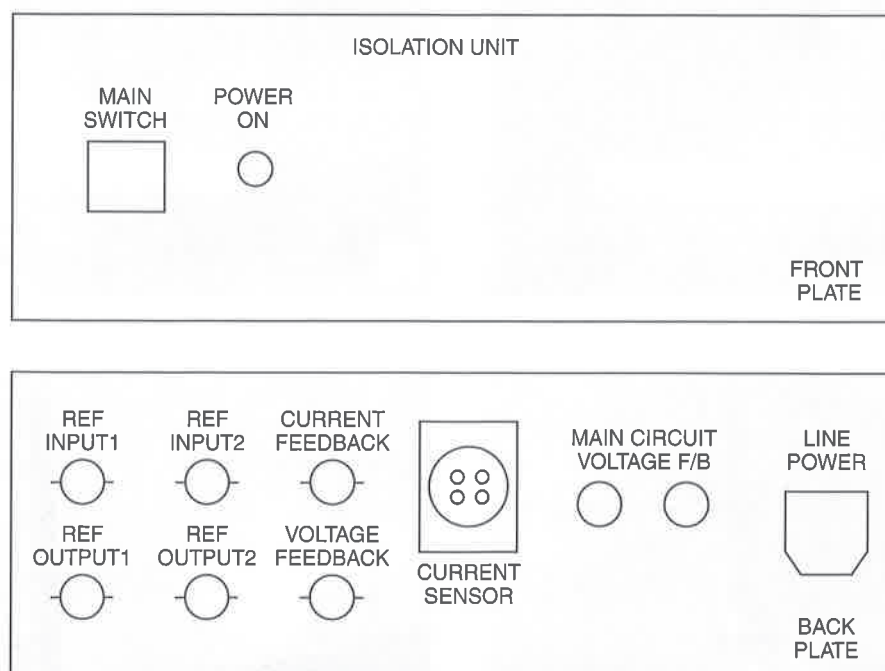


Figure 4. Isolation unit faceplate layout.



be utilised to determine the appropriate reference required for the welding power source.

A real time environment suits the development and application of various control algorithms. The resulting output of the algorithm can be utilised as part of the welding process control or be output for monitoring purposes to the operator interface screen or to spare analog output channels where it can be analyzed from a digital storage oscilloscope.

### DSP system

The digital signal processor control system comprises a personal computer containing a Blue Wave Systems PC/C32 digital signal processor board, based on the Texas Instruments' TMS320C32 digital signal processor<sup>5</sup>. For this application the board is fitted with two high performance analog modules that provide the analog interface for the reference and feedback signals.

The PC/C32 is equipped with a DSPLINK2 communication link for digital expansion interfacing. Digital I/O and interrupt control is via a Digital I/O board built at the UOW that connects to the DSPLINK2 for Digital I/O interfacing with the DSP system.

Control of the DSP system is via an external interrupt, which is generated by external timing circuitry connected through the digital I/O board. Through the interrupt the DSP program is executed every 40  $\mu$ s. This offers an adequate sampling rate for control of all forms of GMAW welding processes.

The DSP control software is written in "C" and is compiled with a dedicated Texas Instruments compiler.

## Signal isolation

### Signal isolation unit

When interfacing any form of electrical equipment, isolation is important, as the ground references for the connected equipment may not be at the same potential because of different supplies.

In the case of digital input and outputs, the logic levels and their compatibility depends greatly on the family of the logic devices. Digital isolation techniques need to be applied when incompatible logic families are interfaced<sup>6</sup>. With analog signals, the reference and feedback ranges for many devices vary. Analog signal specifications will vary depending on whether it is configured as a voltage or current source, and the operating range of the signal. The signal isolation unit provides the interfacing between the digital signal processor and the external equipment.

### Isolation unit layout

The isolation unit is housed within a metal instrumentation enclosure. It is powered by an external AC supply and is designed to operate from either 115V 60Hz or 230V 50Hz AC power supplies. Field cabling connections to the isolation unit are via plugs and sockets, requiring no tools. It can be installed and operational within a very short time. The unit is relatively lightweight and compact. The isolation unit faceplate layout is shown in Figure 4.

Three isolation and scaling interface boards reside within the isolation unit. The boards are positioned to ensure segregation between the AC power supply and the control signal cabling.



