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Verstatile welding power source controller for research and product development

Dominic Cuiuri
University of Wollongong, dominic@uow.edu.au

John Norrish
University of Wollongong, johnn@uow.edu.au

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A VERSATILE WELDING POWER SOURCE CONTROLLER FOR RESEARCH AND PRODUCT DEVELOPMENT

Dominic Cuiuri   John Norrish

The diminishing cost and increasing speed of microprocessors has made them ubiquitous in modern welding control equipment, whether it is mass produced or custom made for research purposes.

Flexible, programmable controllers for gas metal arc welding research at the University of Wollongong are described. This equipment has been used to conduct both government funded research and industry funded development of specific process control algorithms for implementation onto existing commercial equipment platforms.

An overview of various equipment architectures is given, with examples of embodiments that have been used over a period of nine years for various projects, including:

- implementation of conventional power sources with accurately controlled inductance, resistance and OCV,
- replication of pre-existing controlled short-circuiting transfer techniques,
- investigation of benefits of adding fast current turnoff capability to the process,
- testing & development of alternative methods of controlled short-circuiting transfer,
- research to combine short-circuiting transfer and dynamic reversing wire feed systems and
- twin wire pulsed transfer welding research.

1. INTRODUCTION

In order to effectively conduct both basic research and process parameter development, a flexible welding power source controller is essential. The central controller should be easily programmed, and should have sufficient processing speed to meet the likely welding process control requirements.

The interfacing equipment should be capable of electrically isolating the output command signals applied to the power sources being controlled. It should also provide clean and responsive feedback signals that can be reliably used to control the process.

The associated data acquisition system is required to faithfully capture and analyse the feedback signals from the process, so that detailed analysis of the process can be made with confidence.

This paper describes how such a flexible controller has been designed and used within a variety of equipment architectures to investigate and improve a number of gas metal arc welding control techniques. The auxiliary equipment that is controlled and co-ordinated by the controller is also described.

2. DESCRIPTION OF CONTROLLER

The welding controller is based on a DSP processor board that is installed into a desktop computer (PC). The processor has a 32 bit floating point core capable of 50 MFLOPS (million floating point operations per second). Hardware on the board is configured to generate an interrupt every 40 us (25kHz), and this is used as the basis for repeated execution of the various process control programs. Once initiated, this execution is independent of the host PC's operating system. Other functions, such as data transfer to the PC and auxiliary "background" calculations, are performed in the free time between servicing the process control program interrupts. The control program is programmed in C high level language. An appropriate proprietary compiler is used to produce the downloaded executable file. The availability of floating point operations allows for fast, simple code which uses engineering units (such as Volts, Amperes and metres per minute).

The controller's function is adaptable to a range of welding processes and different equipment that may be fitted to the welding test facility. This is done by changing the control software that is executed by the processor board. Corresponding changes are made to the operator's graphical user interface (GUI) software that is executed in the host PC, so that the appropriate parameters can be modified and monitored during welding trials. Changing between control techniques is a matter of loading the relevant software package into the DSP board, and executing the associated operator interface software. The changeover time is very short, and this is extremely valuable for back-to-back comparison of competing control techniques. The simple changeover is also convenient where a number of people are using the same facilities for different projects.

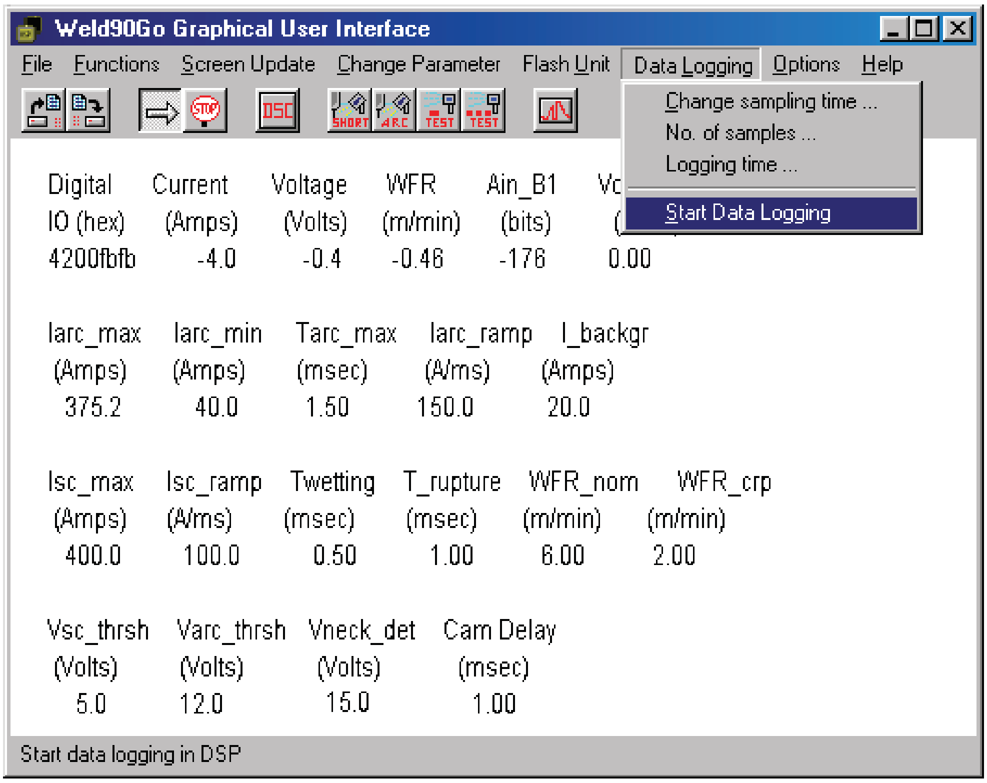
Figure 1 shows the host PC, electrical interface equipment, and other equipment that is associated with the test facility.

