

Performance of cryocoolers in a High Temperature Superconducting ECR ion source (HTS-ECR) and its application for the High Current Injector Programme at IUAC, New Delhi

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Abstract At the Inter University Accelerator Centre, a high current injector programme (HCI) is being developed as an alternate injector to the superconducting linear accelerator (SC-LINAC). For this purpose, a high temperature superconducting ECR ion source, PKDELIS, based on Gifford McMahon cryocoolers was designed, installed and commissioned in the Low Energy Beam Transport section of the high current injector. The ion source will inject multiply charged ions having $A/q \sim 6$ for further acceleration into the downstream RFQ and DTL accelerators before final injection into the superconducting linear accelerator. The details of the design, and experimental results of the ion source together with performance of the cryocoolers are presented in this paper.

Introduction

A High Current Injector (HCI) [1] is presently being installed and commissioned in various stages of the project to further augment the beam intensities and energies than those presently available from the existing 15 UD Pelletron and SC-LINAC combination. The heart of the high current injector is based on a high performance, high temperature superconducting (HTS) 18 GHz ECR ion source called PKDELIS, which uses Gifford McMahon cryocoolers for cooling two HTS coils. The ion source has the capability to produce multiply charged ions for all elements throughout the periodic table. Ions having $q/A \leq 6$ will be further accelerated using radio frequency quadrupole accelerator (RFQ) and drift tube linear accelerators (DTL) before final injection into the superconducting linear accelerator. Further details of the source design can be found in the following references [2-4]. The constraints for this type of ion source is that it should be as compact as possible with minimum power and cooling requirements on a high voltage platform

With the advancement of technology of Gifford McMahon cryocoolers, most of the superconducting magnets have been designed using these cryocoolers, depending on the cooling requirements of the magnets. These cryocoolers broadly fall into two categories; viz., single stage cooling for magnets above 20 K or two-stage cooling for magnets which are designed for operation at 4 K. Together with these improvements, the high temperature superconducting (HTS) materials have gained more popularity over low temperature superconducting (LTS) materials due to their higher operating temperatures. Although the cost estimates are orders of magnitude higher than those of LTS materials, a one-time capital investment will minimize the long term power requirement for the system and the system is more compact. These types of cryocoolers which deliver cooling power at 20 K are commercially available and require a few kW of AC power. The advantage of HTS over LTS makes the system compact and simpler to construct, and make the system cryogen-free for operating the ion



source on a high voltage platform. The power consumption is reduced by a factor of 10 compared to room temperature ECR ion sources and water cooling requirements are further minimized. A schematic of the 18 GHz high temperature superconducting ECR ion source is shown in figure 1 depicting the connection of the cryocoolers with the HTS coils.

