Universität Rostock

Traditio et Innovatio

Impedance bench and beam-based measurements - Summary

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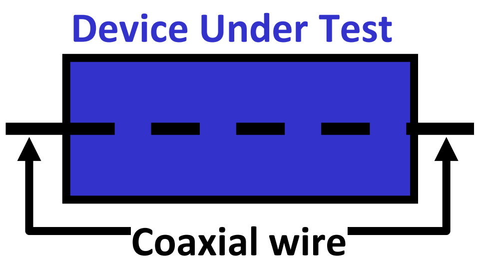
Presentations:

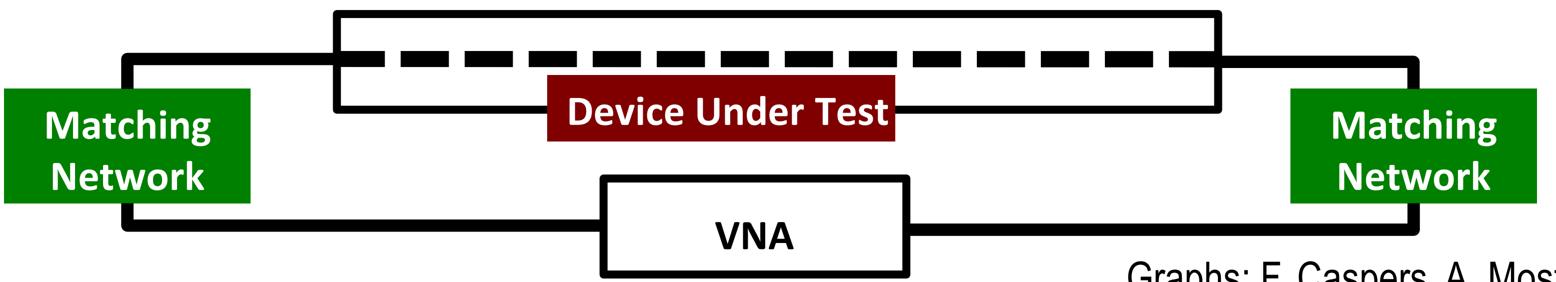
- Fritz Caspers, Andrea Mostacci: History and development of bench measurement techniques for impedance evaluation
- Vadim Sajaev: Review of Beam-Based Impedance Measurement Techniques



Bench measurement techniques

Fritz Caspers, Andrea Mostacci

- Basic coaxial wire concept exploits analogy of ultra-relativistic bunch and TEM-mode in coaxial waveguide; first paper by M. Sands, J. Rees, SLAC Report PEP-95, 1974
- Detailed review is given of
  - Early concepts pointing out sources of errors and misinterpretation
  - Two-wire method to measure transverse impedance
  - Single displaced wire and pair of wires for dipole and quadrupolar impedances
  - Advanced and special methods, e.g. without wires or for slow beams, matching networks, beat pull measurements



Graphs: F. Caspers, A. Mostacci

RELATIONS BETWEEN FORMULAS

Distributed impedance

Lumped element:
DUT length << λ, pipe diameter

Improved log formula (Vaccaro, 1994)

$$Z_{LOG} = -Z_c \ln\left(\frac{S_{21}^{DUT}}{S_{21}^{REF}}\right)\left[1 + \frac{\ln\left(S_{21}^{DUT}\right)}{\ln\left(S_{21}^{REF}\right)}\right]$$

High frequency/long DUT

Hahn-Pedersen formula (1978)

$$Z_{HP} = 2Z_c \frac{S_{21}^{REF} - S_{21}^{DUT}}{S_{21}^{DUT}}$$

Exact in the frame of lumped element hypothesis

$$Z_{\parallel}(\omega) \ll Z_c$$

$$S_{21}^{DUT} \approx S_{21}^{REF}$$

Log formula (Walling et al, 1989)

$$Z_{log} = -2Z_c \ln\left(\frac{S_{21}^{DUT}}{S_{21}^{REF}}\right)$$

$$S_{21}^{DUT} \to 1$$

$$\ln(x) \approx x - 1$$

Sands-Rees formula (1974)

