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DEPENDENCE OF TUNE-SWEEP WAVEFORMS IN DIAMOND ON MODE NUMBER

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Abstract

At Diamond, it was previously observed that the response of the beam changes with mode number when excited by the transverse multi-bunch feedback. This study presents the results of various experimental campaigns carried out to investigate the behaviour of tune-sweep waveforms for a variety of stored beam conditions and TMBF settings. This study identified that not only does the mode dependence appear at a moderate-high beam current but also with a single-bunch only and without the beam. Therefore, there are intensity-independent sources distorting the TMBF output when excitation is applied on different modes. Investigations to explain what is causing the mode-dependent behaviour are ongoing.

INTRODUCTION

It was observed in Diamond that the response of the beam to excitations on the mode 0 differs from the response on the mode 80 [1]. Normally, the excitation is provided by the transverse multi-bunch feedback (TMBF) [2] system performing a tune sweep on all bunches in the frequency range close to betatron tunes, and the excitation mode is 80. Although it was not investigated in a systematic way, long-range wakefields were suggested to cause the discrepancy between the beam responses on modes 0 and 80. If this hypothesis is correct, the beam response must change with beam current and fill patterns. This work summarises the results of various experimental campaigns that have been conducted to validate or disprove the hypothesis.

CURRENT-DEPENDENT MEASUREMENTS

This section presents the results of measurements obtained with the beam. The beam intensity has been varied, and the results are compared when the long-range wakes are the strongest (uniform fill pattern) and when the long-range wakes are negligible (single-bunch measurements).

Uniform Fill Pattern

First, the beam response, also referred to as TMBF output tune waveforms, was measured using the uniform fill pattern at 20 mA, 100 mA and 200 mA. When the gaps in the fill pattern are absent, the coupling between the bunches increases, i.e. the effects related to the long-range wakefields are expected to be stronger. In addition, the beam in this configuration is typically unstable at 70-80 mA. Therefore, transverse multi-bunch feedback was turned on to accumulate up to 100 mA and 200 mA.

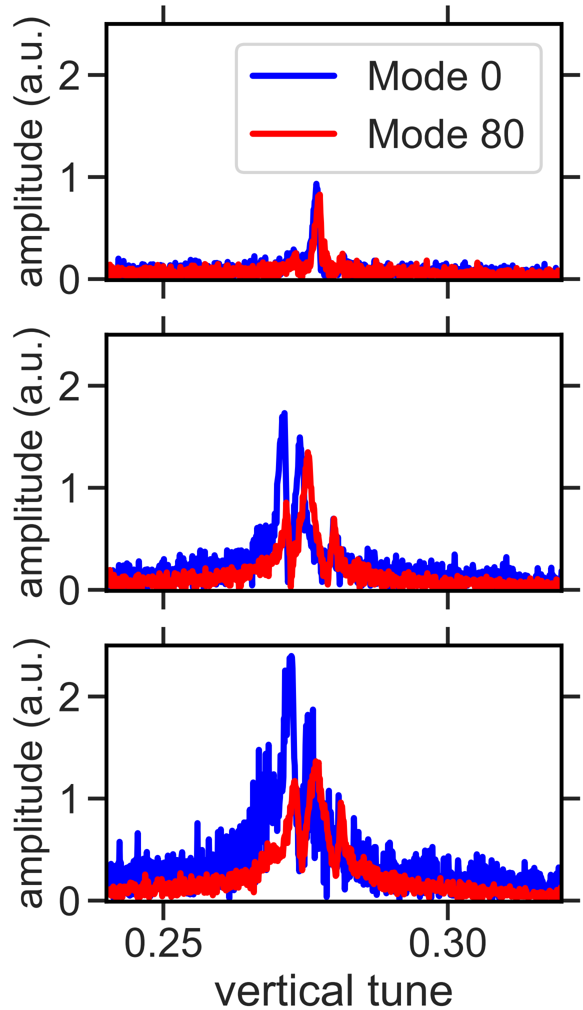

Figure 1: Beam-response waveforms obtained at different beam currents (top 20 mA, middle 100 mA, bottom 200 mA) with the tune excitation set to the modes 0 and 80.

Figure 1 shows the output signals of the TMBF detector recording all bunches. The excitation is applied to all bunches. The blue and red curves correspond to the TMBF excitation applied at modes 0 and 80. The top panel (20 mA) shows a narrow peak which has almost no shift and distortion with the mode number. The middle panel corresponds to a moderate beam intensity of 100 mA, where the blue curve has a stronger amplitude than the red curve. The blue and red curves in the bottom panel (moderate-high intensity, 200 mA) have an even larger difference in their amplitude.

Note that the output signal of the bunch-by-bunch TMBF detectors is proportional at the same time to the bunch offset and the bunch charge. Therefore, the waveforms in Fig. 1

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scale with the beam intensity. However, the noise level increases with intensity only in the case of the blue curve, whilst the signal-to-noise ratio remains the same in the case of the red curve.

