DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **CD-2**

MEASUREMENT OF THE VACUUM CHAMBER EFFECTS ON TIME VARYING FIELD MAGNET

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Introduction

In a conductive material vacuum chamber immersed into a time varying magnetic field eddy currents are generated. Two effects are caused by these currents. The first one, in the frequency domain, is to attenuate the magnetic field inside the chamber and to introduce a time delay between the internal and external (to the chamber) field. The second effect is heat production along the chamber because Joule effect. In this paper we will concern only about the first effect.

If a real time harmonic correction method will be adopted in the DAΦNE Main Rings, the orbit correcting magnets will be all supplied by time varying currents. However a time varying correction only in the interaction regions will be used in order to improve the stability of the IP's.

We have measured the frequency response of the magnetic field inside aluminum pipes of several different thickness (simulating the DAΦNE Main Rings vacuum chamber [1]). We have also measured the effects of a thin ribbed stainless steel chamber similar to that adopted for one of the DAΦNE Transferline pulsed magnets [2].

1. Measurement description

Figure 1 shows a sketch of the two coil system used for the measurement. The larger pseudo-rectangular shaped coil (**main coil**), with 50 turns, about 1.4×10^{-2} m^2 surface was divided in two parts each one positioned in two parallel planes at a distance 3.3×10^{-2} m each other. It was used to generate a dipolar field simulating a correcting magnet (no iron magnetic circuit has been used in order to avoid eddy currents which could generate errors on the measurements). The **probe coil**, with rectangular shape, 16 turns and 6.3×10^{-4} m^2 surface, was mounted with the magnetic field of the main coil central part perpendicular to its surface (maximum magnetic field coupling condition).

The two coil system was firmly assembled on a solid PVC strongback in order to maintain the mutual position fixed. The probe coil support was able to sustain different thickness aluminum cylinders and the stainless steel ribbed chamber around the probe coil itself.

If the main coil is driven by a time variable current, an induced voltage V will be measured at the probe coil output:

$$V = - NS \frac{dB_p}{dt}$$

where N is the number of turns, S is the surface of the probe coil and B_p is the magnetic field of the main coil perpendicular to the probe coil plane. To measure the magnetic field is then necessary to integrate the signal. Figure 2 shows a schematic of the measurement set-up. A voltage driver (function generator) deliver a signal to a voltage to current amplifier (bandwidth equal to about 500 Hz) which is able to supply a current of up to 10 amperes to the main coil. The signal from the probe coil is applied to an active integrator. The response of the probe coil-integrator system is ~ 4 mVolt/Gauss.

Figure 3 shows the integrator electric circuit. The output signal is then monitored by an oscilloscope via the high impedance input.

