

MEASUREMENT OF THE LONGITUDINAL COUPLING IMPEDANCE OF THE HERA-B VERTEX DETECTOR CHAMBER

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Abstract

The HERA-B vertex-chamber has been installed in the HERA proton ring during the 1995/96 winter shut down. The vertex detector is placed inside a conical vacuum chamber due to the detector design. If not properly shielded, the complicated detector structure would interact with the circulating beam, inducing large amplitude wakefields which would eventually drive instabilities. In order to compare the effectiveness of various shielding solutions, a half-size model has been built and the impedance of the vessel alone, and of the vessel with the different shields have been measured by means of the coaxial wire method.

1 INTRODUCTION

The Hera-B experiment [1] at the proton storage ring HERA in Hamburg is a fixed target experiment designed to find violation of CP symmetry in the neutral B meson system. The target and Silicon Vertex Detector (SVD) are mounted in a vacuum tank close to the proton beam (see Fig. 1). The SVD consists of 28 modules which are mounted inside Roman pots.¹ These modules are arranged in quadrants at 7 different locations downstream the target. The complicated shape of the tank and the large number of detector modules are consequences of the large acceptance of the apparatus.

Likewise all the equipment surrounding the beam, the vertex detector can be characterized by a global parameter, the coupling impedance, which is the ratio between the response (longitudinal electric field) and the source of the field (longitudinal perturbation in the beam). This quantity appears as a multi-resonant device. Single and multi-bunch instabilities can be driven by the resonant behaviour of the detector impedance. Electromagnetic shielding of the beam in the detector is therefore required in order that the source of the em waves (the bunch) does not see the multi-resonant surrounding equipment. This fact conflicts with the function itself of the vertex-detector, because a minimal amount of screening material must be employed in order to reduce multiple scattering for particles produced at the target. Note that these particles will traverse the shielding at a typical angle of 20 mrad and the scattering length is therefore about 50 times the thickness of the shield. A compromise solution can be found by means of bench measurements and

¹During injection, due to wider betatron oscillations, a larger aperture is required and the silicon detectors have to be retracted. For this reason the modules are mounted in Roman Pots.

numerical codes.

This article describes the study of different shielding options. Both measurements and simulations were performed. For the simulations the MAFIA program [2] was used while a coaxial wire method [3, 4] was suitable to measure transient and resonant effects.

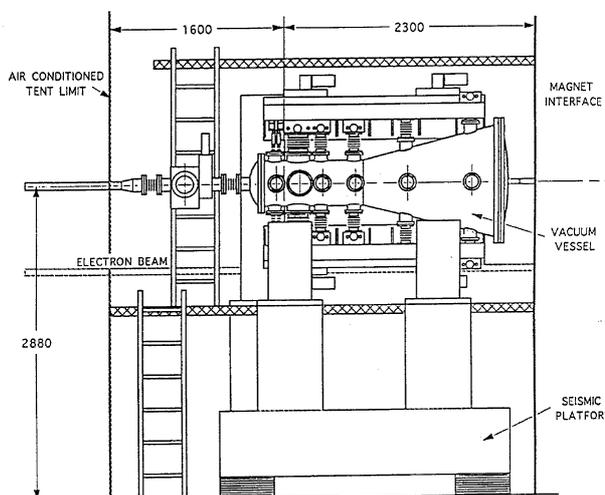


Figure 1: HERA-B vertex chamber

2 IMPEDANCE FROM SCATTERING MATRIX MEASUREMENTS

The measurement method we used works in the frequency domain and is based on the fact that we transform the Device Under Test (DUT) in a coaxial line by introducing an on axis wire in the structure.

In Ref. [3] it is shown how it is possible to get the coupling impedance by means of an ad hoc manipulation of the scattering matrices of the DUT and of the Reference line (REF) (a simple tube with diameter equal to the entrance and exit ones of the DUT).

The philosophy of the measure consists in the following points:

- 1) the characteristic impedance and the propagation constant of REF and DUT differ because of a change in the longitudinal parameters per unit length of the equivalent lines;

2) the measured scattering matrices of REF and DUT contain all the informations necessary to evaluate the propagation constants and the characteristic impedance of the relevant devices;

According to [3] point 1) can be expressed by the following formula

$$Z_{\parallel} = jZ_0 \frac{(k_D^2 - k_R^2)l^2}{k_R l} \quad (1)$$

where Z_0 is the REF characteristic impedance, k_D and k_R are the propagation constants of the DUT and the REF respectively and l is the length of the coaxial line.