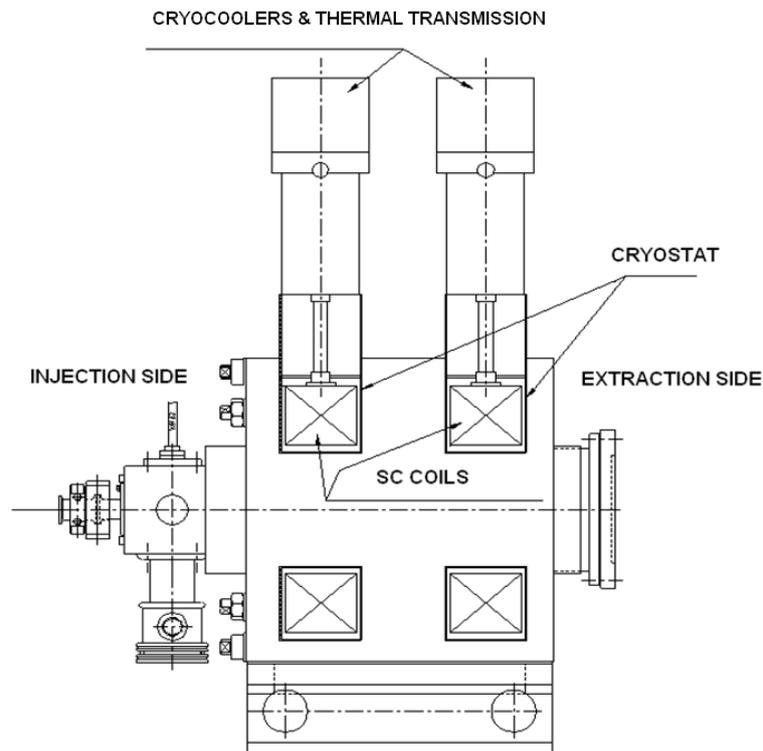


Figure 1. Schematic of the 18 GHz HTS ECR ion source

Details of the 18 GHz High Temperature Superconducting ECR ion source, PKDELIS

Table 1. Specifications of the HTS coils

Conductor	BSCCO-2223
Peak radial field	1.4 T
Inner coil diameter	240 mm
Outer coil diameter	320 mm
Operating injection current	181 A
Operating extraction current	145 A
Operating temperature	23 K
Number of pancakes	10
Number of coils	2

Cryo-cooler selection

The maximum heat load to be removed by the cryocooler is given in the following table below (Table 2.)

Table 2. Design heat loads for the 18 GHz HTS ECR ion source

Warm leads	16.0 W
Cold current leads	0.2 W
Radiation and internal coil heating	5.7 W
Supports	0.9 W
Contingency (20 %)	4.6 W
Total	27.4 W

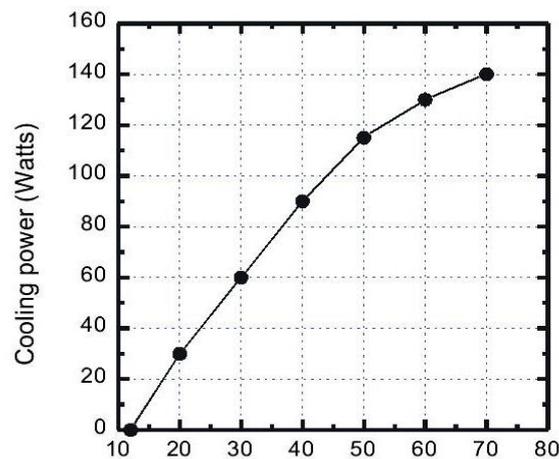


Figure 2. Cooling efficiency of AL230 cryo-refrigerator.

It can be seen that the maximum heat load is determined by the warm leads. For reliable operation of the magnet, the coil former must be below 29 K, and preferably 25 K or less. Since HTS materials are expensive, the aim was to operate the magnet at lower temperature and at higher currents using less of the HTS materials. The most cost-effective cryocoolers currently available which are suitable for this application are those manufactured by Cryomech, USA and the model AL230, a single stage cryocooler with a nominal capacity of 30 W at 20 K (Figure 2) was chosen [5]. From the operational characteristics supplied by Cryomech, USA, the cold head can be expected to operate at 21.0 K if the heat load is 27.4 W and the cooler is powered at a frequency of 50 Hz. The magnetic field experienced by the cold head of the cryocooler should be within the limits specified by the manufacturer to guarantee performance and reliability.

Performance of injection and extraction cryocoolers

The operational status of the injection and extraction cryocoolers of the 18 GHz high temperature superconducting ECR ion source is shown in figure 5 below, starting from the year 2003 until the present year 2016. Figure 3 depicts the temperatures in Kelvin achieved for the cold head and cold formers for the injection and extraction coils without iron shielding. Due to the absence of iron, the coil currents could not be ramped to maximum. On the other hand, typical operating temperatures of the coils during stable operation of the ion source were as follows. The cold head without load is typically 21.6 K and cold former is 20.8 K. The temperature increases roughly about 1 K with

dynamic load. Typical cool-down times are ~ 10 to 12 hours. The cryocooler operating pressures are in the range of 1.447 MPa to 1.723 MPa for the high pressure side and 0.413 to 0.551 MPa for the low pressure side. The vacuum in both the cryostats are in the operating region of high 10^{-6} mbar due to outgassing from cables in the system. Over the period of time depicted in figure 5, each cryocooler has operated on average about 5000 hrs per year. As depicted in the figure 4, both the cryocoolers have performed reasonably well, except for the major problem with the extraction cryocooler with a feeble sound of movement.

