BEAM EXTRACTION AT THE COOLER SYNCHROTRON COSY

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Abstract

The circulating COSY proton beam can be extracted by the conventional resonant extraction mechanism as well as with the method of stochastic extraction. In several machine runs the extraction mechanisms were studied in the momentum range from 800 MeV/c to 3.2 GeV/c. A new digital noise generator developed at COSY [1] was used for stochastic extraction. At present an extraction efficiency of up to nearly 30% is realized. Spill times up to 30 s were obtained. Results from different machine runs will be presented. It turned out that a spectrogram mode of a vector signal analyzer is a powerful tool to observe acceleration as well as the extraction process itself.

1 INTRODUCTION

COSY Jülich [2] is a cooler synchrotron and storage ring with a proton momentum range from 270 to 3300 MeV/c. Since its inauguration in April 1993 substantial progress in developing beams for the experiments has been achieved and the physics program is now running. Proton beams in a wide energy range have been delivered to internal as well as external experiments.

Briefly, the COSY-ring has a race track design with 40 m long straight sections. Sixteen quadrupoles in each section grouped as four triplets allow the ion optics to be tuned such that the sections act as telescopes with a 1:1 imaging giving either a π or a 2π phase advance. The arc sections have a length of 52 meters each. They are composed of three identical elements that have in themselves a mirror symmetry. A half-cell has a QF-bend-QD-bend structure with the option to interchange focusing-defocusing for added flexibility in adjusting the tune. This structure leads to a six fold symmetry for the total magnetic lattice of the ring. In many synchrotrons it is unavoidable to cross transition energy during acceleration. In previous machine experiments the flexibility of the COSY-lattice was proven which allows a shift of the transition point upwards during acceleration without changing the machine's working point [3]. Eighteen sextupoles are located in the ring, four in each straight sections and five in each arc. They can be grouped in seven families.

2 RESONANT EXTRACTION

At COSY conventional slow extraction extraction is done by creating a resonant condition in transverse phase space through sextupole excitation. For this, the beam is accelerated to the desired flat-top energy. After debunching an orbit bump is introduced in order to move the beam closer to the electrostatic septum (ESEP). At present bumps up to 30 mm are used. The horizontal tune Q = 3.63 is then moved from below close to 11/3. Generally, at least three sextupole groups are necessary for resonance extraction. One group located in the cooler telescopes is used to excite the resonance, the other two placed in the arcs of COSY are used for chromaticity correction in the horizontal and vertical plane. Finally, the beam is extracted by sweeping the horizontal tune linearly through the resonance. An example for preparing the extraction at 835 MeV/c is shown in figure 1. We used an HP 89440A vector signal analyzer in spectrogram mode to observe the time evolution of acceleration and extraction.

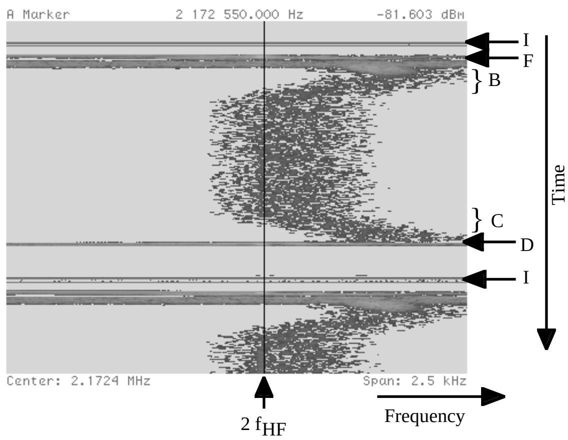

Figure 1: Longitudinal Schottky-spectra versus time. The spectrogram shows a complete cycle of the machine. For details see text.

The spectrogram, figure 1, shows the longitudinal Schottky spectra with a span of 2.5 kHz versus time. It represents one complete cycle of 12 s, label (I) to (I) in the figure. The marked frequency is the 2nd harmonic, 2.1726 MHz, when flat top is reached. The intensity is displayed in a gray scale, the darker the color the higher the intensity is. At (I) the beam is injected and approximately 1 s later flat top energy is reached (F). Due to the small span the acceleration phase appears as a horizontal line (I) in the figure. At flat top the radio frequency is switched off adiabatically and orbit correction is done. This will shift the revolution frequency of the beam upwards by nearly 332 Hz. The beam stays there for 1 s (B). After that an orbit bump with raise time 500 ms is set up, moving the beam outwards closer to the ESEP. By this, the revolution frequency is correspondingly reduced by 192 Hz. The beam with $2 \cdot 10^{10}$ protons and total momentum spread of $1 \cdot 10^{-3}$ will stay there approximately 6 s until the orbit bump is removed. In the time interval (C = 1 s) the beam has again the same revolution frequency as at the beginning of flat top after orbit correction. Finally, the beam is de-accelerated to flat bottom energy (D). The next cycle with a length of 12 s starts at (I).

