A COMPACT, PERMANENT MAGNET, ECR ION SOURCE FOR THE PSI PROTON ACCELERATOR

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Abstract

The multi-cusp ion source presently used at the PSI proton accelerator suffers from a poor proton ratio and a limited life time. It will be replaced in 2008 by a compact, 2.5 GHz ECR source compatible with the present beam extraction system. The plasma chamber is located in a rectangular waveguide surrounded by a CoSm permanent magnet structure. It consists in an air cooled cylindrical Quartz pot, the bottom of which is protected by a BN disk. The choice of basic parameters, i.e. the magnetic field configuration, the geometry and material of the plasma chamber, and the micro-wave injection system, has been confirmed by the tests. A power of ~400 W is used to produce the requested 10 mA proton beam. The stability of the source is excellent. In a life time test of 900 hours no dramatic degradation of the plasma chamber has been observed. Particular features of the source and emittance measurements are presented..

INTRODUCTION

In the frame of the upgrade of the PSI Proton Accelerator Facility to 1.8 MW [1] a detailed analysis of all components along the beam path has been performed. The beam current limit of the whole system is given by the losses at some critical components, in particular at the extraction elements of the accelerators. Since the tolerated loss level is in the range of 10^{-4} of the beam intensity, beam jitter or other instabilities originating from the source may significantly contribute to this figure. A device equipped with filaments is not an ideal solution: filament erosion, the need to reverse polarity or to switch to another set after some operating time cause periods of instability. The replacement of the filaments requires an interruption of the beam production every 2 weeks and set in this way more severe boundary conditions on the operating schedule of the facility than other components.

Another drawback of the present source is its poor proton fraction, which results in an unnecessary high load of the HV power supplies and of the beam cleaning diaphragms. Another complication is the need of powerful current sources and associated control electronics at high voltage. Since these problems could be eliminated by the implementation of an ECR proton source such a device has been designed and tested on the Ion Source Test Stand.

It has been demonstrated at different laboratories (for example in Ref. [2-7]) that this type of source can reliably produce very intense beam of good quality. With the harmonic double buncher system recently installed [8] a proton beam intensity of about 10 mA extracted from the source is sufficient in order to inject currents in excess of 3 mA in the first cyclotron. Since the needed beam intensity lies far below those reached by the most advanced sources, a "light" version can be envisaged for our purpose. Special requirements are the wish to keep the present electrode system which shows excellent performances (less than one spark per week) and the need of a compact design to incorporate the new systems in the very limited space in the dome of the Cockcroft-Walton pre-accelerator. Simplicity and easy dismantling should allow for fast maintenance. Ideally, the life time should exceed 1000 hours.

SOURCE DESIGN

To satisfy the compactness requirements the source consists in a small plasma chamber surrounded by a permanent magnet system. The operation of a small plasma chamber in a rectangular waveguide has been demonstrated by Cui et al. [7]. In our design the plasma chamber is basically a Quartz pot 56 mm in diameter and 42 mm long. Its bottom is protected against back streaming electrons by a 2 mm thick BN disk. BN disks of 1 mm thickness cover also the flange on the extraction side. The chamber is cooled by compressed air.

A magnetic field structure suitable for the generation of ECR zones is produced by a permanent magnet system. A small coil allows for fine adjustments. The field along the axis of the plasma chamber is shown in Fig. 1.
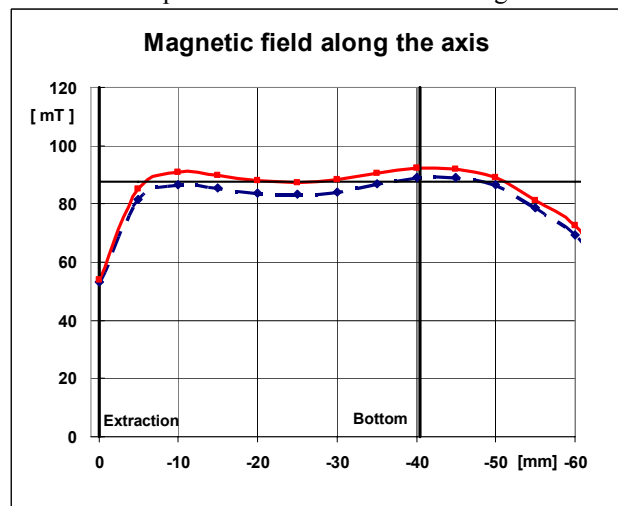

Figure 1: Magnetic field in the plasma chamber. The lower curve is the measurement with the permanent magnet only, the upper one indicates the range of the correction achieved with the trim coil. The 87.5 mT (value at resonance) is shown by an horizontal line.

The magnet system is made of rectangular CoSm pieces mounted in three stacks in a supporting structure surrounding the rectangular waveguide. CoSm was chosen because of its superior temperature stability. The trim coil is inserted between the two first stacks on the extraction side. An iron plate on this side is an essential part for the field shaping. It also reduces the field strength in the electrode system in order to avoid Penning discharges in this region. With the help of the trim coil it is easy to select a configuration with resonance zones close to the ends of the plasma chamber. The whole system is 140 mm in diameter and 80 mm long.
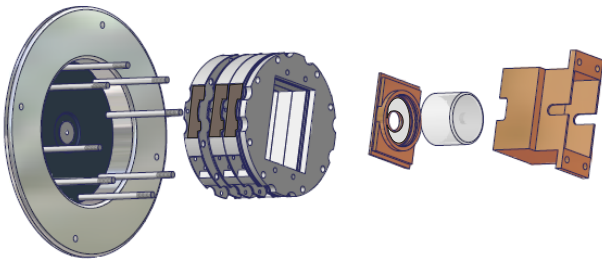
The source components are shown in Figure 2.

