DESIGN OF A SCALED HIGH DUTY FACTOR HIGH CURRENT NEGATIVE PENNING SURFACE PLASMA SOURCE

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Abstract

The Front End Test Stand (FETS) at the Rutherford Appleton Laboratory (RAL) requires a 60 mA, 2 ms, 50 Hz H^- beam. The present source can only deliver the current and pulse length requirements at 25 Hz. At 50 Hz there is too much droop in the beam current. To rectify this, a scaled source is being developed. This paper details the new source design and the experiments conducted that are guiding the design.

FETS

The FETS project aims to produce a very high quality, perfectly chopped H^- ion beam as required for high power proton drivers. The beam parameters are 3 MeV energy and 60 mA beam current at 50 Hz repetition rate and up to 2 ms pulse duration.

DUTY CYCLE LIMIT

FETS uses a Penning Surface Plasma Source (SPS) [1] (Fig. 1). The current FETS source uses the same plasma electrodes, and has the same plasma volume, as the ISIS operational source. The operational source has successfully delivered beam for ISIS operations for 30 years. It runs with a 760 µs discharge pulse length at a 50 Hz repetition rate.

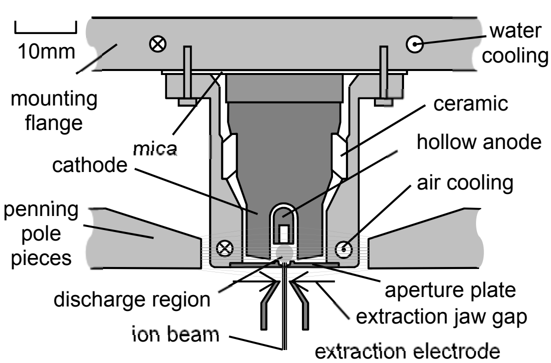

Figure 1: Existing FETS Penning SPS schematic.

FETS specifies a 2 ms 50 Hz 60 mA H^- beam. To cleanly extract a 2 ms beam it is necessary to produce a 2.2 ms long discharge pulse in the ion source. This gives the plasma 0.2 ms to stabilize before beam extraction begins. 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.

Although adequate for FETS commissioning, extra development work is required in order to meet the full FETS duty cycle requirements. ISIS is also interested in developing sources with longer lifetimes for ISIS operations.

NEW DESIGN

Scaled Source

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 will also reduce the sputtering rate and should yield longer source lifetimes. The proposed new design is shown in Fig. 2.

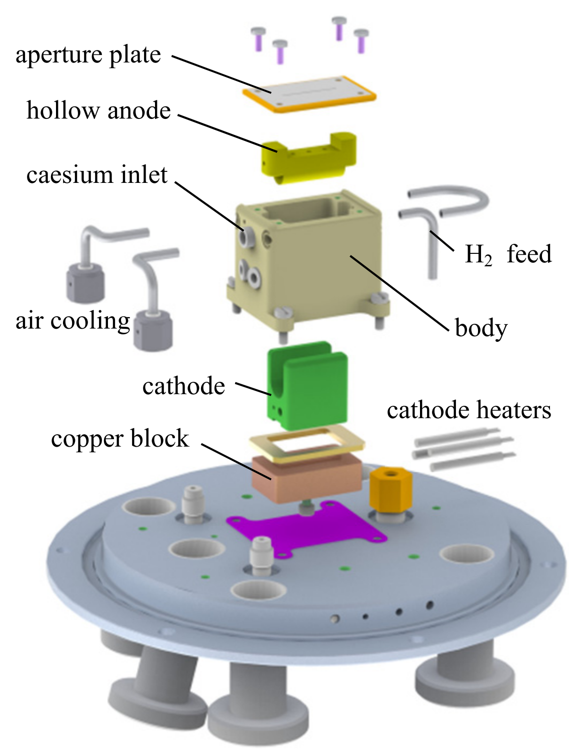

Figure 2: Scaled source exploded view.

The basis of the design is to double the plasma volume in each dimension, creating an 8 fold increase in plasma volume. 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. 3). The flange has three large $Nd_2Fe_{14}B$ permanent magnets on each side of the source body to produce the required 0.2 T Penning field.

Several other design features are also implemented including: a biasable aperture plate to improve emittance by electron suppression; improved cooling; and an electrode pre-heater to give longer lifetimes for multiple startups.

