BEAM LOSS DAMAGE IN A WIRE SEPTUM

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The beams for the Large Hadron Collider LHC will be extracted from the Super Proton Synchrotron SPS in points LSS4 (Long Straight Section) and LSS6 in fast mode during a single turn. For this purpose a new fast extraction will be designed in LSS4. In LSS6 the existing slow extraction channel needs modification such that it can provide fast extracted beam for LHC, while continuing to provide the West Experimental Area with long spills. Both fast and slow extraction must be available from the same point, although in an interleaved mode. This imposes the retention of the thin electrostatic wire septum ZS actually in use.

The present article focuses on the effect of total beam loss in the electrostatic septum as it could occur e.g. due to a kicker magnet failure during fast extraction in LSS6. Then the entire SPS beam of $4.13 \ 10^{13}$ protons would impinge on the septum wires. The damage caused by the resulting electromagnetic and hadronic particle showers is determined and the need to protect the ZS is evaluated.

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1 INTRODUCTION

The transformation of the SPS into the injector for LHC requires major modifications to many hardware and software systems [1]. Among the hardware changes are two new fast extractions from the SPS to be provided: a completely new extraction channel is required in LSS4 and the existing resonant extraction in LSS6 must be modified to allow also for fast extraction. Existing LSS6 equipment will be reused and is vulnerable to beam induced damage. Here the effect of a high brightness LHC type fast extracted beam impinging on the ZS wire septum (Figure 1) is studied. The electromagnetic and hadronic cascade provoked after beam impact and the resulting energy deposition, is simulated by the Monte Carlo code FLUKA [2]. The corresponding wire heating might lead to material sublimation and destruction of the wire septum. Possible remedies to protect the ZS are proposed.

2 SPS FAST EXTRACTION IN LSS6

The reuse of the existing extraction channel in LSS6 offers many advantages [3], the most important of which is the economy involved. However, the LSS6 extraction is designed to supply resonantly extracted beams to the West Area, and as such is more complex than is necessary for a standard fast extraction (Figure 2). During fast extraction the electrostatic septum ZS has to be used at nominal field, which is a potential source of problems for operation. The ZS septum is made up of five units each of 3.1 m electrode
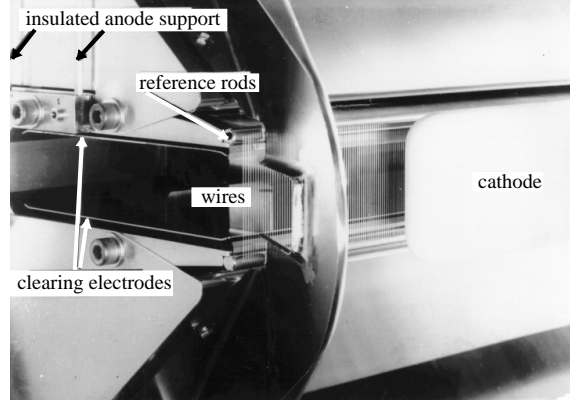

Figure 1: Thin electrostatic wire septum ZS as installed in the SPS long straight section LSS6.

length, with anode elements (septa) made up of arrays of 2080 stretched wires at 1.5 mm spacing. These wires are made from a W74Re26 alloy and are only 25 μm in radius for the first two ZS to minimise the losses during resonant extraction. In the subsequent septa wires twice as thick are used. The rhenium admixture is added to obtain better mechanical characteristics of the wires, in particular better ductility. In theory fast extraction should be a loss-free process, and a certain amount of protection can be obtained from a well conceived interlock system involving the verification of the status of the extraction septa, the bumpers, the kickers, the orbit, etc.

Despite these precautions, however, it will not be possible to guarantee that the fast extracted beam will never strike the fragile ZS wires, either through equipment failure, software problems or human error. The consequences of a mis-steered LHC type fast extracted beam impinging directly on these wires are likely to involve serious equipment damage.

3 SPS BEAM TYPES

During the LHC era three beam types will be extracted from the SPS: a 450 GeV/c proton beam for LHC, a 400 GeV/c proton beam for CNGS (CERN Neutrino beam to Gran Sasso) or fixed target physics, as well as a 177 GeV/u Pb^{82+} lead ion beam for LHC or fixed targed physics. From the point of view of expected damage in case of beam loss on the ZS wire septum, the proton beam for LHC represents the most critical case, because of its high intensity and brightness. The present study focuses on this beam whose parameters are listed in Table 1.
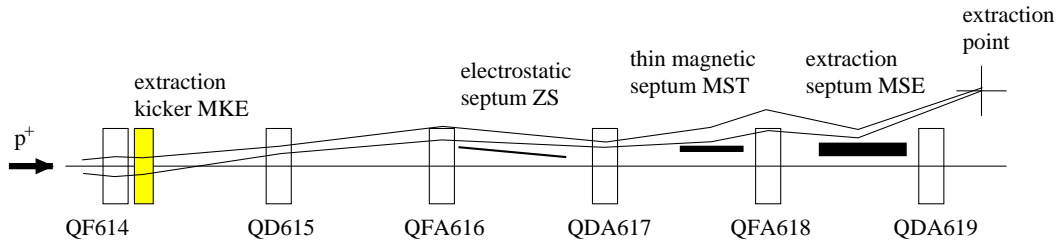
Figure 2: Schematic layout of fast extraction in LSS6 using existing equipment.