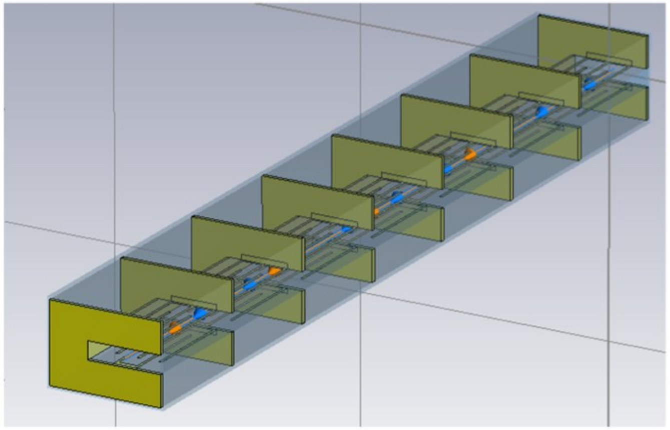
$$Z_{SR} = 2Z_c \frac{S_{21}^{REF} - S_{21}^{DUT}}{S_{21}^{REF}}$$

Very versatile formula, also for lumped elements with reduced accuracy.

The wire method is strictly valid for frequencies below cut-off.

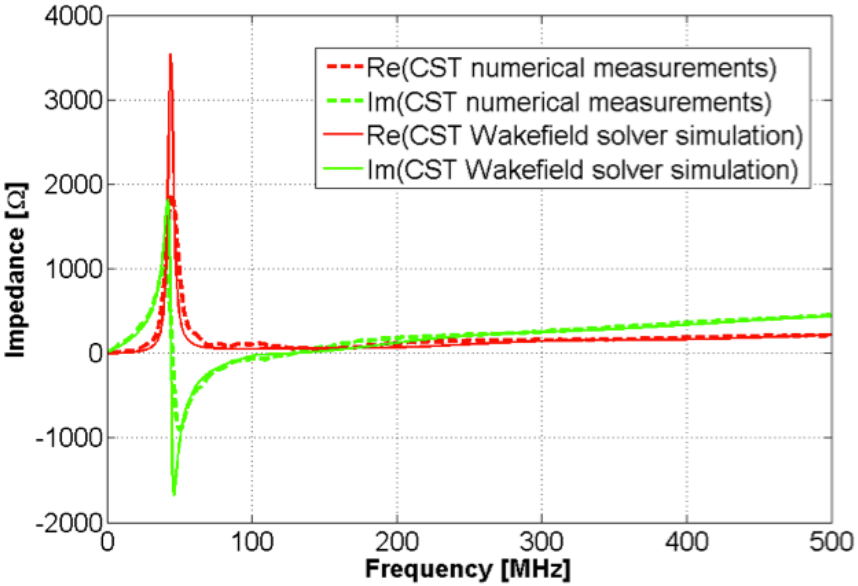
NUMERICAL INVESTIGATIONS OF WIRE METHOD

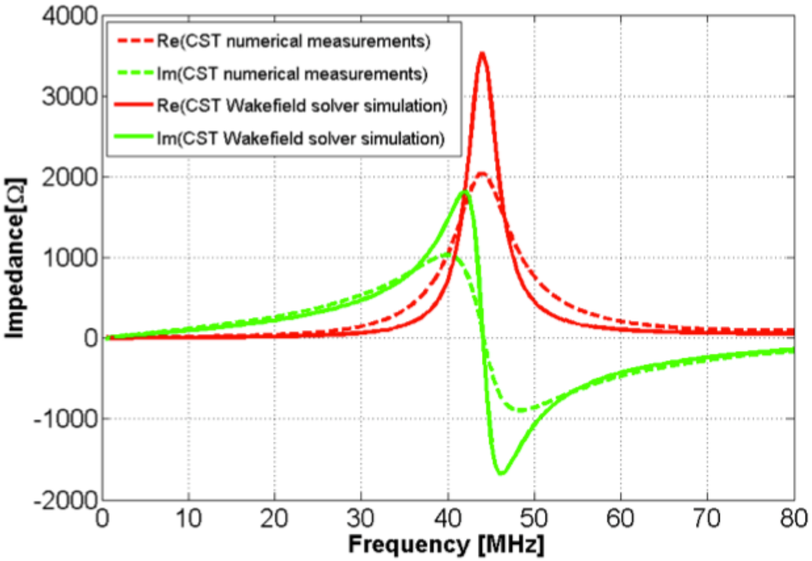
Simulation of the MKE SPS extraction kicker with serigraphy (7 cell).