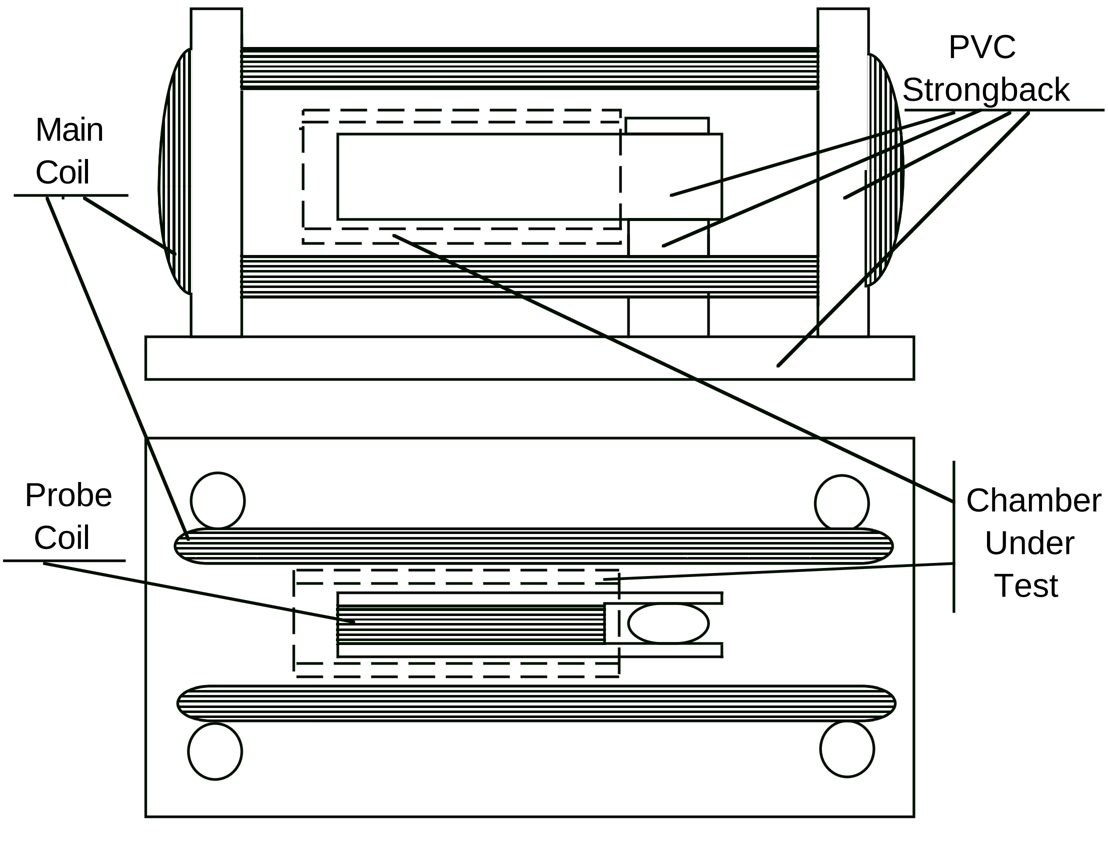

Figure 1. Two Coil System.

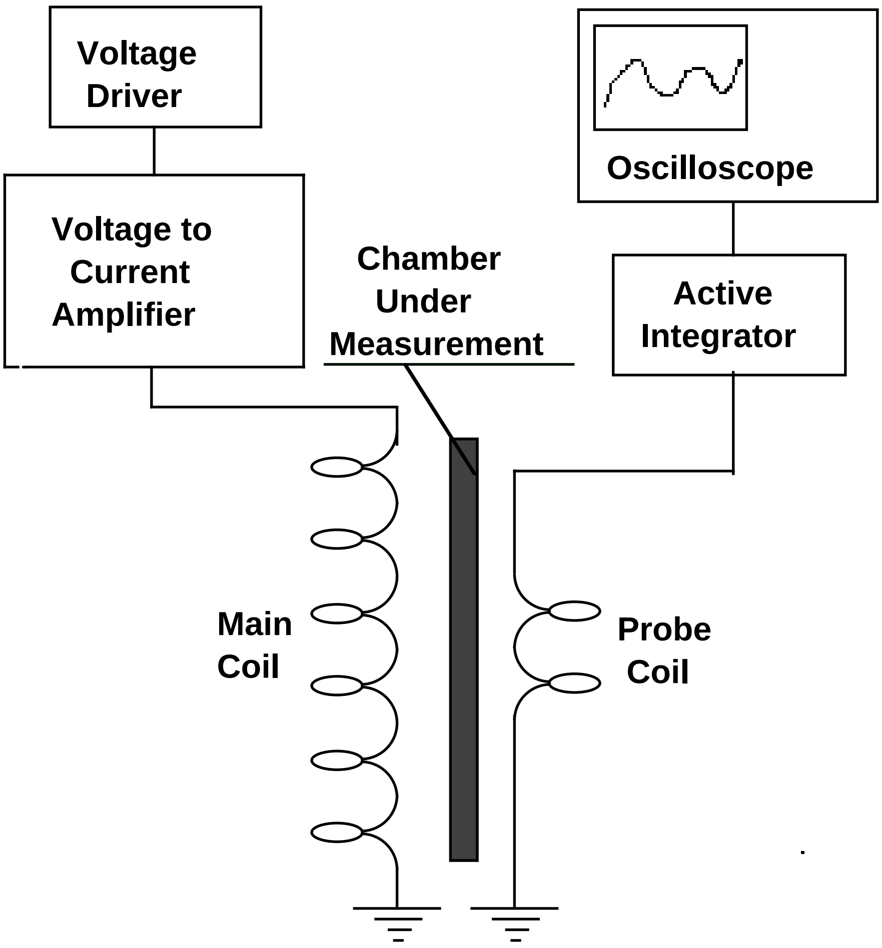

Figure 2. Measurement Set-up.

