DESIGN AND INTEGRATION OF A PASSIVE CAESIUM DELIVERY SYSTEM FOR THE ISIS RF H^- ION SOURCE

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Abstract

The ISIS Neutron and Muon Source has developed a new RF-driven H^- ion source to replace the caesiated Penning source in use since the 1980s. The new source operates without caesium and has achieved extracted beam currents of up to 18 mA. To increase the beam current further toward operational requirements, a passive caesium delivery system using Cs_2CrO_4 dispensers has been designed and integrated into the RF ion source. The system releases caesium by heating a Cs collar with the plasma, while forced-air cooling and thermocouples provide temperature control. This paper describes the design, materials, cooling approach, and manufacturing process used to convert the source to a caesiated configuration. Important design features include caesium distribution, thermal isolation between components, and cooling of the main flange. Future work will focus on commissioning the system and optimising caesium delivery for stable, high-current operation.

INTRODUCTION

The ISIS H^- ion source has used a caesiated Penning surface-plasma source since the 1980s [1]. To improve the ion source reliability and lifetime, an RF-driven volume-mode H^- ion source has been developed at ISIS [2] and currently produces extracted beam currents of up to 18 mA without caesium [3]. To reach the operational target current of 45mA (after the installation of a beam chopper), a passive caesium delivery system based on Cs_2CrO_4 dispensers has been designed and integrated into the source, following the approach used routinely at the Spallation Neutron Source (SNS) [4, 5]. This paper describes the system architecture, materials, thermal design, and the two manufacturing routes investigated for the main flange.

CAESIUM DELIVERY SYSTEM DESIGN

System Architecture

The caesium delivery system uses Cs_2CrO_4 dispensers housed in a slotted collar, with forced-air cooling regulating the operating temperature (Fig. 1). A spacer between the collar and the converter acts as a thermal break, allowing the two components to operate at different temperatures. The converter is isolated from the plasma electrode by ceramic balls, which provide both mechanical support and thermal insulation.

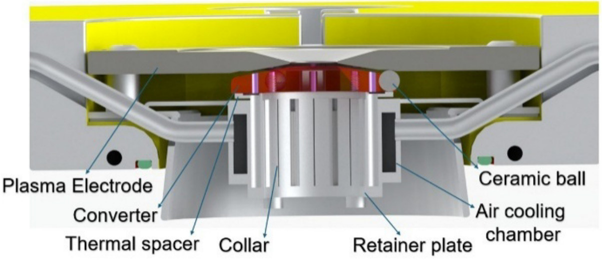

Figure 1: Caesium delivery system — cross section.

Materials and Instrumentation

The converter and plasma electrode are made from molybdenum because of its favourable interaction with caesium for efficient H^- production. The remaining components of the caesium system are manufactured from stainless steel 304. Four type-K thermocouples - two in the collar and two in the converter for operational redundancy - are integrated into the assembly to provide temperature monitoring and closed-loop control of caesium delivery.

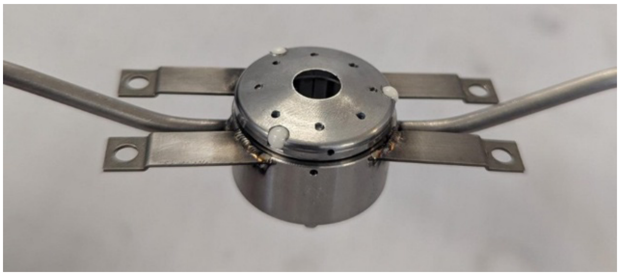

Figure 2: Collar and converter assembly.

Thermal Design

The thermal design is based on calculations for airflow rate, spacer contact area, and O-ring protection. During operation mode the airflow cools the collar from its 550 °C caesiation temperature down to approximately 200 °C, while a thermal-break spacer (25 % contact area) limits heat transfer from the plasma-heated converter and allows it to sit at its 350 °C operating set-point. O-rings located near the heated region are protected by a heat shield and a layered stainless-steel sleeve, which together extend the heat-conduction path and keep elastomer temperatures within safe operating limits.

The airflow rate was sized from a steady-state sensible-heat balance, $\dot{Q} = \dot{m} c_p \Delta T$, where $\dot{Q}$ is the plasma-deposited heat load on the collar (50kW at 2% duty factor), c_p is the specific heat capacity of air at the film temperature, and ΔT is the permissible air temperature rise across the cooling chamber. The convective heat-transfer coefficient between the collar and the cooling air was evaluated from the Dittus–Boelter correlation, $Nu = 0.023 Re^{0.8} Pr^{0.4}$,

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applied to turbulent flow in the annular gap of the cooling chamber. To maintain the collar at 200 °C during operation, a volumetric flow of 20 L/min was sufficient to reject the collar heat load, and the design point was confirmed by verifying $h\cdot A\cdot(T\_collar - T\_air) \geq \dot{Q}$.

The collar-to-converter temperature drop was set by treating the thermal-break spacer as a one-dimensional conduction path described by Fourier's law in resistance form, $R\_th = L / (k\cdot A)$, where L is the spacer thickness, k its thermal conductivity, and A the effective contact area. With the cooling system holding the collar at approximately 200 °C, the 25 % nominal contact area of the spacer - which enters directly through A and raises R_th by a factor of four relative to full contact — limits heat leakage between the cooled collar and the hot converter at the design heat flow.

O-ring temperatures were predicted using a series thermal-resistance network through the layered stainless-steel sleeve, with each layer contributing an $L/(k\cdot A)$ term. The sleeve extends the conduction path between the heated region and the elastomer and was found to reduce the O-ring-facing surface temperature by approximately 100 °C compared with an unsleeved configuration, holding the elastomer below its continuous service-temperature limit with margin.

