An Overview of the Beam Abort System for the 820 GeV/c HERA Proton Ring

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Abstract

In storage rings like HERA-p the total stored energy of the proton beam is very high. In order to avoid the quench of superconducting magnets or damage to the accelerator an efficient beam abort system ("beam dump") is needed. In the beginning the necessity of such a system is motivated and its usage will be described. Subsequently to the introduction the main components absorber, kicker and pulser of the beam dump system are discussed.

1 INTRODUCTION

The HERA proton ring is designed to store 220 bunches equally spaced with 96 ns and filled with 10^{11} p^+ per bunch at a momentum of 820 GeV/c. The total beam energy of 2×10^{13} protons at 820 GeV/c amounts to 2.6 MJ. This is equivalent to the kinetic energy of a 6.7 t lorry at 100 km/h, but it should be mentioned, that the total beam momentum is only $8.7\,\mathrm{g} \cdot \frac{\mathrm{m}}{\mathrm{s}}$. A better illustration can be find in table 1. It shows the masses m and corresponding volumes V of different materials, that can be heated up to their melting point (starting at room temperature) with the proton beam energy.

Apart from the high beam energy with the risk of damaging accelerator components, the particle type proton, i.e. hadron, gives rise to radiation problems, when hitting matter. They interact with the nuclei, whereas electrons "see" the whole atom. Therefor hadron beams are more penetrating than electron beams.

According to the mentioned risks, especially in the presence of superconducting magnets (quench limit 1 mJ/g), there is need for a beam abort system. Even if the beam is removed out of the ring in a well controlled way, one can not avoid to induce radioactivity. But with such a system it is localized at the absorber and not distributed along the whole ring.

The system will be used in normal case by operator, when the luminosity has deteriorated to an unacceptably low level and a new filling is foreseen, i.e. roughly every 5 hours. Automatic triggering will occur in emergency case either due to external reasons given by machine security (sizable beam instabilities, quench) and by radiation safety (human interlock) or due to internal reasons, i.e. main faults in the beam dump system itself.

Besides the controls the system consists of one absorber, 8 kickers and 8 pulsers. Each pulser is connected to one kicker separately, so there are 8 independent units, which are fired all together. With this number one unit is allowed to fail or fire spontaneously without dangerous consequences [1]. Duplication of the trigger electronics ensures that a high reliability level is attained.

Table 1: Equivalent Masses to be melt by 2.6 MJ

	Fe	Cu	Al	C
m [kg]	3.6	6.2	4.2	0.36
V [cm^3]	459	691	1553	159

2 THE ABSORBER

The absorber is mounted inside the HERA tunnel 80 m south of the center of hall west. First this position is far enough from the superconducting section and secondly in the neighbourhood of the proton injection, which is also expected to give higher radioactivity levels.

The vacuum vessel of the circulating beam is surrounded by the absorber. That is why only a small displacement of the beam is required to hit the absorber. Apart from the surrounding air the absorber is not cooled additionally. Before penetrating the surface of the absorber, the beam traverses ≈ 30 cm of air (used for a fluorescent screen to monitor the deflected beam) after leaving the vacuum system through a 3 mm thick steel window. The design of the absorber [2] expects, that the whole filling of the ring (2×10^{13} protons) has to be distributed on the absorberface along a vertikal line downwards between the displacements of 116 mm and 58 mm. By means of this sweep the beam energy is distributed into a larger volume, thus reducing the resulting energy densities and mechanical stresses. For the same reason the absorber is a composite structure of diameter 22 cm, where the front element is a 2.75 m length of graphite, followed by 1.75 m of aluminium, 0.5 m of copper and ending up with 1.5 m of iron. This cylindrical core combines the constraints of minimizing energy densities, dimensions and weight. Without the iron the core would already absorb 62 % of the primary energy. Table 2 shows the maximum expected temperatures in the core for 2×10^{13} protons at 1 TeV with and without sweep. Mechanical and thermal stresses produced in

Table 2: Maximum expected temperatures in the core

	Cu	Al	C
with sweep	≤ 30	100	200
without sweep	≤ 50	400	900
melting point [°C]	1080	650	3800

each material are kept well under their plasticity limit or melting point even without sweep; except for aluminium, where the mechanical stresses exceed the plasticity limit by a factor of 5 in case without the sweep. The longitudinal temperature profile near the shower axis is measured to inform about abnormal behaviour. The core is built with a hole near its top to accommodate the beampipe for the stored beam. The whole core is contained in an iron cylinder of wall thickness 14 cm, which itself is housed in a box, open at both ends, constructed from iron plates 20 cm thick.