Fig. 1 Equipment including controller host PC (left) and interfaces (bottom)

The user interface (GUI) offers a medium through which welding parameters are transferred to the DSP controller, and also is used to display the process data and status. It is programmed in C++, and is compiled using a commonly available compiler with convenient debugging facilities. The GUI also incorporates the mechanism that selectively downloads the DSP executable and initiates the execution within the DSP board. Program download and data exchange is performed through dual port RAM, a shared area of memory that is accessed by both processors. Low level arbitration is transparently performed by the hardware. An additional level of software arbitration is incorporated into both PC and DSP programs, to ensure that consecutive transfers of data always contain fresh data.

The facility for data recording is contained in both DSP and GUI programs. This feature is not intended to replace the general data acquisition function, which is performed by a separate dedicated system with significantly greater storage capacity. Instead, DSP data recording is used as a fault-finding or debugging tool for process development. This software has the advantage of access to all data within the DSP controller, not just the basic external signals. By collecting, logging and analysing this data, subtle errors in the programming code can be uncovered, feedback noise & incorrect A/D conversion can be checked, and access can be gained to multiple real-time internal calculations which would otherwise be inaccessible. This has been a useful tool in the development of complex control processes.

A typical interface screen is shown in Fig. 2. It shows the various process parameters that are adjustable. Parameters are altered as required through pull-down menus and dialog boxes.



Digital IO (hex)	Current (Amps)	Voltage (Volts)	WFR (m/min)	Ain_B1 (bits)	Vc (
4200fbfb	-4.0	-0.4	-0.46	-176	0.00

Iarc_max (Amps)	Iarc_min (Amps)	Tarc_max (msec)	Iarc_ramp (A/ms)	I_backgr (Amps)
375.2	40.0	1.50	150.0	20.0

Isc_max (Amps)	Isc_ramp (A/ms)	Twetting (msec)	T_rupture (msec)	WFR_nom (m/min)	WFR_crp (m/min)
400.0	100.0	0.50	1.00	6.00	2.00

Vsc_thrsh (Volts)	Varc_thrsh (Volts)	Vneck_det (Volts)	Cam Delay (msec)
5.0	12.0	15.0	1.00

Start data logging in DSP

Fig. 2 Typical user interface screen

The flexibility of the overall system is illustrated by the examples in subsequent sections.

3. DESCRIPTION OF WELDING TEST FACILITY

An example of the architecture of the welding test facility is shown in Fig. 3. Due to its flexibility, the “slave” equipment within the facility can vary, but the controller and interfacing equipment is relatively static. Fig. 3 shows the configuration for a twin wire system, which is one of several options investigated. This application illustrates the most intensive requirement for analogue I/O.

