Beamloading effects and their influence on cavity detuning in multi-cavity operation in SIS100

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One possibility to reduce the beam impedance in SIS100 is to detune those cavities that are temporarily unused. Beamloading effects during this detuning are still an open topic. Especially the influence of empty buckets as arising in SIS100 scenarios has to be clarified. We show that the resulting side bands in the beam current limit the degrees of freedom for the impedance reduction strategies.

Critical points during the ramp

Previous results have demonstrated that empty buckets have only a small impact on the beam quality, if only one sum cavity is considered [1]. However, the planned SIS100 heavy ion synchrotron will possess 14 ferrite cavities (20 in the final configuration). Especially during injection and at flat top not all cavities will be active, e.g. during the planned $^{238}U^{28+}$ extreme cycle 18 cavities will be in idle mode during injection and are going to be switched on successively. Up to now the effect of the beam current (including empty buckets) on the induced gap voltage in these idle cavities has not been rigorously investigated. Especially it is an open question if the impedance reduction procedures from SIS18 can be applied unaltered while guaranteeing the desired beam quality.

One of the main approaches besides gap switches is the detuning of the idle cavities to some parking frequencies which are sufficiently separated from the exogenous beam loading disturbance. Anticipating that a single bunch may be sufficiently modelled by a Gaussian distribution during regular operation the corresponding Fourier transform of the beam current is:

$$I_B^{SB}(\omega) = \hat{I}_B \sigma \sqrt{2\pi} e^{\frac{-(\omega\sigma)^2}{2}}$$

The frequency components of the circulating bunch train can be obtained by sampling with a Dirac comb with the frequency $1/T_R$, with T_R being the period of revolution. The result is [2]

$$I_B(\omega) = \left(I_B^{SB}(\omega) \sum_{k=1}^{h} \epsilon_k e^{-j\omega k T_{RF}} \right) \sum_{k=-\infty}^{\infty} \delta(\omega - k\omega_R)$$

with σ being the variance of the normal distribution of the particles inside the bucket, h denotes the harmonic number and ϵ_k is parameter equal to 1 or 0 depending on whether the k-th bucket is filled or empty. Figure 1 shows the resulting Fourier coefficients in the cases that eight and ten out of ten buckets are filled with bunches. While in the case that all buckets are filled, only the harmonics appear, the existence of empty buckets leads to considerable sidebands. Consequently, the choice of suitable parking frequencies for the idle cavities is restricted due to the existence of these parasitic components.

Figure 1 shows that for the choice of the resonance frequency of

$$\omega_n = (1/2 + n)\omega_{RF}, \qquad n \in \mathbb{N}_0,$$

the amplitudes of the Fourier coefficients are zero. These frequencies represent natural candidates for detuning of the cavities via the resonance control loop. Due to symmetry, this result also holds during injection, when two buckets are perpetually injected in the synchrotron.

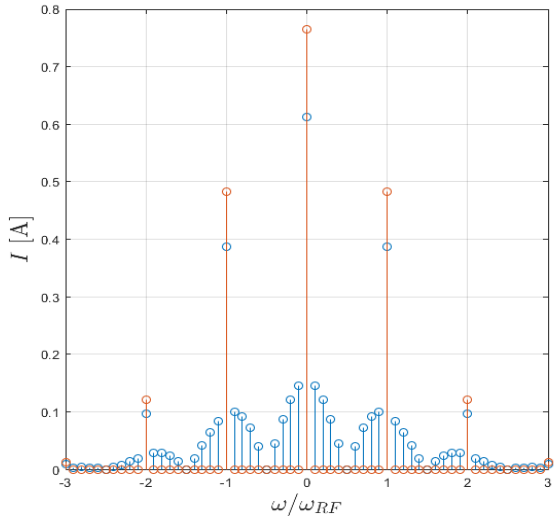

Figure 1: Fourier coefficients of the beam with eight out of ten filled buckets (blue) and Fourier coefficients of the beam with ten out of ten filled buckets (red).

Outlook

For the operation of the SIS100 accelerator with up to 20 ferrite cavities additional investigations are indispensable. Due to the existence of empty buckets, previous impedance reduction strategies from the predecessor SIS18 cannot be directly applied to SIS100. In the case that the cavities will be detuned, extensive simulations will be needed to specify the requirements on the transient detuning dynamics. The assumption underlying this analysis is the Gauss distribution of the particles in the beam. Especially during slow extraction this assumption is not justified. Thus, this case has to be treated separately towards clarifying the question, if impedance reduction via detuning alone suffices to guarantee successful operation.

References

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