

VERTICAL EFFECTIVE IMPEDANCE MAPPING OF THE ESRF STORAGE RING

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Abstract

As more and more low gap vacuum chambers are installed at the ESRF, the single bunch instability threshold tends to decrease dramatically and, in order to anticipate the evolution of vertical impedance, there is a real need for it to be tracked.

Two type of experiments based on closed orbit distortion measurements will be presented and compared. The first one is a local measurement using the closed bump technique, while the second one allows the measurement of all impedance around the ring using a single measurement. Results and improvements of both methods as well as the evolution of machine vertical impedance will be discussed.

A particular focus will be put on in-vacuum insertion devices. Indeed, these devices have variable gap and enable us to make gap dependent measurements.

THE LOCAL BUMP METHOD

The local bump method was first introduced around the same time at BINP[2] and ALS[1] and implemented at ESRF in 2002[3]. The principle of the method is to locally displace the beam from its axis by applying a closed bump of 1mm, and to record the effect of impedance on the closed orbit.

Once the beam is displaced, its closed orbit will be affected by an impedance kick proportional to the beam displacement, the imaginary part of the effective impedance, and is current dependent. Assuming a gaussian distribution for the bunch, the kick angle is

$$\theta_{Kick} = \frac{I \times z_{Bump}}{2\sqrt{\pi} \times f_0 \times \sigma_t \times \left(\frac{E}{e}\right)} \times \Im(Z_{\perp eff})$$

related to the effective impedance by[6]:

Where θ is the kick angle, z is the bump amplitude, f_0 the revolution frequency I the bunch current and σ_t the RMS bunch length in seconds.

The effective impedance is here defined by the formula:

$$Z_{eff} = \frac{\sum_{\omega} Z_{(\omega)} \times |\sigma_{\omega}|^2}{\sum_{\omega} |\sigma_{\omega}|^2}$$

Were $Z_{(\omega)}$ is the impedance and $\sigma_{(\omega)}$ is the longitudinal amplitude spectrum of the beam.

Once the strength of this kick is recorded, one can deduce the imaginary part of the effective impedance of the section where the bump is applied. Therefore, this method allows local measurements, which is interesting in order to compare different elements.

MEASUREMENT SEQUENCE

The first step is then to record the reference orbit. This measurement is done with a very low current per bunch (10mA in 992 bunches). The bump is applied in the positive and negative direction. The two closed orbits are subtracted leading to cancellation of residual orbit errors and an equivalent bump twice as large as the physical one. As this measurement is done at almost zero current, it is not sensitive to impedance.

The second step is to record a test orbit, by repeating the same process with a single bunch at high intensity. This time we are sensitive to impedance and the impedance kick induces an oscillation of the closed orbit all along the ring.

Subtracting the reference orbit from the test orbit leaves only the closed orbit distortion due to impedance. The strength of the kick is obtained by fitting this oscillation by the response of the beam to a kick located at the bump position.

Two points should be stressed in order to obtain clean measurements. It is important to cycle the bump in order to avoid hysteresis and to get a reproducible bump. Furthermore, the bump should be well closed. If residual oscillations are left outside the bump, the beam becomes sensitive to impedance all around the machine and the measurement will be spoiled. This problem was solved by applying a bump correction scheme, which allowed reducing the residual oscillation to a few percents of the bump height. A correction in the processing taking into account the parasitic impedances was also implemented.

Using both corrections, the fitting errors went down from about 10 μ m RMS to less than 2 μ m.

MEASUREMENTS ON LOW GAP VACUUM VESSELS

As a first step, the linearity in bump amplitude and current dependence have been checked and are in accordance with theory.

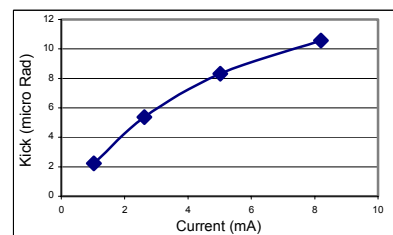


Figure 1: Current dependence of the impedance kick. The linearity is not perfect because the bunch length varies with current

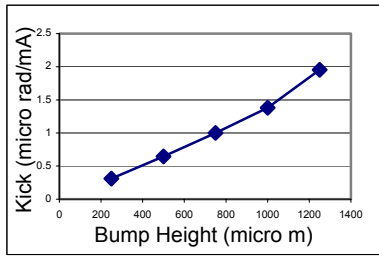


Figure 2: Dependence of the kick on bump height. Linearity is very good up to 1mm bumps.

