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Recent development in ECR sources

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Abstract Recent developments and improvements on the ECR ion source family at PANTECHNIK S.A. are presented. A lot of work has been done in the Ion Implantation Technology with the MICROGAN Industry® source: more than 3 mA have been produced on B^{1+}, P^{1+} and few hundred μAe on charge state 3+, 4+. Three other developments are described in this paper: a) the construction of the first source using high temperature superconducting coils (30 K) PKSUS® – Space Cryomagnetics (UK), in collaboration with NSC (New Delhi); b) the construction of the PHOENIX ECR source (used in the "1+/*n*+" process for radioactive beam) for different laboratories; c) and the first results on PK 2.45 (a cheap source working at 2.45 GHz) able to produce high current of monocharged beam. We will also present some special products for beam acceleration and diagnosis.

Key words ion source • ECR source • superconducting coils • high temperature superconducting wires • high charge state ion source • ion implantation

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Introduction

PANTECHNIK S.A. has recently developed and improved the ECR ion sources family, particularly in the ion implantation technology with MICROGAN Industry and in the hadron therapy with SUPERNANOGAN.

New developments have also been done in a high current compact source, PK 2.45 (working at 2.45 GHz), for pulsed beam of proton and deuteron or other single charge state heavy ions.

Other developments are described in this paper:

- study, construction and test of the first source using high-temperature superconducting coils (25 to 30 K), PKDELIS, a collaboration with NSC, New Delhi (India);
- construction with the collaboration of ISNG, Grenoble of the second PHOENIX ECR source, used in the "1+/*n*+" process for the acceleration of radioactive ion beam (RIB);
- PHOENIX 28 GHz for high intensity, high charge state beam production;
- ion beam transport and diagnosis tools.

PKDELIS: a high-temperature superconducting ECR source

NSC (New Delhi) and PANTECHNIK have decided to develop jointly a copy of the source HYPERNANOGAN, but with the use of high temperature superconducting coils. The conventional HYPERNANOGAN needs a DC power of 200 kW in the coils. So, it is extremely difficult to put this source on a 350 kV high voltage platform. A superconducting source, using conventional superconductors, needs a cryostat with liquid He and N.

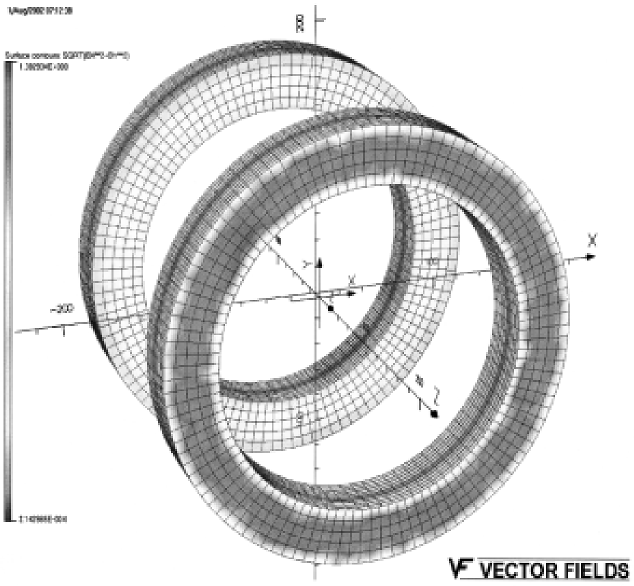

Fig. 1. Radial magnetic field on the coil surface.

Now, we can use the new super-conducting wire, at high temperature [1]. This idea has been patented by PANTECHNIK [3, 6] and can be used on other sources (SUPERPHOENIX and others). A description of the PKDELIS coils and cryogenerator is given in the paper presented by Dr. Kanjilal (NSC, India) during the INPAC'03 Conference [4]. In Fig. 1 we can see the radial magnetic field distribution on the coil surface.

Table 1. Cooling requirements.

