MEASUREMENT OF RESONANCE DRIVING TERMS IN THE ATF DAMPING RING

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Abstract

The measurement of resonance driving terms in the Damping Ring of the Accelerator Test Facility in KEK could help finding possible machine imperfections and even to optimize single particle stability through the minimization of non-linearities. The first experimental attempts of this enterprise are reported in this note.

INTRODUCTION

Resonance driving terms have been successfully measured in CERN [1, 2], BNL [3], Fermilab [4], ESRF [5], ALS [6] and BESSY-II [7]. Most of these measurements have served to find machine errors and/or to minimize the non-linear content of the machine. An overview of the resonance driving term techniques can be found in [8].

For the measurement of resonance driving terms two contiguous BPMs are used in order to reconstruct the transverse momentum of the particle:

$$p_{12}(N) = (x_1(N) + \sqrt{\frac{\beta_{x1}}{\beta_{x2}}} x_2(N) \sin\delta)/\cos\delta \, , \quad (1)$$

where $x_{1,2}(N)$ represent the BPM readings of two contiguous BPMs at turn N, and δ is the deviation from $90°$ of the phase advance between the two BPMs ($\delta = \phi_2 - \phi_1 - \pi/2$). This reconstruction assumes that there are no coupling sources in between the two BPMs. In [9] an analytic expression for the turn-by-turn complex variable $x(N) - ip(N)$ was given as

$$\begin{aligned} x(N) - ip(N) \;=\; & \sqrt{\beta_{x1}} \Big\{ \sqrt{2I_x} e^{i(2\pi\nu_x N + \psi_{x1})} - \quad (2) \\ & 2i \sum_{jklm} j f^{(1)}_{jklm} (2I_x)^{\frac{j+k-1}{2}} (2I_y)^{\frac{l+m}{2}} \times \\ & e^{i[(1-j+k)(2\pi\nu_x N + \psi_{x_1}) + (m-l)(2\pi\nu_y N + \psi_{y_1})]} \Big\} \end{aligned}$$

where $I_{x,y}$ are the horizontal and vertical actions, $\nu_{x,y}$ are the tunes, ψ_{x_1,y_1} are the initial phases and $f^{(1)}_{jklm}$ are the generating function terms. The generating function terms are directly related to the Hamiltonian terms $h^{(1)}_{jklm}$ as follows,

$$f^{(1)}_{jklm} = \frac{h^{(1)}_{jklm}}{1 - e^{-i2\pi[(j-k)Q_x + (l-m)Q_y]}} \, . \quad (3)$$

The terms f_{jklm} can be measured from the spectral line with frequency $(1 - j + k)\nu_x + (m - l)\nu_y$ of the complex variable. For example the term f_{3000} is related to the (3,0) resonance and is responsible of the spectral line with frequency $-2\nu_x$. We represent this spectral line by: line(-2,0).

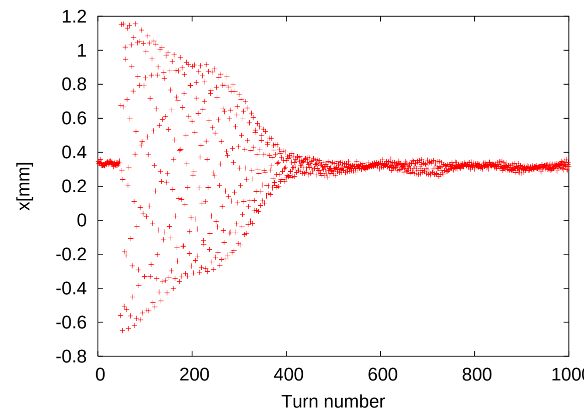

Figure 1: Typical turn-by-turn horizontal signal.

INSTRUMENTATION

The key machine instruments in the measurement of resonance driving terms are the BPM turn-by-turn system and the transverse kickers to excite oscillations at large amplitudes. The ATF DR is being equipped with a large number of turn-by-turn BPMs. However in this paper we restrict to the four double plane turn-by-turn BPMs that have been operational since the beginning. These four BPMs are placed in two sets of two BPMs that allow the reconstruction of the transverse momenta at two locations.

The ATF DR is equipped with horizontal and vertical kickers. Normally two amplifiers are used to feed these kickers. Eventually the two amplifiers can be used to feed the same kicker obtaining larger kicks.

MEASUREMENTS

A series of experiments have been performed to explore the possibilities of measuring different resonance terms.

Measurement of f_{3000} with Large Horizontal Kicks

By using the two amplifiers to kick in the horizontal plane oscillations in the mm level were produced. An example of the typical horizontal turn-by-turn data is shown in Fig. 1. The transverse oscillation is damped due to the decoherence introduced by amplitude detuning.

