A TEST FACILITY FOR DEVELOPMENTS IN ION SOURCE PLASMA POWER SUPPLIES

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Abstract

A new test facility is being designed and constructed at the ISIS spallation neutron source, Rutherford Appleton Laboratory, for the purpose of developing and experimenting with new plasma power supply topologies and modes of operation. The test facility will allow better control of power supply parameters such as discharge pulse current and plasma ignition voltage along with the possibility for closed loop feedback control. The design and technical construction details are presented with an overview of the plasma power supply developments.

INTRODUCTION

The ongoing development work on the ISIS Ion-source has created a need for a more adaptable plasma discharge power supply with a higher power output capability. In order to make the unit more adaptable and provide scope for future changes to some components, the original design of a combined bulk power supply and power output stage within a rack mount unit will be split into two. The bulk power supply, low voltage PSU and main controls will be contained in a separate rack mount unit from the power output stage Insulated Gate Bipolar Transistor, RC snubber and current monitor. All control and interlock functions from the original design [1] will be preserved in order to make the control board compatible with the original ISIS power supply units. External control and interlock signals will connect to the bulk power supply unit which will supply bulk DC power and the necessary IGBT drive and control signals to the output stage unit, current monitor and interlock signals will be received back. The overall layout of the system is shown in Figure 1.

THEORY OF OPERATION – BULK DC POWER SUPPLY

The bulk DC power supply takes 240 V AC power from the mains supply and is full-wave bridge rectified to 400 V DC, smoothing and filtering is provided by a 1500 µF electrolytic capacitor bank. Provision is made for soft-start using a high current relay in parallel with a 100 ohm high power resistor and under-voltage lock-out using a relay to operate a control interlock. Isolation between AC mains supply and ion-source electrodes is provided by an isolating transformer with adjustable tapping in order to be able to adjust the turns ratio around the nominal 1:1 point.

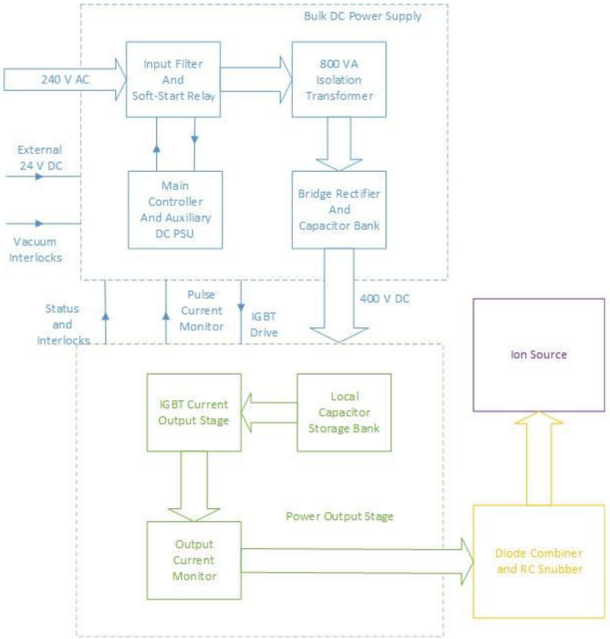

Figure 1: System Block Diagram.

The power transformer has been upgraded from previous iterations of the power supply, the reason for this is both to provide greater adjustment of turns ratio and a better continuous power rating. This new power rating of 800 VA will allow for pulse currents up to 50 A with a 700 µs width and a pulse repetition rate of 50 Hz or an increased current pulse with a corresponding decrease in either pulse width or repetition rate. The bulk power supply unit also houses an auxiliary power supply that is used to provide low-voltage DC supplies for the control board and instrumentation. The completed unit is shown in Figure 2.

THEORY OF OPERATION – POWER OUTPUT STAGE

The pulsed power output stage uses six Insulated Gate Bipolar Transistors of 1200 V, 400 A rating to output a current pulse with arbitrary amplitude and width, limited only by bulk DC power supply ratings and available power dissipation of the IGBT device packages and heatsink. Ion-source timing is provided by a series of timing pulses from the main control system, the system provides a timing signal that precedes the signal to enable the main ion beam. This initial timing signal is used to provide a Hydrogen gas pulse and then ignite the main discharge. The

