

STUDY OF RESISTIVE-WALL EFFECTS ON SOLEIL

R. Nagaoka, Synchrotron SOLEIL, Gif-sur-Yvette, France

Abstract

The paper describes the way the machine data on the resistive-wall is organised and the impact of the resistive-wall evaluated for the SOLEIL storage ring. The instability is expected to appear from low beam currents in both transverse planes. The degree of incoherent tune shift arising from the chamber cross section asymmetry is estimated in multibunch as well as in single bunch. It is found that the NEG coating adopted to enhance the vacuum pumping performance nearly doubles the reactive part of the impedance.

INTRODUCTION

The presence of low-gap chambers for insertion devices, along with a relatively small vertical gap of 25 mm chosen for the standard vacuum chambers, implies a significant influence of the resistive-wall (RW) on the beam in the future SOLEIL storage ring. Unlike previous machines in which the RW predominantly caused transverse instability in multibunch, it is expected to affect the coherent single bunch motion as much as the broadband impedance. Furthermore, its impact on the incoherent motion is likely to be non-negligible, due to the ring being composed mostly of low gap non-circular chambers, which in turn may interfere with the coherent instability in a non-trivial manner. With enhanced sensitivity to RW, the impact of metallic coating on the chamber surface, either to improve the wall conductivity or the vacuum pumping capacity, needs also be studied.

MACHINE DATA ORGANISATION

Although the RW impedance is generally known analytically, an accurate evaluation of its magnitude, as well as its product with the beta function over the entire machine, may not be simple when both the vacuum chamber and the optics vary rapidly around the ring.

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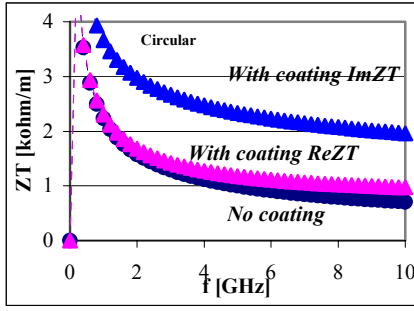
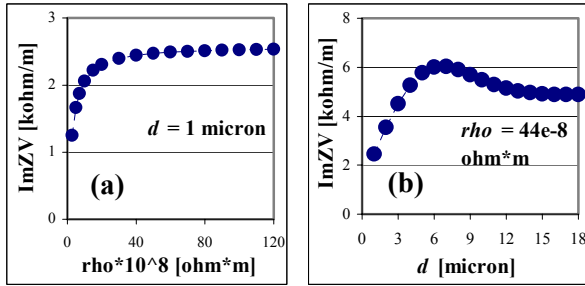


Figure 3: Transverse impedance with and without NEG coating.

Though the effective resistivity of NEG is not known, the impedance is found to saturate fast with increasing resistivity (Figs. 4a). This, along with the measurement of E. Plouviez finding $\sim 1600 \times 10^{-8} \Omega\text{m}$ for NEG [4], would indicate that the result in Fig. 3 represents the plausible cases. The impedance also saturates fast with increasing thickness, correctly to the value determined by the coating material (Figs. 4b).



Figures 4: Dependence of the vertical impedance (calculated at 2 GHz) on the resistivity ρ (left) and the coating thickness d (right).

With all straight section coated with NEG, it follows that for SOLEIL, the NEG nearly doubles the total imaginary impedance as well, though the increased value is still roughly half of what it would have been had all the chambers been made in stainless steel. As long as the increase occurs only on the imaginary part, the resistive-wall instability is supposed to be unaffected. On the other hand, the threshold of the transverse mode coupling instability (TMCI) in single bunch may be seriously reduced. The latter is quantified in a later section.

Despite the qualitative agreement, the present model fails to reproduce the Elettra observation quantitatively by as much as an order of magnitude. Staying within the model, one is obliged to assume unreasonably large values for both the thickness and the resistivity. This discrepancy, along with an additional observation at ELETTRA suggesting a simultaneous increase of the real part of the impedance, may indicate that the origin may well be other than the model considered here. One good candidate would be the surface roughness, which is already known for NEG coated aluminium chambers. Collaboration is made with ELETTRA and the ESRF to analyse the ELETTRA observations.

RESISTIVE-WALL INSTABILITY

Instability thresholds were calculated in the frequency domain, by solving the Sacherer equation and equating the growth rate with that of the radiation damping. Only the uniform filling was considered. At zero chromaticity, the preferred value for the operation, unstable modes appear at around 30 mA vertically and 80 mA horizontally, whose number grow up to around 90 and 30, respectively (Fig. 5). The computation assumed no broadband (BB) impedance, which anyway has little effect at zero chromaticity.

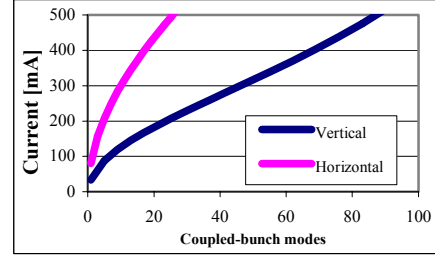
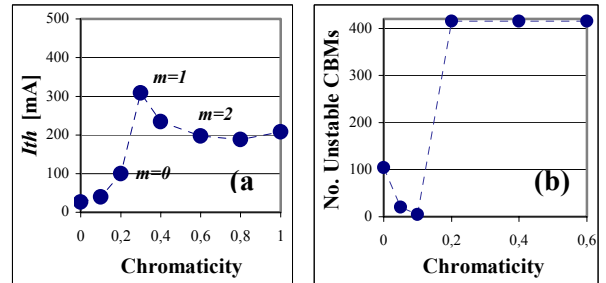


Figure 5: Number of unstable modes versus current at zero chromaticity.

