NON RESONANT SLOW EXTRACTION OF PROTONS FROM THE IHEP ACCELERATOR TO THE SFINX APPARATUS

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Introduction

One of the working modes of the experimental facility SFINX requires a slowly extracted 70 GeV proton beam with intensity of 10^6-10^7 ppc [1]. A very high quality of the time structure of the extracted beam of relatively low intensity is necessary in this case, the extraction time being maximally possible. The resonant slow extraction system cannot provide the required quality of the time structure for the extracted beam in the intensity range of 10^6-10^{11} ppc. Simultaneous extraction of primary protons and secondary particle beams from the internal targets (IT) allowed one to increase the efficiency of using the accelerated beam. In this case the duration of the beam extraction for the consumers working simultaneously, was doubled. Owing to the insertion of a thin internal target [2] we managed to obtain a new quality of the extracted beams: the modulations of the time structure were reduced several times as compared with that when working with "thick" targets [3] and a new level of 10% was provided.

The present paper is devoted to the results on extracting a proton beam, obtained from elastic scattering of the particles on the internal targets in the process of secondary particle production, into beam line No 21.

1. Some Characteristics of Proton Beam

Some time ago (see, e.g., [1]) it was suggested to obtain proton beams with the intensity of 10^6-10^9 ppc through diffractional scattering of protons with primary intensity of $5\cdot10^{11}$ ppc on the targets, installed in the bending magnets with a further forming of the beams obtained. In spite of the fact that, this technique solves the impose problem, but it still has an essential disadvantages: very large planned losses of intensity inevitably result in an unjustified irradiation of the magnetic optical elements and such high levels of induced radiation, that make the maintenance and repair of this equipment quite problematic.

A nonresonant slow extraction (NRSE) [3,4] allow one to avoid such losses. As it turned out this technique has a number of advantages in the case of the IHEP accelerator, the most important among them is a possibility to extract proton beams of intermediate intensities (10^6-10^{11} ppc), to provide high quality time structure and to work simultaneously with several (3-4) internal targets.

The efficiency of the NRSE is not very high at present, and the main reason for that is a very thick septum of the first septum magnet (SM-18). The efficiency of 5% was recorded in the extraction of the beam to the FODS facility, the septum thickness being 1 mm. The new installed SM-18 with a thinner septum of 0.47 mm [5] allowed one to decrease particle losses, and the replacement of the optical elements SS-30 with the units with larger apertures made the acceptance of the beam channel segment adjacent to the accelerator, 1.5-2 times larger. As a result, after estimating the recent modes the efficiency of about 15-20% was achived, which allowed to reduce the intensity of the accelerated beam, spilled onto the internal target. The estimates the efficiency of NRSE for the present structure of the IHEP accelerator made it clear that after putting into operation a 0.1 mm thick electrostatic deflector and choosing optimal parameters of the target (material, thickness, location) one can obtain 90-95%, which agrees with the data [6,7] for the CERN SPS machine.

As is known after the beam passing through the target the behaviour of particles is determined by the following processes: absorption, elastic nuclear and multiple Coulomb scattering, ionization losses of energy. Proton absorption, causing the production of secondary particles, is the main mechanism leading to the decrease of the beam intensity as a result of multiple passing through the internal target at the magnetic field flat-top.

Multiple Coulomb, elastic nuclear scattering and ionization losses of energy change the amplitude and phase of betatron oscillations in each interaction with the target. Besides, because of the ionization losses the equilibrium orbit of particles shifts. These processes taken together result in the accelerated proton beam blow-up, which allows the particles to be caught by the field of the septum magnet and be extracted from the machine.

Fig.1 presents the effective transverse beam sizes, thrown into the SM-18 aperture (fig.1a) and fig.1b shows the horizontal distribution of the particle density. As is seen the amplitude spread for the particles is 12-15 mm. The phase space of the ejected beam is formed right from this initial distribution. The dashed lines in fig.1a are the boundaries of the vertical aperture of SM-18. "Thin" carbon targets of beam line No 2 installed in the 24-th block of the machine (0.3 mm thik along the beam axis) [2] and "thick" Be target of beam line No 4 in block 27 (30 mm thick along the beam axis) were used to scatter the beam. As the calculations have made it clear the time of life of particles is mainly determined by the thick Be target.

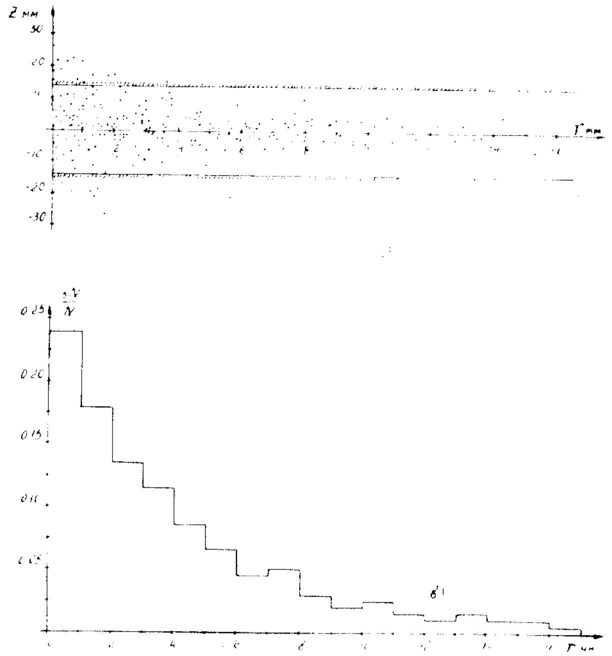

Fig. 1. Distribution of particles in the SM-18 aperture, a - effective cross size, b - horisontal distribution of particle density.

