EVALUATION OF THE VERTICAL TRANSVERSE IMPEDANCE OF THE ESRF-MACHINE BY ELEMENT-WISE WAKEFIELD CALCULATION

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Abstract

At the ESRF a particular strong detuning of the head-tail modes is observed in the vertical plane. It was explained by a corresponding transverse impedance following a fitted Broad-Band model [1]. To examine more thoroughly the origin of the vertical impedance a systematic evaluation of the impedance of all elements of the machine was started. A new electromagnetic field solver in 3 dimensions, GdfidL, was used for the calculation of the wakefields. The calculations allow to establish the impedance budget of the machine and to improve the characterisation of the spectral form of the transverse impedance. In particular they show that the vertical transverse impedance weighted by the local vertical betafunction of the tapering of the RF-liners (RF-fingers) is more important than the one of the low-gap chambers and is one of the main contributions to the whole budget.

1 INTRODUCTION

The interest to study the origin of the transverse impedance of the storage ring of the ESRF is manifold: It allows to explain the strong vertical tune shift in single bunch [1] and in particular to estimate the effect of the very numerous low-gap chambers in the ESRF-machine.

The study presented here is focused on wakefields whose origin is exclusively geometrical. Hence the resistive wall impedance is not included. Furthermore space charge effects were neglected due to the high energy (6 GeV) of the ESRF-machine. The calculations of the wakefields were carried out in 3D except for axially symmetric geometries. The obtained impedance budget is still not complete. Absorbers, BPMs, antechamber slots, crotches, vacuum valves and the current transformer are still missing, however, it it expected that they don't change the total result substantially. All transverse impedance contributions are weighted by the local vertical β-function of the concerned element because it is this quantity which plays the decivise role in the transverse motion of the beam and not the transverse impedance alone.

2 DETAILS OF THE CALCULATION

The program GdfidL [2] was used to carry out the calculations except for the axially symmetric cavities where ABCI [3] was used. The length of the exciting bunch was set to 5mm, it corresponds to the natural bunch length of the ESRF-machine. In the most cases the mesh was refined to a size of 0.125mm (bunchlength/stepsize =40) to attain a mesh where wake no longer diminishes. Convergence studies showed, however, that the wake amplitude still diminishes slightly if a smaller stepsize is used. However, it was a good compromise between sufficient precision and available computing resources. For pumping ports and invacuum undulators a larger stepsize was used, the computing resources didn't allow a smaller one. To cope with the enormous computing resources needed the calculations were carried out on a Beowulf cluster with 8 and 11 nodes respectively allowing parallel processing. The communication between the nodes is realised by PVM (Parallel Virtual Machine).

The correctness of the GdfidL results was examined. For taper pairs with a circular cross section the results of GdfidL and ABCI agree up to almost 20GHz. The results of GdfidL were also compared to those of MAFIA [4]. The difference at relaxed stepsize is not significant up to 10GHz [5], however, GdfidL needs a smaller stepsize to obtain the same result as MAFIA. In case of a taper geometry the indirect method was used (i.e. the sequence of the entry and the exit of a low-gap chamber is exchanged along the beampath) to assure a more stable numerical evaluation.

In case of geometries with variable components (i.e. invacuum-undulators, scrapers) the direct method (takes the geometry as it is) was applied. For tapers both methods provide very similar results up to 20GHz.

In the most cases the wake calculation was extended to a distance (trailer) of 0.2m behind the exciting bunch. The trailer was sometimes extended to up to 1m for elements whose wake fields have not sufficiently faded away. This allows a better reproduction of the impedance spectrum.

3 THE IMPEDANCE BUDGET

Henceforth the term "budget" is used for the sum of the imaginary part of the transverse impedance weighted by the local vertical β-function of all contributing elements.

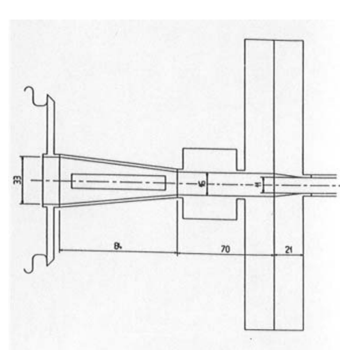

Figure 1: Typical taper of a low gap chamber.

