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WIRE EXCITATION EXPERIMENTS IN THE CERN SPS

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Abstract

In order to study the effect of long range interaction and its wire compensation experimentally, current carrying wires are installed in the CERN Super Proton Synchrotron (SPS). In this paper we summarize the main results of the 2007 wire excitation experiments at 26, 37 and 55 GeV including scans of wire current, beam-wire distance and chromaticity. A strong dependence on the chromaticity and indications of a threshold effect at 37 and 55 GeV were found. The results are compared with simulations, with a simple analytic scaling law and with experimental results from RHIC. Wire driven resonances have been observed through the Fourier spectrum of experimental BPM data and also studied in simulations.

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Abstract

In order to study the effect of long range interaction and its wire compensation experimentally, current carrying wires are installed in the CERN Super Proton Synchrotron (SPS). In this paper we summarize the main results of the 2007 wire excitation experiments at 26, 37 and 55 GeV including scans of wire current, beam-wire distance and chromaticity. A strong dependence on the chromaticity and indications of a threshold effect at 37 and 55 GeV were found. The results are compared with simulations, with a simple analytic scaling law and with experimental results from RHIC. Wire driven resonances have been observed through the Fourier spectrum of experimental BPM data and also studied in simulations.

INTRODUCTION

The long-range beam-beam interaction (LRBBI) will become one of the main limitations of the CERN LHC. Therefore the effect as well as a possible remedy – the wire compensation – have been, and still are, exhaustively studied in simulations [1, 2, 3, 4]. In order to also gain experimental insight and to benchmark the dedicated simulation code BBTrack [5], BBLR wire excitation experiments were performed in the SPS, and also at RHIC [8]. For this purpose two sets of wire compensators, each consisting of two units like the one shown in Fig. 1, were installed at the CERN SPS in 2002 and 2004, respectively. During the 2007 machine studies these wires were utilized to mimic LRBBI encounters of variable strength under various beam conditions.

The experiments were performed on a SPS cycle, where the beam is stepwise accelerated from 26Gev to 37GeV and finally to 55GeV with a few second long plateau at each energy. All experiments were performed within the few available seconds at constant energy and repeated several times for one setting. The powered BBLR reduces the dynamical aperture and therefore causes beam loss. In most of the cases the short measurement intervall was sufficiently long to observe the complete beam loss.

Pertinent optics parameters at the wire locations are summarized in Tab. 1.

It was initially attempted to perform these experiments at the design LHC tunes (0.31, 0.32), but finally (0.31, 0.28) was chosen instead, as the decoupling of the two beams turned out to be too strong for certain wire excitations where the vertical and horizontal tunes approached each other.

The simulations were performed with the particle tracking code BBTrack [5], and the border of stability was determined by following twin particles for 300.000 turns around the ring and examining the corresponding Lyapunov exponent.

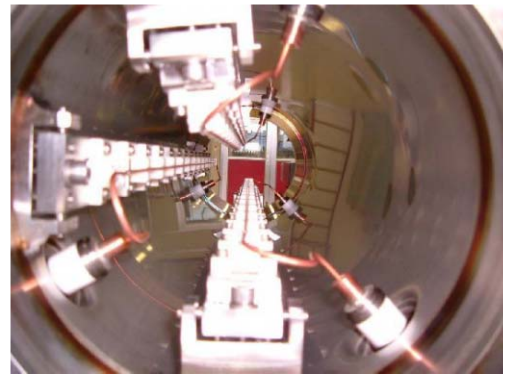


Figure 1: This SPS prototype compensator contains three wires that can be powered, one at a time, with up to 300 Am integrated strength.

Table 1: Optics parameters at the SPS compensator location, and the corresponding beam sizes for transverse emittances of 0.1 μm and $\delta_{\rm rms} \approx 10^{-3}$.

Variable	Compensator 1	Compensator 2
length l [m]	1.2	1.2
location s [m]	5168.6	5170.8
β_x [m]	47.6	54.1
β_y [m]	50.8	44.6
α_x	-1.4	-1.52
α_y	1.46	1.32
D_x [m]	-0.58	-0.61
D_y [m]	0	0
σ_x at 26 GeV [mm]	2.3	2.4
σ_y at 26 GeV [mm]	2.3	2.1

EXPERIMENTS

Beam-wire separation scan at 37GeV

The data obtained in two beam-wire separation scans with a wire excitation of 180 and 240 Am at the working point (0.31, 0.28) are shown in Fig. 2. For a wire strength of 240 Am first small losses are observed at a distance $d \approx$ 12 mm (8 σ), but a steeper increase occurs at 9.5 mm (6.3 σ). This two stage increase is reproduced in the simulations of Fig. 3. However, the simulated beam loss for the 180 Am case is slightly higher than in the experiment, where the onset of beam-loss was found at $d \approx 8.5$ mm (5.6 σ, threshold not shown). A simple scaling law [6] suggests that the wire excitation should have the same effect on the beam if the ratio I/d^2 is identical. In Fig. 2 additional points indicate the 180 Am data scaled to 240 Am according to this law, supporting the expected scaling behavior.

