ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-WEA02

THE DEVELOPMENTS OF THE RF SYSTEM RELATED TO THE K-800 SUPERCONDUCTING CYCLOTRON UPGRADE*

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Abstract

The K-800 superconducting cyclotron has been in operation at Laboratori Nazionali del Sud for almost 25 years. It has been subjected to continuous upgrades and modifications since 1994: the RF couplers have been redesigned, the new dees have been changed from aluminium to copper, as has the new central region from radial to axial injection of the beam, the hybrid configuration solid state - tube of the power amplifiers, the digital LLRF, etc. The next scheduled important upgrade of the Cyclotron mainly consists in a new extraction beam line able to support the increase of the beam current intensity. The accelerated beam will be extracted in two ways: by stripper and by electrostatic deflector and, consequently, one of the most important features of the new upgrade is the new cryostat. Further upgrades and refurbishments of the other main parts of the cyclotron, such as a new liner, the modification of the RF cavities and dees, the refurbishment of HLRF-LLRF, the insertion of the stripper extraction system, to name but a few, are in progress, too. This work focuses on the RF system upgrade.

INTRODUCTION

The LNS Superconducting cyclotron has been operating at LNS since 1995. The original design was thought up to produce beams for nuclear physic experiments in the range of a few dozen watts. In the initial configuration, the cyclotron was a booster of the 16 MV Tandem. The injection was radial and the Tandem and Cyclotron operated together as a coupled accelerator system. The introduction of the axial injection and the redesign of the central region means the cyclotron has been a stand-alone accelerator since 2000. The two accelerators, Tandem and Cyclotron, have been operating independently for the last 19 years. In the meanwhile, the cyclotron's good results with the axial injection were a sort of flywheel to develop, through the EXCYT project, the production of radioactive ion beams on a thick target with the ISOL technique [1]. However, the limitation, in terms of maximum output power (<150 Watts) of our extraction system due to some intrinsic constraints and efficiency around 50 - 60% of the electrostatic deflector (ED), became quite clear. Yet the strong interest, in terms of demand, for high intensive beams is still valid. A new important project, in fact, has requested this kind of beam. The project, called NUMEN (NUclear Matrix Elements for Neutrinoless double beta decay), proposes an innovative technique to measure the nuclear matrix that is of relevant interest for the double β decay without neutrino emission. This ambitious technique needs beams of $^{12}C^{4+}$ $^{18}O^{6+}$ $^{20}Ne^{4+}$ mainly, with a maximum beam current intensity of 10^{14} pps, which means a cyclotron beam power between 1 and 10 kW. This is more or less 10 - 100 times the present maximum beam power of 100 W. In any case, some preliminary experimental results, obtained at the INFN-LNS with the present version of the superconducting cyclotron, have provided an encouraging indication of the capability of the proposed technique to access relevant quantitative information for NUMEN [2]. Another facility, strongly interested in high intensive beams, using the inflight technique to produce RIBs is FRIBs@LNS (in Flight Radioactive Ion BeamS at LNS), already installed at LNS, allows one to carry out nuclear physics experiments investigating the properties of short-lived nuclear species. The maximum power delivered with the upgraded Superconducting Cyclotron, suggests a specific study to design, a proper beam line with a new fragment separator, named FRAISE (FRAgment Inflight SEparator) too [3].

MAIN MODIFICATIONS

The main difference between the present configuration of the cyclotron and the future upgraded one, is the introduction of a second extraction technique by stripping. In this way the extraction efficiency is enough to achieve the high intensity requests. The new median plane of the cyclotron with both extraction channels, by stripper and through electrostatic deflector (E.D.), is shown in Fig. 1.

