THE TR16/8, A DUAL PARTICLE CYCLOTRON FOR CLINICAL ISOTOPE PRODUCTION

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(Abstract)

The accelerator design group at TRIUMF has developed a 16 MeV, 100 μA proton and 8 MeV, 50 μA deuteron cyclotron with a low power H^-/D^- ion source to satisfy the requirement for an accelerator for the production of isotopes in a clinical environment. The novel features of this fully automated, strong focussing, self shielded cyclotron are discussed in this paper.

GENERAL DESCRIPTION

The TR16/8 dual particle cyclotron is based on the EBCO-TRIUMF design for strong focussing negative ion cyclotrons developed for isotope production. They are low loss H^- machines utilizing cryogenic pumping and external ion sources as described by R. Baartman et al.[1]. In the 4 sector magnet the hill to valley field ratio (about 4) is adjusted to keep the vertical beam oscillation frequency below the Walkinshaw resonance value to ensure that the normalized emittance of the beam available from the ion source (<.2 pi mm_mrad) is not degraded. The small size of the beam in the 4 cm gap between the poles of the magnet ensures that the losses are small.

The ions are accelerated by two "45°" dees positioned in two opposing valleys of the cyclotron as shown in the general assembly in Fig.1.

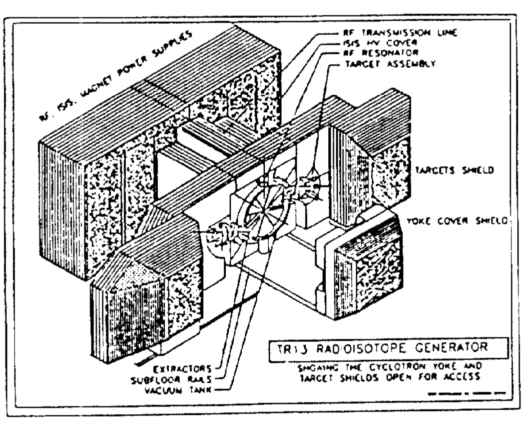

Fig. 1 General Assembly of Cyclotron and Targets

Aceleration is accomplished in the fourth harmonic mode for both particles. An intermediate shorting plane in the extended dee stems allows the retuning of the dee system in the deuteron
configuration.

The beam is extracted by stripping foils positioned in diametrically opposed hills so that the extracted beams are directed into external target stations through the two valleys which do not contain the accelerating structures. A four position target system is positioned at the end of each extraction line which allows for the simultaneous irradiation of two targets for isotope production and for the exchange of targets without sliding seals or disconnects.

The entire cyclotron is shielded so that minimal precautions need be taken to reduce radiation fields to reach acceptable levels at clinical installations.

The facility is controlled using industrial control techniques and commercial industrial process control hardware. The control system is shown in the block diagram in Fig.2.

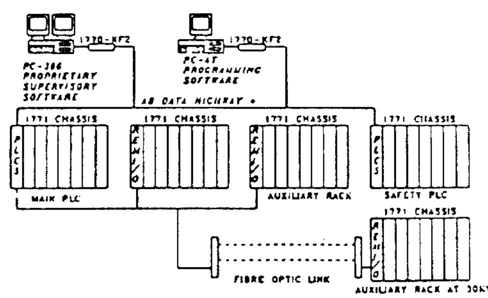

Fig. 2 Schematic Diagram of Control System

The operator console is a 386 PC with color graphics screens for control, and monochrome alphanumeric screens for data display. The control screens are designed to be user friendly and highly informative by the use of color to denote functions such as system off, system ready, interlock failure, system on, etc.. Macros can be written by the operators to control all major functions of the system and the radiochemical processing hardware. The usual hardcopy output necessary for process control and verification is also available.

CYCLOTRON MAGNET

The magnet is positioned with the beam plane vertical instead of horizontal as is done in most conventional designs. It is a cut down version of the TR30 cyclotron and the field shape is adjusted to be the same up to the maximum energy that can be accommodated, 17 MeV. The 4 holes in each pole are used as pumping ports and as connections for the RF system. The actual energy that can be reached in the self shielded cyclotron in its proton configuration is restricted to 13 MeV by the addition of beam stops in the magnet valleys that do not allow the beam to pass the radius corresponding to this energy. In the dual particle machine the stops are flipped up out of the way during deuteron acceleration so that the negative ions can reach an energy of 8 MeV before before stripping for extraction. If the cyclotron is installed into a shielded vault there is no need for the maximum energy limiting beam stops.

To isochronize the field for deuterons, trim coils are placed in the valleys not used for the RF system. The 2nd harmonic introduced into the magnetic field by the isochronizing coils is not sufficient to increase the emittance of the beam at these energies for the small field corrections required.

SYSTEM

The RF resonators are "45°" dees. Although the dee angle is a full 45ø for the central orbits, the dee edge is tapered to 41° toward the outside edge of the magnet to reduce the dee capacitance and hence the power required to reach the nominal operating voltage. Each dee has a single radial dee stem that has a length corresponding to the 4th harmonic frequency necessary for acceleration of the particles. They are coupled together at the centre of the cyclotron by a strap which connects the tip of one resonator to another. A diagram of a resonator is given in Fig. 3.