Table 1: SPS parameters for ultimate LHC type proton beam at extraction.

Beam parameter	Value
Momentum	450 GeV/c
Revolution time	23 μs
Number of bunches	243[a]
Particles per bunch	1.7 10^{11} p
Total intensity	4.13 10^{13} p
Trans. norm. emittance	3.5 μrad

[a]Recent adoption of the triple bunch splitting technique in the PS lead to a new LHC filling scheme including an increase in the total number of bunches in the SPS from 243 to now 288. This involves an increase in ultimate beam total intensity from 4.13 10^{13} p to 4.90 10^{13} p and makes the situation for the ZS even worse.

4 SIMULATION RESULTS

4.1 Energy Deposition Calculations

A small amount of energy dE deposited in a volume dV of a material with density ρ causes a temperature rise ΔT determined by $dE = c_p \rho \, dV \, \Delta T$. The proportionality constant c_p is the specific heat of the considered material. The larger the value of c_p, the smaller the temperature rise caused by an energy deposit dE. For important energy depositions the specific heat can no longer be considered as constant, but its temperature dependence must be taken into account. The specific heat $c_p(T)$ for W74Re26 and other material properties can be found in [4]. Now ΔT must be extracted from

$$\frac{dE}{dV} = \rho \int_{T_0}^{T_0+\Delta T} c_p(T) \, dT \qquad (1)$$

by solving numerically for the upper limit of the integral. The conductor temperature before the beam impact is T_0.

4.2 Heating of a W74Re26 Wire Septum

Beam impact on the ZS wires produces a hadronic and electromagnetic cascade resulting in energy deposition all along the septum. The total energy deposited was computed by FLUKA and, due to the short pulse length of 23 μs, was assumed instantaneous. The equivalent temperature distribution induced on every single wire was deter-
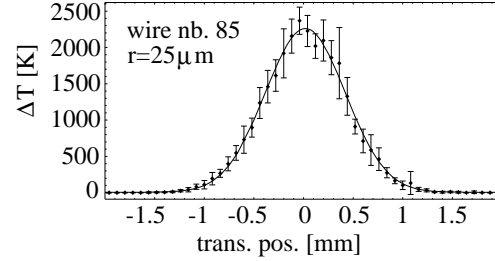

Figure 3: The temperature profile along a single W74Re26 wire (the hottest) reflects the Gaussian profile of the incident beam. A peak temperature of 2300°C is reached.

mined and the central 4 mm of every wire, the region covering the lateral width of the particle cascade, were divided into 50 cylindrical bins of 25 μm radius. For the hottest wire the obtained transverse temperature profile is displayed in Figure 3. A peak temperature of about 2300°C is reached, which is well above the operating limit of 1000°C. Similar temperature profiles are obtained all along the septum and the temperature distribution on the septum as a whole is shown in Figure 4. The first 50 cm of the septum heat to very critical temperatures of more than 1500°C, with the first 30 cm to even more than 2000°C. Clearly, taking also into account the 500 g pretension applied to every wire, the septum does not resist such temperatures and a remedy must be found.
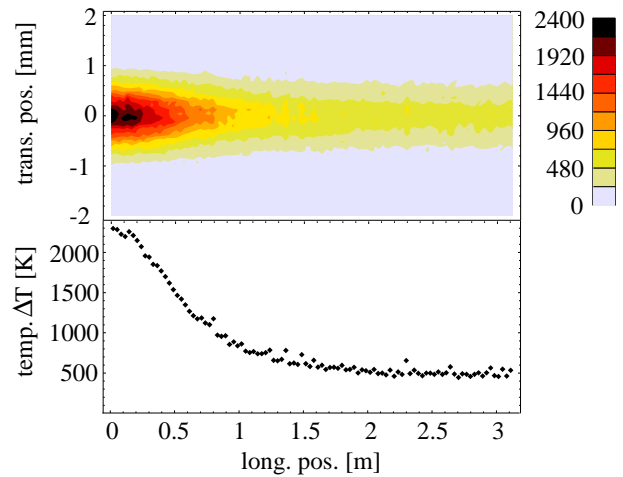

Figure 4: Transverse and longitudinal temperature profile on the 3.1 m septum ZS1 with r=25 μm W74Re26 wires.

