

## MD 1856 - Landau Damping: Beam Transfer Functions and diffusion mechanisms

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### Abstract

In the 2012, 2015 and 2016 several instabilities were developing during the betatron squeeze where beam-beam interactions become stronger modifying the tune spread provided by the octupoles magnets. Studies of the stability area computed by evaluating the dispersion integral for different tune spread couldn't explain the 2012 observed instabilities during the squeeze. The size of the stability area given by the computed dispersion integral depends on the transverse tune spread but its shape is defined by the particle distribution in the beams. Therefore any change of the particle distribution due to for instance a diffusion from excited resonances can lead to a deterioration of the Landau stability area. The Beam Transfer Functions (BTF) measurements are direct measurement of the Stability Diagrams (SD). They are sensitive to the particle distribution and contain information about the transverse tune spread in the beams. In this MD we wanted to verify the findings of MD 1407 and try to explain observed instabilities. A scan of the beam-beam separation and crossing angles have been performed to quantify the tune shift measured during the MD 1429.

**Keywords:** Accelerator Physics, beam-beam effects, beam instabilities, BTF, stability diagram

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## 1 Motivation and introduction

The end of LHC run 1 (2012) and the beginning of run 2 (2015) run have been characterized by several instabilities not yet fully understood. Studies of the stability area computed by evaluating the dispersion integral for different tune spread couldn't explain the observations in the squeeze [1]. However the tune spread is not the only ingredient to compute Landau damping. If the particle distribution is changing, due to diffusion mechanisms, it may lead to a deterioration of the stability area. Several diffusive mechanisms have been probed in simulations as possible cause of lack of Landau damping. The Beam Transfer Functions (BTF) measurements are direct measurement of the Stability Diagrams (SD) [2, 3] and therefore they can help to understand if a deprecation of the distributions is occurring and if the non-linearities of the machine are producing the expected spread. The BTF system has been set up and tested during 2015 for several machine configurations [4, 5]. We aim to measure the SD in the presence of beam-beam effects and diffusion mechanisms caused by beam-beam excited resonances. During the previous MD an instability was observed for Beam 1 in the vertical plane [6]. This instability seemed to be correlated to an overlap of the betatron tune and a frequency of a second coherent peak observed in the BTF response. Afterwards this second unexpected coherent peak, present in both beams, was identified as the betatron coherent peak of the pilot bunches accidentally left in the beams during the whole MD. During this MD we also aim to measure the compensation between octupoles and long range interaction with negative octupole polarity since this configuration was never tried in the previous BTF MDs.

## 2 MD Procedure

The experiment was carried out the 10<sup>th</sup> of October 2016. The first part of the MD was dedicated to the observation of the second coherent peak observed in the previous MD 1407. This time the pilots bunches were removed from the beams and the BTF measurements did not show any second coherent peak in the BTF response. Then we injected one lower intensity bunch per beam and acquired BTF for different octupoles current. The second part of the MD was characterized by the studies of Landau damping properties of the beams through BTF measurements. We injected a lower intensity bunch in Beam 1 (B1) of intensity  $I_{B_1} \approx 0.622 \times 10^{11}$  p/bunch and a train of 48 nominal bunches in Beam 2 (B2). As in the previous MDs, the BTF measurements were performed only on the single bunch of B1 with the transverse feedback switched off. At the end of the betatron squeeze a crossing angle scan in IP1 and IP5 was performed with fully separated beams. We reduced simultaneously the crossing angles from  $370\mu\text{rad}$  (full) crossing angle to  $210\mu\text{rad}$  in several steps and acquired BTF measurements in both planes at each step. No instabilities were observed, therefore at the end of the crossing angle scan we performed an octupole current scan after the linear coupling correction in the machine. With the smallest angle, we reduced the octupole current in step of 200 A reaching negative octupoles polarity  $-245$  A.

