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THE IHEP UNK PROJECT. STATUS AND DEVELOPMENT

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Abstract The project of the IHEP Accelerating and Storage Complex (UNK) has repeatedly been reported and discussed (see, for example[1-3]). It envisages a possibility to accelerate in the UNK protons up to 3 TeV and provide collisions of 6 TeV c.m.s. energy beams. Presently, the 1st phase of the machine, the fixed-target accelerator, is being built.

1. OPERATION IN THE ACCELERATION MODE

Figure 1 shows the cross sectional view of the UNK tunnel and the equipment placed in it. The presently existing 70 GeV proton synchrotron, whose intensity is planned to be upgraded up to $5 \cdot 10^{13}$ ppp, will inject protons into the UNK. The U-70 beam will be injected into the 1st phase of the UNK, the 600 GeV conventional machine (UNK-1), which will be the booster for the 2nd phase, superconducting accelerator UNK-2. The UNK circumference is 14 times as large as that of U-70, which will make it possible to stack in UNK an intensity of $6 \cdot 10^{14}$ during multiple (up to 12 times) injection. The beam accelerated in U-70 is prebunched in it at a UNK frequency of 200 MHz. On stacking within 72 sec the beam is accelerated in UNK-1 up to 400 GeV and transferred by single-turn injection into UNK-2 to be accelerated further up to 3 TeV. The UNK-2 cycle is as follows: 40-s field rise, 40-s flattop and 40-s drop.

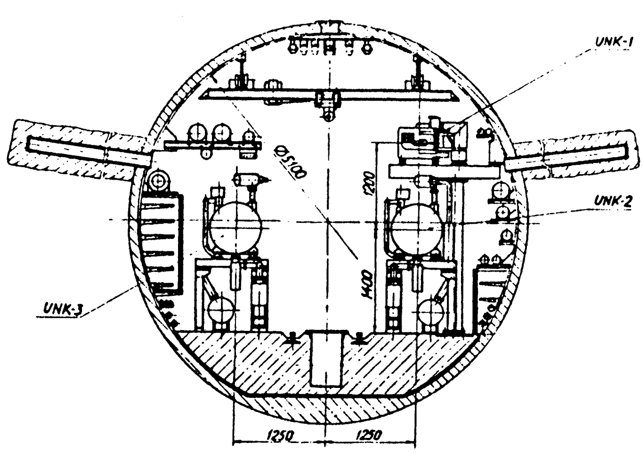

FIGURE 1 Cross section of the tunnel with the equipment placed there.

Three modes of beam extraction from UNK-2 are foreseen: 40-s slow resonance extraction, 2-3-ms fast resonance extraction of up to 10 pulses and fast single-turn extraction. Fast resonance extraction may take place simultaneously with slow one. The operating resonance of the slow extraction system is chosen to be $3Q_r$=110.

Resonance extraction leads to 1-2% of beam loss at the septum of the 1st extraction device, electrostatic deflector[4]. The secondaries produced in the septum matter irradiate the superconducting elements downstream in the straight section for extraction. To reduce the radiation-induced heating of the magnets placed close to the extraction systems special measures[5] enabling one to bring the radiation effect down to the tolerable level have been elaborated. With an uncertainty in the extraction efficiency taken into account, the temperature reserve in the critical current of the magnet coils placed in the radiation areas is chosen to be at least 0.5 K.

To protect the equipment during emergency situations fraught with a feasible beam loss the beam is aborted onto the external absorber.

2. COLLIDING BEAMS IN THE UNK

Figure 2 presents the UNK lattice. To arrange 6 TeV c.m.s. p-p collisions, two superconducting rings, UNK-2 and UNK-3, placed in the same horizontal plane and intersecting in Matched Straight Sections (MSS), 2, 3, 5, 6 will be used. MSS2 will house the experimental colliding beam facility, the Universal Calorimeter Detector (UCD), MSS3 will be used for the experimental internal jet target facility (NEPTUN experiment) and MSS5 will house another colliding beam facility, a track strimmer detector. The systems of "forward" injection, acceleration, beam loss localization and beam abort systems will be put in MSS1, while those for beam extraction from UNK-2 and transfer from UNK-1 into UNK-2 and UNK-3 will be placed in MSS4.

