DRESDEN EBIS-SC – A NEW GENERATION OF POWERFUL ION SOURCES FOR THE MEDICAL PARTICLE THERAPY

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Abstract

A new generation of EBIS sources, the Dresden EBIS-SC, is being designed for applications in medical particle therapy. The Dresden EBIS-SC is a superconducting compact ion source which is based on the most modern principles of refrigeration technology as well as electron-beam technology. Besides DC currents of protons, C^{6+}, O^{8+} and other ions the Dresden EBIS-SC provides ion pulses for single-turn and multi-turn injection into a synchrotron with pulse widths varying from 1 μs up to 100 μs. The Dresden EBIS-SC will produce up to (2...3) $\times10^{10}$ protons and (2…4)$\times10^9$ C^{6+} ions.

INTRODUCTION

Three generations of high-innovative room-temperature EBIS/EBIT ion sources of highly charged ions have been developed by the collaboration of the Technische Universität Dresden and the DREEBIT GmbH Dresden since 1999 [1]. These sources differ in the extractable currents of highly charged ions and can be applied in research, in industrial technologies as well as in medicine.

In the past it was demonstrated at different scientific centres that EBIS devices are reliable for the use as ion sources for injectors to synchrotrons. Based on such experiences the combination of an EBIS as source of C^{6+} ions and protons for the use in medical synchrotrons was already proposed 15 years ago [2,3] and is recently again under discussion [4]. However, a practical realisation of this idea has not been achieved, but the enormous progress in ion-source technologies should now allow the introduction of EBIS devices into the medical particle therapy now.

Actually a new class of high-current ion sources for particle therapy, the so-called Dresden EBIS-SC, is under construction. This source will feature beam parameters satisfying the requirements for medical synchrotrons [5,6] leading to a compact and a low-cost solution for medical applications in particle therapy.

THE DRESDEN EBIS-SC

The operation principle of an EBIS can be found for example in [7,8]. EBIT and EBIS were characterized by their capability to produce ions with the highest ion charge states now available. Furthermore, beside the property to produce highly charged ions for some applications intense currents of highly charged ions are of interest. This is the motivation for the development of a fourth ion source generation using the most advanced techniques for forming high magnetic fields and for the transport of intense and high dense electron beams. This ion source, the Dresden EBIS-SC, will produce ion currents of highly charged ions like C^{6+}, H_2^+ and protons high enough to use this source for particle therapy purposes.

Figure 1: 3D presentation of the Dresden EBIS-SC.

A 3D presentation of the Dresden EBIS-SC is shown in Fig. 1. This ion source is actually under construction and will be available in 2008. The device will be very compact with an overall length of about 50 cm and a diameter based on DN200CF. No liquid gases are required. Simply water as coolant for the anode and the electron collector should be available with regular water pipe pressure.

Table 1: Design parameters of the Dresden EBIS-SC

Parameter	Value
Total length	circa 50 cm
Magnetic field	up to 6 T
Electron energy	up to 30 keV
Electron current	up to 1 A
Electron current density	up to 1000 A/cm^2
Trap length	20 cm; 8 drift tube segments
Trap capacity	up to 5×10^{10} elementary charges

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Table 1 summarises the projected technical parameters of the Dresden EBIS-SC. In contrast to other known sources the new ion source is characterised by a very compact construction abandoning additional correcting coils, as it is required for other cryogenic EBIT/EBIS.

APPLICATION FOR MEDICAL PARTICLE THERAPY

When using a medical synchrotron and active beam scanning the required number of particles per spill is about $4x10^8$ C^{6+} ions or $1x10^{10}$ protons. Taking into account beam losses between the source and the beam delivery at the patient, fluxes of up to $3.2x10^{10}$ protons and up to $1.5x10^9$ carbon ions are required to be extracted from the ion source per spill [9]. In Table 2 we indicate projected values for the Dresden EBIS-SC in comparison to the target values for medical application.

Table 2: Particle numbers for application in medical particle therapy

Projectile	**Source requirements ions/pulse**	**Projected Dresden EBIS-SC ions/pulse**
Protons	3.2×10^{10}	$(2\ldots3)\times10^{10}$
C^{6+}	1.5×10^9	$(2\ldots4)\times10^9$

The introduction of ion sources of the Dresden EBIS-SC type into particle therapy facilities based on synchrotrons can lead to some benefits as

- the Dresden EBIS-SC provides ion pulses of H^+, H_2^+, C^{6+}, O^{8+} and other ions;
- ion pulses can be extracted with variable pulse width;
- providing C^{6+} ions directly reduces LINAC dimensions;
- it abandons an additional stripper dive for converting C^{4+} into C^{6+};
- C^{6+} in combination with H_2^+ relaxes the accelerator design by reducing the dynamic range of magnetic rigidities;
- long-term stability of the ion source;
- the high purity of the extracted ion beam;
- fast intensity variation of 1:100 within milliseconds;
- optimal emittance values and ion extraction energies of (3...5) keV/u for ion injection into the RFQ [10].

Most medical irradiation facilities are completely occupied by particle therapy during the daytime on workdays, but during nights and weekends the accelerator can be used for non-clinical research, e.g. for physics, radiation biology, materials research and others. For these activities many different ion species are required should be available from the installed ion source.

Table 3: Expected particle numbers per pulse from the Dresden EBIS-SC for non-clinical research

Particle species	**Number of particles per pulse**
Ne^{10+}	5×10^8
Ar^{18+}	2×10^8
Fe^{26+}	5×10^7
Kr^{36+}	6×10^6

Here an additional advantage of the Dresden EBIS-SC is of importance: in contrast to ECR ion sources the Dresden EBIS-SC can produce a wide spectrum of ions with the same *q/A* ratio as required for the medical particle therapy. Characterising these possibilities, some expected particle numbers per pulse for different ions for non-clinical research are given in Table 3.

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REFERENCES

[1] http://www.dreebit.com, http://www.dresden-ebit.de.
[2] R. Becker, M. Kleinod, A. Schempp, E.D. Donets, A.I. Pikin; An EBIS/RFQ-Injector for a cancer therapy synchrotron; Review of Scientific Instruments, 63 (1992) 2812.
[3] O. Kester, R. Becker, M. Kleinod; The Frankfurt MEDEBIS: A prototype of an injector for a synchrotron for cancer therapy; Review of Scientific Instruments; 67 (1996) 1165.
[4] T. Satogata, E. Beebe, S. Peggs; Ions in a Rapid Cycling Medical Synchrotron; C-A/AP/#226, Collider-Accelerator Department, Brookhaven National Laboratory, Upton, NY, May 2006.
[5] E. Griesmayer, T. Schreiner, M. Pavlovic, The MedAustron project, Nuclear Instruments and Methods in Physics Research Section B, 2007.
[6] J. Debus, K.D. Gross, M. Pavlovic, Proposal for a dedicated ion-beam facility for cancer therapy, GSI Darmstadt, DKFZ Heidelberg, University of Heidelberg, September 1998.
[7] F.J. Currell; The Physics of Electron Beam Ion Traps, in: Trapping Highly Charged Ions: Fundamentals and Applications, NOVA Science Publ., ed. by. J.Gillaspy, New York, 2001.
[8] V.P. Ovsyannikov, G. Zschornack; First investigations of a warm electron beam ion trap for the production of highly charged ions; Review of Scientific Instruments, 70 (1999) 2646.
[9] T. Auberger, E. Griesmayer et al., Das Projekt MedAustron – Designstudie, Fotec - Forschungs- und Technologietransfer GmbH, Wiener Neustadt, 2004.
[10] A. Schempp; private communication, September 2007