ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA018

LOSS FACTOR AND IMPEDANCE ANALYSIS OF WARM COMPONENTS OF BERLINPRO*

H.-W. Glock[1,2], M. Abo-Bakr[1], J. Kolbe[1], F. Pflocksch[1], C. Potratz[2], Andreas Schälicke[1]
[1] Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), BESSY II, Berlin, Germany
[2] Compaec e.G., Rostock, Germany

Abstract

The ongoing component design for the HZB 50 MeV, 100 mA ERL project bERLinPro is accompanied by loss factor and impedance computations. A list of accelerator components that are likely to induce geometric wake fields including bellows, collimators, tapers, shutter valves etc. is given. Loss factors and impedance spectra, both calculated using CST-ParticleStudio®, are presented. Scaling of the loss factors with respect to the bunch length is calculated on base of the numerical simulations and is used to extrapolate down to a rms bunch length of 0.6 mm, which is hard to reach directly in numerical simulations.

INTRODUCTION

Future single-pass accelerators, in particular high-brilliant next-generation light sources or colliders for high-energy physics, will demand for beam power levels hardly to be maintained by classical set-ups, which dump the beam with most of its kinetic energy. This led to the "energy recovery linac" concept with a recirculation of the used beam through the accelerating cavities, where it is decelerated by a proper choice of the beam-to-field-phase to a small fraction of its maximum kinetic energy. Thus the beam feeds back the accelerating cavity mode, which in turn accelerates a fresh beam. Such a mode of operation will be most effectively applied to a high current, continuously operated (cw) accelerator with low loss, i.e. super-conducting cavities. It is the aim of the bERLinPro project [1] (cf. Fig. 1), now under construction at HZB, to demonstrate energy recovery operation with a cw (1.3 GHz repetition rate), 50 MeV, 100 mA, $\sigma_t < 2$ ps bunch length, low-emittance beam.

This demands for a careful analysis of all beam line components according to their potential to excite wake fields. This paper is focussed on so-called geometric wakes; effects of coherent synchrotron radiation (CSR), resistive walls or surface roughness are only cited for comparison. Since the bunch spectrum reaches far above 100 GHz most wakes are able to propagate through the machine, in principle causing a strong rf-coupling between individual components. It would demand for excessive supercomputing capabilities to compute the field interaction with each other and the beam for such a long chain of coupled components, which – even if available – would not be practicable for any design optimisation. Thus the two following figures of merit, computable for every single component, were used (cf. Fig. 2, Tab. 1): a) the loss factor; b) the impedance close to the beam-harmonic frequencies of N·1.300 GHz.

*Work supported by German Bundesministerium für Bildung und Forschung, Land Berlin, and grants of the Helmholtz Association.
hans.glock@helmholtz-berlin.de, glock@compaec.de

SIMULATION TECHNIQUE

All simulations were performed with the wakefield solver of CST ParticleStudio® [2], running on a dedicated workstation (2x Intel Xeon E5 2643v2-6-core, 3.50 GHz, Intel S2600 board, 256 GB of DDR3-1866 RAM). The solver uses an explicit time stepping scheme on a hexahedral mesh. In most cases 15 mesh lines were applied longitudinally per bunch rms length $\sigma_s = c \cdot \sigma_t$ of Gaussian shaped bunches. σ_s usually was chosen as 1 mm (computed impedance spectra up to 100 GHz), 3 mm and 5 mm. The number of mesh cells was in most cases up to a few 10^8, largest possible meshes reached $1.3 \cdot 10^9$ cells. Indirect wake integration was used (option "indirect interfaces"), mostly applied to on-axis beams. As a trade-off between spectral resolution versus grid dispersion error and computation time typically a wake length of 10 m was computed for at least one of the three bunch lengths. In most cases two more runs were performed with a wake length of 200 mm, which is sufficient for the program to determine the loss factor.

