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A Flexible Computer-Controlled Experimental Power Source for Welding Research

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

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

Christopher David Cook
University of Wollongong, chris_cook@uow.edu.au

A FLEXIBLE COMPUTER-CONTROLLED EXPERIMENTAL POWER SOURCE FOR WELDING RESEARCH

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ABSTRACT

Control of the Gas Metal Arc welding process is becoming increasingly sophisticated, due to improvements in technology and a better understanding of the process itself. To effectively conduct research in this area, it is necessary to have equipment that is extremely flexible in both architecture and operation.

Experimental power sources and a welding test facility have been developed at the University of Wollongong which meet these criteria. The core time-critical control functions are performed by an independent digital signal processor (DSP). Non time-critical functions such as data storage and operator interface are performed by a desktop personal computer. Both computing platforms are readily programmable, allowing a variety of control strategies to be tested merely by changing software. Welding current is supplied to the process using a custom-built electronic power source with very high dynamic response and rapid current turn-off. The electrode feeding is accomplished by a bidirectional wire feed unit with a time constant of approximately 2 milliseconds. Visualisation of the welding process is achieved through the use of a CCD camera and high-power xenon flash unit, which are both synchronised to process events by the DSP controller.

The construction of the welding test facility is modular, allowing for upgrading of submodules as technology improves. The inherent flexibility of the architecture also allows for another arc welding process, such as Gas Tungsten Arc welding, to be operated simultaneously.

KEYWORDS

Experimental power source, controlled current waveform, digital signal processor, operator interface, process visualisation

AUTHOR DETAILS

Dominic Cuiuri is a Post Doctoral Fellow at the University of Wollongong

Professor John Norrish is CRCWS Chair of Materials, Welding and Joining at the University of Wollongong

Professor Christopher Cook is Head of Electrical Engineering at the University of Wollongong.

1. INTRODUCTION

In order to study and develop control processes for the Gas Metal Arc welding process, a flexible and sophisticated experimental test facility is needed to conduct effective and timely research. The equipment must provide a convenient means of controlling and monitoring the process under test. The power source needs to supply current for the arcing process with a high dynamic response. The central controller should be based on a processor that is easily reprogrammed, and should have sufficient speed to meet the processing requirements that may be required for research. The monitoring equipment is required to faithfully capture and analyse the electrical feedback signals from the process, so that close scrutiny of the process behaviour can be made with confidence. To verify interpretations of the process behaviour made from the electrical signals and experimental observations, a means of process visualisation is also desirable.

This paper describes a facility that has been developed at the University of Wollongong which meets all of these requirements.

2. DESCRIPTION OF TEST FACILITY EQUIPMENT

The architecture of the welding test facility is represented schematically in Figure 1. As shown, the facility is presently configured to simultaneously control a GMAW and a GTAW process. The overall operation is coordinated by a DSP processor board housed in the control PC. The operation of the DSP is interrupt-based and occurs in real time, independently of the host PC which uses a general desktop operating system that is not suited to real time control. However, the PC is very well suited to providing mass data storage, and a flexible graphical user interface for data logging and parameter exchange. This is described later in more detail.