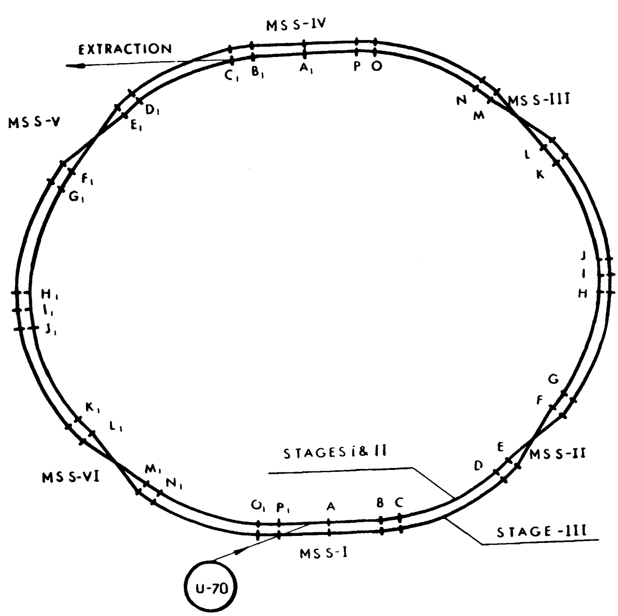

FIGURE 2 UNK lattice in the pp-mode.

In the p-p mode, the beam is stacked according to the same pattern as in the acceleration one. The U-70 beam is injected into UNK-1 12 times to fill its orbit in succession. After that the stacked beam is accelerated up to 400 GeV and transferred into UNK-2 to be retained there for some time. Then the stacking procedure is repeated but the beam is injected into UNK-1 in the "backward" direction with the help of the system of injection into MSS6 with the field polarity reversed. On acceleration in UNK-1 up to 400 GeV the beam is transferred into UNK-3. The final stage is the simultaneous acceleration of protons in UNK-2 and UNK-3 up to 3 TeV and making them collide. The parameters of pp colliding beams are presented in Table 1. As is seen from this Table, very stringent requirements are imposed on the U-70 beam intensity and emittance. At present, both transverse and longitudinal phase volume of the U-70 beam exceed the required value.

Table I The Parameters of Colliding Beams in the UNK

<table>
<tr><th>Parameter</th><th>p</th><th>p</th><th>pp</th></tr>
<tr><td>Intensity</td><td>$6 \cdot 10^{11}$</td><td>$1.5 \cdot 10^{13}$</td><td>$2.4 \cdot 10^{14}$</td></tr>
<tr><td>Number of bunches</td><td>66</td><td>66</td><td>8600</td></tr>
<tr><td>Number of particles per bunch</td><td>$9\ 10^{9}$</td><td>$2\ 10^{11}$</td><td>$2.8\ 10^{10}$</td></tr>
<tr><td>RMS transverse emittance, mm mrad</td><td>3</td><td>5</td><td>5</td></tr>
<tr><td>RMS longitudinal bunch emittance, MeV/s·m</td><td>30</td><td>30</td><td>10</td></tr>
<tr><td>RMS bunch length, cm</td><td>20</td><td>20</td><td>12</td></tr>
<tr><td>Bunch-to-bunch distance, m</td><td colspan="2">297</td><td>1.5</td></tr>
<tr><td>Stacking time, h</td><td>20</td><td>0.2</td><td>0.2</td></tr>
<tr><td>Beam-beam tune shift (per 1 intersection)</td><td>$5\ 10^{-3}$</td><td>$3\ 10^{-4}$</td><td>$1\ 10^{-3}$</td></tr>
<tr><td>β-function in intersection, m</td><td colspan="2">1</td><td>1</td></tr>
<tr><td>Free space for the detector, m</td><td colspan="2">±20</td><td>±20</td></tr>
<tr><td>Luminosity, $cm^{-2}s^{-1}$</td><td colspan="2">$1\ 10^{31}$</td><td>$4\ 10^{32}$</td></tr>
<tr><td>Number of events per collision</td><td colspan="2">1</td><td>0.3</td></tr>
<tr><td>RMS beam diameter, mm</td><td>0.06</td><td>0.08</td><td>0.08</td></tr>
</table>