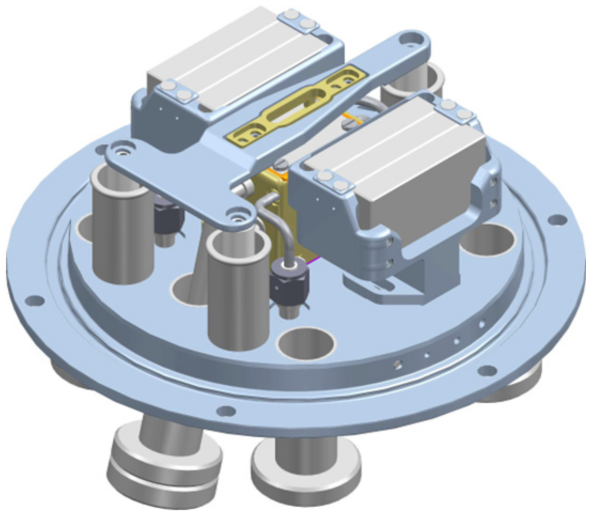

Figure 3: Scaled source mounted on the flange.

Thermal Model

It is essential to maintain the electrode surfaces within a range of temperatures for optimum H^- production [2]. A steady-state ANSYS simulation of the scaled design, (validated using the existing source design) is shown in Fig. 4.

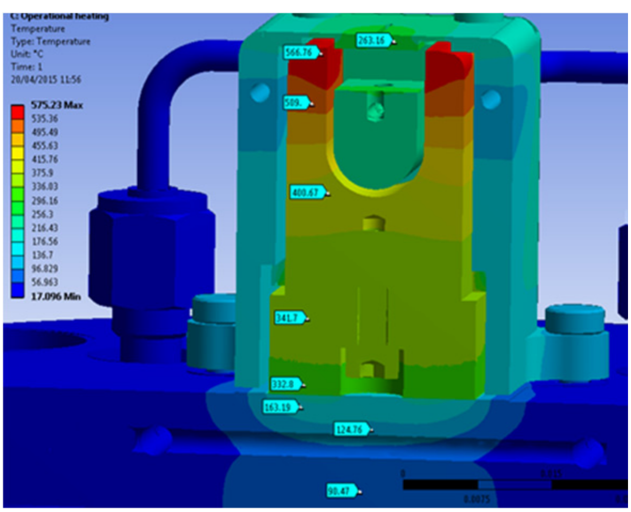

Figure 4: Cross section through scaled source steady state temperature simulation.

Cooling

In order to maintain the electrode temperatures in their optimum range at the higher duty factors additional cooling is required. Figure 5 shows the ANSYS computational fluid dynamic (CFD) simulations for the new cooling channels. Three parallel water cooling channels are implemented in the source flange.

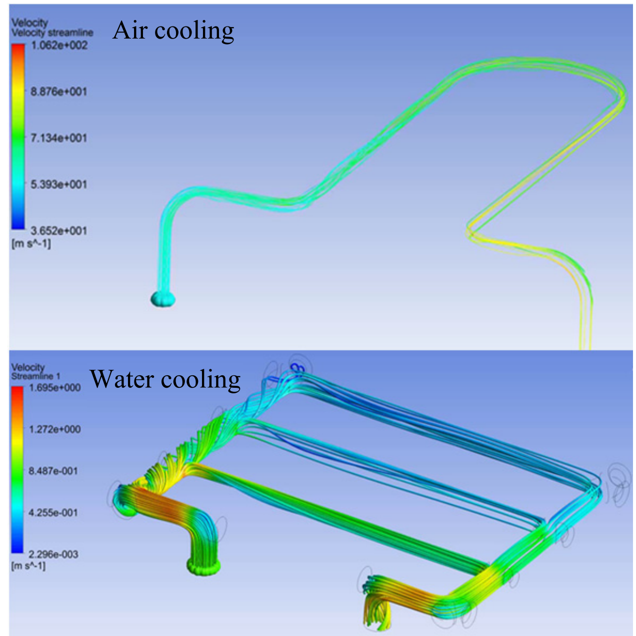

Figure 5: Air and water velocities in cooling channels calculated by CFD.

Biasble Aperture Plate (Plasma Electrode)

The positive high voltage (+17 kV) applied to the extraction electrode (Fig. 1) is used to extract the H^- ions from the source. Large numbers of electrons are also extracted and separated from the H^- ions by the stray Penning field. The co-extracted electron current is between 2 and 5 times the H^- current. The co-extracted electrons significantly increase the space charge forces that blow the beam apart.

By applying a few volts to the aperture plate (also called the plasma electrode) the amount of co-extracted electrons can be reduced and the beam blow-up reduced. This should result in a lower emittance beam.

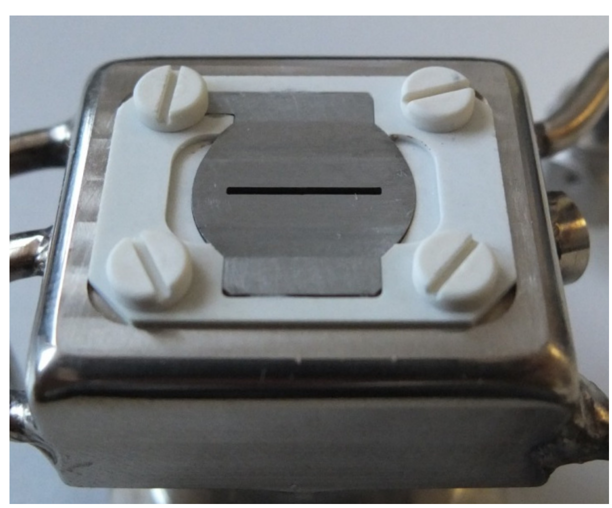

Figure 6: Biasable aperture plate before use.