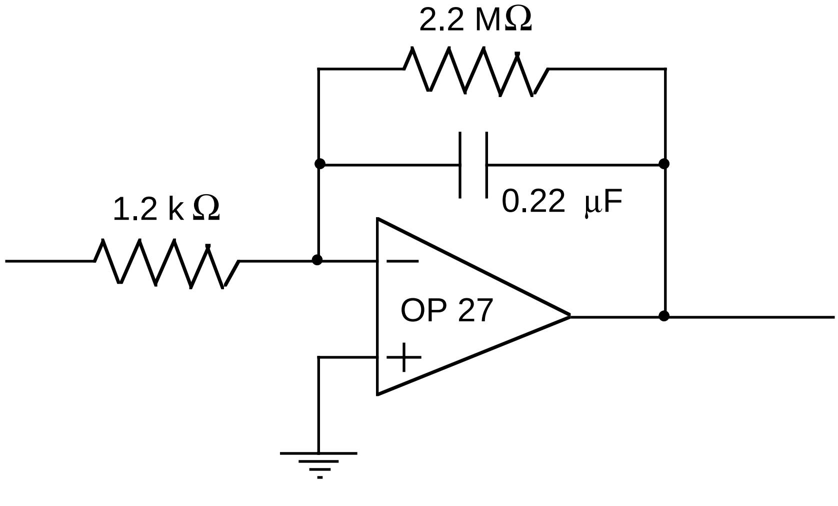

Figure 3. Active Integrator Circuit.

2. Aluminum vacuum chamber

The vacuum chamber inside most of correcting magnets in DAΦNE Main Rings will be in aluminum with thickness varying from 2 mm up to few centimeters. In our measurement we prepared five aluminum 'pipes' with different thickness:

ALPI1.5	(1.45 ± .05)	mm
ALPI3.0	(2.80 ± .05)	mm
ALPI5.0	(5.0 ± .1)	mm
ALPI7.0	(6.80 ± .05)	mm
ALPI10.	(9.6 ± .1)	mm

For each of the pipes around the probe coil we did the following measurements. The voltage driver sent sinusoidal signal with ~ 6 Volts amplitude; in these conditions the voltage to current amplifier delivered a sinusoidal current of 3 Amperes amplitude to the main coil (because of the not perfect linearity of the voltage to current amplifier this current slightly changes with frequency); the frequency of the signal was varied from 2 up to 600 Hz. The amplitude and the phase of the integrated signal of the probe coil, measured by the oscilloscope, were compared with the current of the voltage to current amplifier. In this way the effects of the different thickness aluminum chambers on the system bandwidth were determined.

Table 1 gives the experimental results.

Figure 4 shows the normalized amplitudes and Figure 5 the phase lags for all the five cases. These have been obtained subtracting the values of the "No chamber" column in the table to each of the "ALPI" ones.

