PKDELIS : AN ECRIS USING HIGH TEMPERATURE SUPERCONDUCTING WIRES AND OTHER SPECIALIZD ECRIS

C. Bieth[a] *, S. Kantas[a], P. Sortais[b], D. Kanjilal[c] , G. Rodrigues[c], S. Milward[d], S. Harrison[d], R. Mc Mahon[d]

[a)] PANTECHNIK, 12 rue Alfred Kastler, 14000 Caen, France

[b)] Laboratoire de Physique Subatomique et de Cosmologie, 53 avenue des Martyrs, 38026 Grenoble Cedex, France

[c)] Nuclear Science Centre, Post Box 10502, Aruna Asaf Ali Marg, New Delhi 110-067, INDIA

[d)] Space Cryomagnetics Ltd. , Building E1, Culham Science Centre, Culham, Abingdon OX14 3DB, United Kingdom

Abstract

Producing highly charged ions in an ECRIS requires high resonance frequencies, hence a high longitudinal magnetic field. Electromagnets can produce limited magnetic fields, bellow 2 Tesla, with a significant amount of electrical power, powerful DC power supplies and large cooling systems. As a consequence, producing highly charged ions with a source setup, at ground, is rather difficult and becomes a serious technical and financial challenge if the source is on a high voltage platform. The use of low temperature superconducting coils 'LTC' has a clear advantage when it comes to electrical power. A reduction factor of 10 to 20 in the total AC power is obtained. However, handling cryogenic liquids is a difficult and expensive issue. An elegant solution consists of using high temperature super conducting wire 'HTS'. Cryogenic generators with sufficient cooling power at 20 K are commercially available and need only few kWatts of power. In addition to that, the coils are very compact and easy to handle. The following paper presents PKDELIS, the first ECRIS, in the world, using HTS wires, jointly designed and constructed by PANTECHNIK and NSC 'New Delhi' and constructed by PANTECHNIK. ECR sources for other applications like mA proton beam, heavy ion beam for hadrontherapy, ion implantation and surface treatment are also presented.

INTRODUCTION

In the frame of a collaborative development project between PANTECHNIK and Nuclear Science Centre, a high performance ECR ion source 'PKDELIS' using high temperature superconducting wire HTS (BI-2223) for the longitudinal field coils, was constructed. The radial field is made of (NdFeB) permanent magnets. The HTS coils are operated in a superconducting mode at 23 K and connected directly to the two cryogenerators. Two identical cryogen free cryostats are used. PKDELIS will be used for ions injection (A/Q< 7) into a superconducting linear accelerator being constructed at NSC . PKDELIS is the first ion source, world wide, using the HTS technology. [1,2]

Other sources are developed and produced at PANTECHNIK for various applications like carbon and proton beams for hadrontherapy, nitrogen beam for surface treatment , boron and phosphorous for ion implantation, compact ECR ion sources for pelletron terminals. [3, 4, 5]

* Corresponding author. Tel.: + 33 (0) 231 951 379
Fax : + 33 (0) 231 951 391
E-mail address : claude.bieth@pantechnik.com

SUPERCONDUCTING ECR ION SOURCE PKDELIS

HTS solenoid coils and magnetic field

As the source will be placed on a high voltage platform, the electrical power and the cooling available were limited. The source design was optimized in order to keep the power below 20 kW rather than 180 kW and the cooling to 200 l/h rather than 3800 l/h.

BI-2223 high temperature superconducting wire was chosen for the construction of the two solenoid coils of the source. The HTS wire has a thickness of 0.3 mm, and a width of 4 mm. Each coil is composed of 10 similar pancakes. Calculations using simulation codes were done during the study and design phase. The most restrictive magnetic field limitation is the value of the field perpendicular to the wire surface. After the construction and successful test of a prototype coil, the two final coils were constructed. Tests of the coils, in their cryostats, with and without the iron yoke gave the expected results.

Hexapole for radial field

Rare earth element magnets (NdFeB) were used for the construction of the hexapole of the HTS ECR ion source. The typical residual magnetic flux density (Br) and coercivity (Hc) of the magnets are: 13.5 kG and 13.1 KOe respectively. A Halbach configuration using 36 magnets was chosen in order to have a higher radial field. The hexapole is 200 mm long, 70 mm inner diameter and 160 mm outer diameter.

Assembly and beam test

The source was assembled first at Space Cryomangetics in England, were the coils and the cryostats were constructed. (see Fig.1). Then the source was installed on the PANTECHNIK source test bench. The beam line of this test bench consists in a focusing lens after the extraction system, an analyzing dipole and a diagnostics box with Faraday cup and emittance measuring device. Preliminary results are summarized in Table 1
The Fig. 4 shows a typical Xe beam spectrum obtained at the image point of the analyzing dipole. Due to the lack of time, results were not optimized. We can reasonably expect a current of 1 mA of A8+ after a longer period of test.

PKDELIS HTS ECRIS was operated in afterglow mode with Oxygen beam O4+ and O5+, The peak value of the beam was 3 times higher than the DC value. For higher charge states factors of 5 are obtained. Fig.5 shows a typical afterglow diagram with a pulsed beam of 500 µS width.
Beam profile and emittance measurements were performed using a new diagnostic system based on multi-profile acquisition and beam envelope reconstruction. An example is given in figures 3,4.

