IMPEDANCE, LOSS FACTOR AND BEAM STABILITY CALCULATIONS FOR THE ANKA STORAGE RING

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Abstract

The ANKA storage ring is designed to store 400 mA at 2.5 GeV. The injection will be done at 500 MeV and then the beam will be ramped up to the nominal energy. The overall impedance of the vacuum chamber has been evaluated in order to calculate the intensity threshold of single bunch instabilities for both ramping and storage beams. Given the different types of components (bellows, flanges, cavities, step transitions, BPMs, ...) that conform the vacuum chamber, we evaluate the impedance of each component separately and sum up its contribution to the overall impedance, which results to be less than 2 Ohms. This has been done by using the usual simulation codes and analytical formulae. The results show that the instability thresholds at 2.5 GeV are safely far away from the nominal current. On the other hand, the calculation of the loss factor allows the determination of the power dissipated on each component. The main conclusion is that the bellows have to be shielded in order to avoid heating damage. The detailed results of these calculations are presented in this paper.

1 INTRODUCTION

The ANKA storage ring will be a relatively small machine, 110.4 m of circumference with an harmonic number of 184, but with a high beam current, 400 mA. That means that the current per bunch will be high in comparison with other synchrotron radiation sources. It is then necessary to design the vacuum chamber with a small broad band impedance in order to assure the stability of the beam. This is mainly important at low energy, where the emittance and the bunch length are smaller and single bunch instabilities may become evident.

First, the broad band impedance and the loss factor are calculated. Next, the intrabeam scattering from injection up to the storage energy is calculated. Finally, the single bunch instability threshold is calculated in the whole energy range, from 500 to 2500 MeV, and RF voltage, from 0.5 MV to 2.5 MV.

Coupled bunch instabilities are studied elsewhere in this conference [1].

2 BROAD BAND IMPEDANCE

The impedance of the single components has been evaluated by using mainly the ABCI code [2] and analytical expressions [3,4].

The code has been used to obtain the wake potential and classify the components in three groups: cavity like, inductive and resistive. Then, with the help of the analytical expression [4] that relates the maximum of the wake potential with the impedance, the impedance has been evaluated:

Cavity like: $|Z/n|\ (n) = 1.225\ (\sigma/c\omega)^{1/2}\ W_{max}/n$

Inductive: $|Z/n|\ (n) = \omega\ (2\pi)^{1/2}\ (\sigma/c)^2\ W_{m,ax}$

Resistive: $|Z/n|\ (n) = (2\pi)^{1/2}\ \sigma/c\ W_{m,ax}/n$

Where σ is the bunch length, c is the velocity of light, ω is the frequency, W_{max} is the maximum of the wake potential and $n = \omega/\omega_0$, where ω_0 is the revolution frequency.

The wake potential of the cavity (cavity like) and of the tapering (inductive like) to adapt the cavity tube to the vacuum chamber are shown in figure 1. The summary of the results is shown in Table 1.

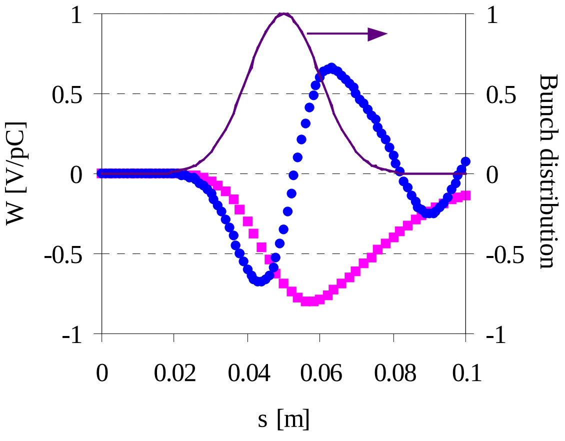

Figure 1. Wake potential of the cavity (squares) and its tapering (dots), and the bunch distribution (solid line).

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Table 1: Longitudinal Impedance at n = 880

Element	Number	Total Z/n [Ohms]
Cavity	4	0,21
Cavity Tapering	2	0,13
Cavity Bellow	6	0,06
Bellow	32	0,70
Flange	57	0,05
BPM	32	0,02
Bending Chamber	37 m	0,00
Resistive Wall	110.4 m	0,08
TOTAL:		
No-Shielded bellows		1,25
Shielded bellows		0.50

If the bellows are not shielded they have an overall contribution to the impedance of the 60%. Considering shielded bellows, the total broad band impedance is only 0.50 Ohms at n = 880, i.e. at the cut-off frequency of 2.4 GHz.