This necessitates the following major upgrading of U-70:

- replacement of the corrugated vacuum chamber for a smooth one with a view to bring the value of the longitudinal coupling impedance down to 10 Ohm;
- replacement of the ring electromagnet power supply system;
- upgrading the field correction system;
- development of the charge exchange injection system;
- decrease of the injection and extraction mismatches by about an order of magnitude.

With all these measures accomplished, the luminosity attainable may be as high as $4 \cdot 10^{32}\ cm^{-2}s^{-1}$.

The colliding beam mode imposes heavier demands on the UNK as compared with the fixed-target operation, which entails rather stringent requirements on the vacuum chamber impedance, the noise level of the accelerating systems and beam injection and transfer mismatches.

To have a fairly small beam spot at the collision point the complicated schemes of the straight sections have been developed. Figure 3 shows the beam shaping scheme for collisions in MSS2. The beam intersection angle is 1 mrad. The section is transparent for the circulating beam, has a unity transfer matrix and zero dispersion at the intersection point.

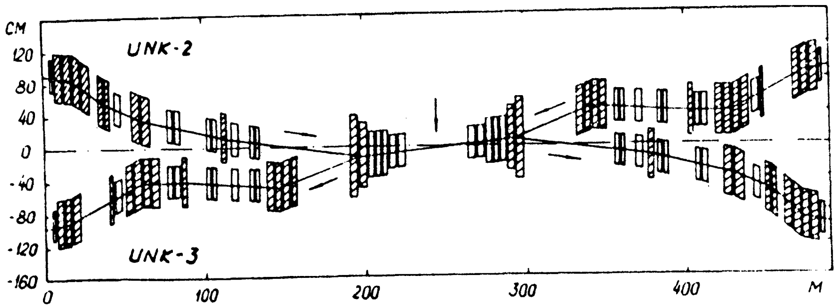

FIGURE 3 Optic system of a section for pp colliding beams.

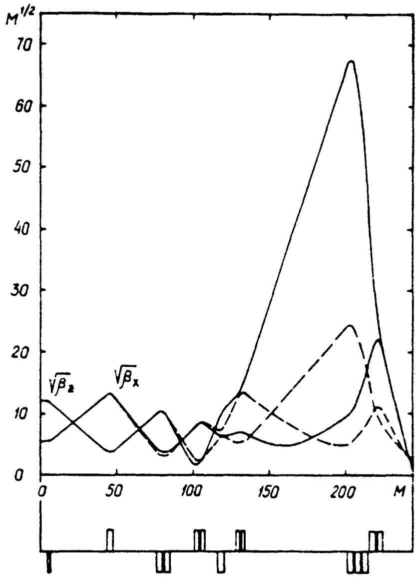

FIGURE 4 β-functions in the pp collision section.

Figure 4 shows the cyclewise variation of the -functions in MSS2. The dashed lines denote particle acceleration and stacking. As is seen, the maximum values of the amplitude functions in the section actually do not exceed those in the regular part of the lattice. This makes it possible to construct the MSS beam line having the acceptance equal to that in the regular part, while keeping the dimensions of the magnet element apretures reasonable. After acceleration of the beams up to the maximum energy their emittances are reduced by a factor of 7.5 which allows one to increase by the same factor the values of -functions. Retuning will be carried out by varying the currents of a few quadrupole lenses of the straight section. The solid lines of fig.4 show the -functions for the colliding mode. For the phases, $\beta_x^*=\beta_z^*=1$ m in the section centre. The optics of UNK-2 and UNK-3 contain some common elements in the straight section. The lifetime of pp-beams should be at least 1 hour.

