CYCLOTRON C235-V3 FOR DIMITROVGRAD HOSPITAL CENTER OF THE PROTON THERAPY

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Abstract

JINR-IBA C235-V3 isochronous cyclotron for 1st Russian hospital center of the proton therapy has been assembled and tested. Shimming of the magnetic field, optimization of the acceleration modes and testing with the extracted proton beam were done in frame of this work.

The paper presents experimental results of the beam dynamics in the accelerator. Proton transmission from radius 30cm to 103cm is 72% without beam cutting diaphragms. The extraction efficiency is 62%.

This cyclotron is a substantially modified version C235-V3 of the IBA C235 serial cyclotron. C235-V3 has the improved extraction system which was constructed and tested. This system allows raise the extraction efficiency up to 77% from 50% in comparison with serial C235.

Special mapping system (for $B_r$-component) of the magnetic field was developed and constructed by JINR for the shimming of the $B_r$-field in the middle plane of the cyclotron.

Total efficiency of the machine is 45%. Further improvement of the parameters expected after final tuning of the cyclotron in Dimitrovgrad.

PROTON THERAPY AT JINR

Dubna is one of the leading proton therapy research centers in Russia [1-2]. The JINR Phasotron with the proton energy of 660 MeV has been used for medical applications since 1967. The modern technique of 3D conformal proton radiotherapy was first effectuated in Russia at this center, and now it is effectively used in regular treatment sessions [1-2]. The irradiated dose distribution in 3D conformal proton therapy coincides with the tumor target shape with an accuracy of 1 mm. About 100 patients undergo a course of fractionated treatment here every year. About 880 patients were treated by proton beams during the last 12 years. Using of the accelerators intended for the fundamental researches is not lucrative. Thus a number of special machines were developed by industrial companies over the world.

C235-V3 PROTON CYCLOTRON

Federal Medico-Biological Agency in collaboration with JINR developed the Dimitrovgrad project of the first hospital proton center in Russia. The JINR-IBA collaboration has developed and constructed the C235-V3 proton cyclotron for this center.

C235-V3 has modified extraction system [3-4]. Basing on results of complete study of the beam dynamics in C235 geometry of the electrostatic deflector was optimized. The new extraction system was constructed and tested at the IBA C235 cyclotron for Orsay (France). The experimentally measured extraction efficiency was improved from 50% for the old system to 77% for the new one (Fig. 1). Up to the moment such an extraction system used in more than ten C235 machines.

Figure 1: Circulating and extracted beam current in C235 cyclotron with old and new version of deflector.

CYCLOTRON ASSEMBLY AND MAGNETIC FIELD MEASUREMENTS

The assembling of the machine started in June 2011 at JINR. A special engineering center (Fig. 2) was created at JINR for testing of the medical accelerators.

Figure 2: JINR engineering centre for the assembling and testing of the medical accelerators and equipment.
The magnetic measurements and shimming of the cyclotron magnetic field was done. The axial magnetic field mapping is based on the Hall probe technique. The special platform was designed for fabrication of all sector edges simultaneously. The accuracy of the mechanical fabrication of the sector edge surface modification is about 20 µm. Precision geometrical measurements of the sector edges at the shimming of the magnetic field are produced by the Eclipse 3D Carl Zeiss machine. The new JINR calibration magnet applied for magnetic field up to 2.9 T was implemented in the scheme of the magnetic measurements. Estimated RF-phase motion in the final magnetic field map (see Fig. 3) in the limits ±15°RF [5].

The new equipment [6] with the search coils for measurements of the average radial component \(<B_r>\) of the magnetic field and for correction of the magnetic field median plane in the C235-V3 cyclotron was developed and tested at JINR.

The \(<B_r>\) measurements are based on integration of the signal from the coil during its movement in vertical direction near median plane. The measurement coil of the specified radius is moving in vertical direction from \(\Delta z\) to \(+\Delta z\) (from median plane of cyclotron). During this motion the coil covers the cylindrical surface. The radial component magnetic flux change at this surface induces the voltage in the measurement coil and can be integrated by electronic equipment.

**C235-V3 BEAM TESTS**

Magnetic measurements and shimming of the magnetic field finished at mid-2012. After full assembly of the all cyclotron systems tests with the circulating and extracted proton beam were performed.

The machine was finally isochronized (Fig. 4), operating RF-frequency is 106.270 MHz, \(I_{mc}=760.7\) A.

Calculated beam RF-phase motion (Fig. 5) based on Smith & Garren data (Fig. 4) confirms that there would not be remarkable phase beam losses during the acceleration in final configuration of the magnetic system.
CONCLUSIONS

C235-V3 version of serial C235 IBA cyclotron was developed by JINR-IBA collaboration. C235-V3 has the improved extraction system. It allows raise the extraction efficiency up to 80% from 50% in comparison with serial C235.

C235-V3 (for Dimitrovgrad) tests with accelerated and extracted beam were performed in JINR. Transmission from r=30cm to r=103cm is 72% without beam cutting diaphragms. Extraction efficiency is 62%. Total efficiency of the machine is 45%.

Proposal for further optimization of C235-V3 magnetic system was formulated. It concerned to increase the $Q_z$ from 0.2 to 0.4 at the extraction radii which can lead to decreasing of possible losses during the acceleration.

With increased intensity of the extracted beam C235-V3 has advantages in treating of large-volume tumors using pencil scanning.

REFERENCES