PERFORMANCE OF THE FIRST HIGH TEMPERATURE SUPERCONDUCTING ELECTRON CYCLOTRON RESONANCE ION SOURCE PKDELIS

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Abstract

A new type of high temperature superconducting electron cyclotron resonance ion source (HTS-ECRIS) called PKDELIS has been developed as a collaborative project. The source is operational at 14 to 18 GHz and is suitable for use on a 300 kilo volt (kV) platform with minimum requirements of electrical power and cooling water. The design of this high performance positive ion source is based on the required mass to charge ratio of ~7 for the high current injector (HCI). PKDELIS is suitable to provide high current multiply charged positive ion beams for injection into the superconducting linear accelerator (SC-LINAC) after pre-accelerating the beams to matching energy using radio frequency quadrupoles and low velocity resonators. Since no cryogen can be transferred across the high potential of 300 kV, high temperature superconducting coils of Bi-2223 have been chosen to reduce the power and cooling requirements for producing the large axial magnetic fields corresponding to a frequency of 18 GHz. The HTS coils are operated in a superconducting mode in a temperature range of about 20 to 22 K by using Gifford-McMahon type cryo-coolers which can be placed on the high voltage platform The hexapole for producing the radial field is made of permanent magnets. The beam from the source will be mass analyzed on the deck using an air cooled magnet placed on the HV platform and subsequently accelerated up to suitable energy for subsequent transport and further acceleration to match with the energy required for injection into the superconducting linear accelerator. Some of the typical analyzed beams obtained from the source are 2.0 mA of C^{2+}, 2.037mA of O^{2+}, 2.044mA of Ne^{2+}, 1.023mA of Ar^{4+}, 617.0 μA of Ar^{7+}, 28.0 μA of Xe^{21+}, 27.0 μA of Ta^{25+}, 10.0 μA of Au^{28+} and 12.0 μA of Pb^{29+}.

INTRODUCTION

This high temperature superconducting electron cyclotron resonance ion source (HTS-ECRIS) called PKDELIS has been designed and developed to be operational at 14 to 18 GHz and suitable for use on a 300 kilo volt (kV) platform with minimum requirements of electrical power and cooling water. Other sources like SHIVA at the University of Tsukuba and RAMSES in RIKEN [1,2] which also untilise Gifford-McMahon type refrigerators for cooling the coils at much lower temperatures viz., below 5 K used conventional superconducting coils. The PKDELIS being operational at higher superconducting temperature (> 20 K) requires simpler cryostat. This source is suitable for operation on a high voltage deck.

DESIGN SPECIFICATIONS

The design of this high performance positive ion source is based on the required mass to charge ratio of ~7 for the high current injector (HCI) of NSC. PKDELIS is suitable to provide high current multiply charged positive ion beams for injection into the superconducting linear accelerator (SC-LINAC) after pre-accelerating the beams to matching energy using radio frequency quadrupoles and low velocity resonators.

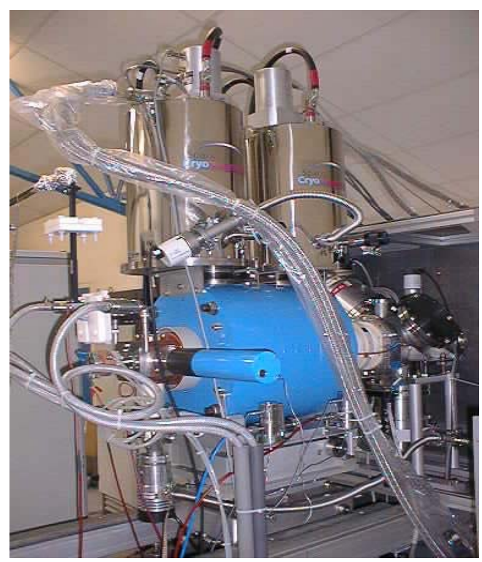

Figure 1: View of the HTS ECR ion source PKDELIS

HTS coils and Axial Field

Since no cryogen can be transferred across the high potential of 300 kV, high temperature superconducting coils of Bi-2223 have been chosen to reduce the power and cooling requirements for producing the large axial magnetic fields corresponding to a frequency of 18 GHz. The HTS coils are operated in a temperature range of about 20 to 22 K by using Gifford-McMahon cryo-coolers. The calculation of the axial field profile by the POISSON group of codes [3] using solenoid coils made of BSSCO-2223 HTS wires at an operational current density of 90 A mm^{-2} is shown in figure 3.

