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OBSERVATIONS OF SPS SLOW-EXTRACTED SPILL QUALITY DEGRADATION AND POSSIBLE IMPROVEMENTS

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Abstract

The Super Proton Synchrotron (SPS) delivers slow extracted proton and heavy ion spills of several seconds to the North Area (NA) fixed target experiments with a very high duty factor. Reduced machine reproducibility due to magnetic history and power supply ripples on the main circuits lead however to frequent degradation of the spill duty factor. In this paper, the measured effect of the SPS magnetic history on spill quality and principal machine parameters is presented. Another detailed measurement campaign was aimed at characterising the frequency content and response of the spill to noise on the main power supplies ripples. The main findings of this study will also be reported. Finally, simulations of possible improvements based on the data acquired are discussed, as well as an extrapolation to the possible spill quality after the implementation of the improvements.

INTRODUCTION

The SPS provides slow extracted protons and heavy ions to the North Area fixed target (FT) experiments. The need to guarantee very high duty factor for the FT experiments imposes meticulous control of the spill quality. The main sources of spill quality degradation have been identified as the hysteresis effects after modifying the magnetic history of the main magnets and power supply (PS) noise on the main circuits. The effect of these two sources of spill quality degradation can be investigated through the concepts of macro and the micro spill structure, respectively.

As already discussed in [1], the necessity to fulfil the beam requirements of all users, the SPS operates as a cycling machine. Combination of different magnetic cycles are organised in so-called super cycles (SC). Changes of the SC composition causes a different magnetic history, impacting the machine reproducibility and hence the spill macro structure. The quantity used to quantify the effect is the effective spill length [2] calculated from the intensity measurements in the SPS ring using the BCT (beam current transformer) .

The SPS slow extraction [3] is a chromatic extraction driven with the main machine quadrupoles exploiting the third order resonance. Noise on the quadrupole PS has repercussions on the quantity of beam extracted per unit time, and hence the spill quality. The spill spectrum is measured using the 2.5 kHz intensity monitor installed in the extraction transfer line to the NA.

In this paper, measurements of the effect of SC changes and PS noise on the SPS spill quality are presented. The main focus is the reproducibility of the main machine parameters when the SC is changed and the transfer function between the current in the main quadrupoles and intensity extracted. Also, a semi-analytic model to estimate the spill structure for a given machine configuration is introduced. A first benchmark with analytic formulae is finally presented. It is planned to use the model in the future to investigate the effect of measured current ripple on the slow extracted spill and to propose remedies.

EFFECT OF MACHINE NON-REPRODUCIBILITY

The various SPS cycles not only differ for the maximum energy reached, but also for the optics used (e.g. [4]). This implies that, following a SC change, not only the magnetic history of the main bends will be different, but also the one of the main quadrupoles. It was observed that the variation of SC reduces, the spill duty factor (red curve in Fig. 1), by a few percent. Interestingly, the losses in the slow extraction channel are not affected instead (black curve in Fig. 1). This can be explained by the fact that the beam position at the electromagnetic septum (ZS) is not significantly perturbed by SC changes.

In Fig. 2, the difference of the measured mean horizontal position of the beam along the slow extraction cycle, before and after a SC change, is shown. It can be seen that, except for the difference at flat bottom, which can be explained as the radial loop is activated at the start of the ramp, the mean of the horizontal orbit does not change.

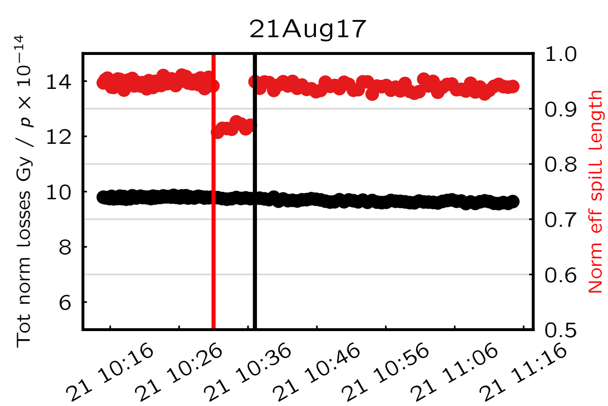

Figure 1: Time evolution of normalised effective spill length and total extraction losses in the slow extraction channel. The vertical red line represents a change in SC and the black vertical line the correction applied on the tune to readjust the spill quality.