Namely by measuring or computing the propagation constants and the characteristic impedance we may derive the longitudinal coupling impedance.

The theory of the measurement[3] gives the relationship quoted in point 2) between the propagation constant and the scattering matrix, as

$$kl = j \ln S_{12} \quad (2)$$

where S_{12} is the 1,2-component of the scattering matrix \mathbf{S} . Equation (2) should be specified for REF and DUT. Upon combining eqs. (1) and (2) we get the formula

$$Z_{\parallel} = Z_0 \ln \frac{S_{12}^R}{S_{12}^D} \left[1 + \frac{\ln S_{12}^D}{\ln S_{12}^R} \right] \quad (3)$$

where R and D mean REF and DUT.

This formula is the guide for the measurements.

3 MEASUREMENT RESULTS

The full-size vertex detector is long 2.4 m, made by a cylindrical section plus a conical one. Our measurements were performed on a half-size model and a reference pipe of the same total length and with a regular diameter of 31.85 mm. A 0.130 mm copper-berillium wire was stretched along the device center line.

Matching sections between the ends of the testing structures (REF and DUT) and the instrumentation were used in order to maintain as much as possible a constant impedance value, Z_0 , from the REF to the instrumentation. The DUT ends on both sides with a small section with a Z_0 equal to the REF one. In general this characteristic impedance is of the order some hundreds Ohms and differs from that of the Network Analyzer (50 Ohms) so inducing unwanted multiple reflections in the detected signal and a bad signal to noise ratio. In our case it was $Z_0 = 330$ Ohms. A particular care was devoted to the realization of these matching sections in order to obtain "clean" data. These small pieces include resistive lumped circuits between the wire and the connectors; very tiny resistors (2 mm length) have been used.

The scattering matrices were measured by using a Network Analyzer (Hp8719C) system, including a sweep oscillator and an S-matrix test-set. An Hp 9000/300 computer was used to control the instrumentation and for the data acquisition. The working frequency range was divided in four

equal parts from 50 MHz to 1970 MHz in order to clarify the frequency dependence of the loss factor as function of the bunch length. The maximum frequency is equivalent to about 1 GHz for the real size device and it was chosen according to the minimum bunch σ of 8.5 cm.

Measurements were performed on the detector tank without and with three different internal shieldings: a tube with holes, a structure with 12 copper-berillium wires (diameter = 0.250 mm) and a structure made by four steel strips (thickness= 0.01 mm).

In Fig. 2 the real part of the longitudinal impedance R is reported as a function of the frequency for the simple detector chamber (case a) and for the tube with holes shielding (case b). A factor ten reduction is visible from the data.

The several resonance peaks are due to the complicate internal structure of the detector. By moving the Roman pots towards the central longitudinal axis of the DUT some resonances disappear or shift in frequency. The data reported in Fig. 2 are for the pots at 13 mm from the DUT central axis (completely outside).

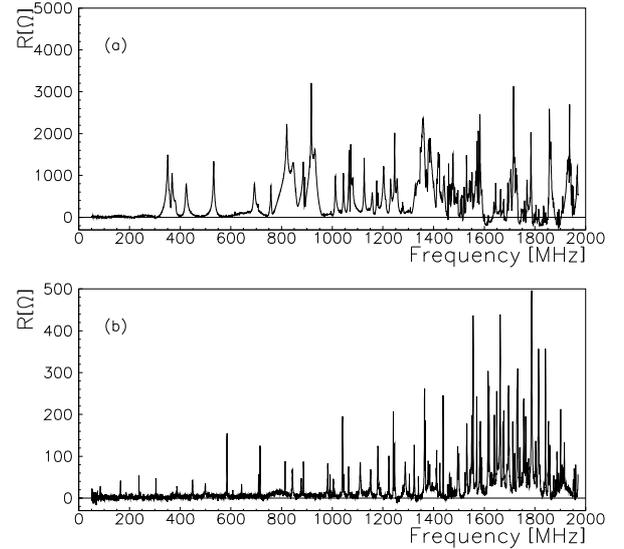


Figure 2: Real part of the longitudinal coupling impedance as function of the frequency: (a) detector with no shielding; (b) detector with shielding by tube with holes

Fig. 3 shows the longitudinal loss factor k_l as a function of the bunch σ for the detector chamber without any shielding for different ranges of integration of the impedance (k_l is essentially the frequency integral of the real part of the longitudinal impedance weighted by the square of the bunch spectrum). It is evident that for long bunches (at the beam injection in the proton ring) all the f-ranges give the same result, whilst for shorter bunches (at normal regime after beam acceleration) it is necessary to enlarge the integration interval of Z_{\parallel} . For our minimum σ measurements in the

range 0 - 1.5 GHz would be sufficient.

