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WAKE FIELDS AND COUPLING IMPEDANCE OF THE DAΦNE ELECTRON RING

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Introduction

Beam measurements have shown that the coupling impedance of the two DAΦNE rings differs by approximately a factor of two [1]. The measured impedance of the positron ring is 0.54 Ω, while for the electron ring it is 1.1 Ω. The difference was thought to be due to ion clearing electrodes (ICE) placed only in the electron ring. Recent preliminary simulations have confirmed this guess [2]. In particular, it has been shown that four 2 m long ICE inside wiggler sections give the dominant contribution to the inductive impedance of the e- ring.

At present to know more precisely the wake fields and respective impedance of the e-ring is getting more and more important since:

1) One of the DAΦNE performance limitations is the longitudinal microwave instability in the e- ring. As it was found experimentally [3], above the instability threshold also transverse beam sizes start growing thus limiting achievable luminosity and making the electron beam more sensitive to blow ups. Moreover, this effect did not allow us exploiting potential advantages of the lattice with a negative momentum compaction factor with the present collider hardware [4]. So, in order to study the effect, to simulate bunch lengthening in the e- ring and to investigate the parametric dependence of the instability threshold precise knowledge of the wake fields is necessary.
2) Besides, all the DAΦNE upgrade options (see [4], for example) rely on shorter bunches and it is mandatory to study collider impedance behavior at high frequencies. In particular, the proposal to use DAΦNE as a source of stable terahertz coherent synchrotron radiation (CSR) [5] is based on assumption that the electron ring coupling impedance at high frequencies is dominated only by the CSR impedance. This point is to be checked.

In this paper we calculate the e- ring wake fields and impedance, simulate bunch lengthening in DAΦNE with positive and negative momentum compaction factors and compare the simulation results with available experimental data in order to verify the proposed e- ring wake field model.

Wake fields and Impedance

The vacuum chambers of both rings are similar except of additional ion clearing electrodes installed in the electron ring. The wake field of the positron ring (see Fig. 1) is well known [6]. Analytical estimates and numerical simulations based on this wake field reproduce very satisfactory not only bunch lengthening in the positron ring, but also predict the threshold of the microwave instability due to the internal bunch mode coupling [7]. So, the wake field for the electron ring can be obtained as a sum of the positron ring wakes and these due to the ICE.

As it has been already shown in [2], the impedance (wakes) of the long ICE in the wiggler sections largely dominate the impedance of all the other short ICE. That is why we perform detailed numerical simulations only for the long ICE and will take into account only their contribution into the overall wake field of the electron ring.

In order to simulate the bunch lengthening process a numerical tracking is performed using a wake potential of a short gaussian bunch as a machine wake function [6]. For this purpose the modeling bunch should be much shorter than typical bunches circulating in a ring. Since for the positron ring the wake potential is known for a bunch as short as 2.5 mm (see Fig. 1) we calculate the wiggler ICE wake field for the same bunch length.

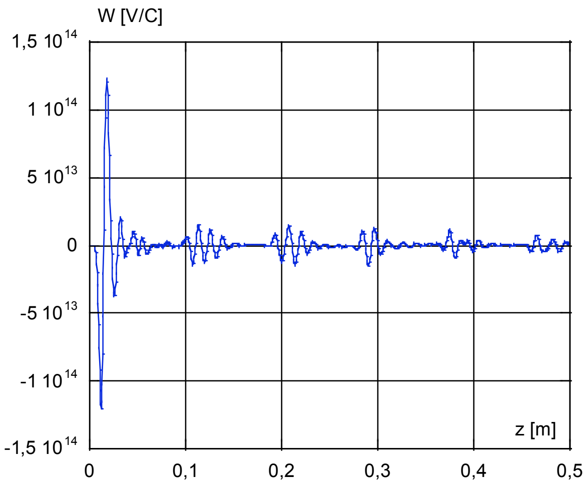

Figure 1: Wake potential of 2.5 mm gaussian bunch in the positron ring.

