DUAL FREQUENCY RESONATOR SYSTEM FOR A COMPACT CYCLOTRON

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ABSTRACT

A dual frequency resonator system operating at 74/37 MHz used in a proton/deuteron isotope production cyclotron is described. The available design options are discussed, the selected concept is described, and results of model measurements are presented.

1. INTRODUCTION

A compact cyclotron for isotope production is under construction at Ebco Technologies in Vancouver. The design is similar to the existing TR30 H^- machine now in operation at Nordion International[1)] (Fig. 1), and it is again undertaken with the technical and design assistance of TRIUMF. The main difference between the two cyclotrons is the added capability to accelerate deuterons so that the rf system must operate at 74 and 37 MHz respectively. The design options for this dual frequency system are the content of this paper.

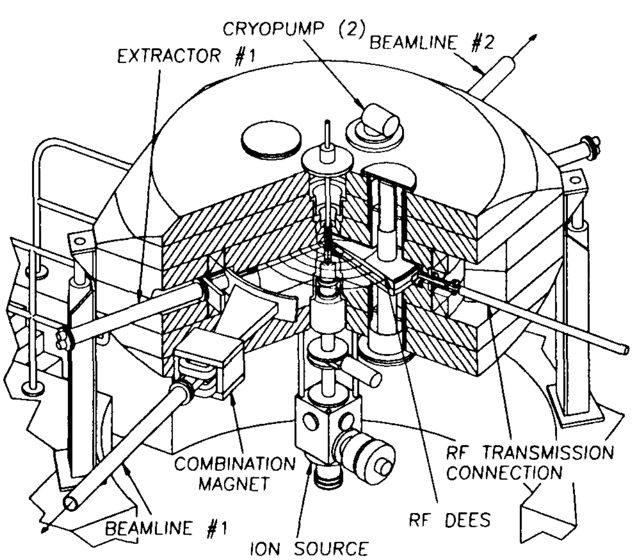


Fig. 1. TR30 cyclotron.

2. SPECIFICATIONS

Mode	Frequency	Dee Voltage
H^-	73.169 MHz	50 kV
D^-	36.654 MHz	25 kV

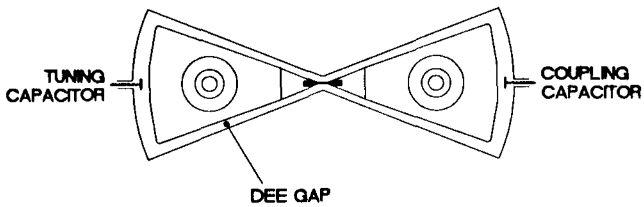
3. DESIGN CONSIDERATIONS

- it is advantageous to retain as many features of the proven design of the existing TR30 cyclotron as possible, mainly the dees and the diameter of the opening in the magnet yokes
- to resonate a system with a constant dee shape and capacity at both frequencies one must increase the inductive reactance of the stem for the 37 MHz mode
- the necessary increase of the stem length must not extend far beyond the magnet; ease of assembly and disassembly is imperative
- the structure must be mechanically and thermally stable (vibrations, frequency drift)
- switching between modes must be done remotely, and under vacuum;
- coarse and fine frequency tuning mechanisms are required

The layout of the system is shown in Fig. 2.

4. DESIGN OPTIONS

Three options have been considered and investigated using analytical calculations, computer modelling and model measurements.



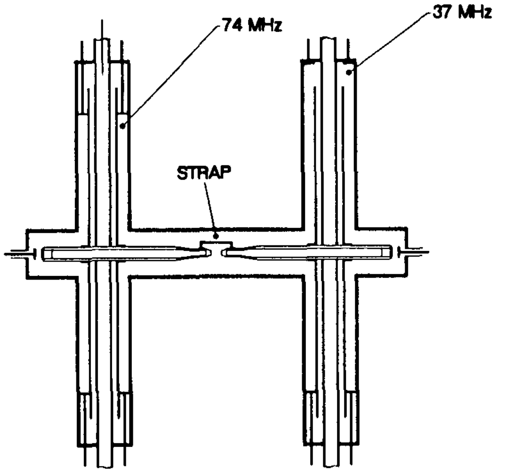


Fig. 2. Schematic diagram of the dual frequency resonator system.