Over the course of time (during the year 2005 to 2006), the sound of the movement of the displacer in the extraction cryocooler became feeble, indicating something was restricting the movement of the displacer. At first, all possible external causes for the in-efficient cooling was ruled out before we embarked upon to open the extraction cryocooler. In the year 2006, after opening the extraction side, the displacer was closely inspected (Figure 6). It was observed that two of the three screws sitting at the bottom of the displacer were found to be loose, which resulted in an asymmetric gap causing restricted movement of the displacer. After replacing with a new displacer, the problem was completely solved.

In the year 2009, after a quite a long shutdown of the ion source and low energy beam transport section (~ 2 months), it was observed that the injection cryocooler could not be restarted. Due to the accumulation of moisture over time, it was observed that the displacer was swollen with moisture. After the moisture was pumped out, the cryocooler was put back in operation.

Both the air-cooled, cryocoolers did not have an option for an air filter. Therefore, due to the unfortunate dusty environment, the heat exchanger was clogged with dust over time and had to be replaced with new cryocoolers having an option with air filters. These air filters can be cleaned periodically to prevent the heat exchangers from getting clogged with dust.

A view of the complete system finally installed on a 200 kV high voltage platform for injection into the superconducting linear accelerator is shown in figure 7. The ion source is now fully operational on the 200 kV high voltage platform.

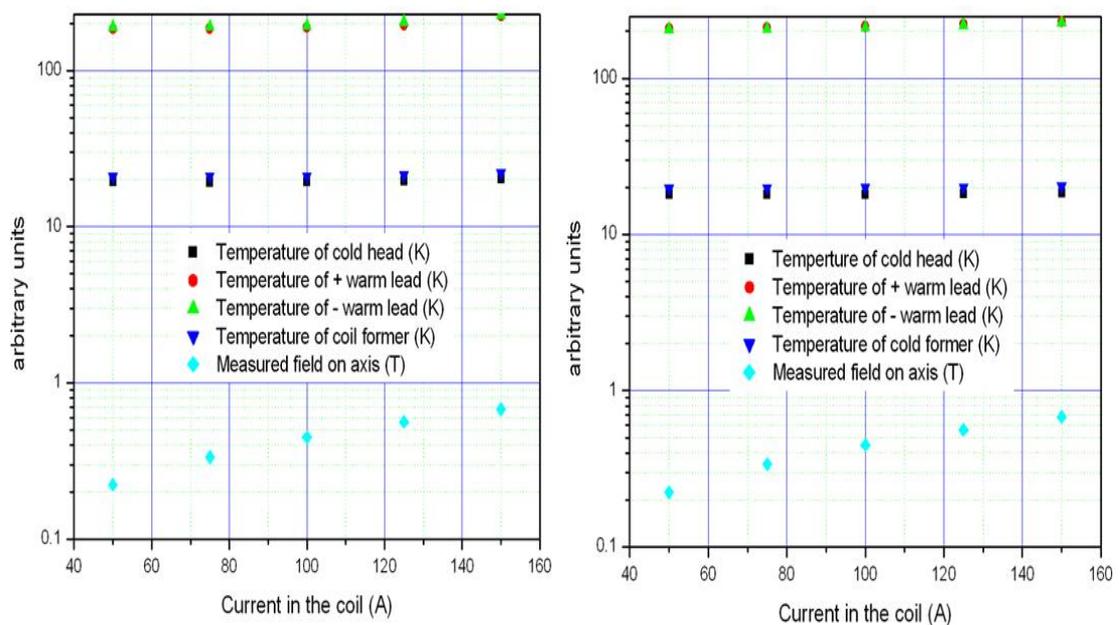


Figure 3. Temperatures of the cold head and cold former, without iron shielding as a function of current in the coil (left: injection, right:extraction)

