OPTICAL DESIGN OF THE PROTON BEAM LINES FOR THE NEUTRON COMPLEX INR RAS AND MEDICAL APPLICATION

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Abstract

The optical design for the layout of the beam lines for the neutron complex INR RAS and medical application based on the basis of the Linear accelerator are presented here. The proposed schemes have been realized at the INR RAS. The necessary size and shape of the proton beam at the location of the neutron target are obtained. Methods and results for the tuning of the high current beams are presented in this paper.

INTRODUCTION

The experimental complex is a part of the heavy current linear accelerator complex Linac INR RAS [1], based in a town Troitsk near Moscow. This facility consists of the proton and H^- beam channels, the multipurpose neutron complex and the complex of proton therapy. The optical layout of the beam has been slightly changed, as compared with initial design, due to changes of the program of researches. The beam channels are used for driving the neutron studies and complex proton therapy (CPT). At the present time four branches of the proton channel are in operation: three for the neutron complex (pulse spallation neutron source PSNS, lead slowing down spectrometer LSD S-100 and RADEX-n-TOF spectrometer) [2], and one branch for proton medical channel [3].

The channels, we are considering in the paper, have been created in the experimental hall of Linac complex INR and are dedicated to proton beam formation with energies ranging from 120 to 500 MeV. Some of the channels have been previously described in [4]. The main characteristics of the equipment and construction of the channels has been considered in the papers [4, 5].

The coils of all electromagnetic equipment have been manufactured from the radiation-resistant cable, similar to "Pyrotenax".

The quality of the magnet elements makes us possible to group by one power supply source and this has greatly simplified maintenance, tuning and operation of the channels.

THE MAIN CHANNEL OF THE EXPERIMENTAL COMPLEX

This main channel of 150 metres is located in the continuous accelerator tunnel and in the experimental hall (Fig.1, vertical cross-section). This channel is a common part of the overall layout of the beams in the experimental complex. It shapes beam for RADEX-n-TOF spectrometer (20 metres branch in the straight direction from the magnet 2MC2 on Fig.1) and is used for matching accelerator beam for other branches in the complex. The magnet 2MC2 at the end of the main channel is used to bend the beam horizontally to different physical installations in the experimental hall.

The channel elevates the beams (H^- and protons) coming from the accelerator by 4.2 m. The system of four magnets is used for bending of the beam with two components that provides the following angle of bending for H^- (blue path through magnets MBV1, MBV2 on Fig.2):

$$\varphi + \varphi = 2\varphi \qquad (H^-).$$

The particles of the opposite sign (protons) will pass this system (red path through magnets MBV1, MBV5, MBV6, and MBV2 on Fig.2), deflecting by the same angle:

$$-\varphi + 2\varphi + 2\varphi - \varphi = 2\varphi \qquad \text{(protons)}.$$

The pair of such bending systems with the intermagnet optics between the effective centres of the bending allows simultaneous transportation of the beams of opposite signs (protons and H^-) in one channel with the required precision.

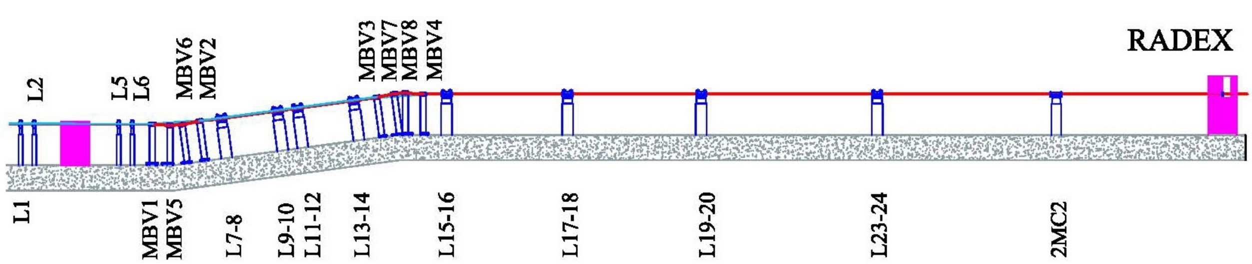

Figure 1: The layout of the main channel of the proton and H^- beams of the Experimental Complex (vertical cross-section). Included are only the main optical components.