This year IHEP has considered a possibility to use the CERN $\bar{p}$ source (the AAC) together with the UNK complex to make $p\bar{p}$ collisions in the UNK. Figure 5 shows this possible scheme. The beam accelerated in U-70 is extracted onto the external target. The 3.5 GeV $\bar{p}$ beam produced there is transferred into the AAC.

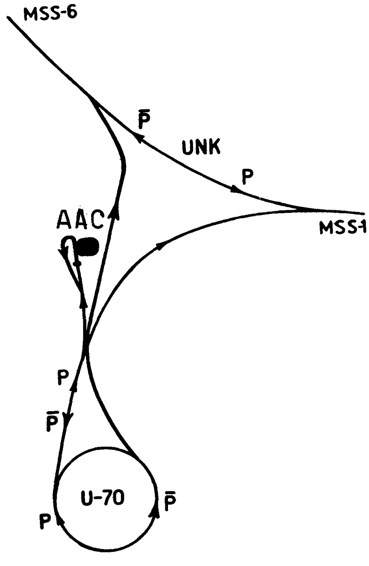

FIGURE 5 Layout of $p\bar{p}$ complex.

Changeover to the harmonic number of 24 is planned to be made in U-70 in order to match its bunch-to-bunch distance with the wave length of the AAC accelerating field. After conversion, the $\bar{p}$ bunches fill 3 buckets out of 6 of the AAC. The U-70 intensity should be at least $2.6 \cdot 10^{13}$ ppp. The field flattop is produced at 50 GeV within which 3 neighbouring bunches are extracted 8 times, each at an interval of 2.4 s, and then the field is reduced to the injection level. In this case, the complete cycle of U-70 is 22 s. With a conversion ratio of $2\ 10^{-5}$ and stacking efficiency of 50% (which seems reasonable), the number of $\bar{p}$ stacked at each extraction is $3.3 \cdot 10^{7}$ and a stacking rate is $4.3\ 10^{10}$ $\bar{p}$/h. Thus, the time of stacking $\bar{p}$ in the AAC is about 18 hours.

The optimum number of bunches of each type in the UNK is 66. In this case, a pair of bunches colliding close to the centres of the MSS's produces 1 event. To facilitate the operation of injection and beam abort systems a 1.5-km section of the beam is left unfilled with particles. Particles are stacked in the UNK in the following way. A $2 \cdot 10^{11}$ proton beam is accelerated in U-70 up to 65 GeV to be transferred into UNK-1. This operation is repeated 66 times, whereupon the beam is accelerated in UNK-1 up to 400 GeV and transferred into UNK-2 within a single turn.

A part of the $\bar{p}$ beam core stacked in the AAC and containing $9 \cdot 10^{-9}$ $\bar{p}$ is formed into a bunch accelerated in U-70 and UNK-1 up to 400 GeV and transferred into UNK-2. This operation is also repeated 66 times. As a result, the $\bar{p}$ beam having the same structure as the p one is produced in UNK-2. After acceleration of the two beams up to 3 TeV the accelerating fields are phase shifted, which provides the collision of bunches at the relevant points of the MSS's. The colliding beam lifetime should be about 24 hours.

Table 1 presents the parameters of $p\bar{p}$ colliding beams. Comparing them with those of pp colliding beams one can see that the maximum luminosity attainable in pp collisions is appreciably higher than that attainable in $p\bar{p}$ ones. The time for stacking an $\bar{p}$ beam is considerably longer. This requires a larger lifetime of collisions which, in its turn, requires a higher reliability of the whole acceleration complex, separation of the p and $\bar{p}$ beams with electrostatic separators, reduction of the level of the RF acceleration system noise, etc. On the other hand, for the pp mode to be realized, an additional superconducting ring will be needed, which might interfere into the collider time schedule.

