OBSERVATION, ANALYSIS AND CURE OF TRANSVERSE MULTIBUNCH INSTABILITIES AT THE ESRF

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Abstract

Characterisation of resistive-wall (RW) instabilities is made by measuring them as a function of filling pattern, chromaticity and the RF voltage. A beam-based modelling of the impedance is compared with expectation and applied to describe the single bunch mode 0 detuning. The description of a nonlinear rise of the threshold with increasing chromaticity requires a stabilising broadband resistive component in addition to the RW impedance. Incoherent betatron tune shifts with the average beam current, observed in both planes with opposite polarities, are suspected be due to a quadrupolar field generated by the RW of chambers having asymmetric cross sections. The effectiveness of a mode by mode transverse feedback to damp the RW instabilities is shown. Transverse instabilities that do not belong to RW are found and identified as being due to ions. First evidences of ion trapping as well as fast ion-beam blow up at the ESRF are presented.

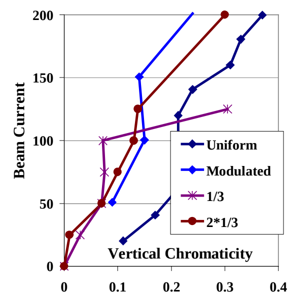
1 INTRODUCTION

Multibunch operations at the ESRF are affected by the resistive-wall (RW) instability in both horizontal and vertical planes. Instability thresholds are raised by shifting the chromaticities to positive values and adopting a partial filling. With increasing number of low gap vacuum chambers for insertion devices, the effect of instability continues to increase. To grasp well the problem as well as to explore better operating conditions, a systematic study of the RW instability was initiated. In parallel, the impact of vertical instabilities on the vertical emittance as well as the effectiveness of transverse feedback were investigated, through which transverse multibunch effects other than the conventional RW have been observed. The present paper gives an overview of the on-gong activities on this subject at the ESRF.

2 RESISTIVE-WALL INSTABILITY

2.1 Observations

Transverse resistive-wall instabilities have long been observed at the ESRF especially in the vertical plane due to smaller chamber gaps vertically. The instability is also enhanced with closure of a scraper as well as of an in-vacuum insertion device gap. Due to the characteristic coupled-bunch (CB) modes $n = h - k$ (k = 1, 2, ...) being excited in the descending order, RW instabilities can be easily identified. Here, h stands for the harmonic number, which is 992 for the ESRF. The instability defines a fixed current above which the beam blows up and injection saturates. As for the transverse single bunch, a positive shift of the chromaticity suppresses the instability as the underlying head-tail motions are stabilised. A successive excitation of head-tail modes m=0, -1, -2, ... driving the CB motion with increasing current and/or chromaticity can therefore be observed.



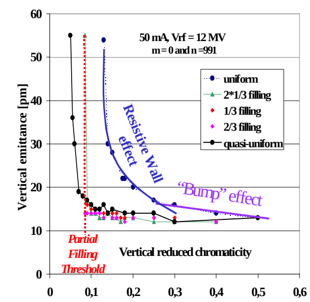


Figure 1: (Left) Vertical RW threshold current versus chromaticity, measured for different filling patters

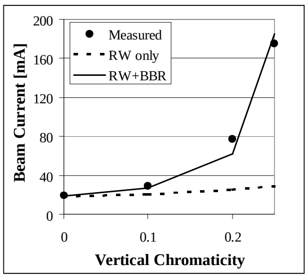
Figure 2: (Right) Vertical emittance measured with a X-ray pinhole as a function of vertical chromaticity, at a given current (= 50 mA) in different fillings

Due to the driving force being the single bunch instability along with a narrow band of RW impedance interacting with the multibunch, the resulting CB instability exhibits a mixture of long and short range nature. Measuring the threshold current as a function of chromaticity, one finds a significant dependence on the beam-filling pattern (Fig. 1). While at low currents, partial fillings are more stable, an inversion occurs at higher currents, suggesting that single bunch effects become relatively important.

Measurement of a small vertical beam emittance (10 pm·rad level) with a X-ray pinhole camera turned out to be an excellent diagnostic for an early detection of vertical instabilities, which came out from coupling correction studies. The vertical emittance growth versus chromaticity measured at a fixed current for different fillings comprises several interesting implications (Fig. 2): - Partial fillings have a clear threshold at around the same chromaticity. - The uniform filling has a long tail of instability effect in terms of chromaticity, and has a threshold at a larger chromaticity (in accordance with Fig. 1). - A non-uniform continuous filling has an extra stabilising effect even compared to partial fillings. Attempts to explain these observations are found below.

2.2 Analysis

RW instability thresholds were computed in the uniform filling to simplify the analysis [1]. A code was written to evaluate the Sacherer's equation including the head-tail and CB degrees of freedom. A threshold is simply defined by equilibrium to radiation damping.



