FAST BEAM-ION INSTABILITY OBSERVATIONS AT SOLEIL

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Abstract

Observations and analysis of fast beam-ion instabilities (FBIIs) at SOLEIL are presented and reviewed since the early commissioning period. The transverse instabilities encountered initially were a full mixture of FBIIs and coupling impedance induced instabilities. Although the relative importance of FBIIs diminished as the vacuum improved, FBIIs remained persistently at high beam current, often leading to complete beam losses. The mechanism of the beam losses, along with the correlation of FBIIs with wake fields is discussed.

INTRODUCTION

SOLEIL is the French third generation light source ring commissioned in 2006 and serving routinely for users in high intensity multibunch mode, as well as in the temporal structure (1 to 8 bunches). Ever since the commissioning times, accumulation of high beam current was severely influenced by transverse instabilities, which are now understood to a large part to be due to fast beam-ion instabilities (FBIIs). The present paper reviews their observations and analysis.

EARLY OBSERVATIONS

Mixture of Different Instabilities

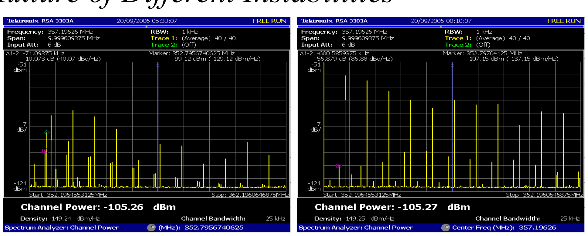

Figure 1: Unstable beam spectra observed in ¾ filling. Left: "Resistive-wall dominated". Right: Ions-dominated

At commissioning times, the transverse multibunch instability thresholds were explored as a function of chromaticity horizontally and vertically [1]. It was observed that the measured thresholds were often not reproducible, and that the unstable betatron lines in many cases contained peaks at some revolution frequencies away from the RF frequency, thus being quite distinct from that expected from the resistive-wall impedance (Figs. 1). These observations led us to consider that the beam is affected by ions in addition to the wake fields.

Analysis with Bunch by Bunch Data

To study these instabilities more in detail, the turn by turn and bunch by bunch data, available with a digital transverse feedback processor were analysed, by switching off transverse feedback over some milliseconds and letting the beam blow up without being lost [2]. A set of measured data taken in the ordinary 3/4th filling (3 times 100 bunches separated by few empty buckets) at several different beam current showed a typical case (Figs. 2-4): At 50 mA, the transverse oscillation amplitude of the bunch centre of mass, averaged over the acquisition period, shows a gradual increase towards the tail of a bunch train by preserving the original beam current distribution (Figs. 2 top), which is expected from the long range nature of the resistive-wall force.

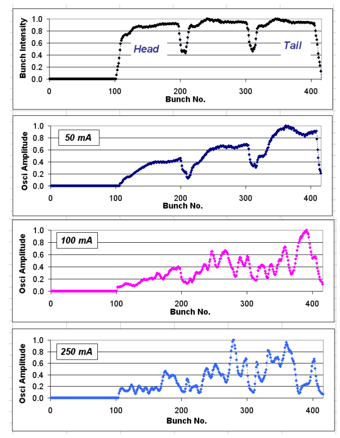

Figure 2: Measured vertical instability in 3/4th filling. Top: Current distribution along a bunch train. Lower three: Oscillation amplitude at 50, 100 and 250 mA.

From 100 mA and above, the oscillation amplitude distribution exhibits a fine structure involving a short period with saturating behaviour (Figs. 2 lower two). The oscillation phase along a bunch train turns out to be ~0.9°/bunch at 50 mA, which is nearly 0.87° expected from the strongest resistive-wall mode (Fig. 3 dark blue). The relation is still not much altered at 100 mA apart from increased fluctuations (Fig. 3 magenta). At 250 mA, a drastic jump of phase to ~40°/bunch occurs.

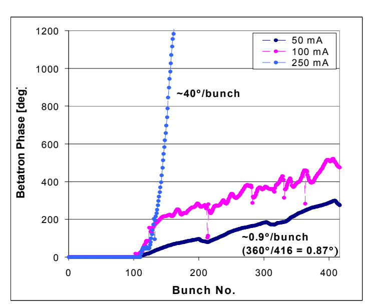

Figure 3: Phase of vertical bunch oscillations measured at 50, 100 and 250 mA in 3/4th filling.

