Interpretation of wire scanner asymmetric profiles in a low energy ring

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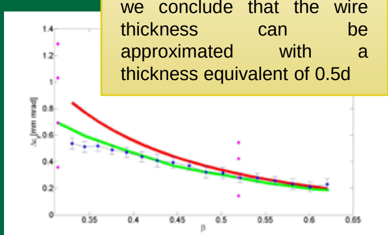
Introduction

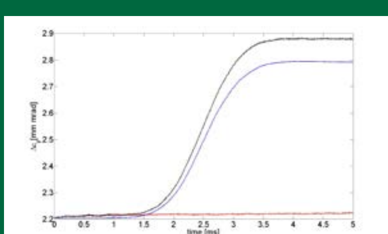
In the CERN PS Booster, wire-scanner profile measurements performed at injection energy are affected by a strong asymmetry. The shape was reproduced with the code PyORBIT, assuming that the effect is due to the beam evolution during the scans, under the influence of space-charge forces and Multiple Coulomb Scattering at the wire itself. Reproducing the transverse profiles during beam evolution allows to use them reliably as input for simulation benchmarking. We assume that the asymmetry is due to two effects and their superposition. The first effect is the Multiple Coulomb Scattering of the beam at the wire itself. Protons of the beam interacts with the atoms of the material of the wire scanner and due to electromagnetic interactions change theirs transverse momenta, which results in emittance growth. The second effect is the space charge, which is very strong in the range of the PSB operation energies (50 MeV – 1.4 GeV), and the fact that the beam might evolve during the measurement time.

Reconstruction of the asymmetric profiles

Based on the presented data we conclude that the wire thickness can be approximated with a thickness equivalent of 0.5d



Theoretical (in red), simulated (in green) and measured (in blue) normalized rms emittance blow up as a function of the beam relativistic beta. Wire speed 10 m/s, assuming 99% confidence interval. The magenta points are a scan over the wire equivalent thickness. We tested a wire equivalent thickness deq of 1.0d, πd/4, 0.5d and 0.25d for the current and future PSB injection energy: 50 MeV (β = 0.314) and 160 MeV (β = 0.52).



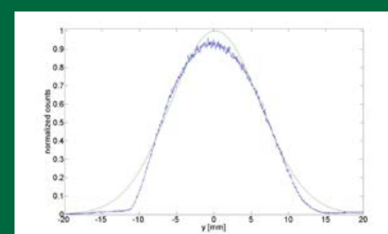
Simulated emittance increase with respect to the time. In red: emittance blow up only due to the space charge, in blue: only due to the Multiple Coulomb Scattering, in black: both effects combined.

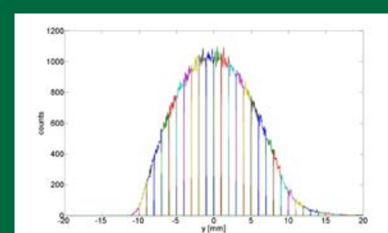
We have modelled in PyOrbit a wire scanner passing through the beam and we have developed a routine to post-process the data and reconstruct the profiles taking into account the time needed to perform a measurement, i.e. a few ms for a 2 mm.mrad beam.

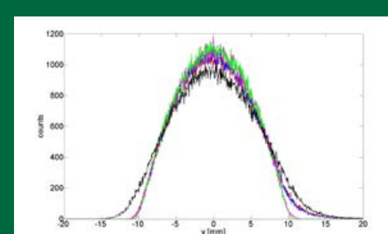
The upper figure on the left present the comparison of the theoretical, simulated and measured data of the normalized r.m.s. emittance blow up as a function of the beam energy during the scan. Based on the presented data we conclude that for purposes of further simulations, the wire thickness can be approximated with a thickness equivalent of 0.5d.

In order to reconstruct the measured beam profile we needed multiple samples of the beam at different time stamps. We dumped the beam profiles every 0.1 ms, simulating the sampling coming from the flying wire scanner. The profile presented on the right (in the middle middle) is therefore a reconstructed profile with the y-position correlated to the movement of the wire, such that the bins around a given position are taken from the profile dumped at the corresponding time. There is a strong, visible asymmetry in the reconstructed profile, to be compared with the experimental data of the upper plot.

In order to identify the different contributions to the profile asymmetry, we simulated five different cases: with/without space charge and with/without Multipole Coulomb Scattering and an artificial case, where we increased the beam intensity by 50% to see whether a strong space charge also leads to the profile asymmetries. The reconstructed profiles are reported in the bottom figure on the right. The dominating phenomena is the scattering at the wire, however the space charge also contributes slightly to its asymmetry.







Measured (top) and reconstructed (middle) vertical beam profile of the shaved beam. Lower plot shows different studied cases. In red: space charge + the wire scanner, in blue: only wire scanner, in magenta: only space charge, in green: none of the effects. The case with an increased intensity is marked with a black line.

Conclusions :

We have measured the emittance blow-up due to Multiple Coulomb Scattering at the wire, as a function of the beam energy and we have compared it with analytical formula and simulations. Based on the results, we identify the wire thickness equivalent needed for further simulations.

With our recipe, we successfully managed to reproduce the asymmetry observed in the measured profiles at low energies in the CERN PS Booster. We have focused our analysis on the profiles measured after beam scraping, during the “shaving” process in the PSB, occurring at around 60 MeV and after which we expect tail repopulation. Our conclusion, for this particular case, is that the Multipole Coulomb Scattering at the wire was the dominant phenomenon, while the tail repopulation driven by space charge had a negligible effect on the measured profile asymmetry.

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