In figure 2 the extraction process (E) is initiated. The resonance was excited by two sextupoles located in the telescopes. Their necessary strengths and phases can be precalculated depending on the optic of the machine and the desired angle of the outgoing arm of the separatrix at the ESEP. The horizontal tune was linearly swept across the resonance with speed $6 \cdot 10^{-3}$ s^{-1}.

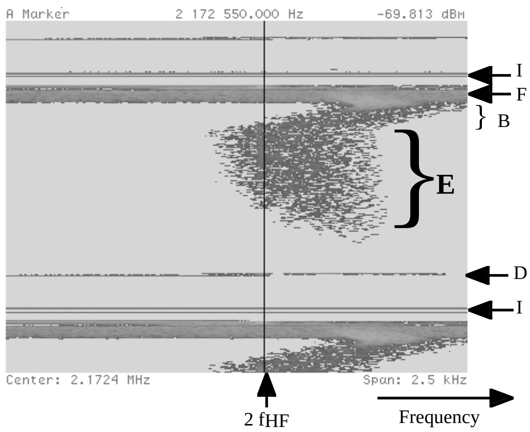

Figure 2: Extraction is initiated. The beam is peeled off from left to right. The high frequency side is not affected.

In this extraction scheme the beam can be considered as a rigid body from which single slices, corresponding to certain momenta, are consecutively taken. Consequently, the spill signal reflects the momentum distribution of the particles circulating in the ring. Due to the negative horizontal chromaticity and the positive frequency slip factor the beam distribution is peeled off in 6 s from left leading to the sharp edge on the right side of the distribution (figure 2). The triangular shape results from the linear increase of the horizontal tune.

As can be seen from figure 3 the derivative of the beam current transformer (BCT-Signal) is proportional to the spill signal. The extraction efficiency was ≥ 10 %. The horizontal and vertical measured emittances of the extracted beam were 3π mmmrad and 5π mmmrad, respectively.

It should be mentioned that the spectrogram display has been found to be a comfortable diagnostic tool to watch and prepare the extraction, especially when using longer spill times. Furthermore, it is a well suitable tool to analyze the time behavior of instabilities or to monitor the vacuum during long time internal experiment runs.

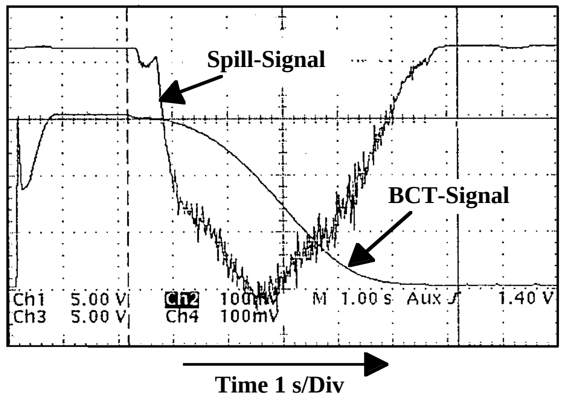

Figure 3: Spill-Signal and beam current transformer signal (BCT) showing extraction at 835 MeV/c with spill time of nearly 6 s.

3 STOCHASTIC EXTRACTION

On contrary to conventional resonance extraction using a linear tune ramp the stochastic extraction mechanism makes use of a diffusion process [4]. A new digital rf-noise generator [1] has been used to apply band-limited white noise of variable spectral amplitude patterns around a harmonic of the beam. The electronic design offers the possibility to tailor sharply band-limited noise spectra of arbitrary shape at center frequencies up to 20 MHz. High resolution components guarantee signal-to-noise ratio better than 60 dB. The bandwidth can be chosen in the wide range from 1 kHz up to 100 kHz. Typical roll-off characteristics of the order of 180 dB/octave are achieved. Two independent digital noise generators are available. Both allow to control the amplitude of the signal and can be triggered by COSY-Control. One module is capable to deliver swept noise with controlled speed < 1 kHz/s. The fully digital design makes the circuit completely predictable, including finite bit resolution. The frequency resolution of the created spectra is 6 Hz.