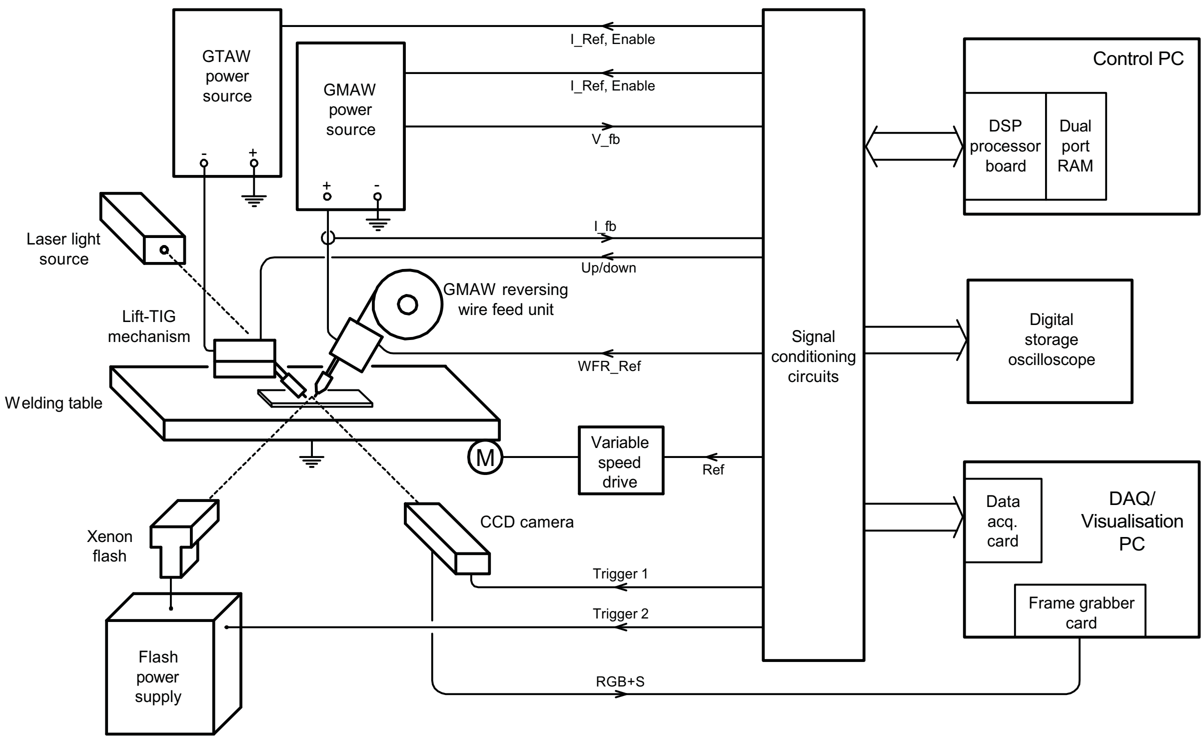

Figure 1 Welding test facility schematic diagram

The arc power required by the welding processes is supplied by current-controlled power sources having a high dynamic response. Both of these power sources have been custom-built at the University of Wollongong for welding research. The GMAW power source is a transistor secondary-switched type with a rapid current turnoff capability of 20,000 A/ms into an output short circuit [1]. It is especially suited to the short-circuiting GMAW process, as it incorporates the necessary design

features needed to control this process [2,3]. Of course, it can also be used for open arc processes such as pulsed-spray transfer, which are often less demanding in terms of required response time. The GTAW power source has water-cooled linear output stage for producing a ripple-free output current at up to 900A peak with a maximum response rate of 7000 A/ms. The GTAW arc is initiated by touch-striking, to avoid electromagnetic interference to surrounding computer equipment that is created by high voltage arc striking. The power sources are shown in Figure 2.
The mechanical feeding of the electrode in the GMAW process is performed by a reversing wire feed unit (Figure 3). It is capable of changing the feeding rate from full speed in the forward direction (+40 m/min) to full speed in the reverse direction (-40 m/min) in approximately 4.5 milliseconds. The mechanical design minimises feeding friction and wire "springing" effects. While this wire feed unit can be used as a conventional constant speed feeder, it is also being used to conduct research similar to that described by Huismann [4].