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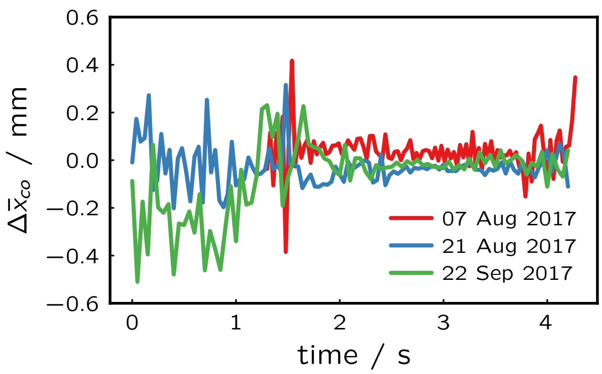

Figure 2: Difference of mean horizontal beam closed orbit along FT cycle before and after a SC change on three different dates.

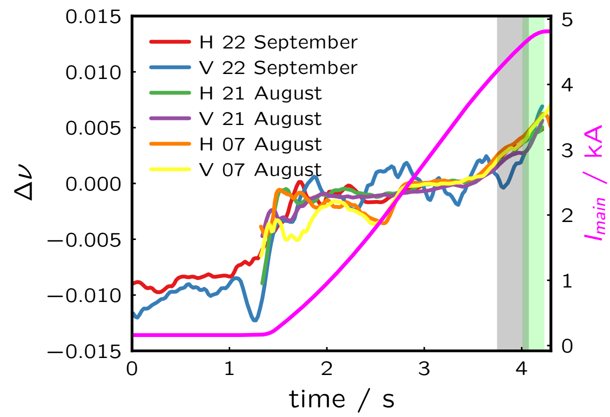

Figure 3: Difference of horizontal and vertical tune along FT cycle before and after a SC change. The magenta line represents the current time evolution of the main SPS PS.

During the same measurement period as in Fig. 1, the transverse tunes were also measured (Fig. 3). At injection, the SC change shifts both horizontal and vertical tune by 0.04%. Then, thanks to the radial loop, the difference in tune from one cycle to another is kept zero for more than half of the acceleration ramp. When approaching the flattop (starting from around 310 GeV/c), the difference diverges from zero reaching about 0.02% at flat top. Such a difference, mainly on the horizontal tune, provokes the above mentioned spill quality degradation. Earlier investigations of the response errors of the main dipoles and quadrupoles, as well as their compensation, are detailed in [5]. It was already observed that, starting from 300 GeV/c and until the flat top is reached, an error between the demanded and measured field is present on all SPS cycles. This effect is more critical for the FT cycle due to its faster ramp.

The difference in the tune functions could originate from the different behaviour between main bends and quadrupoles when the saturation levels are approached. Also, the radial loop is still active at that moment, which could have an additional effect.

The good reproducibility of the tune variation following a SC change shown here could be used to eliminate the observed spill quality degradation by feed-forward compensation. Further analysis and measurements are still needed to fully conclude on the origin of the observed effect to possibly cure it at the source.

EFFECT OF POWER SUPPLY NOISE ON SPILL QUALITY

The spill quality is also significantly influenced by noise on the machine power supplies. At the SPS, the main source of noise has been identified to originate from the main PS, focusing quadrupoles (QF) above all, as consequence of the quadrupole driven slow extraction (in the horizontal plane). As already shown in literature [6, 7], the figure of merit of the sensitivity of the spill to PS noise is the transfer function (TF) between each individual converter and the extracted intensity.

