IEEE Transactions on Nuclear Science, Vol.NS-24, No.3, June 1977

ON DESIGNING THE IHEP ACCELERATING STORAGE COMPLEX

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Further development of elementary particle physics requires construction of accelerators and systems with colliding beams of a new generation. To realize a wide-scale program of physical experiments whose final goal will be a solution of such important problems (as for example, a subnuclear particle structure and creation of general theory of interactions), one needs accelerated proton and electron beams with an energy of hundreds and thousands of GeV respectively, as well as colliding beams with energy in the c.m. system of more than 200-200 GeV.

The project of an accelerating storage complex (UNK) is being worked out on the basis of the presently existing IHEP 70-GeV proton synchrotron (U-70) that is planned to be used as a booster to the UNK. Much work has been done to modify the accelerator so as to provide the required parameters of the proton beam and to increase its intensity. At present the maximum achievable intensity is 5×10^{12} protons per cycle and for a considerable period of time the machine can operate with the intensity 4.5×10^{12} protons per cycle.[1] Beam emittance is $\epsilon_r = \epsilon_z = 1.2\ \pi$ mm-mrad.

To make the intensity even higher, use will be made of an intermediate synchrotron with energy 1.5 GeV that will operate in the mode of a fast booster. A beam from the booster (its intensity is 1.7×10^{12} protons per cycle) will be stored in the main ring for 1.5 sec; this should provide beam intensity up to 5×10^{13} protons per cycle and an emittance ~ 2π mm-mrad. When filling the main ring the booster will operate with the frequency of 20 Hz; its perimeter (circumference) is 100 m. The parameters of this system were presented in the Proceedings of International All-Union Conferences. The booster is presently under construction.

Many scientific and research institutions along with IHEP, SRIEPhA, RTI AS USSR participate in designing the UNK. Intensive work is going on in choosing the lattice of the UNK, superconducting magnets, vacuum chambers, cryogenic systems, power-supply systems, and rf acceleration. The wide-scale and tremendous cost of the UNK make it necessary to provide possibilities to carry out many investigations and to make the complex universal. From the same considerations stage-by-stage construction of the complex follows. The control of the complex is to be realized with a cybernetics system.[5]

During the past years, various versions of the UNK have been considered.[3-5] Currently a two-stage version has been approved for further study. The two-stage version forsees a superconducting proton synchrotron with the field at the orbit 4.5-5.0 T and an iron electron synchrotron with the field at the orbit up to 1.7 T. Possibilities of constructing a second superconducting ring have been forseen. The aperture of the first-stage accelerator is 100 mm × 50 mm, and for the superconducting ring it is 70 mm × 60 mm. The aperture of the second superconducting ring will be chosen later after some experience is gained with the magnets in the first ring. The electromagnet of the electron synchrotron is also planned to be used as a first stage for the proton storage accelerator. This stage is essentially a slow booster. It will allow us to increase the intensity and to reduce the influence of the residual fields in the superconducting magnets and to make the conditions easier for particle ejection into the second stage. A 5 T field may presently be achieved in the magnet with the help of a twisted superconductor made from NbTi with a filament diameter of 10 μm in the copper at CuNi matrix. Use of the superconductors with higher critical parameters will provide a possibility in the future of increasing the field at the orbit and the energy of accelerated particles, up to 5000 GeV.

The circumference, optimal in many parameters, is the one that equals 13 lengths of the U-70 circumference. The proton energy that can be obtained in the superconducting synchrotrons is up to 3000 GeV. If 5×10^{13} protons per cycle are ejected from the U-70, up to 6×10^{14} particles may be stored in the UNK.

At the first stage it is reasonable to construct the first iron ring and one of the superconducting rings. Thus it will become possible to have colliding ep beams with an energy 20 × 3000 GeV and start experiments with an ejected 3000-GeV proton beam on the external target.

A classical dipole with a multilayer winding is considered as a version for the superconducting magnet. The calculations and experience gained in manufacturing such magnets[5,6] make our hopes quite realistic for obtaining a good quality field both from the standpoint of acceleration and organization of proton extraction from the accelerator. A program on modeling of the superconducting magnetic system is currently underway.