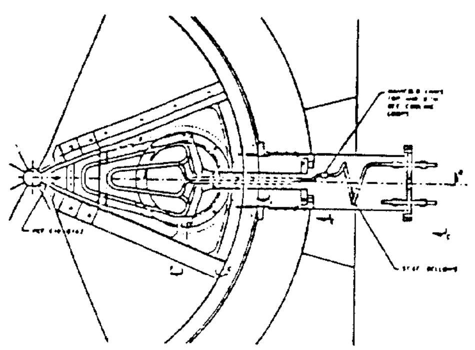

Fig. 3 TR13 RF Resonator

The resonators require 11 kW to excite them to the nominal accelerating voltage of 50 kV for the proton mode and less than 5 kW for the deuteron mode. The system parameters as measured using a full scale model constructed of copper covered plywood agreed with the theoretical calculations to within 10%.

The RF amplifier is a copy of the system developed for the TR30 by the modification of a commercial FM transmitter. The dual frequency version was developed for the dual particle TR30/15 . The power stage is a water cooled EIMAC 4CW 30,000 tetrode which has a plate dissipation of 30kW and can be tuned to both 73MHz and 37MHz for the two particles. The amplifier is coupled to the resonators using a 50 ohm half wavelength line between the amplifier and the capacitive coupler to the dee through one of the holes in the yoke of the magnet. This system has been tested in the TR30, is easy to set up, and gives no operational problems. The resonator tuning is effected by a variable capacitor mounted in one of the holes in the other side of the yoke. It enables the system to be tuned over a frequency range of 100kHz.

ION SOURCE AND INJECTION SYSTEM

The ion source is a development of the multicusp high current negative ion source developed at TRIUMF by D.H. Yuan and colleagues [2]. The source has been miniaturized by adjusting the strength of the cusp fields and decreasing the size of the containment vessel so that the arc power has been reduced by a factor of 10. To achieve the required 1 mA of current from the source now requires less than 500 Watts of arc power. It is anticipated that the filament will have a life of 6 months in its isotope production operational mode. The filament is removable by shutting the source valve between the source mounting box and the injection line. The general layout is given in Fig.4 with dimensions showing the short distance between the source and the cyclotron center.

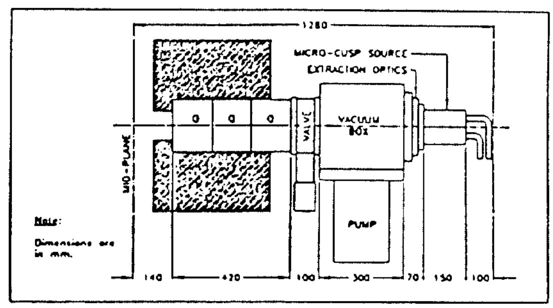

Fig. 4 TR13 Ion Source and Injection System

The properties of the inflector and the central region geometry are discussed by Baartman et al. [3] and this ion inflection system is duplicated in the TR13. The optical system for the injection line between the ion source and the inflector has been modified by replacing the Glaser lens and two quadrupoles with a three quadrupole focussing element. This has allowed for the shortening of the distance between the source and the cyclotron mid plane and reduced the mechanical complexity without adversely affecting the beam quality (M. Dehnel, Internal report). The injection voltage is 25kV for protons and 12.5kV for deuterons.

TARGETRY AND SHIELDING

The beam is extracted in the usual way for H^- cyclotrons by the insertion of a 4 micron graphite foil to strip off the electrons at the requisite position. The extracted beams which come out of the cyclotron at a small angle to the horizontal enter a 4 position target body which can be rotated to any of the four positions without interrupting the vacuum in the connecting tube to the cyclotron tank. Two targets of the eight available can be irradiated simultaneously. Switching from one target to another takes less than a minute. The target bodies can be valved off from the cyclotron for replacement of the targets without venting the tank and hence disrupting the isotope production schedule. The extractor which is introduced into the hill gap through the side of the magnet yoke can also be serviced by valving off the tank and replacing the foil cassette.

The entire target assembly which occupies a small volume on the side of the magnet yoke is shielded with a composite shield approximately spherical and having a thickness of 80 cm.

TR 13 CYCLOTRON

Basic Specifications

Magnet

Number of Sectors	4
Hill Field	$1.9W/M^2$
Hill Angle	Variable 40° - 44°
Valley Field	0.5W/M2
Valley Angle	46° - 50°
Excitation Energy	22kW
Weight	22T

R.F. System

Number of Dees (location)	2 (in valleys)
Dee Angle	45^0
Amplifier Output	15kW
Radio Frequency	73MHz
Proton Harmonic Mode	4th
Deuteron (Optional) Harmonic Mode	4th

Ion Source

Type	Multi-Cusp
Power Requirement	5kW
Output Current	<1mA
Emittance (normalized)	0.2 Pi mm/Mrad
Bias Voltage	25kV

Vacuum System

Pressure	$5x10^7$torr
Pumping	4000 l/s (H_20)
	1500 l/s (air)
Cyclotron	1 X 4000 l/s Cryopump
Ion Source	1 Turbomolecular pump
	1 Cryopump

Control System

Industrial PC-386 based with industrial control modules

Extraction System

Multiple 4 micron graphite foils on removable support rod

REFERENCES

[1] R. Baartman, K.L. Erdman, W.J. Kleeven, R.E. Laxdal, B.F. Milton, A.J. Otter, J.B. Pearson, R.L. Porier, P.W. Schmor, H.R. Schneider and Q. Walker "A 30 MeV H^-Cyclotron for Isotope Production", Proceedings of 1989 Particle Accelerator Conference Chicago Page 1623

[2] D.H. Yuan, M.McDonald, P.W. Schnor and K. Jaym "A compact DC Cusp Source", Proceedings of Fifth International Symposium on the Production and Neutralization of Negative Ions and Beams. AIP 1990 Brookhaven NY Page 323

[3] R. Baartman, "Injection Line Optics", Triumf design note TRI-DN-25, 1989