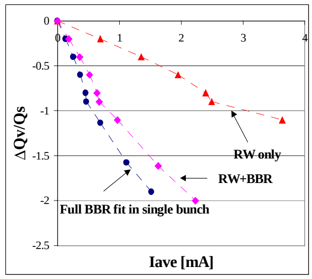


Figure 3: (Left) Measured threshold current versus chromaticity of the vertical RW instability in the uniform filling, in comparison with model calculations

Figure 4: (Right) Single bunch vertical mode 0 detuning using the obtained RW and BBR impedance

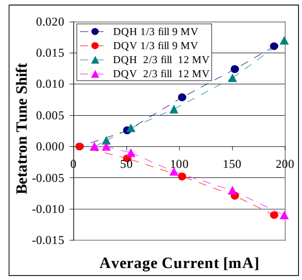
In the vertical fit, use of the RW impedance alone underestimates the measured curve, implying the presence of a stabilising effect, presumably due to the broadband impedance. The Broad-Band Resonator (BBR) impedance was then added. At zero chromaticity, the threshold is unaffected by the BBR, which enables to quasi uniquely determine the beam pipe radius b of the RW impedance, giving 8 mm. It agrees well with b_{eff} =7.3 mm, derived from the evaluation of the RW impedance of the actual low gap chambers. Data points at higher chromaticities were fitted with the shunt impedance R_T of the BBR with Q = 1, while fixing its resonant frequency to 22 GHz, found from the fit to the mode-merging instability. The resulting combination of RW and BBR impedance fairly well reproduces the required amount of mode 0 detuning in single bunch (Fig. 4). Analysis in the horizontal plane as well as in partial fillings is in progress.

2.3 Transverse Feedback

A prototype vertical feedback was installed at the ESRF that makes a mode by mode suppression of instability on two independent (CB) modes. It was demonstrated in the uniform and a partial filling that it suppresses the two strongest RW CB modes (991 and 990), restoring both the vertical emittance and lifetime. The machine can thus be operated at a reduced chromaticity, possibly achieving some gain in lifetime. The mode by mode feedback is to be put in operation in the coming month.

3 MULTIBUNCH DETUNING

Betatron tune shifts with the average current (Fig. 5) remained long as a puzzle not finding their origin. This was especially true after verifying that it is not due to orbit shifts, because if it were an impedance effect, it would imply that the beam sees a capacitance horizontally, whose effect is as strong as the vertical. When a RW effect was suspected due to its long-range nature, we came across Ref. 2 that showed that RW chambers with non axis-symmetric cross sections induce a mean quadrupolar field. This means that observed tune shifts are incoherent, which is consistent with the observation that all head-tail modes shifting in parallel.



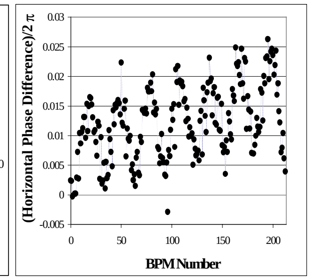


Figure 5: (Left) Observed betatron tune shifts with current in different fillings

Figure 6: (Right) Difference of horizontal phase advance around the ring, measured with thousand-turn BPMs

The low gap chambers distributed around the ring for insertion devices must then be suspected. The larger horizontal betas at these positions are also in favour of the larger horizontal tune shifts. Another indirect evidence was obtained from a horizontal betatron phase advance measurement attempted with the thousand-turn BPMs developed at the ESRF, which has a micron resolution on the turn by turn basis. The method was capable of detecting a quadrupole error of 10^{-4} level introduced in the ring. The measured phase difference between 5 and 190 mA in 1/3 filling indeed showed a quasi steady increase around the ring (Fig. 6). Note that a beating of 7 periods is due to the optical structure. What counts is the way the average of the oscillation increases around the ring. This detuning effect may also explain the extra stabilisation found in the quasi-uniform filling (Fig. 2): i.e. Landau damping with tune spread due to the short range part of the mean field. A small horizontal tune shift measured between the head and the tail of the bunch train in 1/3 filling favours this explanation. Quantitative analysis of the described multibunch detuning is in progress.

4 EFFECTS OF IONS

4.1 Ion Trapping

The long chromaticity tail of the residual vertical instability in the uniform filling (Fig. 2) was initially supposed to be due to an enhanced RW instability in the respective filling owing to its short range nature. Through feedback studies looking at suppression of different CB modes, however, it became clear that the tail is actually due to excitation of modes that do not belong to the RW instability. They are typically around five times the revolution frequency (5F0) and constitute a *bump* like shape (Fig. 7). The fact that the bump only exists in the uniform filling, notably in the vertical plane, raised the suspect towards ion trapping[1].

