THE STATUS AND DEVELOPMENT OF THE UNK

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Introduction

The project of the IHEP Accelerating and Storage Complex (UNK) [1-5] envisages the possibility of accelerating protons up to 3 TeV with the beam extracted onto the fixed target and of the collision mode at 6 TeV in the c.m.s. The 1st phase of the UNK incorporating the 3 TeV machine with system extracting the beam onto the fixed target is presently under construction.

The UNK is placed in the Ø 5.1 m ring tunnel having a circumference of 20.77 km. Figure 1 shows the ring cross section with the equipment layout. The presently existing 70 GeV proton synchrotron, whose intensity is to be raised up to $5 \cdot 10^{13}$ ppp, will be the injector into the UNK. The 1st phase of the UNK, UNK-1, i.e., the 400 GeV conventional machine, is the booster for the 2nd superconducting phase, UNK-2. Another ring of the same superconducting magnets, UNK-3, is intended for arranging proton-proton collisions. The orbits of the 1st and 2nd phases actually coincide whereas those of UNK-2,3 interchange going from the inner tunnel wall to the outer one and vice versa to intersect in 4 points in the centres of Matched Straight Sections (MSS) 2, 3, 5, 6, where the detectors for colliding beams are to be placed. In addition to these 4 MSS's (2, 3, 5, 6), each 490 m long, for experimental setups, the project also envisages another two 800 m long technological sections, MSS1,4. MSS1 will house the injection, loss localization and beam abort systems as well as the accelerating stations for all the phases. MSS4 is intended for the systems of extraction and beam transfer from UNK-1 into UNK-2 and UNK-3.A part of MSS6 is to be occupied by the system of reverse beam injection from U-70 into UNK-1 in the 3x3 TeV pp colliding beam mode. Figure 2 shows the layout of the UNK components and the status with tunnelling.

Operation in the Acceleration Mode

On rebunching at a frequency of the accelerating field of the UNK, 200 MHz, the U-70 beam is injected into UNK-1. Here an intensity of $6 \cdot 10^{14}$ is stacked within 72 s as a result of multiple injection, up to 12 times. After 20-s acceleration in UNK-1 up to 400 GeV the beam is transferred into UNK-2 by single-turn injection to be accelerated further up to 3 TeV. The cycle of the superconducting phase, UNK-2, is as follows: 40-s field up, 40-s flattop and 40-s down. This cycle ensures a mean intensity of $5 \cdot 10^{12}$ p/s. Three extraction modes from UNK-2 are foreseen: 40-s slow extraction, fast resonant extraction of 10 pulses, each lasting 2-4 ms, at an interval of 3 s and fast single-turn one for neutrino experiments. Fast resonant extraction can be carried out simultaneously with slow one. The third-order resonance at sextupole nonlinearity has been chosen as the operating one of the slow extraction system. The extraction efficiency planned is 98%.

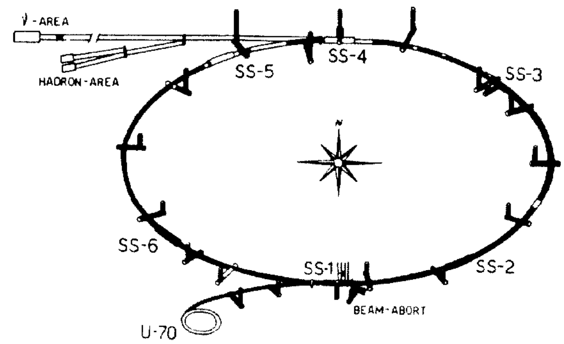


Fig. 2. UNK underground structures and status of tunnelling.

The basic parameters of the fixed-target mode are presented in Table 1.

In addition to beam extraction into the external targets of the experimental area the 1st phase of the UNK envisages the experiment at the internal jet hydrogen target in MSS3 in the circulating beam of both UNK-1 and UNK-2.