Radial Magnet Configuration

The hexapole design is based on the design of the Halbach [4] configuration and is made of permanent magnets comprising of Nd, Fe, and B. Surface treated magnets are to be used for high temperature and high humidity applications. The 3D calculations of hexapole fields using minimum possible values of B_r have been calculated for both 24 sectors and 36 sectors and the results are shown in figure 4 and 5. The design is aimed for maximum field using 36 wedge shaped magnets.

Figure 2: View of coil pancake

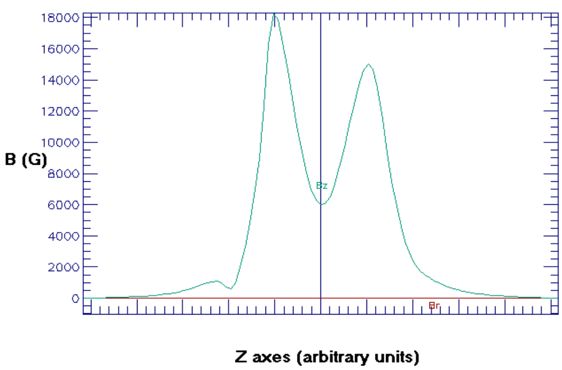

Figure 3: Calculated axial field due to the HTS coils

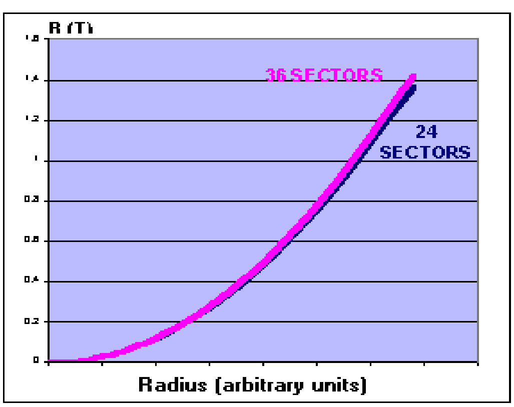

Figure 4: Radial field of hexapole

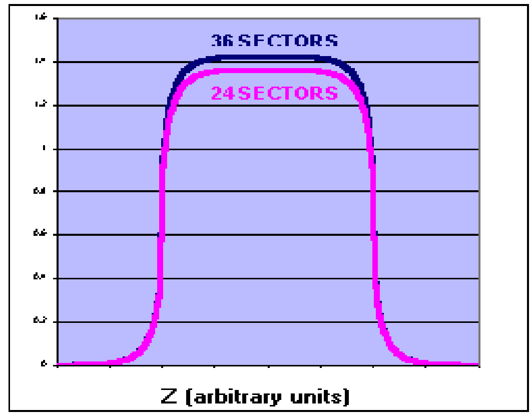

Figure 5: Longitudinal variation of radial field

Extraction System

The ion optical calculations of the extraction system in the presence of the strong axial field produced by the HTS coils has been worked out using the IGUN code [5].The total extraction system comprises of the plasma electrode, puller electrode, focus electrode and a last electrode with the same potential as the puller electrode. The puller electrode is polarised to a negative potential of -20 kV in order to obtain better optics. For example, trajectories of oxygen beams in various charge states, for an extraction voltage of 35 kV and puller voltage of -20 kV for total source current of 10 mA inside the puller electrode is shown in figure 6.

Source Configuration

The plasma chamber is made of high purity aluminium so that the oxide formation on the aluminium surface would possibly enhance the secondary electron emission properties of the source. High quality materials have been chosen for the iron yoke in order to achieve relatively high fields. The cryostat which houses the coils are manufactured entirely from 300 series stainless steel and is in two main sections.

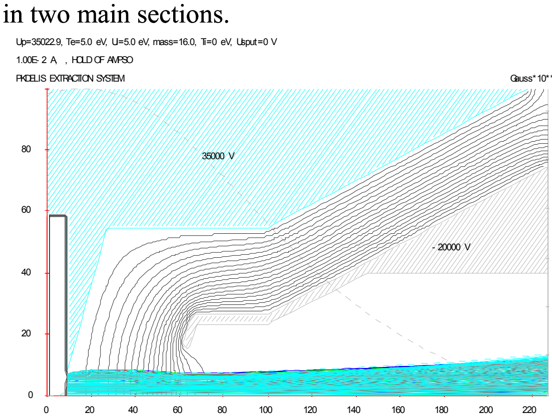

Figure 6: Optics of the extraction system

A very useful design feature is that access can be gained to the cryo-coolers without having to dismantle the iron yoke that the coils sit within. Each coil is made up of 10 pancake layers and wound as double pancakes and separated by epoxy-glass insulation. The coils are wound onto a high conductivity copper former for support and to provide a path for heat to be conducted away from the coils to the cold head of the cryo-cooler.

