THE HERA-PROJECT

presented by

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Abstract

Authorization of the 820 GeV-30 GeV proton-electron (positron) colliding beam complex HERA was given in April, 84. The present schedule calls for a completion of the project and the start-up of the physics program by mid-1990. The electron ring of HERA is close to completion and first storage trials are to start within a few months. Existing rf-hardware should make storage of 26 GeV electrons (positrons) possible. The ultimate energy of 30 GeV or higher will be reached with superconduct- rf-cavities. The development of superconducting magnets for the proton ring has been concluded successfully and industrial production has started. Test of pre-series magnets indicate that HERA magnets will operate with a comfortable safety margin even at 1 TeV. The low injection energy of 40 GeV into HERA will make a programmed compensation and correction of magnetic multipole-fields necessary. The 20 KW He-refrigerator for HERA is operational, the He-distribution system is being installed. The new 50 MeV H- injection linac is close to completion, the new 7 GeV proton accelerator DESY III is ready. The modified former e+-e–storage ring PETRA should begin proton acceleration up to 40 GeV - the injection energy into HERA - within the coming year.

Introduction

Construction of the electron (positron)/proton colliding beam complex HERA was authorized on April 6, 84 and is scheduled to be completed at the end of 1989. The facility will be the first of its kind and involves construction of a number of new storage rings and accelerators and modification of others: A 6.3 km long circular tunnel houses an 820 GeV proton storage ring on top of a 30 GeV electron (positron) storage ring. Beams of both rings can be made to collide at 4 interactions points (at the start only 3 will be available for actual beam collisions) resulting in a centre of mass energy of 314 GeV. The modified electron-positron storage ring PETRA will serve as a 14 GeV injector of electrons or - after polarity switching - of positrons and as a 40 GeV injector of protons into the two HERA rings. The new proton synchrotron DESY III will accelerate 50 MeV protons from the new proton linear accelerator Linac III to an energy of 7GeV, the injection energy of the intermediate proton accelerator PETRA II.

Construction of the HERA complex involves several "firsts": It is the first time that a large accelerator complex at a national laboratory will be built by an international collaboration, involving large contributions of equipment and manpower[1] It is also the first time, that a large superconductiong magnet system will be built entirely by industry.

The HERA complex has been described in a number of papers to which the reader may be referred[1,2,3,4]. The main parameters are shown again in Tab. I.

	electron/ positron ring		proton ring
Energy	30		820 GeV
Circumference		6336	— m
Length of each (of 4) straight sections		360	— m
Number of IP's		3(4)	
Magn. bending field	0.185		4.53 T
Injection energy	14		40 GeV
rf-frequency	500		52/208 MHz
Max. circumfer. voltage	165		0.3/2.4 MV
No. of bunches	210		210
Aver. beam current	58		130 mA
Beam size at IP (sigma x/z)	.29/.077		.293/.066 mm
crossing angle		zero	
Luminosity per IP		1.5 E31	1/cm·cm·sec
Freespace for experiment		11	m

Table 1: Main parameters of the HERA storage rings

Status of the HERA complex

1. Civil Engineering

Certainly another "first" in the history of accelerators is the construction of a large accelerator complex deep underground in the middle of a city, under many private properties and public parks.

Tunneling started in April 1985 and was finished by August 1987. The four experimental halls including control rooms and service halls are all underground. Three of the four halls are on public land. Here, only small entrance buildings are allowed above ground, but the construction of the halls could be done in open pits. The fourth hall is on the DESY site and includes a large service building above ground. Except for some small outside finishing work all construction work has been completed. The last tunnel section and the last experimental hall were turned over to DESY in February of this year. Besides the main tunnel and the underground structures at the 4 straight sections, civil engineering also included two beam transfer tunnels from PETRA with a total length of 400m and two large buildings on the DESY site for the helium refrigerator plant and for measuring and testing of the superconducting magnets of the proton ring.