Very good agreement in the "broadband" behaviour.

Reduction/widening of the peak may be due to the propagation losses in the coaxial line.





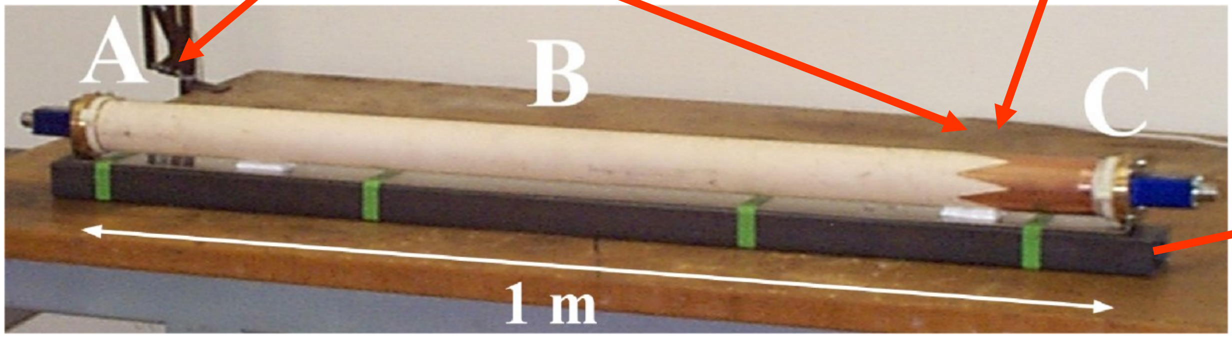
C. Zanini, EM simulations of CERN accelerator components and experimental applications, PhD thesis, 2013

NUMERICAL SIMULATIONS AND WIRE METHOD

First prototypes of LHC kickers ...

RF contacts

Improvement of RF match towards HF.



PS-RF-Note 2002-156

rectangular steel profile

↓

magnet cold conductor

Ceramic test chamber with 30 printed conducting strips (different widths) inside, using the same technology of the final LHC kicker.

Copper tape surrounding the right end of the ceramic tube in order to make a capacitor between the right port and the strip line (point C).

Numerical simulation of the bench measurement

H. Tsutsui LHC Project Note 327 (2003)

Nowadays due to the availability of detailed models, as well as the reliability of RF codes, the simulation comparison is an important help.

Bench measurement techniques - conclusions

Fritz Caspers, Andrea Mostacci

- Reasonable and reliable results with improved instrumentation and understanding
- Generally, the forward transmission coefficient S_{21} should be used
- Transverse impedance measurements with a pair of wires (or a single wire over a metallic image plane) and the laterally displaced single wire
- Matching networks can be implemented, also above cut-off
- Characteristic impedance of the wire obtainable by time domain reflectometry
- Resonant wire methods for high sensitivity requirements
- Cavities: wire measurements only for transverse modes, otherwise bead pull
- Numerical simulation of the coaxial wire set-up to check the validity of the (usually simplified) DUT
- Special methods for slow beams