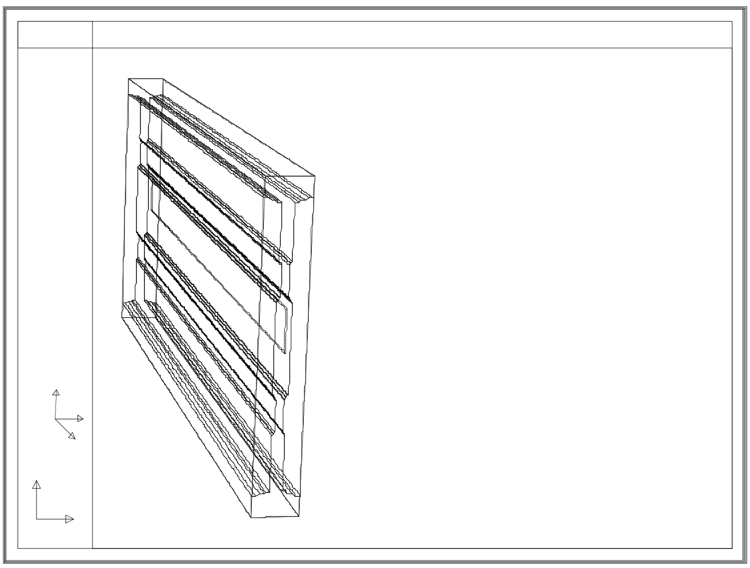

Figure 2: 3D MAFIA model of the wiggler vacuum chamber with inserted ICE.

A 3D MAFIA model of a piece of the wiggler vacuum chamber containing the ICE is shown in Fig. 2, while the transverse cross sections at the section entrance and at the ICE position are shown in Fig. 3 a) and b), respectively.

The flat wiggler vacuum chamber (2x13 cm) is connected to the pumping antechambers through 1 cm wide slots (see Fig. 2). The groove for ICE installation is 4 cm wide and 2 mm deep. It is shifted with respect to the vacuum chamber center (Fig. 3 b)) by amount corresponding to the shift of the beam wiggling trajectory. The electrode itself is simulated as a 0.5 mm thin dielectric plate place inside the groove. As it is discussed in [2], the highly resistive 20 μm thin layer painted on the dielectric material is considered to be transparent for the beam.

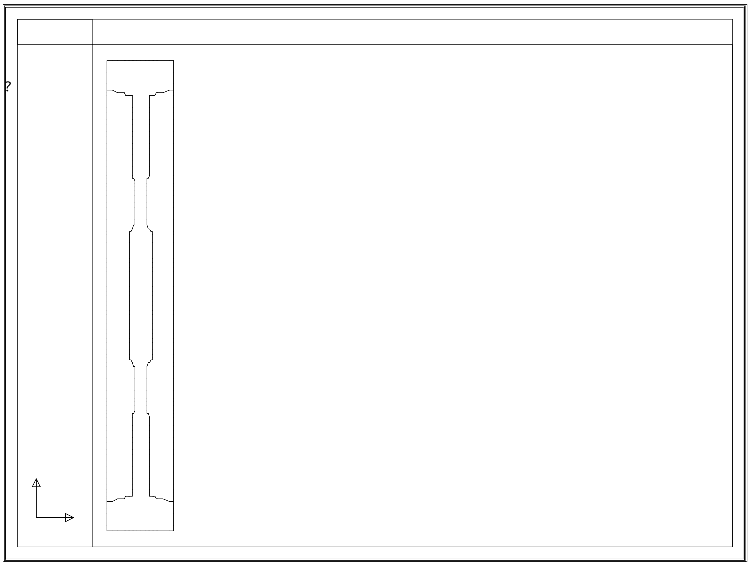

Figure 3 (a): Transverse cross section of the wiggler vacuum chamber (MAFIA input).