Table 1 and Figure 5 show that the RF-liners (Fig. 2) yield a larger contribution to the budget than the tapers (Fig. 1) of all low gap chambers including 2 invacuum undulators.

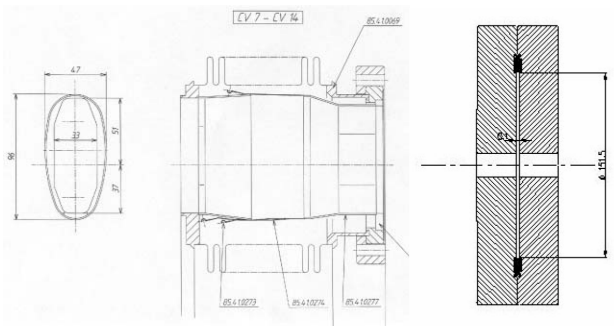

Figure 2: RF-liner and flange with slit of 0.1mm (different scales).

The RF-liners realise the continuity of the chamber wall at the bellows, but also allow flexibility of the chamber during vacuum bake-outs. They are very numerous (290) in the ESRF-machine to provide modularity to the vacuum chamber system. They also represent an important source of longitudinal impedance because their fingers only have a gliding contact to the following vacuum chamber. However, for this study the contact was assumed to be perfect. In fact the found transverse impedance is due to their slight tapering and the little jumps in the chamber wall (the jumps come from the gliding of the fingers over the following vacuum chamber). This tapering is much weaker than that of the real tapers. Even the slits between the fingers don't contribute a lot to the transverse impedance. It is their high number and their location at high vertical β-function in comparison to the low β-function of the tapers (Fig. 3) which render the RF-fingers to be the largest contribution of the whole budget (Fig. 5 and Table 1).

The impedance spectrum of the flanges consists of multiple resonances created by the tiny slit of 100μm res. 150μm all around the chamber wall (Fig. 2) Their high number (571) and their location (Fig. 3) at high vertical β-functions (β=20.7m) create a significant contribution in the budget of the imaginary part until 3-4GHz, followed by an oscillation between negative and positive values. The real part is always positive (at positive frequencies) In Fig. 5 their contribution has been integrated in the contribution of the RF-fingers to keep the spectrum profile discernible.

The 3 scrapers with penetration depths as under operation conditions of the machine excite many resonances. As the wake of the scraper of cell 6 has not faded away sufficiently at the end of the chosen trailer (Fig. 4) the imaginary part of the impedance has an uncertainty leading to a negative value at zero frequency. The scraper of cell 30 benefits from its tapered environment. At about the same penetration depth as the scraper of cell 22 its wake is 3.6 times smaller. The role of the scrapers in the whole budget is finally determined by the vertical β-function of their location. Consequently the contribution of the scraper in cell 22 (β=32m) is more important than that of the scraper in cell 6 (β=2.85m) inspite of the stronger and more slowly decaying wake of the latter. The scraper in cell 30 provides the smallest contribution inspite of its betafunction (β=32m). In total the scrapers have a substantial impact on the total impedance.

With the chosen trailer of 0.5m in the time domain not all resonances in the impedance spectrum of the cavities are resolved. The imaginary part at frequencies below

Table 1: Review of the Vertical Impedance of All Contributing Elements

Element	Number	$\beta_{vertical}$[m]	Im Zt(ω=0)[kΩ/m]	total Im Zt(ω=0)$\beta_{vertical}$[kΩ]
vertical pumping ports	130	19.64	0.014	36
horizontal pumping ports	450		0.000	0
kicker chambers	5	28.7	0.49	70
cavity taper pairs	3	5.27	2.86	45
standard taper pairs	29	4.95	7.52	1079
minigap	1	4.2	13.61	57
invac undulator gap=8mm	2	3.7	33.80	250
RF cavities	6	3.6	11.76	254
scraper cell 6	1	2.85	-46.50	-133
scraper cell 22	1	32	20.09	643
tapered scraper cell 30	1	32	5.67	181
CV7/14 RF-liners	62	35	0.76	1649
the other RF-liners	228	23.4	0.27	1441
flanges	571	20.7	0.10	1182
TOTAL				**6756**

