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THE DEVELOPMENT OF THE SYSTEMS OF BEAM EXTRACTION FROM THE IHEP ACCELERATOR UNDER HIGH INTENSITY OPERATION

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Abstract This paper reports on some results on the development of the extraction systems for an efficient use of the high-intensity proton beam in the program of physics experiments. It also presents some data on the parameters of fast and slow extracted beams and those of secondary beams produced on the internal targets.

After putting into operation the booster accelerator in 1985 and raising the proton beam intensity the extraction systems of the IHEP 70 GeV machine are developed with a view to increase the feasibilities of the experimental facilities for physics. These activities follow two trends. The first frend should provide the extraction of the high intensity proton beam. The second frend should help develop and refine new extraction modes satisfying the requirements of the setups using the extracted proton beams and of those operating with the secondary beams from the internal targets.

The maximum intensity of the accelerated beam is presently as high as $1.9 \cdot 10^{13}$ ppp while the mean one attained during some runs exceeded $1 \cdot 10^{13}$ ppp and was sometimes kept at a level of $1.5 \cdot 10^{13}$ ppp. Since the requirements imposed by versatile facilities on the accelerated proton beam intensity differ essentially, the mean working intensity is, as a rule, less than the maximum one. Table I presents the recent basic parameters characterizing the operation of the IHEP accelerator.

TABLE I The operational parameters of the IHEP accelerator.

	1986 4 runs	1987 5 runs	1988 4 runs	1989 3 runs
Maximum intensity, 10^{13} ppp	1.2	1.6	1.65	1.9
Total intensity, 10^{18}	3.64	5.38	6.15	4.99
Scheduled time, h	2580	3408	2640	1916
Mean intensity, 10^{12} ppp	3.6	4.1	6.0	6.7
Total intensity (best run), 10^{18}	1.23	2.2	1.85	2.6
Mean intensity (best run), 10^{12} ppp	6.4	9.7	11.8	11.6
Mean intensity of fast ectraction (best run), 10^{12} ppp	4.7	7.4	9.2	9.7

The major way to realize a high intensity is fast extraction providing the extraction of the whole intensity accelerated. Figure 1 shows the behaviour of the mean accelerated intensity (1) and the mean intensity of fast extraction (2) in a high-intensity accelerator run. The remaining part of the beam, not more than 2 10^{12} ppp, was used by the internal targets.

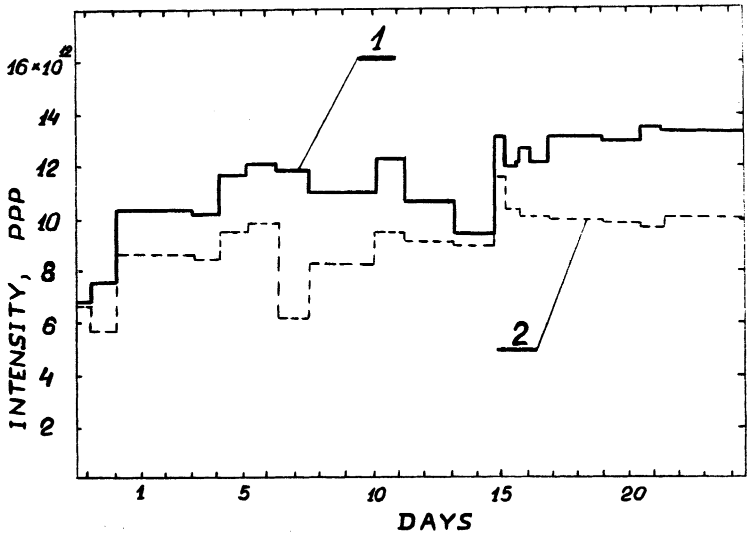

FIGURE 1 Mean accelerated beam intensity (1) and mean intensity of fast extraction (2) in a high intensity run.

The maximum beam intensity attained during slow extraction was $1 \cdot 10^{13}$ ppp whereas the mean intensity in a run does not exceed $4 \cdot 10^{12}$ ppp. This is explained by a high activation of the extraction equipment caused by the 0.5 mm thick septum of the 1st magnet. This keeps the extraction efficiency at a level of 85%.

UPGRADING THE PROTON EXTRACTION SCHEME

To widen the scope of experimental research, a new scheme of slow extraction allowing the operation of three high-intensity proton beam experimental areas has been developed.

Figure 2 shows the scheme of proton beam extraction from the IHEP synchrotron.

