COMMISSIONING AND IMPLEMENTATION OF THE MEDICYC CYCLOTRON PROGRAMME

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ABSTRACT

The MEDICYC radiotherapy dedicated fixed–frequency cyclotron, designed for 65 MeV proton acceleration, is in the commissioning stage. Design and initial test results of the axial injection, RF and magnet systems, as well as the beam transport and the neutron and proton therapy equipment are presented. The facility is to begin regular operation by beginning of 1990.

INTRODUCTION

The MEDICYC cyclotron is a radiotherapy dedicated facility of the Antoine Lacassagne Centre in Nice designed and built to support regular neutron and proton therapy programs based on a 65 MeV proton beam. The facility will initially serve for treatment of different forms of deeply seated tumors susceptible to high LET radiations and ocular melanoma, and is designed to accommodate 400 – 500 patients per year treated by the anti – cancer Institutes of south – eastern France.

Following the initial design based on a 1.6 m diameter magnet and a proton beam energy of 50 MeV [1) , various subsystems of MEDICYC were built, completed and tested. In course of construction, some of the machine elements were redesigned and modified. Major modifications of the design arise from a decision, following initial magnetic field measurements, to raise the beam energy to 65 MeV, and to switch from positive to negative charged ion (H^-) acceleration. Consequently, the ion source was substituted, the axial injection and the central region were redesigned, and the RF system and extraction modified.

MEDICYC is presently entering final commissioning. All subsystems have been tested, and the beam axially injected and accelerated to first few orbits, further acceleration being prohibited due to lack of adequate shielding at the provisional machine site. A view of the completed cyclotron is shown in Fig.1. Following these tests, MEDICYC has been dismantled and moved to the recently completed building, where installation of machine equipment, and patient treatment and reception areas is in course. Regular operation of the facility is expected to begin in the first half of 1990.

AXIAL INJECTION AND CENTRAL REGION

Negatively charged H^- ions for acceleration in MEDICYC are produced in a multi – cusp source supplied by IBA, Louvain – la – Neuve, which is mounted on a platform at 33 kV vertically above the axial injection line, as shown in Fig.2. The beam is cleaned of neutrals and aligned with the transport axes using two 15 deg. permanent magnet dipoles, and is focused with two Glaser lenses located at 37.5 cm and 2099 cm above the median plane. A beam transformer (BT), developed in close collaboration with IPN Orsay, monitors the H^- intensity at the entrance of the first Glaser lens. The DC beam intensities which have been measured along the axial line give the following yield at the injector entrance (IENT) and exit (IEXT):

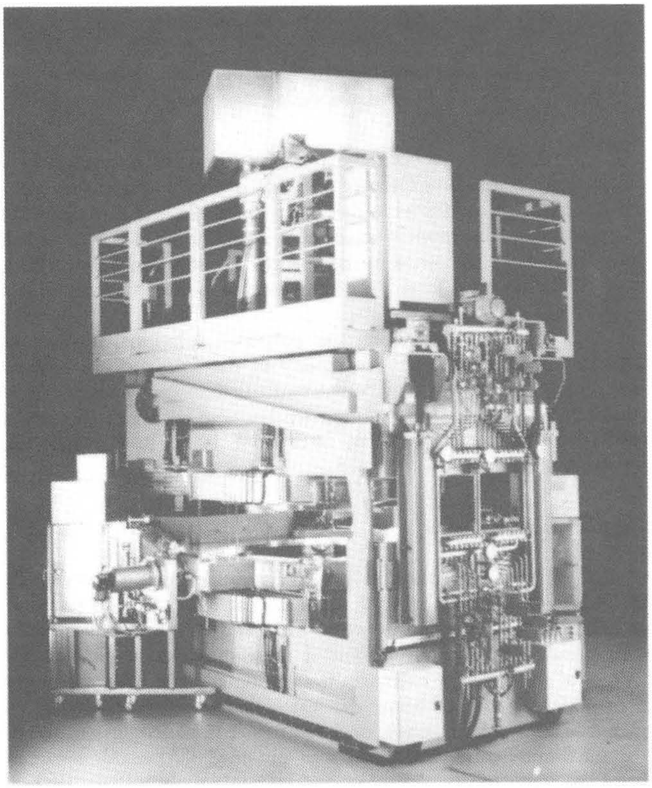

Fig.1. A view of the completed MEDICYC cyclotron

Position	BT	IENT	IEXT
Current (μA)	200	100	50
Preassure (torr)	10^{-5}	10^{-6}	10^{-6}

These preliminary measurements show that the vacuum in the axial beam line has to be improved (presently it is achieved with two turbomolecular pumps (2000 l/s) at the exit of the source and a cryopump (800 l/s) located on top of the yoke). Also, further improvements of the inflector transmission are necessary.

