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Conceptual design of the RF accelerating cavities for a superconducting cyclotron

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Abstract

A superconducting cyclotron accelerating ions up to 250 A MeV, for medical applications and radioactive ions production is being studied at Laboratori Nazionali del Sud in Catania. The radio frequency (RF) system, working in the fourth harmonic, is based on four normal conducting radio frequency cavities operating at 93 MHz. This paper describes an unusual multi-stem cavity design, performed with 3D electromagnetic codes. Our aim is to obtain a cavity, completely housed inside the cyclotron, with a voltage distribution ranging from 65 kV in the injection region to a peak value of 120 kV in the extraction region, and having a low power consumption.

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1. Introduction

A compact superconducting cyclotron is the subject of a project called superconducting cyclotron for exotic nuclei and therapy (SCENT) [1]. The machine should be able to accelerate light ion beams like Carbon, Neon, Oxygen (with $Z/A \approx 0.5$) up to the maximum energy of 250 A MeV. High-intensity proton beams can be extracted by means of stripping H_2^+ molecules. These high-intensity beams could be used as the main ones in the production of radioactive ion beams in dedicated facilities or for producing new radioisotopes in medical centres. Moreover, light ions and protons of lower intensity could be used in hadrontherapy in order to cover most tumour treatments, with an energy of 250 A MeV. A similar machine, able to accelerate only proton beams to the same energy has been studied by MSU and KVI and realised by ACCEL Instruments Gmbh [2,3]. Table 1 shows the main parameters of the cyclotron, while Fig. 1 shows a layout of the machine.

To accelerate particle beams, four normal conducting radio frequency (RF) resonant cavities are foreseen.

The magnetic field and the Z/A ratio being constants, the orbital frequency of the accelerated ions is fixed at ~23 MHz. In order to ensure the maximum energy gain per turn and thus reduce the number of turns inside the machine, it has been decided to operate the RF cavities in 4th harmonic mode. Consequently, the resonant frequency of the cavities has been set as 93 MHz.

The preliminary design was accomplished using advanced 3D codes in order to better predict the behaviour of the resonators and to optimise their performance.

2. The RF system

The resonant cavity proposed for the RF system of SCENT is the standard double gap delta cavity. It can be considered as a deformed $\lambda/2$ coaxial line with a capacitive delta shaped electrode (the DEE) defining the accelerating

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Table 1
Cyclotron main parameters

Parameters	Value
K bending	1000 MeV
Ions accelerated	H_2^+ and light ions ($Z/A = 0.5$)
Energy	250 A MeV
Diameter	4.9 m
Pole radius	1.33 m
Number of sectors	4
Number of coils	2 superconducting
Max magnetic field	4.1 T
Number of cavities	4 normal conducting
Harmonic mode	4
RF frequency	93 MHz

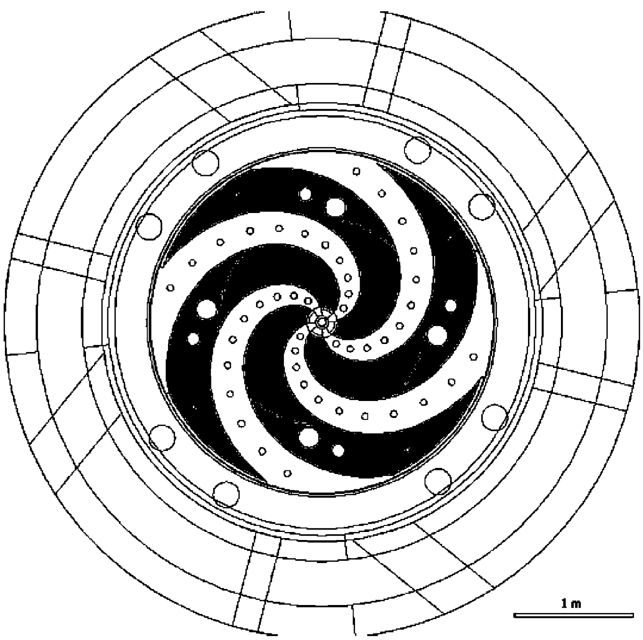

Fig. 1. Top view of the SCENT machine. The black regions are the valleys where the cavities will be housed.

gaps and an inductive part forming the vertical supporting stem. The resonator geometry depends strongly on the shape of the magnetic circuit of the cyclotron. In a compact superconducting cyclotron, the cavities are installed completely inside the machine and they are housed inside the so-called valley regions (see Fig. 1). Since these regions are spiralled to increase the axial focusing effects on the accelerated beams, the copper electrodes of the cavities have to be shaped in the same way (see Fig. 2). Generally RF systems in cyclotrons work in the variable range 10–50 MHz, so they need large vertical apertures in the yoke of the magnetic circuit to house the stems and the moveable short circuits.

In the case of the SCENT machine, the operating fixed frequency of 93 MHz allows to house the resonators inside the valleys, where the available depth is 45 cm from the median plane and moveable short circuits are not required. To minimise the risk of discharge, voltages lower than 70 kV are required in the central region, whilst voltages around 120 kV or higher are required at the outer radii to achieve an adequate turn separation of the beam in the last turns, in order to optimise the extraction efficiency performed by the electrostatic deflectors.

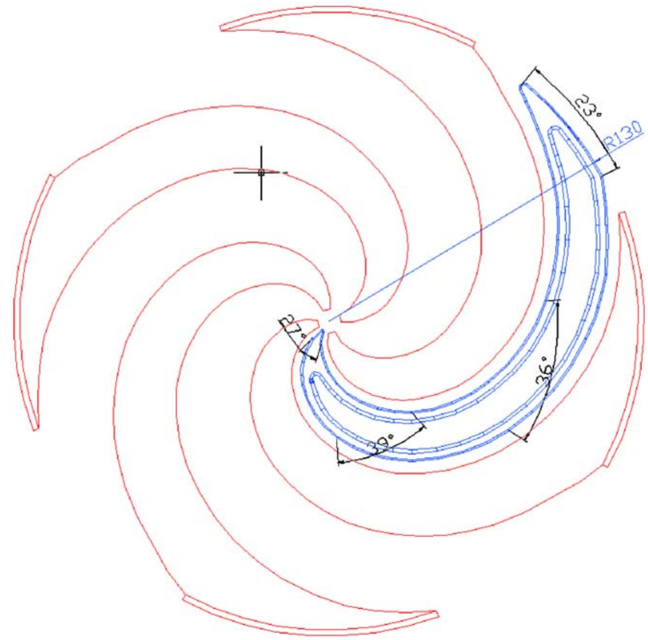

Fig. 2. Layout of a DEE between the poles.

Due to the large spiral angle, the electrode equivalent length is around 2.5 m which results in a LINER-DEE equivalent capacitance of more than 200 pF (see Fig. 2).

In order to compensate such a capacitance and to attain the high resonant frequency, it is necessary to decrease the inductive contribution by increasing the diameter of the stem. On the other hand, since the diameter extension of a single stem is limited by the restricted angular width of the DEE (~35°), the value of the resonance frequency will have an upper limit. In order to increase this limit, it is necessary to introduce new stems.

The advantages of using more stems are as follows:

1. it is possible to shape the voltage distribution along the accelerating gap with voltage increasing along the radius,
2. three supports for the heavy copper DEE (instead of one) provide a better mechanical stability of the cavity,
3. currents are split and flow towards the nearest stem, reducing the local power dissipation (i.e. the current density for each short circuit is lower) and increasing the cavity performance in some case.

Finally in order to control the radial voltage distribution and to obtain the required resonant frequency, a multi-stem configuration appears to be the only feasible solution [3–5].