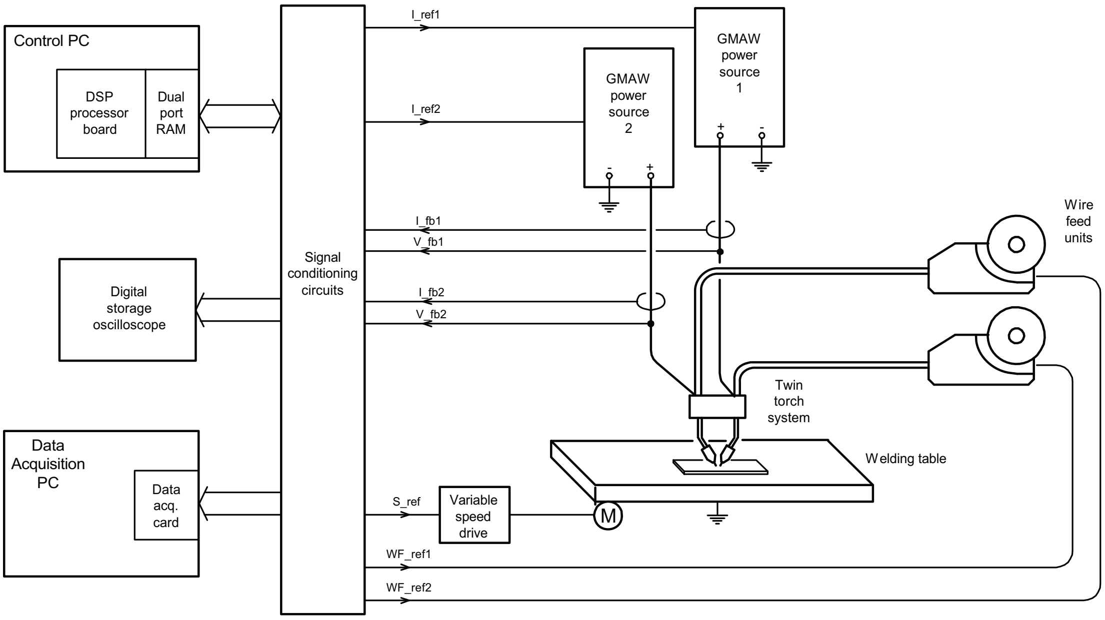


Fig. 3 Test facility configuration diagram – twin wire

The arc power required by the welding processes is supplied by either one or two current-controlled power sources having a high dynamic response. These can be either commercial inverter-based power sources, or custom units that have been constructed at the University of Wollongong for welding research.

The mechanical feeding of the electrode (or electrodes) can be performed by a range of alternatives. For commercial single-wire processes, a commercial wire feeder with external control of the feed rate can be used. For research-oriented tasks, a custom feed unit with closed-loop speed control is used. For high-current deposition with CO_2 shielding gas, a dynamic reversible wire feed system is available (1). As shown in Fig. 3, a dedicated twin-wire feed unit (non-reversing) is connected.

The position and height of the welding torches are fixed above a moving welding table, to which the workpiece is clamped. The main advantage of this arrangement is the ease with which detailed photographic work can be carried out (2). The travel speed of the welding table is regulated by a variable speed drive.

4. CONVENTIONAL GMAW POWER SOURCE EMULATION

One of the earliest tasks undertaken with the flexible controller was to emulate the operation of a conventional constant-voltage (CV) power source, but in a manner that enabled precise and repeatable adjustment of the electrical parameters independently of the “slave” power source that is being used in current-controlled mode. The model of an ideal CV power source is shown in Fig. 4.

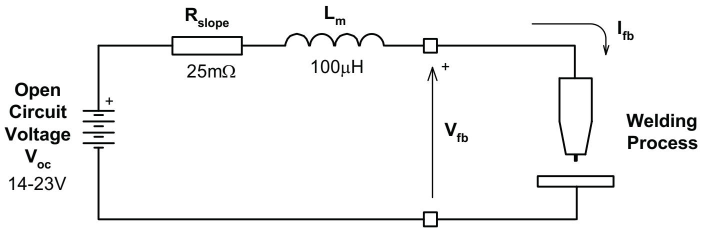


Fig. 4 Model of ideal CV power source

The controller can be programmed to produce the required output current by using the following equations:

$$\Delta I = \frac{\left(V_{oc} - V_{fb}\right) - I_{fb} \cdot R_{slope}}{L_m} T_S$$

$$I_{next} = I_{fb} + \Delta I$$

T_s is the sampling & controlling period of the controller, ? I is the change in current for a particular period, and I_{next} is the current reference supplied to the power source for the next controlling period.

By using this approach, it is possible to emulate other output circuits of more complex design (3).

5. CONTROL OF THE GMA SHORT-CIRCUITING TRANSFER PROCESS

Methods for regulating short-circuiting transfer using current control were first investigated in the late 1960's and early 1970's (4, 5). The first major development involved control of the current waveform (5). The process stability is remarkably improved by this method, and is attributable to the use of a controlled current waveform and the ability to rapidly turn off the welding current just before the end of the short-circuiting period. However, stability could not be maintained for large variations in contact tip to work distance (CTWD) because the prediction of the short-circuiting event was performed by a simple voltage comparison. In the late 1980's and early 1990's, various developments allowed for much more reliable prediction of the short-circuiting rupture event (6, 7) and also allowed for an economical method of fast current turnoff (8) using inverter-based power sources.

Detailed investigations of the current-controlled short-circuiting GMAW process have been conducted using the controller described in section 2 (9). To simplify programming, the process control software has used a state-based programming approach. In this concept, the welding process is considered to proceed in a finite number of sequential steps or states. The current supplied to the process by the power source is regulated in different ways, depending on the state of the weld. The transition between states is determined mainly by voltage changes within the welding process, and sometimes by pre-determined time limits. As an example, for the short-circuiting GMAW process described in (7), the state diagram and corresponding current & voltage waveforms are shown in Fig. 5. This approach simplifies the control of the process, and allows greater flexibility than that possible solely by programming separate voltage-current characteristic into the controller (10).

Having investigated and quantified the performance of this control method, it is then possible to devise and test a simpler method of process control that captured most of the benefits of the more elaborate method, but without the added complexity of a fast current turnoff switch and a short-circuit rupture premonition circuit. This method (11) minimises spatter by limiting the short circuiting current to low values, and allowing surface tension between the weld pool and molten droplet to perform a greater proportion of the metal transfer process. This allows the current at the point of short-circuit rupture to be low, thereby reducing spatter and physical disturbance to the weld pool at the start of the arcing period. The program state diagram and typical waveforms are shown in Fig. 6.

