HERA: TOWARDS HIGHER PROTON BEAM ENERGIES

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Abstract

During the last years physics events have been observed at HERA highlighting a possible deviation from the standard model. Presently an energy upgrade of HERA-p is under discussion in order to increase the corresponding reaction rates. Following the last luminosity run period, a series of technical tests have been performed to establish a safe working regime of the main magnets (dipoles and quadrupoles) at higher excitation currents and to explore the actual limits of the magnet chain. Extensive quench tests at currents corresponding to 900 GeV proton energy have demonstrated that the quench protection system can handle quench scenarios much worse than expected from the operation experience gained from HERA at 820 GeV. In addition, the HERA main magnets have been ramped up to about 6200 A corresponding to 1 TeV and an emergency switch-off has been carried out without any problems. A careful synopsis of these tests will be presented.

1 INTRODUCTION

The HERA collider complex consists of a superconducting proton (HERA-p) and a conventional electron or positron (HERA-e) accelerator. At present, HERA-p is operated at 820 GeV with about 100 mA proton current stored. HERA-e runs with about 40 mA at 27.5 GeV. The record luminosity achieved at the two intersection points amounts to 1.4×10^{31} cm^{-2} s^{-1} which is used by the two experiments ZEUS and H1. HERMES and HERA-B are fixed-target experiments using longitudinally spin-polarized electrons or positrons and unpolarized protons, respectively.

In order to increase the number of events detected by the various experiments, different measures are currently being investigated or realized: (1) increasing the beam currents stored; (2) decreasing the beam sizes at the intersection points and (3) increasing the beam energies. This paper will concentrate on (3).

Increasing the beam energy of HERA-e without reducing the beam current stored is only achievable if the RF power installed is increased. Due to the high additional investment and operating costs this alternative has been ruled out. However, increasing the proton beam energy can be performed much more easily. The possible consequences for the different technical components affected by an energy upgrade will be discussed in Section 2. The technical tests without beam performed in November 1997 will be described and summarized in Section 3. Finally, an outlook for the proposed operating mode during the following years will be presented in Section 4.

2 TECHNICAL LIMITATIONS AND RISKS OF AN ENERGY UPGRADE OF HERA-P

Increasing the beam energy of HERA-p will affect several technical components: superconducting main magnets (dipoles and quadrupoles), correction coils and bus leads; cryogenic system and quench protection system.

2.1 Superconducting Main Magnets, Correction Coils and Bus Leads

All main magnets have been cold tested prior to the installation in the HERA tunnel to explore the individual final self quench currents reached after one or two training steps. At 4.75°K, the quench current distribution of the dipoles is peaking at 6458A with a standard deviation of 114A and at 7383A with 148A for the quadrupoles. The weakest dipole installed is expected to quench at 6154A and the weakest quadrupole at 6512A.

The quench current depends on the temperature of the liquid-helium coolant. It increases by 115A per 0.1°K temperature decrease. Presently the HERA-p main magnets are operated at a temperature of 4.4°K and are excited to 5025A corresponding to a beam energy of 820GeV. An energy of 900GeV would be equivalent to about 5535A and 1TeV to about 6190A.

The current in the superconducting correction coils is limited to 100A by the performance of the current leads. However, scaling the correction currents presently used at 820GeV to values needed at 900GeV would already exceed this limit in some cases. Optics calculations have been performed demonstrating that the required correction currents can be distributed among other correction coils to provide a matched optical solution with good background conditions for the experiments.

Particular emphasis has to be put on the performance of the bus leads of the so-called cold straight sections and of the soldered joints between the magnets. One joint was already destroyed in the past by quenching. Assuming that a quench can be detected instantaneously and the current in the magnet chain is switched off exponentially with a time constant of 25s, a final temperature of less than 125°K is expected even if operated at 1TeV. The corresponding resistance of the leads generates a voltage drop. In the case of the cold straight sections the quench can be detected safely. However, the expected voltage drop along the 1m long interface between two main magnets is about 0.1V at a temperature of 100°K which is the detection limit of the quench protection system.

2.2 Cryogenic System

Increasing the magnet current decreases the margin for a safe operation of the magnets. This can be compensated for by decreasing the operating temperature of the magnets.

The main magnets are cooled by 1-phase helium at 2.3bar delivered by the central cryogenic plant. After expansion by a Joule-Thomson valve, 2-phase helium is generated. It re-cools the 1-phase helium stream in a counter-stream mode. The vaporized helium is finally fed back to the compressors of the cryogenic plant.

Changing the suction pressure of the compressors the temperature of the 2-phase helium and the magnets can be lowered. Tests have shown that the lowest achievable temperature is 3.7°K at 600mbar. However, a sub-atmospheric pressure operation has always the risk of air or water contamination of the helium due to leaks of the system. A couple of tests have demonstrated that contamination of the helium is not expected to be a problem even without operating the existing low-temperature purifiers.

2.3 Quench Protection System

In order to avoid the self-destruction of the superconducting main magnets in the case of a quench a dedicated safety system (quench protection system) is installed at HERA-p.

Every dipole magnet is by-passed by two and every quadrupole magnet by one rectifier diode operated at liquid-helium temperature. If the voltage drop across a diode due to a quench of the magnet will exceed the diode forward voltage of about 1.7V the magnet current supplied by the power supply will pass through the diode and not through the quenched magnet coils. The quench is detected by a well adjusted resistor bridge across the magnet measuring a voltage asymmetry between the half coils of the quenched magnet. To accelerate the quench propagation in quenched magnets, dedicated heaters are charged in the corresponding magnets.

