THE RF-SYSTEM FOR A VICKSI INJECTOR CYCLOTRON

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ABSTRACT

One alternative to the existing electrostatic injectors of VICKSI is a small compact cyclotron. The ions from an external ECR-source shall be axially injected and accelerated by an RF system with the same basic features as that of the existing K = 130 separated sector cyclotron. This means there will be two dees, located in two of the four magnetic field valleys opposite to each other, with an angle of 36° each, working either in push/push or push/pull mode in the frequency range of 10 to 20 MHz. The resonator volume is kept below 0.5 m^3 by the use of coils instead of a dee stem. This compact design concept allows a maximum dee voltage of 70 kV with a power loss of less than 6 kW.

1. GENERAL IDEAS

Nuclear physics at VICKSI[1] usually demand rather low beam intensity in the range of nano- and pico-amperes. But during the past few years, VICKSI experienced a growing demand of beam time for solid state physics experiments, often requiring higher beam currents than available. Today, the VICKSI beams are limited with respect to intensity mainly due to ion source characteristics and stripping efficiencies. Heavy ion beams with micro-amperes of current are produced only at low charge states. Since the "energy booster" cyclotron asks for a minimum charge to mass ratio $q/A \geq 1/8$, stripping is necessary before injection. At best, 30% of the delivered injector beam intensity is stripped to the right charge state. For highest beam energies, stripping efficiencies as low as 0.1% are encountered.

ECR-sources[2] deliver tens of micro-amperes of beam current directly at these high charge states necessary for our cyclotron, which would eliminate the need of a stripper. With the proposed new injector cyclotron, existing ECR-technology can be used to produce most VICKSI-beams at roughly tenfold intensity.

1.1. Basic Machine Layout

The new injector cyclotron will have an extraction radius of 43 cm, which corresponds to the injection radius of the booster cyclotron: The injector runs with the same mean magnetic field of 0.8 T at maximum. Then with the same pole shape symmetry and acceleration system every injected beam is automatically perfectly matched to the booster. Therefore the matching condition directly suggests to choose all the basic machine layout as it is at the booster:

- 4 straight magnetic sector poles with an angle of 50° each.
- 2 accelerating dees, 36° wide each, in two opposite magnetic field valleys, driven either push/push or push/pull at 10 to 20 MHz operating RF frequency (harmonic number 2 to 7).

The ECR-source beams are preaccelerated by a 100 kV platform and axially injected to a radius of 8 cm. The four magnetic poles are attached to a common yoke, which will have small outer dimensions of just 2x1x1 m. The k-factor is k = 8.

This paper deals especially with RF design aspects. Several resonator options have been compared in order to reach small overall machine dimensions.

2. RF DESIGN CONSIDERATIONS

As mentioned in 1.1., most of the basic RF layout is already set by beam matching considerations.

To find the necessary maximum dee voltage level, injection- and extraction-conditions are examined. For single turn extraction a minimum turn separation of 8 mm should be reached. At injection, the first turn radius of 80 mm should be increased by the dee voltage to at least 110 mm for the second turn. Both conditions are met with a dee voltage level of 70 kV even for worst case operation (2nd harmonic and $q/A = 0.5$). To limit the necessary amount of driving power, a high Q resonating structure is mandatory. Complete high vacuum environment is chosen.

The dee structure has been calculated to represent a capacitive load of roughly 55 pF by the use of code EFEBER, which is derived from an old code named EFICAL[3]. The configuration has a minimum dee gap width of 14 mm and a clearance for the beam passage of 20 mm in height.

An unloaded quarter wave resonator at an operating frequency of 10 MHz means a conductor length of 7.5 m. Capacitive loading with up to 260 pF cuts such a resonator of coaxial type down in length to about 2 m at cost of an increase in driving power by roughly a factor of 5. Still 2 m-resonators with 1.5 m outer diameter are large units if compared to the small overall yoke dimensions. A large cost reduction for the project is expected if the injector size can be kept small enough to be realized within existing buildings. Therefore alternative types of resonator construction have been investigated, capable of driving the same dee structure with still low losses but reduced requirement of space.