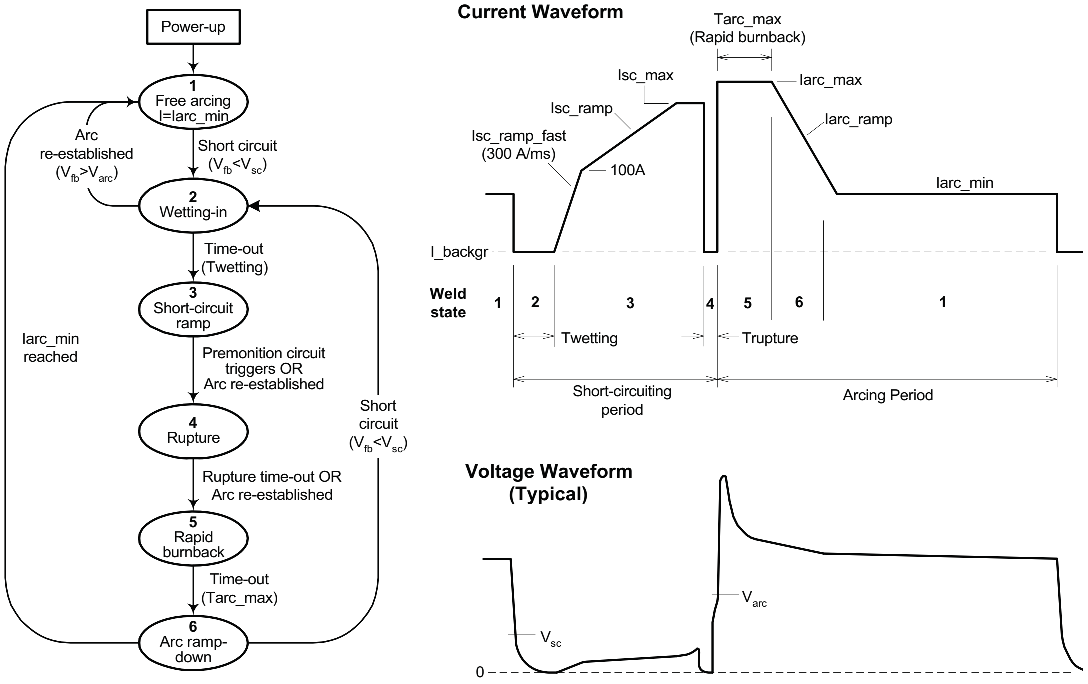


Fig. 5 DSP Program state diagram and typical waveforms for short-circuit GMAW – Method 1

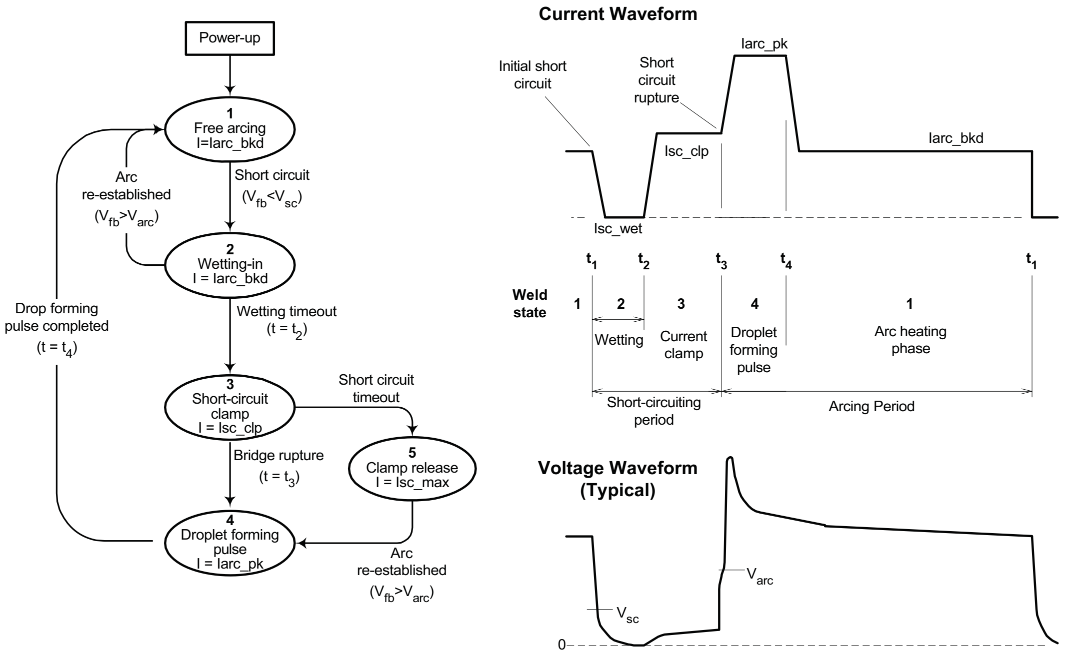


Fig. 6 DSP Program state diagram and typical waveforms for short-circuit GMAW – Method 2

The straightforward implementation of this process control method to standard inverter-based power sources has made this project attractive to industry. Consequently, a significant part of the industry-funded project was devoted to establishing robust parameters for a variety of electrode types (low alloy steel, stainless steel and silicon-bronze) and argon-based shielding gases. The control method has also been patented by the industry sponsor (11).

