A PULSED ION SOURCE FOR THE IUCF COOLER INJECTOR SYNCHROTRON

V.P. Derenchuk, R.R. Kupper, H.R. Petri, G.P.A. Berg, R.J. Brown, W.R. Fox, D.L. Friesel, W. Hunt,
W.P. Jones, W.R. Lozowski, Indiana University Cyclotron Facility, Bloomington, IN 47408

Abstract

A pulsed source of H^- ions has been constructed with minimal cost and is currently being used for commissioning of the Indiana University Cyclotron Facility (IUCF) Cooler Injector Synchrotron[1]. A commercially available duoplasmatron, previously used with the IUCF cyclotrons, was modified for pulsed operation and has produced 25 keV H^- ion beams of up to 1 mA in an emittance of less than 0.38 π-mm-mrad normalized (80%) and can operate up to 10 Hz with 50 μs to 4 ms pulse length. A simple and economical pulsed high-power MOSFET circuit is used to drive the arc and the gas valve. The beam transport line to the 7 MeV RFQ-DTL[2][3], features an Einzel lens doublet immediately upstream to match the beam from the source. The design, development and performance of the ion source and beam transport line is presented.

1 INTRODUCTION

The IUCF 'Cooler Injector Synchrotron' (CIS), a 200 MeV fast cycling synchrotron (up to 5 Hz), is being commissioned at IUCF and will be used to inject beam into the IUCF Cooler ring[3]. In order to save on cost, it was decided to commission the system using an existing DC H^- duoplasmatron ion source, modify it for pulsed operation and to design and build in-house a 25 keV beam transport and diagnostics line. The RFQ was defined as having an acceptance of $\approx$1.0 π-mm-mrad (normalized to β*γ) with Twiss parameters of α = 0.87, β = 0.0137 mm/mrad, and γ = 128.2 mrad/mm. Beam pulses of 300 μA, into the RFQ acceptance, for 300 μs duration at 1 Hz to 5 Hz repetition rates were required.

The duoplasmatron was modified to operate in a pulsed mode by increasing the diameter of the anode aperture and adding a pulsed gas valve. Pulsed power for the arc and gas valve is supplied by a simple and economical MOSFET based circuit with a fast rise time and the capability to easily adjust the pulse length and power level.

An Einzel lens doublet was designed to match the duoplasmatron beam to the acceptance of the RFQ. Ray tracing calculations were performed to test the design and subsequent emittance measurements verified the calculations. The emittance scanner is a moving slit and harp assembly that scans across the beam. Figure 1 shows the layout of the ion source and low energy beam transport line.

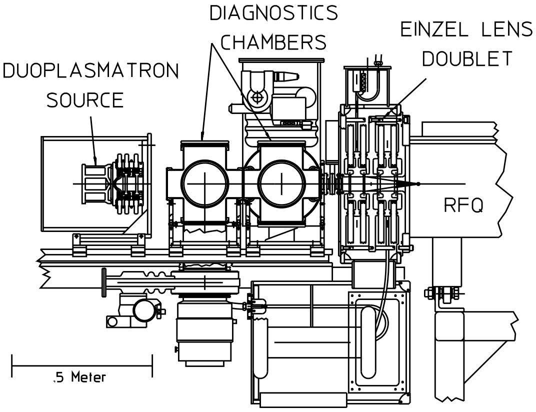

Figure 1: Pulsed H^- ion source and low energy beam transport line layout showing the Einzel lens matching doublet.

2 HARDWARE

2.1 Pulsed H^- Ion Source

One of the first reliable techniques of producing a pulsed low-emittance milliampere beam of H^- ions was by pulsing a negative hydrogen ion duoplasmatron[4]. In order to save cost and development time associated with starting up a source with technology new to IUCF, it was decided to modify one of the two negative ion duoplasmatrons previously used in DC mode.

The conventional General Ionex Duoplasmatron[6] was set up to operate in the pulsed H^- mode. Little modification to the source was necessary other than the use of an extraction aperture of 1.25 mm to increase the extracted beam intensity and allow for faster gas pumping from the large source volume. Originally, the duoplasmatron was designed to run at a maximum of 2.0 A of DC arc current. Due to the low duty factor, operation of the arc with a peak current of 40 A or greater is possible. During the CIS commissioning phase, the source is operated at 5 Hz and with a peak arc current of $\geq$35 A.

An automobile fuel injector gas pulser was first used to pulse hydrogen gas into the source. The fuel injector was very inexpensive but proved to be too variable from pulse to pulse. These valves also tended to leak slightly when closed which increased the average gas load. The fuel injector was later replaced with a General Valve Corporation 'Series 9 High Speed Solenoid Valve'[5] fitted with an optional 3 Ω solenoid. Using this valve and a MOSFET drive circuit, a gas valve repetition rate of over 100 Hz was demonstrated with pulse-to-pulse throughput variations no larger than 5% and a FWHM less than 160 μs. For oper-

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ation with the small aperture and large volume of the duoplasmatron, pulsed gas operation could benefit the beam intensity only up to a maximum repetition rate of 5 Hz.