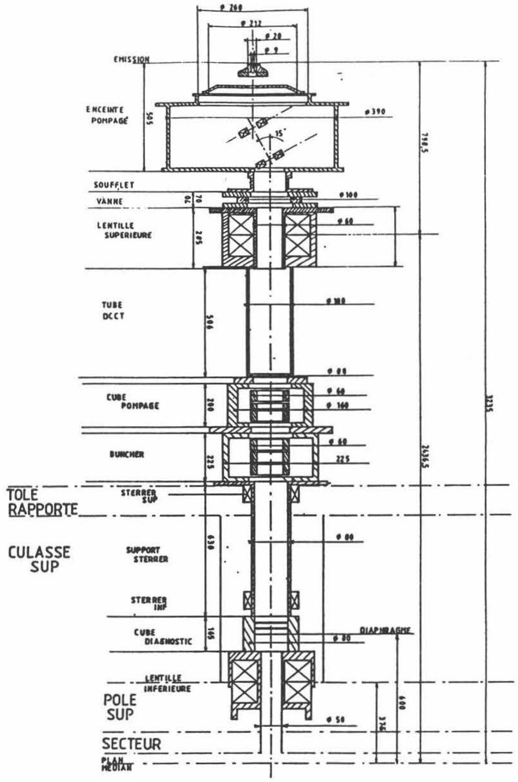

Fig.2. Cross – section of the MEDICYC axial injection line

A 580 V buncher located 69.5 cm above the first focusing lens and working on the fundamental RF frequency gives a bunching factor of 5.7 measured at the exit of the first turn, close to the the theoretical efficiency of 8.67 for a 20 deg phase width. A second harmonic buncher (210 V and 50 MHz) is being developed in order to further increase the inflected beam intensity.

A central region accepting a h = 1 for protons and h = 2 acceleration mode for deuterons and other fully stripped light ions has been designed. The basic features of the design have been reported earlier$^{2)}$. Recently, a new geometry for 24.8 MHz operation has been studied using electrolytic tank measurements and AGORA central region programs. In the current solution, shown in Fig.3, vertical focusing has been enhanced by introducing small steps that reduce the apertures in the first few accelerating gaps, so that the electrical focusing frequency of about 0.05 is achieved. The vertical focusing in the central region is further increased by the customary magnetic bump, which is controlled by the first trim coil.

RF SYSTEM

The initial design of the RF system consists of 2 dees with an 75 deg. aperture, operating at 22 MHz and peak voltage of 50 kV. Each dee is independantly excited by its own amplifier which is in turn driven by a master oscillator. The dees resonate as $\lambda/4$ lines, the shorting piston being in air connected by means of an RF feedthrough of the Philips type. This arrangement has been chosen in order to have the coupling loop, the shortening piston and the fine tuning mechanism, acting by slight deformation of the piston, and the high voltage measurement outside the vacuum. The characteristic impedance of the dees is $Z_n = 25$ Ohms. The amplifier is a 25000 Eimac tetrode driven by a 800 Eimac tetrode. The coupling is of the detuned primary type with a neutralization obtained with a $\lambda/2$ cable.

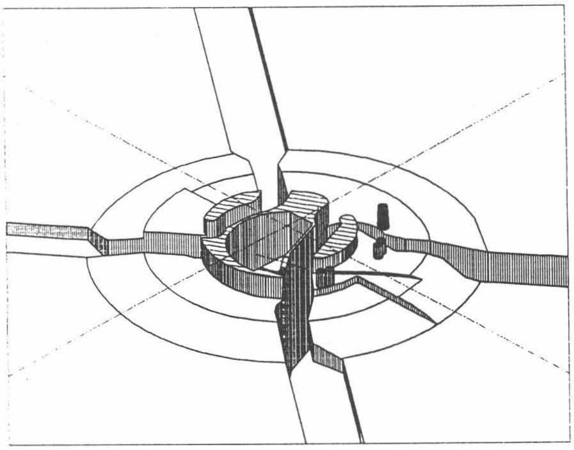

Fig.3. Modified central region design

In order to achieve the desired RF frequency of 24.8 MHz, the cone of the dee was enlarged in order to decrease the inductance of the resonator, the shortening contacts were modified and the cooling improved. The construction of the dees, the amplifiers and the coupling mechanisms, as well as other machine details, may be seen in Fig.4. This ensemble was fully mounted and tested with the magnet on. The operation of the dees was stable, the start – up procedure taking approximately 20 min and the resonant frequency shifting by 200 kHz during this time. The achieved voltage was X – ray calibrated at 55 kV, with the amplifier power of 19 kW and 22 kW power losses per cavity. The outgasing at operation degraded the vacuum from 7 10^{-7} to 2 10^{-6} torr.