After the detection of a quench, the chain of main magnets which are all connected in series is short-cut. The energy stored in the magnets is absorbed by a couple of so-called dump resistors almost equally distributed along HERA. In addition, independent current loops across the HERA-p octants will be formed by connecting the magnet chain at the location of the resistors to a circular by-pass line. The magnet current decays exponentially with a time constant of 25s. The voltage induced by the current change does not exceed ± 310V with respect to ground at 820GeV and ±345V at 1TeV. The diodes will be exposed to a backward voltage of less than 7 V. However in the very rare case that all but one magnet of an octant will quench simultaneously, the backward voltage at the two diodes of the magnet not quenched will exceed the test voltage of 500V for O(10ms) before the current will be redirected by the by-pass line.

An energy upgrade implies an increased power load to the diodes and their leads of a quenched magnet. However, over-heating tests have demonstrated that even an energy deposition 20 times larger than presently applied will not destroy the diodes.

3 TECHNICAL PERFORMANCE TESTS WITHOUT BEAM

After the luminosity run period technical tests have been performed in November 1997 to (1) explore the performance of the technical components affected by an energy upgrade, (2) to explore the actual safety margin and (3) to determine a working regime with almost the same safety margin as available in the present 820GeV operating mode.

3.1 Sub-atmospheric Pressure Operation of the Cryogenic System

Prior to the electrical tests the suction pressure of the compressors of the cryogenic plant has been lowered to 810mbar to establish a cooling temperature of 4°K. The sub-atmospheric pressure operation has been terminated prematurely after 5 weeks by a blockade in the 1-phase helium circuit after the repair of a so-called Kautzky safety valve which was damaged during a quench test. In general, the quench recovery time was found to be less than 2h. In extreme cases of massive quenches 4h have been recorded. The standard operation of the cryogenic system was without any problems.

3.2 Maximum Excitation Current

The maximum excitation of the main magnet chain tested was 6192A corresponding to 1TeV proton beam energy. During ramping up two different dipole magnets quenched once. One of the magnets had shown on the test bench prior to installation a moderate, the other a good quench performance. Both magnets had reached their final quench current limits within one training step.

3.3 Fake Quench Generation

The main source of fake quench generation is the imperfect adjustment of the quench detection measuring bridges. Increasing the magnet current implies an enlarged voltage drop across the magnets in case of an emergency switch-off. In addition, quenches can further locally increase the speed of de-excitation and the corresponding induced voltage drop. Current changes between 220A/s and 400A/s did not trigger any fake quench signal. The lower limit corresponds to a standard emergency switch-off at 900GeV. The upper limit was tested during a massive heater-induced quench at a magnet current corresponding to 900GeV. In total, 16 quench tests at 900GeV have been performed by charging heaters. At the most, 30% of the magnets of a particular HERA octant have been quenched simultaneously.

3.4 Quench Propagation

Quench propagation has been studied in detail. This effect can be triggered by 2 different mechanisms. The flow of warm helium gas after a quench can locally warm up and finally quench the neighbours of magnets already quenched. If HERA-p is operated at 820GeV (5025A) induced secondary quenches have shown up in the past after about 15s after the primary quench. During the quench tests at 900GeV (5535A) it was observed that in a couple of tests secondary quenches appeared within already 3s. However, the quench propagation never exceeded more than 2 neighbouring magnets.

Eddy-currents induced in the Aluminum collars of the magnets during a fast change of the current can deposit heat in the superconducting coils driving the magnets into self quench. The more magnets quenching, the faster the current change and the additional eddy-current heat load is greater. Finally, a “domino”-like chain reaction could be started. However, during the quench tests an eddy-current induced quench propagation has been never observed even at an emergency switch-off at 1TeV.

3.5 Safety Margin

The tests have demonstrated that it is possible to perform an emergency switch-off at 1TeV (6192A) and 4.0°K without inducing quenches. The corresponding current change is 248A/s. These numbers can be used as a reference to estimate the minimum safety margins expected at other magnet excitations and cooling temperatures. The calculations assume a self quench current of the weakest magnet of 7017A at 4.0°K and 6556A at 4.4°K. The safety margin is defined as the difference of the maximum current change determined experimentally and the current change appearing during a standard emergency switch-off. The safety margin is set arbitrarily to ≥ 0% for the reference case. The results for different operating modes are summarized in Table 1.

E / GeV	**I / A**	**dI/dt / A/s (emergency switch-off)**	**(I_{Quench} – I) / A**	**T / °K**	**dI/dt / A/s (maximum)**	**safety margin**
820	5025	201	1531	4.4	≥ 460	≥ 56%
900	5535	221	1021	4.4	≥ 307	≥ 28%
			1482	4.0	≥ 445	≥ 50%
1000	6192	248	364	4.4	≥ 109	-
			825	4.0	≥ 248	≥ 0%

Table 1: Safety margins for different HERA-p operating modes. The safety margin for the 1TeV operation at 4.0°K has been explored experimentally and is a lower limit. It is set arbitrarily to ≥ 0%.

4 OUTLOOK

It was decided among the HERA machine group and the HERA experiments to run in 1998 and the following years at a proton beam energy of 920GeV. It is planned to establish this operating mode during the machine development phase in 1998 prior to the luminosity run period.

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