DESIGN OF A FIXED FREQUENCY DELTA RESONATOR WITH POSITIVE GRADIENT RADIAL VOLTAGE DISTRIBUTION

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Abstract

The design of the RF system for the new injector cyclotron for the SIN 600 MeV ring accelerator is described. This open-sector cyclotron is expected to accelerate a 1 mA proton beam of 0.8 MeV to a final energy of 72 MeV.

To get a high beam pulse compression, the design goal of the fixed frequency RF system is a positive gradient radial voltage distribution. Different types of resonators were investigated, and a half-wave resonator with a delta-shaped resonant line was found most suitable for the required radial voltage increase of factor 2 to 3. Scaled models of delta resonators of different transmission line shapes were constructed to measure the resonator characteristics. From these results the optimum design was selected to fulfil the required voltage distribution and low power loss.

1. Introduction

The project of a new injector for the SIN ring cyclotron has been described at previous as well as at present conferences[1,2] and thus only a short summary of its basic features is given.

The design goal of this new 72 MeV injector was established to be:

1. Average beam current 1 to 2 mA
2. Energy spread <150 keV FWHM
3. Pulse repetition rate 50.7 MHz
4. Pulse width ~15°RF
5. Axial and radial beam quality π•2mm mrad

The protons are accelerated in two stages. The first is a dc accelerator of the Cockcroft-Walton type with an energy of about 0.8 MeV. The second stage is a ring accelerator with four sector magnets and two different RF systems. In previous papers[1] the accelerating system was described to consist of three different RF systems: two dees and two main cavities operating at 50.7 MHz and two flattop cavities operating at 152 MHz. In the meantime, the RF system has been thought over, first to reduce the number of different accelerating structures and secondly to achieve a more suitable volltage distribution along the accelerating gap. The four resonators operating at the fundamental frequency of 50.7 MHz have now been replaced by only two half-wave resonators. After some considerations leading to the choice of this kind of resonator, its design is described.

2. Conditions for the 50 MHz Accelerating System

The space available between two consecutive magnets for each main resonator and its vacuum chamber is limited to a segment which subtends an angle of 40° at the centre of the machine (Fig. 1). Because of the low injection energy (0.8 MeV) with respect to the extraction energy (72 MeV) as well as the axial injection design, the space between the first orbit and the inner wall of the resonator is very restricted (about 15 cm). To get single turn extraction and a high beam pulse compression, the accelerating voltage is expected to increase with a positive gradient from about 200 kV to 500 kV with respect to machine radius. Another limitation factor is the RF power loss. The four cavities in the 590 MeV ring cyclotron are driven by 250 kW amplifiers, making it advantageous to fall back on the same driver stage design.

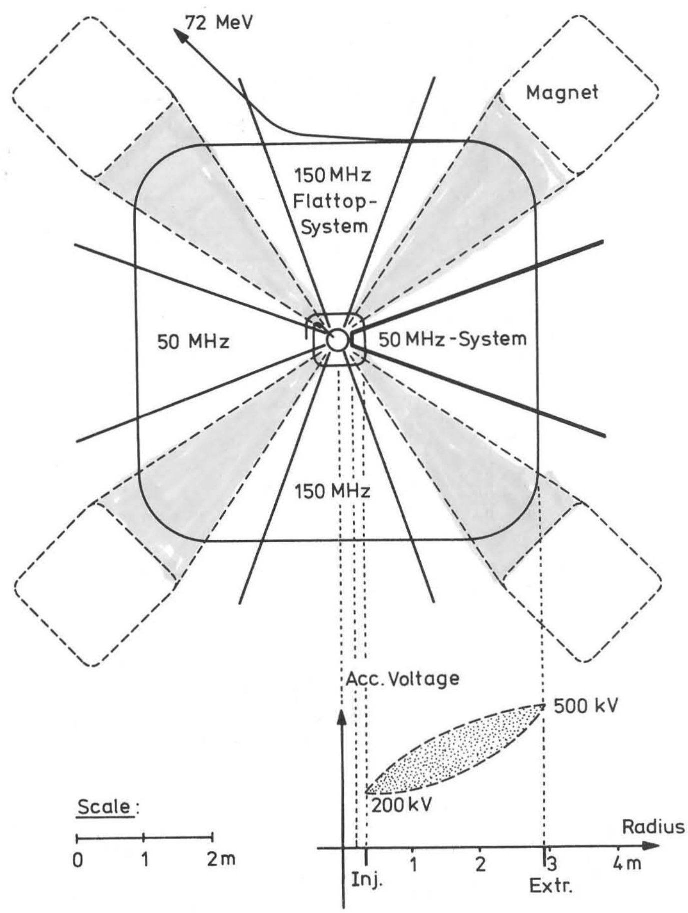

Fig. 1 Location of the RF systems in the injector cyclotron and range of ideal voltage distribution for the two 50 MHz main accelerating systems.