An approximate operational mode of the two stages is shown in Fig. 1. In this mode 13 pulses with the proton energy of 70 GeV are to be injected into the first stage, where they are to be accelerated up to 200 GeV during 3 seconds, and then transported to the second stage during one revolution of the particles. At the second stage, protons are to be accelerated up to 3000 GeV during 15-20 sec. Fast and slow extraction is performed at the magnetic cycle flattop. The duration of the operational cycle is 78 sec.

The operation of the machine in the storage mode goes according to the following scheme. A proton beam circulating in the constant field of the U-70 is debunched by a smooth decrease of the accelerating-field amplitude. Then a special rf system that produces a sawtooth voltage with the amplitude up to 17 kV and frequency 200 kHz, equal to the revolution frequency, is switched on. Thus the length of the bunch may be reduced to 150 m. The extraction system of the UNK allows one to fill 64 bunches into the first stage with an interval of 300 m and consequently 3×10^{15} particles will be stored. The acceleration is carried out with a rf system at the frequency of about 1 mHz. When the particles are transported into the superconducting stage the acceleration goes on in the same way up to 3000 GeV in 30 minutes.

Electrons may be injected into the UNK iron ring from the electrosynchrotron injector with energy 2-3 GeV up to the intensity that would allow a luminosity of 10^{32}-10^{33} $cm^2 sec^{-1}$. Possibilities of obtaining an electron (positron) beam to be stored in the UNK conventional synchrotron are being studied. The scheme is as follows.[8,9] Protons accelerated up to 3000 GeV are ejected in small portions to the target-converter. The intensity of the protons is determined by the admissible heating of the target. Electrons (positrons) with energy 10-20 GeV are extracted from the converter into the iron ring and stored there up to the intensity of 3×10^{14}. Thus it is quite probable that a luminosity on the order of 10^{32} $cm^{-2} sec^{-1}$ will be obtainable in the colliding ep beams. The structure of the ring is such that it may operate with a polarized electron beam. We are also considering an application of electron cooling for creation of $p\bar{p}$ colliding beams with the luminosity required for physical experiment purposes.[7]

The optics of the straight sections 485 m long are designed so that the parameters will be obtained at the intersecting point that would provide maximum luminosity and intersection of the beams with small angular divergence.

Along with consideration of the technological systems for the UNK we treat problems concerning the construction of tunnels and experimental halls.

Figure 2 presents the location of the U-70 ring and the planned location of the UNK in the country. In the same figure we present the cross section of the tunnel and possible location of the equipment in it. Geological and geodetic characteristics of the UNK area are studied. The UNK trace goes through a broken country. Figure 3 presents one of the versions of the UNK location in a developed view. It is assumed that two out of six halls, with the straight sections, will be constructed above the earth surface. These two halls have the largest dimensions. The remaining ones will be constructed underground.

Table I lists the main parameters of the rings at the first stage. Table II lists the parameters of the second stage.

At present we have composed a program for scientific investigation and design work that foresees the development and modeling of all the principal systems and units for the UNK.[10] The program is to be fulfilled in two years.

Table I. Main Parameters of the Iron Ring for the UNK. (1-st Stage)

Magnetic field	16.67 kV
Proton energy	200 GeV
Electron energy	20 GeV
Orbit length	19,300 m
Average radius	3070 m
Number of superperiods	6
Total number of periods	180
Number of dipoles in the period	4
Number of quadrupoles in the period	2
Total number of dipoles	720
Total number of quadrupoles	360
Length of matching insertions	485 m
Length of standard period	91 m
Dipole length	3.49 m
Quadrupole length	1 m
Length of the total straight section	1 m
Length of a complete section	35.52 m
Radius of the orbit curvature	400 m
Gradient ratio to the field	0.115 cm
Betatron oscillations	40.75
Momentum compaction factor	8.9×10^{-4}
β_{max}	152 m
β_{min}	32 m
ψ_{max}	2.9 m
ψ_{min}	1.7 m

Table II. Main Parameters of the Superconducting Accelerator at Energy 3 TeV (2nd Stage).