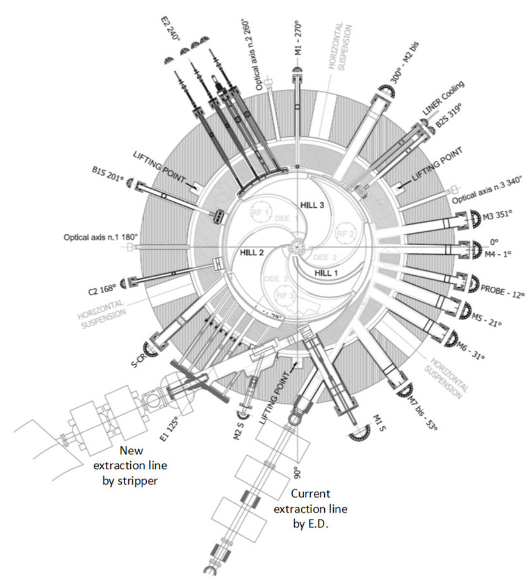

Figure 1: Median plane of the upgraded cyclotron.

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The extraction by stripper requires many parts of the cyclotron to be redesigned. A new hole/penetration along the median plane is necessary to introduce this new extraction channel. This means redesigning the magnet, cryostat and making some other modifications including the RF system. A detailed beam dynamic study has optimized the extraction trajectory of the stripped beams with the extraction trajectory by E.D. This perfect overlap trajectory allows for the interchanging of the two systems in the present ED position [4]. To reduce the interchanging phases, two sessions have been scheduled during the year: one for high intensive beams and the other for the beam extracted by E.D. [5].

RF SYSTEM UPGRADE

The upgrade of the cyclotron involves the RF system too. The most important reasons for changing something in the RF field are mostly related to the power and size of the stripped beam during the acceleration phase, inside the median plane and subsequently in the extraction channel. Two fronts are opened in the RF system to match the next stripper configuration goal of the cyclotron: one related to the new geometry of the median plane, the other related to the final dissipated power. These two reasons can also be seen as two opportunities to improve and refurbish the RF system in terms of mechanics, vacuum quality improvement, with new liner design and high/low level electronic.

Mechanic modifications

The present vertical distance between the upper and lower dees and inside the liner is 24 mm, not enough for all the future beams extracted with the stripper technique. An extra space of ± 3 mm in the vertical gap should be enough to allow for the acceleration of the high intensive beams and to also minimize the beam loss inside the acceleration chamber. To increase the distance between the acceleration electrodes, from 24 to 30 mm, a reduction of the upper and lower conical connection length between the dees and the inner coaxial of ±3 mm has to be made.

In Fig. 2 (ABC), a sequence shows how to increase the vertical gap through decreasing the conical connection length. The red arrows show the present conical length and vertical gap, in green the future (ones) length and gap. Particular attention, in terms of voltage and power dissipation, has to be paid to the main ceramic insulator area. A reduction in length between the connection of dee and stem increases the high voltage around the ceramic of the coaxial cavity. The high voltage ceramic insulator allows for the separation between air and vacuum inside the RF cavity. The position of the ceramic inside the magnet at 62 cm from the median plane of the cyclotron is enough for the sliding short to tune the cavity up to 50 MHz. The shape and the dimension of the ceramic are strongly influenced by this high frequency parameter and consequently the design was particularly critical. The ceramic inside the cavity is shown in Fig. 2D during a maintenance phase, the lower Dee was removed and the white ceramic between the inner and outer coaxial is visible. A detailed vertical cross section of the upper side cavity ceramic insulator is shown too, together with the copper conical Dee-Stem connection.