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3. Some Thoughts on the Choice of a Half-Wave Resonator

As an alternative RF concept to the combination of delta resonators and cavities[3], in which the injected beam is accelerated by two quarter-wave delta resonators up to the useful range of the cavities, a half-wave resonator has been considered. In this type of resonator, two delta-shaped accelerating electrodes are located in the voltage maximum of a vertical half-wave transmission line[4].

In the case of the SIN injector, the azimuthal width of the accelerating electrodes has to be 18° (corresponding to a RF phase width of 180°) and their radial length should be about 3 m. That means that the radial dimension lies in the range of the electrical length of the half-wave resonator. For the accelerating electrodes to be negligible with respect to the length of the resonant line, the two vertical stems have to cover practically the entire electrode area. In this case the radial voltage distribution over the gap is not decreasing in the injection region, as with other types of delta resonators[3,5,6], but is nearly constant over the entire radius. This large cross section implies a low wave impedance of the resonant line and therefore a high power loss of the whole resonator. But the reduction to two main resonators partially compensates this disadvantage. After model studies[6] verified that even the voltage distribution can be brought into the desired range, the concept with two half-wave resonators has been found most suitable for the main acceleration in the new injector (Fig. 2).

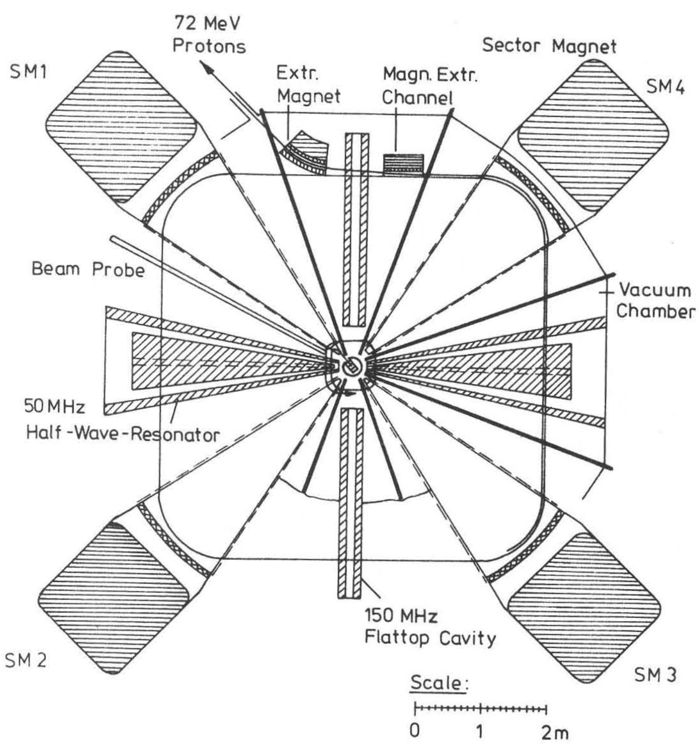

Fig. 2 Layout of the new SIN injector, showing the two half-wave main resonators and two flattop cavities. This project is now in the process of realization.

4. Design of a Half-Wave Resonator with a Delta-Shaped Resonant Line

The voltage distribution along the gap is linked via Maxwell's equations to the magnetic flux crossing the gap vertically. To obtain a voltage variation along the machine radius, the vertical component of the magnetic flux in the gap must be unequal to zero. In the half-wave resonator described above, wherein the stem covers the entire electrode area, the magnetic field lines circle the stem horizontally, and the voltage distribution along the gap is constant. To achieve a voltage distribution decreasing from extraction to injection radius, part of the magnetic flux surrounding the stem in the extraction region is to be bypassed through the gap from one half of the resonant line to the other (Fig. 3). A reduction of the stem width in the extraction region leads to a conical magnetic flux tube, which forces part of the horizontal flux vertically through the gap and thus satisfies the above mentioned requirement.

4.1 Variation of the Radial Voltage Distribution

Because of the complicated boundary conditions it is difficult to determine the characteristics of this type of resonator analytically. Therefore only some approximate calculations have been made. The final resonator design has been determined by measurements on scale models.

To achieve low power loss of the resonator a high wave impedance of the resonant line was aimed for. Therefore the outer conductor was chosen as wide as possible and the stem, which covers the whole length of the inner delta-shaped electrode pair, as narrow as possible. Fig. 3 shows a cutaway view of the 1:2 model.