Measurements were carried out on two different types of chambers with the same geometry: 5m long and 8 mm vertical inner gap. One was built out of extruded Aluminium and has a 1µm NEG coating, the other one is made out of welded plates of Stainless Steel coated with 35µm of copper and 1µm of NEG.

The current tendency at ESRF is to replace the second type by the first one. The horizontal aperture of these chambers is large compared to the vertical one.

Results are presented in table 1 for three Stainless Steel and four Aluminium chambers. The Al chambers were first installed on straight section no 6 to be conditioned and then moved to their final location. We could therefore make measurements for the same chamber at different locations in the machine.

As the bump extends over more than the low-gap chamber, we also measure the impedance of the surrounding. The parasitic impedance correction partially eliminates this effect. However it does not take into account the local fluctuation of this parasitic impedance. This may explain the slightly different values measured for the same low-gap chamber at different location. This effect is included in the calculated RMS error which is of 10kΩ/m.

Table 1: Results for the impedance of different chambers.

	SS 1	SS 2	SS 3	Al 1	Al 2	Al 3	Al 4
Measurement 1 (kΩ/m)	171	330	353	87	136	92	97
Measurement 2	204		376		119		
Meas. after change of location 1				77	109	94	102
Meas. after change of location 1				80		95	

One can conclude that the SS chambers behave much worse than the Al ones whereas calculations give comparable results for both [4]. Even for Al chambers, the results are twice higher than predictions. It is also remarkable that there is a large discrepancy between the three SS chambers. Chamber 1 is measured at around 185 kΩ/m while chamber 2 and chamber 3 have twice more impedance. There is no clear explanation for these results. The effect of surface roughness[5] is currently studied to see if it can explain the high impedance observed.

MEASUREMENTS ON IN-VACUUM INSERTION DEVICES

Eight in-vacuum insertion devices are installed on the ESRF storage ring. They are of great interest for our experiment as their gap can be varied down to small

apertures. This enables us to make gap dependent measurements. Insertion devices are 2m long except "Invac11u" which is 1.6 m long. The return current flows through a Copper/Nickel film which sticks magnetically to the surface of the undulator. Results for 6 devices are shown on figure 3.

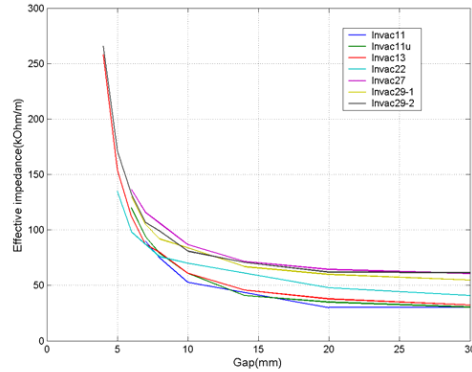


Figure 3: Results for 6 devices. The effective impedance is plotted versus the opening gap. Two measurements were carried out on Id 29 in order to check the reproducibility. It has shown to be less than 5kΩ/m.

From these curves one can derive x so that $Z_{eff} \sim g^{-x}$ where g is the gap. In our case, we find $x \approx -2.5$. It shows that impedance is not exclusively of resistive wall type ($x=-3$), but tapers and imperfections on the Cu film may be of importance. Furthermore, results for "invac11" and "invac11u" are equal within the precision range while "invac11u" is 20% shorter. If the resistive wall dominated, we would see a significant difference.

The discrepancy between the curves can be partially explained by the background impedance of the surrounding, which varies, as the in vacuum devices are not installed on the same kind of vacuum chambers. But it can not fully explain the 30kΩ/m difference observed at large gaps, as this difference tends to reduce at small gaps, while the background impedance should be independent of the gap.

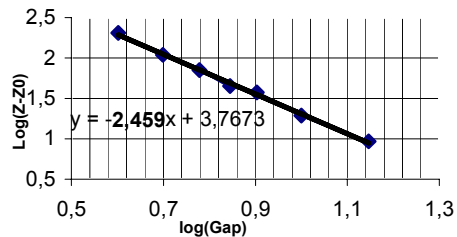


Figure 4: Log-Log graph for the results of "Invac29". Z_0 is the impedance at large gap, supposed to represent the impedance of the surrounding chamber. We see a power dependence of the impedance on the gap equal to -2.46 .

