DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, Jan. 28 1992

Note: **G-12**

LOSS PARAMETER MEASUREMENTS FOR THE ACCUMULATOR KICKER

G. Di Massa*, M.R. Masullo and V.G. Vaccaro

Sez. INFN di Napoli - Dip. di Scienze Fisiche dell'Univ. di Napoli
* Università della Calabria

Summary

The dynamics of a particle beam in a circular or linear accelerator can be strongly affected by the interaction with the surrounding structure, especially when the beam passes through a big discontinuity in the vacuum chamber like a cavity, a bellow or a shape variation. During this interaction new electromagnetic fields are created (wake-fields), that act back on the circulating beam causing energy loss and sometimes instabilities.

In order to measure the energy loss of a real discontinuity, an indirect bench method has been used. It is based on the determination of a parameter called "Coupling Impedance", **Z(ω)**, that usually describes the effects of the interaction between the beam and the surrounding medium in the frequency domain.

In particular the loss factor, **k**, has been computed for an Accumulator kicker prototype, comparing the experimental results with those obtained by numerical simulations with TBCI and MAFIA computer codes [1].

Introduction.

The amount of energy lost by a charged particle, encountering a cross-section variation of the vacuum chamber, can be described by means of the parameter **k**, loss factor, (in Volt/Coulomb). In the time domain the fields induced by a moving charge are described introducing the wake potential, **W(t)** [Volt/Coulomb], proportional to k [2]. In the frequency domain the coupling impedance, **Z(ω)** [Ω], is introduced as the Fourier transform of the wake potential :

$$Z(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} W(t)\, e^{-i\omega t}\, dt \qquad \textbf{(1)}$$

W(t) is a real quantity, meanwhile Z(ω) results to be complex. It is simple to derive from the relation between k and W(t) that

$$k = \int_0^{\infty} Z_R(\omega)\ d\omega \qquad \textbf{(2)}$$

For a gaussian bunch distribution with σ_t standard deviation it results:

$$k = \int_0^{\infty} Z_R(\omega)\ e^{-\omega^2\sigma_t^2}\ d\omega \qquad \textbf{(3)}$$

We proposed to measure $Z_R(\omega)$ by using a laboratory method known as "coaxial wire method" [3]. Because of the high accuracy required, the measurement had been carried out in the frequency domain where high technology is available at lower cost with respect to "time domain" instrumentation.

The method.

The used method was proposed by Rees and Sands [3] in order to measure in laboratory the energy lost by a bunch of particles in a cavity. The basic idea is that a *short current pulse* travelling on a thin wire *simulates a relativistic particle bunch* and if they have the same time shape then the energy lost is the same in both cases. This technique transforms the Device Under Test (DUT) in a discontinuity on a coaxial line, representing the pipe, by putting in a central wire (see Fig. 1).

The measurement is done by comparison sending the same pulse *i(t)* in two different coaxial structures of the same total length with and without the DUT. The transmission coefficient is then measured for both, and the current change is evaluated, $\Delta\mathbf{i(t)} = (\mathbf{i_0(t)} - \mathbf{i_{dut}(t)})$, where $\mathbf{i_0}$ and $\mathbf{i_{dut}}$ are respectively the signals in the undisturbed line (reference) and in the DUT, see Fig. (2). The difference Δi is a measure of the perturbation introduced by the DUT and it depends on the wire thickness.

The differences between the real situation (bunched beam) and the simulation (current pulse) strongly depend on the pulse length and on the thickness of the central wire; the field distribution is least affected choosing a very thin wire. At the same time the wire cannot be reduced too much because a very small center conductor can lead to a pulse distortion, due to resistive loss, higher than for a thicker wire and, moreover, the small difference Δi has to be kept at a measurable value, say from 5% to 20% of the original pulse. A compromise has to be looked for. Wire radius between 10^{-2} and 1 cm might be used.