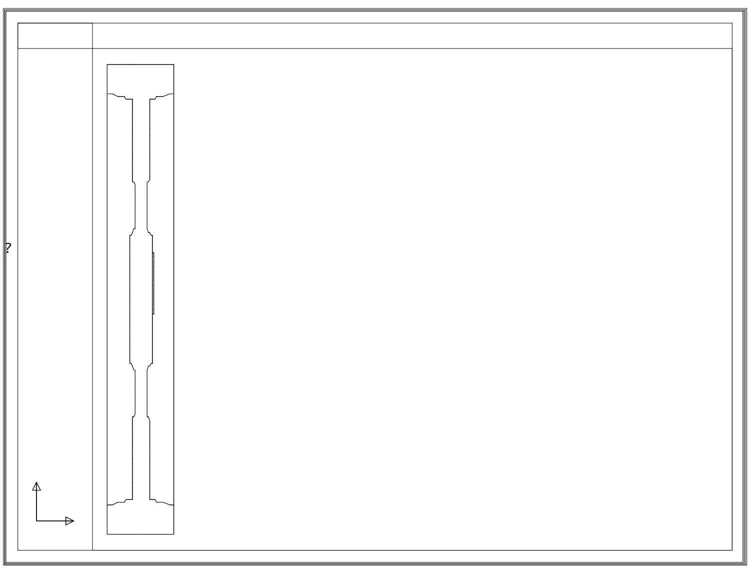

Figure 3 (b): Transverse cross section of the wiggler vacuum chamber with inserted ICE (MAFIA input).

Due to mesh size problems it is impossible to simulate correctly the whole ICE structure for the following reasons:

1) the ICE is very long (2.14 m) and the vacuum chamber is wide including the slots and the antechambers;
2) the ICE plate is very thin (0.5 mm);
3) the longitudinal mesh should be at least by a factor of 5-10 smaller than the considered bunch length (2.5 mm);
4) in order to avoid numerical instabilities the transverse mesh should be comparable to the longitudinal one and also be smaller than the ICE thickness;
5) for the sake of bunch lengthening simulations the wake duration after the bunch passage has to be long enough (50 cm in our case).

Hopefully, as shown in [2], the impedance of the ICE scales pretty linearly with its length. So, in our simulations we consider the10 cm long piece of the ICE and, then, scale the result according to the total ICE length.

The calculated wake potential for the 2.5 mm gaussian bunch is plotted in Fig. 4 (for 10 cm piece). The real and imaginary parts of the longitudinal coupling impedance, obtained as a Fourier transform of the above wake potential, are shown in Fig. 5 (a) and Fig. 5 (b), respectively. In order to make a comparison of the calculated impedance with the experimental impedance measurements we plot the low frequency impedance normalized by the revolution harmonic number $n = f/f_0$ in Fig. 6. For this purpose we have scaled the impedance of Fig. 5 (b) to the total ICE length and multiplied by the number of wigglers in the electron ring.

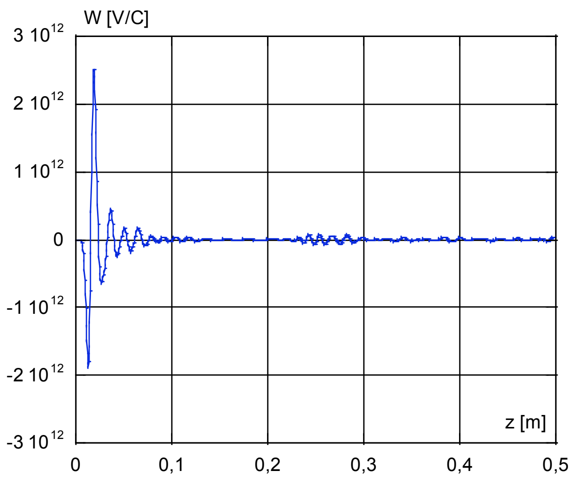

Figure 4: Wake potential of a 2.5 mm gaussian bunch for the structure shown in Fig. 2.