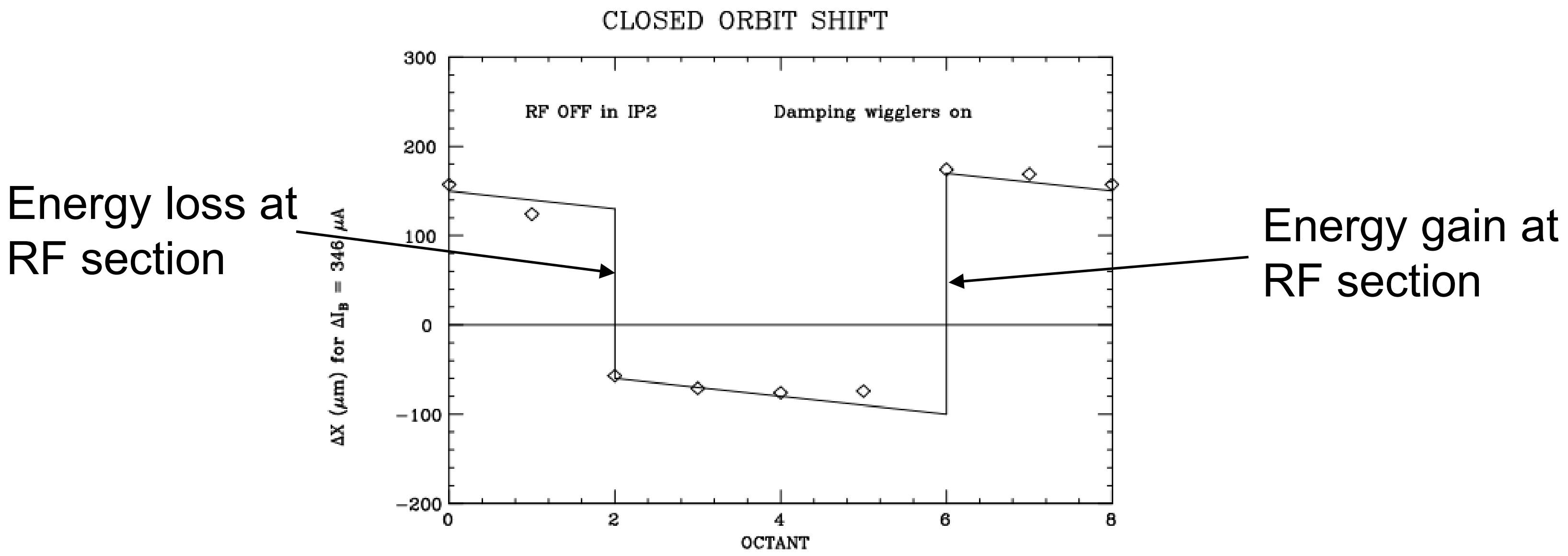
Beam-based impedance measurement techniques

Vadim Sajaev

- Longitudinal impedance
    - Real part – loss factor obtainable via synchronous phase shift which can be measured by various methods, e.g. directly, by streak camera or via orbit changes informing on loss factor distribution
    - Imaginary part – bunch lengthening mostly in combination due to
        - Microwave instability, measurable by streak camera
        - Potential well distortion, often hard to detect – tracking simulations may be very helpful
- Transverse impedance measured via tune shift
    - Local impedance measurements using orbit bumps (several variations in order to improve accuracy) or via local focusing errors (Orbit Response Matrix, ORM)
- Benchmarking the accumulation limit with simulations vs. measurements

Localized Loss Factor – Measurement at LEP[1]

- By turning off one RF section out of two, loss factor of RF section was measured
- Measurement results:
  - One RF section loss factor: 210 V/pC
  - Total loss factor of arcs: 90 V/pC