2.1. Comparison of Resonator Options

The simple quarter wave resonator, a piece of coaxial line connected horizontally to the rear of the dee, has been compared to a half wave structure with vertical dee-connection, and to another quarter wave system with the inner line conductor wound up to a coil.

2.1.1. Horizontal quarter wave coaxial line resonator

Length reduction of this type of resonator is limited by geometrical reasons. In order to limit the decrease of voltage versus increasing machine radius within the dee area, additional capacitive resonator loading should not be applied along the dee. Since the dee tip area is occupied by magnet poles and injection elements, space is available only at the rear of the dee. For 200 pF at a gap of 20 mm a capacitive plate area of $0.5 m^2$ needs to be provided around the dee stem, which means another meter of stem length. Therefore less than 2 meters of total resonator length cannot be achieved.

There are about 1 kW of power losses for 70 kV dee voltage at the open end of an unloaded shorted coaxial quarter wave line, with copper surfaces, outer diameter $D = 1.5$ m, stem diameter $d = D/10$, operated between 10 to 20 MHz. If tuned by shorting piston and loaded by a fixed 260 pF, this resonating line will be cut in length to less than half at cost of an increase of losses of up to 5 kW. With capacitive tuning only, the power loss amounts to a maximum of 3 kW.

Table 1. Coaxial line quarter wave resonator

Dee-capacity (includes fine tuning)	100 pF
Resonator outer diameter	1.5 m
Stem diameter	0.15 m
Resonator stem length	4.09 m
Dee-length	0.52 m
Coarse tuning via shorting piston/piston path length	2.84 m
Power losses at 70 kV dee voltage (copper surfaces)	1.45 kW (10 MHz) 1.8 kW (20 MHz)

Less ambitions with respect to length reduction permit the straightforward design-data given in table 1. At reduced dee voltage of 50 kV less than 1 kW of driving power is necessary, which would allow to run without a special power amplifier, and to use already existent drivers.

2.1.2. Vertical half wave coaxial line resonator

A large capacitive tuning range with a movable plate facing the rear of the dee is achieved easier, if the stem connects elsewhere. Vertical connection of two quarter wave stems through the magnet yoke has been considered, which results in a similar type of resonator as built for the two GANIL SSC's. With this solution the outer line diameter is limited to 0.5 m by the yoke/pole-dimensions. With 5 cm stem diameter, 215 pF tuning capacity and 55 pF dee capacity the results are: Up to 18 kW of driving power for 70 kV dee voltage and 2 m vertical space above and below the beam plane have to be provided.

2.1.3. Helical inner conductor

Smaller resonator dimensions are possible with the replacement of the inner conductor of a quarter wave coaxial line by a coil. Chapter 3 deals with special mechanical and electrical problems encountered with such a resonator; a feasible layout is shown in Fig. 1 and explained with Table 2. The resonator extends only 0.5 m beyond the magnet yoke and will give 70 kV of dee voltage with about 6 kW of losses.

3. SPECIAL FEATURES

A coil cannot support the dee structure mechanically. Cooling is not easily provided, and high currents must be handled at the shorting point.

