Beam impedance measurements.Coaxial Wire Method.

Giuseppe Di Massa*, Maria Rosaria Masullo
Istituto Nazionale di Fisica Nucleare - sez. di Napoli
Mostra d'Oltremare, Pad. 20 - 80125 Napoli, Italy.
* Dip. Elettrico Univ. della Calabria - 87036 Rende (CS), Italy.

Abstract

The measurement of coupling impedance of accelerator vacuum chamber components by wire method using a synthetic pulse technique is presented. A standard instrumentation, like a Network Analyzer able to work in the microwave region, is used in order to perform measurements in frequency domain. An off-line Fast Fourier Transform can be used to treat the data. A suitable time-frequency de-embedding technique is proposed. Experimental results are presented.

I. INTRODUCTION

A Φ Factory machine, DAΦNE [1], has been proposed at the National Lab. of INFN of Frascati - Italy- (a general talk is presented elsewhere at this conference). The goal of this accelerator is to reach a luminosity of 10^{32} cm^{-2} sec^{-1} at 510 MeV. To achieve this requirement high currents, short bunch lengths, long lifetimes and high stable beam are required. All these requirements are strictly related to the design of the whole machine and they can be affected by intrabeam scattering, μ-wave instabilities, coupled bunch instabilities, whose thresholds are linked to the vacuum chamber geometry, to RF cavity properties depending on the interaction of the bunch with the surrounding structure (coupling). A problem of great importance is the controlling of the machine impedance to be kept at a low value(under 5Ω). This means that all the accelerator components like kickers, bellows, etc. that can give a big contribution to the total impedance, have to be carefully designer and tested before the installation. From this the necessity of a laboratory method to measure impedance follows, it has to be used as a feedback on the design of the machine elements.

We propose to use the coaxial wire method [2] instead of the frequency perturbation one [3], because of the low quality factor (Q) linked to the low impedance to be measured in our components. The used technique transforms the Device Under Test [DUT] in a coaxial line by putting in a central wire in order to measure the transmission through the line.

The method was proposed by Sands and Rees [2] to measure the energy loss of a stored beam to a cavity. The basic idea is that a short current pulse, travelling on a thin wire can simulate a particle bunch and if they have the same time shape then the energy lost in both cases is the same. Some examples of bench measurements of energy loss and machine component impedance are reported in [4,5,6].

We performed our measurements in frequency domain where the current technology allows obtaining higher precisions. The transmission through the DUT can be affected by discontinuities met by the pulse along the wire.

In order to minimize the presence of unwanted reflections matching sections are used to maintain as much as possible a constant impedance value till the DUT.The data analysis is than carried in the time domain where is possible to identify the unwanted reflections and to eliminate them by filtering. The new signal is then transformed again in the frequency domain through a Fourier Transform. It has to be mentioned that the goodness of this filtering, called time gating, and de-embendding the main pulse is linked to the right geometry of the matching section and spacers. The presence of spacers is needed in order to separate the main pulse from the others and to "cut" the signal in the time domain without taking away important informations.

II. IMPEDANCE CALCULATION

A current pulse $\mathbf{i_1(t)}$ is fed into a cylindrical coaxial structure (reference pipe) with characteristic impedance $\mathbf{Z_L}$ (Fig.1a). The energy contained in the pulse is given by

$$U_1 = \int_{-\infty}^{+\infty} Z_L\, i_1^{\,2}(t)\, dt \tag{1}$$

The same pulse is fed into the structure with the testing object that replaces a part of the coaxial line (Fig. 1b). Assuming that the pulse is only slightly modified by the testing object, i.e. $\mathbf{i_2(t)=i_1(t)+\Delta t}$, the energy contained in the pulse so perturbed can be written as:

$$U_2 = \int_{-\infty}^{+\infty} Z_L\, i_1^{\,2}(t)\, dt + \int_{-\infty}^{+\infty} 2\, Z_L\, i_1(t)\, \Delta t\, dt \tag{2}$$

where it is assumed (small perturbations)

$$|\Delta i(t)| << |i(t)| \tag{2a}$$

Comparing the energy lost by the pulse, $\mathbf{U = U_1 - U_2}$, with the expression of the energy loss of a bunch of particles