3. THE DEVELOPMENT OF SUPERCONDUCTING MAGNETS

The superconducting machine will contain 2176 dipoles and 474 quadrupoles. The operating field of SC magnets is chosen to be 5 T. To attain a high efficiency of resonance extraction, the region of a good bore field should be at least ± 3 cm. The basic parameters of SC magnets have been chosen proceeding from these requirements.

The cold-iron design has been chosen for serial production of magnets. A few 1-m models of this type used to try out the production technology were manufactured. After that two full-scale prototypes were manufactured and tested. The maximum field, 6.5 T, is attained actually without training, which is well above the operating one.

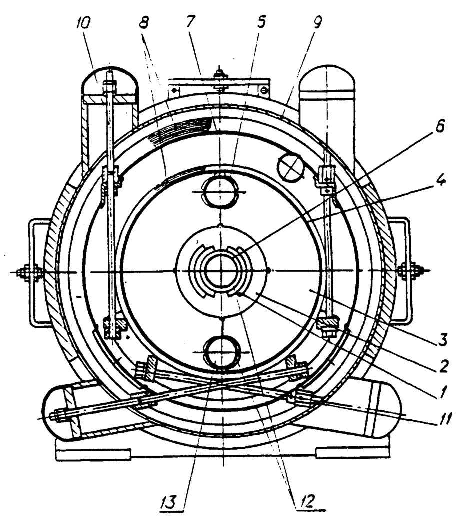

FIGURE 6 Cross section of a cold-iron SC dipole: 1 - coil, 2 - stainless steel collars, 3- yoke, 4- helium vessel, 5 - single-phase helium pipe, 6 - ion pipe, 7- nitrogen shield 8- superinsulation, 9 - vacuum vessel, 10 - suspensions, 11 - extension rods, 12 - single phase helium channels, 13 - two-phase helium channel.

Figure 6 shows the cross sectional view of a SC-dipole magnet. Its basic unit is a two-layer shell-type coil collared with the help of stainless steel collars. The coil assembly and iron yoke are placed into the helium vessel cooled by single-phase helium flow a part of which goes through the coil and another one branches into a bypass channel to exchange heat with a two-phase helium flow going through the inner pipe. The helium vessel is fixed to the warm vacuum vessel with the help of titanium-alloy vertical suspensions and horizontal extension rods. Longitudinal motions are hampered by the anchor extension rods fixing the central cross section and allowing a free motion of dipole end parts in thermal cycles.

The 1st layer of the coil consists of 34 turns and the 2nd one contains 21 turns. The zebra-type cable consists of 19 strands, each 0.85 mm in diameter, 9 of which are coated with a Sn+5% Ag solder. A strand contains 8910 filaments, each 6 μm in diameter. The critical current density in the 5 T field at 4.2 K is $2.3 \cdot 10^5$ A/cm^2.

Figure 7 presents the results on measuring the basic harmonics of field nonlinearities across the 3.5 cm radius. They are in a good agreement with the calculations and fulfil the requirements imposed on the field quality.

