DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, December 14, 1995

Note: **CD-5**

THE TRANSVERSE FEEDBACK KICKER

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Abstract

The DAΦNE transverse feedback system has to provide damping of both the resistive wall instability and the transverse coupled bunch modes. Simulations and design criteria of the transverse kicker are reported. The efficiency, the contribution to the machine impedance and the results from different simulation codes are also shown.

1 - Introduction

The DAΦNE transverse feedback system must provide damping of the resistive wall instability and the control of transverse coupled bunch modes.

In this system the beam position is detected at the location of two button type monitors placed $\pi/2$ betatron phase advance away from each other; the correction signal in quadrature with the position at the kicker, is obtained by summing in proper proportion and amplifying the pick-up signals.

Two transverse kickers, one for horizontal and one for the vertical correction, will be installed in each ring.

In this note the transverse kicker design criteria are described and the results of different simulation codes used in designing the device are compared.

The electromagnetic design has been carried out mainly by means of the Hewlett&Packard High Frequency Structure Simulator (HFSS) code [1], while the High Order Modes (HOMs) study has been based also on MAFIA [2] and ABCI [3] codes.

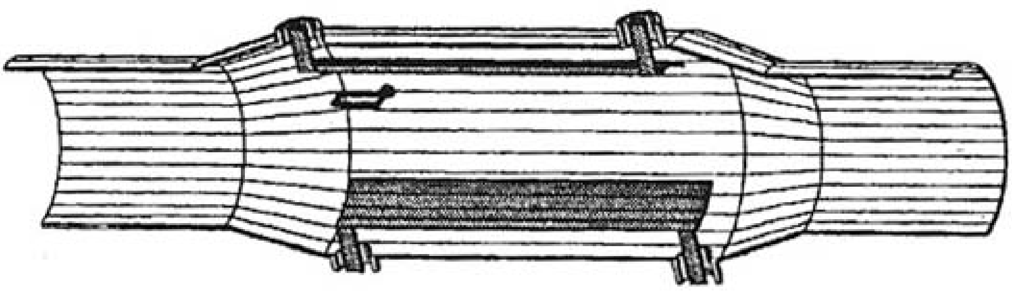

Fig. 1 - Transverse Kicker cut-view.

2 - Electromagnetic design

The kickers are based on stripline pair design (see Fig. 1), where each electrode forms with the vacuum pipe a transmission line of Z_0 characteristic impedance.

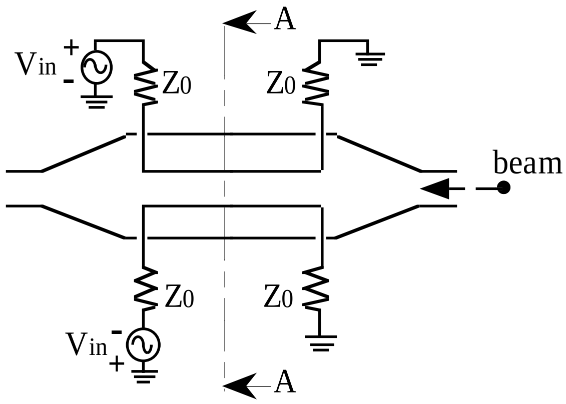

Fig. 2 - Transverse Kicker: working scheme.

The available space limits the maximum length of each kicker electrode to ≈ 20 cm. The stay clear aperture of the device is that of the rest of the straight section beam pipe (88 mm), and the vacuum chamber diameter in the kicker section is 120 mm. The strip thickness is 1 mm.

From computer simulations, an 80° stripline coverage angle has been found to correspond to a 50 Ω characteristic impedance.

Two standard 7/8" coaxial feedthroughs connect the electrode ends with the amplifier and the external load.

Two 50 mm long tapers, joining the kicker vacuum chamber with the rest of the beam pipe, are also needed in order to minimise the losses.

In order to use this device as a transverse kicker, two voltages of opposite polarity drive the ports located downstream the beam direction, with the upstream ports terminated on matched loads (see Fig. 2).

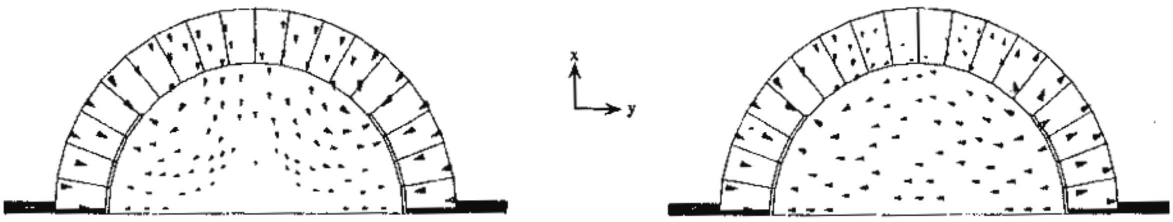

Fig. 3a - E-field distribution on a middle transverse plane in case of even mode (on left hand) and odd mode (on right hand) excitation.