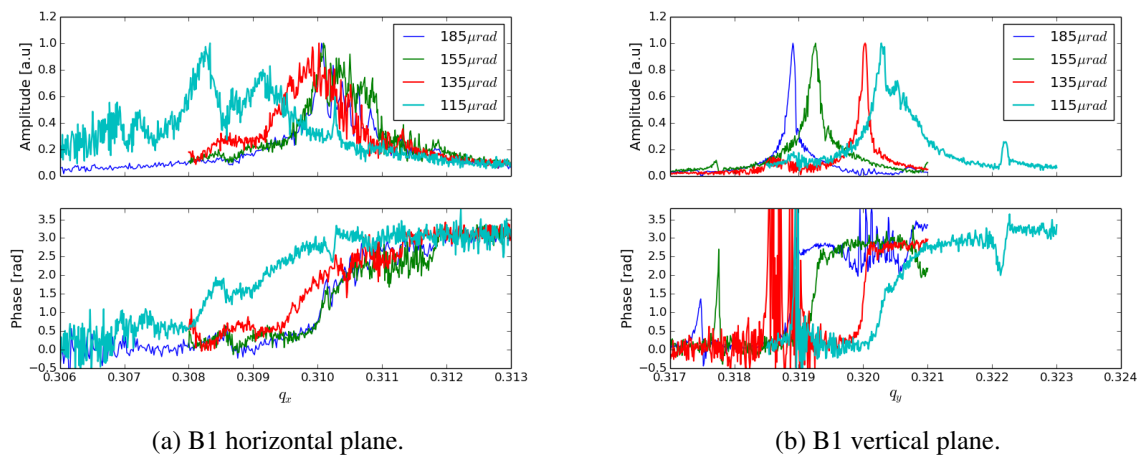


Fig. 1: Measured BTF amplitude and phase response for different crossing angles at the end of squeeze (the given values are half of the crossing angle at the IPs.)

Table 1: Normalized emittances at the end of squeeze.

	Norm. Emittance (H) [ $\mu\text{mrad}$ ]	Norm. Emittance (V) [ $\mu\text{mrad}$ ]
Beam 1	1.8	1.7
Beam 2	1.3	1.2

### 3 Preliminary results

All the BTF measurements were acquired on a single bunch with the transverse feedback switched off in order to avoid its response in the BTF. The BTF response acquired during the crossing angle scan at the end of squeeze are shown in Fig. 1 for some of the crossing angles used during the scan in the first fill. An unexpected tune shift while reducing the crossing angle has been confirmed in [7]. A detailed measurements of the tune shift versus crossing angle was performed and the correction has been implemented in operation based on these measurements [8]. The tune shifts in the horizontal and vertical plane are shown in Fig. 2 as a function of the crossing angle. Measurements were performed on the single bunch of B1. Landau octupoles were set with a current  $I_{\text{oct}} = 470 \text{ A}$ . In this configuration an increase of the tune spread in both planes is expected due to the beam-beam long range and octupole interplay. The beams emittances are summarized in Tab. 1 while the angles used during the scan together with the beam-beam long range separation are summarized in Tab. 2. As shown in Fig. 1, an unexpected asymmetry was observed between the horizontal and the vertical plane: an important tune shift is observed in the vertical plane while reducing the crossing angle. On the contrary in the horizontal plane a big impact on the spread is visible as a function of the crossing angle with a smaller tune shift compared to the one observed in the vertical plane. This configuration was already observed in the previous MD 1407. Further studies are being carried out including global and local linear coupling in the simulations since a coupling correction during the experiment showed a strong impact on BTF response. The coupling correction was performed at the last step with the (full) crossing angle of  $210 \mu\text{rad}$  and the corresponding BTF response is shown in Fig. 3.

After the linear coupling correction (green lines), the tune spread in the horizontal plane reduces while the one in the vertical plane increases. A difference in the local linear coupling at the long range interaction positions between IP1 and IP5 can break the passive compensation of the tune shift leading to possible asymmetries between the vertical and horizontal plane [9]. Simulations are still ongoing for a quantitative comparison with experimental data.

A strong dependency of the spread on the tune value was also observed. A tune correction in the vertical

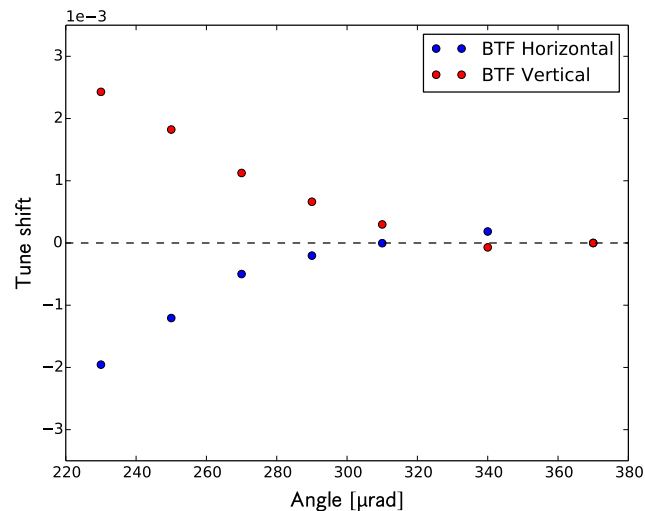


Fig. 2: Horizontal (blue dots) and vertical tune shift (red dots) as a function of the full crossing angle at the IPs.