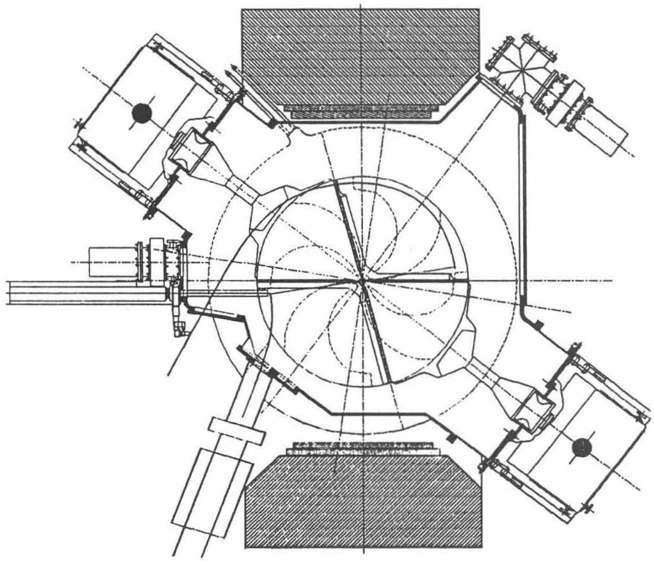

Fig.4. Median plane ensemble of various machine components

POLE SECTORS AND TRIM COILS

The azimuthally varying magnetic field is obtained in MEDICYC by means of four pairs of spiraled sectors with hill and valley gaps of 130 and 280 mm, an average spiral of 60 deg/m, and an angular width of 42.5 deg. The sectors were fabricated from a single ARMCO ingot and machined so as to leave a margin of 10 mm to be used for sector shimming. Initial magnetic field measurements have shown that a higher particle energy than anticipated could be achieved. In order for a 24.8 MHz operation to be optimized several sector modifications were necessary, notably in the extraction region where the shape of the sector "shoes" had to be modified and a sector axial shim 2 mm high added. The results of sector shimming are reported in detail in ref.(3). The average magnetic field distribution for the final sector shape is shown in Fig.5.

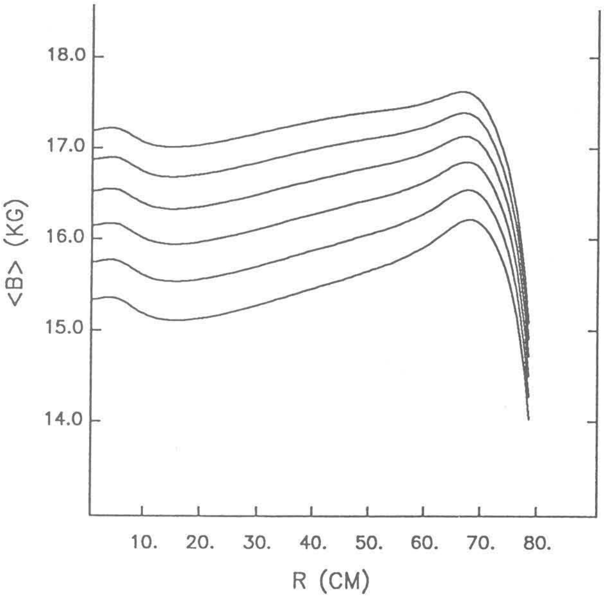

Fig.5. Average magnetic field for main coil excitation of 950 – 1200 A in 50 A steps

For achieving isochronous magnetic field shape and better beam control, a total of nine trim coils were fabricated and mounted on the surface of the sectors, as shown in Fig.6. Trim coils 1 – 8 were wound from a 8 by 1 mm full copper conductor, and are cooled indirectly by water circulation in hollow tubes located on the outside of the coils. After impregnation with Araldite D, the coils measure 10 mm high and support a current of 100 A. Trim coil no. 9, with an interior radius of 66.8 cm, is made of a 5 by 5 mm and $\phi = 3$ mm hollow copper conductor wound in two layers with an intermediate current lead, so that it can be excited as a two independant section coil. The measured form factors of the trim coils are given in Fig.7.