Figure 2 GMAW & GTAW power sources

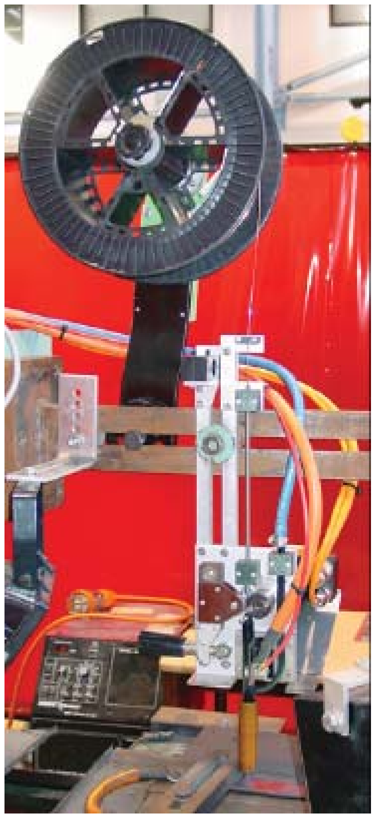

Figure 3 GMAW reversing wire feed unit

Data acquisition of key electrical signals is done through two methods. The first is a PC-based data acquisition system with customised software developed at the University of Wollongong specifically for short-circuit GMAW process evaluation [5]. It monitors feedback data and supplies statistical analysis if the welding process. The acquisition system has a 200μs sampling rate, and generates ASCII data files that can be used later for further data manipulation. The other method of capturing data is through a 4 channel 12 bit digital storage oscilloscope, which can also record data to disk. The sampling rate can be varied from 1 second to 10 ns. The very fast capture rates allow for close scrutiny of transient phenomena in the welding processes, not normally detectable by low cost PC-based data acquisition systems. It is also used for electrical fault-finding within the test facility.
Interfacing, isolation and filtering of the various feedback and control signals is performed by signal conditioning circuits. Level-matching of analogue signals is required at a number of points. In particular, the DSP analogue I/O operates within a +/- 3V range, while other equipment uses a more conventional +/- 10V range. Isolation of references to the power sources and wire feeder ensures that

other signals within the system are not affected by ground loop noise, which may occur since the various equipment is powered from different mains supplies. Digital signals between equipment are optically isolated to ensure signal reliability in the welding environment, particularly during rapid current turnoff events.
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 photographic work can be carried out. The travel speed of the welding table is controlled by a variable speed AC drive.
The photographic work that has been carried out to date takes two forms. The first consists of high speed film photography at 4000 frames per second using laser back-lighting of the electrode and weld bead. When this is done, the film camera is used to electrically trigger the digital storage oscilloscope and data acquisition system. The triggering is initiated when the steady state film speed is reached by the camera. Timing marks laid down on the film allows for correlation between the photographic record and the recorded electrical signals. The second form of photography uses a custom-built high power xenon flash lamp to front-light the electrode and weld pool area. Figures 4a and 4b give examples of photographs taken during short-circuit and arcing periods of the GMAW process.

Figure 4 Flash-lit photographs taken during short circuit & arcing periods

Since the flash lamp can only deliver a single intense pulse of light, the DSP controller is used to synchronise the exposure of a colour CCD camera to the peak of the flash lamp output. To make the most of the single exposure, the triggering of the flash and camera are synchronised by the DSP controller to a desired key event within the welding process. For example, the triggering control software can be written to take the photograph 4.2 milliseconds after the start of a short circuit, but only if the preceding arc time was greater than 15.0 milliseconds. The image captured by the camera is digitised by a standard “frame grabber” card contained within the data acquisition PC. Photographs taken by this method can give stunning results. The effects of the arc light are swamped by the xenon flash if the current is below 50A. Where a photograph of the metal in the welding process is required at higher welding currents, the DSP controller software is written to temporarily reduce the weld current for the duration of the camera exposure (125 microseconds).
As shown in Figure 1, the architecture of the welding test facility is modular. Although this is a result of gradual development over time as much as fundamental design, the result is a flexible system of submodules which can be readily upgraded or reconfigured to the requirements of a new project.

3. DESCRIPTION OF CONTROL AND MONITORING SOFTWARE

The welding test facility offers a system that is adaptable for different welding processes. This is done by changing the control software that executes in the DSP processor board. Corresponding changes are made to the operator interface software that is executed in the PC, so that the appropriate

parameters can be modified and monitored during welding trials. Switching between control techniques is a matter of loading the relevant software package. The changeover time is very short, and is extremely valuable for back-to-back comparison of competing control techniques. The benefits are particularly evident in time-constrained research projects where development and testing occur concurrently. The simple changeover is also convenient where a number of researchers are using the same facilities for different projects.