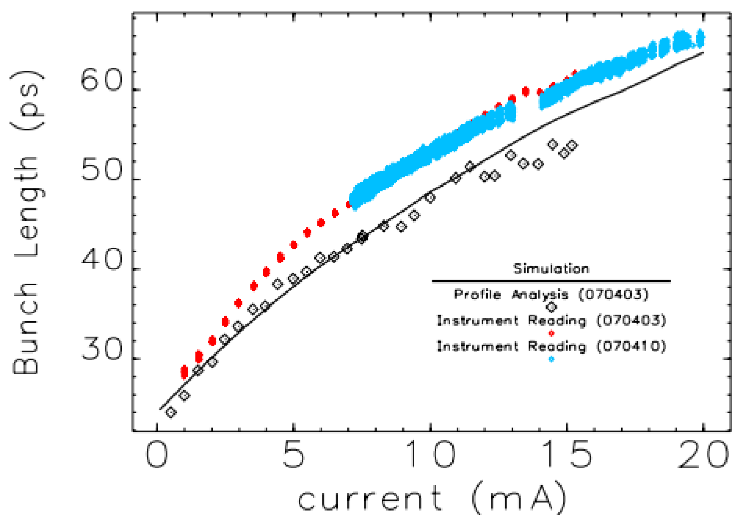


[1]D. Brandt, Proceedings of PAC 1995

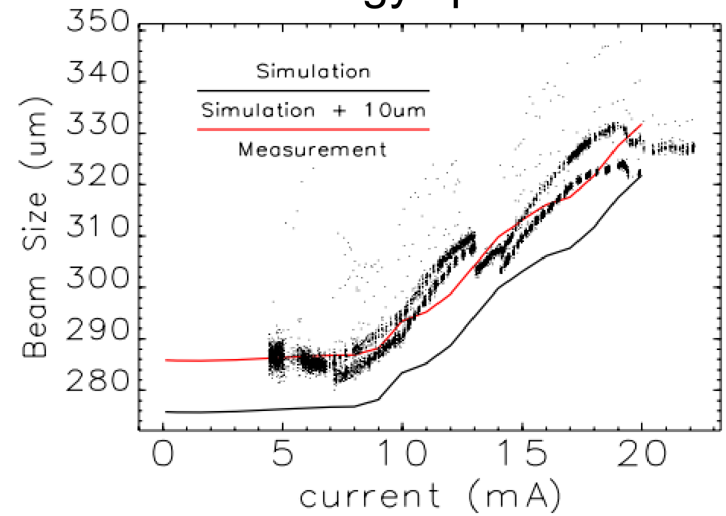
Bunch lengthening (2)

- Sometimes bunch lengthening due to PWD cannot be neglected
- Simulations (tracking) can be used to deal with complex cases
- Calculated wake function was used to simulate bunch lengthening at APS[1]

