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RF SYSTEM DESIGN OF THE MILAN SUPERCONDUCTING CYCLOTRON

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Abstract. - The accelerating system of the Milan Superconducting Cyclotron will have three symmetrical coaxial cavities, tunable on the 15 ÷ 48 MHz frequency range, with a peak voltage of 100 kV.
The mechanical and thermal problems call for a design where the part of the cavity where the sliding short circuit is moving will be in air. High voltage ceramic insulators will likely be used.
This paper will present the detailed design of the cavity and its expected performances. It will also discuss the solution adopted for the three power amplifiers.

1. Introduction

The accelerating system for the Milan Superconducting Cyclotron consists of three dees, placed in the valleys. Each dee is the high voltage inner part of a resonator which consists of two $\lambda/4$ half cylindrical cavities tied together at the center and symmetrically placed about the median plane [1,2].

Two alumina insulators, placed at 630 mm from the median plane, connect mechanically the coaxials. To tune the resonators in the 15 ÷ 48 MHz frequency range two sliding shorts move along the cylindrical walls of the cavity.

The accelerator design calls for a peak dee voltage of 100 kV in the injection and extraction regions. Depending on the harmonic used, the three dee voltages can be either in phase or $\pm$ 120° out of phase. The design phase stability is $\pm$ 0.2° for an AM noise on the accelerating voltage better than $1 \cdot 10^{-4}$.

A low level splitted signal from a high spectral purity synthesizer feeds three high-linearity independent amplification chains. A 50 ohm coaxial cable connects each amplifier to its cavity via a coupling capacitor.

This paper will present the cavity design and its expected performances. The amplification chains, presently under construction, are also described.

2. RF Cavity

The three cavities of the Milan Superconducting Cyclotron differ only in those parts of the dees which are determined by the central region geometry and by the extraction path of the beam.

Fig. 1 shows a schematic drawing of the upper half of a cavity fitted in the cyclotron. Fig. 2 shows the dee of the cavity placed in the valley between the two electrostatic deflectors. Only a few comments are in order:

- The central region of the cyclotron, as concerning the possible use of an internal ion source, or an axial injection system, has not been designed yet. The dee shown in fig.2 refers therefore to the cyclotron operation as a booster and is the one being built as a prototype for RF tests.
- The external contour of the dee shown in fig. 2 is determined by the envelope of the 100 Mev/n beam when going from the first electrostatic deflector to the second (R_t), whereas the external contours of the two other dees are determined by the maximum envelope of the last accelerated beam (R_e).

Looking again at fig. 1 we note that the main difference from previous designs [3] is the ceramic insulator.

Since magnetic field calculations [4] showed that it is possible to increase the diameter of the main RF holes in the magnet (from 410 to 500 mm) and since recent results of tests performed at MSU indicate that 100 kV insulators can reliably work [5], we have decided to modify our cavity design. The advantages of the insulator are evident. In particular we expect to offset the problem caused by stem strains, due to a non uniform strengh distribution pattern around the short circuit plate or to a dissimetry in the coaxial cooling circuits. Mechanical vibrations induced by coupled motions of external elements (pre-vacuum pumps, trim capacitors, etc.) will be reduced while their frequency will be almost independent of the short circuit position. Finally the sliding short works in air.

Some details of the main components of the resonator are given in the following.

2.1 Coaxials

The two coaxial tubes along which the sliding short moves, have diameters respectively of 470 mm and 208 mm. They will be manufactured by cold-drawing 4 m long and 8 mm thick tubes of a OFHC copper billet. The price of the bigger one, which has an unusual diameter, will be about 7,000 $.

2.2 Dee

Each half dee is composed by two separate parts which are marked in fig. 2 with Al and Cu.

The first one, connected to the inner coaxial, is an internally beaded box made from 3 mm thick soldered copper sheet. Its main purpose is to contain the high vacuum pumping facility described in the following. The second part is a solid aluminum piece machined with a numerically controlled milling machine.

This design allows a simple and reliable modification of the central region geometry. A central region geometry modification seems necessary everytime one changes harmonic in internal or external source configuration.

2.3 Ceramic Insulator

After consideration of sophisticated options like a conical shaped insulator with copper flanges brazed on the ceramic or with plated edges, we decided for a simpler design suggested by technological constraints and cost considerations.