Warm current 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 shows the maximum radial and axial field in coil cross section. With these values, at different level of the magnetic field (or coil current), we can see in Figs. 3 and 4 that, if we want to be below the coil load line, for the perpendicular field with 200 A in the coil, we must work at ~25 K, with a safety factor. The cooling requirements are summarized in Table 1.

The cooler, which matches the cooling requirements for the present magnet, is a single stage cryorefrigerator with a nominal capacity of 30 W at 20 K.

From the operational characteristics supplied, the cold head can be expected to operate at 21.0 K, if the heat load is 27.4 W.

Ion implantation

A first important step in this field has been successfully achieved with MICROGAN Ind. (Fig. 5) for ion implantation [5]. Tables 2 and 3 show the running parameters and the beam intensity for ion implantation.

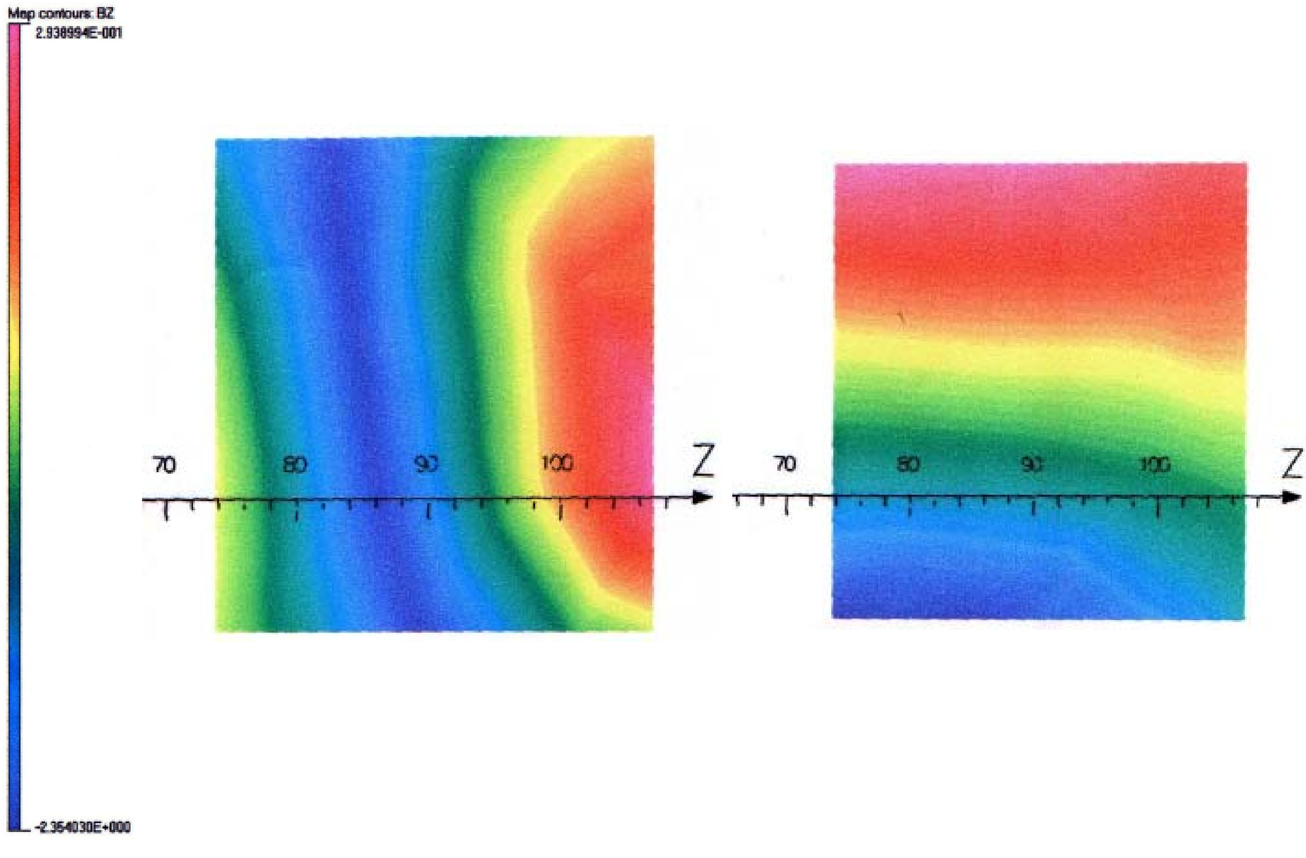

Fig. 2. Maximum radial and axial field in the coil cross section.