Looking at Fig. 5 and Fig. 6 one can already draw a few important conclusions:

1) The ICE contribution to the low frequency impedance is estimated to be ~ 0.6 Ω (see Fig. 6). This value corresponds almost exactly to the measured impedance difference of the two DAΦNE rings.
2) The inductive impedance remains high till rather high frequencies – almost up to 20 GHz (see Fig. 5 (b)). So, not only CSR, but also the ICE impedance would affect short bunches considered for DAΦNE operation as a terahertz CSR source [5]. This would certainly reduce the CSR flux and spectrum content estimated in [5]. From this point of view the positron ring would be a better candidate as a stable CSR source.

3) The real part of the impedance grows very fast with frequency reaching its peak at about 20 GHz. This means that one can expect strong increase of beam power losses for shorter bunches.

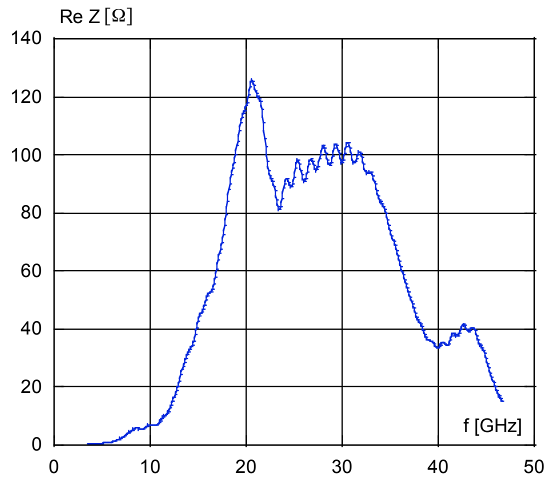

Figure 5 (a): Real part of the ICE longitudinal impedance.

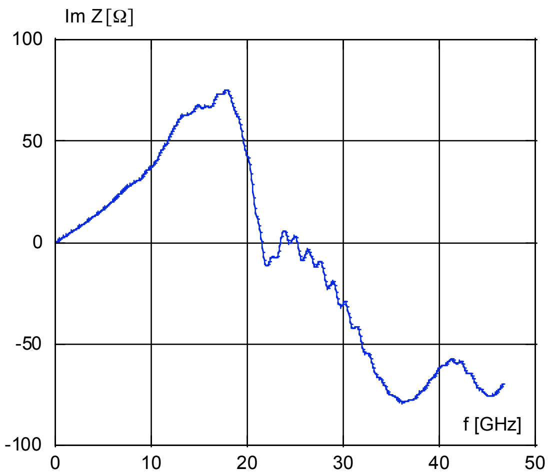

Figure 5 (b): Imaginary part of the ICE longitudinal impedance.

Bunch Lengthening

The resulting wake potential for the electron ring obtained as a sum of the positron ring wake and that of the ion clearing electrodes (scaled) is shown in Fig. 7 (a). For comparison, in Fig. 7 (b) we also plot together the e- and e+ rings wake potentials.

The above wake field has been used in the standard tracking code [6] in order to simulate bunch lengthening in the electron ring. Here we compare the numerical results with recent experimental data on bunch lengthening in the e- ring with negative and positive momentum compaction factors [8, 9].

For the lattice with a positive momentum compaction factor the measurements and simulations have been carried out with the momentum compaction α_c = 0.02 and the RF voltage V_{RF} = 135 kV. For each bunch profile acquired by the streak camera and stored in the database we have calculated the rms bunch length. In this way the experimental results can be compared with rms bunch length given by the simulations. As it is seen in Fig. 8, the agreement is quite satisfactory.

