Status report of the RF system for the VINCY Cyclotron

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Abstract

A status report of the RF system for the VINCY isochronous cyclotron is presented. The mechanical problems that had to be resolved are mentioned. Results of classical approach calculations, preliminary 3D calculations with the MAFIA code and full scale cavity model measurements are compared. The coupling system aiming to match the power amplifier through the whole frequency range is also described.

1. INTRODUCTION

The main parameters of the VINCY Cyclotron as a part of the TESLA Accelerator Installation have been already presented in this conference [1]. In this isochronous cyclotron, the acceleration of the ions in the first, second and fourth harmonic is accomplished by the two opposite dees settled in the first and third magnet valley The resonator type is implied by the basic design constraints. The use of the magnet based on the modification of the CEVIL magnet from Orsay, France, implies application of the horizontal $\lambda/4$ type. The cavities design is based on the use of the prototype cavities of the LNS Catania Superconducting Cyclotron [2], (208mm I.D./ 470mm O.D.,d=8mm) following the collaboration agreement in progress between the VINCA Institute of Nuclear Sciences and INFN which is to include the transfer of the know-how for the design of the sliding short [3] and electronic control too . The main problem with a $\lambda/4$ resonator is the need of a piston to tune throughout the frequency band between 17 and 31 MHz. Following this range the excursion of the piston is around 2m, i.e. the stem lenght is over 2 m and total lenght over 4m. Due to the high accelerating voltage, ceramic supports can not be safely adoped and cantilever type structure is taken into consideration. This type of structure has to be analysed with respect to the dynamic stability margin due to the possible effects of the ponderomotive forces. Following given constraints and electromagnetic caracteristics of the cyclotron, main parametars of the RF system are:

Table 1

Accelerator dees	2 x 30 deg.
Beam aperture	22 mm
Min. RF gap	10 mm
Frequency range	17-31 MHz
Max. voltage	100 kV
Installed power	2 x 100 kW

2. RF SYSTEM LAYOUT

The VINCY RF system main components are settled in the cyclotron hall. The layout of the components which are in the vacuum chamber are presented in fig. 1. The whole RF system can be slided out from the vacuum chamber (1) and settled in the cyclotron hall. The upper part of the liner (2) can be lifted together with the upper magnet yoke (3) for inspection pourposes.Every resonator (4) is energized by a separate power amplifier (5). To avoid complex matching system, thus limiting the action to only one variable vacuum capacitor, each amplifier constitute a $\lambda/2$ resonator (6) which is inductively coupled to the corresponding dee (7).
The amplifiers are housed below the basement of the machine and the possibility of an adequate screen to allow access during machine operation could be envisaged (fig 2). The remote control system is settled in the TESLA Accelerator Installation control room and the main current and demineralised water supplies are settled in the other parts of the building.