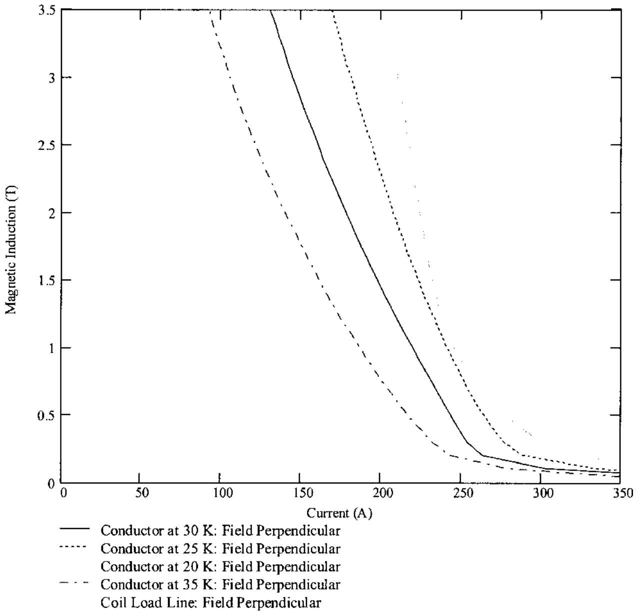

Fig. 3. Coil load line, field perpendicular to the conductor.

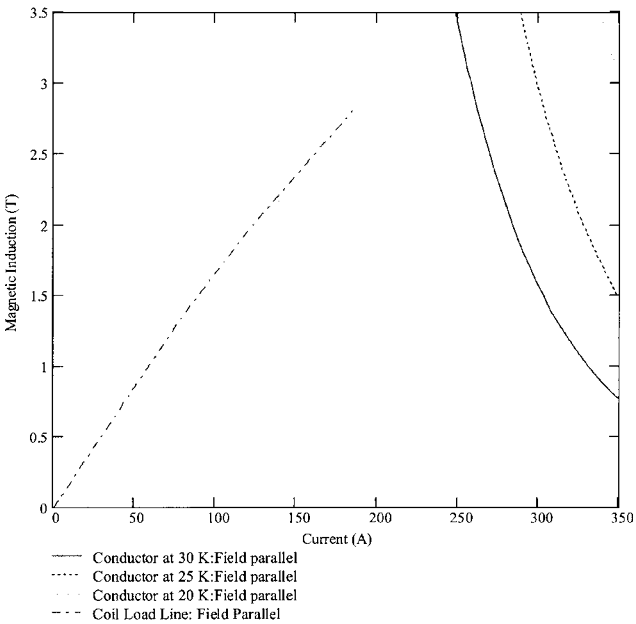

Fig. 4. Coil load line, field parallel with the conductor.

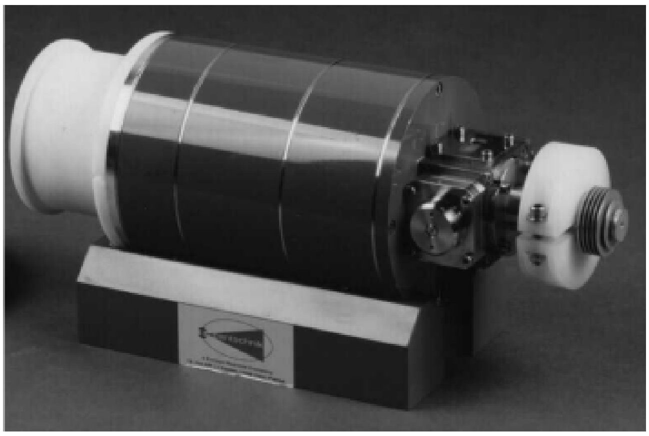

Fig. 5. MICROGAN Industry.