Deducing the amplitude growth rate of each bunch, we see that, on the average, it still follows that expected from the resistive-wall for all three currents, though a much larger error bar (rms value over different bunches) appears at 250 mA (Fig. 4).

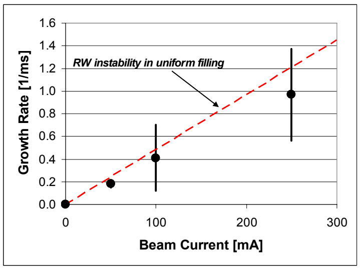

Figure 4: Measured vertical growth rate averaged over all bunches versus beam current, in comparison with that expected from RW instability.

A number of data sets revealed large peaks on the beam spectra, at the frequency of the ion mass 28 and 2 (Figs. 5 left and right), corresponding respectively to CO and H_2, which are the two most expected ion species in the ring. Along with the fact that the head of a bunch train is never excited, we may conclude that the observed ion instability is of the type FBII rather than classical ion trapping [3].

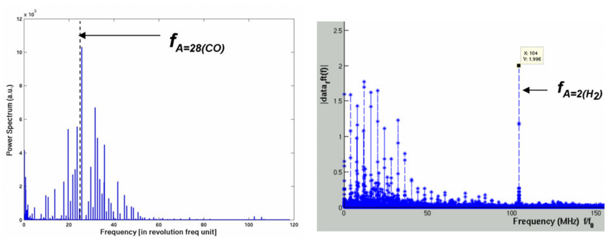

Figure 5: Deduced beam spectra showing ion frequencies.

Evolution of the Instability with Vacuum Level

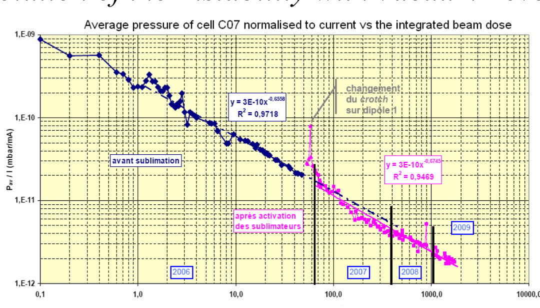

Figure 6: Average pressure normalized to beam current versus beam dose.

With improvement of the vacuum level in the ring as a function of the increasing accumulated beam dose (Fig. 6), the relative importance of FBII expectedly diminished especially at low current. The oscillation amplitude of the bunch centre of mass measured under the same condition at different times best describes the trend (Fig. 7). Here, the amplitude of different data sets were normalised under the assumption that the head bunches are always not affected and therefore have the same amplitude. At high current, on the other hand, sudden and complete beam losses persistently occur, which are attributed to ions as their signature is found in the post-mortem data. These beam losses tend to occur when the machine is operated with beam current higher than usual, or when insertion gaps were closed to minimal values.

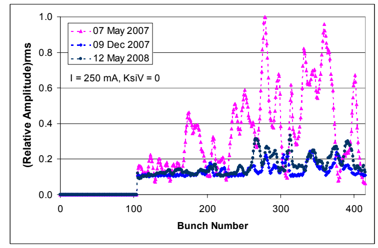

Figure 7: Oscillation amplitude along a bunch train at 250 mA in ¾ filling with zero chromaticity, measured with feedback switched off. Different colours correspond to measurement made at different times.

RECENT OBSERVATIONS UP TO ACHIEVING 500 MA

Many of the beam losses at high current occurred some 10 minutes after beam fill, until which the beam was kept completely stable by transverse feedback in most cases. Closer investigation revealed that these beam losses were preceded by local vacuum bursts, as shown in Fig. 8. These observations led us to consider that it is the beam-induced heating of vacuum components via wake fields that triggers the observed vacuum bursts, once the materials exceed a temperature threshold for outgassing over this 10 minutes period, giving rise to FBIIs.

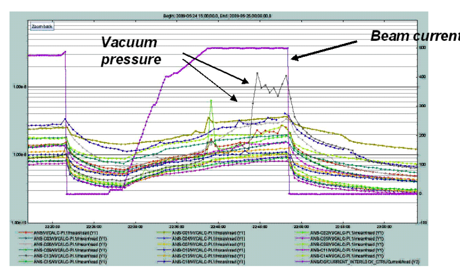

Figure 8: A local vacuum pressure rise followed by a beam loss encountered at 500 mA.