The main sextupolar line in the horizontal plane is (0,-2), this means with frequency equal $-2Q_x$, and it is produced by the resonance term f_{3000}. This term drives the resonance $3Q_x = N$, N being any integer. The ratio line(-2,0)/line(1,0) is proportional to f_{3000}. The measured ratio for the data acquired on the 11$^{\text{th}}$ of April of 2006 is shown

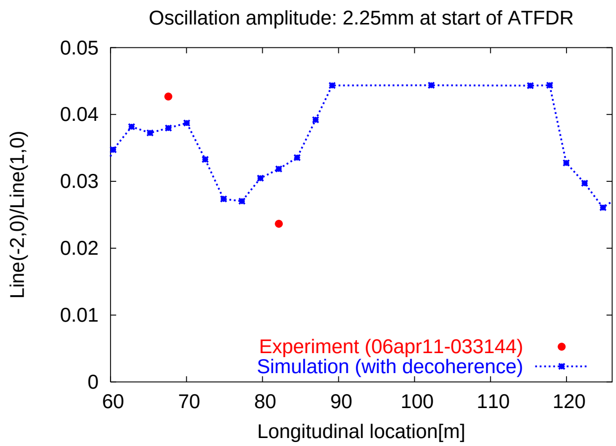

Figure 2: Normalized spectral line (-2,0) from experimental data and simulation.

in Fig. 2 versus longitudinal location together with a prediction from simulations. Since the transverse oscillations are damped due to decoherence, a decoherence factor of two is applied to the simulated spectral line (-2,0) as described in [1].

Measurement of Coupling: f_{1001}

The ATF DR tunes are not particularly close to any coupling resonance, however coupling errors are one of the most important limitations to achieve low vertical emittances. It is possible to measure the resonance driving term of the difference coupling resonance in a way that is BPM-calibration independent and kick amplitude independent. We use the normalized amplitude of the vertical tune in the horizontal spectrum, line$(0,1)_h$ and vice-versa, line$(1,0)_v$ in the following way [2]:

$$2|f_{1001}| = \sqrt{\frac{\mathrm{line}(0,1)_\mathrm{h}}{\mathrm{line}(1,0)_\mathrm{h}}\frac{\mathrm{line}(1,0)_\mathrm{v}}{\mathrm{line}(0,1)_\mathrm{v}}} \qquad (4)$$

During December 2007 a scan over the tune space was carried out to assess the effect of the neighboring resonances. We used this data to evaluate the machine coupling ($2|f_{1001}|$) without expecting big changes on this quantity since the machine tunes are far from the difference resonance. The results are shown in Fig. 3. The average coupling over the tune space is $2|f_{1001}| = 2.5\% \pm 0.3\%$ concluding that there is indeed some important coupling in the machine. The variation of the coupling within this tune area is relatively small as we expected.

Measurement of a Skew Sextupolar Resonance

On Fig. 3 we have seen that the tune scan was limited on the right side by the skew sextupolar resonance (2,1). This resonance is mainly driven by the tilt errors at the machine sextupoles. It can damage the equilibrium emittance if tunes are sitting close by [12] but even more important could be the deterioration of the Dynamic Aperture (and beam lifetime) at nominal tunes if this resonance is not properly compensated. This resonance is observed through the spectral line$(2,0)_v$, i.e. the $2Q_x$ line in the vertical plane. The driving term is f_{2001}. The amplitude of the line has been computed for the tune scan data and is plotted in Fig. 4. A clear increase of the amplitude of the spectral line$(2,0)_v$ is observed as the resonance is approached clearly indicating that this resonance is not fully compensated.

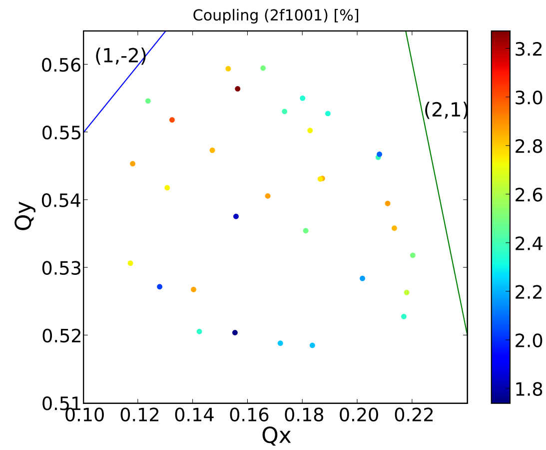

Figure 3: Measurement of the difference resonance coupling term $2|f_{1001}|$ for different tunes. $2|f_{1001}| = 2.5\% \pm 0.3\%$.