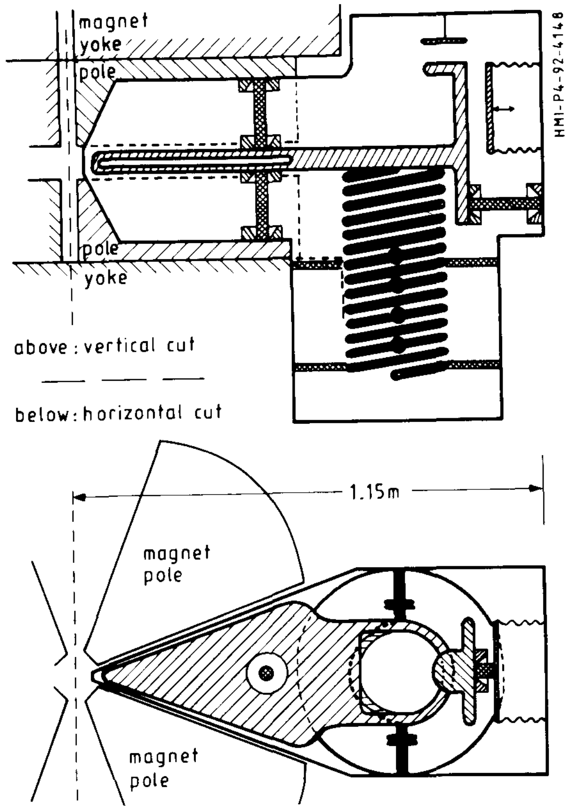

Fig. 1. Quarter wave resonator with helical inner conductor

Table 2. Double-helix quarter wave resonator

Dee-capacity:	55 pF
Tuning capacity (rear of dee)	10 to 40 pF
Coupling:	capacitive
Dee support: 3 BeO rod insulators/length 17.5 cm/ diameter 3 cm / protected by corona rings	
Coil: Double-helix in shielding box / Box diameter 0.5 m / Each coil is made from silvered, unmagnetic stainless steel tube with 2 cm tube diameter and 0.6 cm bore-radius / Coil-mean-diameter 22 cm, turn-pitch 7.2 cm / Both coils are turned into each other to form a double-helix with the connections oriented by 180° to the rear of the dee / Coil support by BeO rod insulators / Coil Q ~5000 (at 20 MHz) and ~4000 (at 10 MHz)	
Frequency-tuning: capacitively within four sub-bands by tuning plate facing the rear of the dee / Sub-band selected by pressing two ground studs to one out of the four pairs of taps on the double-helix	
Power loss at 70 kV dee voltage:	4 kW (10 MHz)
	6 kW (17 MHz)
	4,5 kW (20 MHz)
Shorting current, at 70 kV/17 MHz	700 A, total
divided to two studs, 10 cm contacts	35 A/cm

To support the dee and the coil mechanically, rod insulators have been used. At the metal / insulator-junction the electrical fields are strongly reduced with conical metal rings. With BeO as insulator material, the maximum losses per rod amount to about 60 W. This gives a maximum temperature rise of 20° K between the midpoint of the rod and the cooled end surfaces.

Cooling water is brought through the coil to the dee. In fact, two identical coils are used, fitted together as a double-helix with the hot ends connected to the rear ring of the dee at 180° apart from each other. This parallel connection allows the one coil tube being used as water feed, the other as drain.

Model measurements on a prototype double-helix showed the coil Q to be increased by about 10% over the single-helix case. The minimum Q-value is 4000. This results in 700 A of shorting current at 70 kV dee voltage, which excludes the use of sliding coil taps for frequency tuning. Therefore only a frequency sub-band is selected at the double-helix coil by means of switching one out of four fixed tap-pairs at the lowest four windings. The total maximum of 700 A divides onto two taps, one for each helix, with a contact ring of 10 cm in circumference. During RF operation the contact rings are under pressure, which gives a large safety margin over the anticipated maximum current load of 35 A/cm. Frequency tuning within the sub-bands is achieved with a movable capacitive plate facing the rear of the dee. To cover the sub-bands completely, a maximum capacity change of about 22 pF must be provided.

4. CONCLUSION

One important problem for the construction of an injector cyclotron for VICKSI is the design of the RF system.

The quarter wave coaxial line resonator described in table 1 is the simplest solution. It just requires space, which in turn easily means as much additional costs for a new building as the complete expenses for the injector alone. In the tradeoff between a simpler RF design with high building costs and a more complicated but smaller double-helix resonator the latter is favoured. With this solution the overall dimensions of the injector cyclotron are mainly defined by the magnet yoke and kept very small.

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