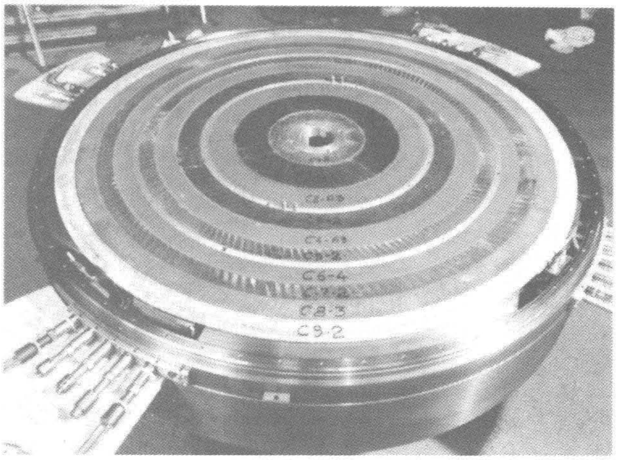

Fig.6. Trim coils in the stage of completion

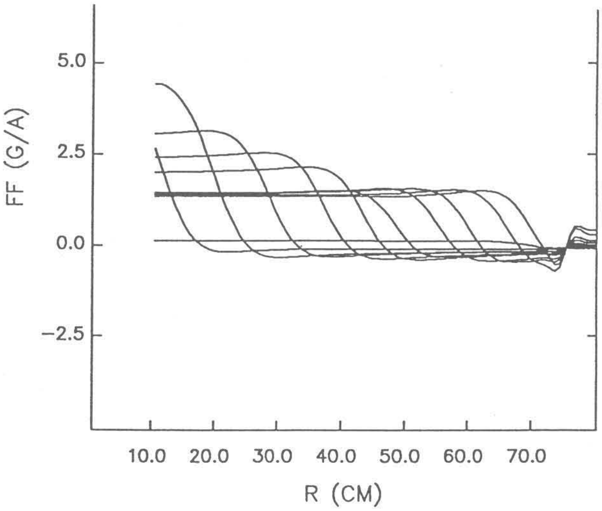

Fig.7. Form factors of the trim coils at $I_c = 1150$ A

Recent magnetic field measurements of 360 deg. maps have shown that a satisfactory degree of field isochronization can be achieved with this trim coil arrangement. In Fig.8., the residual isochronous error δB_{iso} and the respective central phase $\delta\phi$ are shown for the central field of $B_o = 16.2627$ kG, which corresponds to final proton beam energy of 64.5 MeV at the extraction radius of 68.8 cm. It should be noted that this isochronous field profile is obtained with trim coil currents that are smaller than 60 A.

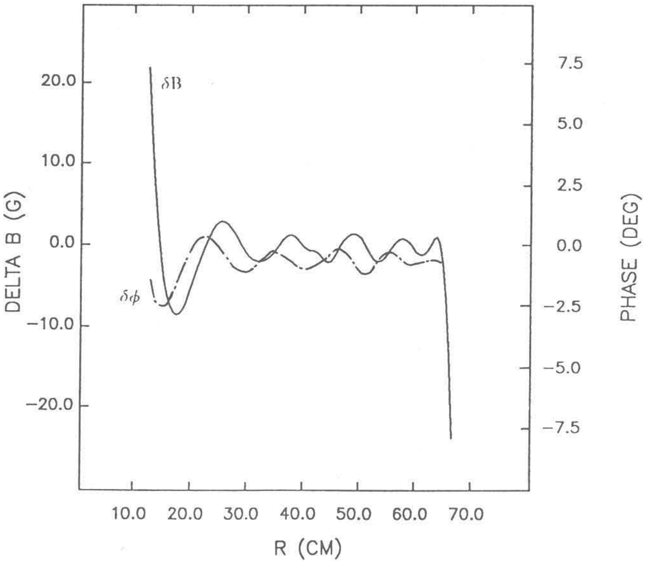

Fig.8. Residual isochronous field error δB_{iso} and central phase $\delta\phi$ for 24.8 MHz isochronous field

BEAM EXTRACTION AND TRANSPORT

As a consequence of the conversion to H^-acceleration, initially designed and tested resonant extracting system was substituted by stripping extraction. The latter consists of a 100 $\mu g/cm^2$ carbon foil mounted on a movable support which retracts 750 mm, covers an angle of $\Delta\theta = 2$ deg., and encompasses an area of 55x45 mm for beam stripping.