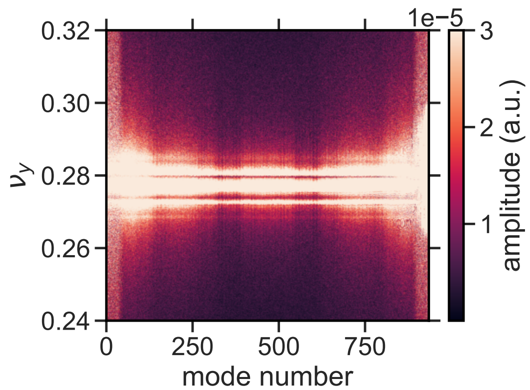

Figure 2: Beam-response waveforms obtained at all excitation modes, the total beam current corresponds to 200 mA.

Next, Fig. 2 demonstrates how the beam response varies throughout the mode-number scan when the TMBF detector records all bunches. It can be observed that the output is symmetric over the central line 936/2, and the strongest amplitudes correspond to the mode number around 0 and 935. Also, the scan features some discontinuity, i.e. sharp lines appear at modes 0-10, 110-120, etc.

Although the results above depend strongly on the mode number with varying beam intensity, there is no clear evidence that this effect is directly determined by the long-range wakes.

Single Bunch Measurements

This section provides a detailed description of the results obtained with a single bunch, or in other words, the scenario where the long-range wakes are negligible. A 0.13 nC bunch in the 9th bucket was used in the same tune sweep on different modes.

Top and bottom panels in Fig. 3 illustrate the single-bunch response recorded by two TMBF detectors. The first detector (top) integrates the signal throughout one turn (all buckets), whilst the second detector (bottom) integrates the signal only throughout the 9th bucket. Note that the colour bar is different because the signals are not normalised. More noise is integrated without gaining any signal when increasing the integration window up to 936 buckets when measuring tunes with a single bunch. Therefore, the colour plot in the top panel is noisy and the tune line with sidebands (compared to the bottom panel) almost disappears, though not completely. There is absolutely no dependence on a mode number when the signal is integrated over the populated bucket. This might be naively interpreted as the evidence of long-range wakes causing the change of the beam response to the tune excitation on different modes. However, using the data from

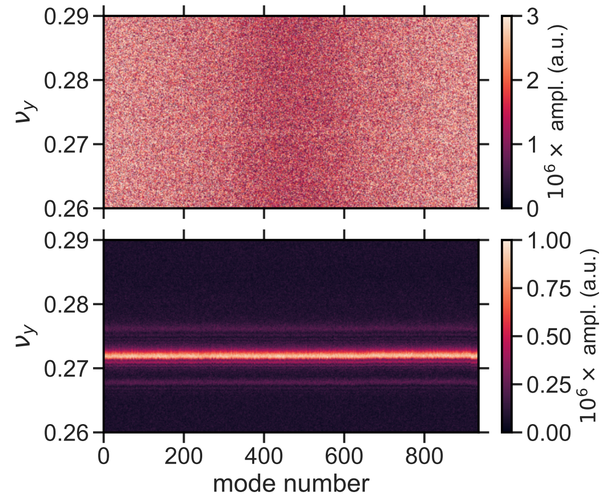

Figure 3: Response of a single bunch to tune excitations applied on different modes when a TMBF detector records all buckets (top panel) and only the populated bucket (bottom panel).

the detector which integrates the signal throughout all 936 buckets, we can observe that more noise is accumulated on lower (0-150) and higher (800-935) modes. Therefore, the mode-dependence shown in Figs. 1 and 2 might be caused by noise amplified on the corresponding excitation frequencies.

MEASUREMENTS WITHOUT BEAM

In this section, it will be argued that the mode dependence occurs not only outside of the beam frequencies but also without any beam in the machine. Figure 4 summarises the results, the amplitude curves are averaged over ν_y for different types of excitations with and without beam.

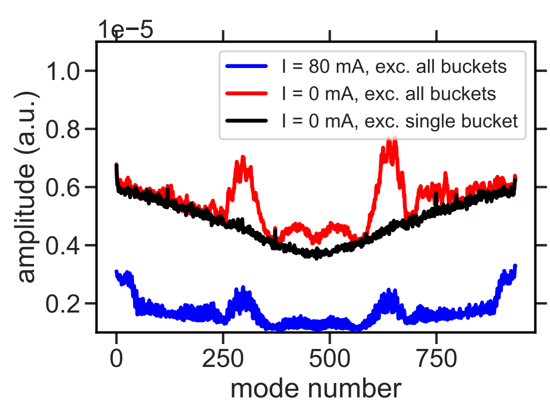

Figure 4: Recorded output signals of TMBF detectors with (blue) and without (red and black) beam, various excitations applied.