Operating Modes

In caesiation mode the dispensers are heated by the plasma itself; the RF repetition rate and pulse length are increased until the collar reaches 550 °C, at which point caesium is released. The system then switches to operation mode, in which forced-air cooling is activated to hold the collar at approximately 200 °C while the converter sits at its 350 °C set-point for stable H^- production, with the thermal spacer maintaining the temperature gradient between the two.

MANUFACTURING AND ASSEMBLY

Manufacturing

Figure 3: Collar assembly with the main flange without retainer plate.

The collar slots for the Cs dispensers were produced by wire EDM to achieve the tight tolerances required for repeatable dispenser seating (Fig. 2). The forced-air cooling chamber was welded around the collar, and the connecting air pipework was bent to suit the main flange interface (Fig. 3). The thermal-break spacer was machined to give 25 % contact area with the collar and converter, minimising conductive heat transfer while maintaining mechanical alignment. The converter was machined and drilled to receive the ceramic isolation balls that decouple it from the plasma electrode.

Assembly

The caesium system was inserted through the ultra-Torr Swagelok fittings welded onto the flange (Fig. 4), after which the plasma electrode was assembled against the ceramic balls. Alignment and positioning of the caesium system relative to the flange was achieved using the heat shield features and support legs. Finally, the thermocouples were connected to the collar and converter via the thermocouple feedthroughs. Once the assembly was complete, the caesium system and flange assembly was installed into the ion source insertion unit (Fig. 5).

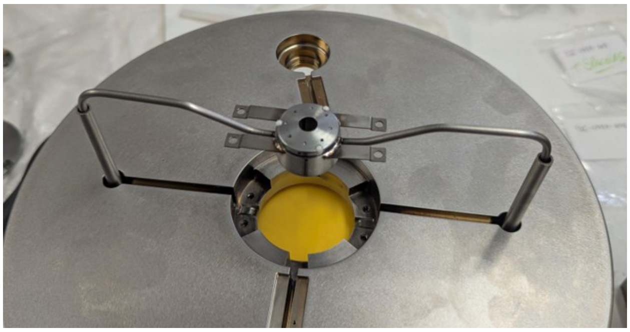

Figure 4: Caesium delivery system during assembly.

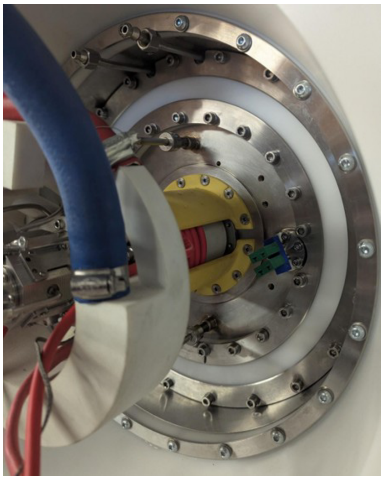

Figure 5: Caesium delivery system integrated with the RF source.

MAIN FLANGE – MANUFACTURING AND ASSEMBLY

Modifications

The existing RF ion source main flange was replaced with a new flange (⌀260 mm × 15 mm) that integrates the caesium delivery system, thermocouple feedthroughs, and a cooling channel positioned close to the inner O-ring groove. Two manufacturing approaches were explored: a conventional machining and brazing route, and an additive manufacturing route with post-machining.

Torch Brazing Route

The flange was initially machined with a relief feature, and a 1/8″ cooling pipe was silver-soldered adjacent to the inner O-ring groove (Fig. 6). Torch brazing was selected instead of vacuum brazing due to lower cost and shorter lead times. Post-braze inspection identified a small number of areas where full contact between the pipe and flange had not been achieved.

Figure 6: Main flange — machined and brazed.

Additive Manufacturing Route

In parallel, a metal additive manufacturing approach using DMLS in 316L stainless steel was developed, with the cooling channel printed conformally within the flange body. Following the AM design and validation methodology described in [6], a flange with an internal cooling channel was successfully produced (Fig. 7), with sealing and O-ring surfaces post-machined to meet fit and finish requirements.

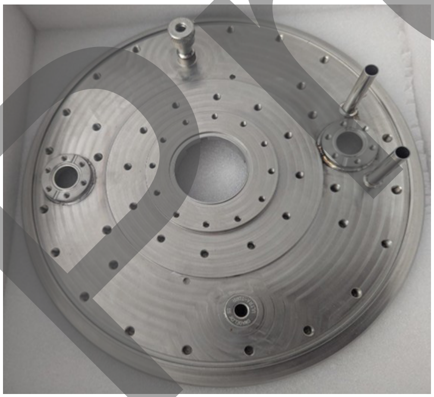

Figure 7: Main flange — 3D-printed and machined.

Comparison

Compared with the brazed assembly, the additive manufacturing route eliminates the braze interface, enables more compact cooling-channel routing, and offers improved cost and lead time. As a result, it is considered the preferred option for future builds.

CONCLUSION

A passive Cs_2CrO_4-based caesium delivery system has been designed and integrated into the ISIS RF H^- ion source. Key outcomes are summarised below:

- The system uses plasma heating for caesiation and forced-air cooling for operation, with closed-loop thermocouple feedback.
- Both torch-brazed and DMLS-printed main flanges have been manufactured; the additive manufacturing route is preferred for compactness, cost and process repeatability.
- Commissioning, performance characterisation and Cs-delivery optimisation for stable high-current operation are the next steps.

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