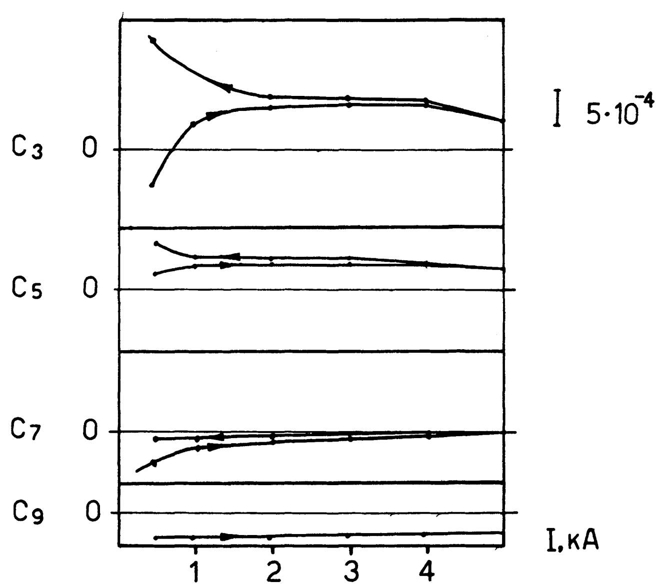

FIGURE 7 Nonlinearities versus bore field.

The heat load on the cryogenic helium system calculated from the results on measuring static heat leaks and ac loss in the dipole coil in the accelerator and collider cycles is 35 kW. This value is about the same for either mode.

The superconducting quadrupole is at the stage of operational development.

4. STATUS OF THE CONSTRUCTION OF THE UNK

Figure 8 shows the undeground structures and status of boring the tunnel. By the 1st of July 16.6 km had been bored. The construction of the southern part of the ring tunnel and of the injection line are being completed. Here work is being done on the preparation for assembling the equipment, the construction of the surface technological buildings for the equipment of the power supply, cryogenic and monitoring systems is being completed.

THE UNDERGROUND CONSTRUCTIONS OF UNK AND THEIR STATUS.
THE BORED SECTIONS OF THE UNK TUNNEL ARE SHOWN IN DARK.

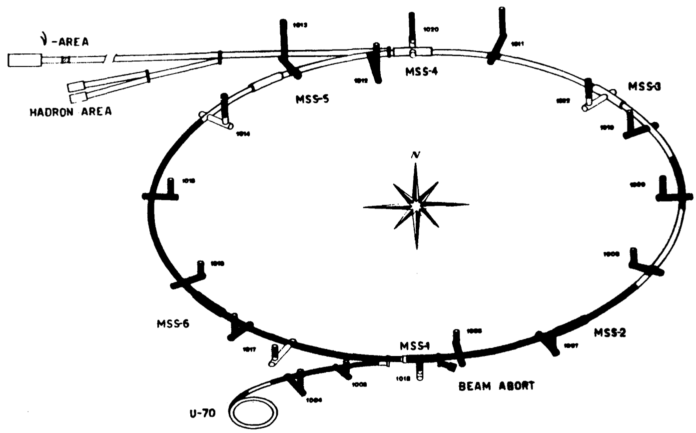

FIGURE 8 Undeground structures of the UNK and status of boring the tunnel.

The mass production of the equipment for UNK-1 is going on. The whole electromagnet and vacuum equipment for the 2.7 km injection line between U-70 and the UNK is actually ready.

Magnets of the warm ring are being supplied (there are about 300 magnets supplied), about 10000 m of the vacuum chamber are also ready. The equipment for the acceleration and ring magnet power supply systems is developed and its production has started. The tests will be done and the equipment prepared in a special 10000 m^2 building, where test facilities are now being constructed. The electromagnetic equipment will start to be assembled this year.

The superconducting dipole has actually been developed and tried out. The production lines for the serial manufacturing of SC magnets are now being prepared. An experimental string consisting of 100 magnets and serviced by the standard cryogenics will be assembled in the tunnel in 1990-1991. The whole cryogenic equipment is developed and produced at the scientific and industrial corporation "Cryogenmash".

5. CONCLUSIONS

The scope of the construction work on the UNK has been expanded. Orders for the production of all standard equipment have been placed with industry. Some nonstandard equipment is manufactured at the IHEP workshop. Orders for the equipment of UNK-2 are being placed with the industry. Next year a batch of 100 standard SC magnets will be produced. The course of the work confirmes the feasibility of finishing the construction of the machine in 1993 and putting into operation the 1st phase and its experimental facilities in 1994.

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