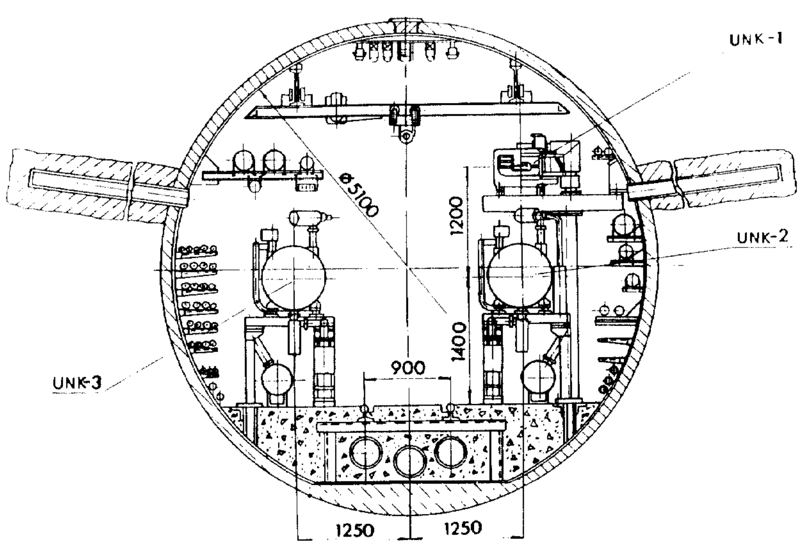


Fig.1. Equipment layout in the cross section of the UNK tunnel.

Table 1. The Basic Parameters of the Fixed-Target UNK

Parameter	UNK-1	UNK-2
Maximum energy, GeV	400	3000
Injection energy, GeV	65	400
Orbit length, m	20771.9	20771.9
Maximum field, T	0.67	5
Maximum injection field, T	0.108	0.67
Total cycle duration, s	120	120
Acceleration time, s	20	40
Harmonic number of accelerating field	13860	13860
Total amplitude of accelerating voltage, MV	7	12
Maximum energy gain per turn, MeV	2.1	4.5
Transition energy, GeV	42	42
Betatron frequency (without special section of lattice taken into account)	36.7	36.7
Total intensity	$6\cdot10^{14}$	$6\cdot10^{14}$
Mean intensity, s^{-1}	$5\cdot10^{12}$	$5\cdot10^{12}$
Invariant transverse beam emittance, mm·mrad, not more than	150	200
Invariant longitudinal bunch emittance, MeV·m/s, not more than	100	120

Colliding Beams in the UNK

Further upgrading the UNK is related to operation in the collider mode. Three different schemes of colliding beams in the UNK have been studied: 0.4x3 TeV pp beams from UNK-1 and UNK-2 [2], 3x3 TeV p$\bar{p}$ beams in the ring of UNK-2 [4-6] and 3x3 TeV pp beams from the superconducting rings of UNK-2 and UNK-3 [3-5].

In the pp collider mode, particles are stacked following actually the same scheme as is the acceleration mode. One of the requirements imposed on the colliding beams is that the bunch-to-bunch distance should be at least 9 m (30 ns). This can be accomplished by having in the U-70 another 33 MHz recapture system (the harmonic number is 165). The frequency of the accelerating field in the UNK still remains equal 200 MHz. Therefore when this beam is transferred into UNK-1, every sixth bucket will be filled. After UNK-2 is filled, the beam is retained there at the injection field. In UNK-1, the field polarity is reversed and other operations required for particle acceleration in the opposite direction are carried out. After that the ring magnet is trained. According to the data available, 10-20 cycles are sufficient for this purpose. Then the stacking operation is repeated but the beam is injected into UNK-1 in the opposite direction with the help of the injection system into MSS6. On acceleration up to 400 GeV the beam is transferred into UNK-3. Then the beams are accelerated simultaneously in UNK-2 and UNK-3 up to 3 TeV to be collided.

These operations will take 15-20 minutes. The duration of the colliding mode should exceed that of the preparation for it by at least an order of magnitude, i.e., it should last 2 hours at least. This determines the minimal requirements imposed on the beam lifetime. If the real lifetime proves to be longer, the colliding mode can definitely be prolonged.

Table 2 presents the basic characteristics of the UNK pp collider. The chosen acceleration time is such that running UNK-3 would not require an increase of the total power of the cryogenic system.