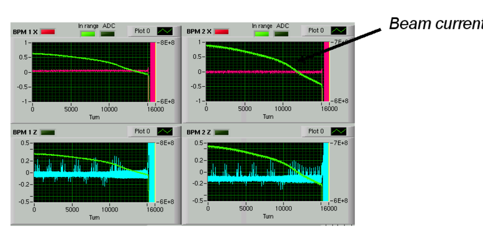

Figure 9: Post-mortem BPM showing a continuous beam current drop.

With the vacuum bursts reaching more than one order of magnitude higher vacuum level than usual, along with extremely short instability growth times predicted by the theory of FBIIs [3], it can be understood that transverse feedback is not effective against the instability. However, the origin of beam losses was not clear as FBIIs would merely blow up the beam without losing it.

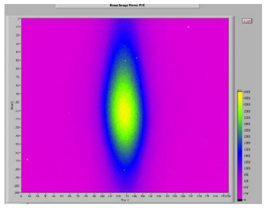

Figure 10: Beam blown up at 500 mA but kept in the machine with a large chromaticity.

It turned out from the analysis of post-mortem data that the beam was actually scraped against the chamber wall, to hit an RF interlock against reflected power (Figs. 9). Namely, the direct cause of the beam losses was the RF interruption. Several attempts were made to avoid the beam losses, namely the underlying FBIIs. An increase of the vertical chromaticity from the standard value of 2.6 to 3.6 (un-normalised) managed to keep the beam from being lost at the target current of 500 mA, although the beam was totally blown up after hitting the outgassing threshold (Fig. 10). These blown up beams possessed a strong self-stabilising (Landau damping) force that transverse feedback could even be switched off.

Table 1: Comparison of beam-induced power and the FBII growth rate in several exotic filling patterns.

	Filling modes	Uniform	13*(25 bunches+7 empty)	3/4th	8*(32 bunches+21 empty)
Number of bunches	nb	416	325	312	256
Number of empty buckets	h - nb	0	91	104	160
Bunch current [mA]	ib	1.20	1.54	1.60	1.95
Beam induced power	nb*(ib)^2	601.0	769.2	801.3	976.6
(tau-1)FBII	(nb)^2*(ib)^1.5	2.28E+05	2.02E+05	1.97E+05	1.79E+05

Exotic beam fillings composed of numerous beam gaps were also tried in order to suppress the FBII (Table 1). For a given beam current, increasing the empty buckets has the advantage of reducing the FBII growth rate that scales as $(n_b)^2 \cdot (i_b)^{1.5}$ [3], while it has simultaneously the disadvantage of increasing the bunch current, which in turn enhances the beam induced power that scales as $n_b \cdot (i_b)^2$. Here, n_b and i_b denote the number of bunches and the bunch current, respectively.

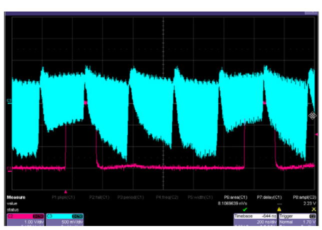

Figure 11: Modulated 4/4 filling attempted.

It turned out at 500 mA that the beam behaves in the best manner against FBIIs under a modulated 4/4 filling (Fig. 11), where the magnitude of the vertical blow up could be considerably reduced. This implies that reducing the beam induced heat is more effective than suppressing the cascading ion production with beam gaps in fighting against the FBIIs. Extrapolating this idea, reduction of the RF voltage from the standard value of 4 to 3 MV was attempted in the ordinary 4/4 filling. It turned out that FBIIs could be entirely suppressed in a repetitive manner, while maintaining the vertical beam size at its nominal value.

SUMMARY

The multibunch transverse instabilities observed at SOLEIL were a mixture of those induced by classical coupling impedance and ions. The latter was identified as fast beam-ion instability (FBII), whose features were well distinguished from the former with the available beam diagnostics including the turn-by-turn and bunch-by-bunch transverse feedback data. Although with improvement of the vacuum, the relative contribution of FBII diminished, beam losses due apparently to FBII persisted. These FBIIs were attributed to localised vacuum pressure bursts arising from beam (wakefield)-induced vacuum chamber heating. To achieve a stable beam at 500 mA, lowering of the RF voltage turned out to be effective, most likely due to suppressing the ions by reducing the beam-induced heating of the chamber materials. However, the mechanism of the beam blow ups leading the beam to be scraped against the chamber walls remains to be understood, as the ratio of the chamber aperture to the vertical beam size is roughly 100 and being far above what would be expected from the theory.

ACKNOWLEDGEMENT

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