THE EINDHOVEN MINICYCLOTRON ILEC

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Summary

The Isochronous Low Energy Cyclotron ILEC, which has been built to accelerate protons to a fixed energy of 3 MeV is near the moment of first beam. The machine is equipped with a double dee system for 2nd harmonic excitation. To obtain low energy spread in the accelerated beam also a double dee system for 6th harmonic flat topping will be installed. During the last few months various problems with the RF power system have been solved. We are able now to apply a 38 kV voltage on the 2nd harmonic dees, which corresponds to the design value. For successful operation the stability of the dee voltage has to be improved some what.

Introduction

The minicyclotron ILEC has now entered the stage of first beam experiments. This small cyclotron for 3 MeV protons has been designed, to a considerable degree, by students and was almost completely home made in the university workshops. The ojectives of the ILEC project, its design considerations and the main features of the static magnetic field have been described in ref.1. Calculations concerning orbit behaviour in the central region as well as in the extraction region for which a passive magnetic channel was considered and constructed have been published in ref. 2. In Kleeven's thesis (ref. 3) a theory for space charge effects is developed and applied for the ILEC geometry. The project status of summer 1988 is given there also. The high frequency power system for 2nd harmonic excitation will be dealt with now. So far the 6th harmonic system is not yet in use although the electronic equipment is ready.

RF system

A fourfold symmetrical AVF field structure was chosen for the static magnetic field [1]. The straight sector shaped hills and valleys allowed positioning of the 2nd harmonic dees in two of the four valleys. In this way the average gap width between the magnetic poles could be minimized, if the pole faces could function as parts of the high frequency circuit. For this purpose the segment plates in which the hill and valley structures of the pole faces were machined have been electrolytically cop-

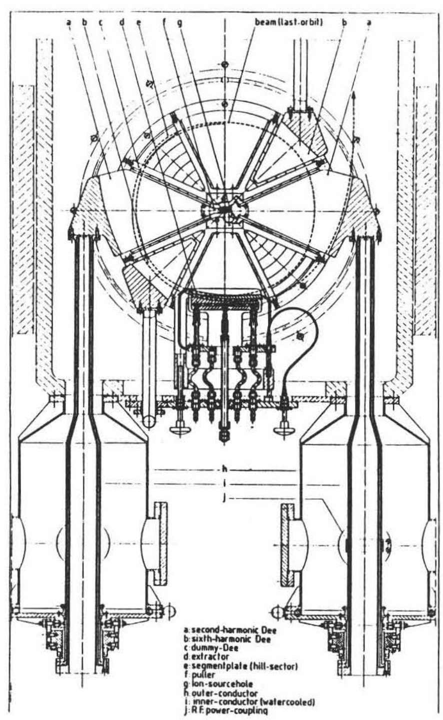

Fig. 1: Layout of the ILEC RF system

per plated. About 200 microns for good RF conduction and leserve for corrosion wear were applied. From the average measured B-value of 1.43 T it followed that for 2nd harmonic excitation a frequency of 43.6 MHz had to be used resulting in a skin depth of about 10 micron for copper.