The present design anticipates a 99.7% Alumina cylindrical insulator 200 mm high, with an external diameter of 280 mm and 8 mm wall thickness. The upper and lower edges of the cylindrical wall will be thickened to 12 mm. The cost will be about 3,000 $.

Vacuum sealing between the two coaxials and the insulator will be ensured by Inconel C/seals coated with an Ag-In alloy, like those used at MSU.

2.4 Sliding Short

Although the design has not been detailed yet, we plan to ensure the electrical short between the coaxial walls and the shorting plate with two concentric rings of massive Elconyte D58 (Ag 99% - C 1%) rolls. The rolls will be pressed against the coaxial walls and the plate by one Cu-Be spring.

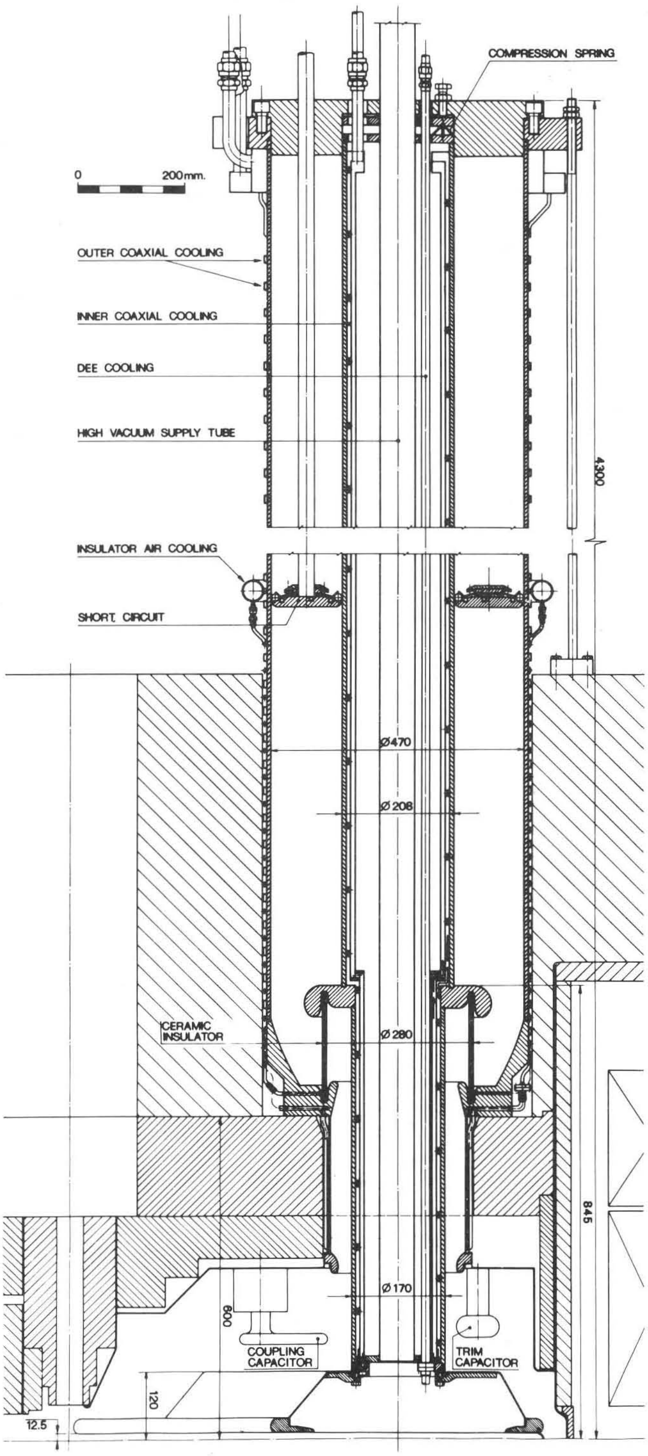

Fig. 1 - Schematic drawing of upper half of a cavity fitted in the cyclotron.

The anticipated solution should withstand a much higher current density than the RF design requires, and allow a total mechanical tolerance of the order of 1mm. With a careful mechanical design we think it should be possible to move the sliding short at full RF power.

