ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR19

PRACTICAL DESIGN AND MANUFACTURING OF THE NEW ISIS MEBT CHOPPER*

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Abstract

The electrostatic chopper for the new ISIS MEBT is a fast deflecting device which will create gaps in the beam coming out of the RFQ, which will improve the trapping efficiency when injecting the beam into the ISIS synchrotron. The fundamental design (including electromagnetic and thermal calculations, and sensitivity studies) are presented elsewhere. The practical aspects of the mechanical design and the assembly of the prototype chopper are presented here. This includes how challenges were resolved, such as insufficient transmission from the fibre thermocouples through the feedthroughs, ease of life design features, such as the use of o-ring screws, tests performed to feed into the analytical design and the promising progress made to date.

OVERVIEW

The chopper is located within the new ISIS MEBT. This area is densely populated with equipment, restricting the space available for the chopper. To summarise the details given in [1], the chopper is a 243 mm long, ±7.5 kV device, which chops away up to 40% of each H^- beam pulse to create smaller 'micro-pulses' and removes the leading edge of each pulse to create a squarer pulse shape. The chopped beam is dumped to water cooled tungsten beam dumps.

A vacuum level of 10^{-6} mbar should give a very low breakdown probability at the working voltage (and associated electric fields of <3 MV/m) [2], which is a much rougher vacuum than required by the nearby QWR RF bunching cavities (10^{-7} mbar). For this reason, no pumps are included on the chopper, instead relying on pumping via the QWR cavities. The chopper layout is shown in Fig. 1.

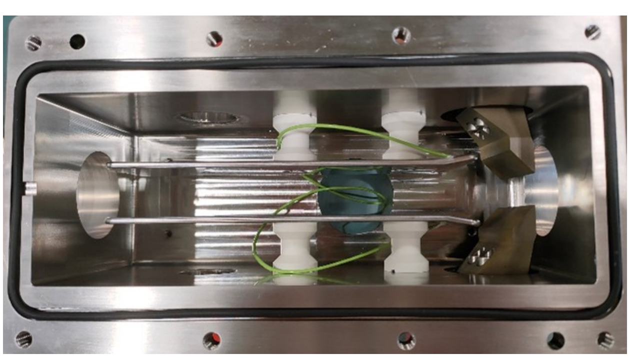

Figure 1: The internal components (excluding feedthroughs) of the prototype MEBT chopper.

COMPONENT DETAILS

Electrodes

The electrodes were machined from solid aluminium, with the 'flared' end described in [3]. These were machined with a surface finish of Ra0.8 around the radii and Ra1.6 elsewhere to reduce the risk of sparking. The electric fields within the chopper are not high enough to require more complex polishing processes.

Electrode Mounting

The electrodes were mounted using two machined Shapal insulators per electrode. Shapal was chosen for its machinability and high thermal conductivity, to maximise the heat transfer if the beam scrapes the electrodes, as described in [3]. To minimise the capacitances, the insulators should be as thin as possible, but to maximise thermal contact, they should be as large as possible (although it is likely that most of the heat may transfer to the insulators via the screws). This led to the cotton bobbin shape shown in Figs. 1 and 2 [3]. Tapers were added to the original design in [3] to minimise the risk of the brittle material fracturing.

These were fitted with Helicoil inserts and screwed to the electrodes and vessel. To maintain the vacuum when fixing them to the vessel, welded caps over the screw heads and threaded studs welded using a gun were considered, but ultimately, off the shelf o-ring screws were used , as they would make assembly and disassembly easier and enable more accurate alignment of the insulators. These were vacuum tested to 1×10^{-7} mbar and found to have an acceptable leak rate.

Despite the flared end, there is still a risk of a small amount of beam scraping on the electrodes at both ends [3]. This would lead to thermal expansion of the electrode, primarily at the downstream end. While this is expected to be very small, any larger than expected temperature rise could then lead to warping the electrode between the insulating mounts or fracturing of the mounts if the electrode is unable to expand. This has led to the use of a counterbored screw at the downstream end – meaning the electrode is able to slide past

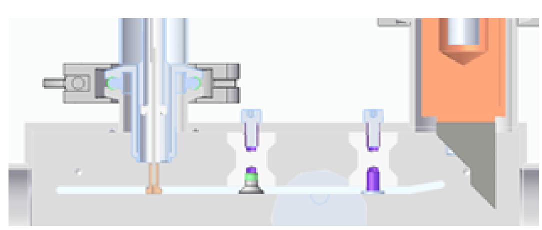

Figure 2: Chopper cross-section.

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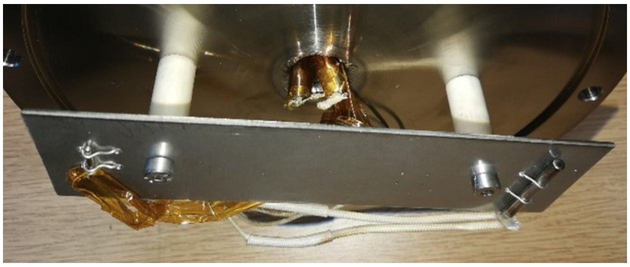

Figure 3: Insulator heat test setup.

the screw head (overcoming the friction from the clamping force) before warping. A countersunk screw is used at the centre to ensure that the electrode positions can't change through thermal expansion and contraction, Fig. 2. To keep track of this temperature rise, and prompt beam steering if it does scrape on the electrodes [4], a fibre optic thermocouple was also mounted on the back of each electrode, near to the flared tip. These were glued in place and routed out via a long KF port at the base of the chopper.