Following the stripper, the proton beam is transported 35 m down the beam line to the two treatment rooms equiped for neutron and proton therapy. The transport consists of a quadrupole pair at the cyclotron exit and a FODO channel consisting of two identical bending magnets and three equally spaced quadrupoles, which has unit magnification. This arrangement is followed by a quadrupole pair and a vertical bending magnet, which directs the beam to the vertical neutron collimator. In order to reduce the cost of the focusing elements, the design seeks to achieve a small beam diameter throughout the transport system. The calculated beam size is within ±2.4 cm both horizontally and vertically. The bending magnets and the quadrupoles are presently in construction at Bruker and Sigmaphi, and are expected to be delivered by mid-year.

TREATMENT ROOMS FOR NEUTRON AND PROTON THERAPY

Two treatment rooms are located one above the other, so that the primary proton beam is switched vertically into the neutron room and horizontally into the proton room. The ground surface of the proton and neutron rooms is 29 m^2 and 40 m^2, respectively. The access to the irradiation areas is through labyrinths avoiding the use of heavy doors.

The shielding of the treatment area was determined using the formulas proposed by Braid, Tesch and Stevenson[4], taking into account the radioprotection recommendations. As construction materials, barium concrete, concrete and earth were used. The choice between those materials is a result of a compromise between the price and the available space for a given mass surface density. The layout of the rooms and shielding is shown in Fig.9.

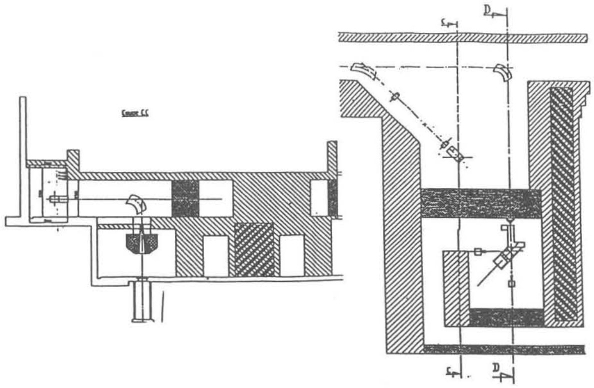

Fig.9. Layout of neutron and proton therapy rooms

Neutrons are produced in a Be target which is retractable at the end of the treatment, avoiding unnecessary irradiation of the medical staff. The emerging neutron beam is defined to obtain square fields varying from 5x5 to 25x25 cm at 160 cm from the target by using two collimators, the first one made of iron with a fixed aperture, while the second one is a continuously adjustable multi-leaf collimator of the Scanditronix design which has been slightly modified and is being constructed by CRC, Louvain-la-Neuve. This multi-leaf collimator consists in 44 steel leaves placed in two groups of 22 parallel and opposed leaves. Each leaf can reach the beam axes and may be independantly moved to obtain complex field shapes. All collimator movements as well as the security interlocks are controlled by a local station from the medical control room.

The beam leading to the proton room is left to spread freely from the last dipole magnet and is collimated to 35 mm before entering the treatment area. This diameter is the maximum width of the eye tumor. Only the central part of the beam is selected so as to obtain a flat dose profile. For an initial beam intensity of 120 nA, only 9 nA are transmitted, corresponding to a rate of 50 pA/cm2.

Once inside the treatment area, the proton beam continues to travel in air before being modulated by a rotating plexiglass wheel with variable thickness angular sectors. The diameter of the beam is kept at 35 mm by a number of Al collimators mounted on the optical bench. At the end of the bench, it is finally collimated to the treated tumor shape. This arrangement follows closely that of PSI, Villigen.

CONCLUSIONS

The MEDICYC cyclotron is in the final completion stage. All machine components have been built and tested and initial operation performed at the provisional site. Machine equipment and controls and neutron and proton therapy rooms are presently being assembled in the new building, shown in Fig.10. Regular treatment of the patients of the Antoine Lacassagne Centre is expected during the first half of 1990.

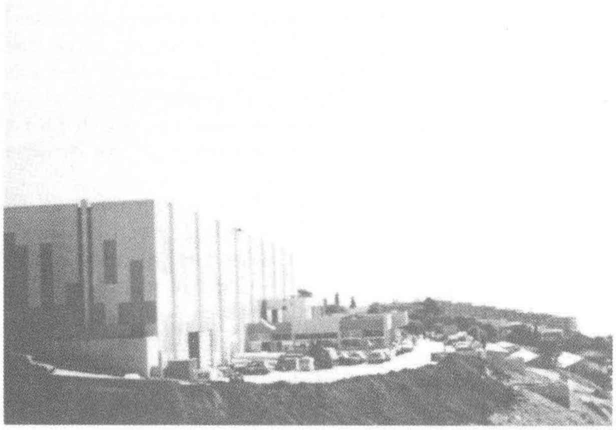

Fig.10 View of the new MEDICYC building

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