The DSP processor board is based on a 32 bit floating point processor capable of 50 MFLOPS (million floating point operations per second). The internal hardware is configured to generate an interrupt every 40μs (25kHz), and this is used as the basis for repeated execution of the process control program. Other functions, such as communication to the PC and auxiliary "background" calculations, are performed in the free time between servicing the control loop interrupt. 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).

To date, 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 [3], the state diagram and corresponding current & voltage waveforms are shown in Figure 5. This approach simplifies the control of the process, and allows greater flexibility than that possible solely by programming voltage-current characteristic into the controller [6].

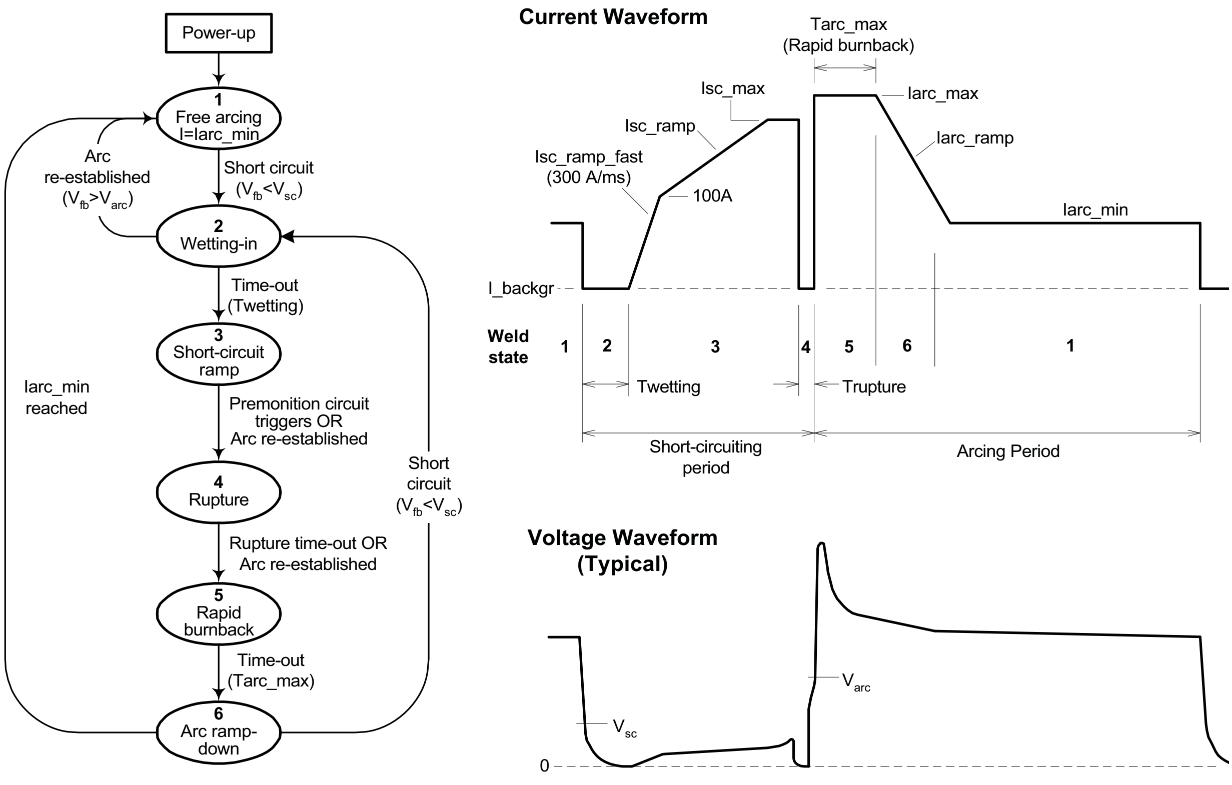

Figure 5 State diagram and typical waveforms for short-circuit GMAW

As stated earlier, the graphical user interface (GUI) which is executed in the PC offers a medium through which welding parameters are transferred to the DSP controller, and to display the process data and status. The GUI 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 accessible 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 logging is contained in both GUI and DSP programs. Because of the fast DSP interrupt/control rate and the relatively slow & inconsistent data transfer rate through the dual port RAM, storage of logged data is done in the static RAM on the DSP board (up to 256k