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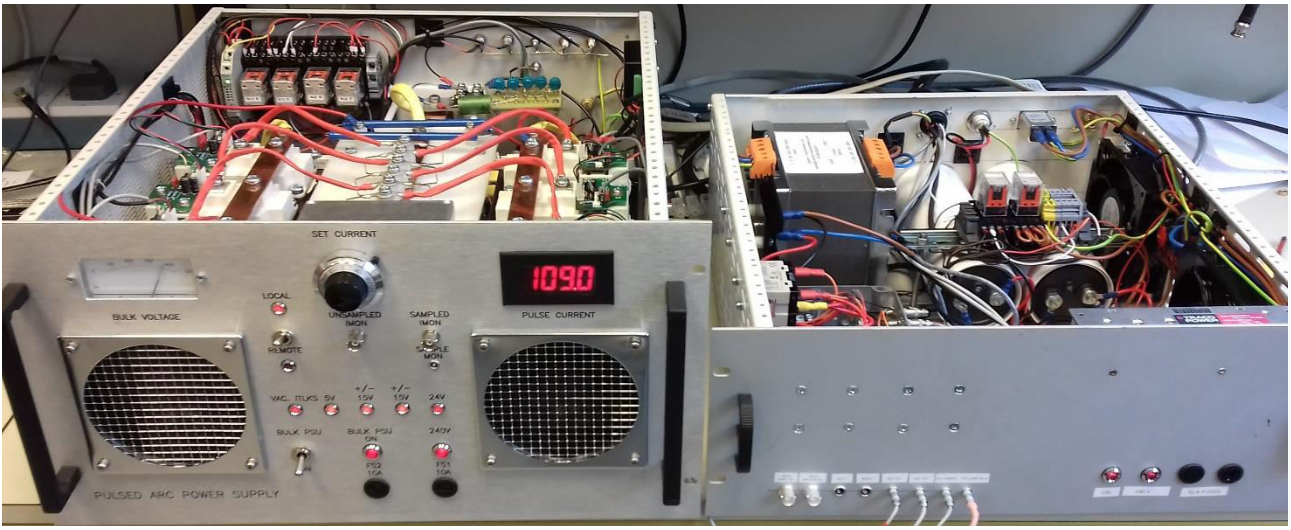

Figure 2: The completed Bulk DC Power Supply and Power Output Stage.

initial impulse ignites the Hydrogen plasma discharge within the ion source and sustains it for the required main beam duration. After the plasma is ignited it must be allowed to stabilise for 400 – 500 µs before ion beam can be extracted. The level of current supplied to the plasma during the pulse has a direct effect on the temperature of the plasma and consequently the extracted ion beam current. The current output pulse therefore needs to be able to be variable in order to optimise for the manufacturing tolerances of different ion-sources and to accommodate ion-source design changes. The variable pulse amplitude is achieved by operating the IGBTs in their linear region as Transistor current sources. IGBTs are usually operated in saturation as switching devices, it is therefore necessary to have a several devices in parallel in order to achieve the required current. When operating Transistors in parallel special precautions must be taken in order for the individual devices to share current correctly and not cause thermal runaway. This is done by adding a 0.1 Ω Resistor in series with the emitter of each device used in parallel (a) and using the voltage drop across this resistor as a negative feedback to stabilise the drive voltage to that individual device. [2] The current demand signal for each IGBT device is sent from the main control PCB using a differential line driver and corresponding receiver in order to provide immunity to noise and voltage spikes from switching events. It is then distributed to a dedicated high current OP-Amp driver PCB that is mounted on each individual device (b). The differential receiver and driver boards are operated from a floating +/- 15 V power supply. In order to be certain of the devices turning off when there is no current demand between pulses the gate is driven to a negative voltage. The positive 15 V rail is also interlocked using a solid-state relay, this is to prevent turn-on in the event of an over current detection or any machine interlocks opening. With the splitting of the system into bulk power supply unit and output stage, it has been possible to provide dedicated energy storage capacitors (c) for each bank of IGBTs, in order to try to minimise the stray inductance, heavy duty copper bus bars have been used and the capacitors located close to the power rails and output terminal, this is shown in Figure 3.

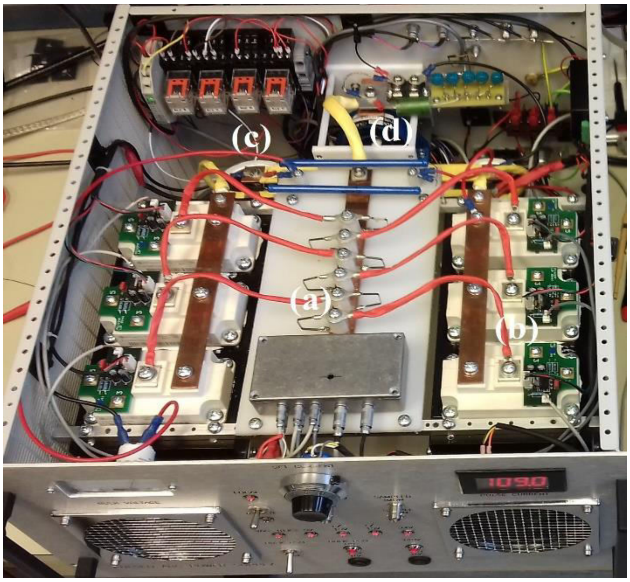

Figure 3: Power Output Stage.