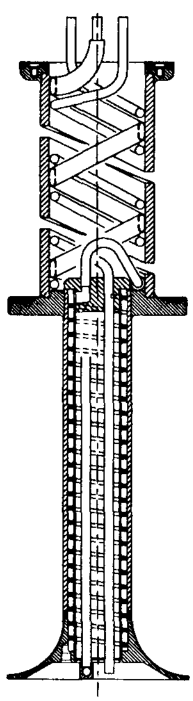


Fig. 3. Stem extension by a helix.

4.1. Stem Extension with a Helix

Figure 3 shows the inner conductor with the helix extension. A cooling line is run on the inside of the helix without crossing the gap. Not shown is a tuning and switching mechanism. By using this helical construction, the total weight of the inner system, including the dee, is supported by the lower helix which is then mechanically unstable. There are several possible solutions to this problem. The obvious one is a ceramic insulator inside the helix, or increasing the helix stiffness by using composite materials etc.

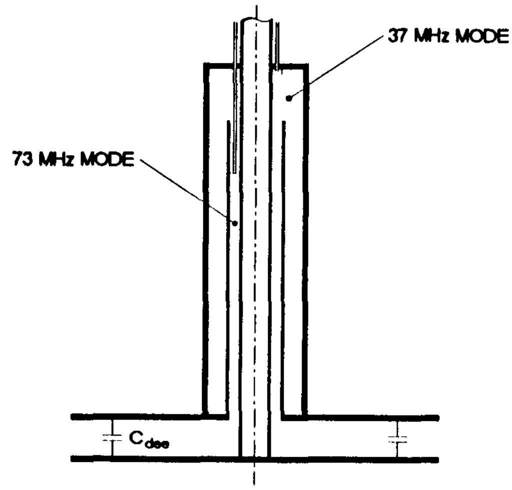


Fig. 4. Folded cavity.

4.2. Folded Line

4.2.1. Version A

The shortening of the line for 37 MHz operation can be achieved by "folding" it as shown in Fig. 4, which is self explanatory. In both cases the frequency can be adjusted by moving the shorting plate; when operating at 37 MHz the tuning is achieved by the capacitive effect of the shorting plate, still adjustable within limits.

For the geometry as shown and for D = 20 cm, d_1 = 11 cm, d_2 = 6 cm, then at f = 37 MHz and with a dee capacity C_{load} = 70 pF, simple calculations indicate that with equal characteristic impedances $Z_1 = Z_2 = 36\ \Omega$ the total resonator length is l_{res} = 134 cm.

When operating the same system in the 74 MHz mode the length reduces to 45.5 cm, bringing the difference in length between the modes to 21.5 cm. The current amplitude at the short is $I_0 = U_0/Z = 1426$ A; for the specified voltage of 50 kV the power for one quarter of the system is ~7 kW or ~28 kW of total power. The system was also modelled by SUPERFISH and the above results confirmed.

The limitation in the resonator diameter does not allow for an increase of the characteristic impedance, and hence in a reduction in the power.

4.2.2. Version B

It is possible to modify the system such that at 74 MHz the dee is resonated using the shorted outer half of the folded cavity as in Fig. 5, where the radii of

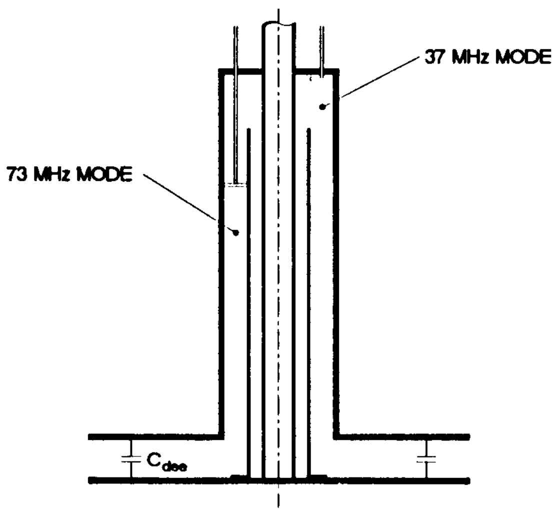


Fig. 5. Low loss folded cavity.

the coaxial line are large. Under those conditions for the same dimensions, characteristic impedances and loading capacity the skin loss is reduced by the ratio D/d_1 to ~4 kW, or for the total system to ~16 kW, in agreement with SUPERFISH results. This concept yields the shortest stems, and it appears to be the most elegant solution to the problem. On the other hand no model measurements and feasibility studies have been made so far (mechanical stability, tuning, cooling, and voltage holding); they are planned for the future.

