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RESONANCE COMPENSATION FOR HIGH INTENSITY BUNCHED BEAM

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Abstract

Mitigation of periodic resonance crossing induced by space charge is foreseen via classic resonance compensation. The effect of the space charge is, however, not obvious on the effectiveness of the compensation scheme. In this proceeding we report on the experimental campaign performed at SIS18 to investigate experimentally the effect of space charge on the resonance compensation. The experimental results and their consequences are discussed.

INTRODUCTION

Long term beam loss are due to several factors, but lattice nonlinearities and high intensity certainly rank among the main causes for long term beam loss. In fact, numerical and experimental studies have shown that periodic resonance crossing induced by space charge in a bunched beam is a deleterious effect for beam survival [1, 2]. The focus in the mentioned studies was on one dimensional resonances: in Ref. [1] with $4Q_x = 25$, and in Ref. [2] with $3Q_x = 13$. The underlying mechanism leading to beam loss is explained, for 1D resonances, in terms of instantaneous stable islands in the two-dimensional phase space and their crossing of particles orbits [3].

Detailed studies for SIS100 have shown that in the injection scenario of the uranium ions, random components of magnet nonlinearities excite a significant web of resonances including 2D resonances [4], the simpler of which is the $Q_x + 2Q_y = N$. The details of the periodic resonance crossing induced by space charge for coupled resonances have never been studied due to its complexity. In fact, while for 1D resonances the mechanism is relatively well understood, for 2D resonances it is not, as the dynamics is now fully 4-dimensional in phase space. Indication of this complexity have been observed in the experimental campaign at the CERN-PS in 2012, where space charge studies near the resonance $Q_x + 2Q_y = 19$ have shown that beam profiles for some machine tunes acquired an anomalous asymmetry. In this scenario new nonlinear dynamics objects called fix-lines play a similar role as the fixed points for the crossing of the 1D resonances. A full study of the fix-lines is reported in Ref. [5].

In SIS100 operational requirements do no allow beam loss to exceed ~ 5%, and the issue of whether a resonance compensation may be carried out for a long term storage of a high intensity bunched beam or not is of high relevance. Recent numerical studies have shown that resonance compensation in simulations using a *frozen space charge* model has a beneficial effect on long term beam loss [4, 6, 7]. However, it remains to be established if this procedure is effective in a real high intensity bunched beam. In fact, resonance compensation is obtained by creating an artificial driving term that counteract the driving term of the machine nonlinearities. This procedure relies on the assumption that a resonance is excited mainly by a single harmonics. While this assumption works well in standard operational regimes for low intensity beams, it is not obvious what are the consequences for multiple periodic resonance crossing induced by space charge. For these reasons at GSI a campaign for testing the effectiveness of a resonance compensation in presence of space charge has been undertaken.

THIRD ORDER RESONANCE MITIGATION

Figure 1 shows the resonance chart of SIS18 after the recent re-alignment of the accelerator magnets. The apparent mismatch of some of the resonance lines with the theoretical solid lines is due to small systematic tune-shifts present in the machine model used by the control system. The third

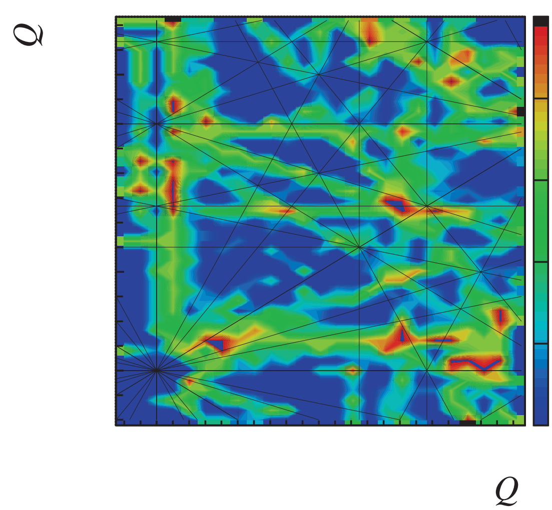

Figure 1: Resonances of SIS18 measured on the 16/7/2014 after the magnets re-alignment. This picture have been obtained by using SISMODI control system.

order resonance $Q_x + 2Q_y = 11$, visibly excited, is of particular interest because a similar resonance will affect the SIS100 for the preliminary working point for ions (example for the uranium beam scenario at the working point $Q_x = 18.84, Q_y = 18.73$) and fast extraction [8].