Table 1. Measurements data

Frequency	No Chamber		ALPI1.5	ALPI3.0	ALPI5.0	ALPI7.0	ALPI10
2.005±.006 (Hz)	A (dB)	-32.4±.1	-32.4±.1	-32.5±.1	-32.5±.1	-32.2±.1	-32.3±.1
	Phase	-11.9±.4°	-10.2±.7°	-9.7±.4°	-9.1±.4°	-9.4±.7°	-8.6±.7°
5.000±.001 (Hz)	A (dB)	-32.3±.1	-32.3±.1	-32.3±.1	-32.3±.1	-32.0±.1	-32.1±.1
	Phase	-5.9±.5°	-5.0±.5°	-3.2±.5°	-2.3±.5°	-1.4±.5°	0.00±.01°
10.02±.01 (Hz)	A (dB)	-32.2±.1	-32.2±.1	-32.3±.1	-32.3±.1	-32.1±.1	-32.1±.1
	Phase	-3±1°	-1.8±.4°	.4±.4°	2.5±.4°	4.7±.4°	6.9±.4°
20.03±.04 (Hz)	A (dB)	-32.2±.1	-32.3±.1	-32.3±.1	-32.5±.1	-32.3±.1	-32.5±.1
	Phase	-3.6±.7°	.72±.01°	2.88±.01°	8.64±.01°	11.9±.4°	15.84±.01°
50.01±.03 (Hz)	A (dB)	-32.1±.1	-32.3±.1	-32.5±.1	-33.0±.1	-33.4±.1	-34.1±.1
	Phase	-3.60±.01°	6.1±.2°	12.2±.5°	23.40±.01°	31.3±.2°	40.50±.01°
100.8±.1 (Hz)	A (dB)	-32.1±.1	-32.6±.1	-33.4±.1	-35.0±.1	-36.1±.4	-37.5±.1
	Phase	-5.4±.4°	14.9±.4°	25.8±.4°	41.2±.2°	53.3±.4°	65.1±.2°
200.0±.1 (Hz)	A (dB)	-32.0±.1	-33.8±.1	-35.7±.1	-33.8±.1	-40.7±.2	-42.9±.2
	Phase	-9.36±.01°	25.2±.7°	40.5±.2°	59.0±.7°	71.6±.4°	88.7±.1°
300.7±.3 (Hz)	A (dB)	-31.8±.1	-35.1±.1	-38.0±.1	-41.7±.1	-44.1±.2	-46.9±.2
	Phase	-13.6±.5°	32.6±.4°	48.5±.3°	64.9±.6°	80.12±.01°	101.4±.9°
400.0±.1 (Hz)	A (dB)	-31.8±.1	-36.6±.1	-39.8±.1	-44.0±.1	-47.0±.2	-50.1±.2
	Phase	-15.7±.6°	36.7±.7°	51.12±.01°	69.5±.4°	86.40±.01°	112±1°
500.3±.7 (Hz)	A (dB)	-31.6±.1	-37.7±.1	-40.8±.3	-45.8±.2	-49.3±.2	-53.3±.2
	Phase	-18.5±.5°	39.6±.9°	49.8±.6°	70.20±.01°	88±1°	120.2±.7°
600.5±.3 (Hz)	A (dB)	-31.4±.1	-38.7±.1	-42.1±.3	-47.0±.5	-51.1±.3	-56.4±.3
	Phase	-22.2±.5°	40±1°	49.4±.7°	68±1°	90.0±.4°	130±2°