Directions A and C are foreseen for slow extraction into beam lines N24 and N22, respectively. Fast and slow extraction are carried out in direction B for beam lines N8, N21, N23 and can be done in one cycle.

Prior to the upgrading, slow extraction was carried out along trajectory 1 (see fig.2) with the help of a septum magnet SM-28 placed in straight section 28 of the machine and a magnet EM-30 extracting the beam in direction B. The beam could not be extracted in direction C due to a large angle of the trajectory in the straight section and an insufficient strength of the magnet EM-30. In 1987, the septum magnet SM-26 of the fast extraction system was replaced by a new one having a current pulse duration of 2 s, which allowed the slow beam extraction along trajectory 2 (see fig.2) and beam separation in directions B and C.

A high-intensity hadron beam line N22[1,2] was built in direction C which has been running for two experimental setups since 1988. The mean proton intensity extracted in this direction is now 4 10^{12} ppp.

As is seen from fig.2, the upgrading of the slow extraction scheme required running in fast extraction along the common trajectory 2. Its specific feature is the increasing length at a large distance from the central orbit in the focusing elements of the machine. This leads to a deterioration of the focusing capacity and to an increase in the horizontal beam dimensions due to the field nonlinearity. In this case, the dimensions of the beam extracted from the machine have a nonlinear dependence on both the accelerated beam emittance and the momentum spread. The dependence of the beam dimensions on the trajectory displacement (the position of the bending magnets) with respect to the equilibrium orbit and on the extraction energy (the field values) has been calculated numerically. A possibility to decrease the beam dimensions by using an additional local orbit distortion in the region of the beam extraction from the machine has also been studied.

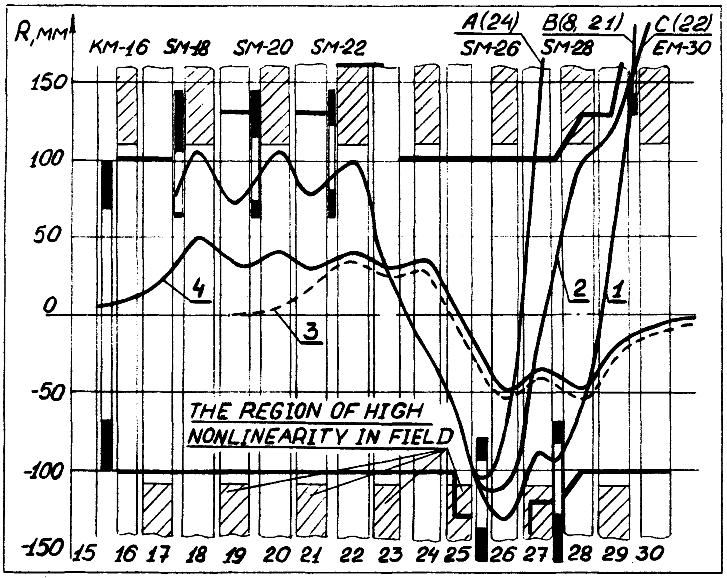

FIGURE 2 Scheme of proton beam extraction from the IHEP synchrotron: 1 - traditional extraction trajectory, 2 - new extraction trajectory, 3 - local orbit distortion for targets 24 and 27, 4 - local orbit distortion for simultaneous operation of slow extraction and of the internal targets.

An efficient performance of beam extraction along trajectory 2 maintains the program of experimental research at the intensity level attained and helps increase it further provided that the beam emittance does not exceed 2.5 π mm.mrad.

OPERATION OF INTERNAL TARGETS

A specific feature of the machine operation is a wide use of the internal targets with fast and slow extraction. Presently, one of the following modes of extracting the beam during the flattop (see fig.3) is realized:

1. In the beginning of the main flattop, fast extraction (FE) is done, then up to three internal targets, T24, T27, T35, producing secondary beams extracted within 1.7 s (see fig.3, mode 1) are turned on.

2. The main flattop is shared between slow extraction and the operation of the internal targets. Fast extraction can be done simultaneously. In this mode, the length of slow extraction spill and that of the internal targets is cut down to 0.75 s (see fig.3, mode 2).