$$U = q \int_{-\infty}^{+\infty} W_b\, I(t)\, dt \tag{3}$$

it can be derived that the signal difference $\Delta i(t)$ times ($-2\, Z_L/q$) is equal to the wake potential $\mathbf{W_b\ (t)}$ of a bunch of particles with the same shape

$$W_b\,(t) = -2\,\frac{Z_L}{q}\,\Delta i(t) \tag{4}$$

0-7803-0135-8/91$01.00 ©IEEE

PAC 1991

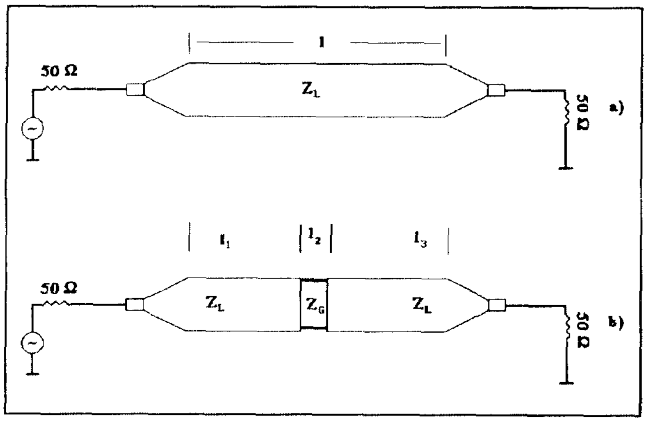

Figure 1 - Schematic diagram of experimental set-up: a) reference pipe; b) test structure.

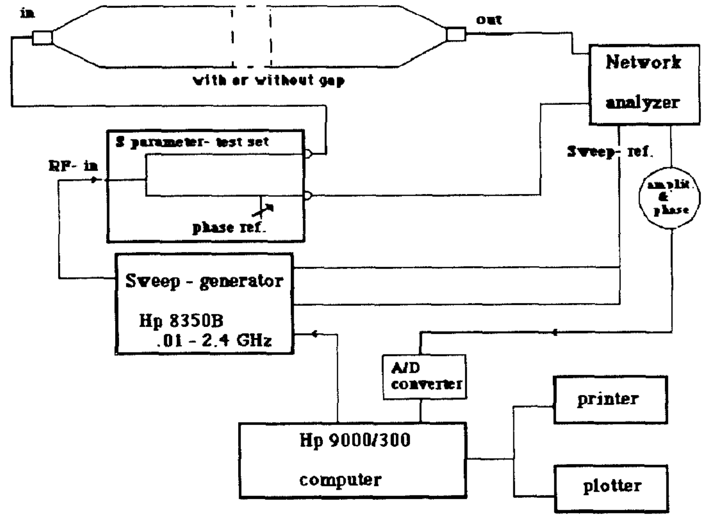

Figure 2 - The layout of the set-up used for the measurement.

Transforming eq. (4) into the frequency domain yields

$$Z(\omega)\, I_1(\omega) = -2\, Z_L\, [I_1(\omega) - I_2(\omega)] \qquad (5)$$

The eq. (5) suggests to perform the measurement directly in frequency domain (Fig. 1) measuring the scattering parameter **S_{12} (w),** that gives the transmission coefficient. According to eq. (5) the longitudinal coupling impedance is given by:

$$Z(\omega) = 2\, Z_L \frac{S_{12} - S_{12}^{ref}}{S_{12}^{ref}} \qquad (6)$$

where S_{12} and S_{12}^{ref} stand for the structure with the discontinuity and for the reference pipe respectively.

It has to be pointed out that the use of small perturbation approximation (eq. 2a) is better satisfied the thinner is the central wire (Z_L increases), but to keep $\Delta i(t)$ at a measurable value the wire cannot be reduced too much. A good compromise needs [2,7].

III. EXPERIMENTAL RESULTS.

A first measurement was performed on a 10 mm gap in a copper beam pipe. Two little metallic strips are used to assure the electric continuity between the two pipe pieces. The total length, tube plus gap, is 477.6 mm, with a diameter of 69 mm. Two matching cones, 500 mm long, are used in order to slowly adapt the 69 mm diameter pipe to an N connector. A .95 mm wire is stretched in the center of the tube. A line with the same dimensions, put between the two cones, is used as reference pipe.