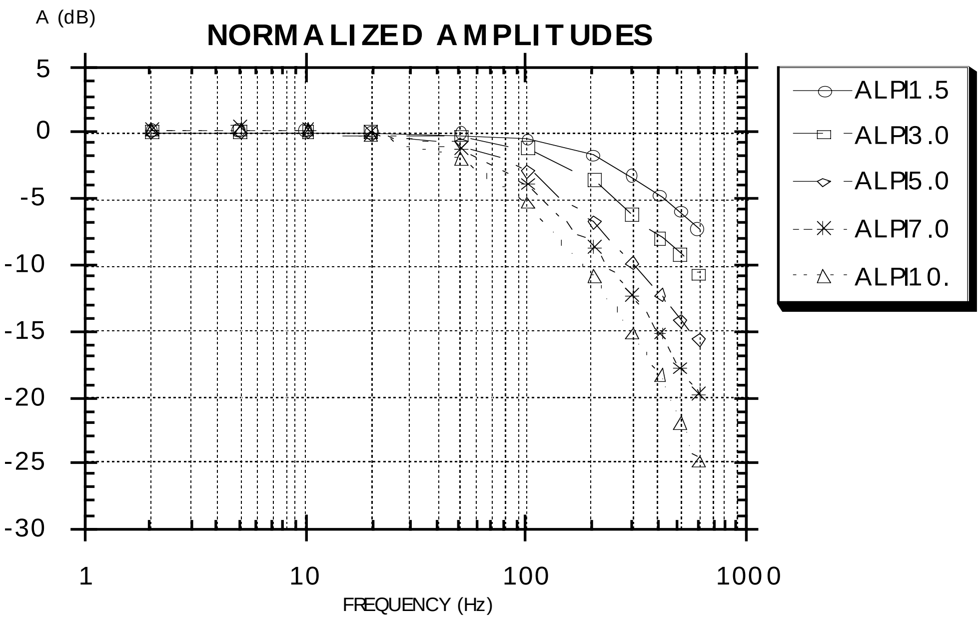

Figure 4. Normalized Amplitudes.

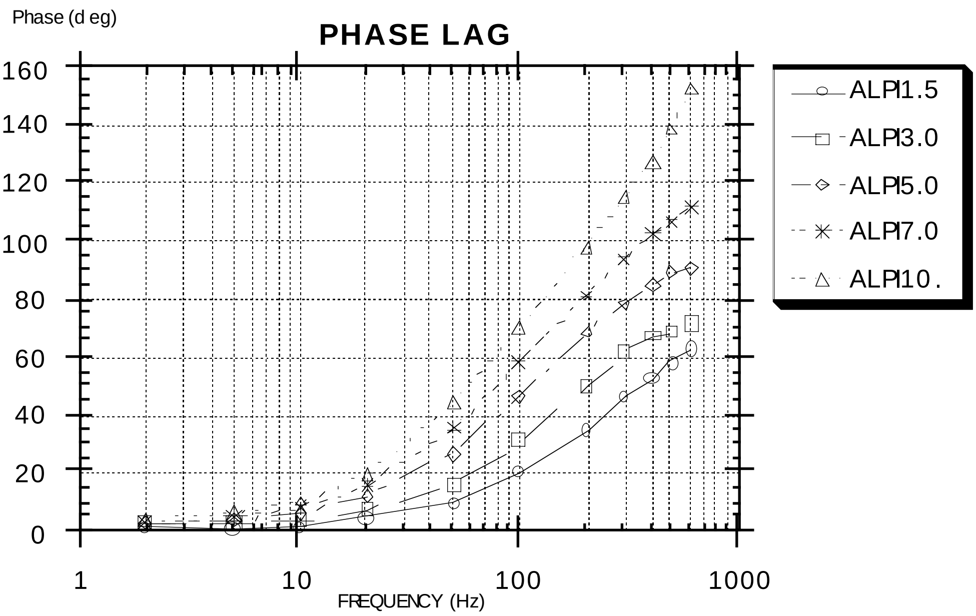

Figure 5. Phase Lag.

From the data it is possible to calculate the effects that the aluminum pipes have on the system bandwidth. We can write with good approximation (see figure 6):

Aluminum Pipe	**Bandwidth (- 3 dB)**
ALPI1.5	275 Hz
ALPI3.0	160 Hz
ALPI5.0	100 Hz
ALPI7.0	75 Hz
ALPI10.	60 Hz

Now let us try to fit these values by the function

$$f_{3\ dB} = a\, s^{m}$$

where $f_{3\ dB}$ is the frequency value at -3 dB, s is the aluminum pipe thickness and a and m are values to evaluate. By using a least square method one obtains

$$\boldsymbol{f_{3\ dB} = 372\ s^{-0.82}}$$

where $f_{3\ dB}$ is in Hz if we express s in mm.