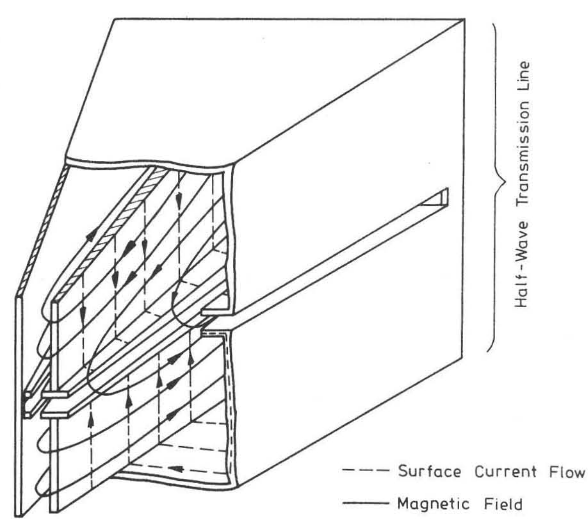

Fig. 3 Field distributions in a half-wave delta resonator with radially increasing gap voltage.

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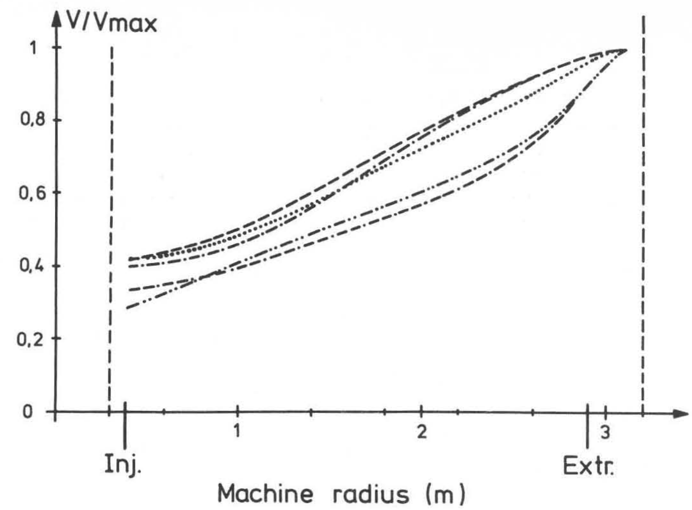
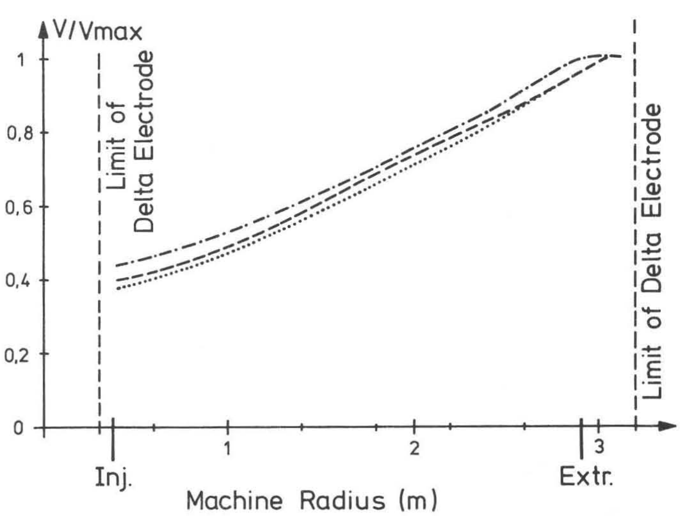
In Fig. 4 the measured radial voltage distribution is plotted for different stem widths. Variation of the stem width has negative side effects on mechanical stability, Q-value optimization, and resonant frequency. Instead of controlling the horizontal magnetic flux by variation of the flux tube, the magnetic flux crossing the accelerating gap may be controlled by varying the gap width (Fig. 5).

A third possible way of changing the voltage distribution within a certain range is to vary the capacity between the inner delta-shaped electrodes and the chamber wall at the radial periphery of the resonator (Fig. 6). The second and third method of varying voltage distributions are also linked to a change of resonant frequency, but in an opposite way. For instance to lower the voltage distribution at injection: increasing the gap width in the injection region results in a higher resonant frequency, while increasing the capacity between electrodes and chamber wall causes a lower resonant frequency. Hence, by combining and balancing these two methods, the voltage distribution may be varied without influencing the resonant frequency.