The layout of the set-up used for the measurement is reported in Fig. 2. For the data acquisition and for the control of the Sweep oscillator we've used an Hp 9000/300 computer connected to a measurement system (Network Analyzer (N.A.), Sweep oscillator , etc.) trough an Hp-IP bus. The signals (Amplitude and Phase) from the N.A. are sent to a A/D convert and read from the computer for the subsequent analysis. Transmission measurements are performed in the frequency domain over some range of frequency values. An inverse Fourier Transform is performed on the frequency-domain data. A train of pulses is then observed in the time-domain trace. These pulses are due to multiple reflections from mismatches in the matching section and at the test device. Then the first pulse is isolated by gating (is kept) and is Fourier-transformed to yield a frequency response with the beating caused by multiple reflection removed.

In fig. 3 the amplitude of the transmission coefficient, S_{12}^{ref}, for the reference pipe (solid line) is compared to the transmission coefficient, S_{12}, of the gap discontinuity (dashed line). The phase of the signals are dropped due to lack of space. In fig. 4 and 5 the time domain transforms of the detected signals are reported, they clearly show multiple reflections due to mismatches in the feeding structure. In fig. 6 the frequency domain transmission coefficients S_{12} and S_{12}^{ref} obtained after a time domain gating of 4 nsec around the main pulse, are reported. Finally, in fig. 7, according to (6) and using the gated signals, the real and imaginary parts of coupling impedance $Z(\omega)$ are depicted. Instead of using spacers, when the structure assumes too big dimensions, a numerical expansion technique, like Chirp-z, can be used. Another possibility is to use a more sophisticated technique of de-embedding [8]. The two mentioned techniques are particularly useful when the impedance of large object have to be measured. Experimental verifications of these techniques are in progress.

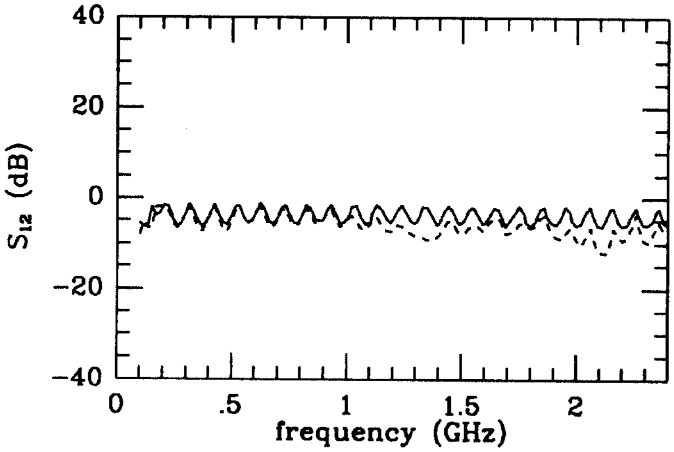

Figure 3 Transmission coefficient. Reference pipe (solid) gap-discontinuity (dashed)

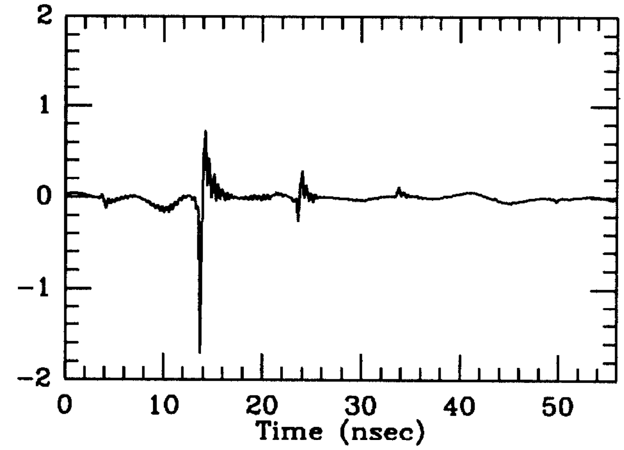

Fig. 4 Time domain transform relevant to reference pipe.

