SPS SLOW EXTRACTED SPILL QUALITY DURING THE 2016 RUN

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Abstract

The flux of particles slow extracted with the 1/3 integer resonance from the Super Proton Synchrotron at CERN should ideally be constant over the length of the extraction plateau, for optimum use of the beam by the fixed target experiments. The extracted intensity is controlled in feed-forward correction of the horizontal tune via the main SPS quadrupoles. The Mains power supply noise at 50 Hz and harmonics is also corrected in feed-forward by small amplitude tune modulation at the respective frequencies with a dedicated additional quadrupole circuit. In 2016 the spill quality could be much improved with respect to the situation of the previous year with more performant algorithms. In this paper the improved tools are described and the characteristics of the SPS slow extracted spill in terms of macro structure and typical frequency content are shown. Other sources of perturbation were, however, also present in 2016 which frequently caused the spill quality to be much reduced. The different effects are discussed and possible or actual solutions detailed. Finally, the evolution of the spill quality during characteristic periods in the 2016 run is presented.

INTRODUCTION

The third order resonant extraction at 400 GeV/c from long straight section 2 (LSS2) at the Super Proton Synchrotron at CERN serves the fixed target experiments in the SPS North Area. For an ideal spill, the rate of extracted particles dN/dt should remain constant over the 4.8 s long extraction plateau. The spill is corrected in feed-forward by adjusting the tune directly through the main quadrupoles all around the SPS [1]. Also the fluctuations at 50 Hz and its harmonics are corrected in feed-forward. The servo-quadrupole system in long straight section 1 of the SPS is equipped with a 50, 100, 150 and 300 Hz current modulation of adjustable phase and amplitude for that purpose.

Limitations

The feed-forward based spill control was introduced in 2015 to remove the continuous trajectory changes on the North Area targets caused by the feedback controlled slow extraction [1]. The feed-forward is calculated only upon request. On a shot-by-shot basis, the spill quality relies on the reproducibility of the machine.

The hysteresis of the SPS magnets is not sufficiently modelled in the SPS control system. Any changes to the set of magnetic cycles played one after the other, the so-called super-cycle, have an impact on the beam parameters and hence on the flux of extracted particles during slow extraction. A measure of the uniformity of the spill is the "effective

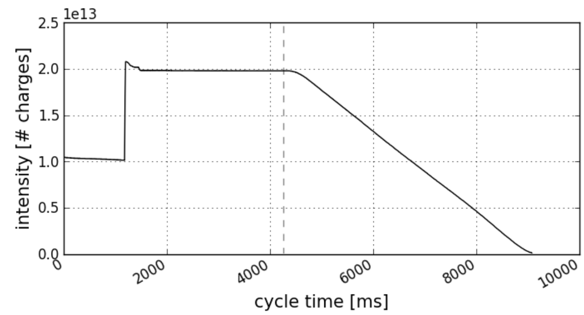

Figure 1: Evolution of the intensity through the fixed target cycle in the SPS in 2016. The dashed line indicates the moment at which the slow extraction starts.

spill length" [2] which is defined as:

$$t_{efs} = \frac{[\int_{t_1}^{t_2} f(t)dt]^2}{\int_{t_1}^{t_2} [f(t)]^2 dt} \quad (1)$$

where $f(t)$ is the extracted intensity as a function of time. Figures 1 and 2 show the evolution of the circulating intensity and extracted intensity calculated from the decay of the intensity during the extraction flat-top. The extracted intensity ramp-up at the beginning of the spill is introduced on purpose as the RF structure takes roughly $\approx$ 500 ms to diminish to an acceptable level for the North area experiments. Any events during this time are not taken into account. The situation in Fig. 1 corresponds to a well adjusted spill and the effective spill length calculated according to (1) is $t_{efs} \approx$ 4500 ms. If LHC 450 GeV/c cycles are added to the super-cycle or the dynamic economy mode is enabled, where the cycles are not fully played in case no beam is injected, the beam parameters will change. The effect on the extracted intensity before running the feed-forward algorithm is shown in Fig. 3 and 4. The effective spill length is reduced to 3800 ms for that case.

2016 EFFECTIVE SPILL LENGTH

The typical value of the effective spill length for the 10.8 s long fixed target cycle in the SPS with a 4800 ms flat-top was $\approx$ 4500 ms. Due to hysteresis reasons, as explained above, the expected spill length could however be much reduced for extended periods. Figure 5 shows the evolution of the effective spill length during 24 h where the LHC was in machine development (MD) and LHC beam had to be provided frequently by the SPS leading to many super-cycle changes. Whereas the first few hours of Fig. 5 are representative for a so-called production super-cycle with

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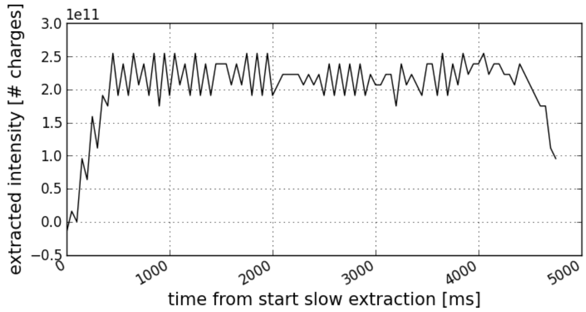

Figure 2: Extracted intensity as function of time on the extraction plateau of the fixed target cycle calculated from the intensity evolution in Fig. 1.