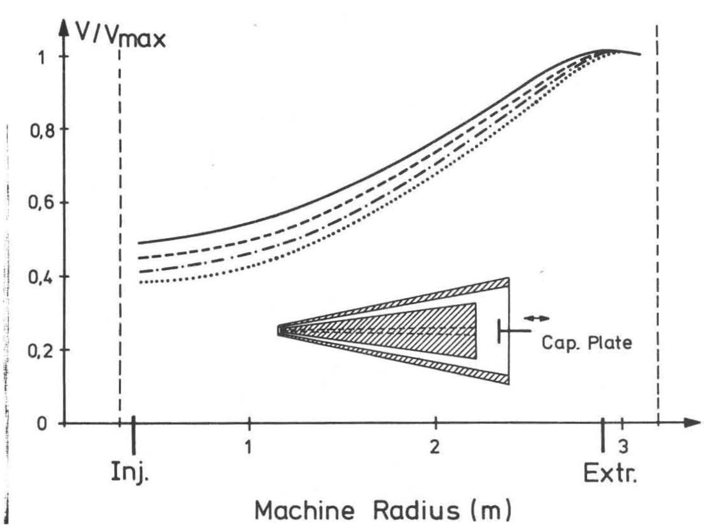
Graph	Gap Width (cm) at Radius 0.3	3.0	Resonant Frequency (MHz)
---------	2	9	49.6
-·-·-·-·-	3.6	9	50.5
·········	3.8	14.6	52.2
-·-·-·-··	1.6	18.2	52.5
--·-·-·-·	3.6	17.8	52.9

Fig. 5 Normalized radial voltage distributions for the half-wave resonator, measured in a 1:2 model with variable gap width. Data is scaled to full size.



Graph	Stem Width (cm) at Radius 0.3	3.2	Resonant Frequency (MHz)
---------	2	10	51.23
·········	4	10	51.6
-·-·-·-·-	4	20	52.7

Fig. 4 Normalized radial voltage distributions for the half-wave resonator, measured in a 1:2 scale model with variable stem width. All data is converted to full size.



Graph	Resonant Frequency (MHz)
————	51.75
---------	51.15
-·-·-·-·-	50.75
·········	50.25

Fig. 6 Normalized radial voltage distributions for the half-wave resonator, measured in a 1:2 model with a variable capacity between delta electrodes and the chamber wall at the radial periphery of the resonator. Data is scaled to full size.

4.2 Frequency Tuning and Coupling Systems

All three aforementioned methods for varying the voltage distribution enable us to tune the resonator. But by measuring the attainable tuning range as well as for mechanical design reasons the variation of the capacity between accelerating electrodes and chamber wall has been found to be most suitable. To eliminate undesired coupling between voltage distribution and frequency variation, the voltage pick-up probe for the amplitude regulation loop has to be positioned in the effective pivotal point of the radial voltage distribution curve. This point is specified by the requirement that the integrated accelerating voltage along the gap remains constant during variation of the tuning capacity.

RF power from the 250 kW final amplifier stage will be fed through a coaxial line into the capacitive coupling system, located between the two tuning plates (Fig. 7). Varying the beam current from 0 to 1 mA will result in an input impedance change of the fixed coupling system from about 40 to 60 Ω, which is still in a tolerable range for the 50 Ω final amplifier. Should higher beam currents be required, a variable coupling system might have to be implemented.

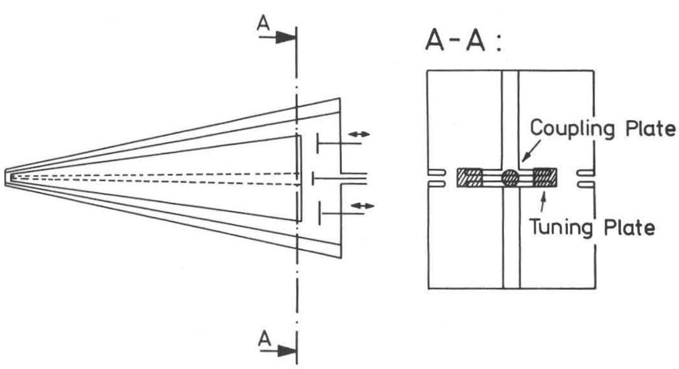


Fig. 7 Top and side view of the half-wave resonator with the simplified tuning and coupling systems.

4.3 Electrical Characteristics of the Resonator

The following characteristics were obtained from measurements on the 1 : 2 scale model and converted to full size:

Resonant frequency	:	50.7 MHz
Bandwidth (no load)	:	3.5 kHz
Power consumption for voltage at extraction of about 250 kV and 1 mA beam current	:	180 kW
Voltage at extraction to voltage at injection ratio	:	2.5
Q-value	:	14500

In order to get more detailed data of this RF structure, a 1 : 1 scale prototype will be designed and built within the next year.

Acknowledgements

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