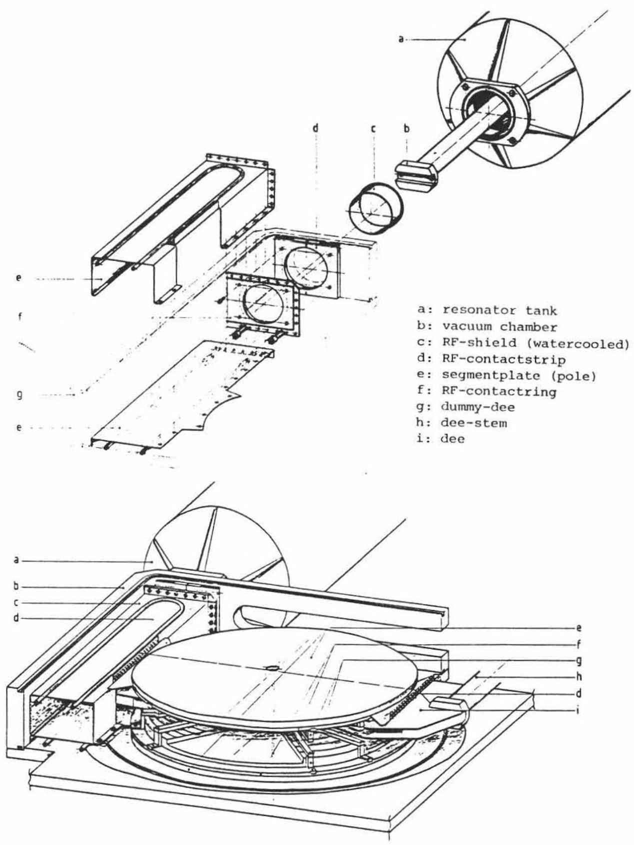

Fig 2: View of dee-stem and liner construction

In Fig. 1 the dees and resonators are drawn. For clarity the liners of the dee-stems inside the rectangular aluminium vacuum chamber are not indicated here but shown in the perspectivic view of Fig. 2a as well as in the exploded view of Fig. 2b. The copper plated pole faces are connected with watercooled copper shields via contact rings. The bottom plates of the rectangular liners are clamped to the lower pole face in such a way that no sharp edges or discontinuities are seen by the dee and dee stem. The upper magnet pole and yoke parts can be lifted hydraulically allowing easy access to the central region [1]. When the upper part is lowered to its proper position an RF contact-strip mounted on contact ring and upper pole face presses tightly to a vertical rim on the liners. Using connection bushes and clamp plates (see Fig. 2) care is taken that the liners in the vacuum chamber are firmly pressed against the copper resonators in order to achieve good RF contacts. In the spaces between dees and walls of the vacuum chamber (see Fig. 1) a pair of trimming plates is mounted. These plates allow a frequency range of ± 0.5 MHz. It appeared however that this range was too small to cover the desired frequency.

For this reason the resonators were made longer. Furthermore a pair of annular copper disks adjustable by hand and provided with crowns of silver contacts were mounted in front of the resonator end flange (not shown in the drawing). These disks short the dee-stems and outer conductors and give an additional tuning range.

The dee plates are cooled via the connections with the dee stems which are water cooled. Cooling of the resonator outer walls is achieved by pairs of flanges on which a cooling pipe was soldered.

The system described so far showed to have a RF circuit quality factor well above 2000. This figure corresponds to an expected value (ref. 1) on the basis of which an electronic power system has been built.

From the description given above, it may be clear that we do not apply a bias voltage on the dees for suppression of multifactoring effects which occur for RF voltages well below 1 kV.

The RF excitation voltage is applied inductively in one of the two resonators. A coupling capacitor, is via a feedthrough in a PTFE vacuum flange connected to a dee stem. Keeping the resonators evacuated eliminates the need for two high voltage feedthroughs.

RF power circuit

It was not our intention to built a variable frequency machine and for this reason we did not choose for a self-oscillating RF power source. Instead an independant frequency synthesizer followed by a cascade of three transistorized tuned amplifiers and a amplifier fitted with a 10 kW Eimac tetrode has been built. The frequency synthesizer produces an RF signal with a frequency variable between 41.00 and 41.99 MHz in steps of 10 kHz. It has a stability of 10^{-7}. The three transistorized stages amplify this signal to a maximum of 100 W in 50 Ω. In the tube power end stage this signal is amplified to 10 kW.

At resonance the 2nd harmonic dee system provides a voltage step up of n times, where n, in good approximation, is given by:

$$n = \frac{\lambda \sin\left(\frac{2\pi l}{\lambda}\right)}{2\pi x}$$

where λ = wavelength (= 7.2 m)
l = length of one RF cavity (= 1,0 m)
x = distance of coupling point to the shorting flange

This gives a voltage step up of n = 6 times for our resonator-dee system. So an RF voltage of 6 kV needs to be coupled in to reach a dee voltage of 36 kV. An RF scheme of the tube amplifier circuit is given in Fig. 3a. Clearly the circuit is kept as simple as possible in order to avoid the introduction of stray capacitances or inductances. The grid circuit (inside the dashed lines of fig. 3a) transforms the grid-cathode impedance of the tube amplifier so that at resonance a resistive input impedance of 50 Ω is seen. The grid-cathode impedance has been calculated as a function of the frequency ν. In this calculation the resonator-dee system (Z_{dee} in Fig. 3a) has been considered as a parallel tuned circuit with

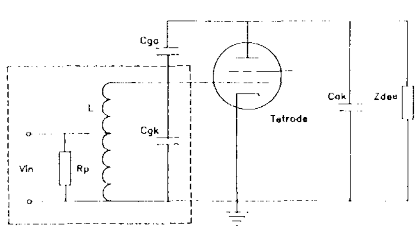

Fig. 3a: RF scheme of tube amplifitier stage R_p = 50 Ω, L = 0.096 μH, interelectrode capicitances: C_{gk} = 120 pF, C_{ak} = 19 pF, C_{ga} = 1 pF, Z_{dee} is resonator-dee-system impedance.

Q-value of 2300, a resonance frequency of 41.7 MHz and a resistance of 2.5 kΩ. The results are given in Fig. 4. In this figure the so called Miller-effect (ref. [4]) can be noticed clearly. This effect caused by capacitive coupling of the grid- and anode circuit through the grid-anode capacitance C_{ga} is very pronounced for triodes. However, when the frequency is high (as in our cyclotron) the effect is also significant in tetrode-tubes.

