INITIAL COMMISSIONING OF THE RUTHERFORD APPLETON LABORATORY (RAL) SCALED NEGATIVE PENNING ION SOURCE

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Abstract

A new high duty factor, scaled Penning surface plasma source is being developed at RAL. This paper provides initial commissioning results. A stable high-current (up to 100 A) pulsed discharge is obtained, but the anode overheats, caused by poor thermal contact at elevated temperatures. The overheating anode yields a noisy discharge, with low output current, and makes high duty factor operation impossible.

The performance of a thermal interface material for aperture plate (plasma electrode) cooling is detailed. An update on the cathode heaters is provided.

The anode to source-body fit is analysed at different temperatures for different combinations of mechanical tolerances. This offers insights when compared to ISIS operational sources.

A new anode with modified tolerance dimensions for improved fit is being manufactured and will be tested in June 2016.

INTRODUCTION AND MOTIVATION

The standard ISIS source has successfully delivered beam for ISIS operations for over 30 years. A variation of this source, with the same plasma dimensions is currently being used for the Front End Test Stand (FETS) at RAL [1]. However, the existing design cannot deliver the full 2 ms, 50 Hz, 60 mA beam requirements. Even with increased cooling the maximum discharge pulse lengths achievable with the standard ISIS electrode geometry are 1.2 ms at 50 Hz or 2.2 ms at 25 Hz [1]. Beyond these duty cycles there is too much droop in the extracted beam current.

Previous work [2, 3] indicates that increasing the surface area of the electrodes presented to the plasma should solve the duty cycle limitations. Increasing the surface area lowers the surface power density and reduces the sputtering rate. This is important for maximising the lifetime of sources for ISIS operations. The new scaled source described in the paper should deliver the full duty cycle requirements for FETS and produce higher beam currents.

A biasable aperture plate should reduce the co-extracted electron current and minimise space charge induced emittance growth in the extraction gap.

Cathode heaters will allow low duty-factor operation and aid start-up, by reducing reliance on the use of destructive DC discharges to achieve operational temperatures. This is especially important for FETS commissioning because daily source shutdowns are planned.

SCALED SOURCE DESIGN

The basis of the design is to double the linear dimensions of the plasma electrodes. This creates a 4-fold increase in electrode surface area and an 8-fold increase in plasma volume.

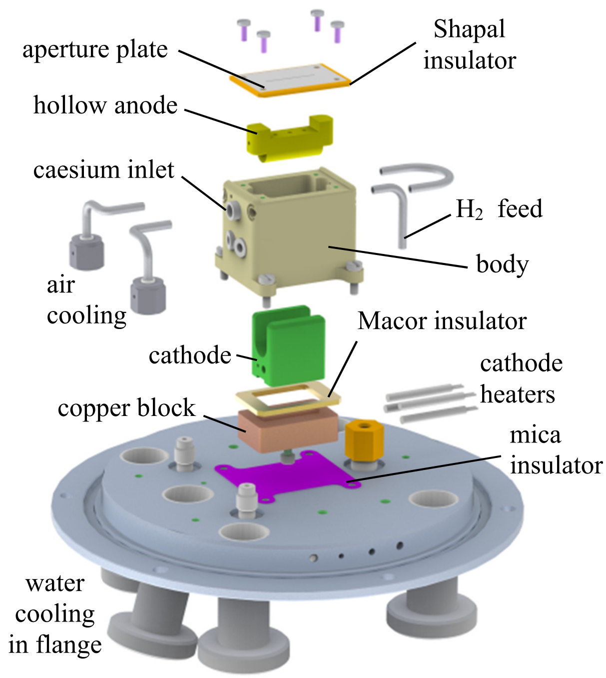

Figure 1: Scaled source exploded view.

Meanwhile, the external dimensions of the source are kept as compact as possible, limited by the requirement to fit the source on to an existing flange (Fig. 2).

Figure 2: Scaled source mounted on the flange with $Nd_2Fe_{14}B$ permanent magnets for Penning field and extraction electrode with support insulators.

INITIAL RESULTS

Start Up

The source cooling is able to maintain the temperature of the cathode at duty cycles up to 2.2 ms, but unfortunately the anode overheats even at low duty cycles. Figure 3 shows thermal contact between the anode and the source body is lost above 170°C.