Table 2. Running parameters of MICROGAN Industry.

Frequency	10 GHz
RF power	200 W max.
Extraction actual	30 kV
Voltage future	65 kV
Total extracted current	25 mA
Emittance	200 mm·mrad at 90%

Table 3. Beam intensity (μAe) for ion implantation.

Ion/Q eμA	1+	2+	3+	4+	5+
B	3000	1000	–	–	–
P	4000	2000	1000	300	30

Table 4. Beam requirements for hadron therapy.

Ion	Hadron therapy requirements	SUPERNANOGAN output
H^+	2 mA	>2 mA
H_2^+	1 mA	>1 mA
H_3^+	700 μA	>700 μA
He^+	500 μA	>800 μA
C^{4+}	200 μA	>200 μA
O^{6+}	150 μA	>200 μA

The next step is to obtain a good repeatability and a long term stability on high current. In the mean time, PANTECHNIK studies the increase of the extraction voltage up to 70 kV. MICROGAN Ind. has also been tested on high charge state and the results on argon 8+ are very promising.

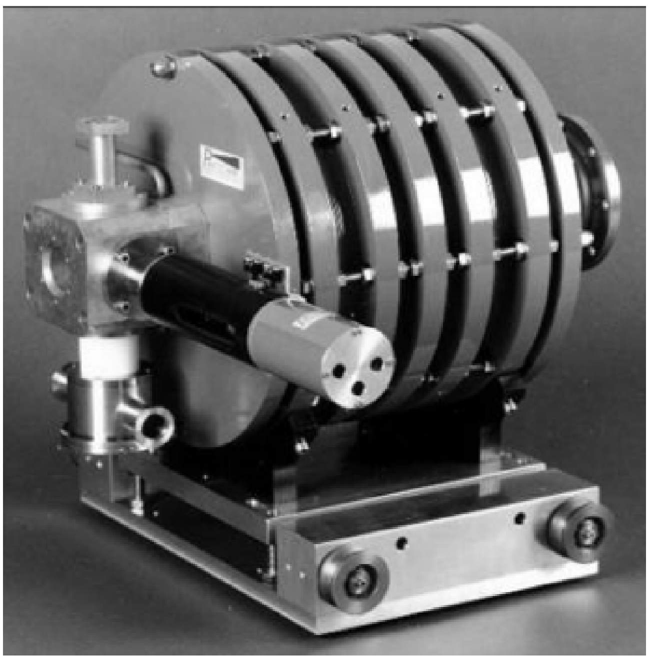

Fig. 6. SUPERNANOGAN "M".

Table 5. Running parameters of SUPERNANOGAN.

Frequency	14.5 GHz
RF power	600 W
Extraction voltage	45 kV
Total extracted current	15 mA
Emittance	150 mm·mrad

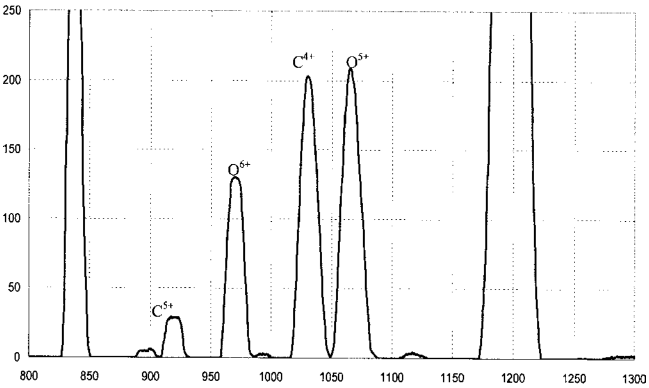

Fig. 7. Carbon and oxygen spectrum with SUPERNANOGAN "M".