2.5 Liner

The liner, which is the external conductor of the RF resonator, serves as a barrier between the high vacuum of the beam region ($1\cdot10^{-7}$ Torr) and the rough vacuum around the hills.

It will be shaped and welded from a 3 mm thick OFHC copper sheet. Its shape is mostly determined by the polar geometry with the trim coils wound.

2.6 Trimming and Coupling Capacitors

In order to avoid unbalanced axial components of the accelerating field, we will use two trim capacitors placed and moving symmetrically with respect to the median plane. The coupling capacitor too has a corresponding element in the lower half of each cavity.

2.7 Vacuum

The required vacuum of $1\cdot10^{-7}$ Torr, after 10 ÷ 15 hours, asks for about 15000 ÷ 20000 l/s pumping speed, which is achieved starting from a pre-vacuum of the order of 10^{-3} Torr.

The pre-vacuum is obtained by means of an external conventional pumping system (rotary + turbomolecular) while the high vacuum panels are located inside the dees. According to the present design, we intend to provide each half dee of two resonators with a total of 16 UL 1250/2 getters (manufactured by SAES-Getters, Milan) and the third resonator with a 10 dm^2 liquid N_2 cooled panel. This panel is provided to increase water vapour pumping speed. Accurate tests will be performed before the end of the present year.

We note that this pumping scheme does not work for helium and therefore it would not be feasible to accelerate α particles with internal source. If not acceptable, two stages cryogenic panels will be employed; the central tube of the inner coaxial, which otherwise contains the electrical connections for getters regeneration and activation, would be suitable for feeding the panels.

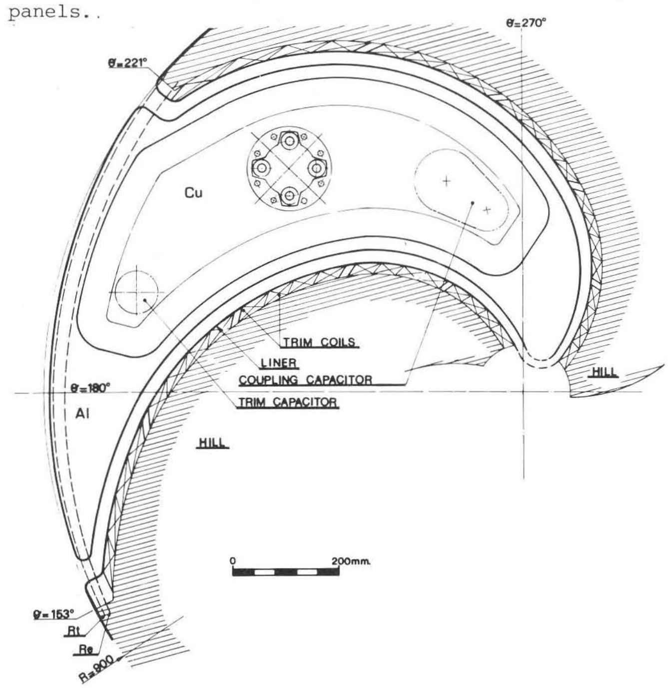

Fig. 2 - Dee schematic top view. The dee presented belongs to the cavity placed in the valley between the two electrostatic deflectors. The dashed central region refers to the prototype.

3. Cavity Expected Performances

Some of the main parameters of the described cavity are given elsewhere in this conference [1].

We summarize in Table I some of the main cavity features, calculated at 15 MHz and 48 MHz, lower and upper limits of the frequency range.

Table I Main cavity features

Power dissipation	=	45 and 70 kW
Short circuit current density	=	27 and 37 A_{eff}/cm
Short distance from median plane	=	3.35 and 0.88 m
Q factor	=	4600 and 4000
Shunt impedance	=	106 and 58 kohm
Coupling capacitor	=	4.6 and 1.9 pF
V_{max}/V_{min} on the dee gaps	=	1.1 and 1.5
V_{peak} in the central region	=	100 and 102 kV

Only a few comments are in order:

- Power dissipation and short circuit current density are computed for an average peak dee voltage at the extraction radius of 100 kV.
- The short circuit current density shows a maximum of 38 A_{eff}/cm for 42 MHz and is always more than 35 A_{eff}/cm for frequencies higher than 30 MHz.
- The Q of the resonator attains a maximum value of 5000 for frequencies around 25 MHz.
- It is worth noting that the cavity shunt impedance is computed as seen by the coupling capacitor; in fact, because of the large radial extent of the dee compared to the wavelength, the dee voltage is a function of the radius. This is shown in fig. 3 where the voltage patterns along the two accelerating gaps are plotted together with the average value.