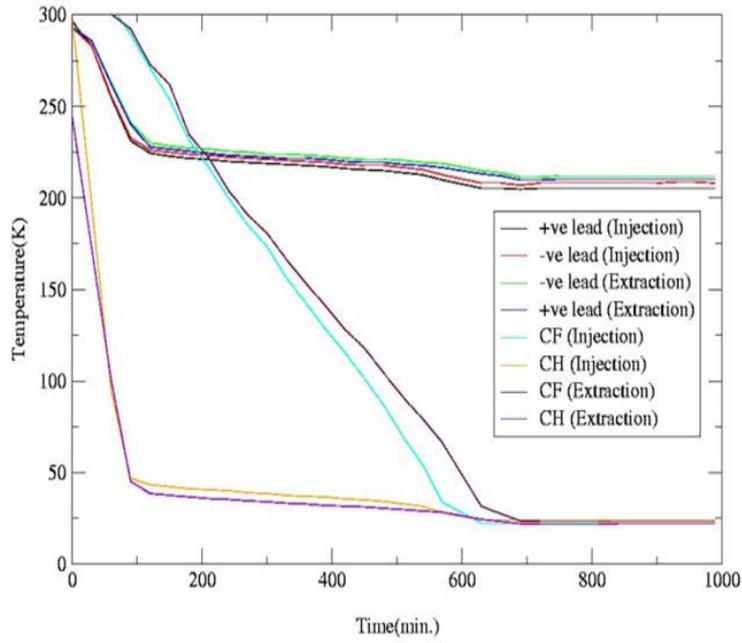


Figure 4. Cool down of cold former, cold heads and warm leads (CF:cold former,CH:cold head)

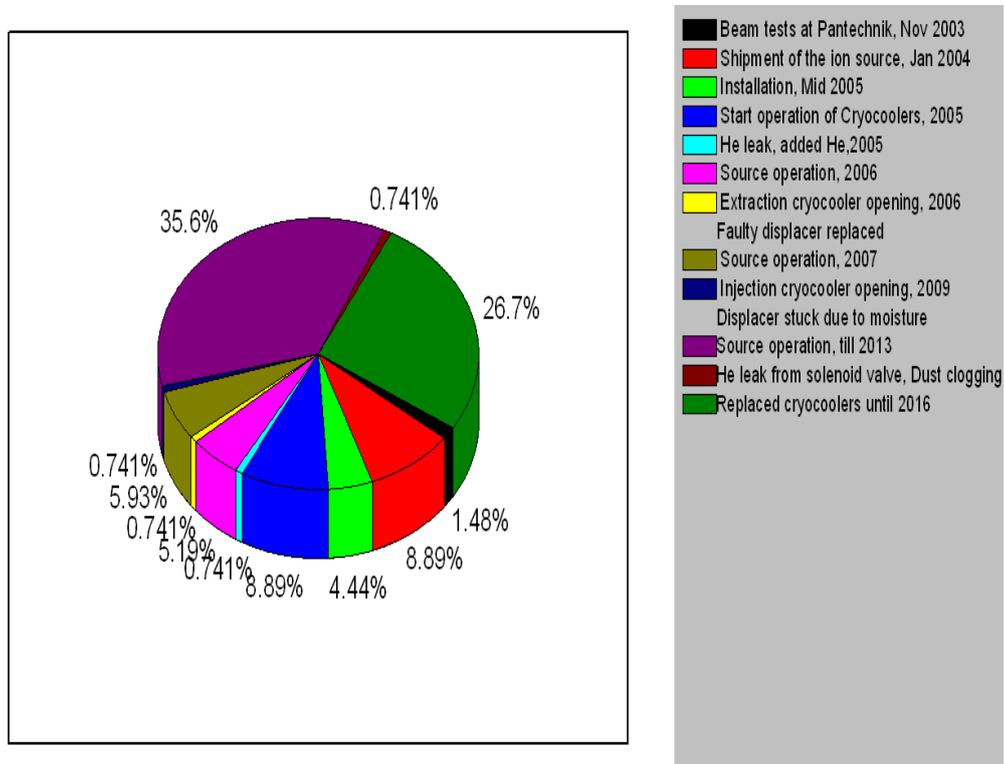


Figure 5. Pie-chart : brief history of operation of both cryocoolers from the year 2003 until 2016