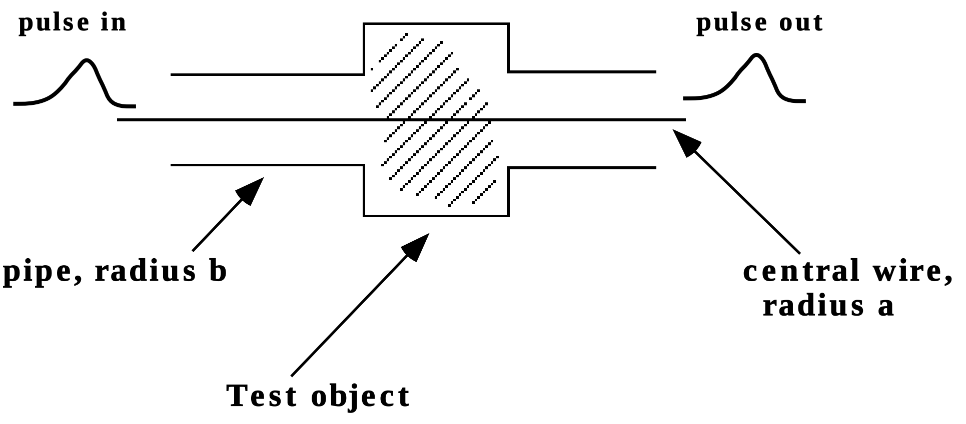

Fig. 1 *- Coaxial wire method, schematic diagram.*

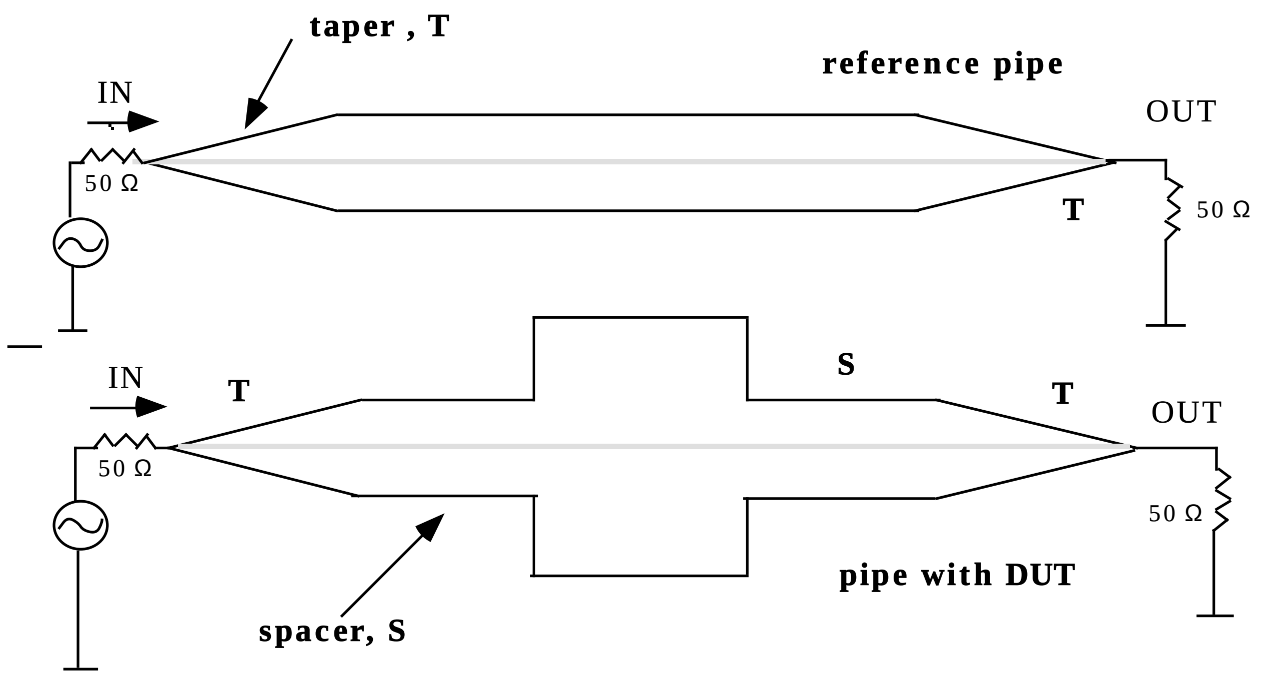

Fig. 2 *- Experimental set-up: diagram.*

As we said before we performed our measurements in the frequency domain. The transmission through the coaxial structure can be affected by impedance discontinuities met by the travelling pulse leading to unwanted reflections. In order to minimize the presence of these reflections, matching sections, called Tapers, are used to smoothly adapt the impedance from 50 Ω (instrumentation) to the coaxial pipe (see Fig. 2). The data analysis can be carried out directly in f-domain or passing before through the Time-domain, by means of a Fast Fourier Transform, and then going back to the f-domain. In the second analysis path it is possible to filter the main peak eliminating the unwanted reflections (Gating process) [4]. The presence of spacers between the DUT and the connectors, see Fig. 2, is useful in order to separate the main pulse from the others and to better "clean" the signal in the time domain without taking away important informations. In any case the filter process is to be done very carefully.