Table 2: Normalized beam-beam long range separation for different (full) crossing angles used during BTF experiment.

Angle [ $\mu\text{rad}$ ]	BB Long Range separation [ $\sigma$ ]
370	14.52
340	13.34
310	12.16
290	11.38
270	10.60
250	9.81
230	9.03
210	8.24

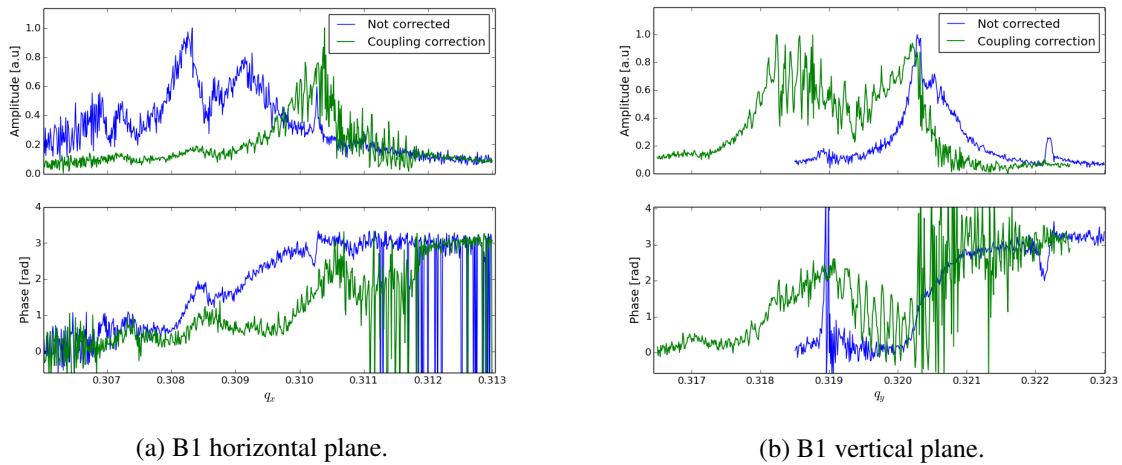


Fig. 3: Measured BTF amplitude and phase response before and after linear coupling correction.

plane for B1 was applied with a negative tune shift of  $\Delta Q = -0.001$  from the configuration with a full crossing angle of  $230\mu\text{rad}$  for which a reduction of the spread is observed. The initial BTF response is therefore restored when increasing the tune of  $\Delta Q = +0.001$ .

Before to conclude the MD, an octupole scan was performed at the last step of the crossing angle scan with the crossing angle of  $210\mu\text{rad}$  (full) in IP1 and IP5). The octupole current was reduced till  $-245\text{ A}$ . The response of the BTF is shown in Fig. 5 for both the horizontal and vertical planes. During these measurements the linear coupling in the machine was corrected. A tune shift is observed while reducing the octupole current in both planes but the vertical one is more affected. A double structure is observed in the horizontal plane with the negative octupole current. The shape of the BTF response in this case is still not understood.