Altogether this comes close to 100 % energy absorption and provides adequate shielding. After 10 years of operation, assuming a dump of 2×10^{13} protons at 1 TeV every 5 hours, the induced radioactivity is expected to give a dose rate of 10 mrem/h at the surface of the outer iron screening 3 days after the last dump.

3 THE KICKERS

The deflection of the beam is achieved by pulsing 8 kickers, which are arranged in two groups of 4 almost symmetrically to the center of hall west, i.e. roughly 80 m upstream of the absorber. The straight section west has no colliding beams and therefor no high energy physics experiment in hall west. With a vertically focussing quadrupol between the two groups and a vertically defocussing one half way to the absorber, 0.1276 mrad in each kicker is required to give 116 mm at the absorber. The deflected and the stored beam are using the same vacuum chamber, which is asymmetrically extended between the vertically defocussing quadrupol and the absorber to allow for the deflected beam.

Each kicker consists of a 2.7 m long vacuum vessel (200 mm in diameter) containing a 2.6 m long simple copper winding creating the magnetic field. The cross section of the conductors is curved to increase the homogenity of the magnetic field. The gapheight of the first group of kickers is h=70 mm and h=80 mm for the second group to accommodate the deflected beam. Magnetic field strength B on the kicker axis normalized to the current I through the kicker and the kick strength K for the two kicker-types are given in table 3. Thus 0.1276 mrad at 820 GeV/c are achieved with 11.9 kA in the $h = 70$ mm kickers and 14.1 kA for $h = 80$ mm.

The resonant modes in the kicker and their relative shuntimpedances R/Q as well as their quality factors Q were measured [3]. In the region up to 1 GHz they were identified as standing waves on the conductors (first mode $2.6\,\mathrm{m} = \lambda/4$ i.e. 28 MHz). Without any damping their impedance was not acceptable from the point of view of beam instability. Furthermore roughly 7 kW would be induced in each kicker for HERA-p design intensity (see section 1). An external low-pass filter and 8C11 ferrites (Valvo) in the shadow of the conductors inside of the kicker manage to damp the existing modes very well. The estimated induced power drops down to 150 W per kicker and the structure will not lead to beam stability problems.

Table 3: Parameters of the two kicker types

Gapheight h	B/I $[\frac{\mathrm{mT}}{\mathrm{kA}}]$	K $[\frac{\mathrm{mrad}}{\mathrm{kA}} \cdot \frac{\mathrm{GeV}}{c}]$
70 mm	11.3	8.82
80 mm	9.54	7.44

4 THE PULSERS

The current through each kicker results from discharging a 2 μF capacitor. All 8 capacitors are charged up to the same main voltage, which is tracked with beam momentum up to 21.8 kV for 116 mm at 820 GeV/c. Due to low repetition rates ($\approx$every 5 hours) a spark-gap (9 *mm*) triggered by an ordinary car sparking plug is used as a switch. To operate the spark-gap independent from the varying main voltage it is kept at a constant ignition voltage (90 % of selfbreakdown $\approx$ 27 kV) and therefor constant timing parameters. Both voltage potentials are separated by a self-built fast high voltage diode (1N5408: 20 parallel, 30 in series).

Each of the 8 pulsers is connected to one kicker via 16 parallel 50 Ω coaxial cables (4.9/17.3 Philips) about 50 m each. When the spark-gap is fired the current through the kicker rises sinusoidally, as in any L-C tuned circuit, here formed by 2 μF capacitor together with cable- ($\approx 0.8\,\mu$H) and kicker-inductance ($\approx 2\,\mu$H). The current has reached 50 % of its maximum after 1.3 μs. When the current wants to fall down after its maximum, a freewheel diode (also self-built type like the other) across the capacitor starts to conduct, converting the circuit into a L-R circuit, in which the current decays exponentially to 50 % in $\approx 20\,\mu$s. The total time between the two 50 % values of the current pulse is $\geq 21\,\mu$s (HERA revolution time), so that the whole filling of the ring is extracted and swept across the absorber.

The spark-gap operates at atmospheric pressure, i.e. the switching time jitter is composed of intrinsic jitter ($\approx \pm 40$ ns) and variation of the operation point (selfbreakdown changes with gas pressure) due to atmospheric pressure fluctuations (± 90 ns for 1013^{+25}_{-55} mbar). To allow for the risetime (1.3 μs) and the jitter (± 150 ns in total) of the deflecting pulse, 20 subsequent bunches are left free ($20 \times 96\,\mathrm{ns} = 1.92\,\mu$s). All 8 pulsers are fired at the same time but synchronized on this "beam-gap".

5 REFERENCES

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