This resonance strength was estimated by measuring beam loss while the resonance is crossed with linear ramp from $Q_y = 3.45$ to $Q_y = 3.35$ in 1 second keeping $Q_x =$

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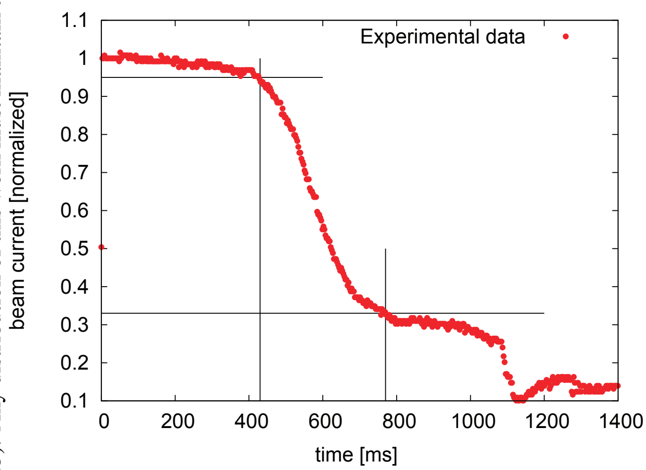
4.2. The beam was coasting with an intensity low enough to prevent space charge effects; in fact, for 2×10^8 ions of U^{73+}, the tune-shift is $\Delta Q_x \simeq -2.5\times10^{-3}$, $\Delta Q_y \simeq -5\times10^{-3}$. In addition, the beam was injected so to fill the transverse acceptances of SIS18, thus emphasizing the beam loss due to resonances. Figure 2 top shows the beam survival during the crossing of the un-compensated machine: only ~ 35% of the beam survives. The beam loss stop-band is found in 450 ÷ 750 ms, which corresponds to $Q_y = 3.375 \div 3.405$.

In order to compensate the resonance $Q_x + 2Q_y = 11$ we created a controlled resonance driving term by using the normal sextupoles of SIS18. We used two sextupoles (GS05KS3C, GS07KS3C) of strength $K_{2,1}, K_{2,2}$, which generate a driving characterized by the strength Λ and by an angle α. As the problem is completely invertible, by setting Λ, α, we obtain $K_{2,1}, K_{2,2}$.



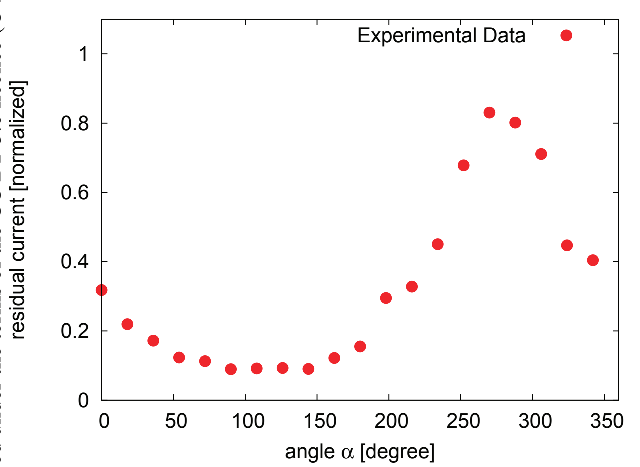


Figure 2: Top: beam survival by crossing the resonance $Q_x+2Q_y = 11$ in 1 second. The survival is ~ 35%. Bottom: best compensation for $\Lambda = 0.025$ at $\alpha = 270$ degree.

Attempts of compensating this resonance at injection energy were obstacled by the resolution of the power supply of the correcting sextupoles. For this reason the resonance compensation was performed at higher energy 300 MeV/u, so that the overall increase of rigidity would also increase the driving term of the resonance allowing the compensation. We proceed first varying α keeping Λ fixed, in this way we found that the angle $\alpha \sim 270$ degree is 180 degree from the phase of the natural driving term. Afterwards we kept fixed $\alpha = 270$ degree and vary Λ to find the optimal value that minimized the beam loss for the crossing the resonance. We find that $\Lambda = 0.025$. (the units of Λ are of integrated sextupole strength, as used in the LSA setting generation system). With this procedure we improved the beam survival from ~ 35% to ~ 85%, see Fig. 3 bottom. The reasons of why a better compensation could not be reached could not be found in the beam time available.

EFFECT OF HIGH INTENSITY BUNCH DYNAMICS

The result of the trade-off with energy plateau for compensating the resonance is the creation of bunches of moderated high intensity. With these bunches the robustness of the best compensation achieved was tested. For this measurement the beam was injected, bunched, accelerated, and stored for 1 second keeping the machine tunes fixed (standard operation mode). We explored the bunched beam survival for several working points along the line $Q_y, Q_x = 4.2$. The beam intensity allowed for a moderate space charge tunes-shift of $\Delta Q_y \simeq 0.05$ corresponding to 6.5×10^8 ions of U^{73+} present in the machine before bunching. This tune-spread is not significantly affected by the chromaticity because the momentum spread of the beam at injection is $(\delta p/p)_{rms} \simeq 7.5\times10^{-4}$, which for the natural chromaticity yields a maximum tune spread of $(\delta Q_y)_{max} \simeq \pm7.2\times10^{-3}$. Hence the space charge is the dominant perturbatoin on the linear dynamics. The same argument shows that the effect of the dispersion enlarges/reduces particles amplitudes of ~ 6 mm, which compared with full machine acceptance, becomes of minor relevance.