words). This ensures that there is no missed data, particularly if the PC processor is servicing its other system interrupts. The data logging is initiated by the PC setting a semaphore word in the dual port RAM. When the available memory has been filled, the DSP clears this word. Once the data is logged, it can be transferred slowly through the dual port RAM into the PC memory, and then stored onto hard disk as an ASCII file if desired. The advantage of logging the DSP controller data is that all variables are accessible, not just the basic external signals. By post-processing 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 found to be a simple yet invaluable tool in the development of complex control processes.

A typical graphical interface screen is shown in Figure 6. It shows the various process parameters that are adjustable. Parameters are altered as required through pull-down menus and dialog boxes.

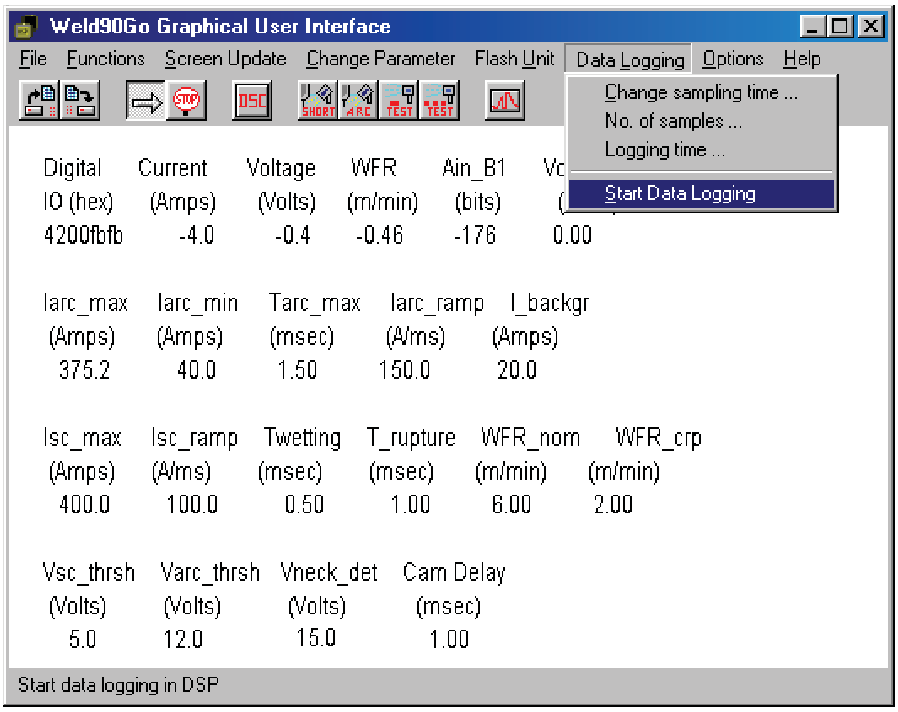

Figure 6 Typical user interface screen

In addition to the integrated DSP data logging, the welding test facility also has an independent data acquisition system (described earlier) which displays important statistics for the welding process immediately after a weld. Although developed in earlier research projects, it continues to be used as a useful data cross-checking facility. It also gives immediate objective data on the performance of the weld, such as mean current, wire feed rate, voltage-current trajectory and stability index. Figure 7 shows the information that is typically available from this package.