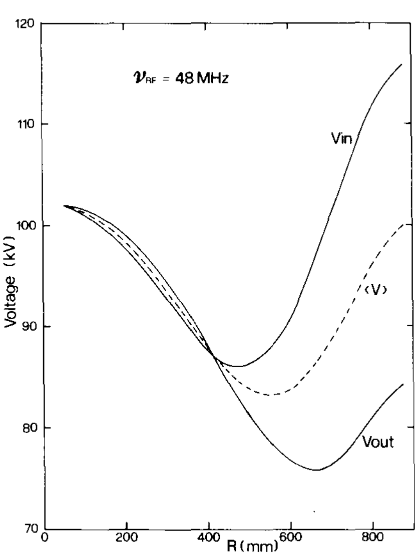

Fig. 3 - Voltage pattern along the two accelerating gaps. The average value is also shown.

4. RF Amplifiers

Three identical amplifier chains, driven by a splitted signal from a single high spectral purity frequency sinthesizer, deliver 75 kW of RF power to the three cavities via 15 m of 50 ohm coaxial cable and coupling capacitor

Each chain consists of a broad band commercial amplifier and an expecially designed power amplifier.

4.1 Broad-band amplifier

It is a 200 W, 53 dB gain broad-band commercial amplifier. All the low level stages are solid state while the final stage employs 12 tubes.

4.2 Power amplifier

It is a two stage power amplifier with wide band input and a final stage in a grounded grid configuration. A schematic diagram is shown in fig. 4.

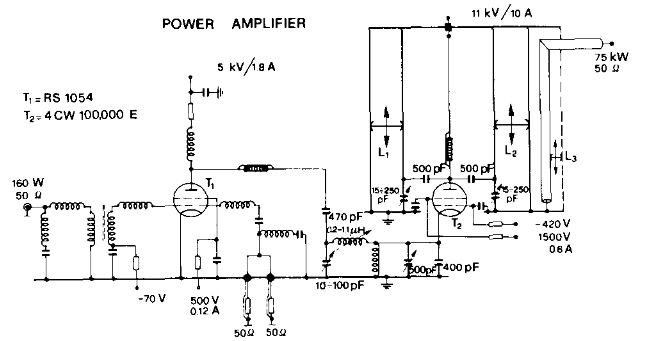

Fig. 4 - Two stage power amplifier schematic diagram

The amplifier is designed and manufactured by Brown Boveri Co., Baden (CH). Its main features are listed in Table II.

Table II. Power amplifier main features

Frequency range	=	15 ÷ 50 MHz
Output power	=	75 kW
Output and input impedances	=	50 ohm
Linearity (from 5 to 75 kW)	≤	10%
Gain	≃	27 dB
Noise level	≤	-60 dB
Harmonic distortion at full power		More than 50 dB below fundamental (up to 200 MHz)
Tuning		Digitally programmable

5. RF System Status

As of this date the design of the resonator prototype is going on; we expect to be able to order its construction by the end of the presenr year.

The first amplification chain will be installed and tested on dummy load by September 1982. We plan to perform a full power testing of a complete prototype of one third of the RF system by the end of 1982.

Prototypes of different low level electronic control systems are now under design. They will be tested together with the resonator.

6. References

1. E. Acerbi et al., "The Milan Superconducting Cyclotron Project" (paper presented at this conference)
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3. C. Pagani and G. Varisco, "Model study of the RF Cavity for the Milan Superconducting Cyclotron", IEEE Trans. Nucl. Sci. NS-26 (1978), 2182.
4. G. Bellomo et al., "Design of the magnetic field for the Milan Superconducting Cyclotron" (paper presented at this conference).
5. J. Riedel, "RF Systems", IEEE Trans. Nucl. Sci. NS-26 (1978), 2133.