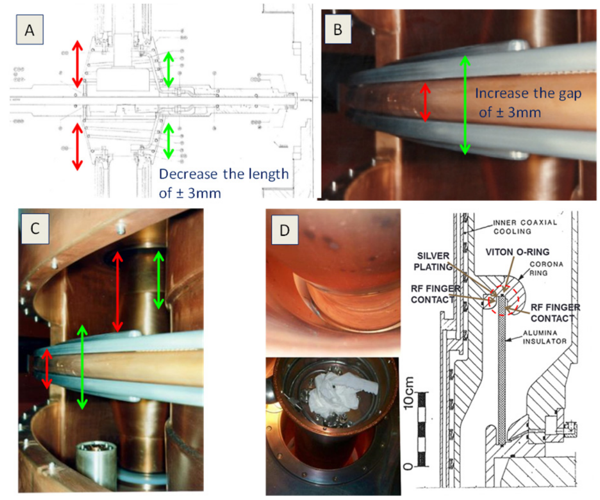

Figure 2: how to increase the gap between the dees.

At the maximum Dee voltage of 100 kV the insulator dissipation should not exceed 200 W [6]. All the geometry design around the insulator (pure alumina 99.7%) allows for safe mechanical and electrical working conditions. With these kind of constraints, even a modification of ±3mm can introduce limitations to the parameters of the cavity, such as bandwidth, power dissipation, voltage distributions, impedance matching, etc. For this reason, a detailed 3D numerical simulation of the modified RF cavity, using 3D commercial electromagnetic simulators, CST Microwave Studio [7] and COMSOL multiphysics [8] comparing them to significant experimental results, through network analyser measurements, has been done. The original frequency range of 15-48 MHz is achieved despite the reduction of ±3 mm. The voltage distribution, especially in the critical area, shown in Fig. 2D, around the main insulator, between the inner and the outer coaxial, near the antinode maximum dee voltage, is under the limit. The input impedance matching, through the coupling capacitor, is more or less within the present range of values [9]. The global RF cavity simulated model of the cyclotron is shown in Fig. 3.

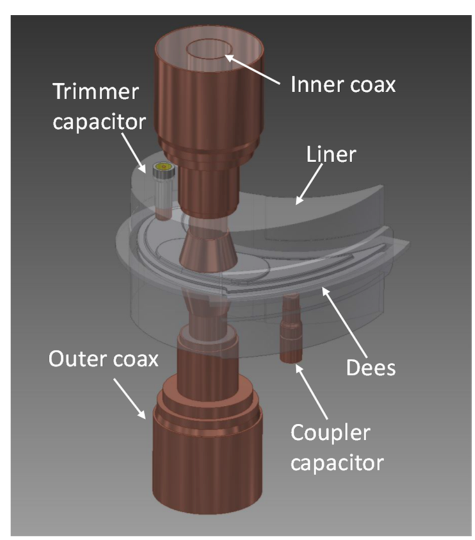

Figure 3: 3D model of RF cavity of the cyclotron.

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The dees, the inner/outer coaxial, the trimmer and the coupler capacitors have been included in the software simulations. Another important modification, to increase the vertical gap in the acceleration chamber, is related to the liner. The modification of the present one is not possible and a new liner has been redesigned. We are confident, using modern construction techniques, of reducing the present 14 mm thickness of 3 mm and of greatly minimizing the welding points too, in order to prevent leaks in the acceleration vacuum chamber. The current vacuum liner level of 1 mbar with a pumping system of 300 m^3/h is nowhere near the value of 10^{-1} mbar with a pumping system of 30 m^3/h, of only 4 - 5 years ago. This is another important reason to replace the upper and lower liner of the cyclotron in Fig. 4.

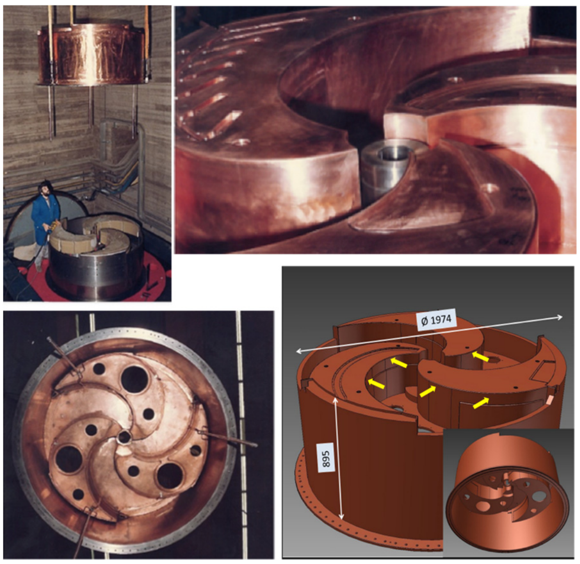

Figure 4: Liner assembling phases, about 30 years ago, the yellow arrows show the possible vacuum leakages in the welding points between vertical and horizontal wall.