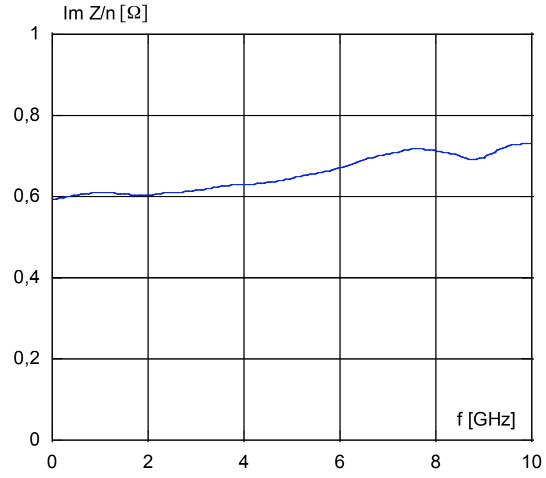

Figure 6: Normalized low frequency impedance of all ICE.

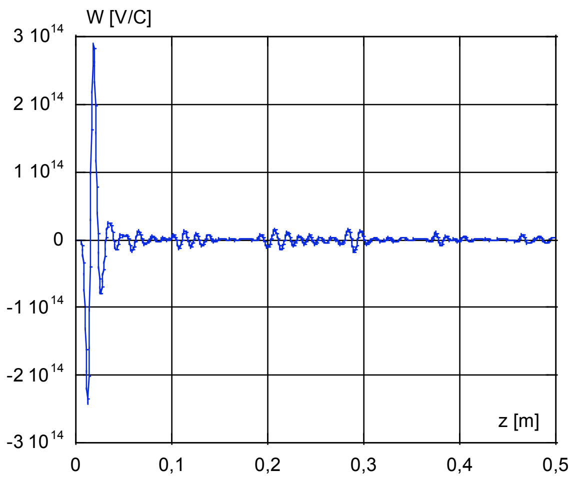

Figure 7 (a): Wake potential of 2.5 mm gaussian bunch in the electron ring.

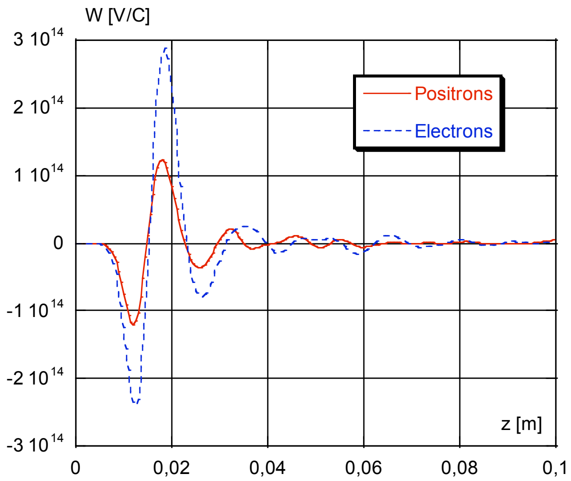

Figure 7 (b): Comparison of wake potentials for the electron and positron rings.

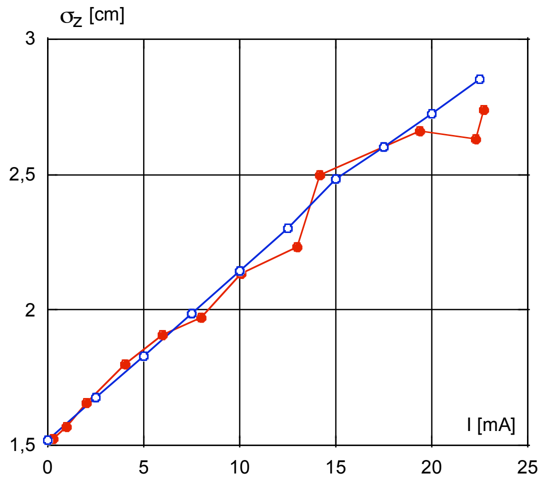

Figure 8: Bunch lengthening in DAΦNE lattice with a positive momentum compaction factor (e- ring)

The same procedure has been done for the lattice with a negative momentum compaction factor α_c = -0.017 and V_{RF} = 165 kV. The full widths at half maximum (FWHM) of the longitudinal bunch distribution were measured at different bunch currents and, unfortunately, only a few beam profiles were stored during the measurements. So, in Fig. 9 we plot the rms bunch length taken from the simulations and the FWHM/2.3548 given by the measurements (we remind here that for a gaussian bunch FWHM/2.3548 is equal to the rms). Only five points (green squares in Fig. 9) correspond to the rms bunch length obtained by elaborating the stored bunch profiles.

