TRANSVERSE TUNES DETERMINATION FROM MIXED BPM DATA *

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Abstract

Decoherence due to non-zero chromaticity and/or amplitude dependent tune-shift, but also damping mechanisms can affect the accurate tune determination by leaving a limited number of turns for frequency analysis of the turn by turn (TbT) position data. In order to by-pass these problems, Fourier analysis of mixed TbT data from all BPMs can be employed. The approach is applied in two different accelerators, a hadron collider as the LHC and a synchrotron light source as the ANKA storage ring. The impact in the accuracy of the method in the case of missing BPM data is also discussed.

INTRODUCTION

The most common technique for measuring the tune involves application of refined Fourier analysis on recorded beam position data. In the presence of decoherence, the available interval of turns for analysis is limited [1]. An alternative method exists [2], [3], which allows a very fast and accurate tune determination and consists of combining the data from all the BPMs and analysing them.

In this paper, this method is tested on TbT data from the ANKA electron storage ring and the Large Hadron Collider (LHC). The Numerical Analysis of Fundamental Frequencies (NAFF) [4] is employed for the frequency analysis. The analysis is repeated after lowering the noise levels of the TbT data with the Singular Value Decomposition (SVD) method [5] and comparisons are carried out.

DESCRIPTION OF THE METHOD

The method requires the mixing of the original TbT BPM data. More specifically, if the number of BPMs is M, and their TbT signal is of the form $x_M = [x_M[1]x_M[2]...x_M[N]]$, where N the number of turns, the data from all BPMs can be mixed together in the form $\tilde{x} = [x_1[1]x_2[1]...x_M[1]...x_1[N]...x_M[N]]$. In this way, the sampling rate becomes $\frac{1}{M}$ and the new tunes are scaled with respect to the old ones as $\tilde{Q} = \frac{Q}{M}$, where $\tilde{Q}$ and Q are the new and old measured tunes respectively. A one turn periodic error exists, due to the lack of BPM symmetry neither in the longitudinal position nor to the machine optics which introduces an extra frequency modulation without affecting the results. Rescaling the new frequencies $\tilde{Q}$ with M, can determine the integer and fractional part of the betatron tune.

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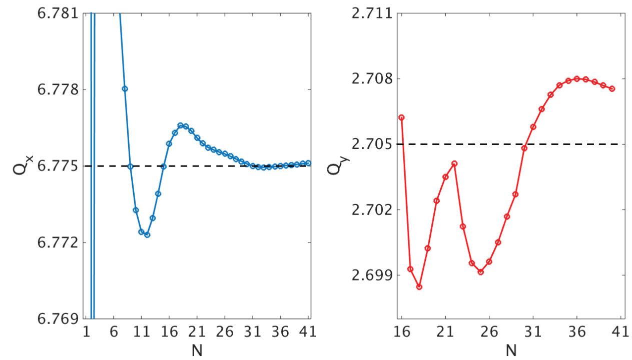

Figure 1: Tune measurements for ANKA. Horizontal tune is in the left column and the vertical tune in the right column. The black dashed line is the measurement produced from the ANKA tune-tracker.

MEASUREMENTS FOR ANKA

ANKA is a third generation light source which features a storage ring with a circumference of 110.4 m. Electron bunches are accelerated to a nominal energy of 2.5 GeV for the production of synchrotron radiation. Betatron oscillations are excited by using the injection kickers and the kick lasts for roughly 3 μs, i.e. 9 turns. Transverse beam position data are recorded from 35 BPMs for about 2000 turns. The ANKA tune-tracker [6] determines tunes of q_x=0.77 and q_y=0.70 for the horizontal and vertical plane respectively. The integer parts of the tunes are Q_x =6 for the horizontal plane and Q_y=2 for the vertical. The frequency analysis of the vertical TbT data shows strong transverse coupling in the frequency spectrum. This can be explained from the fact that the kick delivered to the bunches is horizontal.