Hadron therapy studies

The hadron therapy beams requirements and results obtained are given in Table 4 and compared to the beam

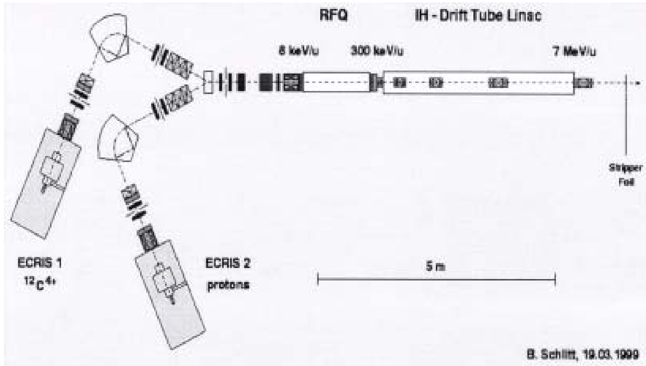

Fig. 8. Ion beam transport from ECR sources to the first accelerating section (Heidelberg/GSI project).

Fig. 9. All permanent magnets ECR source PK 2.45.

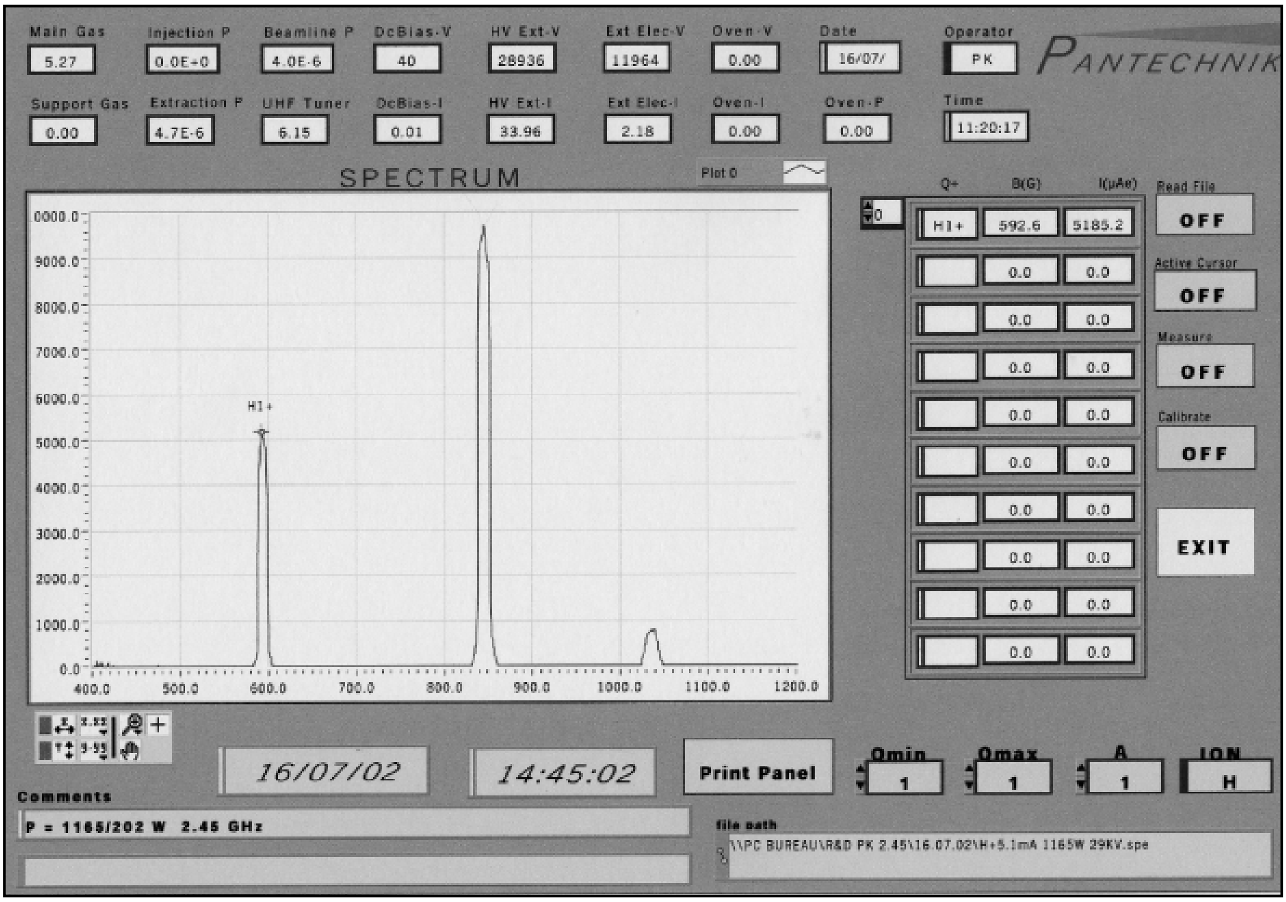

Fig. 10. Preliminary spectrum of H_2^{1+} (H^{1+}, H_2^{1+}, H_3^{1+}).

