INCREASE OF INJECTION ENERGY OF THE 70 GeV PROTON SYNCHROTRON WITH THE GOAL TO INCREASE THE INTENSITY

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(presented by E.A. Mayea)

A project for increasing the intensity of the IHEP proton synchrotron was reported at the 2nd National Conference on Charged Particle Accelerators in Moscow$^{1-3)}$. At the present moment, the project has been modified and clarified. All the changes deal mainly with the ring electromagnet of the booster.

The purpose of the reconstruction is to increase the intensity of the accelerator up to $\sim 10^{13}$ protons/sec by increasing the intensity per pulse up to $\sim 5 \times 10^{13}$ protons/cycle. Such an intensity level does not require any considerable changes in the main accelerator units or the biological shielding. It is assumed that the shutdown of the accelerator, because of transition to the new operational mode, will not be for more than several months.

In achieving the intensity indicated above, the injection energy should not be less than 1 GeV (Fig. 1), but it was decided to increase it up to 1.5 GeV so as to reduce the influence of non-linear resonances. A fast booster, i.e. a synchrotron with an average radius of about 16 m, operating at a repetition cycle of 25 Hz and filling the chamber of the main accelerator during 1.2 sec, i.e. per 30 cycles (each time one separatrix is filled), was chosen as a new injector (Fig. 2).

Other variants were rejected, mainly for the following reasons:

i) A 1 GeV linac seems to be unable to provide the required number of protons. Indeed, at a current of 100 mA, to store 5×10^{13} particles it is necessary to have about 50 revolutions of injection with $\sim 30\%$ efficiency. This is very difficult to realize in practice. Besides, such an injector is certain to be very expensive.

ii) A multitrace slow booster, which operates with the repetition rate of the main accelerator, would have been of too large a size (let us say 5 rings, 300 m each).

iii) A slow booster with multiturn ejection, which provides the ejected beam with required emittance, would have had a very low Coulomb limit, i.e. the booster itself would have needed an injector with an energy of several hundred MeV.

The new booster with the parameters mentioned above is preferable because of its small size and the absence of details that demand new technological solution and new materials; and, what is more advantageous, there is already much experience in constructing the majority of the main units. The main drawback of this booster, i.e. a relatively long injection time into the main accelerator, is not a crucial one in our case, as the increase of the cycle duration by 1.2 sec will decrease the average current by no more than 20%. Additionally, we hope that instabilities that may arise at long beam-circulation times at a constant energy, can be overcome by correction of the magnetic field and by introducing feedback which suppresses coherent oscillations.

The main parameters of the new injection system are given in the table. The choice of the most important parameters is discussed below.

A quite natural desire to construct a booster of possibly small size faces difficulties connected with the storage of a large number of particles along a short path and limitations caused by the magnetic field. To arrange conveniently the synchronization of the booster with the main accelerator, it is required to have the main machine about a multiple of the length of the booster. The harmonic number of the booster and the main accelerator is 1 to 30 correspondingly. The bunch, whose initial length is close to 100 m, by the end of acceleration in the booster becomes $\sim$ 25 m and is easily placed into the separatrix of the main machine. A total of 1.7×10^{12} particles should be accelerated in each cycle of the booster. An operation at a higher harmonic number would have required an increase in this number, and in addition an increase in the accelerating voltage amplitude. The repetition rate of the booster is 25 Hz, and it cannot be increased as it will introduce constructional complications in the accelerating system. The accelerating voltage in the booster will be amplitude modulated so as to achieve the biggest capture and best regulation of the length of bunches when injecting into the main accelerator.

Proceeding from the acceptable Coulomb shift of betatron oscillations, the injection energy may not be higher than 30 MeV. Having analysed the possibilities of using the existing 100 MeV linac as injector, we have found that in spite of the current increase up to 150 mA and application of a 4-turn injection, the linac could not provide the required number of particles, and its modification for the operation at the frequency at 25 Hz would demand big efforts. Besides, the reconstruction of the now-existing linac together with tuning of the booster would have brought us to a further shutdown of the whole accelerator