Figure 5. Layout of the welding table and torch. GMAW (a) with current control; (b) with voltage control.



Figure 6. Photographic images of the dip transfer GMAW process. (a) arcing period (b) short circuit period.

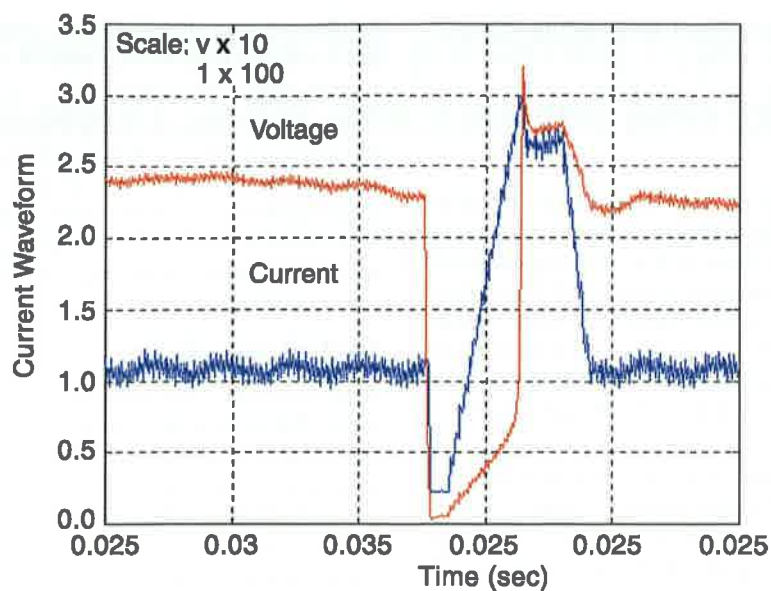


Figure 7. Dip transfer CC waveform (Ar+20%CO<sub>2</sub>).

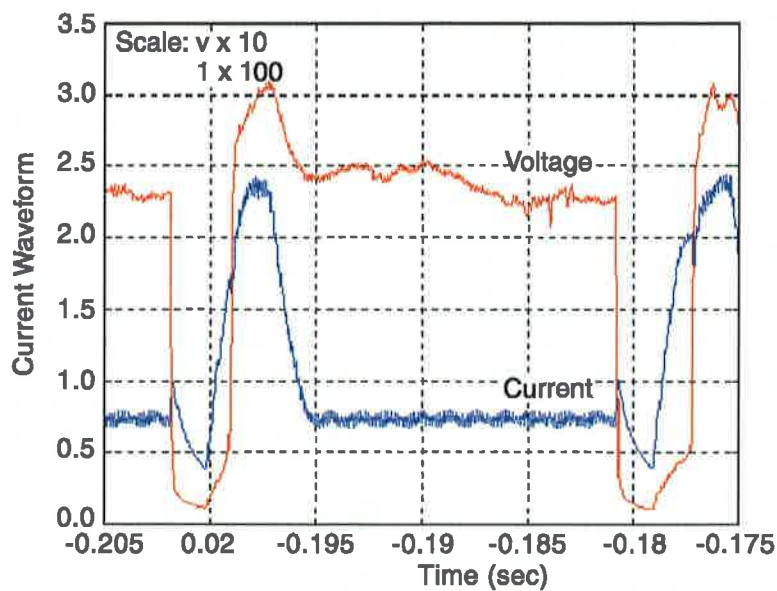


Figure 8. Dip transfer CC waveform (CO<sub>2</sub>).