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To allow a voltage bias to be applied to the aperture plate a ceramic insulator is made with a molybdenum insert as shown in Fig. 6. The molybdenum insert is bonded to the ceramic insulator with very high temperature glue and the ceramic is held to the source body with ceramic screws. Electrical contact is made by a tang that extends to one of the screws where a crimp connector is attached.

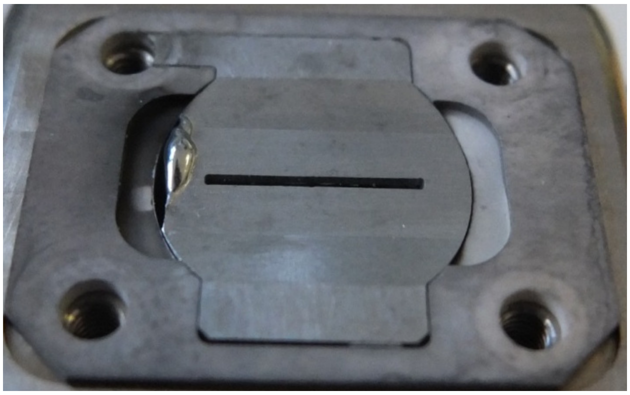

Figure 7: Biasable aperture plate after use.

When tested on a source the insert glowed orange hot and on later inspection exhibited signs of melting at one end (Fig. 7). This is most likely caused by the co-extracted electron beam being dumped on the already orange hot molybdenum. It was not possible to test the effect of biasing because the extracted current was significantly reduced and noisy, caused by the overheated aperture plate.

Aperture Plate Cooling

The biasble aperture plate experiment underscores the need to adequately cool the aperture plate. 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, so to improve the cooling, the surface roughness of the thermal interface between the aperture plate and source body has been improved from R_a <10 to R_a<1.

Cathode Heater

On start-up the electrode surfaces must be raised to operating temperatures (>400°C). This is achieved on the ISIS operational source by running a low current DC discharge for about 30 minutes. The DC discharge causes an appreciable amount of electrode sputtering, shortening the life of the source. For operational sources this life shortening is minimal because the source is only started twice: once for an initial caesation test, and again when installed on ISIS. During commissioning of FETS the source will be started each day because work will only take place during in normal office hours. After ten or more restarts the source begins to age, output drops, noise increases, caesium consumption increases.

If the electrodes can be preheated to operating temperature, or close to it, the length of time the electrodes are exposed to the DC discharge can be significantly reduced.

In normal high duty factor pulsed operation, the power in the discharge is more than is required to keep the electrodes at their operating temperature. However to run the source at lower rep rates and duty cycles, even with the cooling switched off, it is not possible to keep the electrodes at their operating temperature. By partially heating the electrodes it is possible to keep them hot enough even at very low duty factors.

Figure 2 shows cathode heaters installed in a copper block to which the cathode is bolted. The heaters are rated at 40 W each. Figure 8 shows the ANSYS simulation of the temperatures reached with all 4 heaters on. The initial design has 4 heaters, but up to 6 can be accommodated if necessary.

An air heater is also being considered. This will heat the anode up to operating temperature through the air cooling circuit.

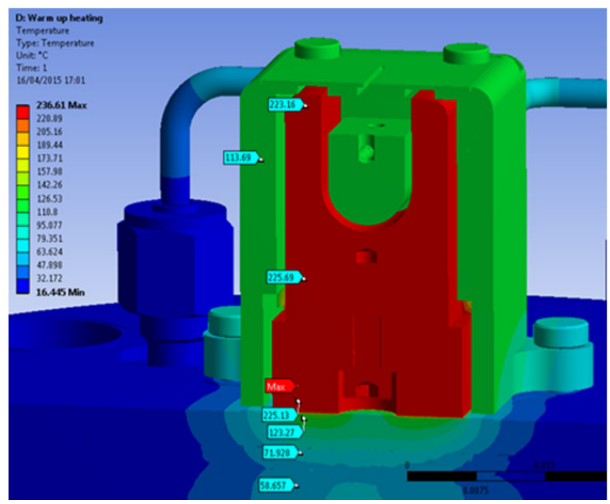

Figure 8: Simulated heating from the cathode heater.

SUMMARY AND OUTLOOK

A fully engineered scaled source is ready for manufacture. Tests on improved thermal contact resistance between the aperture plate and source body will be performed on an existing source this summer. The outcome of these tests will inform any design changes required, with the aim to have scaled source manufacture complete in autumn 2015.

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