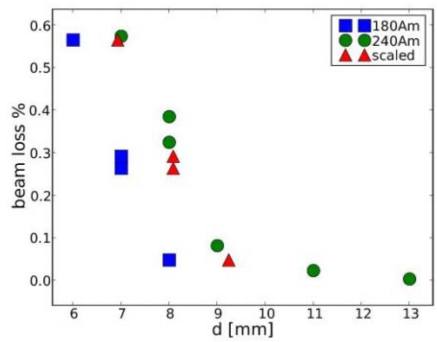


Figure 2: Experimental beam loss at 180 Am and 240 Am wire exctitation as a function of beam-wire distance, and 180 Am data points scaled to 240 Am according to the expected dependence.

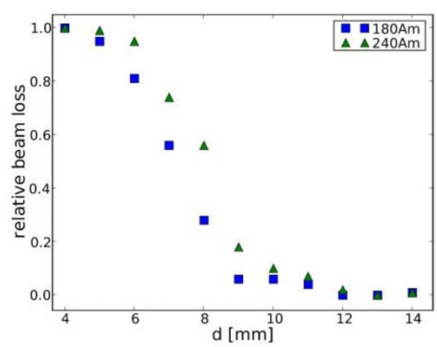


Figure 3: The simulated beam loss reproduces the two stage increase of beam loss at 240 Am but overestimates the one at 180 Am slightly.

Wire current scans

In order to obtain experimental hints on the viability of the LHC phase-2 upgrade optics proposal "dipole zero" [7] (which features few long-range encounter at a reduced beam-beam separation), current scans at various beam-wire separations were performed at 26, 37 and 55 GeV. The three 37 GeV data sets shown in Fig. 4 are consistent among themselves. At a large normalized beam-wire distance, the 26 GeV data set exhibits significantly higher losses already at lowest excitation levels, which must be attributed to the inherently more unstable machine conditions at injection energy (field errors, power converter ripple etc.). The 55 GeV data are similar to their 37 GeV counterparts at low current values, but unlike the latter they do not show any steep increase at about 200 Am.

Figure 5 presents the corresponding simulation results, confirming the previous thoughts: While the 37 GeV data

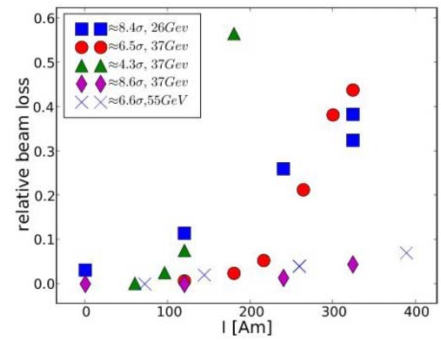


Figure 4: Beam loss as a function of the wire current for various beam-wire separations a t 26 and 37 GeV at $Q_H = 0.31, Q_V = 0.28$.

are reproduced reasonably well, the 26 GeV data are not. The delayed experimental onset of beam loss in the $d = 4.3\ \sigma$ case at 37 GeV is not reproduced in the simulation, possibly because in the experiment some potentially unstable regions of the 6D phase space were cleaned during the preceding 26 GeV plateau. The 6.5–7 σ data reveal similar differences between 37 and 55 GeV in both simulation and experiment: While the 55 GeV data show a smooth slow increase of beam loss, the 37 GeV data are characterized by distinct slope changes.