3 LOSS FACTOR

The loss factor has been calculated by integrating the convolution of the wake potential with the bunch distribution. In Table 2 the loss factor and the dissipated power in each component, for a bunch length of 10 mm and a beam current of 400 mA, is shown.

Table 2: Loss factor and power loss per component

Element	k loss [V/pC] (10 mm)	Power loss [W] (400 mA)
Cavity	0,57	184
Cavity Tapering	0,11	37
Cavity Bellow	0,09	30
Bellow	0,24	77
Flange	0,01	3
BPM	0,00	0,5
Bending Chamber	0,00	0,0
Resistive Wall	0,01	2

The maximum power lost by the beam is in the cavity, but the more dangerous from the point of view of the heat generated is the power lost in the bellows. This is the main reason to shield the bellows, to prevent overheating.

But, on the other hand, the loss factor is dependent on the bunch length. Figure 2 shows the loss factor of some components as a function of the bunch length.

During ramping, the bunch length changes from 6 mm at 500 MeV up to 10 mm at 2.5 GeV, having a minimum at around 1 GeV, see figure 4. Table 3 shows the total power lost by the beam a different energies. These losses will be replaced in the cavities.

Shielding the bellows the power loss and the overall impedance are strongly reduced. For these reasons the bellows will be shielded at the ANKA storage ring.

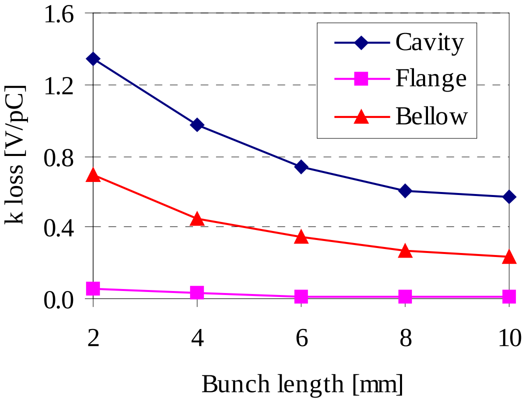

Figure 2. Loss factor as a function of the bunch length.

Table 3: Total power loss for 400 mA beam

Energy [MeV]	Bunch Length [mm]	No-shielded Bellows [kW]	Shielded Bellows [kW]
500	6	5,4	1,7
900	2	13,9	6,6
2500	10	3,8	1,2

4 INTRABEAM SCATERING (IBS)

The first phenomena associated with high current densities per bunch that has to be evaluated is the IBS, mainly at low energies. The ZAP code [5] has been used for that purpose, and the SPEAR scaling [6] for short bunches has been applied.

Figure 3 shows the emittance and the energy spread after taking the IBS into account, as compared with the natural ones.

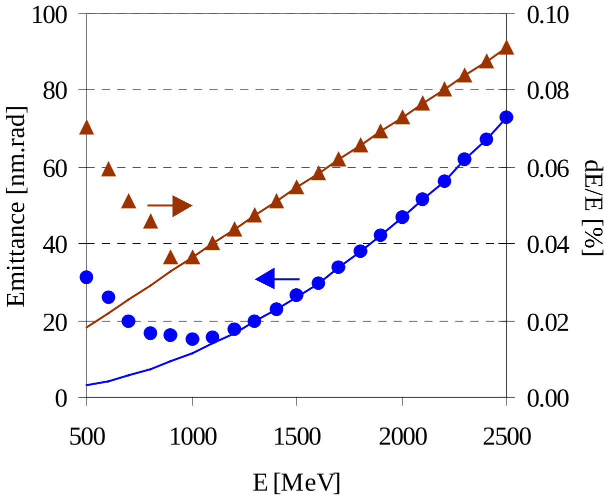

Figure 3. Emittance (dots) and energy spread (triangles) as compared with the natural ones (solid lines).

With these new values, the bunch sizes are calculated. The transverse dimensions are averaged over the ANKA circumference (<βx> = 9.6 m and <βy> = 8.8 m). Figure 4 shows the average transversal dimension and the bunch length after considering the IBS as compared with the natural values.