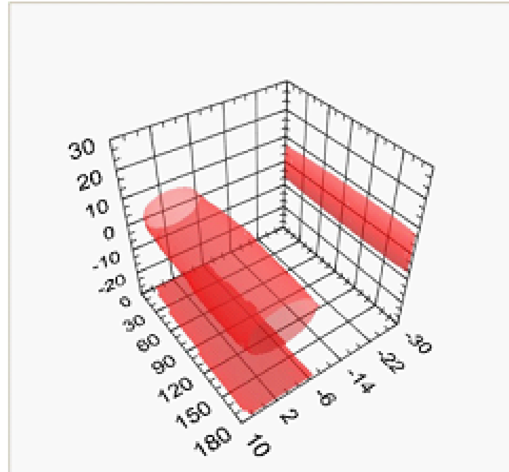

Figure 2 : Beam envelope of C2+

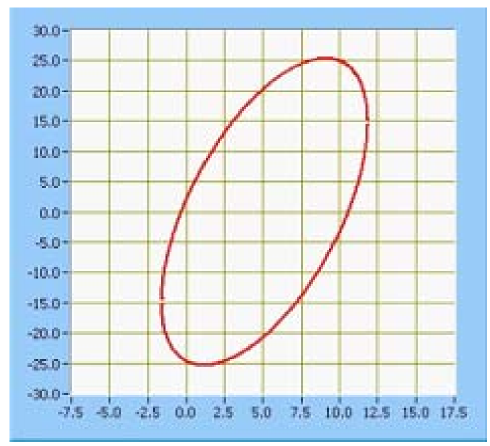

Figure 3 : RMS emittance of C2+ beam

Figure 1 : HTS coils and cryostat assembled with the iron yoke

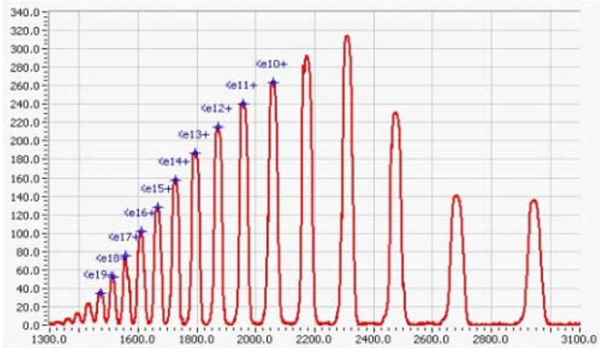

Figure 4: Xe beam spectrum

OTHER ECR ION SOURCES FOR VARIOUS APPLICATIONS

-SUPERNANOGAN is a full permanent magnet ECR source working at 14.5 Ghz, with a maximum RF power of 500W. This source is able to produce the same variety of heavy ions and charge states as HYPERNANOGAN but with lower intensities. This source is particularly used for hadrontherapy. PANTECHNIK is actually testing two sources for proton and C4+ beam for HICAT project (HEIDELBERG). Table 2 shows the requirements and actual results. SUPERNANOGAN ECRIS has good chances to be choosen for other similar projects, in France (ETOILE and ASCLEPIOS) and in other countries (Fig.5)

Figure 5: SUPERNANOGAN

-MICROGAN Industry. Can be used for ion implantation. More than 2 mA of B^+, 0.5 mA of B^{2+} and 3mAe of P^+ can be obtained. This charge state distribution allows the variation of energy with the same accelerating platform.
-NANOGAN is a well known permanent magnet source with a small volume, working at 10 Ghz , with 100 w and able to produce 1µAe of Ar 11+ . This source has been installed in pelletron terminal, and high voltage platform.
-PK 245, under development a permanent magnet ECR source working at 2.45 Ghz with 1kWatt, to produce 10 mA of proton beam.

	A/Q=6	A/Q=7	A/Q=8	A/Q=9
C^{12}	Q=2+, I~1mAe			
O^{16}			Q=2+, I~1mAe	
N^{20}		Q=3+, I~1mAe		Q=2+, I~1mAe
Ar^{40}	Q=7+, I~600µAe			Q=4+, I~800eµAe
X^{129}	Q=21+, I~20µAe			Q=14+, I~150µAe
Ta^{180}		Q=25+,26+, I~25µAe		Q=20+, I~30µAe
A^{197}		Q=28+, I~10µAe		Q=21+, I~15µAe
Pb^{208}		Q=29+, I~12µAe		Q=21+, I~15µAe

Table 1

Io	Requirements for Hadrontherapy	SUPERNANOGAN output
H^+	2 mA	> 2 mA
H	1 mA	> 1 mA
H	700 µA	> 700 µA
He^+	500 µA	> 800 µA
C^4	200 eµA	> 230 µA
O^6	150 eµA	> 150 µA

Table 2

REFERENCES

[1] ECR HTS source using superconducting coils, French Patent N° FR98 06579
[2] C.Bieth, et al, proceeding of 12 th HCI, Vilnius, Sep 2004, to be published
[3] P. Sortais et Al. ECRIS Development at GANIL proceeding of the 12th Int. Conf on Cyclotrons Berlin 1989
[4] P. Sortais et al proceeding of the Int Conf on Ion sources Berkley 1989 pp 288/290.
[5] L. Masure et al 2002 ISS2002 conf. Proc. (Yokohama, Japan, November 2002) at press.