Figure 2: Components of the source. From left to right: waveguide, plasma chamber, vacuum flange, magnet assembly, source supporting flange with iron plate and extractor. For the replacement of the plasma chamber only the three parts on the left have to be disassembled

The installation of the source at the test stand is shown in Figure 3. The microwave power (about 400 W) from a 1.2 kW SAIREM generator equipped with a circulator is injected into the system by means of a 3-step ridged

Figure 3: Installation of the source at the test stand showing also the ridged wave guide and the HV break.

WR240 wave guide acting as impedance transformer. Since the reflected power is reasonably small the use of a tuner is not necessary.

The HV insulation between the parts at ground potential and the ridged wave guide consists in a 5 mm thick plexiglas/Teflon sandwich. The compressed air to cool the plasma chamber region is injected through the ridged wave guide. With water inlet at 30 C in its cooling loop, the magnet temperature does not exceed 65 C during normal operation. Nevertheless, in the final version the wave guide surrounding the plasma chamber will include a water cooling loop. The additional cooling of the source support compensates for the missing main flange cooling at the ISTS.

SOURCE PERFORMANCES

The source is operated with the parameter listed in Table 1.

Table 1: Typical operating parameters

Extraction voltage	60 kV
Microwave Power	400 W
Gas flow	1.2 scc / min
Extraction aperture, Diameter	3.8 mm
Extracted current	16 mA
H^+	80 %
H_2^+	17 %
H_3^+	~0
Heavier species	3 %
rms-emittance, normalized (@Backgroung pressure 2-3 10^{-5} mbar)	0.08 π mm mrad
Noise, rms	< 0.3 %
Stability (24 h)	< +/- 2 %
Lifetime	> 1000 h

The power deposited by the various species on calorimetric probes after analysis by a dipole magnet was used to determine the mass distribution in the extracted beam. While the extracted current remains constant the ratio of the different species may, depending of the power adjustment, vary somewhat during the first day of operation of a new plasma chamber.

With the present extraction aperture the proton current exceeds slightly our needs.

The emittance was measured ~700 mm after the extraction with a two slit system. Space charge compensation is important. Currently, air is let into the vacuum system in order to increase the pressure up to 2-3 10^{-5} mbar. Tests with selected heavy gases have not been performed yet. Figure 4 shows the emittance diagram measured in the horizontal direction. No

distortions are observed at this stage. The quality of the beam is definitely much better than with the multi-cusp source, which rms-emittance is about 3 times larger, due to the 7 mm diameter extraction aperture and to the space charge of a total beam of 25-30 mA.

The source is very stable, as well in respect to the beam noise as in respect to the long term behaviour. The trim coil is very useful to establish the optimal operating conditions. It should however be mentioned, that the appearance of jumps between two states with values of the extracted current about 2 % apart were observed towards the end of the test period. Since deposits of
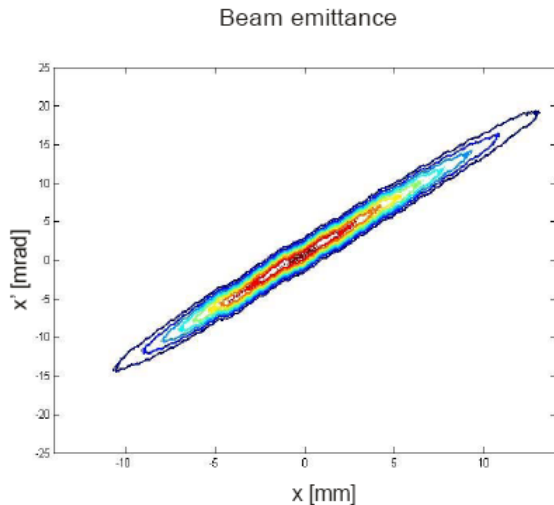
Beam emittance

Figure 4: Horizontal beam emittance measured with a two slit system ~700 mm after the extraction

cracked oil are observed we attribute this phenomenon to the unlucky history of the vacuum system of the test stand. There are evidences that the frequent sparking which occurs periodically in the electrode system is also mainly due to this reason.

The limiting factor of the life time of the source is the robustness of the bottom of the plasma chamber against the bombardment by back streaming electrons. After an operation period of 900 hours the 2 mm thick protecting BN disk was investigated: it showed a pinhole 0.5 mm deep in the centre and a more generally distributed abrasion 0.1 mm deep. No damage of the O-rings tightening the system was observed. Therefore we conclude that the source can be operated during 1000 hours with a sufficient safety margin.

CONCLUSION

A compact, permanent magnet, ECR ion source has been developed and tested in the frame of the power upgrade of the PSI Proton Accelerator Facility to 1.8 MW. The source delivers reliably a ~10 mA, stable proton beam with an excellent optical quality. The life time of the plasma chamber exceeds 900 hours and the replacement is easy and fast. The source fulfils our requirements in all aspects and will be installed at the Cockcroft-Walton pre-accelerator during the shut down in the beginning of 2008.

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