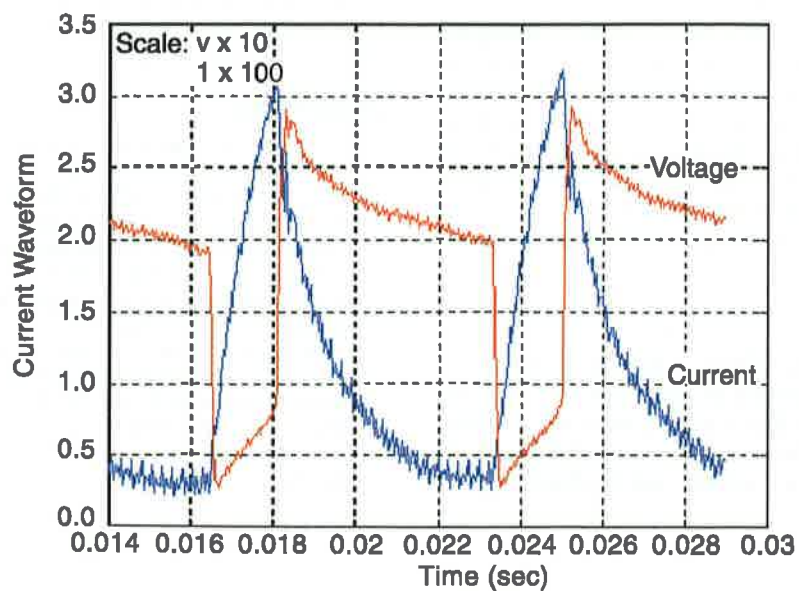


Figure 9. Dip transfer CV control (CO<sub>2</sub>).



This minimises the risk of electrical noise being induced into the control signals.

## Ancillary equipment

### Welding power source

The experimental test rig can be interfaced to any welding power source that has the facility for a remote reference signal. Most electronic power sources have the capability of constant voltage or constant current output control. The power source should offer as features welding mode operation, output inductance adjustment (current rate of rise) and remote/local selection. The mode of operation determines if the remote reference signal controls the voltage or current output of the power source.

For research and comparison purposes, constant voltage and constant current control within a power source can be useful, as some GMAW processes can operate successfully in either mode of control. This is particularly true of processes such as dip transfer welding.

### Experimental welding table

The welding table is part of a converted lathe, with table movement through the lathe's long travel drive. A variable speed drive system is connected to the lead screw motor for control of the welding speed. The welding torch position and height is fixed to a solid frame above the welding table, while the work piece is clamped to the table. The layout of the welding table and torch is shown in Figures 5(a) and 5(b).

The physical configuration of the fixed welding torch with a moving table has a number of advantages. The most obvious is the ease with which photographic work can be carried out. As part of the experimental equipment a digital line scan camera has been integrated into the control system. This has enabled quality photographic work of the welding process. Some typical results of this work are shown in Figures 6(a) and 6(b).

### Data acquisition

Data acquisition is available through two methods. The first is a customised data acquisition system developed at the University of Wollongong. This system has been set up to monitor feedback data and supply statistical analysis of the welding process. The acquisition system has a sampling rate of 200µs and generates a file of the voltage and current data that can be used later for further data manipulation.

The other form of data acquisition available is through a Nicolet 490 storage oscilloscope, where the sampled waveform is captured and stored to floppy disk. The sampling rate of the oscilloscope is variable. However, sampling at 50 µs intervals has been found to be particularly useful for dip transfer GMAW where a number of transition states occur during the welding process and a high resolution of data is essential. Data files are analyzed using customised software developed using either C or Matlab environments.

### Commissioning

Testing and commissioning phases of the experimental test rig initially involved the injection of signals into the DSP and signal isolation unit. From this scaling and signal accuracy was confirmed. Later similar tests were carried out with the welding power source, wire feed unit and feedback devices

connected into the system. Confirmation of the reference and feedback signals was carried out with the aid of digital meters and oscilloscopes.

Process commissioning of the software was achieved by analysing the voltage and current feedback. Process and feedback transitions were confirmed to occur at the programmed detection events within the control software. The complete experimental welding system was tested under normal operating conditions using 115V and 240V AC control power supplies.

### Control waveforms

Typical control waveforms are shown for dip transfer GMAW, using different power sources and shielding gases. Current control (CC) waveforms are shown in Figures 7 and 8, while a constant voltage (CV) control waveform with CO<sub>2</sub> shielding gas is displayed in Figure 9.

Modification to the voltage and current waveform is easily achieved by altering the welding parameters on the operator screen. This may be necessary when using different welding power sources or if the welding conditions have changed.

### Conclusions

An experiment test rig was developed and manufactured for research work into gas metal arc welding processes. The paper deals with some of the issues that relate to the development and layout of experimental test equipment. It has been shown that

- 1) the software configurable experimental test rig is a versatile tool for research into numerous welding processes;
- 2) the development and application of control algorithms can be easily implemented;
- 3) the experimental equipment is both versatile, compact and mobile; and
- 4) innovative control methods can be easily developed with the only limitation being the characteristics of the welding power source.

### Acknowledgements

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