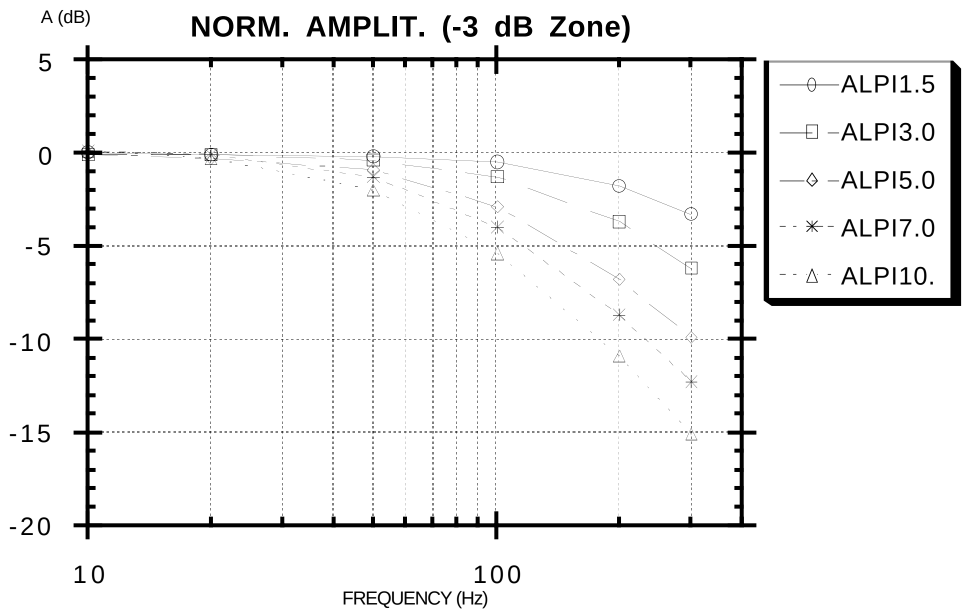

Figure 6. Normalized Amplitude: -3 dB zone.

To design a feedback for the correctors it is important to know the phase behavior of the corrector-chamber system in order to set the proper phase margin for the feedback. Typically the 60° value is chosen. From figure 7:

Aluminum Pipe	**Frequency @ 60°**
ALPI1.5	540 Hz
ALPI3.0	285 Hz
ALPI5.0	160 Hz
ALPI7.0	105 Hz
ALPI10.	75 Hz

In the same way we did for the bandwidth, we can now calculate:

$$f_{60^\circ} = 825\ s^{-1.05}$$

where again f_{60° will be in Hz if s is in mm.

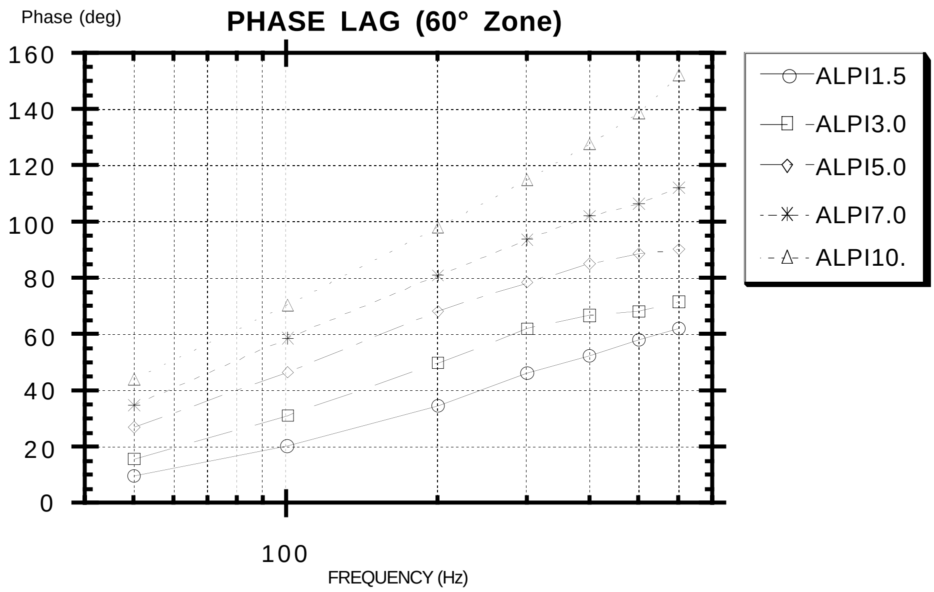

Figure 7. Phase Lag: 60° zone.

3. Stainless steel ribbed vacuum chamber

As briefly said before this special vacuum chamber will be in one of the three pulsed magnet of the DAΦNE transferline. This one, the DHPTT01, will be driven with 200 msec pulses with 1 Hz repetition rate and the magnetic field inside it will be in the tesla range. To avoid strong energy losses in the vacuum chamber, because Joule effect caused from eddy currents, this very thin (250 μm) stainless steel chamber was chosen. The ribbed structure ensures the necessary mechanical rigidity.