The blue curve corresponds to the case of the uniform-fill pattern at 80 mA, whilst the tune sweep was performed at $0.32 < \nu_y < 0.42$ which is well outside the vertical betatron

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tune spread. The red and black curves are recorded without the beam, and they represent two scenarios when the excitation is applied to all buckets and when excitation is applied to a single bucket only. Interestingly, not only do the waveforms feature the linear background increase but also sharp peaks when excitation is applied to all buckets (blue and red curves). In the case of the black curve the mode dependence is quasi-linear. This might be caused by reflections of the applied excitation through the vacuum chamber and signal self-amplification on certain frequencies [3] which depends on the distance between the exciter (stripline) and the receiver (pickup).

In order to test this hypothesis, the same mode scan was repeated, but we simultaneously stored the data recorded by five BPMs adjacent to TMBF striplines including the metrics like the mean value, the standard deviation, minimum and maximum values over 100000 turns without the beam.

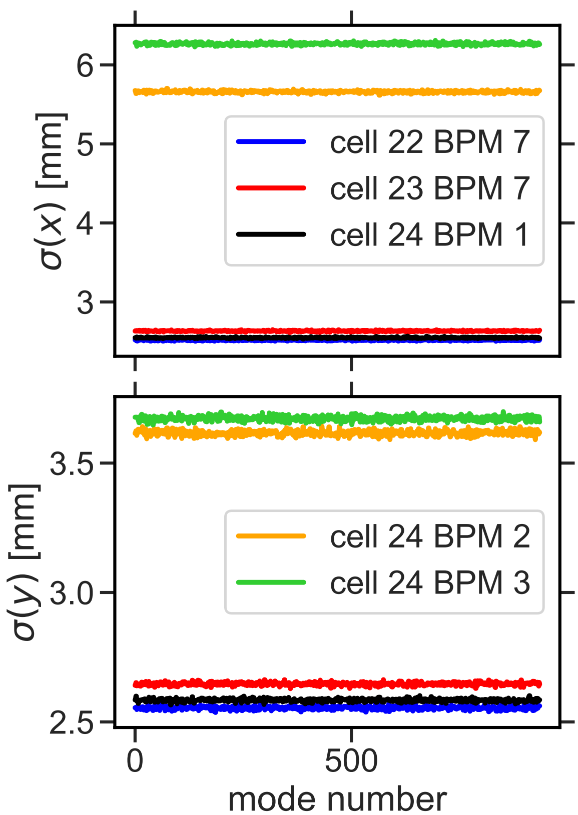

Figure 5: Standard deviation of horizontal and vertical signals recorded by the BPMs adjacent to the TMBF striplines and pickups (100 thousand turns without the beam).

Figure 5 displays the standard deviation in the horizontal and vertical planes (top and bottom panels) for adjacent BPMs depending on the mode number. All curves are flat, and all other metrics follow the same pattern. Regardless of the distance between a BPM and the TMBF striplines, the response is the same on all excitation frequencies. It might mean that all BPMs are located sufficiently far, so the reflected signal decays on a smaller distance, whereas the TMBF pickup is too close to striplines. However, it might also mean that the actual cause of the mode dependence of the waveforms is different, which is to be explored in future studies. For example, considering that the analogue response of BPMs and TMBF pickups is the same, there might be differences in the electronics causing the mode dependence.

SUMMARY AND CONCLUSIONS

Several experimental campaigns were conducted to investigate the mode-dependence of the output TMBF waveforms. First, we compared the waveforms with the beam represented by the uniform fill pattern. It was observed that the output signals depend on the beam intensity, thus long-range wakes were considered as the primary cause. However we then measured the output signals with a single bunch only (long-range wakes are negligible) and the mode dependence was still observed, especially in the case when the TMBF detector integrates the signal throughout 936 buckets. Then, we conducted another set of measurements without the beam and compared them to the output waveforms recorded with the beam but outside of betatron frequencies. The results show a strong variation of the output signals with the mode number depending on the type of excitation applied. Finally, we included BPMs adjacent to TMBF striplines and recorded statistical metrics integrated throughout 100 thousand turns. No mode dependence was observed.

This study identified that not only does the mode dependence appear at a moderate-high beam current but also with a single-bunch only and without the beam. Therefore, there are intensity-independent sources distorting the TMBF output when excitation is applied on different modes. Second, the results of this study show that the amplitude-to-noise ratio is smaller at lower excitation frequencies (modes 0-50). Therefore, for standard tune measurements, it might be beneficial to perform the tune sweeps on higher frequencies but outside of noise peaks (observed in Fig. 2) if the excitation is applied to all buckets. Third, tune sweeps on a single bunch only (locking the TMBF detector to the excited bunch) seem to be beneficial because in this case the mode dependence is absent and the whole beam oscillates with a smaller amplitude, which in turn might increase brightness for the beamlines.

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