Assuming that the pulse is only slightly modified by the testing object presence, $\Delta \mathbf{i(t)} \ll \mathbf{i(t)}$, the comparison between the energy lost by a real particle bunch, with a charge *q*, and that lost by a pulse with the same time shape leads to [3,4]:

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

where Z_L is the characteristic impedance of the coaxial line.

Transforming eq. (4) into the f-domain, the following expression for the longitudinal coupling impedance results :

$$Z(\omega) = -2Z_L\,\frac{I_{ref}(\omega) - I_{dut}(\omega)}{I_{ref}(\omega)} \qquad \textbf{(5)}$$

Measuring directly in f-domain eq. (5) becomes:

$$Z(\omega) = 2Z_L\,\frac{V_{dut}^{out} - V_{ref}^{out}}{V_{ref}^{out}} \qquad \textbf{(6)}$$

Experimental results.

The measurements were performed on an Accumulator's kicker prototype 60 cm long and with a diameter of 20 cm (see Fig. 3). The pipe used for the spacers (5 cm each) has an elliptical shape, as the real vacuum chamber will have, with two semiaxis of 5.2 cm and 1.75 cm respectively. Two cones, 50 cm long, has been used to slowly match the elliptical tube to the N connectors on both ends. A .95 mm wire was stretched in the tube center. An elliptical tube, same spacer shape, of a total length equal to the kicker plus the two spacers has been used as reference pipe inserted between the tapers.

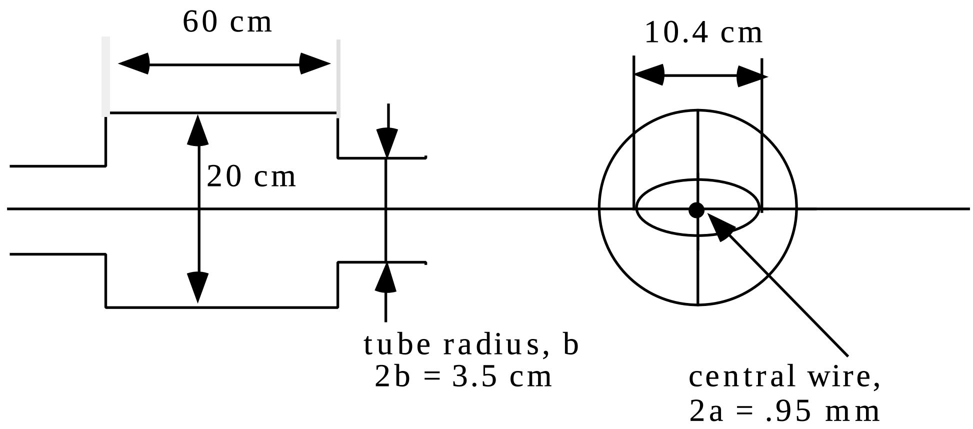

Fig. 3 - *Kicker cavity with elliptical beam pipe.*

The layout of the set-up adopted for the measurement is shown in Fig. 4. For the data acquisition and for the control of the Sweep Oscillator an Hp 9000/300 computer has been used connected to the measurement system (Network Analyzer (N.A.), Sweep Oscil., etc.) through an HP-IP bus. The signals (Amplitude and Phase) from the N.A. are sent to an A/D converter and read from the computer for the following analysis. Transmission measurements have been performed in the frequency range between *.01 and 10 GHz.*

The amplitude of the kicker transmitted signal is shown in comparison with that of the reference pipe in Figs. 5a and 5b for two frequency ranges: 0 - 2 GHz and 2 - 10 GHz. As mentioned before the difference between the two signals is very little. Some multiple reflections due to mismatches are present.

For the $Z(\omega)$ calculation we computed Z_L, tube characteristic impedance, using the following expression obtained under the assumption of a very flat elliptical tube:

$$Z_L \approx \frac{Z_0}{2\pi} \ln\left(\frac{4}{\pi} \frac{b}{a}\right) \tag{7}$$

where Z_0 is the impedance of the free space ($120\ \pi$), a is the wire radius and b the tube minor semi-axis. From (7) we get $Z_L = 231\ \Omega$.

