Commissioning and First Operation of a 500 μA, 30 MeV, H^- Cyclotron: The TR30

B.F. Milton, G. Dutto, P.W. Schmor, H.R. Schneider,
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3
R. Dawson, K.L. Erdman, W. Gyles, J. Sample, and Q. Walker
Ebco Technologies Ltd., 7851 Alderbridge Way, Richmond, B.C., Canada V6X 2A4

Abstract

A new high intensity, 30 MeV H^- cyclotron has been constructed by Ebco Technologies Ltd., for NORDION International to be used for radioisotope production at the TRIUMF site. It is a four-sector radial ridge design with two 45° dees in opposite valleys. An external multi-cusp dc ion source generates the beam for axial injection into the cyclotron. Two multiple foil stripping mechanisms produce two simultaneous beams, each of intensities up to 250 μA. First beam was achieved on May 9 1990. The initial acceptance tests were completed on July 20 1990, thus finishing the project within the 19 month construction schedule. Since then the machine has been used for regular isotope production, and operator training. With two target stations in operation a total of 450 μA at 30 MeV has been extracted from the cyclotron, and at 15 MeV 500 μA has been extracted. We will report on the results of beam tests with a new higher power rf amplifier, and the simultaneous extraction of two beams of different energies . Emphasis will be on typical operating experience and on the customer acceptance tests.

I. Introduction

The 30 MeV cyclotron (TR30) built by Ebco Technologies Ltd. with the technical and design assistance of TRIUMF, achieved first beam on May 9, 1990, within 17 months of project startup date. The basic specifications for the cyclotron [1–4] call for two external beams of current up to 200 μA and energy variable between 15 MeV and 30 MeV, with a total extracted beam intensity of at least 350 μA. More than 500 μA have already been extracted to date.

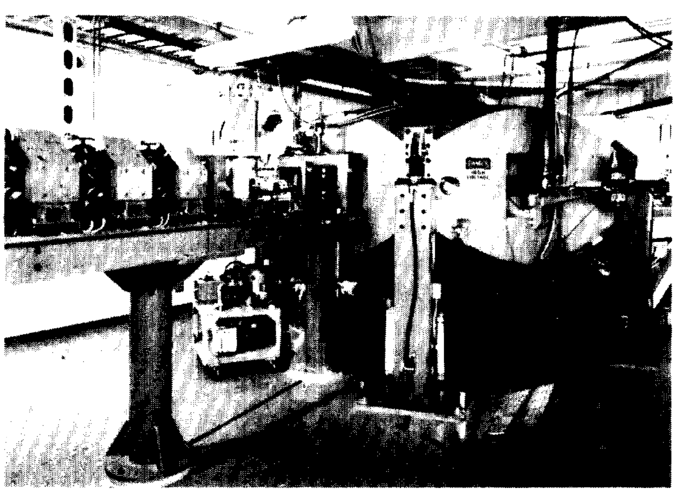

Figure 1: The 30 MeV high intensity compact cyclotron.

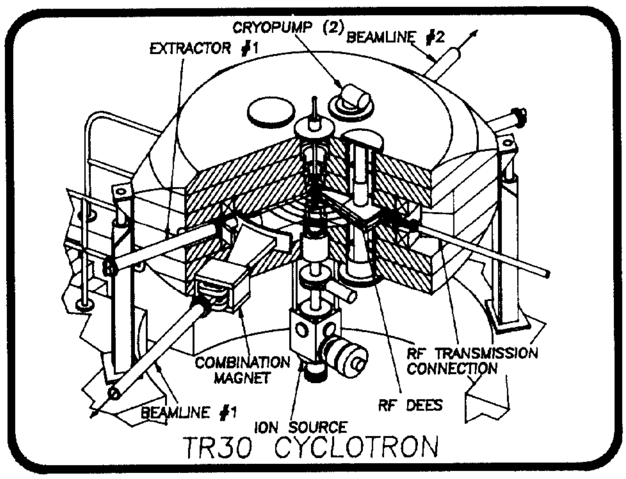

Figure 2: Schematic view of the cyclotron.

Figure 1 shows the cyclotron as it was undergoing commissioning tests recently. Design features are more readily apparent in the schematic view given in Fig. 2. The basic cyclotron parameters are given in Table 1. The cyclotron is a four-sector compact design with radial ridge hills. The magnet is approximately square in shape, 2.3 m flat to flat, 1.26 m high and weighs approximately 46 tonnes. It is split at the midplane, so that four hydraulic jacks located at the corners of the yoke can elevate the upper part approximately one metre to allow access to the cyclotron interior. Two coils, 42750 A-turn each, mounted on the upper and lower poles provide the magnet excitation. Because of the fixed field operation, all magnetic field corrections were made by shimming during field mapping. No trim coils are needed.