Electronic modifications

An important refurbishment of the main power amplifiers has been completed recently. The insertion of a solid state amplifier (SSA) has substituted the obsolete first stage of the full tube RF power amplifier as shown in Fig. 5. All the 3 power amplifiers of the RF system are equipped with this solid state driver configuration plus a matching box to adapt the standard 50 Ω output of the 1st SSA stage with the final stage of the tube amplifier, as Fig. 6 shows. The main reason to transform the full tube amplifier to a hybrid tube-SSA configuration was the end of production of the first stage tube, a Thales RS1054. We were obliged in changing the 1st stage and we adopted a new technology according to the trend of the power telecommunication devices in the range of power and frequency of our interest: 15 - 50 MHz, 1 - 50 kW [10]. The beams produced by the present cyclotron need an RF power below 30 kW CW. To reduce the power consumption and to increase the life of the tetrodes, the original final power of 75 kW was adapted to the more relaxed output power of 20-30 kW. With the cyclotron upgrade, the final power of the extracted beam between 1 and10 kW needs about 30% more of the current RF Dee voltage.

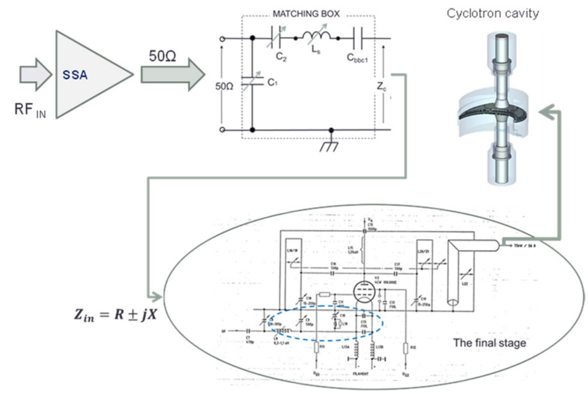

Figure 5: Block diagram of the refurbished amplifier.

It means a new optimization of the amplifier parameter to increase the power up to 40-50 kW. Some preliminary studies are in progress and we are confident to adopt soon the proper modifications to increase the final power.

The LLRF is following the same refurbishment and upgrade trend [11]. The migration from the platform Visual Basic to LabView is on the way, the complete substitution of old and obsolete part of the hardware is in progress, a new automatic tool of phase and amplitude adjustment in order to maximize the output beams is under developing. All the LLRF is made in house, mostly of the HLRF too. The LLRF working in progress between old analog equipment and new digital platforms are shown in Fig. 6.

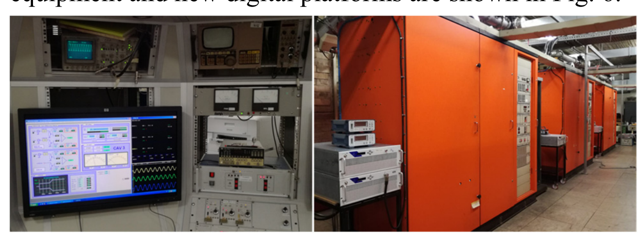

Figure 6: LLRF working in progress and HLRF.

CONCLUSION

The developing of the RF system related to the cyclotron upgrade is already planned and most of the points are on the way. Since the expected time to dismount and to assemble the cyclotron is about 18 months, we expect the restart the RF system and the cyclotron in two years.

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