2. The electron (positron) ring

A novel feature of the HERA electron ring is its **module concept:** A half cell of the electron machine consists of a 9m long bending magnet, a quadrupole magnet, a sextupole magnet and a steering magnet. All of these magnets are assembled and prealigned with respect to each other in a 12 m long module. All 400 required modules have been prepared outside of the HERA tunnel, including the assembly of vacuum chambers with beam monitors, water cooling circuits and interlock wiring (Fig.1). Such completed modules were then taken into the tunnel, driven to their predetermined position by special tunnel vehicles and installed there. At one end, each module has an adjustable support at the location of the quadrupole magnet, the component which is most critical in its alignment with respect to the rest of the ring. The other end of the module rests on the neighbouring module. This module concept has two obvious advantages: Installation work in the tunnel is minimized, allowing one crew to install 60 meters of machine components in a single day, and surveying of machine components is also very much simplified. The only work in the tunnel which is necessary is

[1]At present contributions are being made by Canada, France, Israel, Italy, Netherlands, People's Republic of China, Poland, United Kingdom, United States.

the positioning of the quadrupole end of the module, adjusting its tilt and controlling the tilt at the other module end. At the time of the conference 370 of the 400 modules will have been installed. Completion of the magnet installation including that in the straight sections will take place in the second half of June 1988.

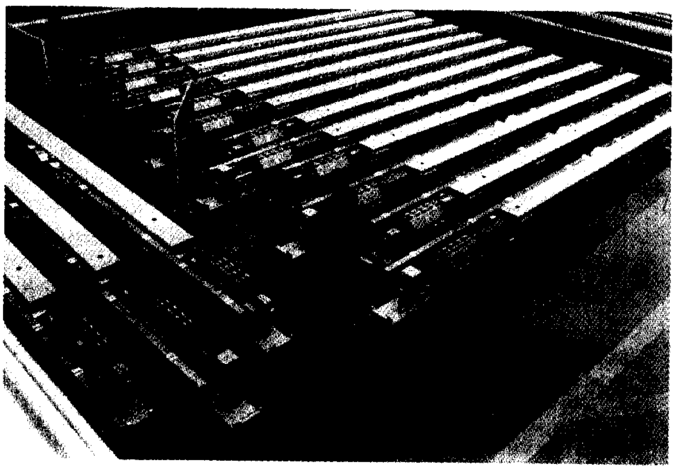

Figure 1: Magnet modules of the electron ring

The vacuum chambers of the electron ring of HERA are made of 4 mm thick extruded copper (Fig.2). 90 % of the synchrotron radiation is thus absorbed in the watercooled chamber walls and any additional lead shielding needs no special cooling arrangement. Brazing the 12 meter long chambers, consisting of cooling channels, beam chamber, pump channel, flanges, beam monitors etc. in a 15 m long oven turned out to be quite difficult. One year ago not a single chamber had been successfully built. But by November '87 most problems were overcome and by mid-May of this year all 400 chambers had been completed. Brazing of the remaining 300 shorter and simpler straight section chambers is in full swing now with the aim of having the vacuum system completely installed by mid-August 1988.

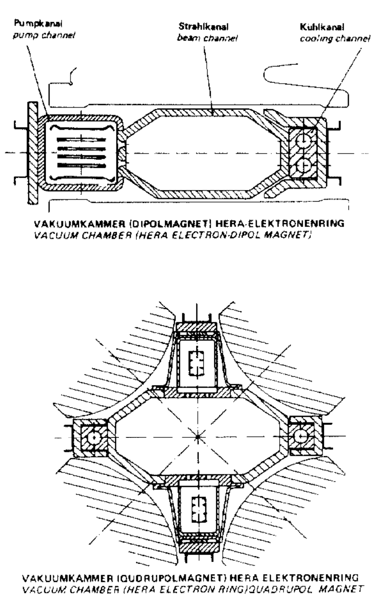

Figure 2a: Vacuum chamber of the electron ring Cross section

Figure 2b: Vacuum chamber of electron ring production

Storage of an electron current of 60 mA at an energy of 30 GeV requires an accelerating voltage of 153 MV per turn and an rf power transfer to the beam of 7.1 MW. After relocation of 7/8 of the PETRA **rf installation** to HERA, PETRA still maintains a 14 GeV storage capability (the original maximum energy in PETRA was 23.5 GeV). At this moment 54 5-cell and 7-cell cavity units have already been installed in HERA, which should be enough to make first beam storage tests possible at 14 GeV in HERA in August of this year. Commissioning of the other 26 cavity units and the total contingent of twelve 600/800 kW klystrons at the end of this year should increase the electron energy of HERA to 26 GeV. The completion of the rf system to a point where 30GeV or more can be reached safely will be done with **superconducting rf cavities**. A prototype of such a cavity, consisting of two 4-cell units in a 4.2m long cryostat, was successfully tested with beam in the PETRA storage ring. An accelerating gradient of more than 5 MVm^{-1} was observed, comfortably more than the 4 MVm^{-1} planned for the HERA operation. 8 cryostats housing a total of 64 superconducting 500 MHz cells with a total active length of 19.2 meters have been ordered and should be installed and operating in HERA in 1990.