To bring the concept closer to production, a stand-alone flexible DSP-based controller was designed and constructed (Fig. 7). This design encapsulates the control and interface functions of the laboratory system, retains the programming flexibility, and provides a more rugged package for field trial.

Fig. 7 Field-trial version of flexible controller

6. SHORT-CIRCUITING TRANSFER WITH DYNAMIC REVERSIBLE ELECTRODE FEED

The methods of controlled short-circuiting transfer discussed in section 5 have focussed on manipulating the current to achieve the desired process behaviour, while feeding the electrode at a constant rate. An alternative is to mechanically adjust the instantaneous electrode feed rate to improve the process, while using relatively simple power sources. Earlier attempts involved the unidirectional stepped feeding of wire (12). This approach used step feeding to dictate the short-circuiting frequency of the process. More recently, Huismann (13) has described in detail the operation of a dynamic wire feeding system which rapidly reverses the direction of the electrode at the start of the short circuit. In this system, the dipping frequency is not enforced. Instead, the control system merely responds to the incidence of a short circuiting event. The withdrawal of the electrode away from the weld pool guarantees that the rupture of the short circuit can successfully occur even at low currents for large electrodes, with minimal disturbance to the weld pool. Once the arc is re-established after the short circuit, the wire is fed forward at the desired feed rate. Tests in (13) were conducted at relatively low wire feed rate and constant current (150A) with a 1.6mm steel electrode in Ar-3%O_2.

At the University of Wollongong, research has been undertaken where the dynamic control of the electrode feed is combined with the advanced current waveform control (1). The objective of this approach is to develop a means of stable metal transfer at high deposition rates with low spatter and high stability when using 100% CO_2 as a shielding gas. In CO_2, it is possible to reach high deposition rates (above 3 kg/hr) only by using pulsed-spray transfer. However, the dissociative nature of CO_2 at high temperatures generates asymmetrical arc forces that destabilize the process and generate very high spatter as metal is transferred in free-flight across the arc (1).

These issues are avoided by using short-circuiting transfer, and the use of a reversing electrode feed system ensures that the short circuit reliably ruptures, even at high average wire feed rates. With a 1.2mm electrode, average feed rates of 10 m/min to 13.5 m/min (5.3 – 7.1 kg/hr) were achieved with very low spatter and high stability.
The current waveform and wire feed profiles are shown in Fig. 8. The equipment used in this research is shown in Fig. 9. Because of commercial interest, the control method has been protected by patent (14).