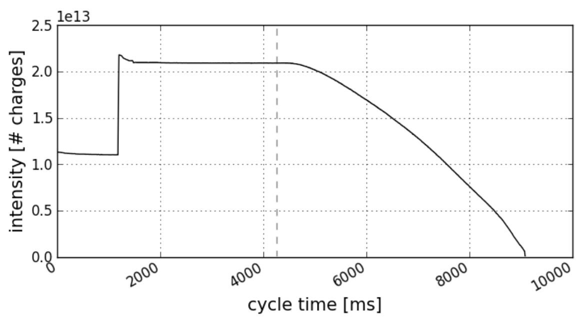

Figure 3: Evolution of the intensity through the fixed target cycle in the SPS in 2016 after a super cycle change. The dashed line indicates the moment at which the slow extraction starts. The beam is not extracted with a constant rate.

high duty cycle for the North Area, the period of the first shaded area is typical for an LHC filling super-cycle in terms of effective spill length. Figure 6 shows the comparison of the distribution of effective spill lengths over 24 h with LHC MD (6th of October 2016) and a typical day with the occasional LHC filling or infrequent super-cycle changes in the SPS(16th of October 2016). Not surprisingly, the more stable running period without LHC MD leads to a narrower effective spill length distribution and also a slightly higher average effective spill length.

The hysteresis of the main dipoles seems to be the main cause of the spill macro structure variations with super-cycle changes [3]. In 2017 online field measurements of the reference magnets will be available. It is hoped that the analysis of this data will allow to build an automated correction algorithm.

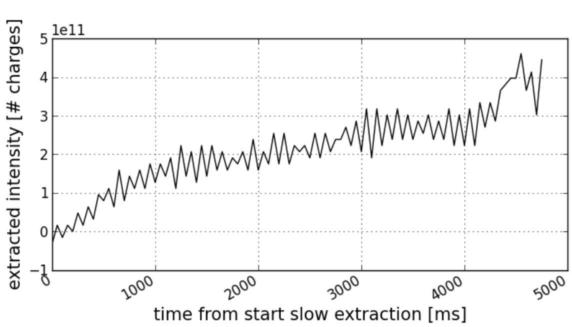

Figure 4: Extracted intensity as function of time on the extraction plateau of the fixed target cycle calculated from the intensity evolution in Fig. 3.

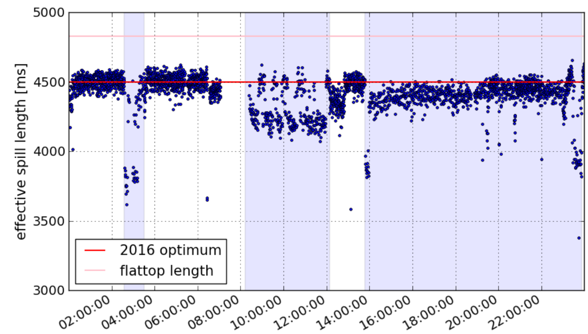

Figure 5: Evolution of the effective spill length during 24 h on 6th of October 2016. The shaded areas indicate times where LHC beam production cycles were in the SPS super-cycle. The first periods included LHC cycles with beam dedicated to the LHC with the LHC not continuously requesting beam such that the dynamic economy was played. During the last extended period a setting-up cycle for LHC beam was in the super-cycle with constant beam request.

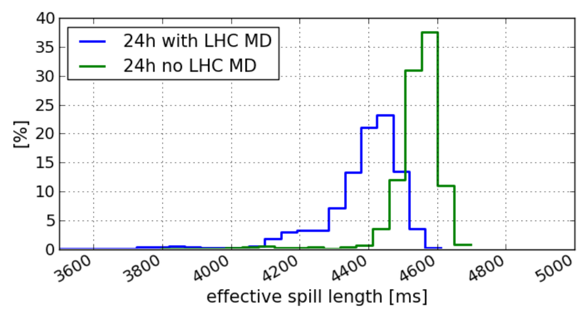

Figure 6: Distribution of effective spill length over 24 h on 6th of October, 2016, with MD in the LHC and 24 h on 16th of October, 2016, without MD in the LHC.

SPILL FREQUENCY CONTENT

As was discussed in [1] the SPS slow extracted spill is strongly modulated at 50 Hz and its harmonics. Without active correction the intensity fluctuations can be as high as 100 %. The amplitude and phase of the 50 Hz and higher harmonics modulations drift over time and the correction has to be frequently adjusted. In 2016 the system used to feed forward a small amplitude compensating tune modulation was calibrated for its spill phase response. As a result of this campaign a deterministic automatic algorithm could be put in place to adjust the modulation parameters. The adequate amplitude of the modulation is derived from an automatic scan.