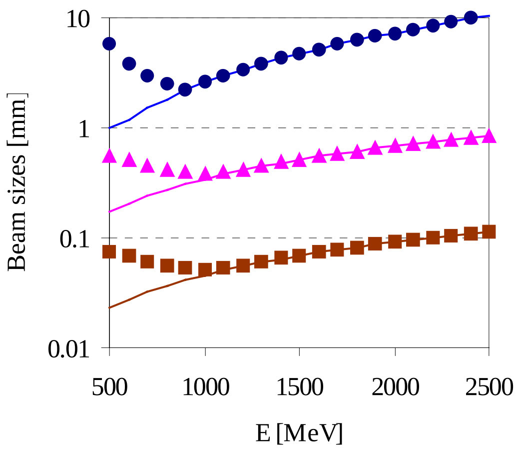

Figure 4. Bunch length (dots), average horizontal (triangles) and vertical (squares) sizes, as compared with the natural ones (solid lines).

At low energy, between 500 MeV and 1 GeV, the beam grows longitudinal and transversally due to the IBS. From 1 GeV onwards, the IBS is not appreciable.

This effect has been taken into account in the loss factor (section 3) and instability (section 5) calculations.

5 SINGLE BUNCH INSTABILITY

The current threshold of single bunch instabilities has been calculated with the code ZAP [5] assuming that all possible 184 buckets are filled. If problems with the ion trapping were found, operation with a gap in the bunch train is foreseen. In any case, the conclusion of this section will not change significantly.

For the calculations we have considered that the bellows will be shielded, but in order to cope with other contributions that may be missing, we have taken a broad band impedance of 1 Ohm (twice the calculated).

Figure 5 shows the beam intensity threshold calculated, as a function of the applied RF voltage, at 500 MeV (injection), at 900 MeV (minimum bunch length) and at 2.5 GeV (storage). At 500 MeV the calculations have been done by considering and not considering the IBS.

At 500 MeV the IBS increase the volume of the bunch by a factor of around 60, see figure 4. This effect avoids the appearance of single bunch instabilities, raising the beam intensity threshold to a value larger than 400 mA.

At high energy, the limits are far away from the nominal current.

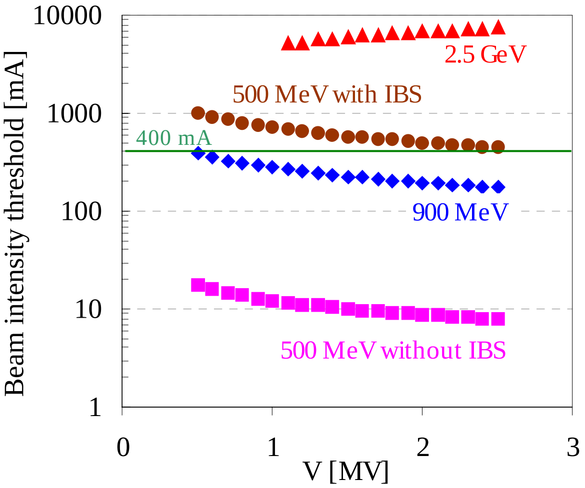

Figure 5. Beam intensity threshold at 500 MeV, 900 MeV and 2.5 GeV, as a function of the RF voltage. The 400 mA beam current limit is shown.

At energies around 900 MeV, the small beam dimensions causes the appearance of the microwave instability for beam currents larger than 200 mA. This instability will only enlarge the beam from around 2 mm to a maximum of 4 mm, which will be, in fact, helpful for improving the lifetime during ramping.

6 CONCLUSION

The ANKA storage ring impedance and the loss factor have been calculated. Because the high power dissipated in the bellows, they have to be shielded. The calculation of IBS and single bunch instabilities shows that the ANKA storage ring is free of instabilities at the nominal energy. At injection and during ramping the IBS and the microwave instability will enlarge the beam, but up to dimensions still smaller than the ones at 2.5 GeV.

Acknowledgements

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REFERENCES

[1] A.Fabris, C.Pasotti and M.Svandrlik, “Coupled Bunch Instability Calculations for the ANKA Storage Ring”, this conference.
[2] Y. H. Chin, “User’s Guide for ABCI Version 8.8”, LBL-35258, UC-414, February 1994.
[3] E. Karantzoulis, “The coupling Impedance of the ELETTRA Storage Ring”, ST/M-TN-90/14, August 1990.
[4] T.Nakamura, “The Broad-Band Impedance of the Spring-8 Storage Ring”. EPAC’96, June 1996.
[5] M.S.Zisman, S.Chattopadhyay and J.J.Bisognano, “ZAP User’s Manual”, LBL-21270, 1986.
[6] A.W.Chao and J.Gareyte, “SLAC Internal Note SPEAR-197”, 1976.