4.3. Straight Transmission Line

A straight transmission line represents at 74 MHz a solution with the smallest skin loss due to the highest characteristic impedance (72 Ω) achievable within the available space.

For the same dee capacity of 70 pF the computed lengths are 26 cm and 91 cm at 74 and 37 MHz respectively. In order to switch between modes, the system length must change by ~65 cm. This is achieved by means of a newly developed coaxial switch which capacitively foreshortens the line in the middle, operates with a stroke of only 10 cm, and thus does not significantly increase the total mechanical length of the system (Fig. 6). The switch can be operated under vacuum in both the 37 and 74 MHz modes, and it is used firstly for adjusting the electrical balance of all four parts of the rf resonator, and also for fine frequency tuning during operation at either frequency.

In Fig. 7 is an equivalent circuit of a $\lambda/4$ resonator at 37 MHz. Figure 8 shows the dual frequency system installed in the magnet.

4.4. Model Measurements

Some results from test measurements on a copper-clad plywood model of the system are summarized below.

1. Voltage distribution at the acceleration gap (Fig. 9)
2. Voltage distribution along the coaxial line (Fig. 10)

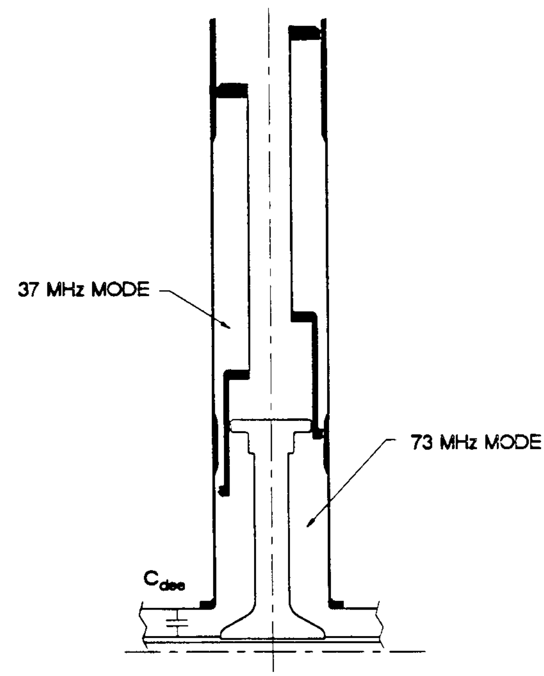


Fig. 6. Solution using a coaxial switch.

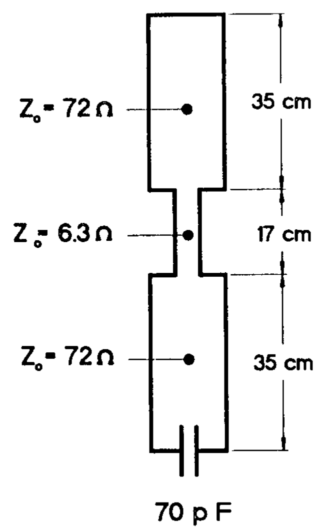


Fig. 7. Impedance diagram.

5. CONCLUSIONS

The straight transmission line option gives the lowest power requirement and highest mechanical stability for the resonator system as well as providing tuning at both frequencies. The capacity loading of the line in the middle at the 37 MHz frequency gives an overall line length of ~87 cm. The skin loss for an accelerating voltage of 50 kV is ~11 kW. The properties of the system at 74 MHz are the same as for the Nordion TR30 cyclotron.

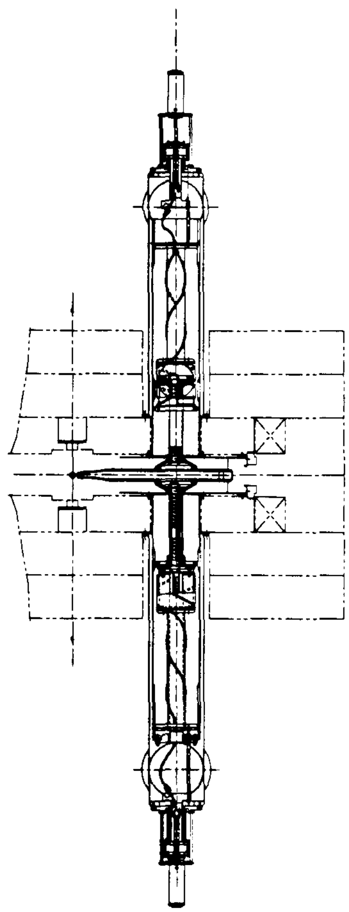


Fig. 8. One half of the TR30/15 resonator.

