Transverse BTF of bunched beams with Gaussian charge density at high energy

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The transverse beam transfer function (BTF) is a widely-used diagnostic tool used in synchrotrons and storage rings. BTFs are commonly used for measurement of the machine tune and of stability diagrams. They can also be used to quantify transverse tune spread due to octupoles [1] or space charge [2] in coasting beams.

In this work the diagnostic power of beam transfer functions (BTF) with respect to bunched beams under the influence of a transverse nonlinearity was investigated in collaboration with Brookhaven National Laboratory (BNL). The work was motivated by the desire to recover the incoherent tune spread introduced by an electron lens such as the one recently installed at BNL for compensation of the incoherent beam-beam tune spread [3] directly via a BTF measurement. At GSI the tune spread caused by incoherent space charge in SIS 100 would be of interest. Building on the work by Berg and Ruggiero [1], transverse BTFs were investigated close to coasting beam conditions. In absence of coherent modes, it could be shown that while the exact distribution of incoherent tunes cannot be recovered from BTFs, the total width of the tune spread can be recovered [4]: In BTFs dominated by transverse tune spread such as BTFs of beams interacting with an electron lens in an otherwise very linear machine, the Landau damping arising from such a transverse nonlinearity dominates the beam transfer function and as a result the width of the peak in the imaginary part of the BTF allows determination of the incoherent tune spread. The recovery of tune spread from analytic BTF is shown in Figure 1.

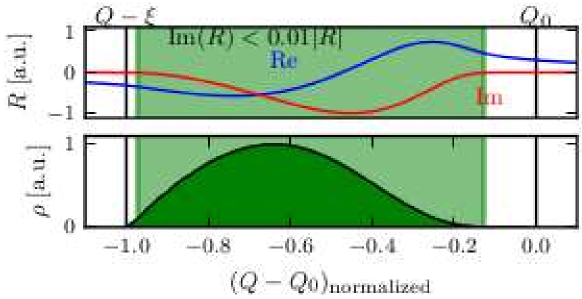

Figure 1: Analytic example BTF R with tune distribution ρ and the recovered tune spread (shaded green).

To apply the analytic coasting beam results to bunched beams, it had to be shown that for the investigated working conditions, the effect of bunching is negligible. Beams in RHIC at high energy show nearly frozen synchrotron motion (synchrotron tunes of 10^{-3} and below). Synchrotron frequencies for SIS 100 proton operation are comparable. The transverse nonlinearity arising from the electron lens acts on particles in a bunch and a coasting beam alike. The assumption was validated in simulation for typical operating conditions. The simulations showed that the BTF did not change notably as a function chromaticity or synchrotron frequency. The recovery of the tune spread introduced by the electron lens works on bunches in simulation. The width of the peak in the imaginary part of the BTF still gives good estimate of the tune spread accurate to about 10-20% when applied to simulated BTF. The uncertainty is primarily caused by noise. The tune spread recovery method can be trivially automatized.

A validation measurement was carried out using the beam-beam effect to replicate the transverse fields of an electron lens while avoiding effects particular to the beam-beam effect. The tune spread recovered by the aforementioned method showed good agreement with the results obtained indirectly from the distance between coherent beam-beam modes in strong bunches and from emittance and beam current measurements.

A generalized theory incorporating conditions for space charge in SIS 100 with protons at high energy is currently under development. The shape of the transverse fields giving rise to the tune spread is identical for a Gaussian electron lens and the self-fields of a transversely Gaussian proton beam. However, while an electron lens acts both on the center of charge of the beam and individual particles and thus also gives rise to a coherent tune shift, this is not the case with space charge: With space charge, the nonlinearity stays spatially aligned with the center of charge of the beam. As a result, space charge is not directly measurable in the BTFs of beams with space charge as the sole source of tune spread. In combination with chromaticity, a characteristic deformation of the BTF was observed for coasting beams [2]. In bunched beams with non-negligible synchrotron motion, a characteristinc pattern of head-tail modes is observed. We are validating the assumption that for near-frozen synchrotron motion, a middle regime exists, where the BTF of bunched beams resemble a superposition of BTF of coasting beams of different currents. In this case, the incoherent space charge tune shift could be obtained by means of a fit against measured BTF data.

References

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