DEVELOPMENT OF A FAST BETATRON TUNE AND CHROMATICITY MEASUREMENT SYSTEM FOR COSY

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Abstract

A fast tune measurement is developed for the Cooler Synchrotron COSY at the Institut für Kernphysik of Forschungszentrum Jülich. Betatron oscillations of the beam are excited with a band-limited RF signal via a stripline kicker. Resonant transverse oscillations are then observed using capacitive beam position monitors (BPMs). Based on the bunch-by-bunch beam position data the betatron tune is determined. The usage of bunch-by-bunch data is characteristic of the new system. It allows for a discrete tune measurement within a few milliseconds, as well as continuous tune monitoring during beam acceleration. The high precision tune measurement also enables determination of the beam chromaticity. Therefore, the beam momentum is varied by means of the RF frequency and the subsequent tune change is determined. For routine use during beam operation and experiments, the developed method is integrated into the control system.

Excitation of betatron oscillations

Beam excitation system:

- Arbitrary function generator
- Four 150 W power amplifiers
- Stripline kicker with 1.05 m long electrodes

Characteristics:

- **White noise** signal in adjustable frequency band
- Excitation duration adjustable: typically 25 ms or 2 s
- Alternative mode for sinusoidal sweep excitation
- Adjustable power and duty cycle

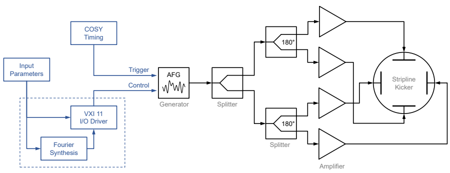

Figure 1: Signal-flow graph of the noise excitation system

Bunch-by-bunch data acquisition and processing

- Beam position measurement with up to 29 COSY BPMs
- **Bunch-by-bunch position** determination with Libera Hadron
- Discrete Fourier transform (FFT or STFT)
- Gaussian fit to the tune resonance $r = f / f_{\mathrm{rev}} \in [0, 0.5]$
- Determination of the absolute tune: $Q = 3 + r$ or $Q = 4 - r$
- Control system integration

Fast tune measurement

- **Fast, non-destructive** measurement
- Measurement time typically 25 ms (triggered)
- Background correction avoids spurious resonances
- Resolution: 10^{-4} (using 2^{13} bunch positions)
- Typical uncertainty: 10^{-3}

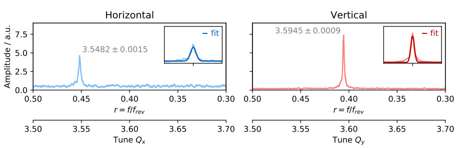

Figure 2: Frequency spectra of a tune measurement with Gaussian fits

Continuous tune measurement

- Short time Fourier transformation (STFT)
- **Tune tracking** for up to 3 s, e.g. during acceleration
- Resolution: 10 ms in time, 10^{-4} in tune (adjustable)

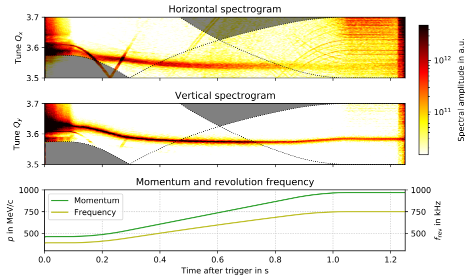

Figure 3: Evolution of the tune as bold line in the frequency spectrograms during bunching and acceleration of a deuteron beam to 970 MeV / c. The dashed lines indicate the excitation frequency band; regions outside the band are shaded.

Chromaticity measurement

- **Momentum change** with RF cavity
- Symmetric frequency sweep of $\pm 0.3‰$
- Linear fits to measured change of tune and frequency
- Separate measurement of slip factor η

$$\xi = \frac{\Delta Q}{\Delta p / p} = \frac{\eta \Delta Q}{\Delta f_{\mathrm{rev}} / f_{\mathrm{rev}}}$$

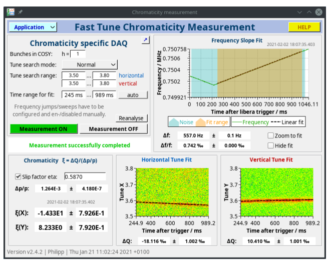

Figure 4: Chromaticity measurement (GUI screenshot)

References

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2. B. Breitkreutz et al. Towards a new Tune Meter for COSY, IKP Annual Report '16
3. P. Niedermayer et al. A Fast Tune Measurement System for COSY, IKP Annual Report '19