Head room requirements in the cyclotron vault are minimized by installing the external H^- ion source and injection line below the cyclotron. This arrangement has the additional practical advantage of avoiding the possibility of material flaking off the ion source filament and falling onto any of the high voltage electrodes of the source or inflector. It does, however, require that the cyclotron be mounted over a 1.4 m deep pit.

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Table 1: Principal cyclotron parameters.

Magnet	
Average field	1.2 T
Hill field	1.90 T
Valley field	0.55 T
Hill gap	5 cm
Valley gap	18 cm
Pole radius	76 cm
Number of sectors	4
Ampere-turns	8.5×10^4
RF	
Frequency	73 MHz
Dee voltage	50 kV
Harmonic	4
Vacuum	
Pressure	5×10^{-7} Torr
Pumping	4000 ℓ/s (H_2O), 1500 ℓ/s (air)
Ion source	
Type	H^- cusp
Output current	7 mA
Emittance (normalized)	0.34π mm-mrad
Bias voltage	25 kV

The H^- beam is injected vertically upward along the magnetic axis toward the centre where an electrostatic spiral inflector bends it into the median plane. Two 45° dees located in opposite valleys then provide acceleration at four gap crossings per orbit. The design voltage for the dees is 50 kV, and the operating frequency is 73 MHz, the fourth harmonic of the orbit frequency. The dees operate in phase.

Four large holes through the yoke in the dee valleys accommodate the coaxial stubs required to resonate the dees at the operating frequency. For magnetic symmetry there are four identical holes in the unoccupied valleys. Two of these are used as vacuum pump ports in which two 20 cm diameter cryopumps are installed.

Beam extraction is by stripping to H^+ in thin graphite foils. Two independent external beams are formed with two extraction probes travelling in opposite hill gaps.

II. Commissioning

Initial commissioning of the TR30 cyclotron is reported elsewhere [4], but it cannot be overemphasized how rapidly this phase of construction was completed. To some degree this can be attributed to the fact that most settings lie very near the calculated values, and no subsystem is strained in order to achieve the design goals.

After completing a one hundred hour endurance test on July 20, 1990, a short period of time was used to train operators, and finish the installation of target stations. On July 28, 1990, the first commercial isotope production began. The cyclotron then ran on a 56 hour a week schedule as more operators were trained. Since then the cyclotron has been operating full time. On average the cyclotron is dedicated to isotope production for 144 hours per week, with the remaining 24 hours split between development work and maintenance.

Production records for the first quarter of 1991 show that there was only 62.2 hours of machine downtime due to cyclotron and beam line subsystem failure. In the same quarter 2233.8 hours of beam were delivered to the targets, and 120 hours were used for setup and tuning of the machine. This means that cyclotron downtime due to all causes (other than target system failure), represented less than 2.5% of the running time, a quite remarkable feat considering that the machine was only in operation for 6 months. Figure 3 shows that number of mA-hours of beam on target since the beginning of production. It is interesting to compare this with the theoretical maximum, remembering that the difference includes time for target changes, cyclotron development work, and routine maintenance such as source filament changes.

Substantial design effort was put into minimizing the sources of personnel exposure, such as reducing spill, reducing concrete activation, and locating equipment in non-radioactive areas. This has resulted in a personnel dose at least 20 times lower than the CP42, also used by NORDION, despite the TR30's higher production.

III. RF Improvements

Rf power for the initial installation of the TR30 was provided by a commercially available, 25 kW FM transmitter. When this amplifier was run at 27 kW, there was sufficient rf power available to accelerate 300 μA of beam to 30 MeV. Provision was also made to install a second identical unit, to be combined with the first amplifier.

However, it was decided that rather than run with two amplifiers, we would run with one upgraded unit. The upgrade was accomplished by replacing the air cooled output tube with a water cooled tube. With this modification, and some small improvements to the dc power supplies, the unit immediately delivered 42 kW of rf power into a dummy load. Since only 33 kW of rf power are required to accelerate 500 μA of beam, this provided a comfortable operating margin.

The new amplifier was installed at the end of December 1990. Its high degree of stability, and the significant over-capacity has helped produce the extremely stable and reliable beam production achieved by the TR30 in the first quarter of 1991, (see Fig. 3).