Despite the more performant tools, the 50 Hz spill ripple seemed to be uncorrectable at times. Recording the evolution of the 50 Hz amplitude without changing the correction

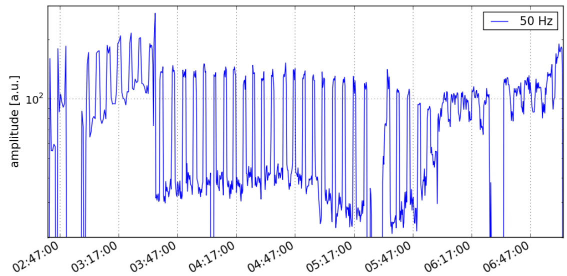

Figure 7: Evolution of the amplitude of the 50 Hz content in the spill. The 50 Hz amplitude bursts occur every few minutes.

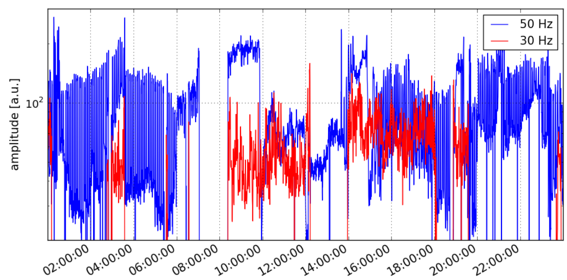

Figure 8: Evolution of the amplitude of the 50 Hz and 30 Hz content in the spill on 6th of October 2016. 50 Hz bursts are also present during most of the time of the observation time.

revealed the cause of this issue. The amplitude of the 50 Hz ripple does not slowly drift over time, but its amplitude is increased by up to a factor 5 for a short period of a few minutes and then decreased again. These bursts re-occur with a period of several minutes. Figure 7 shows an example of such an observation. The bursts are not always present. For the time being no correlation with any modes of operation could be established.

Another problem in 2016 was the fact that strong modulation of the extracted intensity did not only occur at 50 Hz and higher harmonics thereof, but also at about 30 Hz or 65 Hz. The amplitudes of the peaks at these frequencies could be as high as of the 50 Hz lines, Fig. 8, but no active correction is available at these frequencies. The origin of these disturbances need to be found and corrected at the source. The FFT of the current of the QF main quadrupole circuit in the SPS also showed $\approx$ 30 Hz in the spectrum when the disturbance was strong on the spill, see Fig. 9. When the quadrupole power supply was swapped towards the end of the run in 2016, the 30 Hz issue disappeared.

QF CURRENT GLITCHES

Current glitches of the main quadrupole circuit QF were another source of intensity variations during the slow extracted spill. With glitches of sometimes several amperes, large fractions of the intensity are extracted over a short time leading to severe pile-up problems, saturation and trips of detectors for the fixed target experiments. For several years the origin of the glitches could not be identified until an

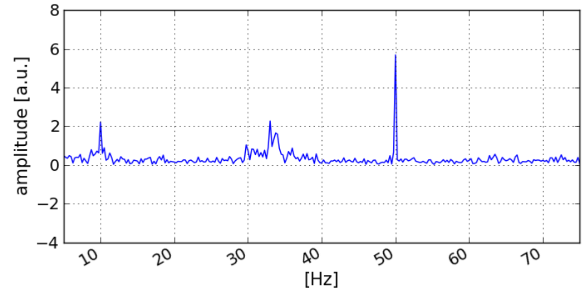

Figure 9: Evolution of the amplitude of the 50 Hz and 30 Hz content in the spill on 6^{th} of October 2016. 50 Hz bursts are also present during most of the time of the observation period.

Figure 10: Photo of the QF busbar location close to QF.12010. The busbar was touching the metallic busbar cover.

extensive and successful investigation was launched in 2016. The culprit had been an intermittent short to ground at one QF busbar location close to the quadrupole QF.12010, see Fig. 10. Since the busbar was repaired on 2nd of November 2016, no more QF current glitches were detected.

SUMMARY & CONCLUSION

The SPS slow extracted spill can be well corrected with feed-forward algorithms controlling the rate of extracted intensity as well as the 50 Hz and higher harmonics spill ripple. Good spill quality on a shot-by-shot basis relies however on reproducibility and several effects lead to that neither the spill macro structure nor the harmonic content of the spill were stable. Uncompensated hysteresis effects of the main field might be the origin of the macro structure changes. Work is underway to understand and model the hysteresis better and make it part of automated correction algorithms. Noise in the spill at 30 and 65 Hz is most probably induced by the main power supplies. Swapping the QF power supply already removed the 30 Hz ripple. More performant tools are now available to correct the 50 Hz and harmonics modulation of the spill. To really profit from these tools though, the origin of the 50 Hz bursts will have to be found and removed. One of the most disturbing problems for spill quality in the years 2015 and 2016, the QF current glitches, could fortunately be resolved in 2016. An intermittent short to ground of the QF busbar was found after thorough simulations and investigations.

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