Transverse Beam Instabilities and Linear Coupling in the LHC

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Transverse beam instabilities were observed in the Large Hadron Collider (LHC) when the effect of linear coupling was known to be large. This motivated a campaign of simulations on the effect of linear coupling on the transverse stability. Measurements and simulations found that the linear coupling was greatly diminishing the effectiveness of the Landau octupoles, leading to a loss of Landau damping. All of the information shown here is summarised from Refs. [1, 2].

I. INTRODUCTION

Transverse beam instabilities had been observed in the LHC when the tunes were moving closer together (Laslett tune shift at injection) or when the coupling was known to be large (the beam measurement of the closest tune approach, $|C^{-}|$ showed an increase to approximately the tune separation). This knowledge, in addition to the examples of transverse beam instabilities see during the energy ramp at the HERA proton ring, hinted at a link between linear coupling and transverse stability [3, 4].

Linear coupling had been used in the Proton Synchrotron (PS) at CERN to stabilise a strong horizontal instability by coupling into the vertical plane [5, 6]. This was possible due to a sharing of the instability rise times between the two planes. These two sets of observations are seemingly in contradiction to each other. This provided the motivation for a study into how linear coupling plays a role in transverse beam stability in the LHC.

II. MAIN RESULTS

It had been known from LHC optics simulations that the presence of linear coupling can change the detuning coefficients from the Landau octupoles [7, 8]. However a link had never been drawn to how this impacts the effectiveness of the Landau damping.

The reduction in the size of the tune footprints due to modification of the detuning coefficients causes a reduction of the stable area of the stability diagram, shown in Fig.1. It can be seen from the figure that instabilities can develop (due to a loss of Landau damping) when the $|C^{-}|$ becomes about 60% of the tune separation, Q_{sep} .

A simple model of the LHC was developed where the strength of the coupling is designated by the value of the $|C^{-}|$. The transverse stability of this model was simulated in the collective effects tracking code PyHEADTAIL [9] and showed similar results to frequency domain computations which were performed using a combination of DELPHI [10] and stability diagram analysis.

Dedicated beam measurements were made in the LHC at 6.5 TeV, where the coupling was accurately measured and the tune separation was slowly reduced until an instability developed. The simple LHC model, as well as frequency domain simulations was seen to agree with these measurements in the machine.

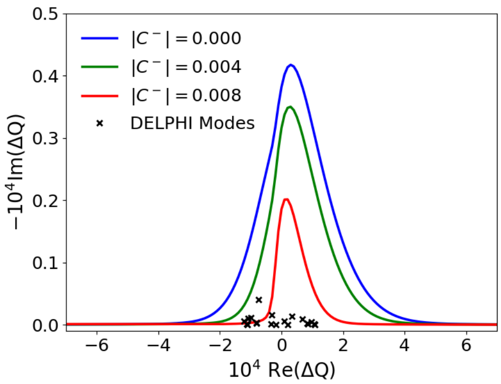

FIG. 1. Comparison of the stability diagrams for fixed tunes ($Q_x = 0.31, Q_y = 0.32$) for different levels of coupling. Shown for comparison are unstable modes computed with DELPHI.

III. FUTURE WORK

Linear coupling is now an integral part of the LHC stability model and must be well controlled in all stages of the machine cycle. New measurement techniques have been employed to ensure that the linear coupling can be measured regularly and accurately to prevent any loss of performance due to transverse instabilities [11, 12].

The studies performed for the LHC only took into account the effect of linear coupling on the tune spread generated by the Landau octupoles. In fact in the LHC there are several other contributors to the tune spread, beam-beam interactions, electron cloud effects and to a lesser extent, space charge (at injection energy). Linear coupling can have an effect on the tune spread generated by each of these effects, it could be either stablizing or destablizing depending on the specific configuration. The full picture of linear coupling and collective effects in the LHC is yet to be studied in detail. With one of the primary sources of unwanted linear coupling coming from the triplets, when the β^* is reduced (as is anticipated for the HL-LHC) the beta-function is increased in the triplets which means that increased linear coupling is expected.

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