Beam transfer channels between PETRA and HERA for electrons (positrons) and protons were completed in 1987 and successfully tested with electrons and positrons. In the last test in Nov. '87 12 GeV electrons were injected through the first 120 meters of completed HERA structure.

The completion of the **electrical powering** system for the electron ring is imminent. More than half of the 200 major magnet powering circuits have been connected and tested and it is hoped that the rest will be ready for the first beam tests in August '88.

The **HERA-control** room will be part of the DESY machine control room from where all DESY accelerators and storage rings are controlled (a total of 10 different accelerators and storage rings will be operated from this room). Controls of the electron ring include some 18 new central process computers and a large number of distributed micro computers. Controls are based on the same SEDAC system (Serial Data Aquisition and Control) which is also used to control all other DESY machines. Although the new HERA controls are a very advanced development of this system they will be totally compatible with the existing hard- and software. How much of all of this will be operational on August 15, remains to be seen. But the minimum amount of controls necessary for first beam storage should be available.

An important aspect of the HERA-project has always been the electron (positron) **polarization**. It always has been a hope that synchrotron radiation will build up a transverse beam polarization (Sokolov-Ternov effect) and that the electron (positron) spin can then be rotated into the longitudinal direction at the interaction points by using special spin rotator magnets. Although a large effort is being made to understand and control all linear and nonlinear depolarization effects, it is still too early to comment with certainty on the possibilities of a high degree of beam polarization in HERA. After the commissioning of the electron ring polarization measurements will have highest priority. After observation of transverse beam polarization a first spin rotator will be installed at straight section East. Preparatory work for that is in an advanced stage. Only after it has been established that beam polarization survives the spin manipulations in a rotator will two more rotators be installed at the location of the two large detectors H1 and ZEUS.

3. The proton machine complex

Of prime importance here are certainly the **superconducting magnets**, which were developed at DESY, Saclay and NIKHEF and will have to be built by industry.

A new type of superconducting magnet has been developed at DESY and is now being adopted for most of the newly planned accelerator projects. This HERA type magnet is based on earlier developments at Fermilab and Brookhaven. The superconducting coil is made out of the "Rutherford-type"-cable and collared and clamped by aluminium collars. The steel yoke surrounding the collar is at helium temperature but far enough removed from the coil that it does not go into saturation (Fig.3). A passive cold diode and an active heater system form the quench protection of this magnet. A total of 7 prototype and pre-series **dipole magnets** have now been built by two independent industrial firms and tested at DESY. All magnets had their first quench at field levels between 5.7 T and 6.3 T, comfortably exceeding the required 4.69 T for 820GeV operation. If the helium temperature is lowered to 3.7°K, field levels of 7 T can be reached corresponding to an energy of 1200 GeV in HERA. But since the HERA-proton ring also includes, near the interaction points, a number of normal warm magnets which saturate at 1TeV, this will be the maximum conceivable proton energy in HERA. This energy is comfortably within the range of the superconducting magnet system even at a helium temperature of 4.6°K. All magnet coils built so far exhibit a field uniformity well within specifications, i.e. for all harmonic components except the sextupole and tenpole components the contribution within an aperture of 50 mm diameter is smaller than $2 \cdot 10^{-4}$. The sextupole contributions at the injection energy of 40 GeV are as large as $40 \cdot 10^{-4}$ but will be exactly compensated by sextupole poleface windings placed on the vacuum chamber within the magnet. The ten-pole contributions are as large as $10 \cdot 10^{-4}$ at injection, but negligible at high energies. Since such a 10-pole contribution is expected to reduce the dynamic aperture at injection to 50 % of the value at high energies, 10-pole correction windings have been designed and are being installed in half of all dipole magnets. This correction scheme is expected to practically restore the full dynamic aperture at injection. Sextupole and 10-pole contributions are due to the well known persistent current effects and they are thus functions of time and magnet history. The compensating and correcting circuits will be programmed accordingly.

A total of 7 prototype and pre-series **superconducting quadrupole magnets** have been built by two independent industrial consortiums after having been designed at the Saclay Laboratory. All quadrupoles built so far exceeded a gradient of 125 Tm^{-1} before quenching and thereby exceed comfortably the required gradient of 111 Tm^{-1} for 1 TeV operation. Field homogeneity in the 46 coils built so far is better than $2 \cdot 10^{-4}$ within the aperture and therefore well within specifications. Exceptions again are the fields produced by persistent currents at injection energy. 12-pole contributions can be as high as $25 \cdot 10^{-4}$ and would significantly reduce the dynamic aperture. Polefacewindings on the vacuum chamber will exactly compensate these effects.