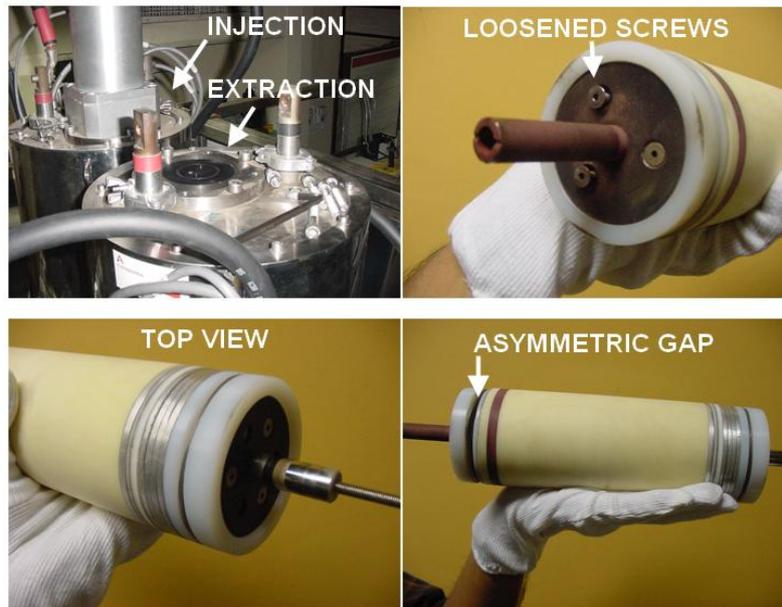


Figure 6. (top:left) Opening of extraction cryocooler; (top:right) View of the bottom part of displacer with loosened screws ; (bottom:left)View of the top part of the displacer; (bottom:right) Side view of the asymmetric gap in the displacer

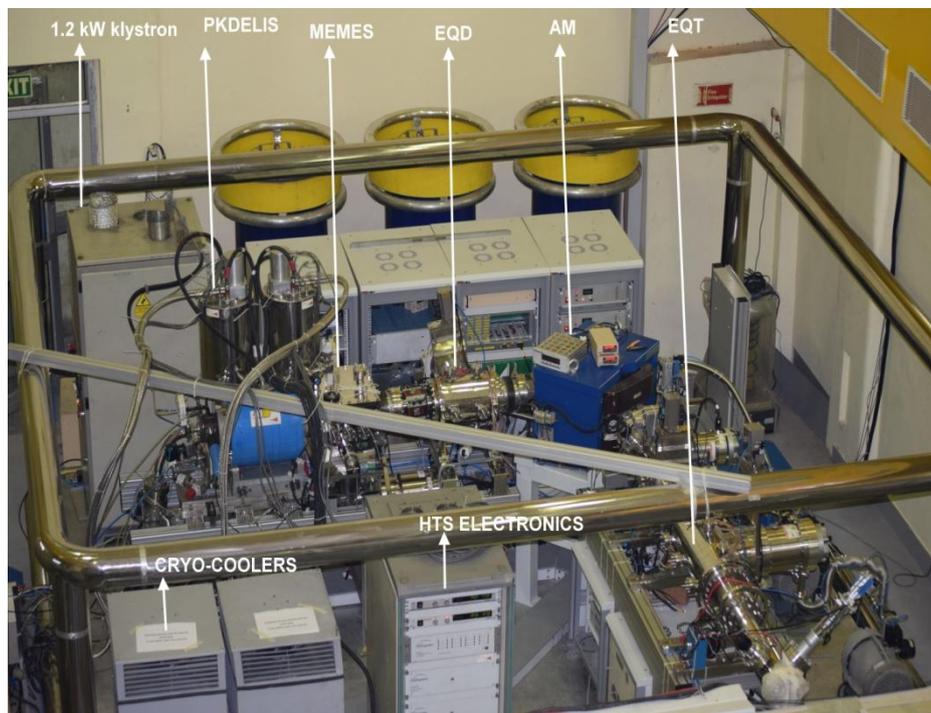


Figure 7. View of the 18 GHz high temperature superconducting ECR ion source, PKDELIS and low energy beam transport section installed on the 200 kV high voltage platform

Conclusion

The performance of both the cryocoolers have been very satisfactory. Although, there have been problems which have been encountered during their course of continuous operation, they have operated reliably for most of the experiments carried out with the ion source. In the near future, the High Current Injector Programme at the Inter University Accelerator Centre, is expected to be in full operation and the reliability will be partly dictated by the ion source performance. It is envisaged that these cryocoolers will be the work-horse to keep the ion source well performing.

Acknowledgements

The authors would like to thank Richard McMahon (ScientificMagnetics, UK), Nigel Ottman and Richard Dausman (Cryomech, U.S.A) for their help and advice.

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