Output current is measured using a Hall-Effect compensated closed-loop current monitor that can measure currents from DC to 150 kHz (d), within the controller this signal is sampled by a sample-and-hold circuit and output using a BNC connector. It is also displayed on the front panel seven-segment LED display. Previous systems have made no provision to operate in a closed-loop current control mode due to the complex electrical characteristics of the Hydrogen plasma discharge, however the development system described here will enable future experiments in this area.

DISCUSSION

The completed system has at time of writing only had initial setup and tests performed, it has not yet been tried with a real ion-source load. Performance during testing with a resistive load has been promising, the expected pulse width and amplitude of 700 µS at 50 A was achieved. However due to a failure of the resistive load no further testing has been possible. Part of the motivation to construct a development power supply was to investigate the differences between IGBT devices of different manufacturing batch and generation as they may exhibit variations in electrical characteristics, for example gate capacitances. Figure 4 shows an oscilloscope trace of the ion-source current pulse from a previous generation power supply with sharp leading edge and some overshoot.

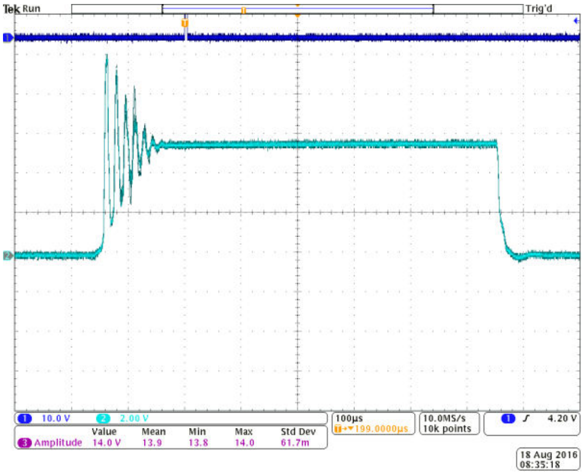

Figure 4: Current Pulse, Sharp Edge.

Figure 5 shows an oscilloscope trace of the current pulse from a new generation power supply, it can be seen that the leading edge is not as sharp, although the cause of this is not currently understood, it is potentially due to the variance in IGBT characteristics. This could be confirmed when the development power supply, which uses IGBTs from different manufacturer is tested with a real ion-source as a load and produces a comparable waveform. Another area of investigation will be to make changes to the gain values of the IGBT gate drive circuit to try to tune the driver to the characteristics of the IGBT.

CONCLUSION

A test facility for ion source plasma power supplies has been designed, constructed and tested. The design has reused a number of standard component from previous power supply designs that are currently in use, the aim of this was to make the test facility compatible with other power supplies. This will enable tests to be performed with real ion-sources on one of the test stands and the results compared with previous generations of ion-source power supplies. The test facility will be used for future development work on the power output stage, this will involve an investigation into the use of Field Effect Transistors as the active devices and any improvements that can be made to the drive electronics. Using the new ability to vary the bulk DC power supply voltage, an investigation will be made into the effect of increasing the bulk DC voltage on the ease with which a plasma can be ignited. The possibility of operating the plasma power supplies in a closed-loop control mode has been considered in the past, however the complex electrical characteristics of Hydrogen plasma have made this difficult and it was decided for engineering reasons not to use closed-loop control. This test facility provides an opportunity to return to the investigation of closed-loop control for this application in light of other work on control of IGBTs in linear mode [3], this would allow better accuracy and repeatability of the power supply output pulse and make investigations into other aspects of ion source plasma much more straightforward. Closed-loop control would also provide the ability to operate the plasma power supply in a more energy efficient way and reduce the large amount of power that is currently being dissipated as heat.

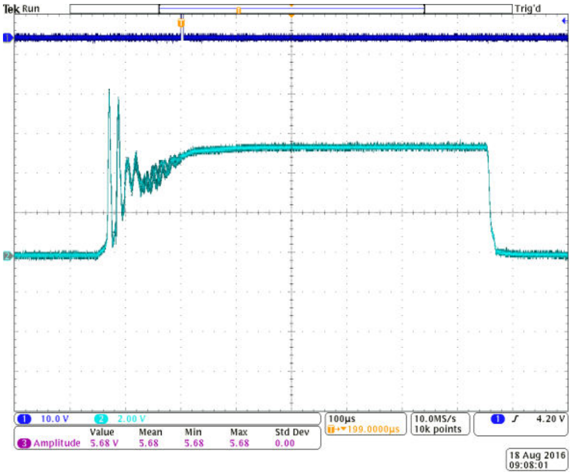

Figure 5: Current Pulse, Soft Edge.

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[1] M. Perkins, ISIS Ion-Source Documentation, internal ISIS document MPHB03.

[2] P. Horiwitz and W. Hill, The Art of Electronics, Cambridge University Press, 2nd ed., July 1989, pp. 213-214.

[3] J.M. Cravero *et al.*,"Control of high power IGBT modules in the active region for fast pulsed power converters", in *Proc. 15th European Conference on Power Electronics and Applications,* Oct 2013, pp. 1-8.