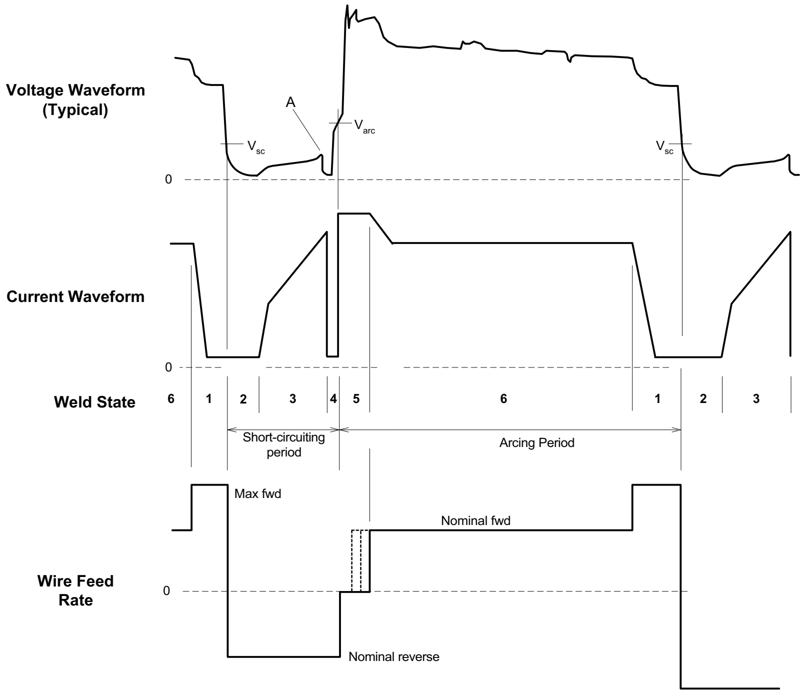


Fig. 8 Typical waveforms for current, wire feed speed, and welding voltage

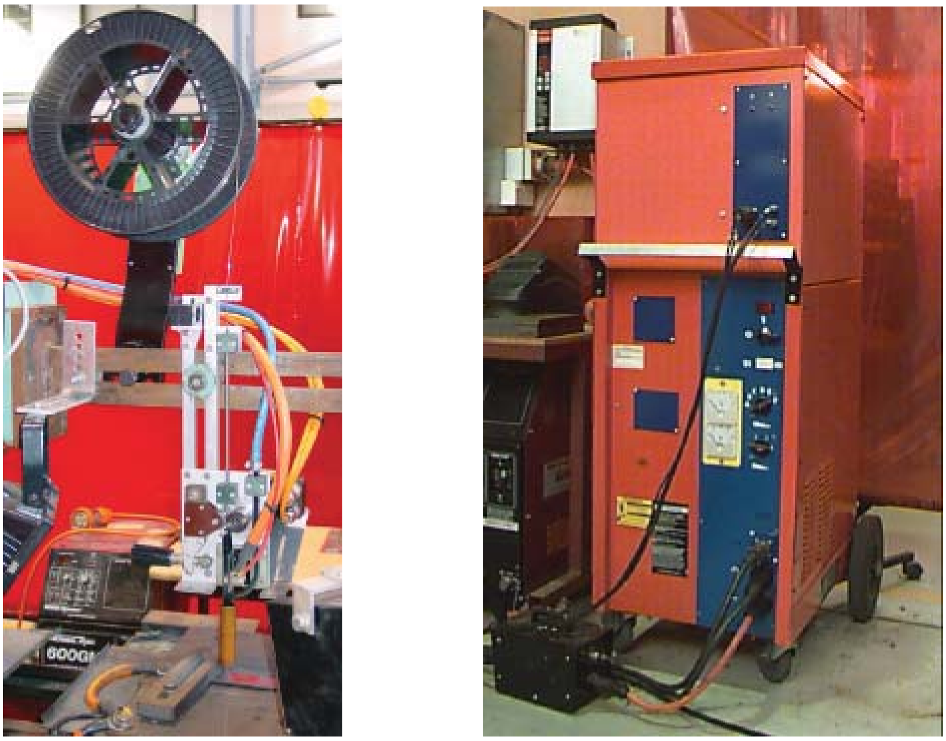


Fig. 9 Reversing wire feed unit and custom power source with fast current turn-off

7. TWIN WIRE PULSED GMA WELDING

With the need to increase travel speeds and deposition rates in manufacturing, the twin-wire process operated in pulsed-spray mode has been successfully adopted in many applications (15). While single wire pulsed-spray transfer is well studied, multi-wire systems are less well known. A major hurdle to research and development is the difficulty involved in constructing the torch and electrode feed system, and the co-ordination of the independent power sources to avoid electromagnetic interference between the adjacent arcs.

The use of a versatile controller with sufficient I/O capability greatly simplifies this task, and lowers the entry barrier to this area of study. This allows more time to be dedicated to the control software, which presents its own unique problems when two electrodes are involved.

Magnetic interaction between the arcs is minimised by introducing a preset time delay between the pulsing period of the two electrodes. This requires the pulsing frequency for both electrodes to be the same. Independent arc length control for each electrode must therefore be performed through adjustment of the background current, rather than adjustment of the background time (16). With this approach, control of the twin-wire system is relatively straightforward, provided that both electrodes operate in open-arc conditions.