To demonstrate that there would be sufficient thermal conduction through the insulators, particularly considering the potentially poor thermal contact between the insulators and the electrodes/vessel wall, a rough test was set up as shown in Fig. 3. This used a cartridge heater to heat an aluminium plate with 4–20 W of power, in vacuum, (significantly more than the worst case 1.6 W beam loss predicted in [3]) and a thermocouple measuring the temperature at the other end. The standoffs used were Macor, not Shapal (lower thermal conductivity), and the contact area was very small due to an unintended angle between the surfaces, suggesting that most of the heat may have been transferred via the bolts/threaded inserts. Over the heat load range, this resulted in a steady-state temperature on the thermocouple of 61–119 °C, suggesting ample heat extraction, even in this non-optimal scenario. The results also guided the thermal contact resistance values used in [3].

Thermocouple Feedthroughs

To allow the fibre thermocouples into the vacuum, additional feedthroughs were needed. These thermocouples were added late in the design process, as an extra precaution, and so the only clear place for them was on the base of the vessel (in a space originally occupied by a vacuum pumping port, which was found to be unnecessary). This has resulted in an oddly long KF16 port for the thermocouple feedthroughs. The standard thermocouples are terminated with ST-type connectors. Multiple ST-ST thermocouple feedthroughs were tested, but none transmitted enough signal to be detected by the control system. Instead, SMA-SMA feedthroughs were used, with ST adaptors.

Electrical Feedthroughs

The feedthrough is an off the shelf item (Allectra 241-CON-SHV10), welded by the supplier to a custom KF flange around the tip, maintaining its 10 kV rating. To connect the feedthrough to the electrode, a barrel connector, designed for the feedthrough, was modified to press fit into the electrode. The length was reduced, and the outer diameter reduced and brought into a tight tolerance range to produce the desired interference fit. Unfortunately, variation in the outer diameter of the connectors meant that many were too small when it came to final manufacture (a minor issue not encountered during initial trials). Once the press-fit is completed and the rest of the chopper assembled, the feedthrough pin is carefully inserted into the barrel connector.

This doesn't allow for any significant movement or alignment correction. This meant that the feedthrough pin and electrode positions were tightly toleranced to ensure that there are no bending forces on the pin that could crack the ceramic within the feedthrough. It also means it cannot tolerate significant thermal expansion without risking cracking. This is one of the reasons why the feedthrough is at the upstream end of the electrode, where the temperature rise is expected to be negligible. Alternatives, such as using fingerstrips in a groove on the electrode or threading the end of the pin and screwing into the electrode were considered, but discounted due to the extra assembly and manufacturing complications they would introduce.

Beam Dump

The beam dump layout is given in [1] and the design details in [3]. Three design proposals were considered for the main body and sealing flange: (a) machine as one from solid copper; (b) machine as one from Glidcop; (c) machine the main body from copper and braze on a stainless steel KF flange. The reason for this is slight concern over the durability of a copper KF flange. Glidcop would be much tougher, but is expensive and hard to source. A steel flange would be a standard KF, but introduces the cost and risk of a brazing operation. Option (a) was tested by making and breaking the vacuum seal over 100 times. There was no visible damage to the flange, or impact on the vacuum leak rate. Should this prove to be an issue, nylon KF clamps are available which should prevent any damage to the copper flange.

The tungsten dump block will be positioned as close as possible to the beam, without scraping it, using copper shims. This will be done using thin shims during commissioning, then replaced by a single machined copper shim once the distance is finalised to maximise the heat transfer. A deep hole is to be included in the flange to allow the insertion of a thermocouple close to the dump, as shown in Fig. 4.

Vessel

The vessel itself has been machined from a solid block of stainless steel (304L), with various KF ports welded in place. It is sealed with an o-ring and a machined lid. The lid has 4 alignment points for target spheres on top and is dowel pinned into position to ensure the alignment between the target spheres and the beam axis is maintained if the lid is removed. The MEBT section has very little space (see Fig. 5, meaning that no bellows could be included in the

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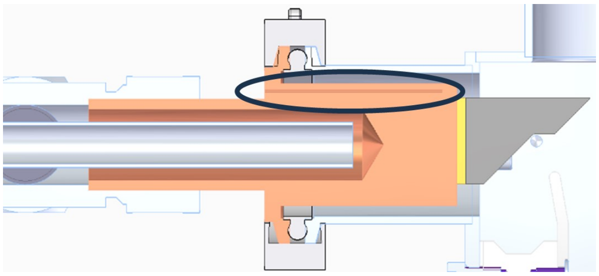

Figure 4: Beam dump with thermocouple hole circled and alignment shim in yellow.