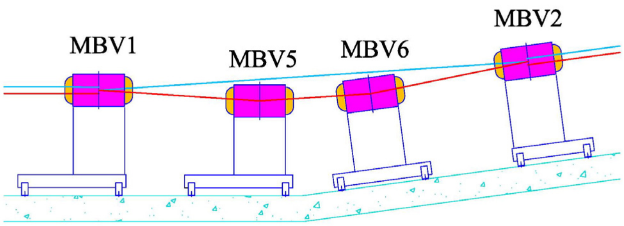

Figure 2: Four magnet's vertical bending system of the main beam line of opposite charged particles (red path for protons and blue path for H^-).

Thus this four magnet's system allows us to carry out independent correcting of the position of the each beam.

Transformation matrix of the channel at switching on the 11 power supplies on 30 elements of the channel are listed below:

Transform matrix for H^-

-0.924	-0.257	0.000	0.000	0.000	0.000
0.034	-1.073	0.000	0.000	0.000	0.000
0.000	0.000	-1.199	0.019	0.000	0.027
0.000	0.000	-0.177	-0.831	0.000	0.011
0.000	0.000	0.001	-0.002	1.000	-0.064
0.000	0.000	0.000	0.000	0.000	1.000

Transform matrix for protons

-0.353	-0.517	0.000	0.000	0.000	0.000
0.913	-1.496	0.000	0.000	0.000	0.000
0.000	0.000	-1.087	-0.141	0.000	0.010
0.000	0.000	-0.177	-0.943	0.000	-0.009
0.000	0.000	-0.012	-0.001	1.000	0.104
0.000	0.000	0.000	0.000	0.000	1.000

The profile of the proton beam in case of the path for H- (blue path on Fig.2) in front of the magnet 2MC2 is presented on Fig.3.

The angular divergence of the beam is less than 1 mrad.

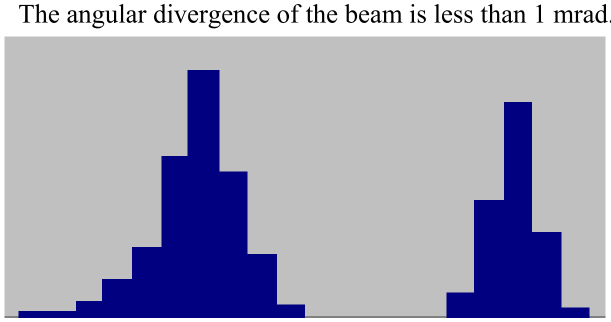

Figure 3: Measured beam profiles before the magnet 2MC2 (left graph - horizontal plane with mean= -2.3 mm, σ_x=5.4 mm and right graph – vertical plane with mean=1.5 mm, σ_y=3.3 mm).

The bending of the beam to PSNS, lead slowing down spectrometer LSD S-100 and the channel of the proton therapy complex is carried out when the magnet 2MC2 is switched on.

In case of the simultaneous acceleration of two beams from Linac (protons and H^-) the beam splitting facility would be installed in place of the bending magnet 2MC2. This system would allow simultaneous work of RADEX-n-TOF spectrometer on the high current beam of protons and channel of proton therapy using the low current beam of H^-. The system for independent adjustment of the beam energy on the channel of proton therapy had been made.

CHANNEL FOR PROTON THERAPY

The placement of the equipment for proton therapy (branch 2MC2-MBV12) is shown on Fig.4. Lenses L47-54 are used only for the system of independent adjustment

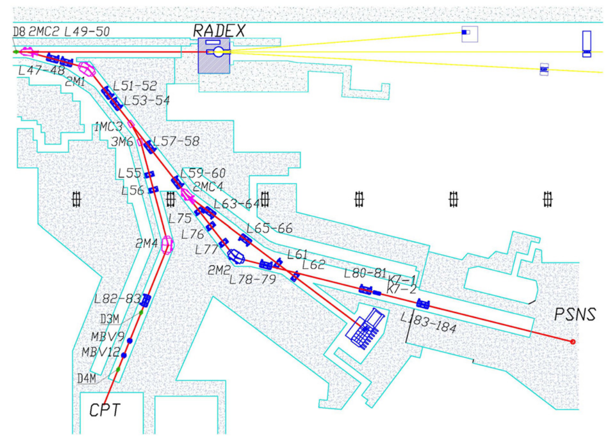

Figure4: The layout of the branches of the proton beam channel at the experimental complex.

beam energy and in the session in November 2010 have been turned off. This branch is the linear dispersion free channel, shaping a beam on the collimator irradiation facility. Optical scheme of the channel is shown in Fig.5. After the channel tuning shaped beam by lenses L82, L83 at the collimator is σ_x=5.5 mm in horizontal plane and σ_y=3.9 mm in vertical plane (based on the results of November 2010 session). The angular divergence of the beam is less than 1mrad. The channel is up and running at energies of 127, 160 and 209 MeV, which meets the requirements of medical physicists.