2.2 Pulsed Power Circuit

A fast (few μs rise and fall time) MOSFET circuit was developed to supply the pulsed power needed for the gas valve drive coil and the arc current. Although the two loads are significantly different in character, the gas valve has a large inductance and the arc has an initially high impedance which drops to nearly the ballast resistance after the arc strikes. In both cases it is desirable to stabilize and control the current and easily adjust the pulse length. Both circuits, mounted in a 25 kVdc platform, provide excellent stability, reliability and immunity from source spark downs.

The driver circuit for the MOSFET receives its on or off signal from a low cost plastic fiber optic line. The driver itself limits the maximum on time and the maximum duty cycle to prevent damaging the power MOSFET as the peak power for valve operation exceeds 250 W. For the maximum arc current of 50 A and 300 V the peak power of the arc circuit is 15 kW. The arc drive circuit and the MOSFET switch are enclosed in a Faraday shield with full protection on the two external wire connections.

Power for driving the valve is derived from a small 75 Vdc regulated power supply. In this case, the MOSFET switch has active current limiting at 4 A. When the drive is removed, the inductive kickback is clamped by a 150 V power zener.

Power for the arc circuit (Figure 2) is derived from a voltage doubler with 120 VAC input and an 1800 μF storage capacitor on the output, resulting in about 300 Vdc, unregulated. The switch is in series with a current limiting ballast resistor and a 100 μH bifilar wound air-core inductor.

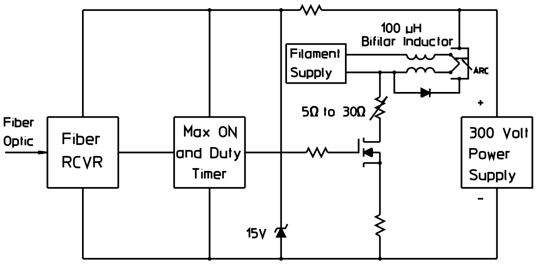

Figure 2: Circuit diagram of an inexpensive and compact pulsed power source for the duoplasmatron arc. The peak current and pulse length is easily adjustable.

2.3 Emittance Scanner

The emittance measuring system[7] consists of a 48 wire harp of 0.5 mm wire spacing 113 mm downstream of a 0.5 mm slit. The system is PC controlled and moves the slit and harp together in step sizes of 0.25 mm or 0.5 mm. Since the beam is pulsed it is necessary to collect data for a full scan over many beam bursts. For example, in taking 0.25 mm steps across a 3 mm wide beam a completed emittance scan will contain at least 12 beam profiles, each from a separate beam pulse. The pulse-to-pulse reproducibility is usually excellent but there is also a provision to signal average several beam pulses for each scanner position. The PC moves the slit and collects and stores the data from which ray angles as a function of position in the beam are then calculated off line.

2.4 Beam Transport Design

The beam transport line consists of an Einzel lens whose first ground electrode is also the extraction electrode of the ion source. An Einzel lens matching doublet is mounted physically onto the RFQ entrance flange, about 110 cm downstream from the ion source. Horizontal and vertical magnetic steering elements and a diagnostics chamber occupy the intermediate section of the beam line. The diagnostics chamber contains a biased Faraday cup, a BeO scintillator, a single dimension 48 wire harp and has provision for mounting the emittance scanner.

The emittance from the duoplasmatron was predicted using a charged particle optics design program, EMP/TRAK[8]. This prediction was used as input for the design of the matching doublet. Several Einzel lens designs, including a triplet, were considered. The matching turned out to be easy enough that it was possible to reduce the number of lenses to two in the final design. The requirement of a strongly convergent beam at the entrance of the RFQ was satisfied with voltages of 20 kV and 60 kV on the upstream and downstream lenses respectively. The lenses were finally designed to operate at up to 40 kV and 100 kV if necessary. Beam properties before and after the matching doublet were measured using a biased Faraday cup and the emittance scanner.

3 SOURCE OPERATION

3.1 Source Optimization

To optimize the peak beam intensity, it was found that the timing and width of the arc voltage and gas valve drive pulse were effective parameters. A timing program allowed one to vary pulse frequency, gas valve delay, gas valve duration arc delay and arc duration. Pulse rate, gas valve duration and arc duration were found to be the parameters that had the greatest effect on beam intensity. Output current was optimized at various pulse rates and combinations of gas valve and arc duration and delay. Other parameters varied were; the position of the intermediate electrode with respect to the extraction aperture, pinch magnet current, and the arc current.