The aim of our measurement was to verify that the effects of this chamber on the system behavior to the driver signals are negligible.

The driver signal rise time will be ~ 50 ms, we tested the chamber with ~ 500 μs rise time signals in order to be (very) conservative. The measurement set-up was the same of figure 2, but this time the voltage driver sent the 160 ms, 16 Volts pulse showed in figure 8. In figure 9 it is possible to see the shape of the 7.5 Amps current pulse the voltage to current amplifier sent to the main coil (1 Amp./Volt). The small damped oscillations on the rise and fall fronts are due to the small trend of the voltage to current amplifier to oscillate @ ~ 500 Hz. We did not take care of this effect because we were interested only in possible rise time differences between the signals with and without stainless steel chamber.

Figure 10 shows the rise front of the integrated signals from the probe coil without (upper one) and with (lower one) chamber. It also shows the rise time measured by the oscilloscope facility. The value 499.002 μs is the same for both the situations. **No measurable effect is introduced by the presence of the stainless steel chamber**.

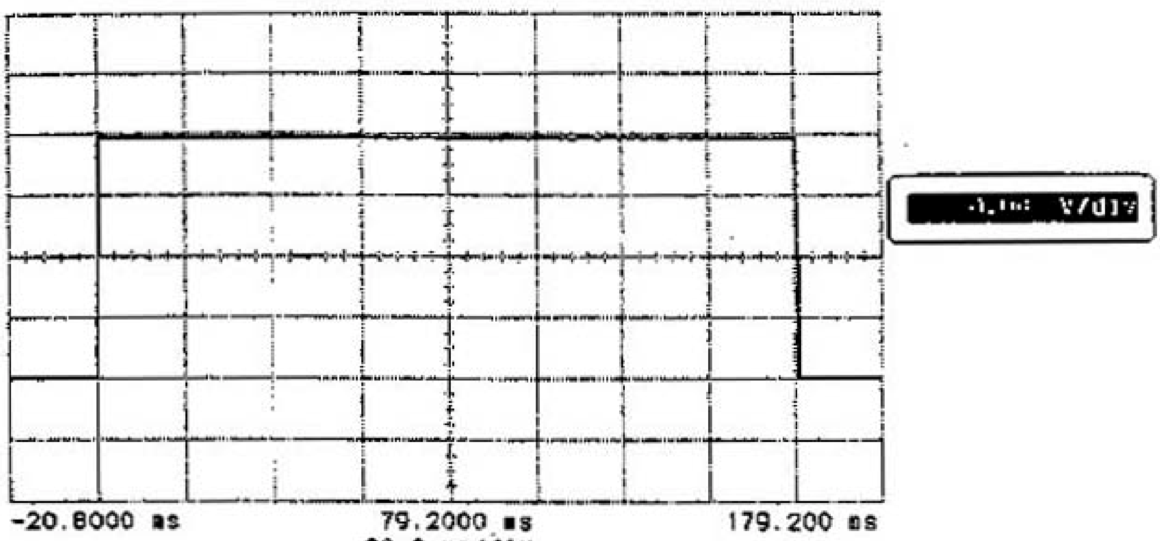

Figure 8. Voltage driver pulse.