Maximum field (NbTi)	4.5-5 T
Maximum energy	2.7-3 TeV
Orbit length	19,300 m
Average radius	3070 m
Number of superperiods	6
Total number of periods	180
Number of dipoles in the period	10
Number of quadrupoles in the period	2
Total number of dipoles	1800
Total number of quadrupoles	360
Length of matching insertions	485 m
Dipole length	7 m
Quadrupole length	3.95 m
Length of a small section	0.8 m
Length of a complete section	2.55 m
Radius of the orbit curvature	2003 m
Gradient ratio to field	$0.15\ cm^{-1}$
Betatron oscillations	40.75
Momentum compaction factor	5.5×10^{-4}
Critical energy	40 GeV
β - function max	150 m
β - function min	32 m
ψ - function max	2.5 m
ψ - function min	1.3 m

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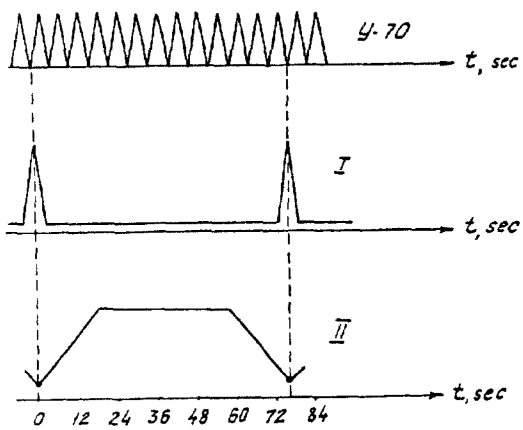

Fig. 1. Operational modes of the UNK.

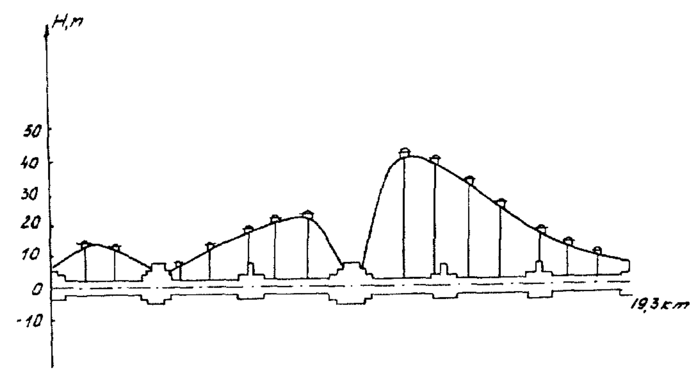

Fig. 3. Elevations of the UNK.

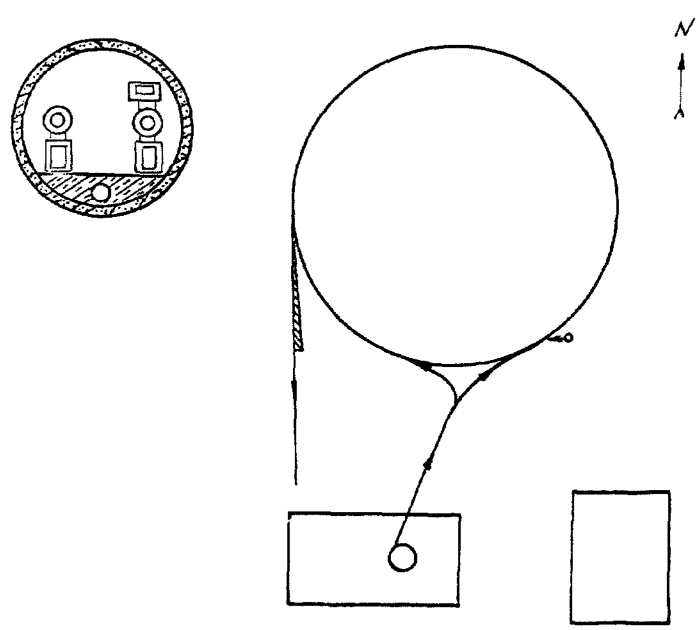

Fig. 2. Layout of the UNK.