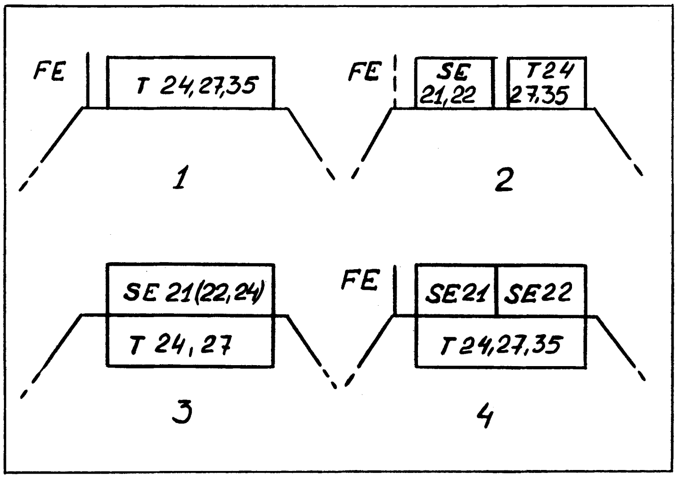

FIGURE 3 Basic operational modes of the beam extraction during the main field flattop.

To prolong extraction onto each experimental setup and increase the number of experiments done concurrently, a possibility to realize mode 3 in fig.3, i.e. the simultaneous operation slow extraction and two internal targets during the whole flattop, is studied[3]. The implementation of this method faces some difficulties. Firstly, three closed beam feedback systems, i.e. those tuning the position of the working point for slow extraction and the beam position with respect to the specified coordinates of the internal targets, are running simultaneously. Secondly, it is necessary to maintain the slow extraction trajectory when creating a complicated local orbit distortion for beam targeting. Figure 2 shows the local orbit distortion for internal target T24 (the coordinate is +35 mm) and for target T27 (the coordinate is - 40 mm) and also the complete local orbit distortion for the simultaneous operation of slow extraction and of the internal targets (curves 3,4). The mode, under which an intensity of $2.5 \cdot 10^{12}$ ppp was shared between slow extraction and the internal targets equally, was also studied experimentally. This mode proved to be stable. The proton beam time pattern turned out to be improved owing to a lower level of low-frequency ripples. The time pattern of secondary beams deteriorated somewhat, frequencies 50 and 100 Hz, specific for the slow extraction system, became more pronounced. A decrease in the proton beam spotsize did not lead to any losses of particles in the beam transport line whereas the losses of protons on the first magnets of the extraction system increased.

Some experimental setups require 10^6-10^{11} ppp beams. However, the system of resonance slow extraction cannot provide such beams of a good quality. A simple and efficient technique applied to attain the beam parameters required was selection of protons scattered of the internal targets (nonresonance slow extraction)[4,5]. In this case, a fraction of protons scattered on the internal targets was transported into the gap of the first septum of the slow extraction system to be extracted further in directions B and C. This extraction technique has the same flattop sharing scheme as mode 3 in fig.3. Such a mode ensures the simultaneous operation of secondary beam lines and of the experimental setups requiring the 10^6-10^{11} ppp beams of the maximum-spill duration. The time modulation of the proton beam is in this case 5-10% and that of secondary beams is 5-15%[4,5].

To produce secondary beams, the internal targets whose useful parts are pieces of carbonic cloth, each 50 mg/cm^2 thick, are presently used. With the new targets applied, this improved the beam time pattern bringing the time modulation of secondary beams down to 7-10%[6].

Table II shows the presently implemented techniques of extracting the proton beam into beam lines and directions, the maximum intensities on the internal and external targets. It also presents the efficiensies and burst durations attained.

TABLE II Extraction modes and their parameters

Extraction modes in directions, beam lines	Max.intensity on target,ppp	Burst duration	Extraction efficiency, %
Fast extraction, B-8	1.7×10^{13}	5×10^{-6} s	95-98
Resonance slow extraction, B-8	1.0×10^{13}	1.3 s	85
Resonance slow extraction, C-22	1.0×10^{13}	1.3 s	85
Nonresonance slow extraction, B-21	1.0×10^{11}	1.8 s	15-20
Nonresonance slow extraction, C-22	1.0×10^{11}	1.8 s	15-20
Internal target N24, 2	1.0×10^{12}	1.8 s	
Internal target N27, 4	1.0×10^{12}	1.8 s	
Internal target N35, 18	1.0×10^{12}	1.8 s	

To raise the intensity of resonance slow extraction it is necessary to increase in the nearer future its efficiency with a view to reduce the level of radiation loads. It is also obligatory to carry on working on a more efficient use of the field flattop (see fig.3, modes 3,4).

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