The results of the scan are shown in Fig. 3. The red markers show the beam survival without resonance correction. We identify three "valleys" corresponding to the effect of three resonances: the half integer $2Q_y = 7$, the third order 2D resonance $Q_x + 2Q_y = 11$, and the third order 1D resonance $3Q_y = 10$. If we set the tune at the edge of the 2D resonance stop-band at $Q_x = 3.405$ of the scan line, the impact on beam survival is dramatic: in 1 second only ~ 10% of the beam survives, whereas in absence of periodic resonance crossing due to space charge, the beam survival on this working point is nearly 100%.

The blue markers in Fig. 3 show the very same measurements with the two correcting sextupoles activated for the best correction of $Q_x + 2Q_y = 11$, i.e. for creating $\Lambda = 0.025$, $\alpha = 270$ degree (Fig. 2 bottom). We find that the partial resonance compensation achieved still yields an advantage to mitigate beam loss induced by the periodic resonance crossing over 1 second storage. In particular the blue markers show an increased beam survival to ~ 70% in the range $3.435 < Q_y < 3.46$. For $Q_y = 3.42$ the ad-

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vantage is evident as beam survival goes from ~ 30% for the machine uncompensated to ~ 75% with compensation active.

At tune $Q_y \simeq 3.43$ the red curve exhibits a localized change of slope indicating the presence of a weaker resonance possibly of higher order. The effect of this weak resonance is evident when the resonance $Q_x + 2Q_y = 11$ is compensated by the appearing of a new valley in the beam survival. We have no information on the nature of this resonance, except of its weak strength suggested by small beam loss.

We also observe that the resonance compensation here implemented does not affect the other two neighbour resonances, one of which is shown in Fig. 3 (yellow band). In fact, in the region $3.35 < Q_y < 3.37$ and $3.45 < Q_y < 3.48$, blue and red markers fully overlap showing that the compensating method really affects only this resonance (green band in Fig. 3). Other resonances far away from the investigated area might be excited by this compensation scheme, but the discussion of their effect is not part of this study.

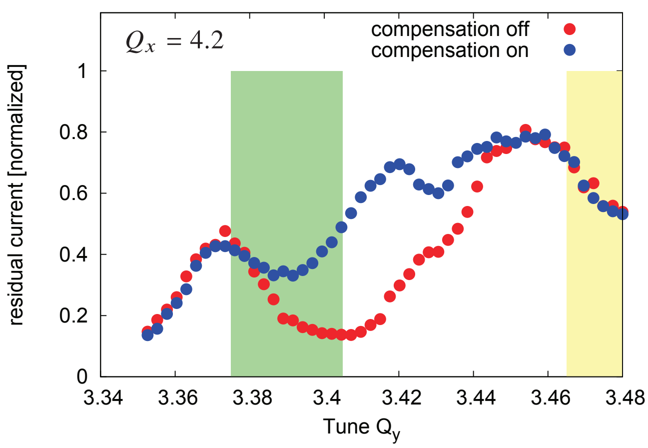

Figure 3: Beam survival for a bunched beam stored for 1 second as function of Q_y. The blue curve is obtained for the partially compensated third order resonance, whereas the red curve is measured for the naked machine.

CONCLUSION/OUTLOOK

The measurements and the results obtained in this campaign allow to conclude the following: 1) The technique used to compensate the resonance seems a promising tool for a first order compensation. The implementation of this "fast" technique completely relies on the feature of the new settings generation system (LSA) for automatizing the data acquisition process. 2) The experimental evidence shows that the resonance compensation for a third order resonance allows to mitigate the beam loss due to the effect of moderate space charge in bunched beams stored for 1 second.

The physics case, and further details on these measurements will appear in dedicated studies.

The following issues remain to be investigated: 1) We have no clear evidences of why we cannot compensate completely the resonance. This may lay in the imperfect knowledge of the optics at the location of the sextupole correctors, or due to other unknown details of the machine. In fact, there are experimental evidences that different pairs of sextupoles excited to create the same driving term do not produce the same beam survival. All these discrepancies require further investigations to consolidate the method and/or to improve it. 2) The verification with the bunched beams was made with a relatively low intensity $\Delta Q_y \simeq 0.05$. The space charge tune-shift here obtained do not compare with that foreseen in the SIS100 scenario, which is expected to be a factor 4 larger. Further measurements on a single third order resonance with more intense beam have to be foreseen to consolidate these first findings.

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