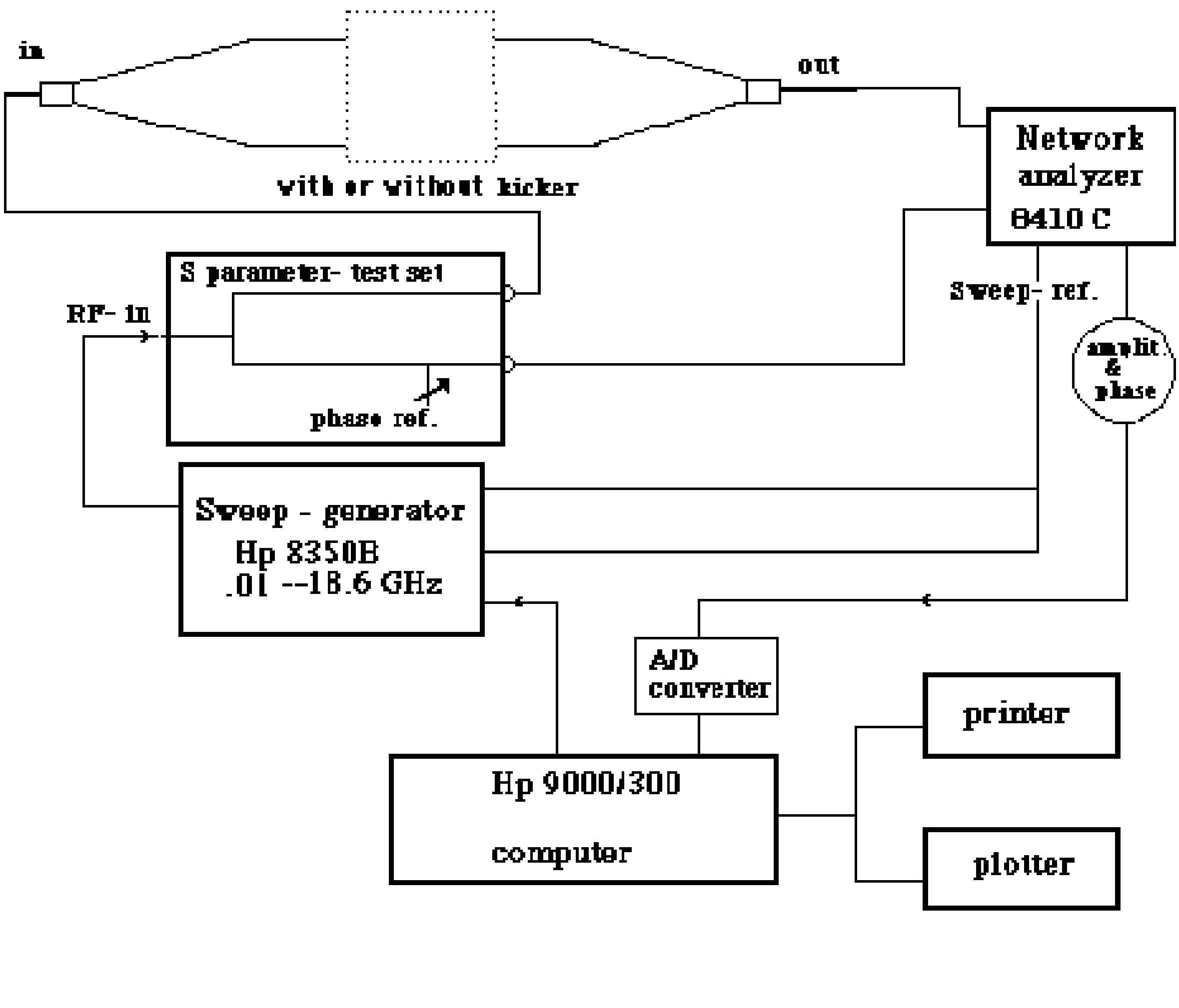

Fig. 4 *- The layout of the set-up used for the measurement.*

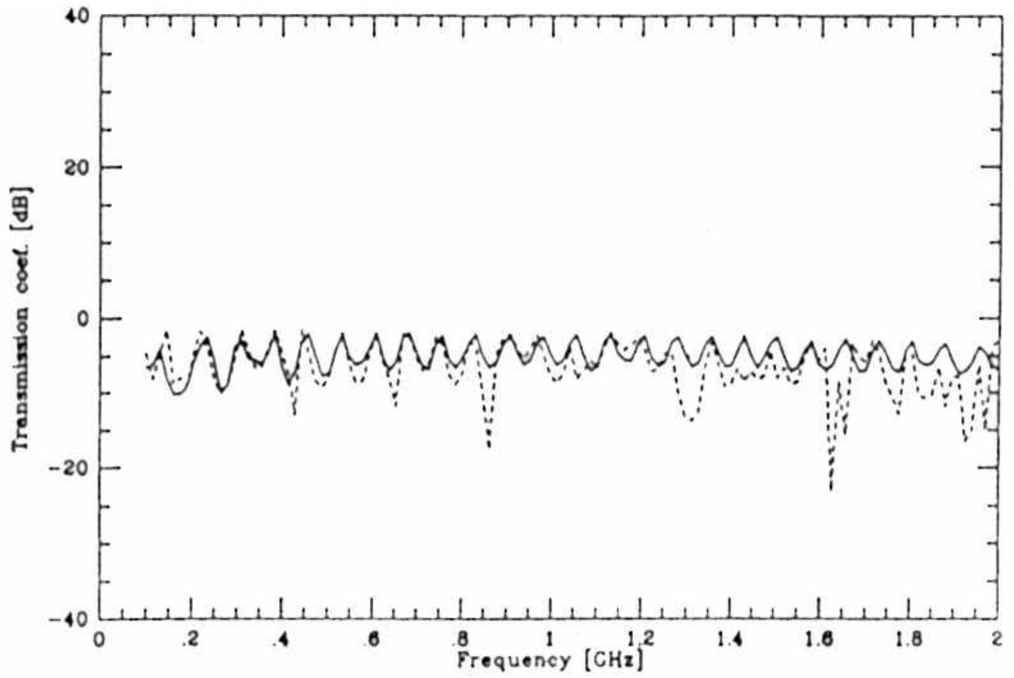

Fig. 5a - *Coaxial wire method. Transmitted signal: reference tube response (solid line) compared with the kicker response (dashed line). Frequency range = 0.01 - 2 GHz.*

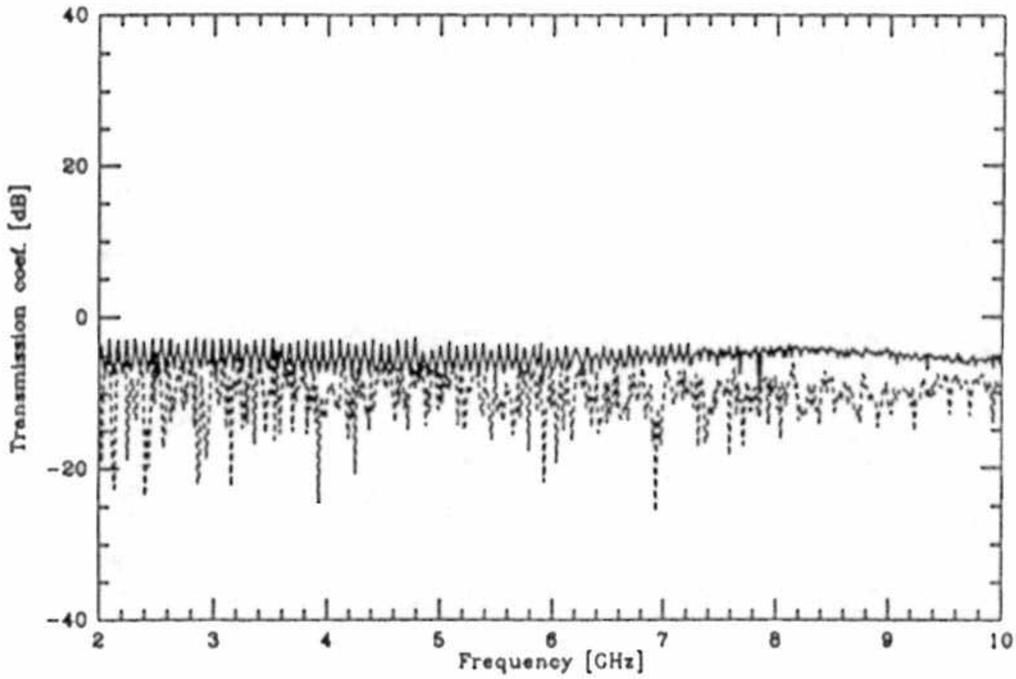

Fig. 5b - *Coaxial wire method. Transmitted signal: reference tube response (solid line) compared with the kicker response (dashed line). Frequency range = 2 - 10 GHz.*

Using the formula (3) we got the loss factor values reported in Table I, for different bunch length, σ_l , in comparison with the data obtained from numerical simulations. The same data sets are reported in Fig. 6 as function of σ_l .