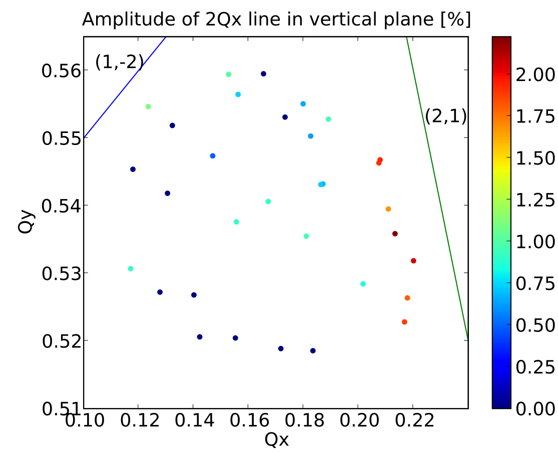

Figure 4: Amplitude of the skew sextupolar resonance (2,1) through the amplitude of the spectral line$(2,0)_v$ versus tunes. The amplitude increases as the resonance is approached.

In order to assess how damaging this resonance can be, we have introduced Gaussian random tilts in the ATF DR model sextupoles with enough standard deviation to reproduce a similar amplitude. The simulated amplitude of the line$(2,0)_v$ is shown in Fig. 5. The required Gaussian distribution of the tilt has a sigma of $\approx$ 10mrad. These tilts should be regarded as effective tilt errors which are a com-

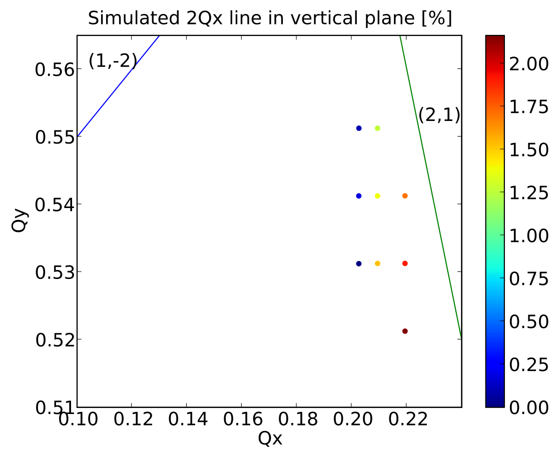

Figure 5: Simulated amplitude of the skew sextupolar resonance (2,1) through the amplitude of the spectral line$(2,0)_v$ versus tunes, matched to the measurements in Fig. 4

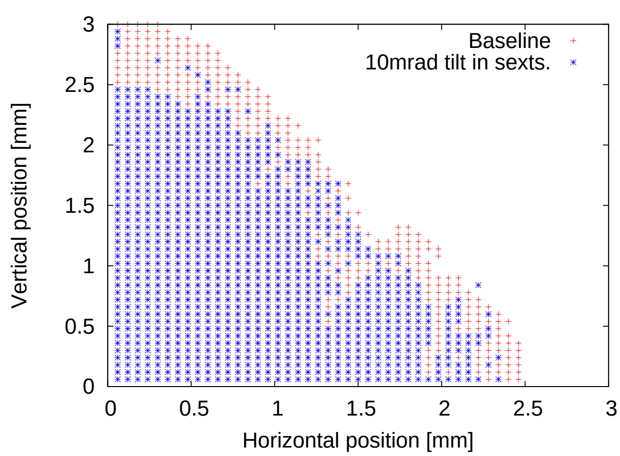

Figure 6: Dynamic aperture of the baseline ATF DR and including the 10mrad random tilts in the sextupoles. A clear deterioration of the DA is observed.

posite of the coupling induced by quadrupole tilts plus the real misalignments of the sextupoles, since the coupling was not zero and it has the effect of rotating the eigenvectors around the machine.

The impact of the estimated tilt errors of the sextupoles is assessed via the computation of the Dynamic Aperture. MADX has been used to determine the DA over 128 turns for the baseline machine and the machine with sextupolar tilt errors. The result is shown in Fig. 6. The DA for the baseline is similar to what has been previously computed for this machine [11]. Roughly a 16-20% reduction on the radius of the stable area is observed due to the sextupolar tilts. This deterioration of the particle stability can reduce beam lifetime and/or injection efficiency.

CONCLUSIONS

The measurement of resonance driving terms has been used to probe the ATF DR. Two sextupolar and one coupling resonance have been targeted. The horizontal (3,0) resonance has been measured at two locations of the ring showing a good agreement with model predictions. This indicates that there are no major errors in the powering of the machine sextupoles. However the skew sextupolar resonance has been found to be excited by an effective random tilt of the sextupoles of the order of 10mrad. These tilt errors can deteriorate the DA amplitude by as much as 20%, possibly reducing beam lifetime and/or injection efficiency. These tilt errors might be the result of adding linear coupling errors plus real sextupole misalignments, since coupling acts like a x-y rotation of the reference system. Therefore the strategy to minimize this harmful resonance should start with a good coupling correction, possibly with a machine realignment. If the resonance would remain strong skew sextupoles should be installed in the machine to minimize it. The spectral line$(2,0)_v$ has proved to be a good observable for this resonance.

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