TEST RESULTS OF HTS COILS AND PERMANENT MAGNET HEXAPOLE

Fabrication and testing of the HTS coils were carried out at Space Cryomagnetics Ltd, UK. Each of the coils were tested stand-alone for reliability of continuous operation. The cool down process for the coils takes about 12 hours to reach the operating temperature. For example, when the individual coils were excited to 150 A, the equilibrium temperatures of the coil former for the injection and extraction coils were at 22 K and 20 K respectively. The test results for both the coils were found to be comparable. Figure 7 shows the axial field measurements at maximum currents of 181 A and 145 A on the injection and extraction coils respectively. The measurements show very well the agreement with the field simulations using POISSON and OPERA 3D.

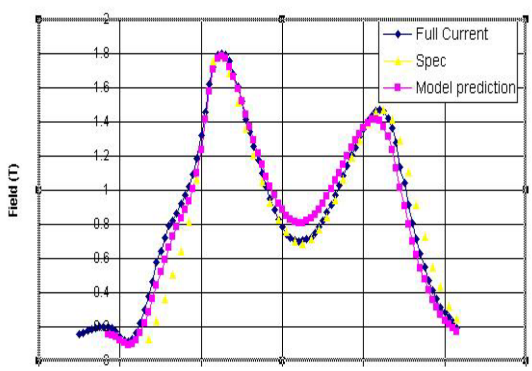

Figure 7: Axial field of HTS coils

The field mapping of the hexapole was done at the factory of Pantechnik. The measured radial field on the chamber wall was measured to be 1.35 T.

TEST RESULTS OF VARIOUS BEAMS

The beam tests were perfomed using the test bench of Pantechnik. 14.5 GHz and 18 GHz RF generators were used for the tests. A medium resolution dipole magnet having a total aperture of 50 mm pertaining to the chamber, and a multi-electrode extraction system were used for transporting and analysing the beams. For metal ions, a special micro-oven and sputtering system was used. Figure 8 shows the charge state distribution for ^{129}Xe optimised on $^{129}Xe^{14+}$. Table 1. shows some of the optimised beams which have been extracted successfully.

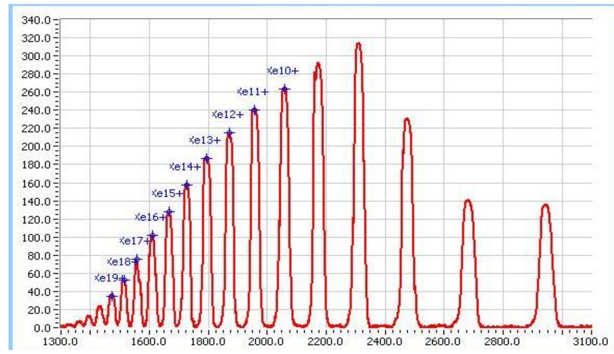

Figure 8: Charge state distribution for ^{129}Xe

Table 1: Extracted currents for various ions

Ion species	Rf power (Watts)	Beam current (eμA)
C^{2+}	597	2000
O^{2+}	193	2037
Ne^{2+}	391	2044
Ne^{3+}	391	1533
Ar^{4+}	496	1023
Ar^{7+}	488	617
Ar^{8+}	521	732
Xe^{14+}	614	157
Xe^{21+}	652	28
Ta^{20+}	426	65
Ta^{25+}	476	27
Au^{21+}	898	28
Pb^{29+}	738	12

CONCLUSION

The performance of the first high temperature superconducting ECR ion source is excellent. The use of BSSCO-2223 HTS wires for the axial field is very suitable for minimising the total power and cooling requirements of the source to be operated on 300 kV platform.

REFERENCES

[1] T.Kurita et al., Rev.Sci. Instrum. 71, 909 (2000)
[2] T. Nakagawa, T.Kurita, M. Kidera, M. Imanaka, Y. Higurashi, M. Tsukuba, S.M.Lee, M.Kase and Y.Yano, Rev. Sci. Instrum, 73, 513 (2002)
[3] POISSON/SUPERFISH group of codes, Los Alamos National Laboratory, Los Alamos
[4] K. Halbach, Nuclear Instruments and Methods, **169,** 1 (1980)
[5] R. Becker, Rev. Sci. Intrum., **63,** 2756(1992)