In Fig. 1, results from tune measurements using the mixed TbT data method, are shown with respect to the number of turns. The method needs less than 10 turns to determine the horizontal tune and converge to a value within 40 turns. Regarding the vertical plane, this method needs 16 turns for the tune measurement due to the transverse coupling, while convergence is obtained in 37 to 45 turns. This is testified in the top plots of Fig. 2 where the absolute difference between consecutive tune values is presented as a function of the number of analysed turns. This difference becomes of the order of 10^{-4} within 25 turns for the horizontal plane and within 35 turns for the vertical plane. The trend of both curves is decreasing and oscillating with respect to the number of turns due to decoherence. The analysis is repeated after the original TbT data are decomposed in their singular modes and modes with not important information are eliminated. The amplitude modulation, due to the local beta functions, is removed with normalization of the data

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before the application of SVD. The removal of random noise from the TbT can increase precision in tune measurements. However due to the statistical nature of the noise and the loss of information due to the SVD operation, precision can be reduced in some cases. This is verified in the bottom plots of Fig. 2, where convergence measurements are shown for the filtered data with different number of eigenmodes kept in each case. Clearly, the filtering of the data does not affect the results dramatically. In addition, adding more modes in the analysis does not seem to change the estimation of the tunes.

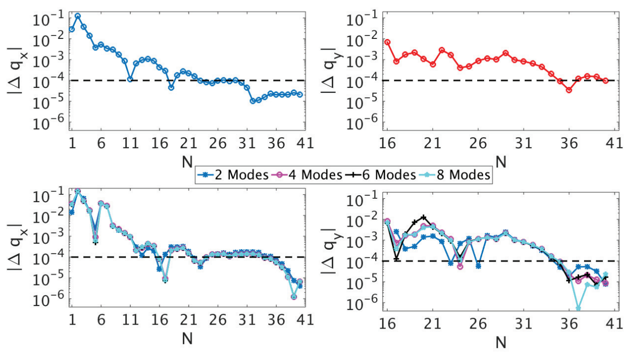

Figure 2: ANKA tune convergence measurements for the horizontal (left column) and vertical (right column) planes. Top row shows measurements with the original data and bottom row measurements for different cases of the filtered data (blue 2 modes, magenta 4 modes, black 6 modes and cyan 8 modes).

MEASUREMENTS FOR THE LHC

The method is applied also on TbT data from a larger and more complicated machine, the LHC. The betatron tunes at injection are $Q_x = 64.28$ and $Q_y = 59.31$. Beam position data are recorded for 2000 turns after using the injection kickers to excite betatron oscillations. At the time of the recording, only 515 BPMs are active. In addition, the analysis reveals 4 BPMs for each transverse plane that are 'noisy'. These are excluded from the TbT dataset, leaving a total of 511 BPMs for the analysis. A further inspection of the TbT data reveals a time synchronization issue for some BPMs. This is shown in Fig. 3 where the turn of the kick is plotted versus the BPMs. In both transverse planes, BPMs between No. 71 and No. 331 do not exhibit betatron oscillations at the turn of the kick. Consequently, this issue introduces an error in the measurement of the phase advance at each BPM. In order to treat this problem, a time-shift of the TbT data is applied on the data from the desynchronized BPMs. The impact of this operation is checked with phase advance measurements using NAFF and there is an agreement between the measurements and the LHC model. Next, the TbT data are mixed and the determination of the fractional is very succesful although the integer part is not well determined. The analysis is also repeated after filtering the TbT data with the SVD method. It is worth noting, that the tunes are always

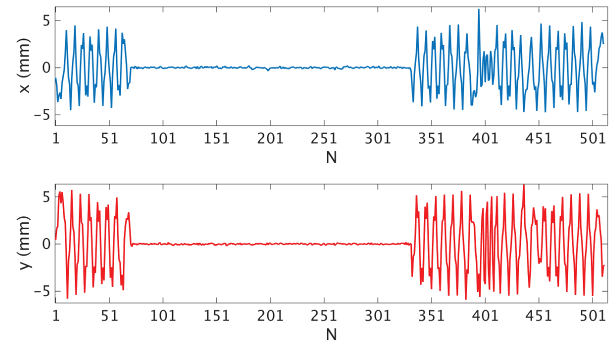

Figure 3: Horizontal (top) and vertical (bottom) LHC data for the turn of the kick with respect to the number of BPMs.

determined since the phase error between the BPMs is one turn periodic.