Bunch length



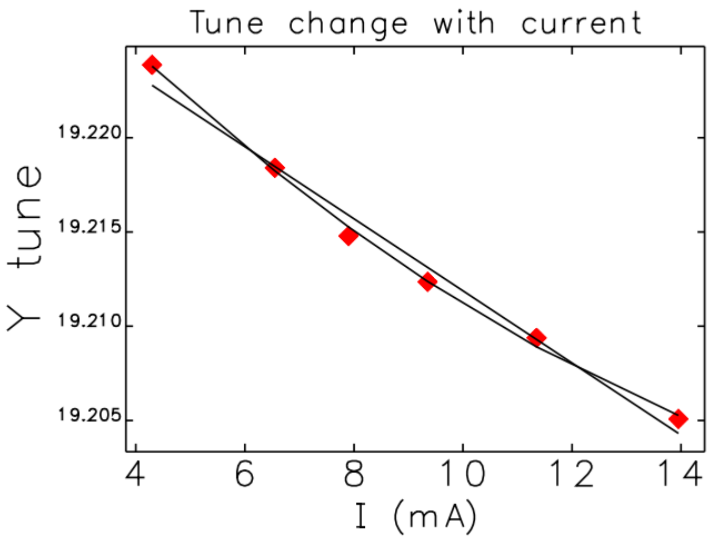
Energy spread

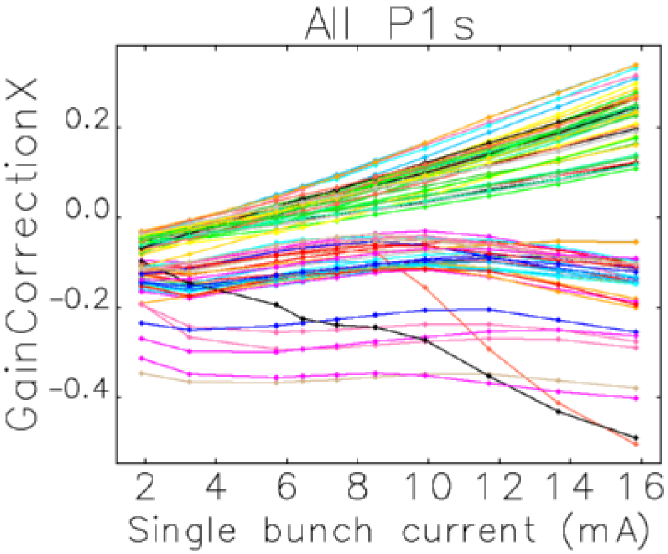


[1]Y-C. Chae, Proceedings of PAC 2007

Some issues of ORM fit method

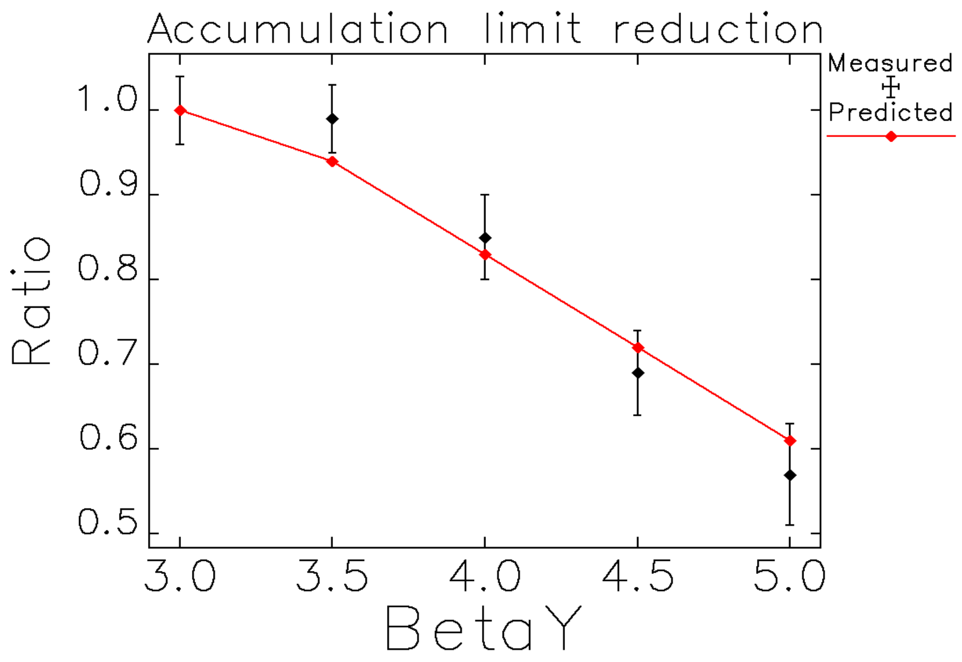
- Bunch length changes over the measurement range (in our case from 50 to 33 ps)
- BPM gains change during single ORM measurement – limits ORM fit accuracy





Accumulation limit measurements

- To improve accuracy of the AL measurement, we followed a procedure of AL optimization that was repeated for all lattices
  - Lattice correction: beta function correction, coupling minimization, chromaticity correction
  - Injection optimization on closed bump
- We found a good agreement with our predictions



Conclusions

- Impedance is measured for almost 50 years now, various methods are used
- Measurement techniques become more sophisticated, but impedances become smaller
- BPMs are a single most extensive diagnostics system in storage rings, can provide local information
- Numerical impedance calculations become more advanced, allow for simulation of complex effects

Summary of Review and State of the Art

- About 40 – 50 years of experience have accumulated a wealth of knowledge which should be kept available for the next generations of scientists
- High maturity of both, measurement and simulation techniques
- Highly elaborated simulation methods together with powerful computer hardware will allow to replace more and more measurements by simulations as it is already usual in industry (rapid prototyping)
- This makes it even more important to make sure that knowledge on measurement techniques doesn't get lost, c.f. e.g. review of F. Caspers in Handbook of Accelerator Physics and Engineering (2012)