THE CARBON ION BEAM EXTRACTION SCHEME FROM THE U-70 SYNCHROTRON FOR RADIOBIOLOGICAL RESEARCHES

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Abstract

The carbon ion beam extraction scheme from the U-70 synchrotron of NRC «Kurchatov institute» - IHEP for radiobiological researches is presented. The double-step extraction scheme Piccioni-Wright is used. The beam extraction operates at magnetic field flat bottom of U-70 synchrotron with carbon ion energy 455 MeV/n. A technique to attain transversally uniform irradiation field and other results on operation are also presented.

THE ION BEAM EXTRACTION SCHEME DESCRIPTION

The table 1 shows some parameters at magnetic field flat bottom of U-70 synchrotron.

Table 1: The Parameters at Magnetic Field Flat Bottom of U-70 Synchrotron

Parameter	Value
Magnetic field (Hs)	355
Carbon ion energy (MeV/n)	455
Magnetic rigidity (Tl·m)	6.89
Betatron frequencies	9.86 / 9.80
Relativistic factors β / γ	0.74 / 1.49
Beam emittances Ex / Ey (mm·mrad)	25 / 15
Width of relative momentum distribution $\pm\delta_0$	$\pm 2\cdot 10^{-3}$

The double-step extraction scheme Piccioni-Wright is used [1]. In accordance to this scheme the internal target (T28) located in 28 straight section (+50 mm from beam closed orbit) and deflecting septum-magnet at 34 straight section (-62 mm from orbit) of U-70. In the extraction process the circulating beam dumped on the target and ion beam particles undergo ionization energy loss. The particles leaving the target make betatron oscillations with new orbit displaced inside the ring. After half the wavelength of the betatron oscillations further along the beam, the spatial separation between extracted part of beam and circulating beam is enough for thin septum of deflecting magnet layout. In this pace (beginning of 34 straight section) SM34 septum-magnet is located. The boundary horizontal trajectories of the extracted particles with momentums ($\pm\delta_0$ - Δ) and scattering angles $\pm 2\theta_{rms}$ are shown in Fig. 1.

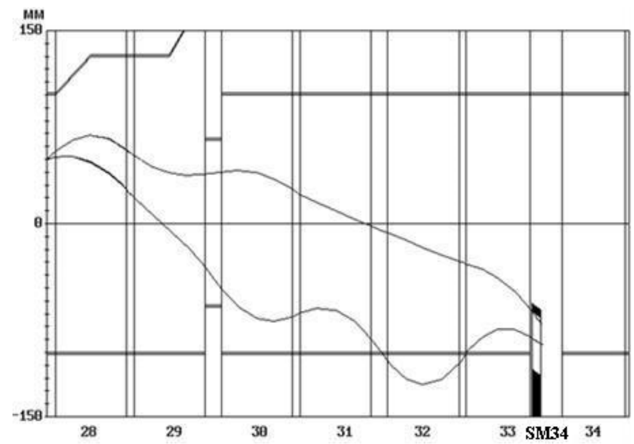

Figure 1: The boundary horizontal trajectories of the extracted particles.

The required value of the loss of the relative momentum of the particle on the target is given by the expression:

$$\Delta \geq 2\delta_0 + \frac{d_{sep} + \Delta R_{gap}}{D_{34} + D_{28}}$$

where d_{sep} –septum thickness, D_{28}, D_{34} – the values of the dispersion functions on the azimuths of the target and septum-magnet, ΔR_{gap} – the required value of the gap between the circulating beam and the coordinate of the septum magnet, $2\delta_0$ - width of relative momentum distribution.

The extracted beam size is estimated as follows:

$$\Delta X_n = 2\delta_0(D_{34}+D_{28})$$

As the target material is used BE. Ionization loss of the carbon ions $^{12}C^{+6}$ with kinetic energy T ≈ 455 MeV/n in BE is equal 15.0 MeV / mm, so the required target thickness is equal ≈ 4 мм. The target height is chosen equal to 10 mm.

Dumping the beam at the target is carried out by transverse noise (stochastic) blow-up of horizontal betatron amplitudes of circulating beam [2]. The uniformity of the extracted intensity supported by feedback from beam loss monitor M28 located near the target T28 (see Fig. 2).