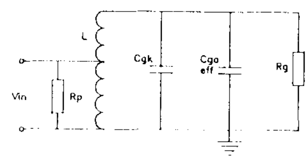

Fig. 3b: Equivalent RF scheme of tube amplifier circuit.

In Fig. 3b we see that due to the Miller effect the grid circuit is extended with the parallel capacitance $C_{ag,eff}$ and the parallel resistance R_g. The resistance R_g as well as the capacitance $C_{ag,eff}$ are functions of the frequency ν.
The input impedance of the tube amplifier has been calculated for this circuit. The results are given in Fig. 5. At resonance the input impedance is indeed 50 Ω and resistive.
In order to maintain the resonance condition a phase control system has been built. This system keeps the phase angle between grid- and anode voltage very near to the resonance value of 180° by adjusting the position of the trimming plates (see Fig. 1). Although the impedance changes quite a lot with changing frequency (i.e. phase angle) the phase control system keeps the input resistance R_{in} between 100 Ω ≤ R_{in} ≤ 25 Ω. This corresponds to a standing wave ration ≤ 2 in the 100 W input cable.

High voltage experience

When RF power is switched on the dee voltage at first does not exceed a value below 1 kV. After one or two minutes of adjusting by hand however the dee voltage suddenly rises to a higher value. Then grid circuit and resonator system can be tuned and during this tuning the voltage jumps in one or two steps to a proper

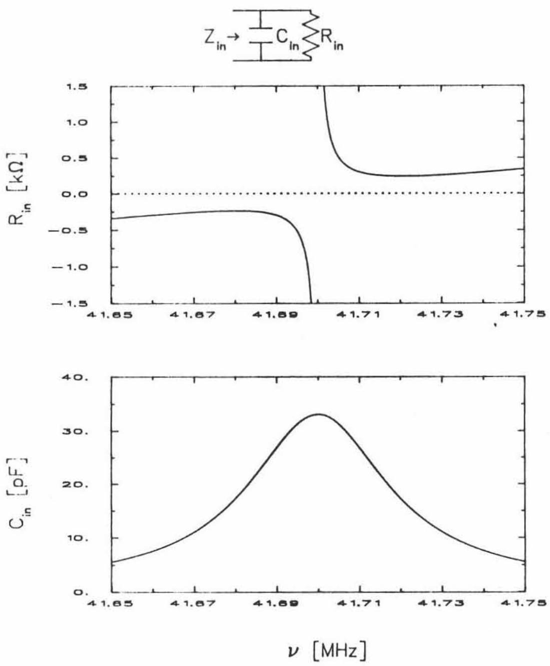

Fig. 4: Grid-cathode impedance of tube amplifier circuit. Resonance frequency: ν=41.7 MHz.

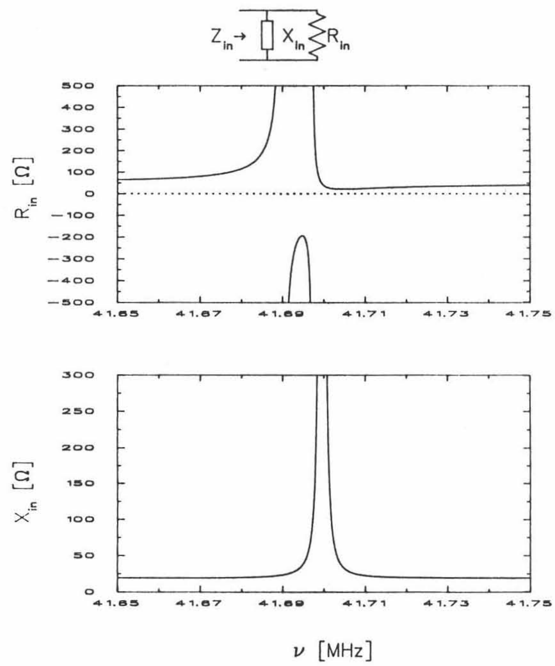

Fig. 5: Input impedance of tube amplifier circuit

value of e.g. 15 kV. From this behaviour it is clear that multipactoring is not a troublesome effect. After having obtained a stable voltage the fase regulation for resonance conditioning is switched on. When the power input is increased further this system in a smooth way corrects fase excursions.

A dee voltage up to 38 kV can be kept upright without breakdown. In view of the small vertical distance between dee and liner of 12 mm in the centre and 15 mm at larger radii this can be seen as a good result. Without voltage stabilization the fase regulation keeps this voltage constant within ± 1 percent.

Above 38 kV breakdowns occur and sparking in the dee centre can be observed visually. If the ion source [1] is switched on it takes more time to reach a stable situation.

From an inspection of colouring of dee centre parts and puller it appeared that extracted ions are intercepted there. A further calculation showed that we have to modify indeed the centre geometry somewhat. At high frequencies like ours the first gap crossing asks particular attention and the ion source to puller distance must be minimized.

References

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