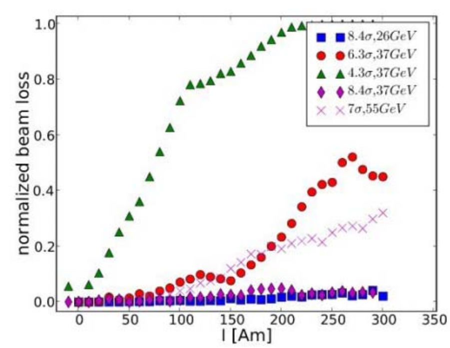


Figure 5: Simulation of beam loss as a function of wire current for various beam-wire separations and three beam energies, at the working point $Q_H = 0.31, Q_V = 0.28$

Chromaticity scan at $d = 6.5\ \sigma$

All experiments mentioned above were performed at low chromaticity $Q' \approx 1$. For nonzero chromaticity, the particles experience a periodic momentum dependent tune variation which causes the particle tunes to oscillate periodically in the $Q_x - Q_y$ plane and thereby to cross resonance lines over and over again. This chromatic effect was studied for a wire excitation of 180 Am at a beam-wire distance $d \approx 9$ mm (6.5 σ).

Unfortunately the limited available measurement interval (a few seconds) was not long enough to reach a saturation of the beam loss. While in the case of horizontal chromaticity variation, at a reduced beam current we observed an exponential decay, heading towards a stable level, the beam losses for large vertical chromaticity did not show any sign of leveling off.

Nevertheless, the available data in Fig. 6 provide a first hint of the strong sensivity to chromaticity. They are summarized in Fig. 6, which also includes the results of a vertical chromaticity scan at 55 GeV. In order to confirm that the beam loss is due to the combined effect of the wire and chromaticity, one case of high chromaticity, $Q' = 12$, but without BBLR excitation was studied as well.

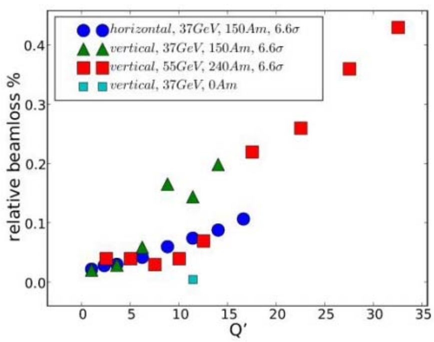
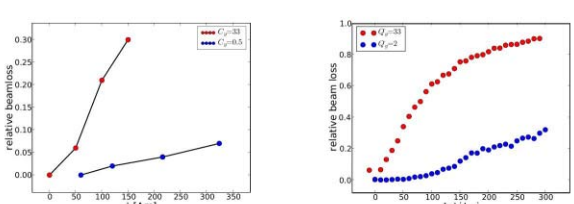


Figure 6: Measured beam loss as a function of chromaticity for $d = 6.6\ \sigma$ at 37 and 55 GeV with varying wire excitations. Simulations reproduce a strong impact of the chromaticity. A quantitative comparison between simulations and experiment is complicated by the fact that the beam loss did not saturate in the few seconds of the measurement interval.

Current scan at $Q'_y = 33$

Finally, a wire current scan was performed for large vertical chromaticity $Q'_y = 33$ at 55 GeV and with a beam-wire separation of $d = 6.6\sigma$. Figure 7 a) compares the result with a scan at low chromaticity. The simulations in subfigure b) reveal a similarly strong chromaticity dependence. The absolute beam loss is about 2–3 times higher in the simulations, which might again be attributed to the limited data taking interval.



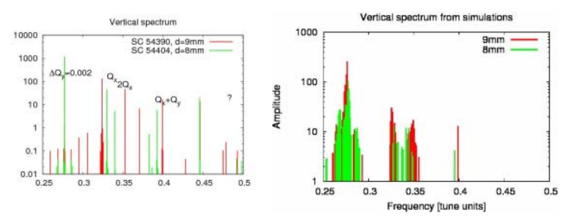
(a) Experimental data (b) Simulations

Figure 7: BBLR current scan at $Q'_y = 33$

1000 turn data

During the 37 GeV measurements 1000 turn BPM data were recorded. These data were analysed and compared with simulated "tracking data" (using an SPS model of single elements in thin-lens approximation). These data can be used to extract the spectral components. Figures 8 a and b compare the experimentally observed vertical spectral lines with the simulated ones for beam-wire separations of 8 and 9 mm at a wire excitation of 240 Am. In the simulation a 6D Gaussian bunch launched with a horizontal offset of 1 mm was tracked over 1000 turns.

The 1mm horizontal offset was put to reproduce the linear coupling. The sextupolar coupling line Qx+Qy is clearly identified in both data and simulations showing a qualitative agreement in the reduction of its amplitude from the 9mm case to the 8mm case.



(a) Experimental data (b) Tracking data

Figure 8: Vertical spectrum

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