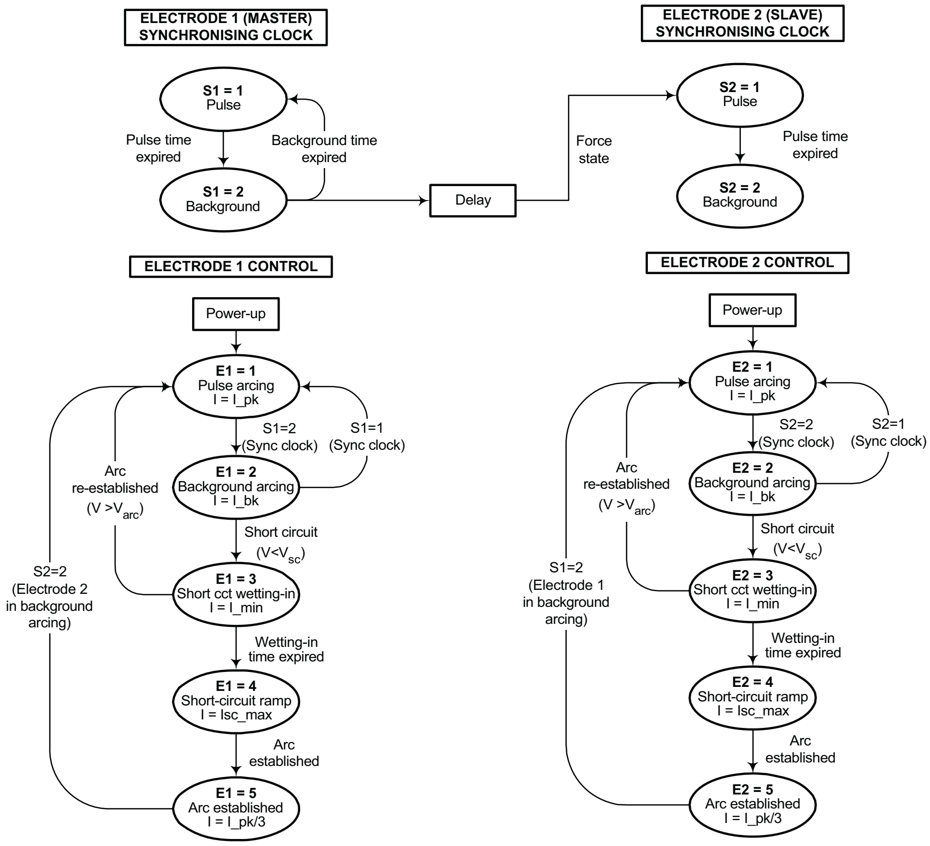


Fig. 10 Program state diagram for twin-wire GMAW

However, complications arise where one electrode is in short circuit while the other is in open-arc mode. This situation can occur either at the start of the weld, or during the weld if there is a step reduction in CTWD. In either case, the control scheme must place priority on not disturbing the open-arc electrode that is operating in a stable condition. To avoid disturbance, the large current pulse that is usually applied to the short-circuiting electrode as a rupture occurs is delayed if the open-arc electrode is in the pulsing period. Once the pulsing period of the open-arc electrode expires, a current pulse is applied to the electrode that is emerging from the short circuit, to increase the arc length and establish a stable open-arc condition.

This control technique produces rapid and reliable arc starting, and recovers well from disturbances during the welding process. Figure 10 shows the program state diagram for this method. Figure 11 shows the wire feed units and twin-wire torch that have been used in preliminary trials.