To provide for the required beam parameters for the experiments to be carried out in MSS2, 3, 5, magnetic optics of these sections have been developed [7]. Low β-function optics, that will ensure $\beta^*=1$ at the interaction point, will be used in MSS2. The range of current variation in the lenses will allow one, if required, to decrease β^* down to 0.5. To avoid large values of β-functions in the section during injection and acceleration, the MSS2 optics is retuned in the magnet cycle by varying the gradients of the section lenses. As to MSS3 and MSS5, the mean β-function optics will be used there. All the aforementioned sections have the unity transfer matrix and zero dispersion at the interaction point.

Table 2. The Characteristics of the UNK pp Collider.

Parameter	Value	
Maximum energy, TeV	3	
Injection energy, TeV	0.4	
Luminosity lifetime, h	>2	
Total time of beam stacking and acceleration, min	<20	
Beam acceleration time, s	300	
Accelerating voltage amplitude, MV	7	
Harmonic number of accelerating field	13860	
Number of bunches	1980	
Number of particles per bunch	$6\cdot10^{10}$	
Total number of particles per ring	$1.2\cdot10^{14}$	
Minimal bunch-to-bunch distance, m	9	
RMS invariant transverse beam emittance, mm·mrad	6.5	
RMS invariant longitudinal bunch emittance, MeV·m/s	8.5	
Bunch length, cm	15	
Beam-beam tune shift	$1\cdot10^{-3}$	
	MSS2	MSS5
Luminosity, cm^{-2}, s^{-1}	$4\cdot10^{32}$	$5\cdot10^{30}$
Amplitude function at the interaction point, m	1	80
RMS beam diameter, mm	0.09	0.8
Mean number of events per collision	1	0.013
Free space for the detector, m	±20	±54

The requirements imposed on the colliding mode are more stringent than those imposed on the fixed-target one. Therefore the UNK project imposes rather heavy demands on the value of the chamber coupling impedance, the level of noise in the accelerating system, injection and beam transfer mismatches.

The UNK parameters will depend essentially on the characteristics of the U-70 beam. The fixed-target operation parameters are chosen proceeding from the design characteristics of the U-70 and booster. Presently, these characteristics are somewhat worse than required. Yet, the colliding mode requires a noticeable decrease of the bunch phase volume. To attain the parameters required, the following upgrading of the U-70 is planned:

- replacement of the corrugated vacuum chamber by a smooth one with a view to bring the longitudinal coupling impedance at least down to 10 Ohm;
- upgrading the power supply system for the ring electromagnet;
- upgrading the field correction system;
- development of the H^- injection system;
- an order of magnitude decrease of the injection and beam transfer mismatches.

Development of Superconducting Magnets

The superconducting accelerator ring of either phase, 2nd and 3d, contains 2194 dipoles and 477 quadrupoles. The maximum orbit field is 5 T. To have a high-efficiency resonant extraction, the region of the good quality field in the bore should be at least

±3 cm. The basic characteristics of superconducting magnets have been chosen proceeding from these requirements.

For the serial production, the cold-iron design has been chosen. Figure 3 shows the cross-sectional view of the magnet in the force-circulating cryostat and the details of the magnet design can be found in ref. [8]. The basic element of the magnet is a shell-type two-layer coil collared with stainless steel collars. The coil assembly and iron yoke are placed inside the helium vessel. The magnet is cooled with a single-phase helium flow a part of which passes through the coil and another one goes into the bypass channel to exchange heat with a two-phase helium counterflow going through the inner pipe. The helium vessel is fixed to the warm vacuum vessel with titanium-alloy vertical suspensions and horizontal extension rods.