A final observation is that, closed at 8mm, a 2m long In vacuum insertion device produces the same amount of impedance as an 8mm vertical gap 5m Aluminium NEG coated chamber.

GLOBAL MEAUREMENTS

Another type of experiment, derived from the local bump method, has been implemented. It makes it possible to measure all high impedance parts of the machine using a fast measurement. The idea is to act on one steerer in order to create a closed orbit oscillation all around the machine.

Combining information from several steerers with an adequate betatron phase difference allows probing the whole circumference.

The same process of orbit subtraction between a reference and a test orbit is then applied in order to extract the closed orbit distortion due to impedance. The closed orbit distortion is then fitted by the response of the beam to kicks distributed according to an assumed structure. A clear model for the impedance is of importance, as non-included impedance will be interpreted by kicks given at a different location from where they really are.

For the ESRF, impedance is supposed to be located in straight sections, because of low vertical gaps, and around the dipoles because of flanges and RF fingers associated with a large β function. The closed orbit distortion will be fitted by applying 32 independent kicks in the 32 straight sections, and 64 kicks in the 64 dipoles, related to the same value of impedance, which means that all dipoles are assumed to be equivalent. It reduces to 33 the number of variables for the fit.

16 steerers are used, and results are averaged. Fits are done using an experimental response matrix taking into account the modulation of the beta function. Those errors have shown to have a large impact on the results.

RESULTS

Figure 5 shows the current map of ESRF vertical effective impedance measured with this method.

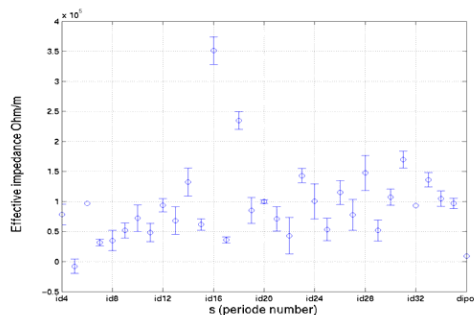


Figure 5: Mapping of ESRF vertical impedance. The error bars correspond to the RMS deviation of the measurements undertaken between June 2003 and May 2004. Two points have no error bars because they correspond to a single measurement (last replacements in the machine). Dipole impedance is evaluated at 9 ± 0.9 k Ω /m. Precision is almost twice as bad as for the local bump measurement.

This method can also be used to compare different types of chambers. On figure 5, it is again evident that Al chambers behave much better than SS ones, and the

discrepancy in-between SS chambers is also pointed out. Finally it is of interest to notice that a 15mm vertical gap SS chamber (non coated) has about the same value of impedance as a 10mm Al NEG coated chamber. This shows the advantage of these chambers.

Performing two different types of measurements allows the results to be crosschecked. Correlation between global and local experiment is excellent. We find a discrepancy of 12k Ω /m in average comparing results given by the two methods.

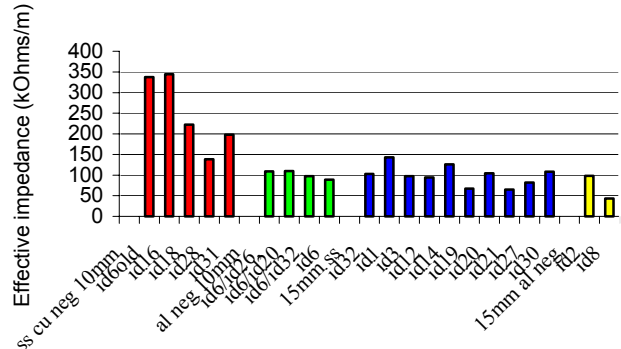


Figure 6: Comparison of different type of low gap chambers.

CONCLUSION

Closed orbit distortion measurements, if done carefully, have shown to be a precise and flexible tool in order to probe the vertical impedance of the ESRF. Two methods have been presented throughout this paper. The local method enables us to measure impedance locally and with a good level of accuracy. Unfortunately it is time consuming. The global method is less precise but it leads to a full mapping and allows a good comparison of impedance all around the ring, pointing out some parts of anomalously high impedance.

The precision of the fit for the local method and the good correlation of results, from crosschecking the methods, show the reliability of the experiment.

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