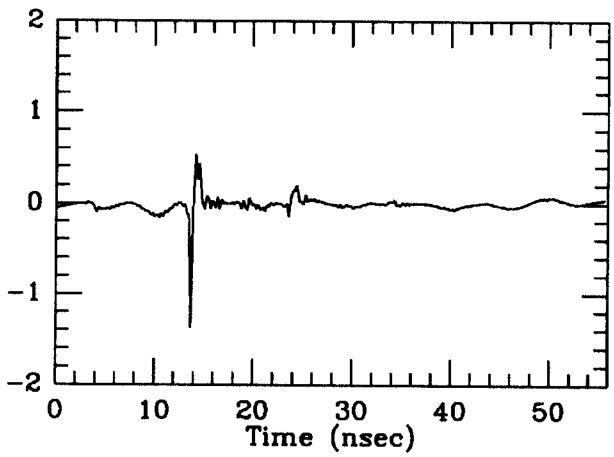

Fig. 5 Time domain transform relevant to gap discontinuity

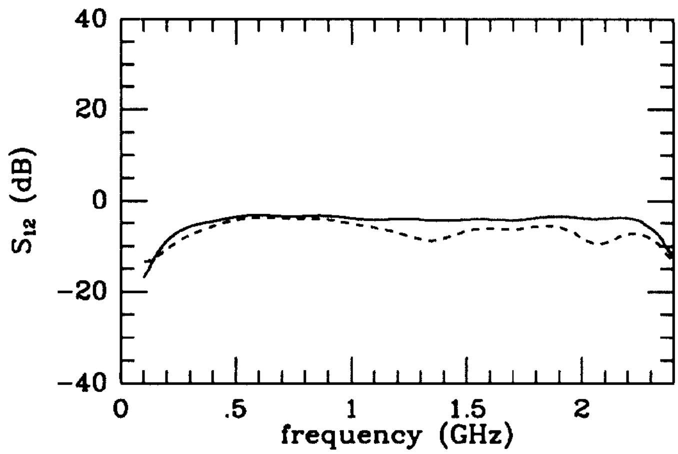

Figure 6 Transmission coefficient after time domain gating Reference pipe (solid), gap-discontinuity (dashed).

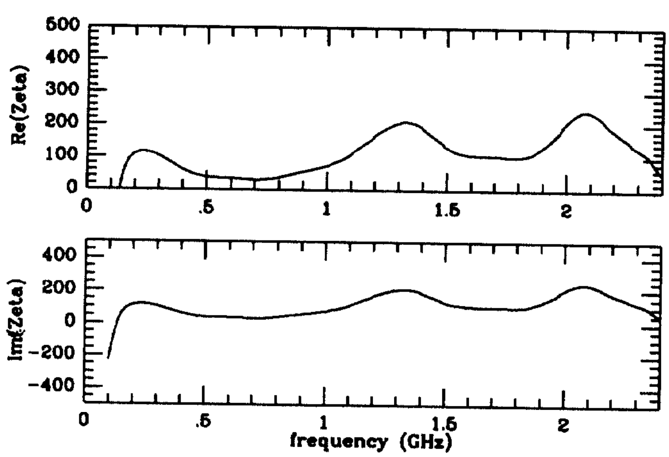

Figure 7 Longitudinal impedance for the gap discontinuity

V. REFERENCES

[1] *PROPOSAL FOR A Φ-FACTORY*, LNF-90/031(R),Frascati, Italy, 1990.

[2] M. Sands, J. Rees: "A bench measurement of the energy loss of a stored beam to a cavity", PEP-95, 1974.

[3] L.C. Maier, J.C. Slater, "Field strength measurements in resonant cavities", Journal of Applied Physics, Vol. 23, pp.68, 1952.

[4] F. Caspers: "Beam impedance measurement by wire method using a synthetic pulse technique ", IEEE Trans. Nucl. Science, vol. NS_32, pp. 1914, 1985.

[5] L.S. Walling, D.E. McMurry, D.V. Neuffer, H.A. Thiessen, "Transmission-line impedance measurements for an advanced hadron facility", Nuclear Instruments and Methods in P.R., A281, pp. 433-447, 1989.

[6] G. Di Massa, M.R. Masullo, "Beam impedance measurements using a synthetic pulse technique", in EPAC European Particle Accelerator Conference, Nice, France,June 1990.

[7] H. Hahn, F. Pedersen: " On coaxial wire measurements of the longitudinal coupling impedance", BNL-50870, Brookhaven, USA, 1974.

[8] G. Gronau, I. Wolff, "A simple broad-band device de-embedding method using an automatic network analyzer with time domain option", IEEE Tran. on Microwave Theory and Tec., Vol. 37, pp. 479-483, March 1989.