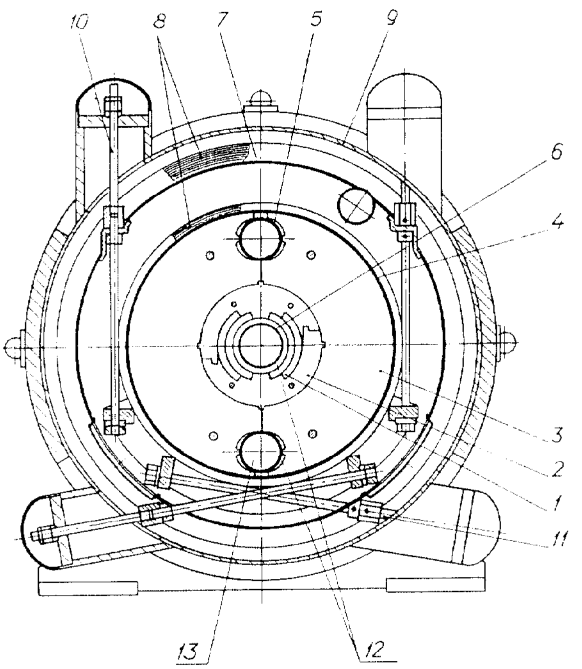


Fig. 3. Cross-sectional view of a superconducting dipole: 1 - coil, 2 - stainless steel collars; 3 - iron yoke, 4 - helium vessel, 5 - two-phase helium pipe, 6 - beam pipe, 7 - nitrogen shield, 8 - superinsulation, 9 - vacuum vessel, 10 - suspensions, 11 - extension rods, 12 - single-phase helium channels, 13 - two-phase helium channel.

The inner shell of the coil contains 68 cable turns and the outer one 42. The superconducting zebra-type cable has 19 Ø 0.85 mm strands, each containing Ø 6 μm 8910 (Nb+50% Ti) filaments, embedded into a copper matrix. The critical current density at 5 T and 4.2 K is $2.3 \cdot 10^5$ A/cm^2.

Fifteen short, 1 m long, and 7 full-scale, 6 m long, superconducting dipoles have been manufactured. These were designed to try out the technology, to study training processes, ramp rate characteristics, heat load in the operational cycle and static heat leaks. Figure 4 shows the training curves for 3 full-scale magnets. The field exceeding the operating one, 5 T, is attained in the 1st quench. The maximum bore field attained at 4.3 K was 6.6 T. The field reserve available allows one to ensure the reliable operation of the dipoles at 4.4-4.6 K under ac and radiation heat releases.

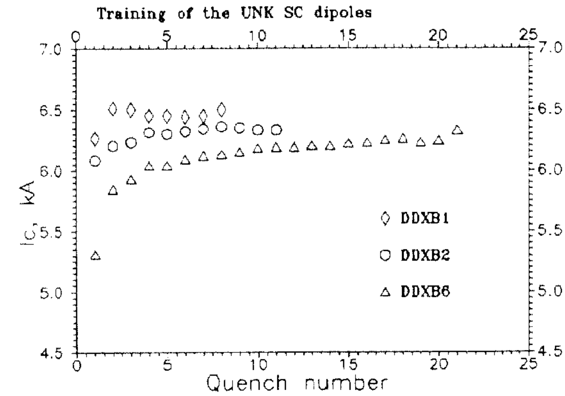


Fig. 4. Training curves for dipoles.

Figure 5 shows the ramp rate characteristics of 6-m dipoles. At a ramp rate of ~100 A/s no noticeable decrease of the operating current is observed. At a ramp rate of 500 A/s corresponding to the maximum rate during the emergency stored energy removal, the value of I_c is reduced by no more than 3%. Hence, the ramp rate characteristics are satisfactory for both operating and emergency modes.

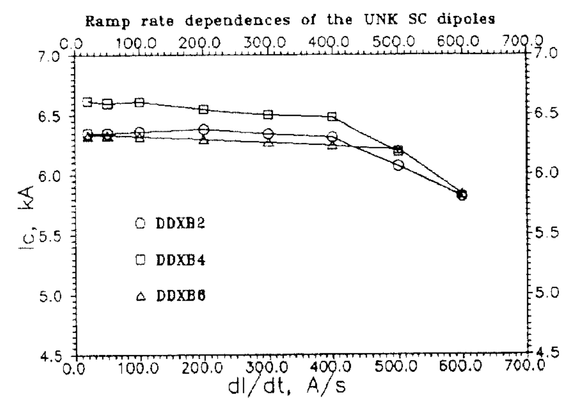


Fig. 5. Ramp rate characteristics of dipoles.

