

STUDY OF ION-INDUCED INSTABILITIES AND TRANSVERSE FEEDBACK PERFORMANCE AT SOLEIL

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Abstract

The high beam current operation at SOLEIL is considered to be seriously influenced, under certain conditions, by ions exciting transverse instability. Its mechanism involving the RF voltage, beam filling and transverse bunch by bunch feedback however appears to be complicated raising several unanswered questions. The present paper reports on the experimental observations and analysis, as well as tracking simulations carried out in order to find clues to the problems.

INTRODUCTION

SOLEIL is the French third generation light source ring routinely operated for users since 2007 in high intensity multibunch and temporal structure (1 to 8 bunches) modes. Since the commissioning times, accumulation of high beam current has been severely affected by transverse instabilities, which are now understood to a large part to be due to fast beam-ion instabilities (FBIs) [1, 2]. While the ion effect on the beam is clearly visible even at a low current when the vacuum is poor, such as after vacuum interventions, the puzzling fact at SOLEIL has been the sudden beam blow ups or losses that occur even under good vacuum, after storing a stable beam with nominal beam sizes at a fixed current up to those instants. In most of such events, the analysis of post-mortem data reveals strong signature of ions.

Attempts were made to alleviate the ion effect by storing the beam in different fillings with gaps and varying the chromaticity. Contrary to our initial guess, what turned out to be most effective in suppressing the sudden instability was paradoxically the continuous filling, namely the one that minimises the bunch current for a given total current. Since the latter should be the most unfavourable filling for ion instabilities, we were led to suppose that the ions that provoke the sudden instability do not exist under the normal condition and that the continuous filling does best to suppress them. This conjecture in turn led to the idea that ions are generated as a consequence of outgassing of the vacuum components that are heated via beam-induced wake fields. Extending the latter, the RF voltage was lowered from the initial 4 to 3 MV to reduce the beam-induced heating via bunch lengthening, which turned out to work markedly in keeping the beam stable at the target current of 500 mA. Increasing the chromaticity, on the other hand, helped stabilising the blown up beam, but did not affect the blow up itself as anticipated.

Experimental and simulation studies remain to be made to verify our interpretation, to pursue the limitation and possibly find other solutions, as well as to understand the

reason for which transverse feedback (TFB) fails in many cases to keep the beam stable against ion-induced beam blow ups.

EXPERIMENTAL OBSERVATIONS

Our biggest concern is the mechanism of sudden beam blow ups and losses that occur typically at some 10 minutes after reaching the goal current (500 mA), when setting the RF voltage to a relatively high value (> 4 MV) and chromaticity close to zero, i.e. one of the preferred conditions for the machine operation. Providing a large buffer for the bunch centre of mass (CM) data acquisition, the process of such a beam loss is captured via post-mortem (Fig. 1).

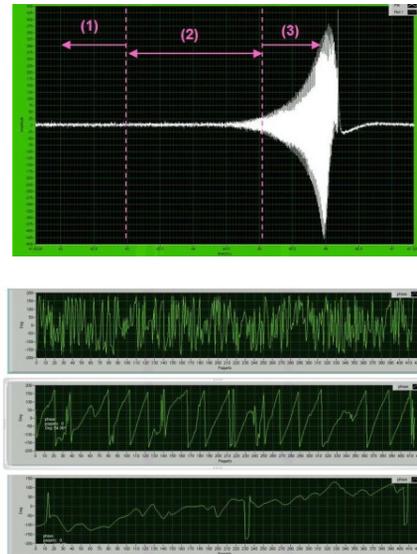


Figure 1: Upper: Blow up of the vertical oscillation leading to a beam loss. Lower: Betatron phase advance along a bunch train extracted at different regimes 1, 2 and 3. Measured at 500 mA with $V_{RF} = 4.2$ MV and $\xi_V = 0$.

Among the extracted information, the betatron phase advance along a bunch train is found to well exhibit the nature of coherent motions. Sampling it at different instants, we identify three regimes in cases as above (Fig. 1 lower): 1. Stable regime with no phase correlation. 2. Ion regime with large phase jumps (> 10 deg) between bunches. 3. Resistive-wall (RW) regime with a smooth phase advance (~ 1 deg/bunch). The change of regime from 1 to 2 implies that ion instability is excited in between, which TFB is not capable of suppressing. In most cases, however, we cannot identify outgassing simultaneously, and even if there is one, it is usually not clear whether it was the cause or the consequence of the

beam blow ups and losses. Besides the question on what abruptly triggers the ion instability, another is the failure of TFB. One may conjecture that the instability growth rate is much too high due possibly to strong outgassing, but a question appears also on its failure in the resistive-wall regime (“3” in Figs. 1) that follows. Two explanations may follow: 1. Reduction of feedback efficiency at higher frequencies of the ion regime. 2. Feedback saturation in regime 3 with the oscillation amplitude already being too large.