The calculated extraction efficiency of the ion beam is ≈ 75%. The practically achieved efficiency estimated as 50÷60%. The carbon ion beam injection intensity in U-70 is (3÷6)×10^9 ions per cycle.

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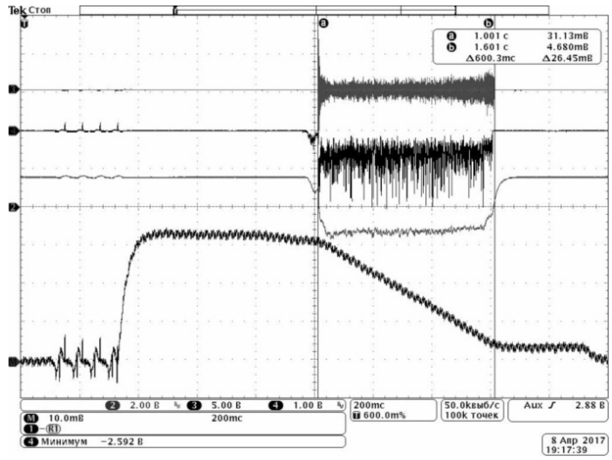

Figure 2: Signals: 1– amplitude of the noise excitation generator, 2 – beam loss monitor M28, 3 - smoothed beam loss monitor M28, 4 – circulating beam intensity.

MAGNETIC ION BEAM TRANSFER CHANNEL

Magnetic ion beam transfer channel to the radiobiological zone consists of:

- deflecting magnets SM34, EM1, EM2, EM3
- beam stopper
- wobbler magnet
- radiobiological test bench

In Fig. 3 magnetic ion beam transfer channel is shown. Territorially, the channel consists of two parts. In U-70 ring zone, after EM3 placed 4 quadrupole (quartet) lenses and beam stopper. Then, after biological protection U-70, in the area of radiobiological researches there are a triplet of quadrupole lenses, a wobbler magnets system for the uniform dose field formation and a radiobiological test bench itself. The length of the channel from SM34 to the wobbler magnets is 26.4 m.

UNIFORM IRRADIATION FIELD FORMATION

For medical and radiobiological application of carbon ion beams it is necessary to use special techniques that allow to forming uniform transverse irradiation field on biological object. The required nonuniformity of the generated field should be no worse than 5%.

In our case we use X-Y wobbler scanning system when the pair of wobbler magnets scans the beam circularly. The method is based on the superposition of many spatially displaced Gaussian distributions, which, as a result, forms a wider distribution with a sufficiently flat top.

A mechanical device representing the assembly of two identical coaxial cylindrical dipole magnets is used. Each of the magnets is assembled on the principle of Halbach (Klaus Halbach) based on 16 ring sectors of permanent neodymium-iron-boron magnets (NdFeB). These dipole magnets can be installed with a different angular solution between the directions of the magnetic fields in the magnets, which allows varying the strength of the wobbler magnet. To ensure the circular beam scanning and the formation of a uniform irradiation field, the mechanical rotation of the magnets assembly with a frequency of up to 50 Hz is used (see Fig. 4) [3].