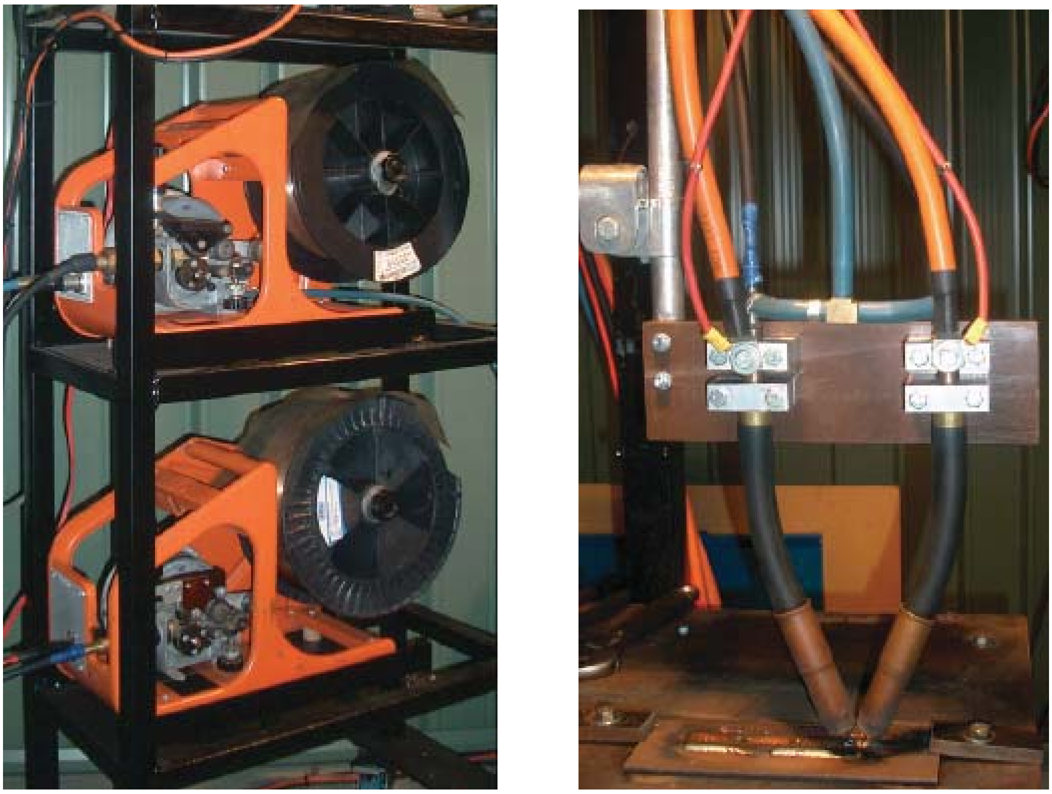


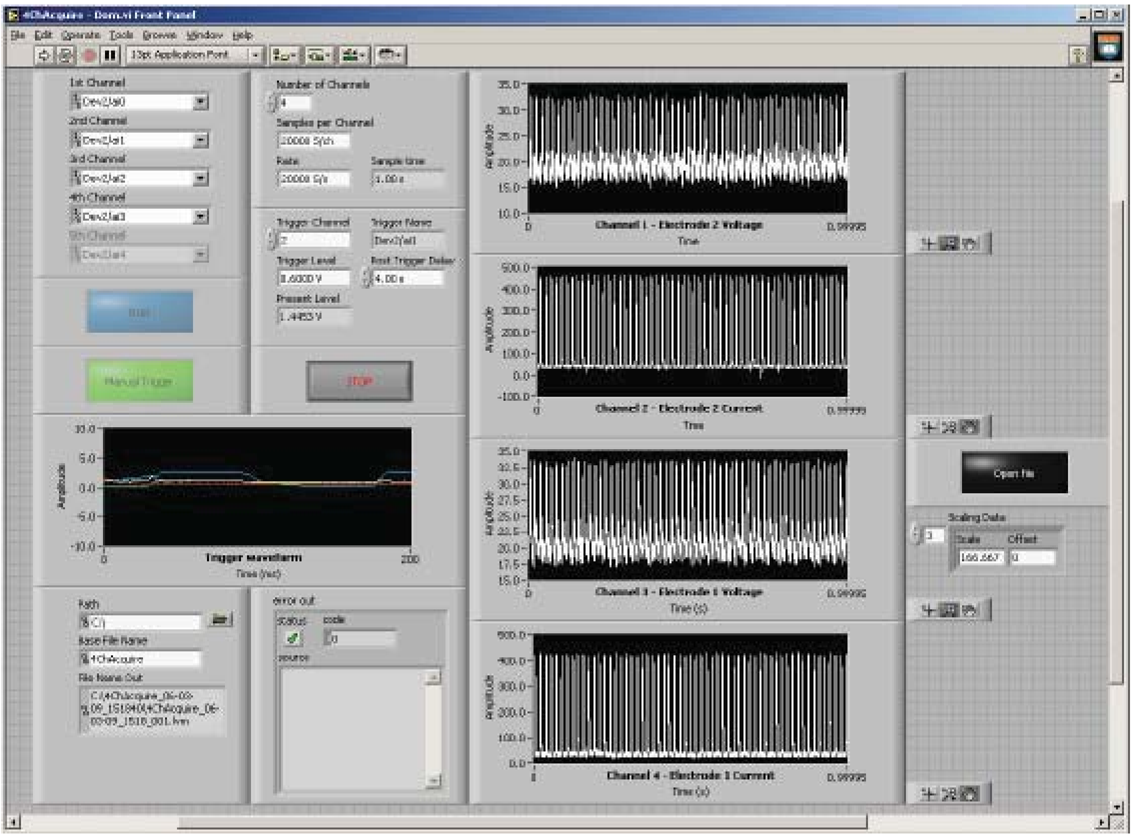
Fig. 11 Twin wire feed units and experimental torch

8. DATA ACQUISITION FACILITIES

A data acquisition system with suitable sampling rate and memory depth is necessary for evaluation and comparison of welding conditions, irrespective of the welding process being investigated. The system that is currently being used is based on a low-cost PC-based acquisition card with eight 16-bit analogue input channels and a maximum sampling rate of 200 kS/s for all channels. For the twin-wire process, four channels are being sampled at 20 kS/s over 10 seconds for most welding trials. The sampled data is streamed to disk, so the memory depth is ultimately limited by the storage capacity of the host PC.

A generic acquisition software package has been written at the University of Wollongong that is readily modified by individual researchers to suit their particular application. It contains the usual facilities such as adjustment of sampling rate, data

scaling, triggering level, triggering delay, and automatic file saving for repeated welding trials.
Figure 12 is a typically adapted operator panel from this software.



1st Channel: Dev2/ai0
2nd Channel: Dev2/ai1
3rd Channel: Dev2/ai2
4th Channel: Dev2/ai3
5th Channel: Dev2/ai4
Number of Channels: 4
Samples per Channel: 20000 S/ch
Rate: 20000 S/s
Sample time: 1.00 s
Trigger Channel: 2
Trigger Name: Dev2/ai1
Trigger Level: 3.6000 V
Post Trigger Delay: 4.00 s
Present Level: 1.4453 V
Path: C:\
Base File Name: 4ChAcquire
File Name Out: C:\4ChAcquire_06-03-09_151840\4ChAcquire_06-03-09_1518_001.lvm
error out
status: ✓
code: 0
source
Scaling Data: 3
Scale: 166.667
Offset: 0

Fig. 12 Typical data acquisition control panel (for twin-wire GMAW)

9. CONCLUSION

A programmable welding controller has been designed and used for research and development of Gas Metal Arc welding processes. The flexibility of the facility is gained from the modularity of the hardware and also from the extensive software control and monitoring of almost all aspects of its operation. The development and application of control algorithms can be easily implemented. The performance of the process can be readily evaluated due to the comprehensive monitoring capabilities. These features make the versatile controller and associated test facility an indispensable tool for welding research.

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