Figure 6 shows the ac loss in the dipoles versus current variation in the cycle with the bore field varying from 0.67 to 5 T. The UNK cycle corresponds to the 100 A/s current rate variation (shown by arrow). The ac loss in the cycle varies from 650 to 800 J/magnet, which corresponds to ~1 W/m heat load on the cryogenic system. The static heat load on the helium vessel is, as measured, 5 W/magnet and that on the nitrogen shield is 40 W/magnet. These values are planned to be decreased by 20-30% by improving the technique of applying the superinsulation. With account of the above values of ac loss and static heat loads, that are the major source of heat releases, the total heat load on the cryogenic system will be ~35 kw. In the colliding mode, the mean heat load on the helium vessel will be about twice as low due to an essential decrease of the ac heat load. Hence, the power of the cryogenic system chosen, 60 kw, will ensure the reliable operation of one superconducting ring in the acceleration mode or two superconducting rings in the colliding mode.

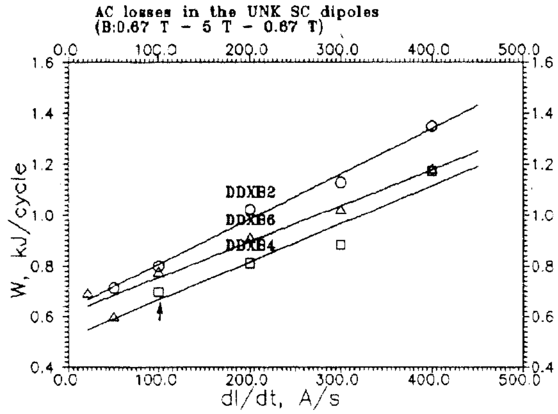


Fig. 6. AC loss in dipoles versus ramp rate.

Figure 7 shows the measured dipole transfer function versus current. The results are in a good agreement with the calculation. As seen from the figure, the reduction of the transfer function for the maximum operating field is $\sim 1\%$. Figures 8a,b present the measured current-dependent values of the integral bore field nonlinearities of a dipole on the 3.5 cm radius. The nonzero values of C_3, C_5, C_7 and C_9 are explained by the effect of the collar magnetization and the deviations of the coil geometry from the design one. These deviations will be decreased noticeably by using stainless steel collars possessing a lower magnetic permeability and by a further correction of the coil geometry proceeding from the results on the magnet measurements of a series of dipoles. The variation of the values of C_5, C_7 and C_9 in the cycle does not exceed $\pm 1.5\cdot 10^{-4}$ and is within the tolerances (see fig.8a). The sextupole nonlinearity varies in the operating current range by $1\cdot 10^{-3}$ (see fig.8b) and is explained by the effect of the superconductor magnetization at low fields. The analysis of the results on the magnet measurements shows that in the operating cycle of the UNK the values of the gradient, sextupole and octupole nonlinearities can be suppressed by the field correction system envisaged.

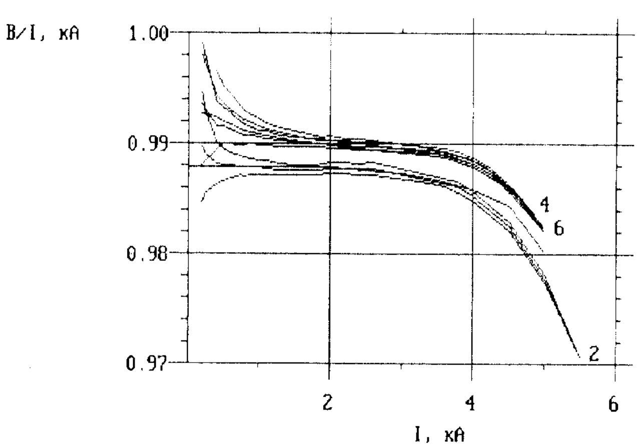
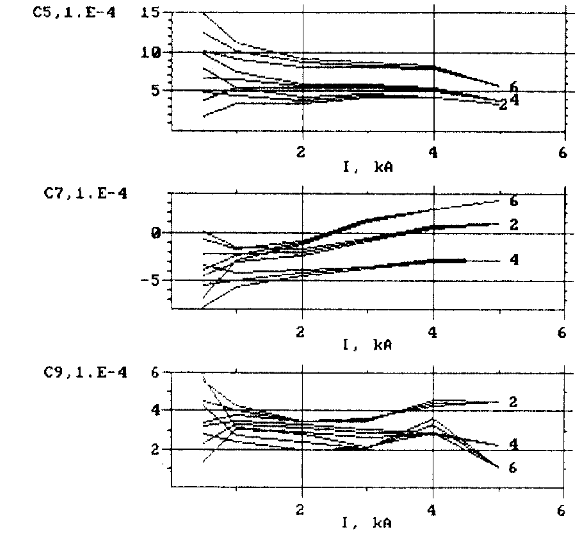
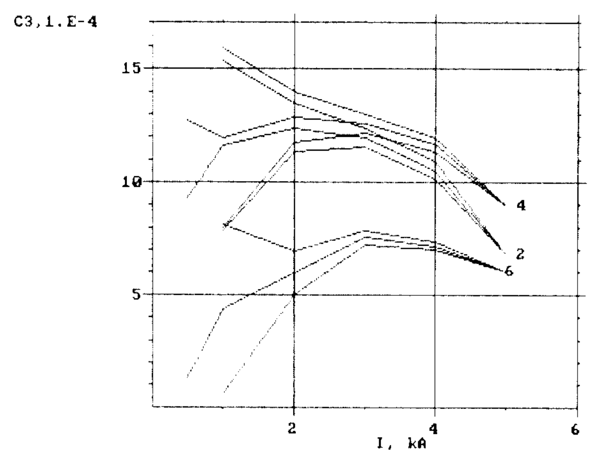