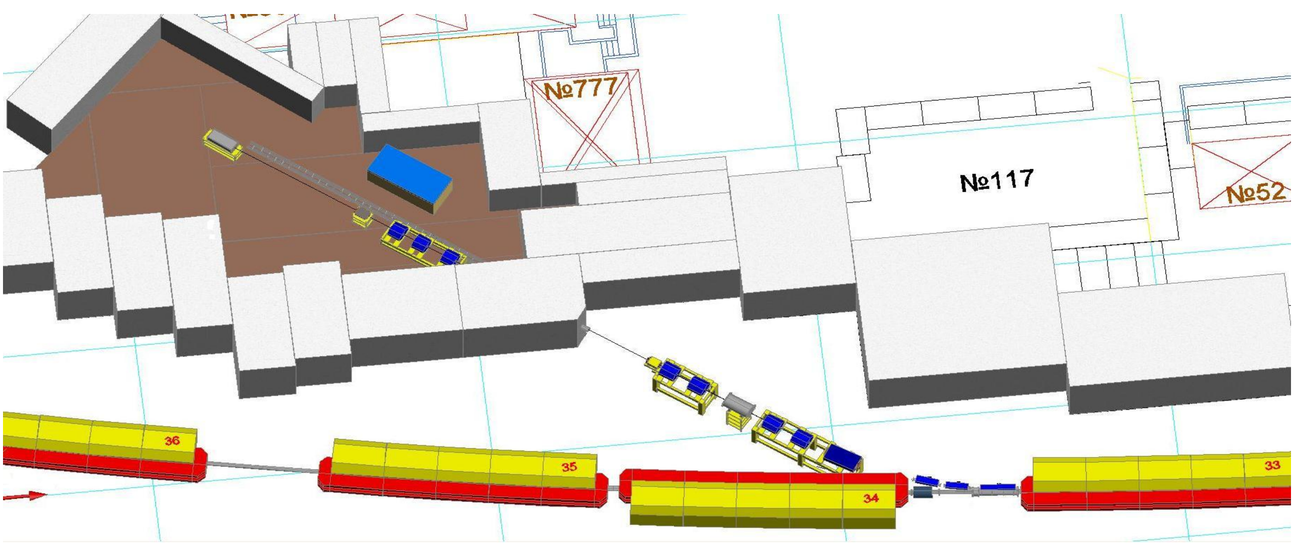

Figure 3: Ion beam transfer channel layout.

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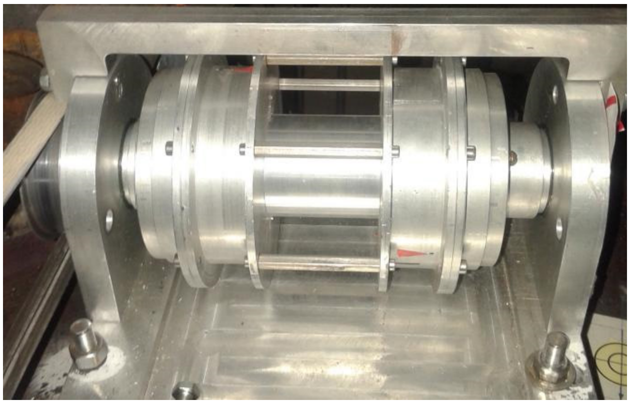
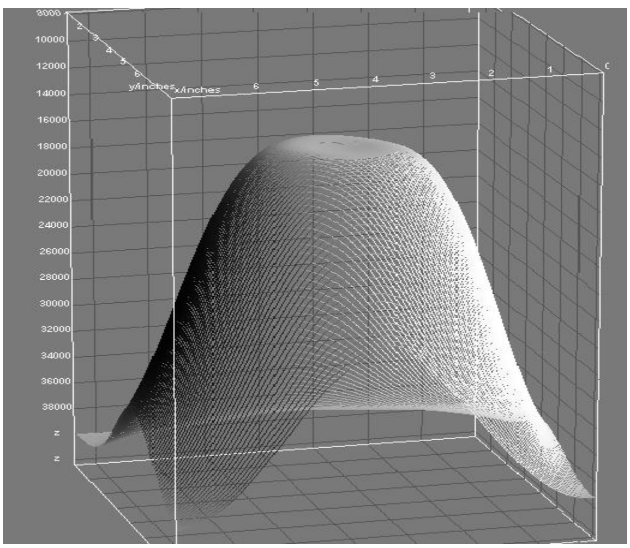


Figure 4: External appearance of mechanical wobbler magnets assembly.

Figure 5 shows 3D density distribution of carbon nuclei in the beam downstream 5 m the wobbler magnets in the image plane in front of the biological object. The distribution obtained using radiosensitive film EBT3.



a) b)

Figure 5: 3D density distribution of carbon nuclei in the beam in the image plane in front of the biological object.

The diameter of irradiation field with less than 5% variation in uniformity is 65÷70 mm.

CONCLUSION

The carbon ion beam extraction scheme from the U-70 synchrotron of NRC «Kurchatov institute» - IHEP for radiobiological researches is presented. The beam extraction operates at magnetic field flat bottom of U-70 synchrotron with carbon ion energy 455 MeV/n. A technique to attain transversally irradiation field is presented. The irradiation field is up to 70 mm in diameter and 32 cm in WEL (water equivalent length) in depth.

REFERENCES

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