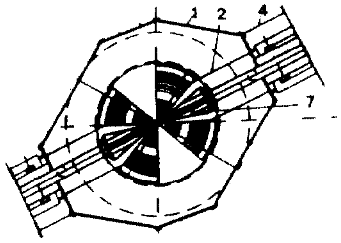

Fig.1 RF components in the vacuum chamber

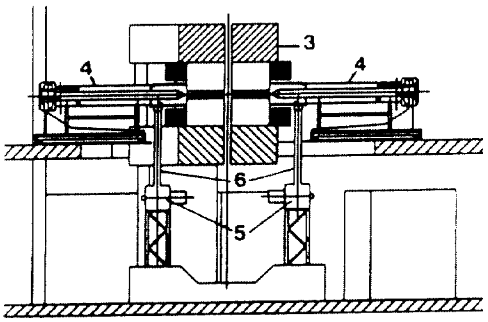

Fig.2 VINCY RF system general layout

3. THE MECHANICAL PROBLEMS OF VINCY RF RESONATOR

The main task of the mechanical study of the resonator is to respond to the demands of high and reproducible dee structure positioning tolerances with respect to the beam aperture and RF gaps in the case of cantilever structure (+/- 0.5 mm) The same level of coaxiality tolerances has to be respected also, on the whole lenght of resonator, particularly considering the possible effects of the ponderomotive forces [4]. Because of this, the dee are supported by means of a light and rigid stainless steel honeycomb structure (weight 390N, moment 20000Nm, sag compensation on supporting flange 1.7 mm).Possible dynamical problem of water cooling pipes vibration is also to be studied. Dee positioning with respect to the stem (3 degrees of freedom), stem and outher coaxial positioning with respect to the supporting structure (5 degrees of freedom) is to be accomplished with mechanical positioning system and compared with the electronic position monitoring system [5].

4. ELECTROMAGNETIC STUDY OF THE CAVITIES

4.1Numerical model

The principal design constraints to the cavity shape are:

1.small vertical aperture allowed for the anti-dee accomodation

2.fixed resonator tubes diameters

3.vacuum chamber dimension limiting the high frequency short position

4.maximal stem length limiting the low frequency short position

5.maximal currents on the short and on the other contacts

The form of the RF cavity was optimised using the classical approach (nonuniform line calculation) [6]. The cavity has been subdivided in number of line segments, each one with supposedly constant characteristic impedance. Impedances of the segments were calculated by EFICAL code [6] (solving the 2D Laplace equation). The basic transmission line equations are used to derive the recursive relation used in a simple program to obtain the lenght of the cylindrical part of the cavity for a given frequency. The segments were cut normally to the horizontal resonator axis wich differ from the equipotential surfaces of the electric field in the cavity. This showed to be of less importance in our case - constant radius segments (much closer to the equipotential surfaces) calculation results differed for less than 2%.

The final optimisation was done by generating the sensitivity curves (by perturbating the section impedances) for the three main design parameters: the low and high frequency short positions and the maximal current. This gave the idea how to change the resonator shape in order to ameliorate those parameters.

Since the final calculated form (31MHz short position at R=190cm, short displacement 17MHz l=183cm, maximal current density i=57A/cm; fig.3) implies a rather long stem.

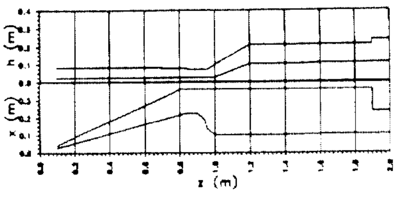

Fig. 2. Geometry for the classical (EFFICAL) calculation

The errors using this kind of calculation could be up to 10% [2], wich was not acceptable in our case because of the very small distance between the high frequency short position and the coupling loop. Therefore, the calculation has been verified preliminary by a 3D calculation, and finaly by a full scale model measurements.

A rather simplified geometry (fig.4) (22650 points, only the 31MHz case) MAFIA code (release 3.0 available in CERN) calculation was performed using the basic module (up to 35000 points) in order to verify the classical calculation. The frequency of the fundamental mode (30.883MHz) differed from the classical calcuation result for 0.117MHz, corresponding to less than 1cm of the cavity lenght.

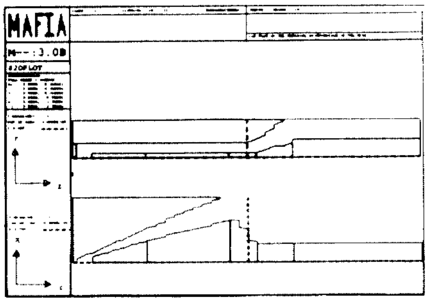

Fig. 3 Form approximation in the MAFIA calculation

4.2 Model measurements

A full scale wooden model covered with copper sheets electrically connected by tin soldering (fig.5) included a 50cm long coaxial part of the resonator wich allowed a 43,5cm displacement of the sliding short. The reproducibility of the frequency measurements was within 0,5%.

Fig. 4 The model of VINCY RF system

Table 2.