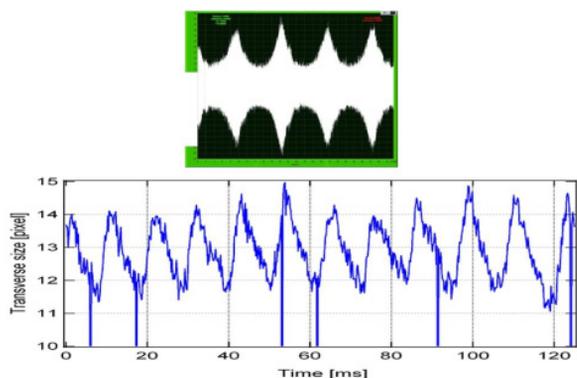


Figure 2: Saw-tooth oscillation measured at 500 mA with $V_{RF}=4.2$ MV and $\xi_I=4$. Upper: Bunch CM positions measured with a BPM. Lower: Vertical beam profile measured with a streak camera.

Increasing the chromaticity, the beam exhibits saw-tooth behaviour instead of being lost, while the relation of the three regimes remains unchanged (Fig. 2). Comparing the vertical beam size measured with a pinhole and the CM oscillation measured with a BPM, both are found to be roughly 2~3 times the nominal vertical beam size σ_V , implying that the beam blows up without associating a strong σ_V blow up, in basic agreement with what expected from FBII studies [3, 4]. Attempts are made to better resolve the CM motion and the beam size with a streak camera. The first measurement suggests that the beam blows up incoherently during radiation damping (Figs. 2 lower).

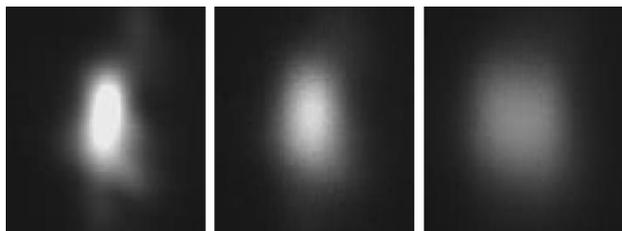


Figure 3: Horizontal beam blow up due to outgassing in an in-vacuum undulator, measured with a visible light monitor. Left: Before blow up. Centre: Initial blow up vertical. Right: Subsequent blow up horizontal.

Direct evidence of outgassing provoking FBII has been obtained by triggering the data acquisition on an ion pump reading hitting a given threshold. Such sudden outgassing occurs among others in in-vacuum undulators,

often associating beam blow ups even in the horizontal plane (Fig. 3), which raises another open question.

IMPACT OF TRANSVERSE FEEDBACK

Data analysis shows that TFB is capable of suppressing FBII at least to a certain degree. However, a big question is the fact that the use of the stripline having the electrode length $L = \lambda/2$ (λ : RF wave length), optimized to generate a strong kick, fails to keep the beam stable against stable \rightarrow FBII \rightarrow RW transitions, while a shorter stripline ($L = \lambda/4$) with a much weaker kick may keep the beam stable under the same condition. In view of FBII involving higher frequency coupled-bunch modes, the narrow band nature of the longer stripline was suspected as a cause of failure. Nevertheless, we confirmed that the longer stripline provides at least damping across the entire bandwidth 0 – 176 MHz (Fig. 4). The impact of cable length on the feedback efficiency is currently investigated.

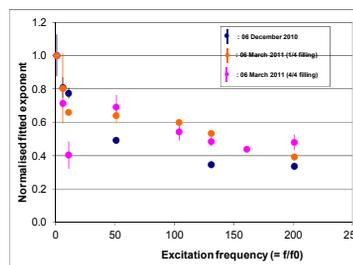


Figure 4: Feedback damping rate measured with a stable beam by exciting it at a given frequency. Different colours correspond to measurement at different occasions.

SIMULATION STUDIES

Our primary goal of the simulation study is to confirm the high frequency nature of coupled-bunch oscillations in the FBII regime as compared to the RW, as well as to verify no large dependence of the FBII on the bunch length. The latter would enforce our idea of the RF voltage, which directly acts on the bunch length, determining the degree of outgassing via beam-induced heating. A multibunch tracking code “*mbtrack*” that performs parallel computation is used to simulate FBII. Initially, a scheme treating both electrons and ions with macro-particles (“weak-weak” model) was developed following Ref. 3. Since a huge amount of cpu time is required to track as many as 416 bunches over thousands of turns, however, a simplified scheme (“weak-strong” model) described in Ref. 4, of treating an electron bunch as a rigid Gaussian distribution was later added. In *mbtrack*, an electron bunch is actually sliced into $2 \cdot N_{slc} + 1$ pieces longitudinally ($N_{slc}=0,1,\dots$) on the basis of its longitudinally Gaussian distribution, to be able to pursue the dependence of FBII on the bunch internal structure.