4.3 Heating of a Graphite Wire Septum

One possibility to reduce the expected peak temperature in the septum is to replace the high-density W74Re26 wires by a light material of high melting point. Wires made of carbon fibres appear to be a possible candidate. Due to their low density of $1.85\,\mathrm{g/cm^3}$ the Bethe-Bloch formula predicts a lower dE/dx and the high values of c_p of $650\,\mathrm{J/(kg\,K)}$ at $20°\mathrm{C}$ causes the corresponding temperature increase ΔT to be modest (Figure 5).

The maximum heating expected with such wires when the ultimate LHC beam of $4.13\,10^{13}$ protons is accidentally dumped at $450\,\mathrm{GeV/c}$ into the ZS extraction septum is only $60°\mathrm{C}$. Compared to the $2300°$ reached in the tungsten alloy the advantage is striking. However, graphite wires are not possible due to the high voltage environment. Any graphite deposit on the cathode would pollute the electrodes surface and lead to a high sparking rate, and eventually destroy the cathode.
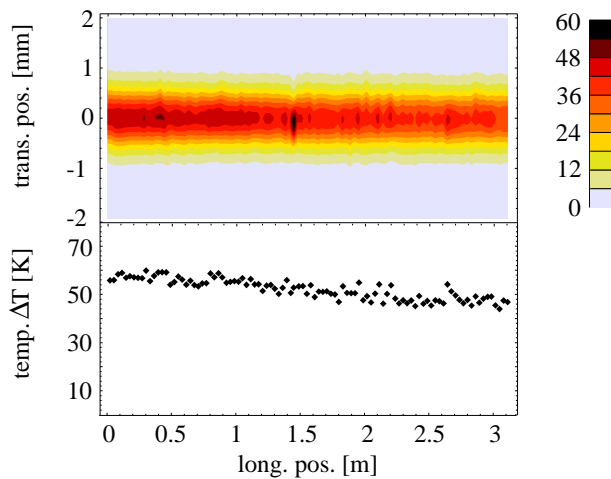

Figure 5: Transverse and longitudinal temperature profile on the 3.1 m septum ZS1 with r=25 μm graphite wires.

4.4 Beam Absorber or Diluter

Another possible and actually favoured approach consists in designing a mechanical protection element, a beam stopper or diluter, to be positioned in front of the ZS when fast extraction is requested. In case of mis-steering this element would absorb most of the beam such that no or only acceptable energy deposition in the septum will occur. However, this element must be mobile so that it can be withdrawn for slow extraction where a thin septum is mandatory. For LHC filling, about three to four times a day, the absorber element would be brought into position to protect the septum from eventual losses during fast beam transfer to the hadron collider.

A preliminary design of such an element is made. Use of a 2.5 m graphite block, followed by 0.5 m aluminum would significantly decrease the peak temperature in the ZS. Use of a few centimetre thick boron carbide plate as

beam spreader in front of the graphite absorber helps to get the cascade going and reduces the wire peak temperatures to very acceptable $100°\mathrm{C}$.
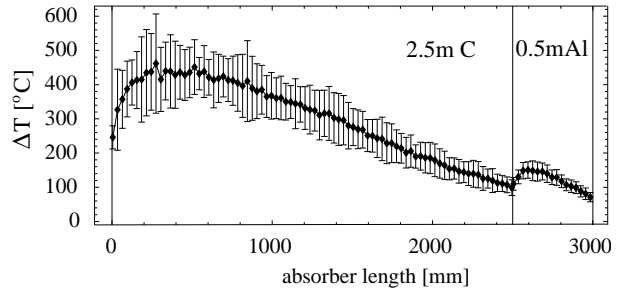

Figure 6: Instantaneous temperature increase on the central axis in a 3 m C and Al absorber right after beam impact.

5 CONCLUSIONS

Given the high cost and radiation constraints associated with the fabrication and replacement of ZS septa, a mechanical protection element will be necessary to protect the wires. This object will have to be moved quickly into place before any fast extraction, and removed when resonant extraction is requested.

Simulations showed that the wire septum in LSS6 needs protection when, with the start-up of LHC, fast extraction of the $450\,\mathrm{GeV/c}$ proton beam will be provided. In case of an extraction kicker failure the entire SPS proton intensity could be dumped in the electrostatic septum and deposit a sufficient amount of energy to sublimate the W74R26 wires. Therefore a protection element in form of an absorber will dilute the beam to such a level that it cannot harm the septum wires. Some concern exists that carbon particles could be deposited on the high voltage cathode and, as surface pollution, cause a high sparking rate in the ZS. Therefore a beryllium absorber will also be considered.

Experimental verification of these results will be provided by a fast wire scanner with W74Re26 wires to be passed through the beam until destroyed by sublimation. The moment at which the wire breaks and the equivalent energy deposited by the beam can be determined and compared to the simulation.

6 REFERENCES

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