To follow the dependence of the instability on the chromaticity ξ , the knowledge of BB impedance is important. Here, a set of broadband resonator (BBR) impedance, deduced from the ESRF case [5], was employed to investigate the more stringent vertical stability: $R_V \beta = 1.43 \text{ M}\Omega$, $f_{res} = 22 \text{ GHz}$, $Q=1$. We note that the value of $R_V \beta$ is close to the estimated budget [6].

It turns out that the current does not rise favourably by increasing ξ (Fig. 6a). Namely, where the higher-order head-tails ($m>0$) are involved, the threshold current remains low. Interestingly, the number of unstable modes shows a minimum around $\xi = 0.1$, where $m=0$ gets stabilised while $m=1$ is not yet unstable (Fig. 6b). Above this point, all coupled-bunch modes become unstable once $m > 0$ modes are excited by the BB impedance. Clearly there is an advantage to work at this minimum for the transverse feedback. The behaviour of $m > 0$ modes at $\xi > 0$, as well as the minimum described here were also observed in a study made earlier [7].



Figures 6: Dependence on the chromaticity (normalised). (Left) Vertical current threshold. (Right) Number of unstable modes. The computation includes the BBR described in the main text.

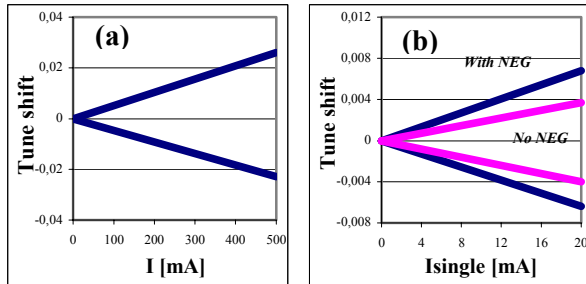
INCOHERENT TUNE SHIFT

Non-circular chambers with finite resistivity create current-dependent quadrupole fields [8], which generate incoherent betatron tune shifts. The scheme developed earlier by the author to quantify the effect [9] was improved as follows: On top of evaluating the chambers piecewise around the machine as already described, the focusing strength derived via the formulation of K. Yokoya [8] has now the time dependence according to A. Chao et al. [10]. Namely, the field diffusion is computed as an explicit function of the aperture, wall thickness, resistivity and time, thus eliminating the artificial parameter used earlier. Other details are found in Ref. 9.

Applying it to SOLEIL, tune shifts of as large as ~ 0.025 are found at 500 mA in uniform filling, horizontally and vertically (Fig. 8a). While the NEG coating is not expected to have any effect in multibunch as the zero frequency field dominates, for single bunch its contribution is taken into account, thanks to the relation in the horizontal impedance $(Z_H)_{incoherent} = -(Z_H)_{coherent}$ for flat chambers. The effective focusing strength felt by a particle in single bunch is then given by

$$\langle k_{eff} \rangle = \frac{4\pi}{Q} \cdot \frac{1}{E/e} \int_0^\infty \tilde{\rho}(\omega)^2 \cdot \text{Im} Z_H(\omega) d\omega, \quad (1)$$

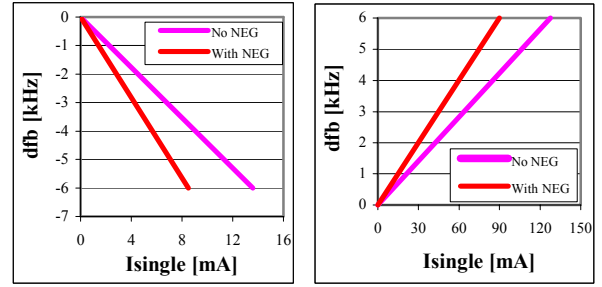
where Q denotes the total bunch charge, E , the beam energy, $\tilde{\rho}(\omega)$, the Fourier transform of the bunch density, and $Z_H(\omega)$ is the coherent horizontal impedance. The two-metallic layer impedance formula of Ref. 2 is used when considering the NEG coating. Tune shifts in single bunch are again found to be comparable in the two transverse planes. With NEG, they reach nearly 0.0035 at the nominal current of 10 mA (Fig. 8b).



Figures 8: Calculated incoherent tune shift in multibunch (left) and single bunch (right). Negative shifts are vertical and vice versa for the horizontal.

The impact of resistive-wall on the coherent dipolar tune shift in single bunch is finally estimated. Tune shifts are computed as the sum of coherent and incoherent parts, both taking account the NEG effect. The results show that the NEG increases the dipolar detuning in both transverse planes (Figs. 9). With the synchrotron frequency being close to 6 kHz, a naïve estimate of the vertical TMCI threshold gives 14 mA without NEG, which is reduced to 8 mA with NEG. Clearly, the important contribution of

numerical calculated BB impedance [6], must be added to make a more realistic estimate.



Figures 9: Calculated dipole mode detuning due to resistive-wall, vertical (left) and horizontal (right).

CONCLUSION

The detailed piecewise data on the RW and the optics around the ring constitutes the basis for a precise and systematic evaluation of the beam dynamics due to the RW. As its dominant contribution was confirmed in the impedance budget [6], the RW was shown to give by itself a significant effect for SOLEIL on the collective stability of multibunch and single bunch, both vertically and horizontally. Not only, but its impact on the incoherent tune shift was found to be non-negligible.

The study is to be extended to include the BB impedance numerically calculated. The beam filling dependence of the RW instability shall be explored in particular, as gaps in the filling have been found to give significant stabilisation in some machines. A multibunch tracking is to be performed for this purpose [5].

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