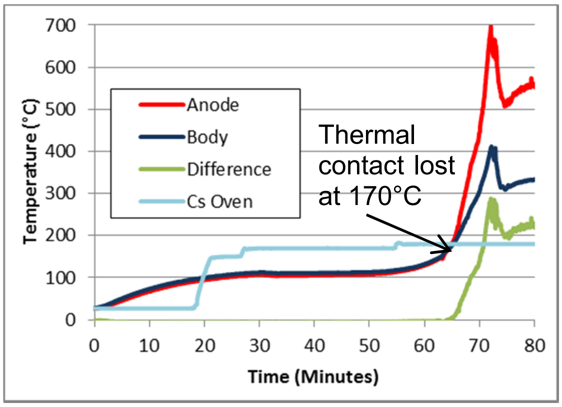

Figure 3: Scaled source start up temperatures.

Pulsed Operation

The source will run stably in pulsed discharge mode at low duty cycles, but the overheating anode causes the discharge current to be very noisy (Fig. 4) with a correspondingly noisy and low output H– current (~20 mA).

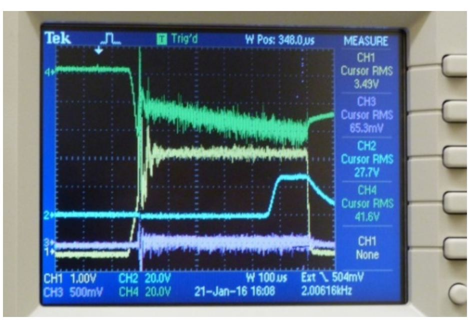

Figure 4: Noisy pulsed discharge.

CATHODE HEATER

The cathode heater can be used for startup and keeping the electrodes at the optimum operating temperature at low duty cycles. It consists of four FIRERODTM cylindrical heater cartridges (150 W total power) inserted into the copper block that the cathode is bolted to (Fig. 1).

Initial tests showed the heaters worked as planned, but after a few minutes of operation with the source plasma switched on the heater filament electrically shorted to its case, connecting the heater power supply to the discharge power supply.

To improve isolation a new copper block has been designed that will allow a mica sheet to be inserted between the cathode and the heater block. A ceramic screw will be used to bolt the two together. Delivery of the new block is expected in June 2016.

THERMAL INTERFACE MATERIAL

Biasable Aperture Plate

By applying a few volts to the aperture plate (plasma electrode) the co-extracted electron current can be reduced, in turn reducing space charge emittance growth. A Shapal ceramic insulator is used to electrically isolate the aperture plate to allow a bias voltage to be applied.

Aperture Plate Cooling

The aperture plate (like the anode and cathode), is a consumable item: it is slowly sputtered away. Therefore it is preferable to keep its design as simple as possible so it can be easily replaced. Integrated cooling pipes would make it too complex and expensive.

To improve the cooling, the surface roughness of the thermal interfaces has been improved from Ra = 0.8 µm to Ra = 0.4 µm and Pyrolytic Graphite Sheet (PGS) thermal interface material is introduced.

Pyrolytic Graphite Sheet

PGS is a thermal interface material which has high thermal conductivity (3-4 times higher than copper), and is made from a highly oriented graphite polymer film. The PGS interface material used is 75 µm thick and laser cut to size. They are under-dimensioned by 1 mm on the plasma chamber side so that no PGS material is exposed to the plasma.

PGS Testing

To test the effectiveness of the PGS thermal interface a thermocouple is clamped to the aperture plate using one of the mounting screws. Different configurations with and without the PGS material are tested.

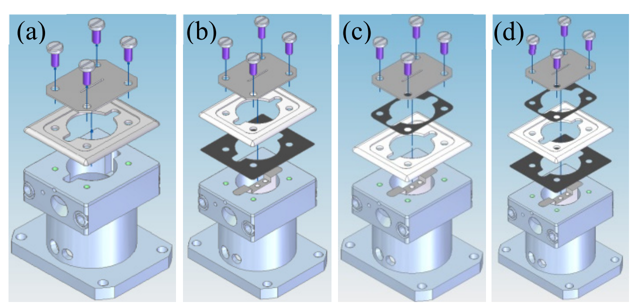

Figure 5: Different setups tested using PGS thermal interface in the thermal interfaces between the aperture plate, Shapal insulator and source body.