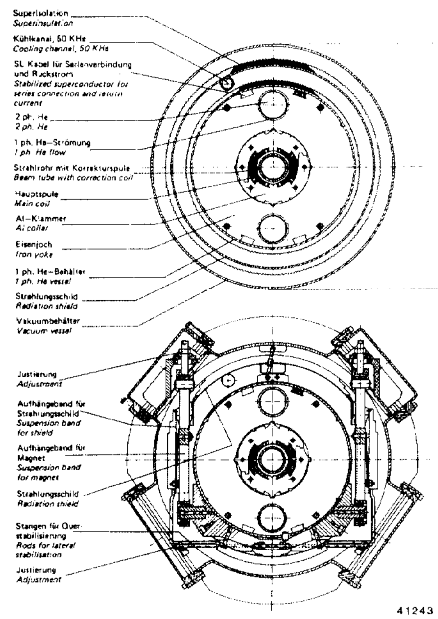

Figure 3a: Superconducting magnet of the proton ring cross section

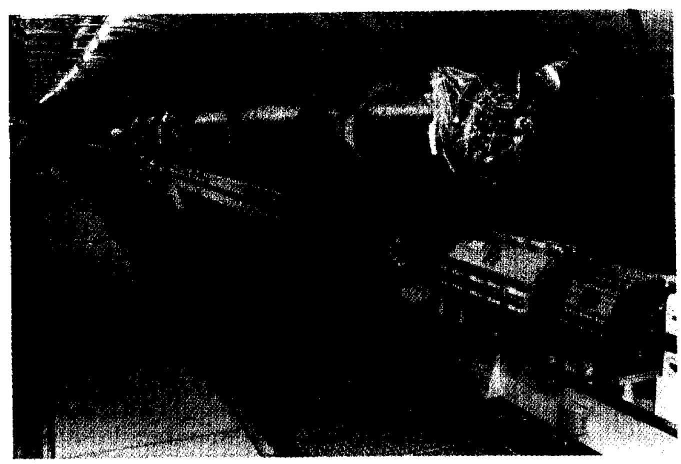

Figure 3b: Superconducting magnet of the proton ring Installation in the HERA tunnel

A total of 3 bending magnets and two quadrupole magnets were assembled in a **string test** to check the quench behaviour of a string of 5 magnets and measure the heat losses. It was found that the active quench detection and protection system together with the passive cold diode system limited an artificially induced quench to the one magnet in which the quench was induced. The measured heat losses of 43 W of the 4.6°K circuit and of 163 W of the 40-80°K heat shield circuit for the string corresponded to the sum of the individual magnet heat losses. These values are well within the refrigeration capability of the central refrigerator. The superconducting magnet system also includes the superconducting quadrupole correction windings on the dipole vacuum chamber (the sextupole and ten pole corrections have already been mentioned), the superferric dipole correction magnets and some superferric quadrupole magnets, both arranged in the quadrupole cryostats. All of these devices have been built and successfully tested. About 50 % of the vacuum chambers together with their pole face windings have been built.

The total of 15 pre-series dipole magnets will be delivered by Aug. '88. On the basis of the successful prototype and pre-series magnet test, production of magnet coils has been authorized for both companies involved in the construction of the required 414 dipole magnets. A total of 62 magnet coils have been built so far. Authorization has also been given for the series production of the quadrupole coils. 46 of the required 224 have been built so far.

To cool down the large number of superconducting magnets a large **refrigeration plant** has been built on the DESY site and commissioned during the last year. The plant consists of 3 independent refrigerators, each one with screw compressors, oil separators, filters and coolers and a cold box with expansion turbines. Each of these 3 refrigerators has a cooling power of 6.5 kW at 4.6°K, a secondcooling circuit at 40°K for cooling of heat shields with a power of 20kW and an additional liquifying capability of 20.5 gs^{-1}. All 3 refrigerators are connected to a switching box, which allows arbitrary connections to be made between the refrigerators and the helium supply lines in the HERA tunnel and the magnet test facility. The total refrigeration power needed for the cooling of the superconducting magnet system can presumably be delivered by two of the three refrigerators thus making it possible to shut one down at a time for repairs and maintenance.

The refrigeration plant had been ordered in Dec. '85. By Dec. '87 the last of the three refrigerators successfully completed its 1000 h acceptance run. All specifications were met. The overall efficiency of the system is remarkable: The line input power of 280 W required to cool 1 Watt at the temperature of 4.6°K is probably the lowest in any existing facility.