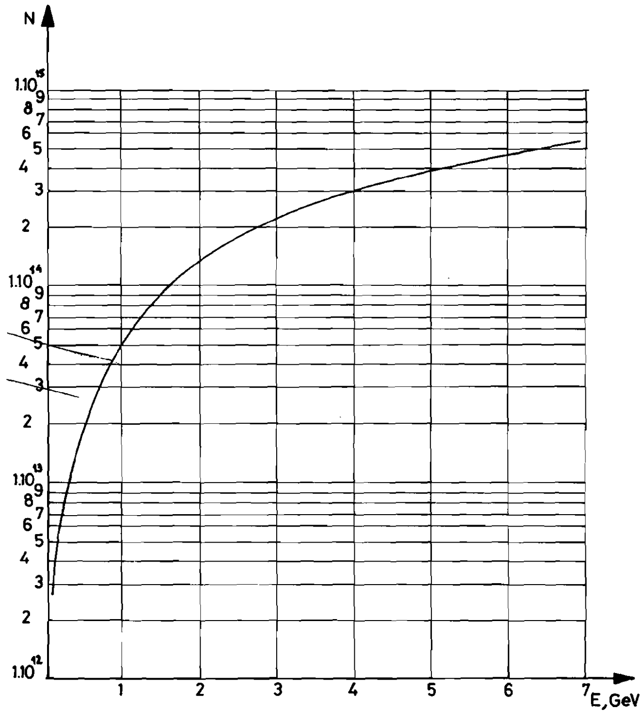

Fig. 1 : Maximal intensity of IHEP accelerator as a function of injection energy.

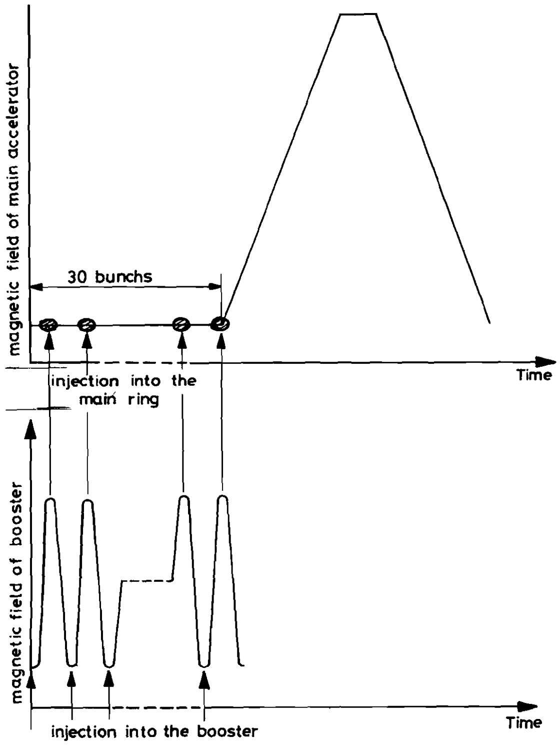

Fig. 2 : Operation of fast booster: top - main accelerator cycle; bottom - booster cycle.

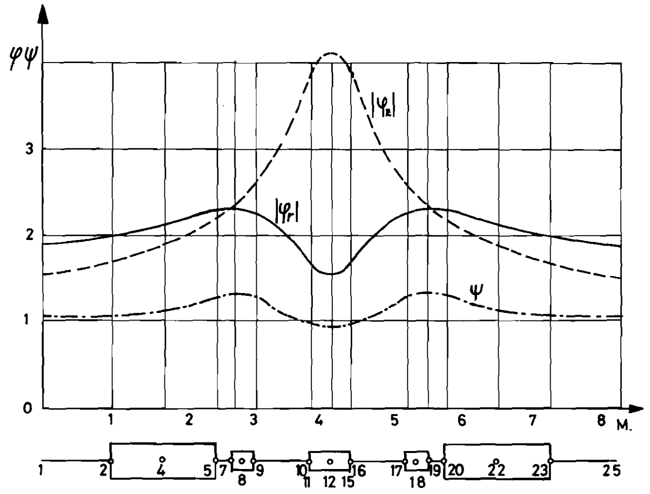

Fig. 3 : Booster lattice.