Results shown here are obtained for $1/4$ filling at 500 mA, assuming ions of the mass $A=28$ ionised at one point in the ring with localised pressure of 1×10^{-6} mbar. In the weak-weak scheme, 1000 macro-electrons were used per

bunch. In both schemes, $(2 \cdot N_{slc} + 1) \cdot 25 \cdot 25$ macro-ions were used to simulate ions generated by a bunch.

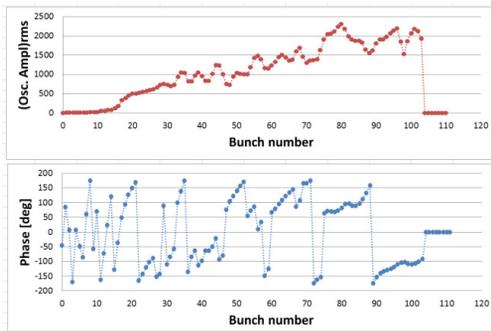


Figure 5: Bunch CM betatron oscillation amplitude averaged over time (upper) and oscillation phase (lower), across a bunch train obtained in the weak-weak model.

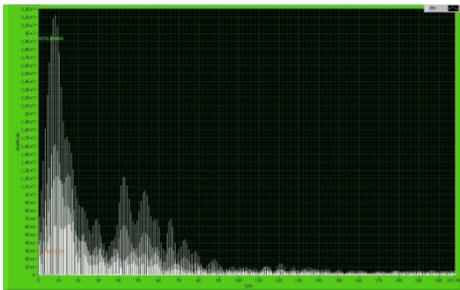


Figure 6: Beam spectrum corresponding to the tracking results shown in Fig. 5. Horizontal axis: Normalised frequency ($= f/f_0$).

The amplitude and phase of the bunch CM motions averaged over time, as well as the beam spectrum show characteristics that are in qualitative agreement with the measurement. Namely, an amplitude growth towards the tail of a bunch train, phase jumps of 20-30 degrees between adjacent bunches and several peaks in $(10-50) \cdot f_0$ frequency range (Fig. 5 and Fig. 6). No significant difference was noticed between the two models regarding these characteristics.

To see if a longer bunch could have a direct impact of relaxing FBII without having to argue outgassing via wake fields, a comparison was made between treating an electron bunch as one CM ($N_{slc}=0$) and seven CMs ($N_{slc}=3$) in the weak-strong model. Although the former tended to give a slightly larger growth rate, no strong dependence of FBII on the longitudinal bunch structure (lengthening) was found (Fig. 7), in favour of the assumption that lowering of V_{RF} suppresses beam-induced heating. The simulation work should be extended to include the effect of outgassing (i.e. a rapid increase of ions), RW wake fields and TFB with a limited damping performance at higher frequencies, to see if the beam blow-up as shown in Figs. 1 could be reproduced and explained. It should also include the option of not

discarding the ions at every turn after the passage of a bunch train, to be able to treat continuous fillings.

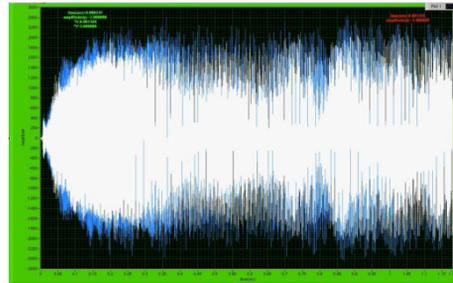


Figure 7: Comparison of beam blow up in the weak-strong model between seven CMs (white) and one CM per bunch (blue).

SUMMARY

Analysis of post-mortem data indicates that a stable beam is driven firstly unstable in the FBII regime, followed by that of the resistive-wall. It remains to clarify the cause of transverse feedback failing to stabilise the beam against the two instabilities. Measurement with a BPM, a pinhole and a streak camera suggests that the beam CM motion saturates at around 2-3 times the original beam size, in agreement with the FBII theory. The beam is seen to blow up incoherently during the damping of the oscillation. More systematic measurement shall be carried out with a streak camera to confirm these findings. Multibunch tracking in the “weak-strong model” suggests that bunch lengthening plays little role in relaxing FBII, in favour of the picture that lowering of V_{RF} suppresses the outgassing.

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