Figure 10 shows the measured and simulated bunch profiles at bunch current of 7.78 mA (This is one of the two profiles taken at a reasonable bunch current).

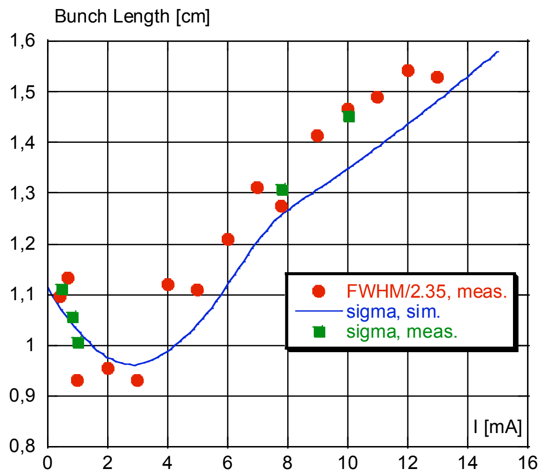

Figure 9: Bunch lengthening in DAΦNE lattice with a negative momentum compaction factor (e- ring).

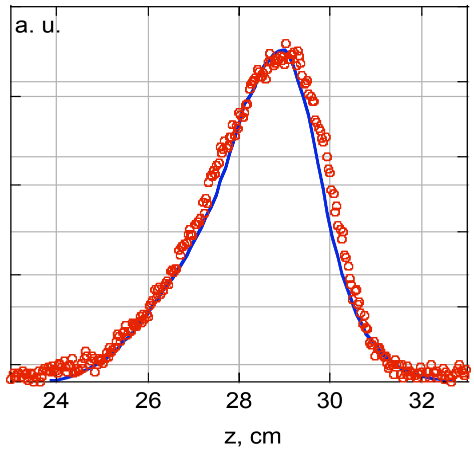

Figure 10: Bunch profile at 7.78 mA bunch current (measurements – empty circles, simulations – solid line).

As it is seen in Fig. 9 both the simulations and the measurements predict the same microwave instability threshold that can be distinguished at the point where the bunch length has the minimum (~ 3 mA).

Below the threshold the results are in a reasonable agreement, while above the threshold the bunch seems to be slightly wider than that predicted by the simulations (see Fig. 9 and Fig. 10). At this point we have to make some comments:

1) bunch length measurements in the electron ring with a negative momentum compaction factor have been carried out only once (June 2004) with a mismatched lattice and a wrong RF frequency. In such conditions the bunch was performing strong bursting oscillations (especially above the threshold) that could have led to the artificial bunch widening. Much more stable conditions were obtained for the matched lattice in March 2005, but unfortunately the streak camera was not available at that time. Thus, it would be highly desirably to repeat the bunch length measurements in a lattice with a negative momentum compaction in stable conditions.

2) Usually, at high currents a bunch in DAΦNE is wider than a gaussian one (more parabolic) and FWHM/2.3548 tends to be higher than a real rms size.

3) The bunch with the negative momentum compaction is shorter than that with the positive α_c, becoming even shorter than 1 cm at the minimum. Since the wake fields in simulations are reconstructed from the wake potentials of modeling gaussian bunches as short as 2.5 mm one can expect that the simulations are less precise for shorter bunches, especially when bunch length gets comparable with 2.5 mm.

So, considering the agreement between the measurement and the simulation results reported in Fig. 8, Fig. 9 and Fig. 10 and the related comments above we can conclude that the wake field model shown in Fig. 7 is quite satisfactory in describing the longitudinal beam dynamics in the electron ring.