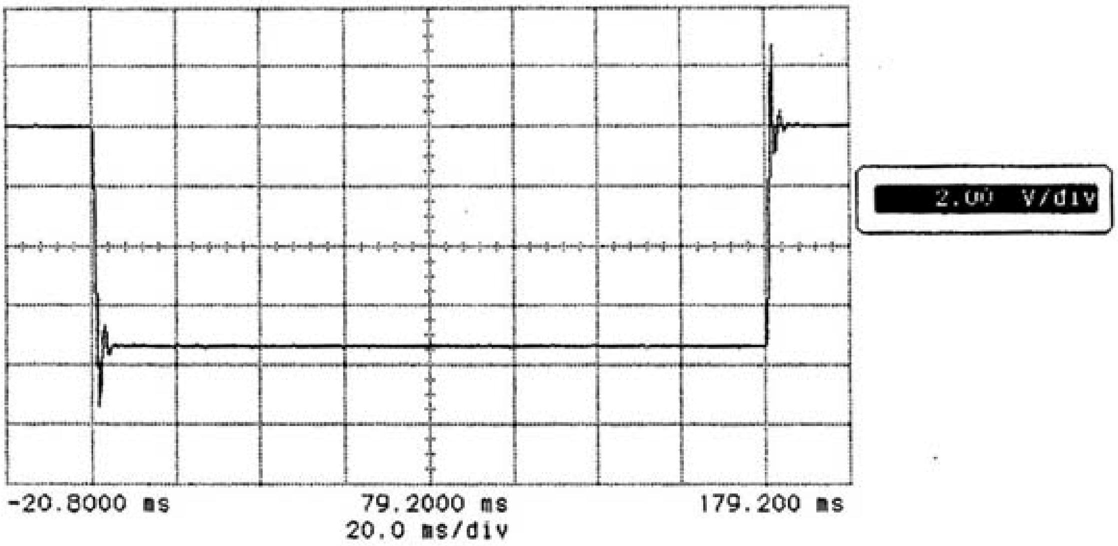

Figure 9. Voltage to current amplifier pulse.

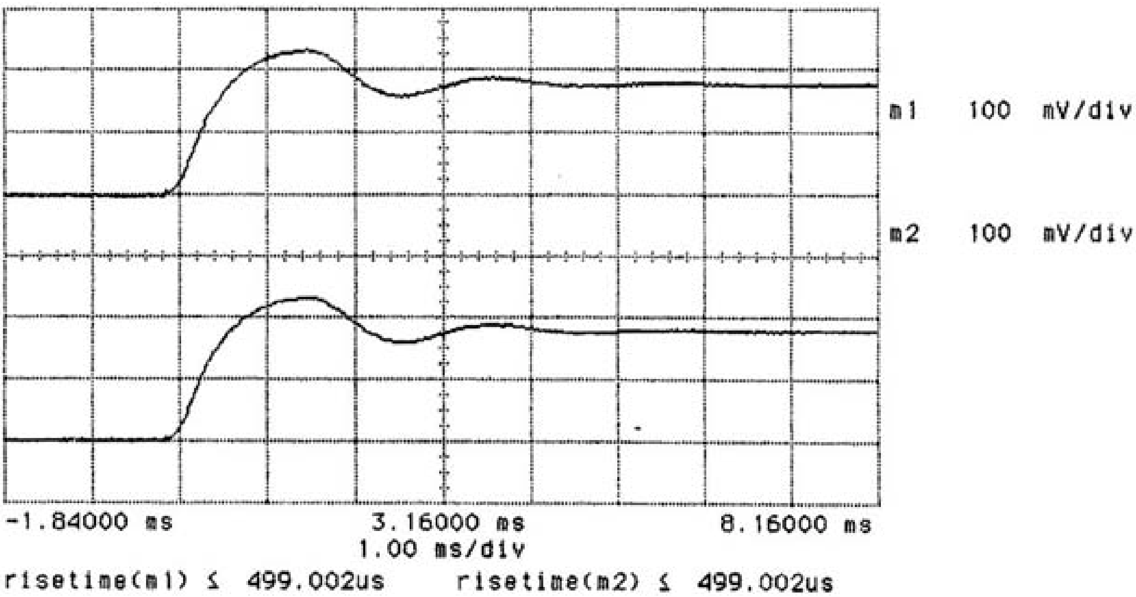

Figure 10. Rise time. Upper one: without chamber; lower one: with chamber.

REFERENCES

[1] H. Halama, V. Chimenti, A. Clozza, C. Vaccarezza *Main Ring Arc Pumping System* DAΦNE Technical Note V-11, Sept. 23, 1992.

[2] L. Pellegrino *Analysis of an elliptical vacuum chamber stiffened with transversal ribs* DAΦNE Technical Note ME-1, Jan. 28, 1993.