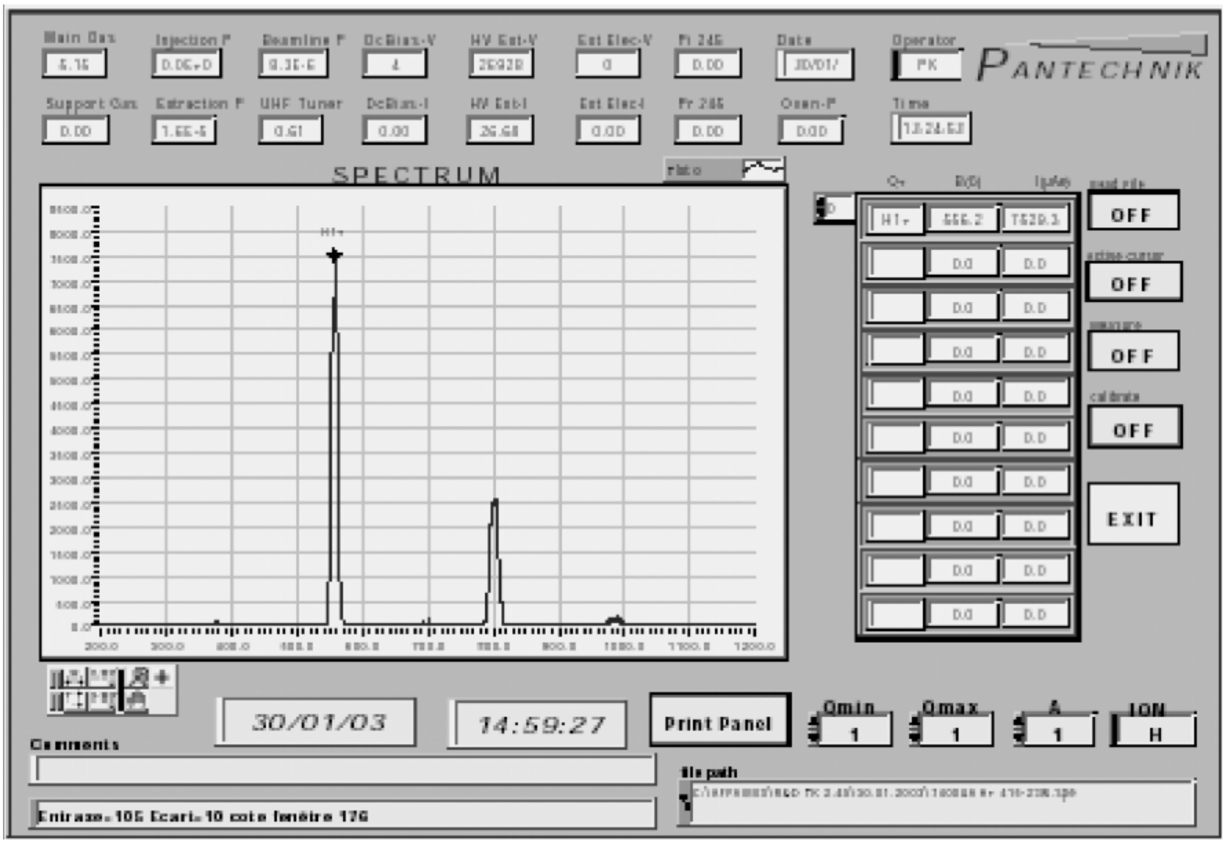

Fig. 11. Preliminary spectrum of H^{1+} (H^{1+}, H_2^{1+}, H_3^{1+}).

currents obtained with SUPERNANOGAN "M" (Fig. 6). The running parameters for SUPERNANOGAN are given in Table 5.

We can see that the measured currents are well above these requirements.

Figure 7 shows a spectrum of carbon with oxygen as support gas. Another main feature of the hadron therapy's source is the repeatability and the long term stability of the beam [8].

For the Heidelberg (GSI) project, we can see in Fig. 8 that two identical sources (SUPERNANOGAN) are used: one for heavy ions C, O, …, and one for light ion H, H_2, H_3, H_e.

PK 2.45: high intensity low charge state ECR source

PK 2.45 is a compact all permanent magnets ECR ion source [2], working at 2.45 GHz for the production of high current (5 to 10 mA), low charge state (1+, 2+) ion beams. The RF power is variable between 100 W to 1200 W. The extraction voltage can be 40 kV with a maximum extracted current of 30 mA. The source is shown in Fig. 9.

Depending on the RF power, the maximum current can be obtained on each beam H^{1+} and H_2^{1+} as shown on the spectrum in Figs. 10 and 11.