In 2017, a campaign of measurements to characterise the TF for all SPS main PS was carried out. The results for the main focusing and defocusing quadrupoles (QD) are shown in Fig. 4 and 5, respectively. The observed behaviour is the one explained and measured in [6, 7], i.e. the machine with its vacuum chambers acts as a low pass filter for noise as well as the slow extraction itself [8]. At about 300 Hz a reduction of about one order of magnitude in the passing amplitudes can be observed. The same measurements were carried out in two different ways. The blue curve in Fig. 4 (Fig. 5) is the normalised ratio between the Fourier spectra of measured current of the QF (QD) and the extracted intensity over time. The yellow markers, instead, are obtained by injecting external noise into the magnet circuits at each individual frequency and measuring the effect on the extracted spill. Both measurements are in very good agreement with the theoretical prediction presented in [6].

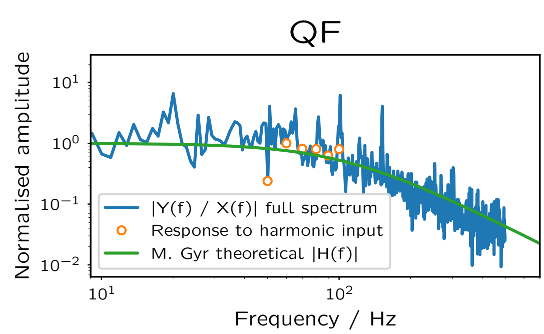

Figure 4: Transfer function between QF PS and extracted intensity.

Simulations of Spill with Power Supply Noise

In order to predict the expected spill quality from a measured current waveform, a semi-analytic model was built. The driving idea is to simplify the slow extraction simula-

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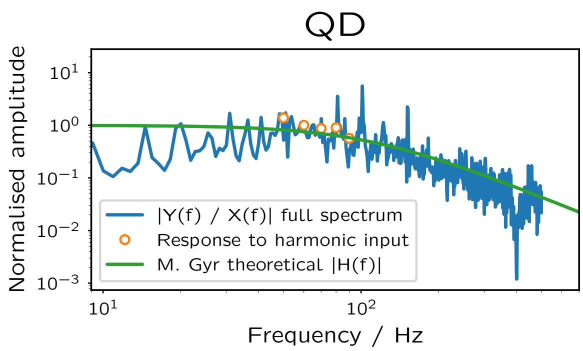

Figure 5: Transfer function between QD PS and extracted intensity.

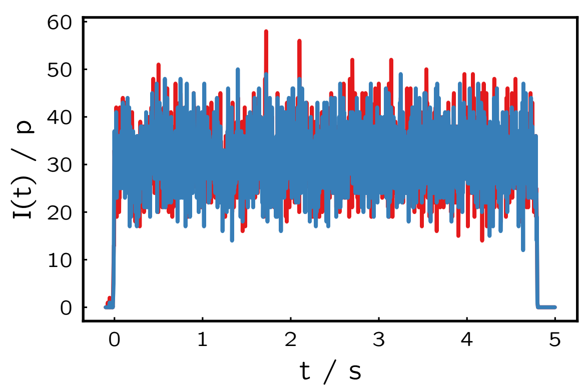

Figure 6: Example of spill structure simulations using the described semi-analytic model. In red, the expected spill structure when 50, 100 and 150 Hz noise on the horizontal tune is injected. In blue, the same noise is used, but the extraction speed was increased by 50 %, together with the extraction sextupole strength.

tions and make them less time consuming. The simplified code was benchmarked with more sophisticated simulations with tools such as MADX [3, 8]. This tool will be used to optimize slow extraction parameters and in the best case reduce the impact of noise, e. g. increasing the absolute value of chromaticity and hence $\dot{Q}_x$.

The first version of this model is built parametrising the probability that a particle can be extracted judging from its transverse amplitude, its momentum and the distance from resonance. Such a probability is parametrised as Gaussian in momentum space and exponential in amplitude space. Then it is shaped using the classic stop-bandwidth definition [9] according to the instantaneous machine tune, hence the distance from resonance, accounting for chromaticity and individual momentum.

The input current is fed into the model decomposing it into its main harmonics and adding it to the main quadrupole current function which is driving the slow extraction. This is used as input to evaluate at each step in time the exact machine tune and the size of the stable area for each particle.