In Fig. 4 the fractional tunes are plotted for both planes and for the two cases of the TbT data, i.e. with and without the time-shift operation. The measurements are very successful even for the desynchronized data. The method produces accurate measurements from only 3 turns for both planes. The data set without the time-shift operation illustrates larger deviations before that point with respect to the time-shifted data. The same situation is demonstrated in the curve of the vertical plane. All the measurements converge to a value within 10 turns, as it is outlined in the convergence plots of Fig. 5, where the left column depicts results for the horizontal plane and for cases of the original data (top) and the time-shifted data (bottom). In the same way, the measurements for the vertical plane are shown for the original data (top right column) and the time-shifted data (bottom right column). The converegence is at the order of 10^{-5} within 10 turns for all measurements.

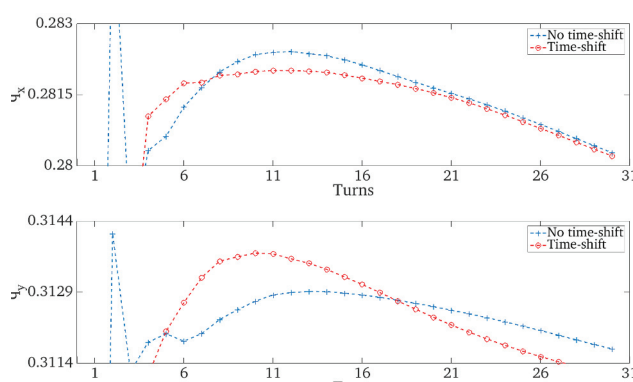

Figure 4: LHC tune measurements for the horizontal (top) and vertical (bottom) for the original (blue) and time-shifted data (red).

In addition, these plots show the measurements for the filtered data by keeping a different number of eigenmodes in each case. Clearly, there are not any significant differences with respect to the results from the unfiltered data. How-

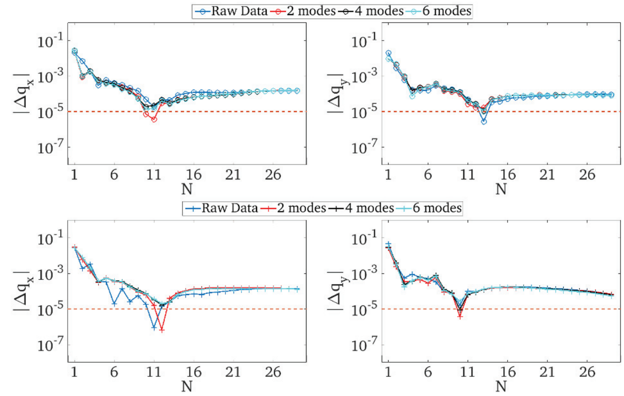

Figure 5: Convergence measurements for the fractional tune of the LHC. Left column is for horizontal plane and right for the vertical plane. Top row is measurements from original data and bottom row is for time-shifted data. The color-code corresponds to filtered data with various eigenmodes kept.

ever some turns exhibit improved convergence and some others decreased. Moreover, the curves follow an oscillatory trend due to decoherence, combined with an improvement in converegence as the number of turns increases.