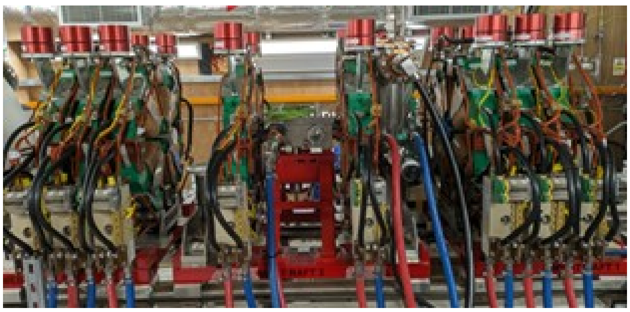

Figure 5: ISIS MEBT, with spaces for RF cavities.

design. This means it is crucial that there is very good axial alignment between the beam ports and the ability to align the internal components accurately to them, as there will be no scope to install the chopper off centre.

CHOPPER SUPPORT

Due to the tight space, the MEBT equipment is installed on 3 rafts, which can each be removed from the rails for maintenance. The chopper is substantially smaller than the adjacent magnets, so the height difference is made up with a simple welded steel frame, with mounting pads precisely machined after welding. The height on the beamline is then set using shims and laser alignment. This frame will also support the pulsed power supply, mounted as close as possible to the chopper vessel to minimise ringing.

PROTOTYPE

A prototype chopper has been assembled and leak tested, such as Fig. 6. The water circuit for the beam dump has been assembled and no major issues have been identified so far. The electrodes were mounted using a CMM to ensure good alignment to the beam axis ports. Since the electrodes have limited in built adjustment, the vessel and insulators were toleranced such that they should assemble in the correct position (to within the tolerances outlined in [3]). The barrel connectors were pressed part way into the electrodes by hand for the test assemble, and aligned well with the feedthrough pins, as shown in Fig. 7.

The overall assembly was awkward, due to the compact nature of the chopper, but quite achievable. Despite the limited adjustability and fragile feedthrough, this was assembled without difficulty. During alignment & doweling to

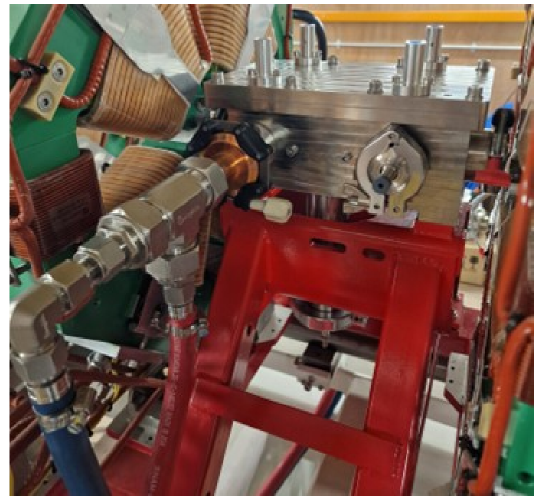

Figure 6: Prototype chopper in the MEBT.

Figure 7: Feedthrough to electrode test assembly.

the beamline, it was noted that the chopper support was not rigid enough, leading to minor movements of the chopper during alignment. The support was remade to a new design to avoid this.

FUTURE WORK

Once the power feedthroughs are properly connected, the next step will be to fully commission the chopper and set the position of the beam dumps (as described in [4]). This requires the pre-injector test stand to progress to the stage where beam is available to the MEBT, [5], (currently commissioning beam to the LEBT), and the pulsed power supply to finish development. This will allow the spacing of the beam dumps to be set, power tests to be completed and then beam chopping tests. Assuming no design changes are required, a spare chopper will then be made.

CONCLUSION

Following on from the analytical design work presented before, detailed, practical design aspects have been developed and a prototype chopper manufactured. This has resulted in a beam chopper capable of meeting the requirements outlined in [1]. Modifications have been made to improve this prototype and minor assembly work is still required ahead of beam commissioning, which is expected mid-2024.

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REFERENCES

[1] I. Rodriguez, S. Lawrie, and J. Speed, “Design of an electrostatic chopper for the new ISIS MEBT”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 2223–2226. doi:10.18429/JACoW-IPAC2023-TUPM016

[2] I. Rodriguez, “Chopper for the ISIS MEBT – Technical design report”, ISIS Neutron & Muon Source, Rutherford Appleton Lab., Harwell, UK, Sep. 2020.

[3] I. Rodriguez, S. Lawrie, and J. Speed, “Dimensional and thermal design of the electrostatic chopper for the new ISIS MEBT”, presented at IPAC’24, Nashville, TN, USA, May 2024, paper THPR17, this conference.

[4] S. Lawrie *et al.*, “The pre-injector upgrade for the ISIS H– linac”, in *Proc. LINAC’22*, Liverpool, UK, Aug.-Sep. 2022, pp. 398–401. doi:10.18429/JACoW-LINAC2022-TUPOJO21

[5] S. Lawrie *et al.*, “Status of the H– pre-injector test stand at ISIS”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 398–401. doi:10.18429/JACoW-LINAC2022-TUPOJO21