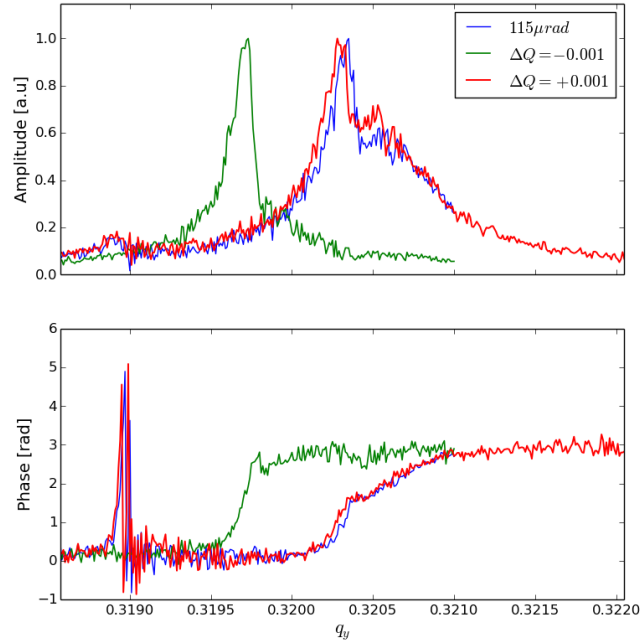
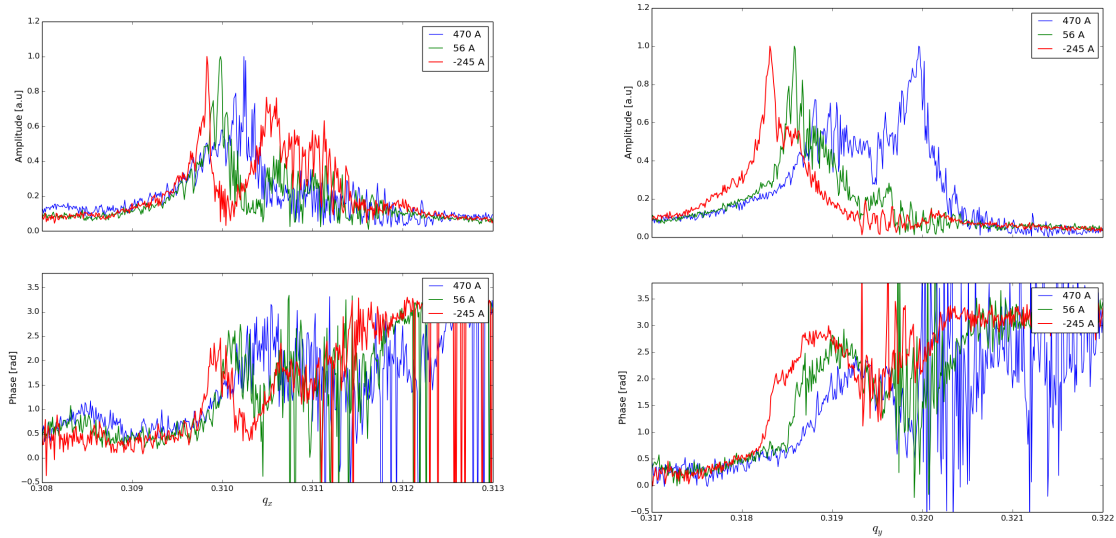


Fig. 4: BTF response for a tune correction in the vertical plane for B1 of  $\pm\Delta Q = +0.001$ .



(a) B1 horizontal plane.

(b) B1 vertical plane.

Fig. 5: Measured BTF amplitude and phase response for different octupole current at the end of the squeeze with a reduced (full) crossing angle in IP1 and IP5 (210  $\mu\text{rad}$ ).

#### 4 Summary

The procedure of the MD has been presented in this note together with some preliminary results. The first part of the MD was dedicated to investigate the presence of a secondary coherent peak observed in the BTF response during the previous MD. No second coherent peak was observed this time in the BTF response, it was most probably due to the betatron tune peak of the pilot bunches left in the beams during previous MD 1407. A crossing angle scan has been performed at the end of squeeze in order to investigate the Landau damping properties of the beams when in the presence of beam-beam interactions

and octupole interplay. An unexpected behavior was observed between the horizontal plane and the vertical plane (as already observed in MD 1407) during the reduction of the beam-beam long range separations. The horizontal tune spread was increasing by reducing the crossing angle while a smaller impact on the tune spread was observed in the vertical plane for several crossing angle steps during the scan. On the contrary an important tune shift was observed in the vertical plane consistent with observations of the beam-beam long range MD 1429. A dependency on the linear coupling was observed after a correction at the last step in crossing angle. An unexpected asymmetric behavior between the horizontal and vertical plane was observed: correcting the coupling the tune spread decreased in the horizontal plane and increased in the vertical plane. Further studies are being performed on this subject to try to explain these observations. At the end of the MD an octupole current scan was performed and measurements were acquired with negative octupole polarity. A double structure has been observed in the horizontal plane with a negative octupole current of -245 A which is still not understood.

## 5 Acknowledgements

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