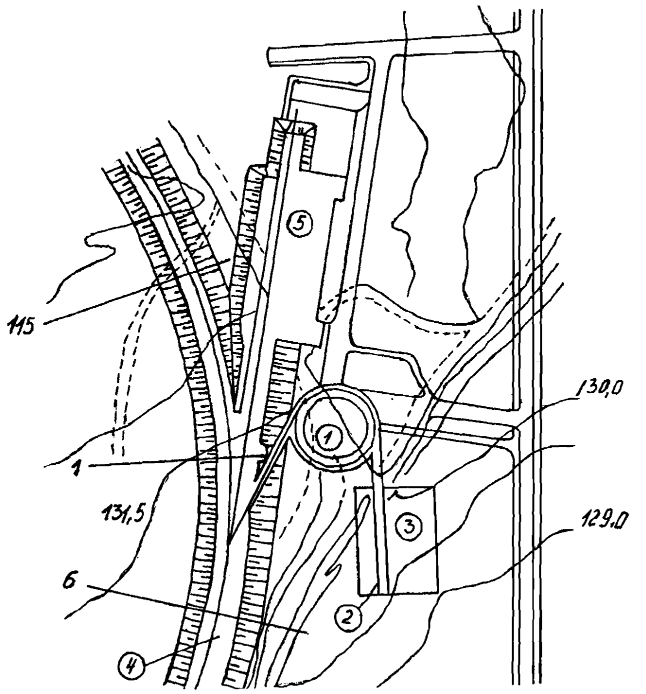

Fig. 4 : Plan view of the new injection complex.
1: booster; 2: 37 MeV linac;
3: laboratory; 4: main accelerator;
5: 100 MeV linac.

complex. A decision was taken to construct a separate linear accelerator-injector for the booster, taking the first cavity of the now-existing injector as the basis (output energy 37.5 MeV). At a current of 100 mA and with a capture factor of $\sim \frac{2}{3}$, one will need 3-4 turn injection to provide an intensity of 1.7×10^{12} protons/pulse.

As there are no strict requirements with respect to the shielding of the linac, it will be constructed on the earth surface, 5 m above the booster orbit. The beam will be directed downwards with the help of an achromatic system producing a parallel shift.

The injection into the booster will be carried out with the help of a magnetic inflector and a system of pulsed magnets that produce local distortions of the orbit. Particle storage will be carried out in the radial phase space. To increase the efficiency of injection, the radial betatron frequency will be shifted from the operational value, $Q = 3.85$, towards one of the resonance values $Q = 3\frac{1}{2}$ (4-turn injection) $Q = 3\frac{2}{3}$ (3-turn injection), $Q = 3\frac{3}{4}$ (5-turn injection). Calculations that take into account the influence of space charge, show that after injection the effective radial emittance of the beam will not be larger than 45 cm mrad. This corresponds to the emittance 0.17 cm mrad at 70 GeV under the condition of adiabatic damping.

In the earlier design it was planned to use the combined function lattice FOFDOD, having 16 elements of periodicity. Further development of the design made it clear that the structure with separated functions, similar to the one used at CERN[4] (Fig. 3), has some advantages:

i) It appears to be possible to correct betatron oscillation frequencies over a wide range without decreasing the accelerator acceptance.

ii) The dimension and weight of the magnet units become smaller, and this is very important from the point of view of manufacturing, mounting, and replacing the units.

iii) The vacuum chamber is of a better construction.

There are a number of preferences connected with the construction of beam injection and ejection systems, magnet power supply, etc. In particular, the possibility of using pulsed operation of the magnet power supply system with an effective duty factor of ~ 4 and an asymmetrical form of magnet current is worth considering. In this case the maximum magnetic field growth rate and the supplying system power will be reduced by factors of 1.5 and 5, respectively.

Space-charge effects are negligible in the booster with the design intensity. However, the betatron frequency shift is rather great, and some correction of the frequencies will be needed to optimize the working point position in the main ring. The longitudinal phase-space volume disturbance near the transition energy and resistance instability are the most important effects expected in the main ring.

The existing injection point will be, perhaps, the most convenient one for injecting protons into the main ring. There is free space in this region, which is necessary for corresponding buildings, and we shall not have to make any changes in positions of the magnets. Also, the possibility remains of passing to injection from the 100 MeV linear accelerator.

The radiation problem seems to be one of the most important ones in the project. Calculations and experience show that we can afford a scattering of $\sim 3 \times 10^{12}$ p/p. It will demand the strengthening of the shielding in only a few places. On the other hand, it means that the efficiency of ejection must not be worse than 95% at the limit of intensity. Such an efficiency is obtainable at the present time even for slow ejection. The width of the earth protection of the booster itself must be 7 m.

The location of the new injection complex is shown in Fig. 4.