2. Extraction of the Beam Filling the SM-18 Aperture

The first experiments on extracting the beam to the SFINX facility were carried out in sequence with the internal targets of beam lines No 2 and No 4, located at the beam extraction region. It reduced more than twice the time of extraction for all the experiments. The beam was scattered by the targets located outside the extraction area. However the main problem still remains, i.e., to increase the beam consumption efficiency for experiments and to realize such modes which would provide maximum (>1.5 s) beam spill for all consumers during one cycle. The main thing which hinders the solution of this problem at the IHEP machine, is the field distortion in the extraction area caused by the system guiding the beam onto the target of beam channel No 2 and No 4 (the principal consumers of the secondary beams). Calculations were made for NRSE protons from the internal targets of these beam lines, which demonstrated a principal possibility to realize these modes simultaneously. The calculated mode has been realized and it is the main working mode, which provides twice larger beam spills for experiments and a good time structure quality.

Fig.2 presents the calculated ejection trace for elastically scattered protons (curve 1), the shape of the local distortions of the closed orbit, produced by the currents of additional windings of blocks 20, 26, 24, 30 when the bumps of beam channels No 2 and No 4 work simultaneously, having opposite polarity (curve 2) and beam lines of negative secondary particles (broken lines) with targets T1 and T2 (marked with asterisks), respectively.

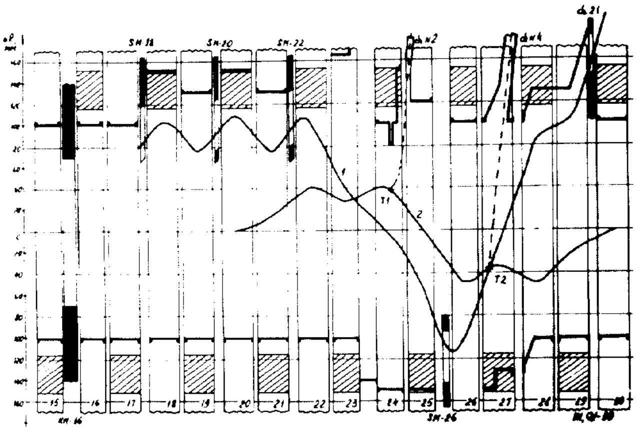

Fig. 2. Scheme of simultaneous ejection of particles: 1 - ejection trajectory of the elastically scattered proton; 2 - local bumps for deflection of the beam onto the targets; - - - - of secondary particles trajectories.

Local distortions of the closed orbit, formed by additional windings in blocks 15, 21 and 16, 22 (not shown) are used to guarantee the particle capture by the field of the SM-18 [3]. Such combinations of bumps provide beam minimum losses on septums of SM-18 and SM-20. Peculiarities of the combined mode

1. Additional currents of blocks 20, 24, 26 made the working modes of SM-20 and SM-26 easier; they provide the required beam parameters at the accelerator output (the coordinate and the angle of the center of gravity in SS-30).

2. A new thin target of beam line No 2 is used together with the "thick" Be target of beam line No 4, which improved the low frequency structure approximately by an order of magnitude and practically suppressed one-turn HF structure of 200 kHz in the extracted beams in all beam lines owing to fast debanching and growth of the time-of-life of particles interacting with the "thick" target.

The beam emittance in the horizontal and vertical planes (at the extracted intensity of 10^9 ppc) $\varepsilon_{r,z}$=2.70x6.0 mm·mrad was used in our calculations. At the intensity of the extracted beam 10^7 ppc the emittance is approximately twice smaller, which allows to carry out experiments with minimum background conditions.

The optical scheme of forming such a beam is presented in fig.3. Ten quadrupole lenses and 15 deflecting magnets transport the beam at a distance of 300 m and focus it onto the target as a spot 10 mm in diameter, which meets the requirements imposed. Aperture collimators CG and CV are used for fine adjustment of the beam sizes.