PK 2.45 source can also be an excellent candidate for 1+ source in the "1+/ n+" system, due to its small price. This source is actually on the PANTECHNIK test bench for proton, deuteron production and ionisation efficiency measurements.

The booster ECR source: PHOENIX

After the successful construction and delivery of the first PHOENIX source to Daresbury (UK), the second PHOENIX built by PANTECHNIK was delivered to TRIUMF (Canada).

This source (Fig. 12) gives a 6% efficiency in the process $1+ \rightarrow n+$ for metallic ions with $A \geq 40$ amu. When injecting 4 eμA of Pb^{2+} in after-glow mode, the Pb^{27+} can have a plateau of 100 μs with a peak current of 30 μA. A maximum of 50 μA has been obtained on Pb^{24+}.

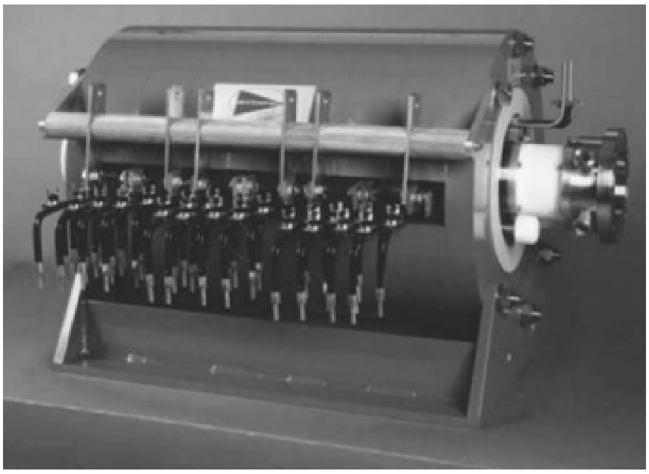

Fig. 12. The PHOENIX ECR source.

PHOENIX 28, for high intensity, high charge state

This ECR source has been developed for the production of high current with high charge state, as, for example, the LHC project with 1 mAe on Pb^{27} with a 28 GHz gyrotron generator [7]. The present results show that a very stable beam of 600 eμA can be obtained in the AFG mode.

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