Position	l=0cm f(MHz)	Q	l=43.5cm f(MHz)	Q	l=183cm f(MHz)	Q
EFICAL	31.000	8688	25.588	8155	17.000	6885
MAFIA	30.883	9599				
model	31.443	6230	25.906	5049		

The calculations (classical-EFICAL; 3D-MAFIA) and measurements results are shown on table 2. The agreement between the classically calculated and measured frequencies (<2%) was much better than expected (10%). Because of the inherently small Q factor of copper-tin models, no realistic estimation of the cavity losses could be deduced from the present model. The very good agreement between the MAFIA calculations and the measurements for the 31MHz case should be verified for the whole frequency range of the model and using a finer mesh (MAFIA 3.0 package available in CERN includes a 150000 points module).

5. THE COUPLING SYSTEM

As there is no direct access to its high voltage side, it has been decided to couple inductively to the power amplifier by means of a $\lambda/2$ line following the diagram on fig. 6.

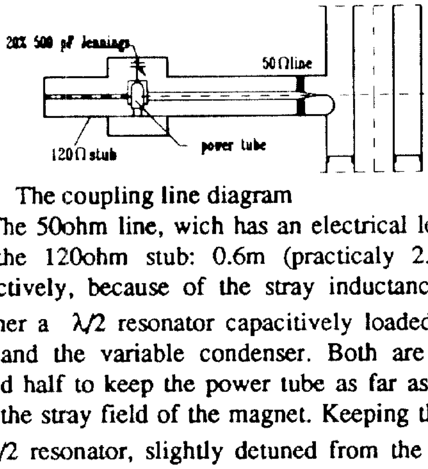

Fig.6 The coupling line diagram

The 50ohm line, wich has an electrical lenght of 2.94m and the 120ohm stub: 0.6m (practicaly 2.2m and 0.3m respectively, because of the stray inductances) constitute together a $\lambda/2$ resonator capacitively loaded by the power tube and the variable condenser. Both are located in its second half to keep the power tube as far as possible away from the stray field of the magnet. Keeping the primary, i.e. the $\lambda/2$ resonator, slightly detuned from the secondary (the dee resonator), it is possible to maintain the primary RF voltage (V_1) at constant amplitude for every working frequency between 31 and 17MHz and for every dee voltage (V_2) in the interval 50 to 100kV peak.

The area of the coupling loop is also constant (50cm2) so that no movement in vacuum is required. Let F_n the natural frequency resonance of the uncoupled secondary and $F_n - \delta$ that of the uncoupled primary. When the two resonators are coupled and a primary impedance Z_1 is desired, then reactive power is balanced among primary and secondary. The latter then oscillates at F_n-δ-ΔF and F_n+ΔF. There exist an infinite set of -/+δ, +/-ΔF which satisfy the condition of Z_1 real dependent of the coupling coefficient k.The following values have been calculated leading to V_1 = 10 kV.

Table 3.

V_2(kV)	F_n(MHz)	d(kHz)	DF(kHz)	C_i(pF)
100	31	-1847.2	30.40	33
100	17	-258.0	9.19	424
50	31	-896.7	61.4	20
50	17	-119.5	17.75	415

The impedance function is far from being flat around F_n. There exist two peaks at F_n-δ-ΔF, which is far away and represents the primary uncoupled resonance, and at F_n+ΔF which represents the working frequency. There is also a zero at F_n where Z_1, though real, reaches only few ohm. The frequency distance ΔF between zero and the pole of the primary impedance function should not be too small, in order to avoid too steep phase shift which would make too crytical the phase control loop. Also at the zero phase , frequency does not correspond the maximum amplitude so that any phase correction affects the amplitude control loop. The stability of these interlaced loops has still to be investigated.

6. CONCLUSIONS

The model and MAFIA studies of the resonators showed that no major problems should arise concerning the main design parameters. If the final mechanical and thermal design of the resonators should impose any considerable changes in the cavity form, using fine mesh 3D calculations could be sufficiently reliable.

7. REFERENCES

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