Table 1: Results of the PGS Interface Material Testing for the Different Arrangements shown in Fig. 5

Configuration	Aperture plate Temp (°C)	Source body Temp (°C)
Standard ISIS source	530	360-380
(a) No PGS	640	350
(b) Lower PGS only	490	390
(c) Upper PGS only	440	370
(d) PGS at all joints	420	360

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From the results shown in Table 1. It is clear that the use of PGS thermal interface material significantly reduces aperture plate temperature.

ANODE TO SOURCE BODY FIT

Anode Press

The anode and source body are designed to have an interference fit for good thermal contact. The anode is pressed into the source body at room temperature using a specially designed press. After the source has been baked out at 250°C and allowed to cool the anode is re-pressed.

Scaled Source Fit

The anode is made of molybdenum and the source body is made of 316LN stainless steel, they have thermal expansion coefficients of 5 and 16 $\mu m°C^{-1}$ respectively. The range of possible dimensions for the given tolerances of the anode and source body slot at 20°C are shown in Table 2.

Table 2: Specified Dimensions and Tolerances (in mm) for the Scaled Source

	Anode	Source body anode slot
Length	33.5	33.5
Tolerance	+0.02 / +0.01	+0.02 / -0.00
Shortest length	33.51	33.5
Longest length	33.52	33.52
Width	8.5	8.5
Tolerance	+0.028 / +0.020	+0.01 / -0.00
Shortest width	8.52	8.5
Longest width	8.528	8.51

The loosest fit will occur when the shortest anode is paired with the longest source body anode slot. Conversely, the tightest fit will occur when the longest anode is paired with the shortest slot.

Table 3 shows the anode length and width clearances. Above 130°C the loosest fit becomes a clearance fit and above 320°C even the tightest fit will become a clearance fit. Therefore anode thermal contact may be lost above 130°C and is guaranteed above 320°C. This makes the 170°C result shown in Fig. 3 unsurprising.

Table 3: Scaled Source Anode and Source Body Slot Clearances (in mm) at Different Temperatures

	Loosest fit		Tightest fit	
@20°C				
Length	0.010	CLEARANCE	-0.010	INTERFERANCE
Width	-0.020	INTERFERANCE	-0.280	INTERFERANCE
@130°C				
Length	0.051	CLEARANCE	0.021	CLEARANCE
Width	0.000	CLEARANCE	-0.018	INTERFERANCE
@320°C				
Length	0.121	CLEARANCE	0.091	CLEARANCE
Width	0.018	CLEARANCE	0.000	CLEARANCE

ISIS Operational Source

The same anode clearance calculations for the standard ISIS operational source are shown in Table 4. Loss of thermal contact is possible above 250°C and guaranteed above 725°C. ISIS sources run with an anode temperature between 360-380°C. This explains why occasionally some sources have a large temperature difference between anode and source body.

Table 4: ISIS Operational Source, Anode and Source Body Slot Clearances (in mm) at Different Temperatures

	Loosest fit		Tightest fit	
@20°C				
Length	0.010	CLEARANCE	-0.020	INTERFERANCE
Width	-0.009	INTERFERANCE	-0.027	INTERFERANCE
@250°C				
Length	0.068	CLEARANCE	0.038	CLEARANCE
Width	0.000	CLEARANCE	-0.018	INTERFERANCE
@725°C				
Length	0.191	CLEARANCE	0.161	CLEARANCE
Width	0.018	CLEARANCE	0.000	CLEARANCE

New Anode Dimensions

The anode length and width tolerances have been modified to +0.04/+0.03 and +0.048/+0.038 respectively. This makes loss of thermal contact possible above 320°C and guaranteed above 535°C. The anode could be made even larger, but then the risk of anode deformation during pressing is increased.

SUMMARY AND OUTLOOK

A stable pulsed discharge has been achieved at low duty cycles, but with an overheating anode. A new anode with modified tolerance dimensions for improved fit is being manufactured and will be tested in June 2016. The use of PGS thermal interface material significantly reduces the thermal contact resistance between key components allowing the implementation of a biasable aperture plate. An electrically isolated cathode heater system will also be tested.

REFERENCES

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