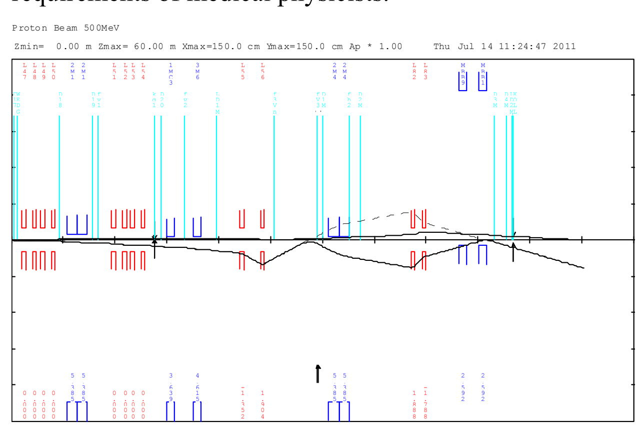

Figure 5: Optical scheme and envelope (-) and linear dispersion (--) of the beam of the channel for CPT calculated by TRANSPORT [6].

CHANNEL FOR PSNS

This is a channel with controlled dispersion, which has common elements with the medical channel. The equipment of this channel is shown on Fig.4 (branch 2MC2-L184). The main requirement for the channel is to exclude the formation of a point beam at the target to protect the first wall of the neutron target from destruction. The worked out optical system of the channel is shown in Fig.6. The doublet lens L83-L84 is used as the lens shaping a beam on the target PSNS. The doublet helps to shape a 'belt' beam with σ=7 mm vertically and between σ=7mm and σ=20 mm horizontally.

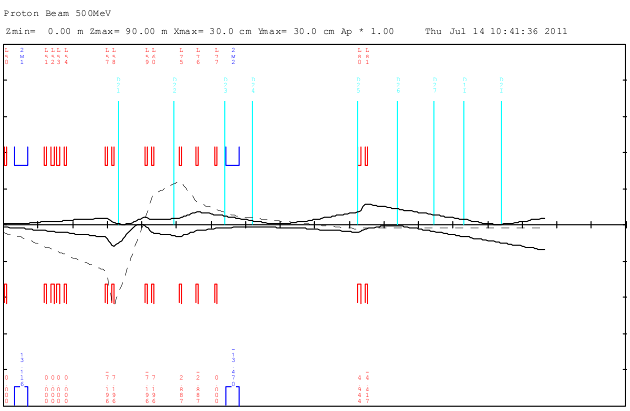

Figure 6: Optical scheme and envelope (-) and linear dispersion (--) of the proton beam of the channel PSNS calculated by TRANSPORT [6].

The channel was previously configured and enabled the first physical session at PSNS with beam power of 7kW. Results of this session have shown that level of induced radioactivity allows to service of the channel equipments without remote controlled manipulators except for the beam stop region.

TUNING THE BEAMS

In our case the main purpose of tuning is obtaining low level beam losses for heavy current beam and the accurately focusing of the medical beam.

For tuning we have used the method for tuning the complicate optical channels likes RF separate beam that was developed by CERN and IHEP [7]. It is very effective and obvious method. For example to correct the field gradients in the lenses we use calculated focusing coefficients to displace the position of the focus in one of the transverse planes without any influence in the other plane.

The sixteen wires secondary emission profile detectors (30 units) alongside the channel are used to measure the position and a spot size of the beam. The profile detectors are penetrated into the beam only in an adjustment mode at the low-intensity beam (1 macro pulse in second). For intensive beam (50 macro pulses per second) the induction current monitors are used to control the beam current. Medical channel has a thin fluorescent screen in vacuum pipe to watch the beam in the mode on-line.

Ionization chambers (30 units) on beam vacuum pipe and neutron detectors (60 units) outside of the channels are used like beam loss monitors.

SUMMARY

Creation of the channels is nearing its completion. It is planned to include the steering magnets, additional detectors on the channel PSPS for fine tuning with a significant increase in the level of power in the beam.

In the nearest future H^- beam from the Linac shall be used for the H- beam therapy simultaneously with neutron complex on protons. The data, obtained during the beam sessions, showed that beam line solution has been found to satisfy the target geometry and beam requirements.

Each channel can operate with different optical schemes depending on the required of an experiment. Implementation of the broad program of experiments with different requirements to the parameters of particle beams implies a high mobility in retuning of the working modes of the channels.

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