The highest peak beam intensities occurred at 1 Hz or less for a gas valve drive pulse duration of 238 μs and an arc duration of over 3.0 ms, see Figure 3 for example. This optimal condition can produce a beam intensity of over 1.0 mA. This behavior is partly due to the ability of the pumping system to efficiently clear out the gas in the ex-

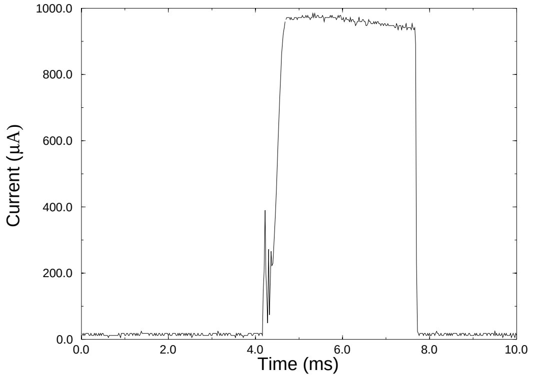

Figure 3: Beam pulse measured on a Faraday cup with ion source conditions typical for 1 mA operation.

traction region of the source before admitting a new pulse, decreasing stripping losses.

Rep Rate (Hz)	1	5	10
Pulse Length (ms)	3.5	1.0	1.0
Peak Beam (μA)	950	620	350
Arc Current (A)	40	40	40
Average Pressure (10^{-5}mbar)	4.7	6.7	6.7

In order to produce noise free, stable beam from pulse to pulse, it was necessary to start the arc in advance of the pressure maximum of the gas pulse. When the arc was struck in this starved mode, the source was less apt to spark and the beam flat top was free of 10 kHz to 60 kHz noise. Later runs were made with much shorter arc durations, on the order of 300 μs at 5 Hz and 10 Hz rates and 620 μA and 350 μA beam intensities respectively. Table I above includes some typical operating values after the addition of a second 500 l/s turbo molecular pump. Emittance measurements were taken with the single pump source configuration.

3.2 Emittance Measurements

The goal of the emittance measurements was to ensure that the RFQ matching lenses were capable of providing beam within the RFQ acceptance for varying source conditions. In particular, the lenses were varied through the predicted values for best matching to the acceptance. A 'best fit' ellipse was calculated for each set of data and the 80% contour used to display the emittance envelopes.

Figure 4 shows a series of three data sets, C 106 to C 108, which refer to measurements in the horizontal plane where the lenses were adjusted through the calculated matching value. The measured beam fits well within the acceptance limits. The normalized vertical emittance was measured to be 0.38 π-mm-mrad and the horizontal emittance 0.21 π-mm-mrad.

The error in these measurements is due to a quantization error that arises from the fixed linear and angular steps in the emittance data. Also, the resolution is dependent on the slit width and the distance between the slit and the harp.

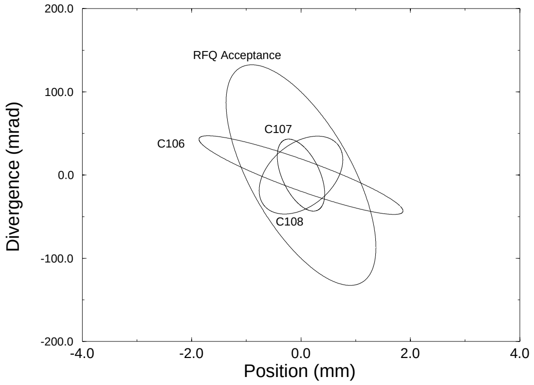

Figure 4: Emittance envelopes of the beam drifted from the emittance scanner back to the RFQ entrance for three settings of the matching lenses.

Using the mathematical formalism developed by Ludwig et. al.[9], it can be calculated that these measurements overestimate of the emittance area by about 25%. The plots are not corrected for this error.

Transmission measurements during initial operating tests of the RFQ-DTL have confirmed the expected matching[3].

4 ACKNOWLEDGMENTS

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5 REFERENCES

[1] D.L.Friesel and S.Y.Lee, 'Status of the IUCF Cooler Injector Synchrotron' this conference, 8B 5.

[2] 7 MeV RFQ-DTL was purchased from AccSys Technology, Inc., 1177 Quarry Lane, Pleasanton, CA 94566.

[3] D.L. Friesel, R.W. Hamm, 'Commissioning of the IUCF 7 MeV H^- LINAC' this conference, 3W 31.

[4] M.A. Abroyan, G.A. Nalivaiko and S.G. Tsepkin, 'Pulsed Source of Negative Hydrogen Ions', Soviet Physics-Technical Physics Journal, **17**(4), 690, October 1972.

[5] General Valve Corp., 19 Gloria Lane, P.O. Box 1333, Fairfield, NJ 07004.

[6] Peabody Scientific, P.O. Box 2009, Peabody, Massachusetts, 01960.

[7] M. Ball, V. Derenchuk, B.J. Hamilton, 'Beam Diagnostics in the Indiana University Cooler Injector Synchrotron', AIP Conf. Proc. **390**, 544.

[8] EMP 3.0 and TRAK 2.0, Field Precision, P.O. Box 13595, Albuquerque, NM 87192.

[9] T. Ludwig, K. Volk, W. Barth and H. Klein, 'Quantization Error of Slit-Grid Emittance Measurement Devices', Rev. of Sci. Inst. **65**(4), 1462, April 1994.