0.5GHz is high, however, followed by a steep descent below zero which is passing into a capacitive behaviour according to the scaling law of $\omega^{-3/2}$. Consequently the cavities don't significantly increase the total budget. To avoid the difficulty of the display of negative contributions in the graphical representation the cavity contribution is integrated in the one of the scrapers. In the simulation of the kicker chambers only the vacuum chamber wall geometry was taken into account. Furthermore it was assumed to be perfectly conducting. The effect of the kicker magnets was neglected because it only plays a role at very low frequencies (<100 MHz).The impedance of the kicker chambers only contribute little to the total budget. The same is valid for the pumping ports. The contribution of horizontal pumping ports was even so little that it was not taken into account. Consequently the vertical impedance budget is only weakly affected by slots in the vacuum chamber wall.

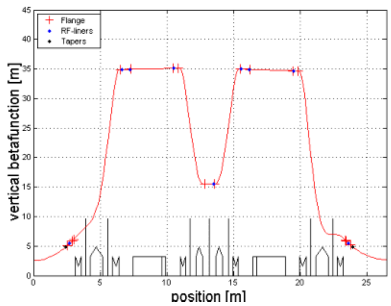

Figure 3: The betafunction in one cell of the ESRF-machine with markers at positions of important elements.

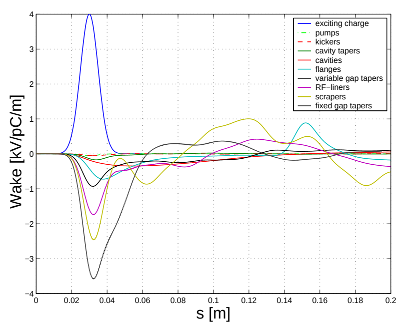

Figure 4: Wake potentials of the different elements.

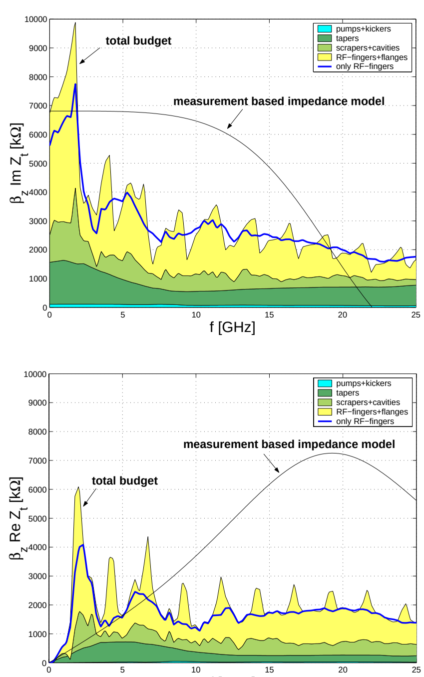

Figure 5: Total vertical impedance spectrum, imaginary and real part. The measurement based model is superimposed.

The budget was compared to the impedance model based on measurements which without resistive wall part is a broad band impedance [6]. The cutoff-frequencies of the budget spectrum and the broad band model are very different. However, the value of the imaginary part of the vertical impedance budget has attained, even exceeded the value of the broad band impedance model at zero frequency. The comparison in Fig. 5 is not completely fair because for the measurement the variable gap chambers and the scrapers were opened. But taking these changes in the budget into account the statement is still valid.

4 CONCLUSION

The largest part of the vertical transverse impedance of the ESRF-machine is created by standard elements (RF-liners and flanges) of the vacuum chamber system. As the vertical betafunction varies a lot in the ESRF-machine its value has a lot of relevance for the impedance budget contribution of an element. The budget will be completed and also established for the horizontal plane. Finally all transverse motion aspects will be recalculated on the base of the obtained impedance budget

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