Fig.7. Transfer function of a dipole versus current.



a)



b)

Fig. 8. Bore field nonlinearities on the 3.5 cm radius versus current.

This year IHEP has started the pre-serial production of 100 superconducting dipoles.

Status of the UNK Construction

Figure 2 shows the status of tunnelling. By 01.05.90, 19.6 km had been bored. The construction of the southern part of the ring tunnel and injection beam line is over, the work on the preparation for equipment assembling is underway. The construction of surface technological buildings designed to house the power supply, cryogenic and control systems is going on.

The equipment for UNK-1 is presently in serial production. All the electromagnetic and vacuum equipment for the 2.7 km long injection beam line has been manufactured. About 11000 m of the vacuum chamber have been supplied, the equipment for the accelerating system and the power supply system for the ring electromagnet is being manufactured (see Table 3).

Table 3. UNK-1 Equipment

Equipment	Q-ty	Ready	1990	1991	1992
Dipoles	2274	20%	22%	30%	28%
Quads	581	35%	40%	25%	-
Correctors	1260	30%	50%	20%	-
Power supplies for ring electromagnet	24	8%	25%	50%	17%
Power supplies for correctors	1260	-	-	50%	50%
Vacuum equipment	21 km	25%	20%	30%	25%
RF transmitters	8	-	70%	30%	-
Accelerating stations	16	-	25%	75%	-
Beam position monitors	470	-	80%	20%	-

There is a special 10000 m^2 building where the equipment is tested and prepared for assembling. The assembling of the electromagnetic equipment in the injection beam line is to start this October. The rate of the work being done confirms the feasibility of having the construction of the UNK-2 complete in 1994 and of starting running it in together with the experimental facilities in 1995.

References

[1] V.I.Balbekov et al. - Proceed. of 12th Intern. Conf. on High Energy Accel. - Batavia, 1983, p. 40.

[2] A.I.Ageev et al. - Proceed. of XIII Intern. Conf. on High Energy Particle Accelerators - Novosibirsk, 1987, v. 2, p. 332.

[3] A.I.Ageev et al. - Proceed. of European Part. Accel Conf. - Rome, 1988, v. 1, p. 233.

[4] K.P.Myznikov. Proceed. of Workshop "Physics at UNK", Protvino, 1989, p. 5-15.

[5] V.A.Yarba. - Proceed. of 14th Internat. Conf. on High Energy Accel. - Tsukuba, 1989.

[6] T.A.Vsevolozhzkaya et al.-Proceed. of VII All-Union Conf. on Charged Part. Accel. Dubna, 1981, v. 1, p. 229.

[7] V.I.Balbekov, Yu.M.Nosochkov.-Proceed. of XI All-Union Conf. on Charged Part. Accel., Dubna, 1988, v. 1, p. 397.

[8] A.I.Ageev et al. Preprint IHEP 89-17, Serpukhov, 1989.