Impedance Reduction

We have almost no doubts that the impedance difference between the two DAΦNE rings is due to the long ICE located in the wiggler vacuum chamber sections. However, there are no simple ways to eliminate the ICE from the vacuum chambers. We propose an alternative way to confirm experimentally that the ICE are the incriminating impedance generating elements and, if so, to minimize their effect on beam dynamics.

For this purpose a dependence of the ICE impedance on the horizontal beam orbit position inside the wiggler can be exploited. As it is seen in Fig. 11, the impedance has its maximum when the beam orbit passes along the ICE center shifted by ~ +1.5 cm with respect to the vacuum chamber center. When the orbit is moved toward the ICE boarders the coupling impedance starts decreasing rapidly. Clearly, that by changing the wiggler polarity and shifting the wiggler magnet symmetrically with respect to the vacuum chamber center in the horizontal plane would bring the central beam orbit to ~ -1.5 cm, thus moving the beam away from the ICE, where the impedance is notably lower. In this case the measured coupling impedance should be close to that of the positron ring.

The idea, in principle, can be checked by performing dedicated horizontal bumps localized inside the wigglers. In practice, this can be done also by varying the RF frequency in order to create dispersive orbits inside the wigglers where the dispersion is high. However, the orbit shifts have to be of the order of 3-4 cm to reveal experimentally an appreciable impedance difference and one has to verify compatibility of such large bumps with the present DAΦNE lattice.

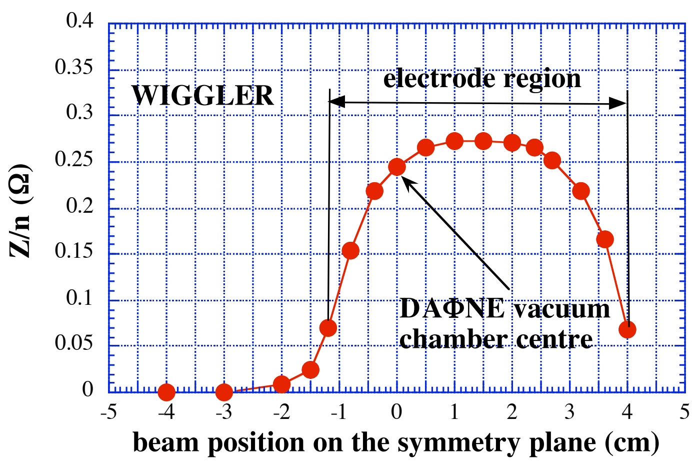

Figure 11: ICE longitudinal coupling impedance as a function of the horizontal orbit offset (The absolute impedance values should be considered only for scaling purposes).

Conclusions

1) We have calculated the longitudinal wake potentials (and impedance) that can be used to study beam dynamics in the DAΦNE electron ring. In particular, numerical simulations based on the calculated wake field predict well the microwave instability threshold and reproduce satisfactorily bunch lengthening in the electron ring with negative and positive momentum compaction factors.

2) The main difference in the coupling impedance (wake fields) between the two DAΦNE rings is shown to be due to the long ion clearing electrodes located in the wiggler vacuum chamber sections. Numerical estimates have shown that:
   a) The total wiggler ICE impedance is estimated to be ~ 0.6 Ω, corresponding almost exactly to the measured impedance difference between the e+ and e- rings.
   b) The impedance remains inductive till very high frequencies. This put a question mark on a possibility to use the DAΦNE electron ring as a source of stable terahertz coherent synchrotron radiation.
   c) The real part of the ICE impedance is high and broad covering the frequency range between 10 GHz and 40 GHz. So, one can expect a strong power loss increase for shorter bunches (with respect to these in present operating conditions).
3) One of the solutions to the ICE impedance problem is the beam orbit shift in the horizontal plane away from the ICE position. This could be done either by means of dedicated orbit bumps localized inside the wiggler sections or by changing the polarity and horizontal position of the wigglers. However, a possibility of practical implementation of these options is to be evaluated.

Acknowledgments

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