LOSS FACTOR DEPENDENCY ON BUNCH LENGTH

Due to its infinitely extended spectrum, which cannot be handled numerically, it is not possible to compute a point charge's wake potential (at least not with bandwidth-limited discretizing approaches). Instead the wakes of Gaussian shaped bunches were simulated, giving wake potentials and loss factors depending on the bunch rms length. Computing various objects (many of them not shown here) and comparing their bunch-length dependent loss factors in a double-logarithmic viewgraph heuristically led to the observation of a loss factor scaling according to:

$$k_{loss}(\sigma) = k_{loss}(\sigma_0)\left(\frac{\sigma}{\sigma_0}\right)^{-\alpha} \quad (1)$$

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA018

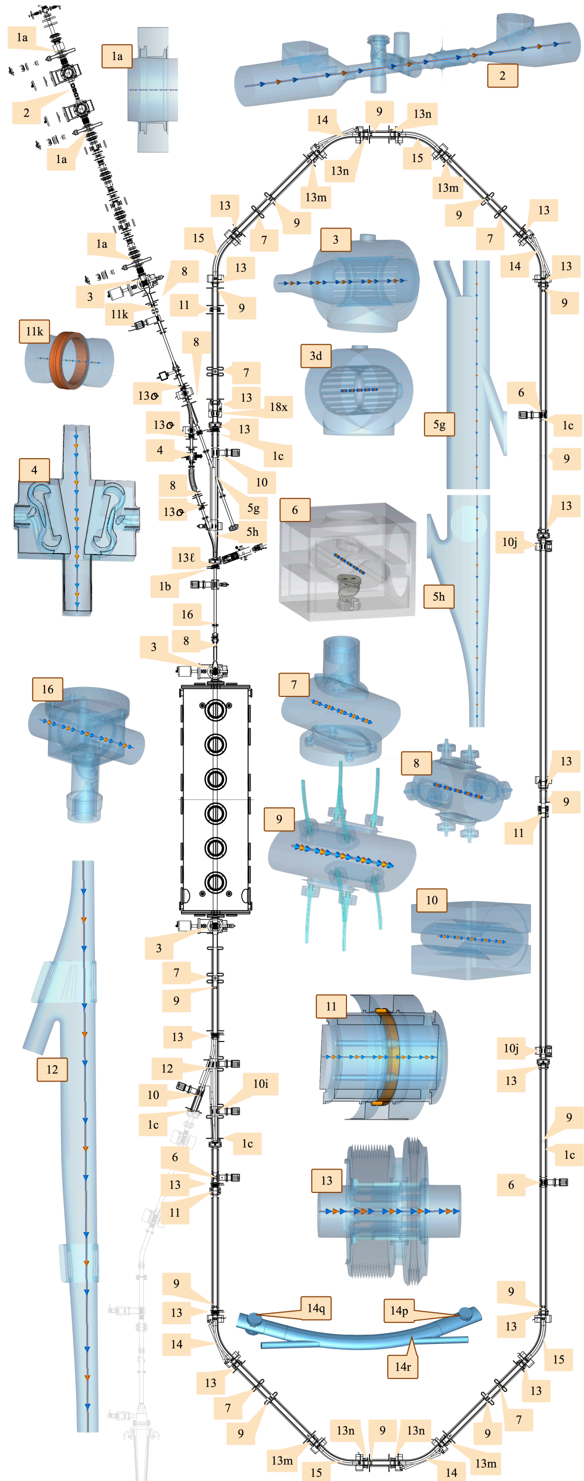
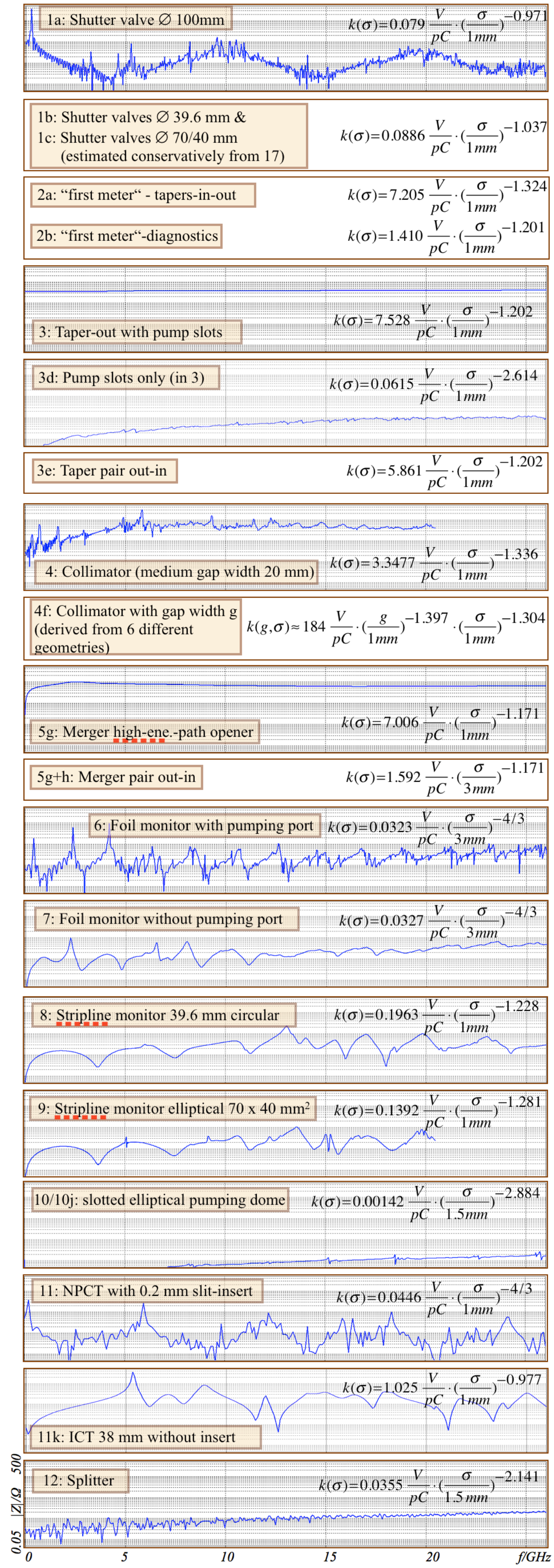