IV. Ion Source Improvements

As an aid in cyclotron commissioning, the emittance of the dc H^- multicusp ion source was restricted to 0.25π mm-mrad by using a small diameter extraction hole. With this geometry up to 4.5 mA of H^- could be extracted from the source, sufficient for a total extracted current of 450 μA from the cyclotron. The large currents, however, required careful source tuning, and resulted in shorter filament lifetimes. Since initial cyclotron tests were done with extracted currents of 250 μA or less, this was not a factor.

In preparation for routine high current production (450 μA), the extraction aperture was enlarged in early

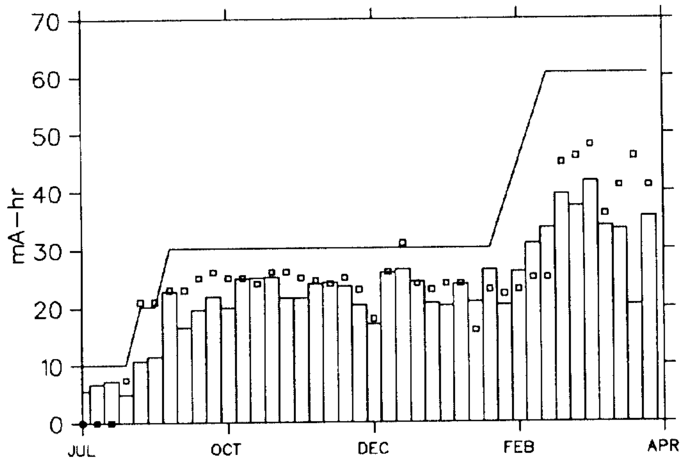

Figure 3: Weekly dose delivered to TR30 targets for isotope production. The small squares show the scheduled dose for each week, while the solid line gives the theoretical maximum possible dose that could be accepted by the targets.

February 1991. Previous tests of the ion source with this aperture [5] demonstrated a measured H^- current of 7 mA, with a normalized emittance of 0.34π mm-mrad. With this small change, the source easily provided the required 4.5 mA of H^-, and to do so required 20% to 30% less arc power, than for the same output with the small aperture. Filament lifetimes at the higher operating currents have been longer than 600 hours. As well this change has had minimal effect on the injection efficiency, and no noticeable effect on machine transmission or beam line spills.

V. Dual Beam

The TR30 cyclotron was designed to extract beam into two beam lines at the same time. Contractual arrangements between Ebco and NORDION required that within 12 months of the completion of the initial single beam line acceptance tests, this feature would be demonstrated by the completion of a second set of tests. These tests required demonstrating a stable beam of at least 350 μA on the target surfaces, at various energies. This, in fact, requires a minimum of 420 μA of beam to be extracted from the cyclotron, to provide sufficient current on the target collimators.

When beams of the same energy are desired, extraction is accomplished simply by inserting both stripper mechanisms, and adjusting the radii of the graphite foils, to achieve the desired current split ratio. Once the above mentioned improvements had been made, operation in this manner became a simple matter. On February 8, 1991, acceptance tests at 23, 27 and 30 MeV, with greater than 350 μA of beam on target were completed. Machine stability proved remarkable, and routine production in this mode started almost immediately.

VI. Dual Energy

The TR30 cyclotron is also capable of simultaneously delivering two beams of different energies. To accomplish this a narrow foil is mounted at the open end of a long U-shaped holder. This stripper is then inserted so that the foil is positioned at the radius coinciding with the lower beam energy. That fraction of the beam that is not stripped by this foil then passes between the two arms of the holder as it is accelerated. This beam is then intercepted by a normal foil located at the higher energy radius. Calculations and experimentation have found that a foil width around 1 mm provides a 1:1 split in the beam current.

On February 16, 1991, a one hour acceptance test with beam energies of 23 and 29 MeV extracted and beam currents of 165 μA and 185 μA on target was completed. We then proceeded to integrate this foil holder, with one that would also contain normal foils in order to allow flexibility in operation. We have now installed a carrousel that includes 2 normal foils for same energy extraction or single beam line operation, and two of the extended holders for different energy extraction. On April 29, 1991, acceptance tests with the energy combinations (23,29), (23,27), and (27,29) were completed. This included a 10 hour endurance test with minimal operator intervention. The successful completion of these tests fulfilled all of the acceptance requirements, at least three months before the deadline.

VII. Acknowledgement

This isotope production cyclotron is the first cyclotron produced by Ebco and is an important example of technology transfer from TRIUMF. TRIUMF and Ebco would like to thank all those who have contributed to this endeavour with ideas, suggestions, hard work or support. A particular thanks goes to those colleagues from the international community who have given useful advice during design and construction.

VIII. References

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