The agreement between the two data sets is satisfactory, showing the goodness of both approaches (simulation and measurement method). The simulation data are always bigger than the experimental ones except for bunches longer than 4 cm. The different behaviour can be explained looking at the formula (3). For longer bunches the contribution to the integral evaluation is mainly due to lower frequencies, where the error can be bigger because of the smallness of the output signal difference between kicker and reference (low impedance).

TABLE I

σ_t [nsec]	.08	.1	.13	.17	.2
σ_l [cm]	2.5	3	4	5	6
k [V/pC] (experim.)	**.282**	**.208**	**.128**	**.0875**	**.065**
k [V/pC] (simulat.)	*.337*	*.255*	*.146*	*.0793*	*.041*

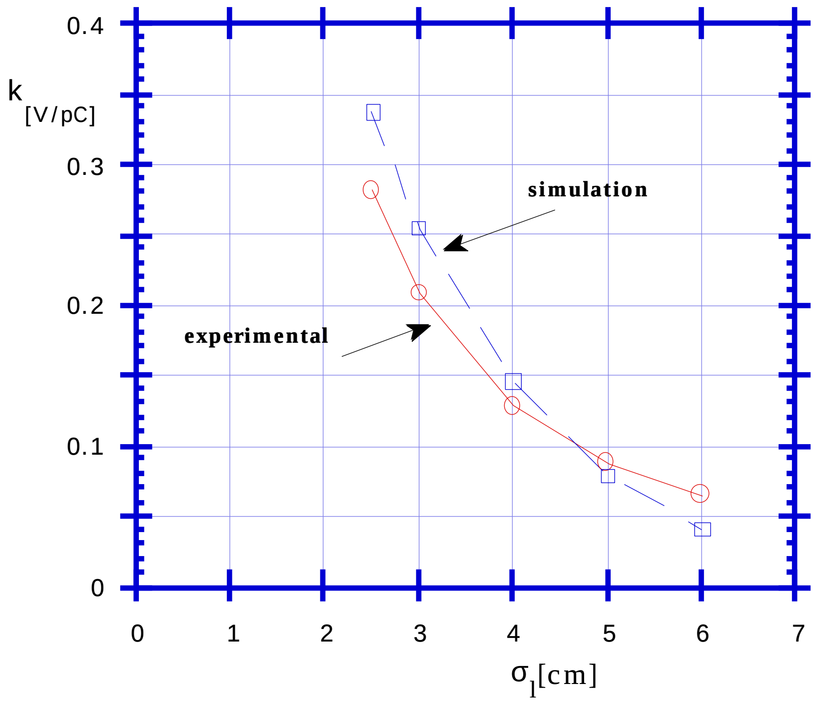

Fig. 6 *- Loss factor, k, as function of bunch length, σ_l : experimental data (solid line) and simulation data (dashed line).*

Conclusions.

Even if the experimental results are very satisfactory for the k loss determination, more precision is required to better compute Z(ω) in regions where the signal difference is very small, some phase problems can arise (very quick phase change).

We are also looking to a better understanding of the theoretical implications contained in the simulation of the beam with a wire. As we mentioned before the similarities between the beam and the wire strongly depend on geometrical parameters and on the length of the pulse sent in the coaxial structure. A better comparison between the field configurations (all propagating modes) in both cases is under study.

Finally the agreement between the measurements and the numerical simulations has clearly shown that a different kicker structure is required in order to reduce the loss factor. Some new ideas, both theoretical and experimental, are in progress.

References.

1) S. Bartalucci, L. Palumbo, B. Spataro, M. Zobov: RF energy losses and impedance of the DAΦNE Accumulator ring vacuum chamber. - DAΦNE Report to be published:

2) L. Palumbo, V.G. Vaccaro: Wake fields measurements. - LNF-89/035 (P), 31 Maggio 1989;

3) J. Rees, M. Sands: A bench measurement of the energy loss of a stored beam to a cavity. - PEP-95, 1974;

4) G. Di Massa, M.R. Masullo: Beam impedance measurements. Coaxial wire method. - Proceedings of Accelerator Conference, San Francisco, May 1991.