Proposal to upgrade the LNS Superconducting Cyclotron

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Abstract – To increase the beam current delivered by the LNS superconducting Cyclotron we recommend to use the stripping extraction. A conceptual design of a new superconducting magnet and a new cryostat is here presented. Beam dynamics simulations along the new extraction trajectories are also presented.

INTRODUCTION

A new experiment, called NUMEN, proposes to measure the element of nuclear matrix using double charge exchange experiments [1, 2]. This measure is of interest also for the double beta decay neutrino-less experiment. The main request for our existing superconducting cyclotron (CS) is to increase the beam current. A higher beam current is also useful for many other experiments that use radioactive ions beam produced with in-flight technique [3] and also for the production of radioisotope of medical interest.

In particular, the aim of present study is to ascertain the feasibility of extraction by stripping from the CS, for the energy and mass range of interest of the NUMEN experiment. The investigated energy range is 15-60 AMeV and the ions investigated are $^{12}$C, $^{16}$O and $^{20}$Ne to span a reasonably wide mass range.

The LNS CS is a three sector compact machine with a wide operating range, being able to accelerate heavy ions with values of q/A ranging from 0.1 to 0.5 to energy from 2 to 100 AMeV. The CS was designed as an accelerator to perform nuclear physics experiments, which require low intensity beams.

The main limitations to extract high beam power are the two electrostatic deflectors. In fact, due to the compactness of the accelerator the last accelerated orbit is not fully separated from the previous one, which implies a extraction efficiency lower than 60%. The lost beam, dissipated mainly in the septum of the first electrostatic deflector, causes serious damages to the device that is not able to hold the high voltage.

The goal of the proposed modification is to make extraction by stripping possible in the CS to achieve high power beams for the set of beams of interest. At the same time the versatility of the CS is to be maintained, since there is a consistent demand of beam types in a wide mass and energy range. For this reason the CS will be equipped with two extraction modes: extraction by stripping and extraction by electrostatic deflectors. The feasibility of extraction by stripping through the existing extraction channel with an increased transversal section has been studied.

In addition, a new extraction channel has been designed to increase as much as possible the number of the extracted ions and energies.

TECHNICAL APPROACH

The code EXTRAZ has been mainly used for the beam simulations: this is the code currently used for determination of the Cyclotron extraction parameters starting from the measured field maps. The procedure consists of few steps. At first, the Eigen-ellipse at the equilibrium orbit at the proper extraction energy and angle is computed by using the code GENSPE. Then a change in the ratio of the charge over the mass simulates the stripping process. For instance, a carbon ion is accelerated with a charge state of 4+, after the stripper its charge state will be 6+. We assume that the entire medium-light ions here considered have a charge state equal at their Z after the stripping, which means they are fully stripped of their electrons. After the change in the charge state, the beam trajectory is strongly perturbed and the three-fold symmetry is lost. The particles orbit generally around the centre of the cyclotron if the ratio between the final charge state over the accelerating charge state, $Q_f/Q_{acc}$, is smaller than 1.5.

Fig 1: example of extraction trajectory of $^{12}$C at 45 AMeV achieved using the code OPERA.

The extraction trajectories that do not rotate around the centre of cyclotron cannot be simulated by the code ESTRAZ. In these cases, we use an OPERA 3D model to track the reference particle and the particles that describe the contour of the radial and vertical beam emittance through the cyclotron up to the extraction channels (see Fig.1). The last part of the extraction trajectories has been evaluated using the code EXTRAZ to compute the magnetic gradients needed to deliver the beam outside the cyclotron yoke. An example of the outcome is in Fig.1 that represents the trajectory of the stripped beam inside the cyclotron. Fig. 2) shows the radial and axial beam envelope computed with Estraz code.
The beam dynamics simulations were made chosen a value of the normalized emittance of $1 \pi \text{mm.mrad}$, which is about twice larger than the expected. The 3 magnetic channels, MC, and their angular positions are shown too. These pictures are just for sake of clearness of the explanation.

**NEW CRYOSTAT AND SUPERCONDUCTING MAGNET**

The design of the two extraction channels requires to build a new cryostat, including a new set of superconducting coils. In particular, it requires a stress analysis of the cryostat structure to evaluate the maximum size of each penetration across the cryostat.

A study report for the “New superconducting magnet for the LNS Cyclotron” has been prepared by the Plasma Science and Fusion Center of MIT (Boston)[4].

Here we recall shortly the main results of this study.
- The form factors of the new coils are very similar to the previous coils;
- The new cryostat fits the same outer size of the previous cryostat;
- The new Liquid helium vessel is radially smaller than the previous;
- There is more room for the liquid nitrogen shields;
- The new magnet can be operated also with a 5 W of nuclear heating due to the 200 W beam losses;
- Hoop stress analyses in the coils shows that the proposed solution is quite safe;
- The size of the Liquid Helium Vessel allow to drill in the mid-plane of the LHe vessel extraction channels with a vertical gap of the room temperature wall larger than 60 mm (+/-30 mm) and the radial width of the extraction channel larger than +/- 100 mm around the reference trajectory (20 cm total width), without significant effects on the safety of the superconducting coil;
- The expected liquid helium consumption will be <20lt/hour (at 4 K) and the Liquid nitrogen consumption <18 lt/hour (at 77 K).

**CONCLUSIONS**

The present study demonstrates that it is possible to achieve the required beam power with good focusing properties to respond to the LNS experiment demands.

**REFERENCES**

[3] Raciti G. et al. Nuclear Physics; Sec A; Vol834; Issue: 1-4; 2010; pp. 780c-783c  