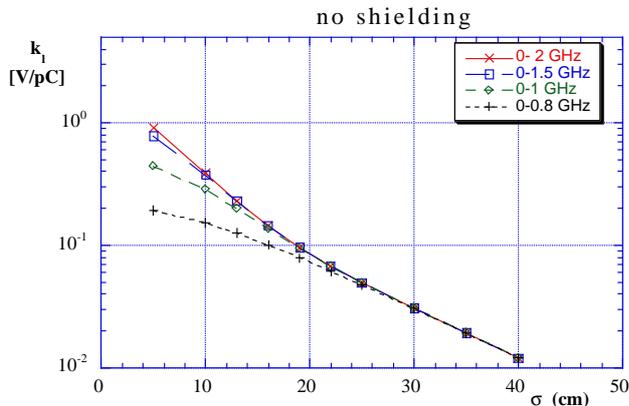


Figure 3: Longitudinal loss factor as function of bunch σ for the configuration without shielding: different integration ranges of measurements

The k_l behaviour for the different shielding structures are compared as reported in Fig. 4 for the full frequency range. A clear reduction (a factor 10 to 100) can be seen with the insertion of the shieldings. The strips and the wires behave in a similar way.

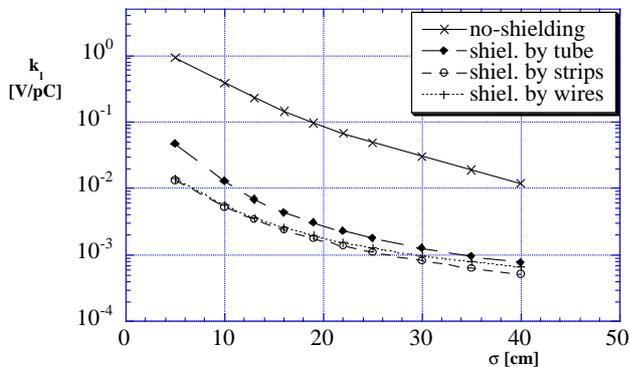


Figure 4: Longitudinal loss factor as function of bunch σ : comparison between different shieldings for the full measured frequency range.

4 SIMULATION RESULTS

The eigenmodes and the transient wake fields have been investigated for different shieldings in detail using the eigenvalue solver, E, and the time domain module, T3, of the MAFIA [2] computer code. All results are scaled to the full size vertex tank. The modes with the highest R/Q are summarized in Tab. 1. Note that the material of the full size vertex tank is mainly stainless steel while the model tank is made of Aluminum. The Q values of the model tank are

therefore about a factor 3.5 higher than the values for the full size tank.

Table 1: Results from the eigenvalue calculation scaled for the full size tank without any rf-shielding

Mode	f [MHz]	Q	R/Q [Ohm]
9	193	1500	29
10	250	5900	56
14	304	3800	40
18	377	4200	58

The time domain calculation gave a total loss parameter of $0.59 \cdot 10^{12} V/C$ (for a bunch with $\sigma = 8.5$ cm), in excellent agreement with the measured value of $0.51 \cdot 10^{12} V/C$.

Furthermore, three different rf-shieldings have been investigated: a beam pipe with holes, wires, and metal strips. Typical values for the modes with the highest R/Q are at least two order of magnitudes smaller compared with the results with no rf-shielding. For details see Ref. [5].

5 CONCLUSIONS

All the shielding models produced a reduction of at least a factor 100 in the loss parameter and hence also in the power loss. Thus the important considerations in choosing and constructing an effective shielding for the proton beam will be in the engineering. For the wire and strip shieldings, one has to take skin depth into account as it is possible that one or two wires or one strip must carry all the induced current when the beam is off axis. It is also important that the contact between the paddles and the shielding be well defined, to avoid induced effects and local heating.

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