Spectral Analysis

Harmonic analysis is carried out, in order to investigate the frequency spectrum of the mixed BPM data. In Fig. 6 a sample of the harmonics is shown with respect to their amplitudes and rescaled with the number of BPMs, for the case of 10 turns as at this number of turns, precision of the results is already quite qood. The figures in the top and bottom rows concern the cases of the horizontal and vertical data respectively. Since the TbT data have a different reference in time due to the synchronization issue, the fundamental frequencies of the mixed data are driven to values other than the tunes (62.28, 57.31), while the harmonics that represent the betatron frequencies (64.28, 59.31) are driven to smaller amplitudes. Even if the desynchronized TbT data are time-shifted, the problem still persists. The reason for this is under investigation. However, with the use of the spectral information, it is possible to identify the harmonics which give the betatron frequencies from the original data.

In Fig. 7 the betatron tunes are measured with respect to the number of turns (top row), along with the precission measurements in logarithmic scale (bottom row) for the horizontal (left column) and vertical (right column) planes. The measurements were performed using the original data (blue curves) and the time-shifted data (red curves). For the horizontal plane, the tune is determined in about 10 turns for the non-shifted data but not in successive way as the tune could not be found from turns 15 to 30. The time-shift of the data allows the measurement of the tune in less than 5 turns and succesively. For the vertical plane and for both cases of data the tunes are determined in less than 5 turns. The precission measurements in the bottom row testify the fast convergence of the method. For both planes, convergenece is below the order of 10^{-4} at less than 15 turns for the time-corrected data indicating an improvement in precission with respect to the uncorrected data.

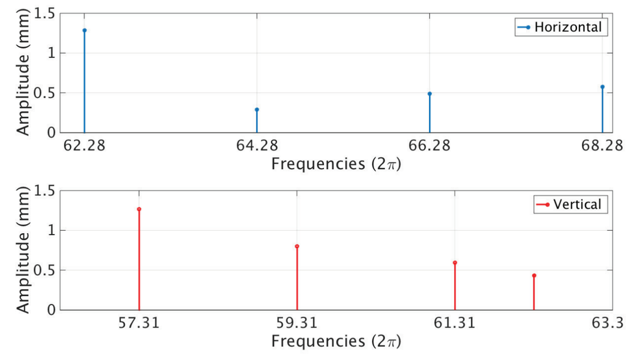

Figure 6: Sample of rescaled frequency harmonics of mixed BPM data from the LHC. Top row conserns results for the horizontal plane while bottom row illustrates the harmonics of the vertical plane.

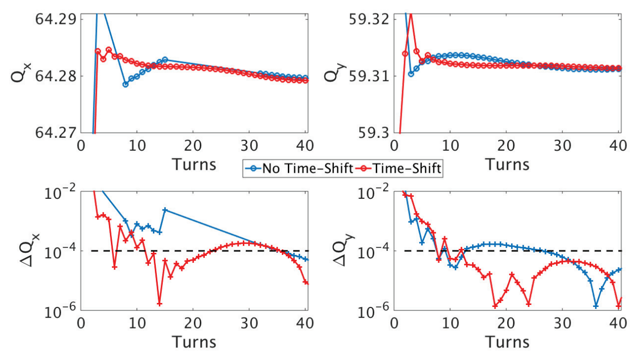

Figure 7: Tune measurements for the LHC. Top row concerns the horizontal (left) and vertical (right) tunes. Bottom row illustrates the tune convergenece measurements. In all figures, the blue curves are the results from uncorrected data while red curves are for the time corrected data.

CONCLUSIONS

Ultra-fast and accurate determination of the betatron tunes is possible with NAFF and the method of mixed BPM data. Concerning the ANKA ring, the horizontal tune is determined from 5 turns while the vertical from 16 turns after the kick. In the case of the LHC a desynchronization issue is observed in the TbT data, however the fractional part of the tunes is measured successfully from 5 turns. In addition, further inspection of the frequency spectra allows the quick and accurate determination of the integer parts from less than 5 turns. The reduction of noise with SVD does not drastically improve the precision of the method for both machines.

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