Figure 1 (above): Layout of bERLinPro with locations of various beam pipe insertions. Some components (1, 10, 11, 13) have similar sub-types, not all of them were analysed separately. Because of the limitations of the solver [2], only straight beam paths were computed.

Figure 2 (right, continued on next page): Log.-scaled impedance values vs. frequency, loss factor scaling rules for components from Figure 1. Scaling derived from computations with at least two bunch lengths (σ_0 given as the shortest one computed); otherwise $\sigma^{-4/3}$ was assumed.



ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA018

Table 1: Numbers n1 / n2 of beam-passed items and loss factors in V/pC for σ = 1.5 mm (upstream to collimator „4") / σ = 0.6 mm (rest of the machine) resp., total loss factors = n1·k(1.5) + n2·k(0.6); †: one unpaired closing taper omitted; @: collimator with 20 mm gap; *: straight beam path only; #: approximated as straight beam path.

Object	n1	k(1.5)	n2	k(0.6)	$k_{tot}(1.5)$	$k_{tot}(0.6)$	k_{tot}
1a	3	0.05	0	0.13	0.16	0.00	0.16
1b/c	0	0.06	7	0.15	0.00	1.05	1.05
2a	1	4.21	0	14.17	4.21	0.00	4.21
2b	1	0.87	0	2.60	0.87	0.00	0.87
3e†	0	3.60	2	10.83	0.00	21.66	21.66
4 @	0	1.95	1	6.62	0.00	6.62	6.62
5g+h*	0	3.58	1	10.48	0.00	10.48	10.48
6	0	0.08	3	0.28	0.00	0.83	0.83
7	0	0.08	7	0.28	0.00	1.96	1.96
8	2	0.12	3	0.37	0.24	1.10	1.34
9	0	0.08	15	0.27	0.00	4.02	4.02
10	0	1.4E-03	5	0.02	0.00	0.10	0.10
11	0	0.03	3	0.09	0.00	0.26	0.26
11k	0	0.69	1	1.69	0.00	1.69	1.69
12*	0	0.04	1	0.25	0.00	0.25	0.25
13	2	0.31	27	0.95	0.63	25.75	26.38
14p	0	2.2E-03	4	0.03	0.00	0.13	0.13
14q	0	4.3E-03	4	0.07	0.00	0.26	0.26
14r#	0	8.0E-03	8	0.04	0.00	0.29	0.29
15	0	6.5E-03	4	0.10	0.00	0.39	0.39
16	0	0.08	4	0.60	0.00	2.39	2.39
17	5	0.03	35	0.08	0.15	2.63	2.78
∑					6.25	81.88	88.13