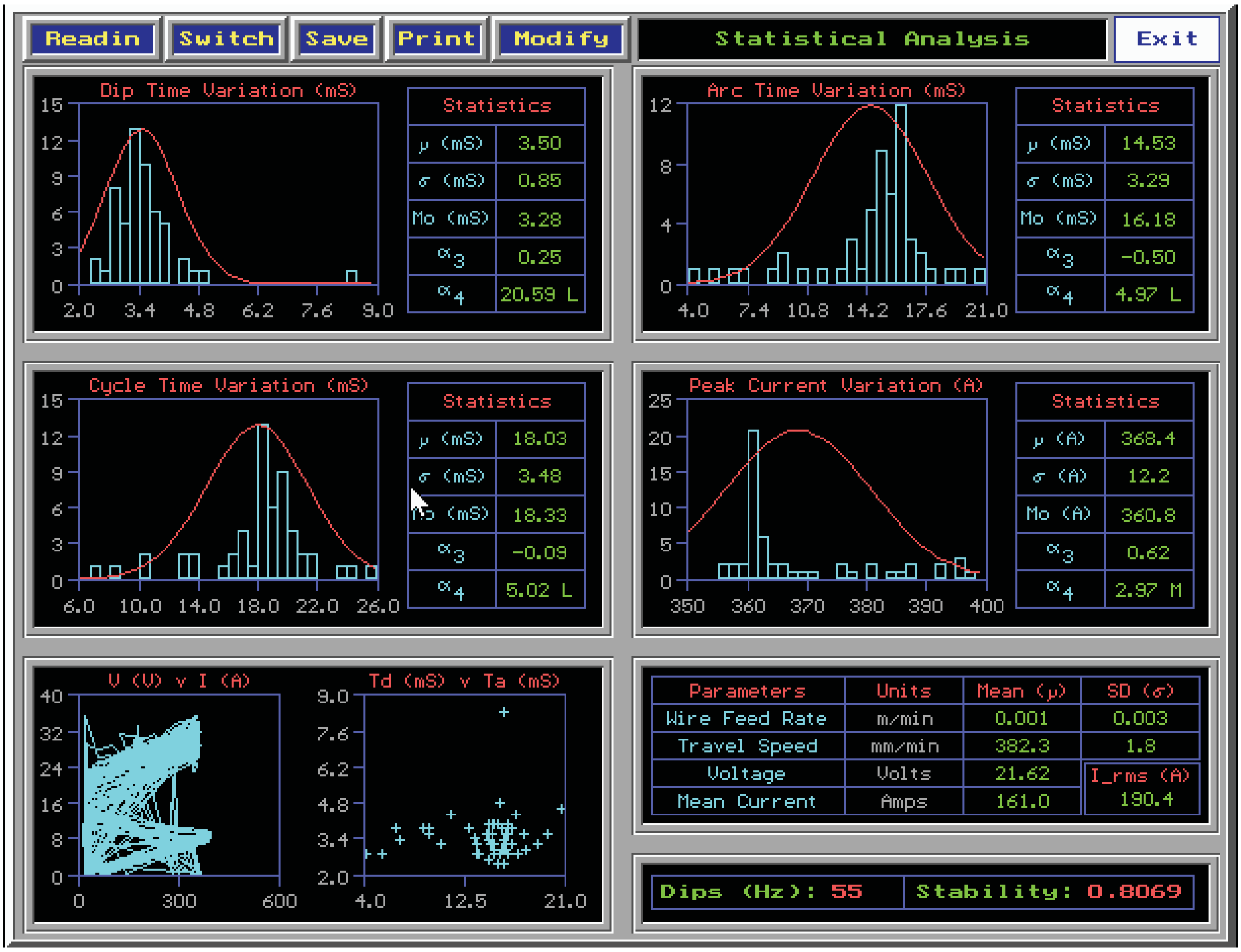

Figure 7 Statistical information screen from data acquisition system

4. CONCLUSION

Experimental power sources and a welding test facility have been developed for research of Gas Metal Arc welding processes. The versatility and flexibility of the facility is gained partly from the modularity of the hardware, but more importantly 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 test facility an indispensable tool for welding research.

5. ACKNOWLEDGEMENT

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