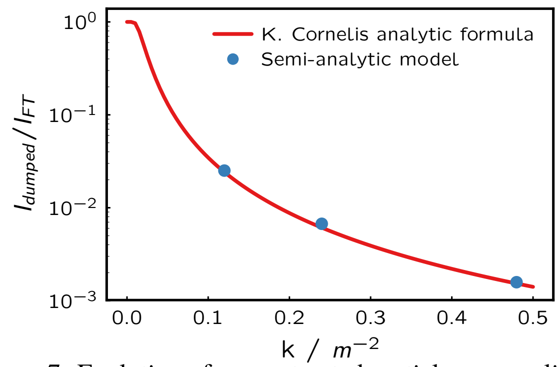

Figure 7: Evolution of non-extracted particles, normalised by the total intensity, as a function of the sextupole strength. In red, the analytic formula presented in [10] is shown. The blue markers represents the results obtained with the described semi-analytic model.

The main SPS machine and beam parameters that play a role in the slow extraction process are taken into account, i.e. chromaticity, sextupole strength, emittance and momentum distribution. An example of two simulated spills (using two different machine configurations) is shown in Fig. 6. The gain in the spill noise level achievable increasing the machine chromaticity (hence the slow extraction speed) by 50 % was simulated to be about 30 % for the main harmonics (50, 100 and 150 Hz). Measurements are still needed to benchmark these predictions.

As a first benchmark, the results from this model have been compared with the analytical description [10] of the effect of faster tune sweep on the non-extracted intensity(Fig. 7).

CONCLUSIONS

For the SPS FT experiments, high spill quality is essential for high quality data taking. The SPS machine non-reproducibility, mainly the horizontal tune, following a SC variation has been identified as the main spill macro structure degradation. Measurements have shown that the horizontal tune changes are reproducible, opening the possibility to correct for them. Investigations are still needed to fully conclude on the origin of these changes and to possibly cure the issue at the source.

The noise on the main SPS power supplies is the cause of unwanted harmonics in the spill structure. Spill transfer function measurements have been carried out confirming the results found in literature. A semi-analytic model that permits fast simulations of spill quality as a function of power supply ripple was also presented. This model, together with the information present in the measured transfer functions, will be used to improve the specifications for the noise on the power supplies and to evaluate possible changes of the slow extraction machine parameters.

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REFERENCES

[1] F.M. Velotti *et al.*, "Investigation of the remnant field of the SPS main dipoles and possible solutions for machine operation", CERN Technical Note no. CERN-ACC-2017-180, http://cds.cern.ch/record/2289649, 2017.

[2] V. Kain *et al.*, "SPS slow extracted spill quality during the 2016 run", CERN Technical Report no. CERN-ACC-2017-121, http://cds.cern.ch/record/2289708, 2017.

[3] F.M. Velotti *et al.*, "Characterisation of the SPS slow-extraction parameters", in *Proc. 7th International Particle Accelerator Conference (IPAC'16*,: Busan, Korea, May 8–13, 2016.

[4] H. Bartosik *et al.*, "Optics considerations for lowering transition energy in the SPS", in *Proc. 2nd International Particle Accelerator Conference*, San Sebastian, Spain, Sept. 4–9, 2011.

[5] J. Wenninger *et al.*, "Dipole field, tune and chromaticity correction at the SPS : from converter tracking to eddy currents", CERN Technical Report no. AB-Note-2007-009 OP, 2007.

[6] M. Gyr, "Proposal for a new servo-spill system: power requirements for different configurations", CERN Technical Report no. SL 95–103 (BT), 1995.

[7] J. Wenninger, "SPS spill quality",CERN Technical Report no. AB-Note-2004-0YY OP, 2003.

[8] J.P. Prieto, "Beam dynamics simulations of the effect of power converter ripple on slow extraction at the CERN SPS", presented at IPAC'19, Vancouver, Canada, paper TUPAF050, these proceedings.

[9] M. Benedikt, "Optical design of a synchrotron with optimisation of the slow extraction for hadron therapy", PhD thesis, Vienna, Tech. U., Geneva, Oct 1997.

[10] K. Cornelis, "Momentum cleaning in the LHC with resonant extraction", LHC Project Note 176, CERN, 1998.