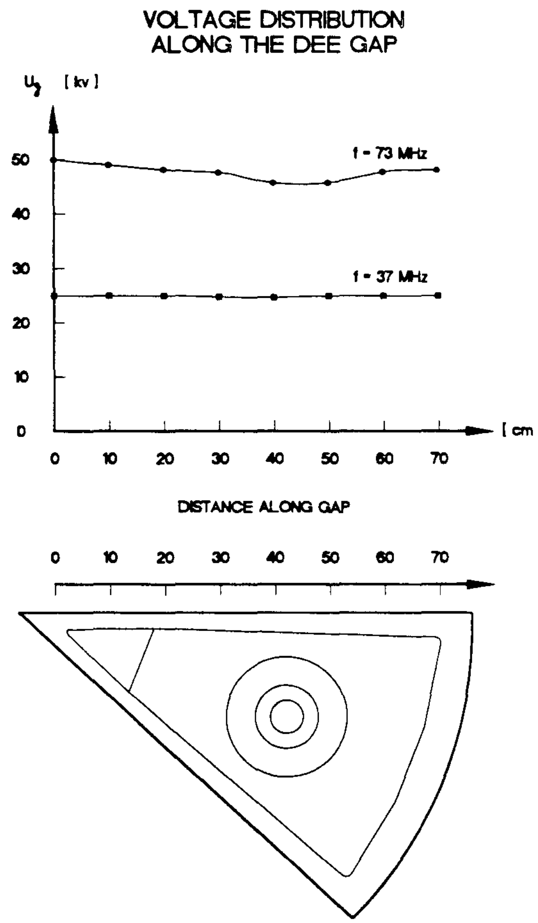


Fig. 9. Voltage measured at dee gap.

6. REFERENCES

1) B.F. Milton *et al.*, *First beam in a new compact intense 30 MeV H^- cyclotron for isotope production*, Proc. of the European Particle Accelerator Conference, Nice (1990) p.1812.

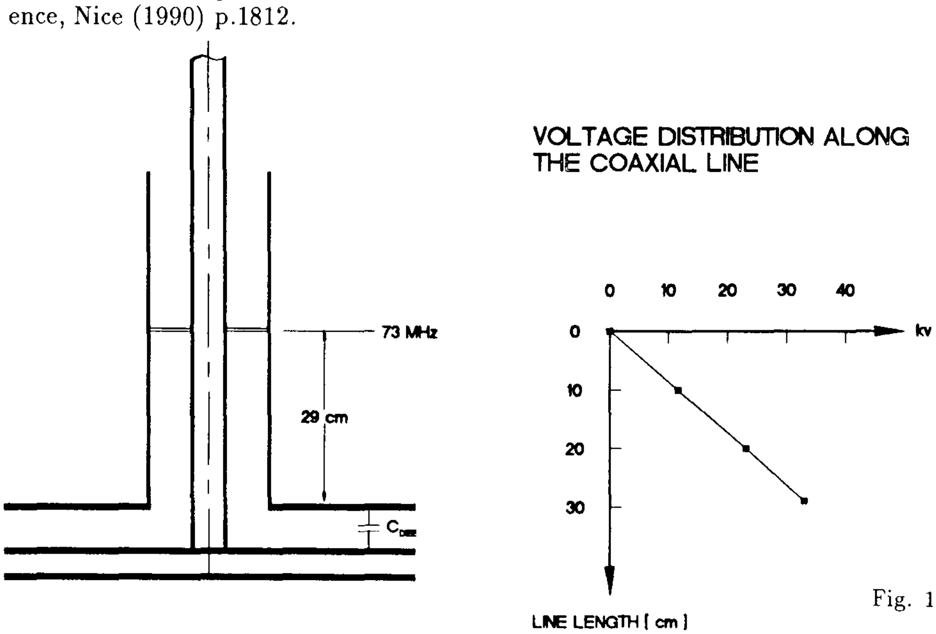


Fig. 10. Voltage measured along stem.