Longitudinal beam shaping using the novel noise generator was studied in earlier machine runs [5]. In the present case the extraction is set up as described above, however the tune ramp is replaced by noise of constant spectral amplitude and the bandwidth was chosen to cover permanently the resonance. From theory [4] it is then known that the particles will diffuse into the resonance. As expected, both, the circulating beam and the spill signal decrease exponentially. According to theory [4] a flat spill signal can be achieved if the noise power is increased during extraction. A first result is shown in figure 4. The spill time is about 18 s in this case and the spill distribution is more flatten as compared to figure 3. The figure shows that the noise amplitude is increased linearly with increased slope in the second half of the extraction cycle. The data are taken from an earlier run at 800 MeV/c with $5 \cdot 10^9$ protons in flat top.

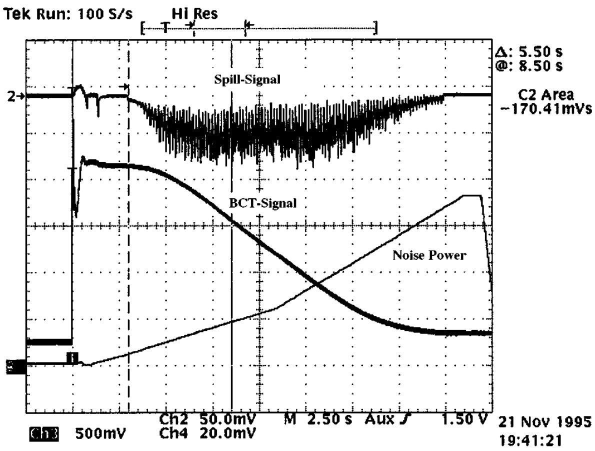

Figure: 4: During extraction the noise voltage is increased to flatten the spill signal. Time scale is 2.5s/Div.

It is known that the maximum spill time in conventional extraction is limited by power supply ripple. Moreover, it creates an unwanted modulation of the spill rate. In order to reduce the latter effects a resonant extraction was set up superimposed with band-limited noise applied around a revolution harmonic. The noise permanently covered the extraction resonance.

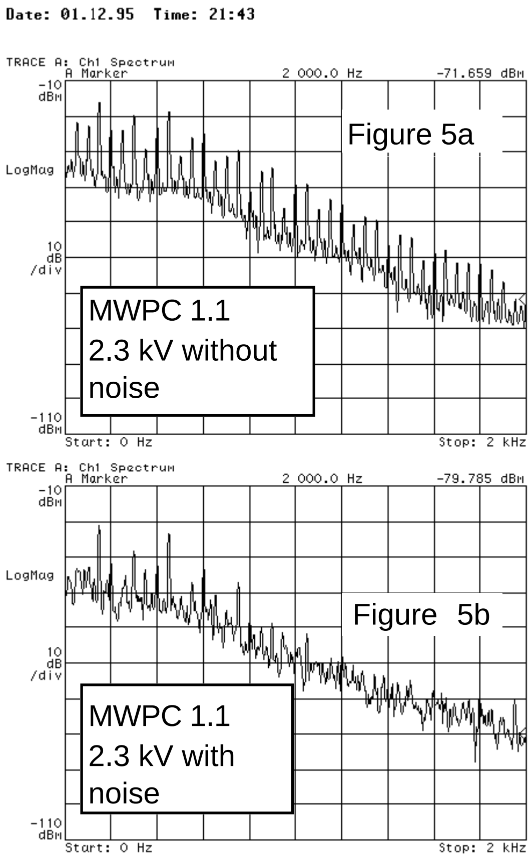

Figure 5: FFT of the spill signal with and without additional noise applied

Figure 5 shows the FFT-magnitude of the spill signal in the frequency range up to 2 kHz with and without additional noise. Without noise the spectrum shows up lines being multiples of 50 Hz, figure 5a. Application of noise significantly suppresses these lines, figure 5b.

4 CONCLUSIONS

At COSY resonant extraction is now used in a wide momentum range serving several external experiments. As an example, conventional resonant extraction at 835 MeV/c has been presented. The spectrogram mode of a spectrum analyzer turned out to be a helpful tool to adjust and to control the extraction process. Possible beam instabilities arising in flat top became clearly visible and could be cured.

The extraction efficiency, being sufficient for the experiments at present, is the major topic which will be examined in future machine runs. To increase the efficiency, different sextupole pattern in the ring will be tested and the relative position of the ESEP to the beam will be optimized to reduce losses. In addition, diagnostic tools to measure the extraction separatrix at the ESEP will be available in future runs.

First results of stochastic extraction were outlined using a novel digital noise generator. This method helped to reduce the power supply ripple significantly. In further machine runs the ultra slow extraction will be brought into operation.

5 REFERENCES

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