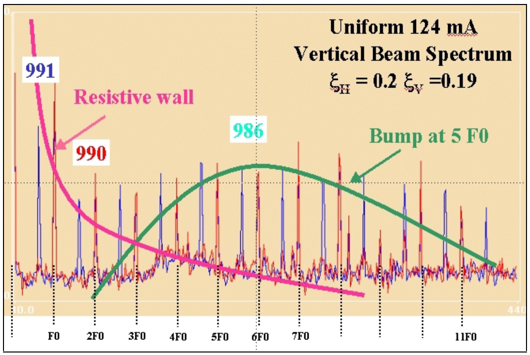


Figure 7: Vertical CB lines up to 12*F0, in the uniform filling, consisting of RW lines and those peaked at 5*F0

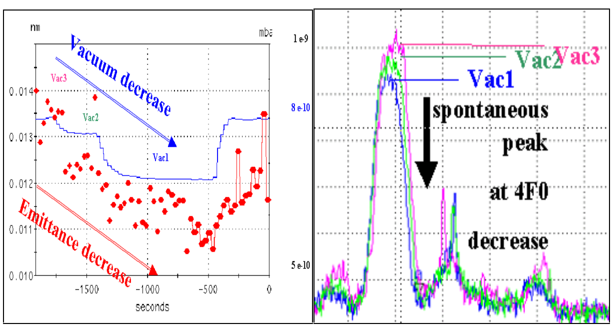


Figure 8: Changes of the vertical beam size (left) and the magnitude of CB lines (right) with the vacuum level

A series of experiments performed collected following characteristics for the spontaneous lines, which are in favour of ion trapping [3]: - Peaked around 5F0 and 7F0, which vary with the beam current (Fig. 8). - Amplitude and frequency are sensitive to the vacuum level (Fig. 8). - Dependence on the vertical beam size. - Can be suppressed by increasing the chromaticity.

4.3 Fast Beam-Ion Instability

The effect observed in the uniform filling cannot a priori be concluded to be an ion trapping instead of a fast beam-ion blow up. The observation made at a start up of a machine run when the vacuum level was much higher, however, would indicate that the latter was due to a fast beam-ion blow up. With a beam gap of less than 10% (90 empty buckets), the amplitude of the spontaneous line at 7F0 (peak of a bump), was measured with a gating of 50 buckets on the tune monitor signal along the bunch train (Fig. 9). The following observations resulted: - An increase of amplitude at the head of the train. - Saturation of the excitation towards the tail. - 90 unfilled buckets being sufficient to truncate the instability. - Earlier saturation with an increased current or a worse vacuum. Repeating the measurement against 2/3 filling gave qualitatively the same result. Further characterisation of the observed ion effects as well as simulation, e.g. identification of the spontaneous peak to an ion frequency, is on the way.

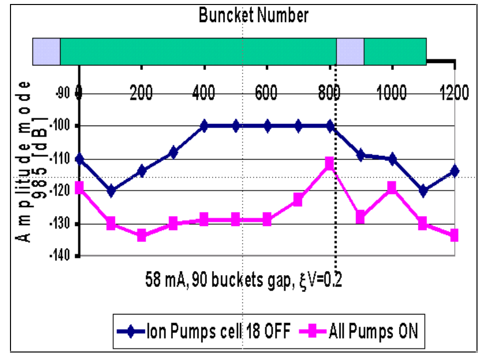


Figure 9: Vertical spontaneous line (7F0) at different positions in the bunch train, in a fill with 90 consecutive empty buckets, measured at different vacuum levels

5 CONCLUSION

The modelling of RW instabilities gave the RW effective chamber radius b_{eff} a value close to expected and suggests that thresholds at positive chromaticities be raised by the broadband impedance. A mode by mode feedback was found sufficient to damp the RW instability. The study of RW instability revealed several other interesting findings, such as betatron tune shifts with current, impact of vertical instability on the coupling correction, and particularly the ion effects, both trapping and fast blow ups. All these observations deserve further analysis, which is to be carried out. Of interest is to clarify whether the extra stabilisation found in the quasi-uniform filling comes from the RW effect or the ions. A hint may also be given to the reason that no effect of transverse cavity HOM has been observed so far.

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REFERENCES

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[2] R. Gluckstern, J. van Zeijts, B. Zotter, "Coupling Impedance of Beam Pipes of General Cross Section", CERN SL/AP 92-25.

[3] J.L. Revol and R. Nagaoka, "Beam/Ion Instabilities at the ESRF', ESRF report 14-00/MDT, May 2000.

[1] A bump was also observed in the horizontal plane (at 3F0) at a later stage.