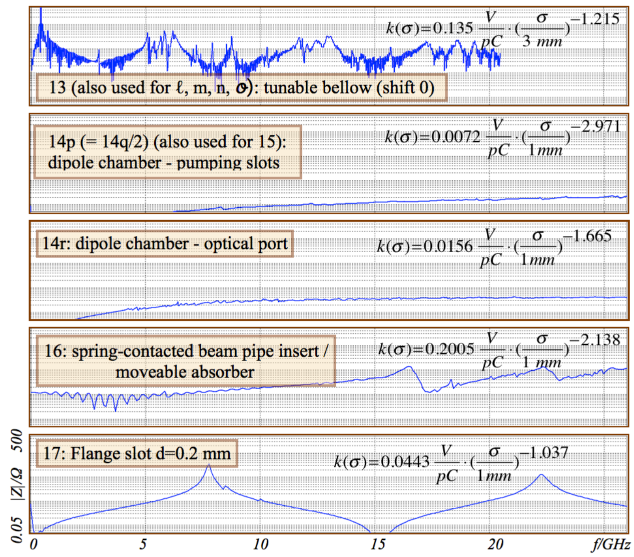
Based on this collection of numerically computed loss factors some observations about scaling properties can be formulated:

- pumping slots in parallel to the beam, though of small absolute loss factors, scale fast by α ~ 2.5…3;
- slots perpendicular to the beam scale by α ~ 1;
- collimator- (reducing the cross section) or cavity-like (enlarge the cross section) shaped devices (with the same beam-pipe cross sections at start and end) scale by α ~ 1.2 … 1.3;
- a good mean value in lack of any more precise knowledge is α = 4/3, which we applied for some devices, where only a single run was performed.

The entire budget of geometrical wakes of ~ 88 V/pC derived from this scaling (cf. Table 1) makes it neither dominant nor negligible compared with estimations [3] of CSR wakes (~ 500 V/pC), resistive wall wakes (~ 17 V/pC) and surface roughness wakes (~ 175 V/pC).

SPECIAL ENGINEERING

Several devices (4, 5, 6, 7, 12, 13, 16; 8 to improve matching of the signal lines) underwent design iterations



in order to reduce loss factors and primarily to avoid field localisation and impedance peaks coinciding with harmonics of the beam repetition rate (1.300 GHz). This holds especially for the length-adjustable bellows (13, cf. Fig. 3), designed without sliding contacts in order to avoid particle production. Since it was not possible to find a shape which was resonance-free for any length to be expected in operation, some mechanical tuning opportunity was introduced by splitting the bellow in two parts, connected by an adjustable disc.

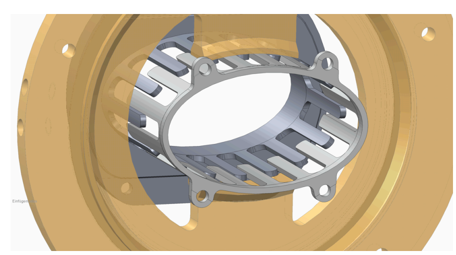


Figure 3: Internal design of the tunable bellow. The inner bars of the adjustable disc (ocher) between the bellow segments are extended close to the shielding fingers in order to enhance the tuning sensitivity.

CONCLUSION

A loss factor budget of the geometrical wakes of all warm bERLinPro components suspected to be of some relevance was computed for a single-bunch excitation, thus neglecting coherent effects. It results in a total loss factor significantly smaller than those of CSR- and surface roughness wakes, but clearly more important than resistive walls. Impedance spectra analyses to identify and avoid resonant excitations at harmonics of 1.3 GHz caused redesign steps for several components. Moveable components (4, 6, 7, 13) also were checked at different positions. General rules for bunch-length dependent scaling of the single-bunch loss factors were derived from heuristics of a large set of numerical computations.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA018

REFERENCES

[1] M. Abo-Bakr et al. “Progress Report of the Berlin Energy Recovery Project bERLinPro“, TUPWA018, Proc. of IPAC’15, Richmond, VA, 2015.
[2] CST-ParticleStudio®, Versions 2014 and 2015β, CST – Computer Simulation Technology AG, Bad Nauheimer Str. 19, 64289 Darmstadt, Germany
[3] M. Abo-Bakr, priv. comm.