<u>List of parameters</u>

1. Energy	37.5 MeV - 1.5 GeV
2. Intensity	1.7×10^{12} p/p
3. Repetition frequency	25 Hz
4. Lattice	triplet of lenses between two bending magnets
5. Bending magnet length	1.5 m
6. Lenses lengths:	
focusing	0.333 m
defocusing	0.571 m
7. Straight section lengths:	
long	2.000 m
medium	0.763 m
short	0.250 m
8. Magnet bending radius	5.730 m
9. Average radius	15.782 m
10. Vacuum chamber aperture	14×6.4 cm^2
11. Frequency of betatron oscillations:	
radial	3.85
vertical	3.80
12. Maximum closed orbit deviation for $\Delta p/p = 1$	1.329 m
13. Momentum compaction factor	0.07235
14. Transition energy (kinetic)	2.55 GeV
15. Field of bending magnets	1560 to 13100 G
16. Maximum field increase per second	0.9×10^6 G/sec
17. Gradient of lenses	127-1067 G/cm
18. Harmonic number	1
19. Orbit frequency	0.83-2.79 MHz
20. Maximum radio-frequency increase per second	225 MHz/sec
21. Sum maximum equilibrium accelerating voltage	51.5 kV
22. Sum maximum amplitude of acceleration voltage	70 kV
23. Injection magnetic field of main accelerator	386 G
24. Radio frequency of main accelerator	5.60-6.06 MHz

References

1) Yu.M. Ado et al., "The increasing of an intensity of 70 GeV Proton Synchrotron by increasing of injection energy". Proc. 2nd National Conf. on Particle Accelerators, Moscow, 1970.

2) A.A. Artiomov et al., "Fast booster-injector of IHEP Proton Synchrotron", Proc. 2nd National Conf. on Particle Accelerators, Moscow, 1970.

3) F.A. Vodopjanov et al., "The new radio-electronic and control systems of IHEP Proton Synchrotron", Proc. 2nd National Conf. on Particle Accelerators, Moscow, 1970.

4) "The second stage CPS improvement study", preprint CERN MPS/Int. DL/67-19, 3rd October, 1967.

DISCUSSION ON THE THREE PREVIOUS PAPERS

L.C. TENG: Have you observed transverse beam instability?

E.A. MYAE: Yes, we see transverse coherent instabilities at about 1.2 x 10^{12} protons per pulse.

M.Q. BARTON: You described in your talk an instability which is characterized by bunch shape oscillations. Can you describe this instability in more detail?

E.A. MYAE: We are investigating this instability at this moment. There are two places during the acceleration cycle where the bunch shape oscillations exist. One is near the transition energy (slightly above and below it), and the other is at approximately 100 msec. after injection. The acceleration time up to the transition energy is $\sim$ 380 msec.

K.H. REICH: What were the considerations underlying the change of your booster lattice?

E.A. MYAE: There are several reasons: the cross sections of the magnet units are smaller in a separated-function structure than in a combined one, and it is easier to vary the Q-values in such a lattice.

E.D. COURANT: In designing your Booster, what is the advantage in including a new 37 MeV linac rather than re-using your existing 100 MeV linac?

E.A. MYAE:

1. It would be difficult to convert the existing linac for 25 Hz repetition rate.
2. For an intensity of 1.7 x 10^{12} protons/pulse in the Booster it is only necessary to have an injection energy of about 30 MeV, not 100 MeV.
3. At an injection energy of 100 MeV the number of injection turns in the Booster will be approximately twice that at 37 MeV.

W.A. WALLENMEYER: What is the status of the Booster with regard to the possibility of its construction?

E.A. MYAE: We think that it will be possible to construct the Booster in a few years.

R. WIDERØE: Do you have any proposals for intersecting storage rings?

E.A. MYAE: We have begun to think about it.

A. SØRENSSEN: Why did you prefer to increase the intensity of your machine, rather than the repetition rate?

E.A. MYAE: We have not excluded the possibility of increasing the repetition rate. But it is another problem; moreover, it is only possible to increase the average intensity by not more than 2-3 times through increasing the repetition rate.

B. KUIPER: What are the proposed applications of the 5 x 10^{13} protons/pulse obtained with your proposed Booster?

E.A. MYAE: At an intensity of 5 x 10^{13} protons/pulse we will have a mean intensity of the order 10^{13} protons/sec. There are several proposals for experiments which need such an intensity; for example, neutrino experiments.