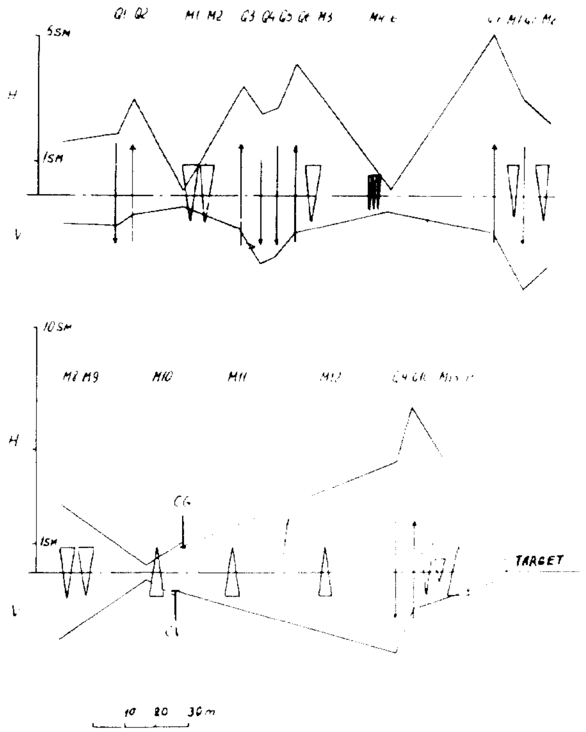

Fig. 3. Optical scheme of beam channel No21 with sagitta of proton beam. $Q_1 \div Q_{10}$ - quadrupole lenses; $M_1 \div M_{15}$ - deflecting magnets; CG, CV - the horizontal and vertical collimators.

3. Experimental Results

Fig. 4 presents the oscillograms showing the simultaneous operation NRSE and internal targets. The oscillograms of the time structure of the secondary beam for beam lines No 2 and No 4 (upper and lower lines) are shown in fig.4a. Fig.4b presents the oscillogram for the time structure of the proton beam extracted to SFINX facility (top line) and the one, characterizing RF structure attenuation in the extracted beams (line at the bottom), which is connected with the operation of the thin target in beam line No 2.

Two circumstances which allow to increase the efficiency of the investigations with SFINX facility are to be mentioned. They are:

- Owing to the pulsed supply of magnets M4-M6 (see fig.3) the NRSE of the beam toward beam line No 21 was realized in the same cycle with the fast extraction of high intensity beam (10^{13} ppc) towards beam line No 8, which has a part of the beam line common with beam line No 21. This all at once imposed particular

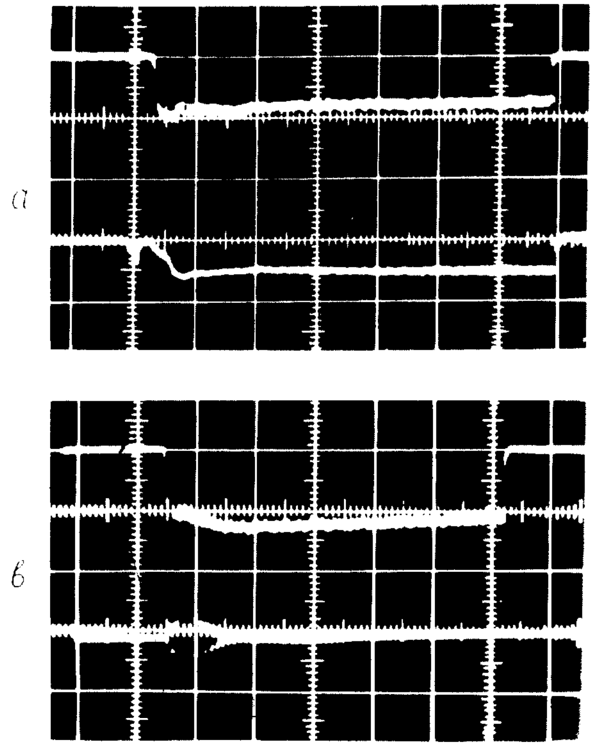

Fig. 4. The oscillograms of simultaneous work of NRSF and IT. a - the secondary beams of the channels N 2 and No 4 time structure, 200 ms/div; b - the proton beam time structure at NRSE (up) and diminution of HF 200 kHz structure under the thin target operation (down), 200 ms/div.

requirements for the quality of beam adjustment, stability of the extraction systems and reliability of power supply synchronization.

- as is seen in fig.2 the target of beam line No 4 (T2) installed on the coordinates $r \approx 35$-40 mm w.r.t. the central orbit may be a source of elastically scattered protons for beam line No 21. The production angle for protons is 5-7 mrad, which causes the beam intensity of 5×10^6 ppc, which allows to carry some experiments. This operating mode seems rather attractive because it does not require the SM power supply to be switched on, no need for local bumps and what is more, the consumption efficiency for the beam from the internal target becomes considerably higher. Under such operational conditions one can provide the duration of the beam extraction in beam line No 21 equal to that of the secondary beam extraction, which is up to now is not possible because of SM-18 (the reduction of the time for the beam extraction in beam line No 21 can be seen in fig.4b). The duration of the secondary beam extraction when working in turn with the fast extraction at the flat top of the magnetic cycle may be 1.4 s; and without fast extraction it makes up $>$1.7 s. Non-resonance slow extraction without the septum-magnets has been tested and it is used at present depending on the requirements for the intensity.

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