Supercritical helium at 4.5°K and 3.5 Atm will be piped around the 6.3 km long ring. Cold helium gas will flow back to the refrigeration plant. For this helium distribution, a transfer line is being installed in the tunnel, shown in Fig.4. This line will also provide liquid helium to the two particle detectors H1 and ZEUS, which use superconducting magnets as part of their particle detection and analysis system.

In order to store protons in HERA a whole new injector chain had to be built at DESY. The **50 MeV proton linear accelerator** Linac III is the first in this new chain. Its 750 KeV radiofrequency-quadrupole injector built by the university of Frankfurt has been in operation for some time, delivering more than 30mA of negative hydrogen ions into the first of the three Alvarez tanks, three times more than needed in the multiturn injection. The assembly of these three tanks is now close to completion. The 2 MW pulsed transmitter for powering these cavity tanks is ready and first beams in the linac are expected in the autumn of this year.

The 50 MeV protons will then be injected into DESY III, the new **7 GeV proton synchrotron**. **DESY III** is in the location, and uses the magnets of the old DESY I electron synchrotron. With the addition of quadrupoles, the optics of that machine has been changed such that the transition energy is now at 8.5 GeV, well above the actual maximum proton energy. A new thin-walled stainless steel vacuum system allows the acceleration time to be as short as 1.3 s. A CERN PS-type rf accelerating system works on the 11th harmonic of the circumferential frequency. DESY III has been completely assembled. The magnet powering system has been tested, the rf system is operational and the ring is under vacuum. DESY III is ready for the first proton injection.

After successful acceleration to 7 GeV, protons will be injected along existing channels into **PETRA**. The bending magnets of the former 23GeV e^+-e^--storage ring should allow maximum energies of 40 to 45 GeV.

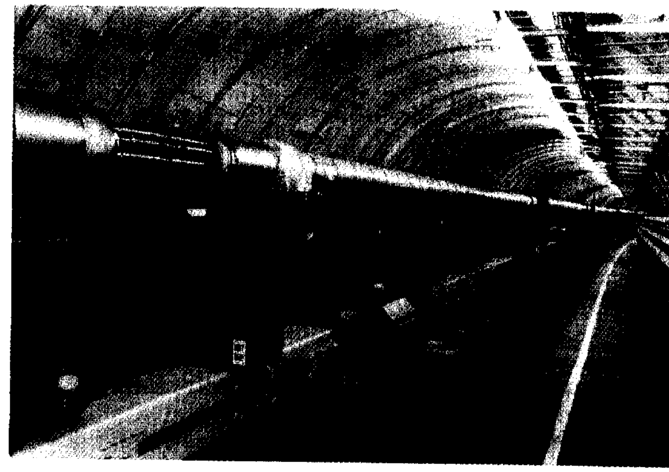

Figure 4: Installation of the helium transfer-line in the HERA tunnel.

At that energy the quadrupole focusing system will still produce a modest focusing, characterized by a maximum dispersion smaller than 15 meters. The corresponding transition energy is 6.5 GeV. In the whole proton acceleration chain transition can therefore always be avoided. PETRA has to be modified though to allow for proton acceleration. An rf-system at 50 MHz was built by Chalk River Lab. and is ready now for installation. It is also necessary for protons to by-pass the high impedance electron acceleration system to avoid severe instabilities. The by-pass, involving 11 additional quadrupoles and 4 additional bending magnets, has been installed in the straight section South of PETRA and should be operational in the spring of 1989. Modifications are also necessary in the injection kicker and septum system. A new type of ejection kicker with variable pulse length is also under construction. This kicker will be able to eject single 40 GeV proton bunches from the PETRA circulating proton current and use them to test the transfer channel and injection into HERA but it will also be capable to eject the whole filling of 80 bunches with one ejection pulse.

Present plans call for the commissioning of PETRA II with protons and injection tests into HERA in the first half of 1989. By mid-1990 the whole complex of electron-proton storage and collisions should be ready for the start-up of the physics program.

References

1. HERA-Proposal, DESY HERA 81-10, July 1981

2. G.-A. Voss, 12th Int. Conf. on High Energy Accelerators, Fermilab, August 1983

3. B.H. Wiik, 1985 Particle Accelerator Conf., IEEE Trans Nuc. Sci. Vol. NS-32, 1587 (1985)

4. G.-A. Voss, 13th Int. Conf. on High Energy Accelerators, Novosibirsk, USSR, August 1986 and DESY M-86-10, Sept. 1986