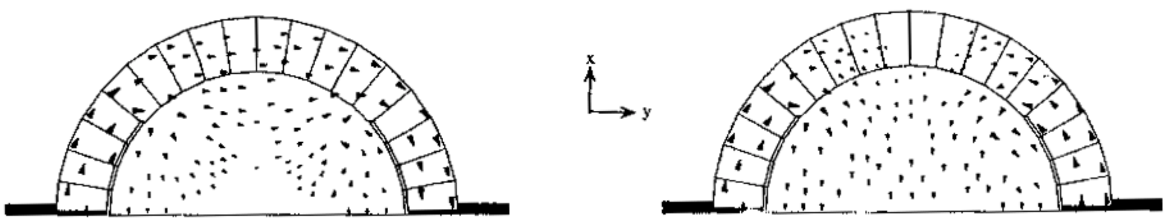

Fig. 3b- B-field distribution on a middle transverse plane in case of even mode (on left hand) and odd mode (on right hand) excitation.

The combined magnetic and electric field gives a net deflecting Lorentz force in the transverse plane. Fig. 3a shows the electric field in the *A-A* transverse section of Fig. 2 with the downstream ports driven either in the common mode or in the differential mode. It results that only the differential mode is effective for the transverse deflection.

Fig. 3b shows the magnetic field in the same transverse plane: the contributions of the electric and magnetic fields to the deflecting force $\mathbf{F}=q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$ add up when the beam and the kicker e.m. wave travel in opposite directions (see Fig. 1). If the particle and the wave propagation velocities are equal, from TEM wave theory [4] it turns out that:

$$|\mathbf{E}| = |\mathbf{v} \times \mathbf{B}|$$

so that the transverse force is $F_{\perp}=2qE$ when the kicker is driven from the downstream ports, while the electric and magnetic deflection forces cancel out if the excitation is applied to the upstream ports.

3 - Simulations

3.1 - Strip line characteristic impedance matching

The design parameter optimisation has been carried out by means of the HFSS code; a "cut and try" procedure was used in order to achieve good performances of the kicker within the machine constraints.

In order to optimise the amplifier power transfer to the load, it is necessary to match each strip line to the 50 Ω external transmission lines in the working frequency range. Since the deflecting electrode radius is equal to that of the straight section stay clear (44 mm), matching has been obtained by enlarging the vacuum chamber diameter to 120 mm in the kicker region and setting the electrode coverage angle to 80°.

The reflection to the amplifier has been also minimised by optimising the position of the transitions from the stripline to the coaxial input/output lines.

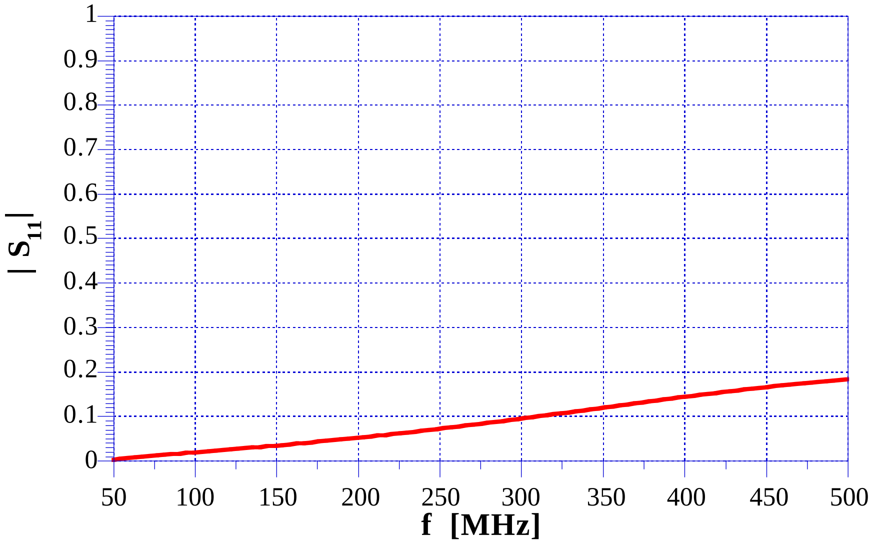

Fig. 4 - Reflection frequency response at the input ports (driven in the odd mode).

Fig. 4 shows the reflection coefficient (S_{11} parameter) vs. frequency at the input ports: the reflected power is less than 4% of the forward one in the operating bandwidth.

3.2 - Transverse Shunt Impedance

The kicker efficiency is described by the transverse shunt impedance parameter R'_S [5], defined as the ratio between the square of the "transverse voltage" $V_\perp$ and twice the forward power P_{fw} at the kicker inputs:

$$R'_S = V_\perp^2 / 2P_{fw}$$

where the transverse voltage $V_\perp$ is defined as the integral of the transverse component of the Lorentz force per unit charge along the beam axis:

$$V_\perp = \int_0^l (\overline{E} + \overline{v} \times \overline{B})_\perp dz$$

For a stripline transverse kicker driven in the differential mode the transverse shunt impedance can be calculated accordingly to the following formula [6]:

$$R'_S = 2\, Z_c \left(\frac{g_{trans}}{kh} \right)^2 \sin^2(kl)$$

where Z_c ($\approx 50\Omega$) is the characteristic impedance of the transmission line having each electrode and the vacuum chamber as inner and outer conductors, g_{trans} is the coverage factor ($g_{trans} \approx 1$), $k=\omega/c$, h is the stay clear radius (44 mm) and l the electrode length ($\approx$20 cm).

The results given by the previous formula can be compared to those obtained from the integration along the kicker axis of the electric and magnetic fields as computed by the simulation code.

The HFSS code gives the field values at each specified input frequency and phase. If we consider:

$E_y(x=0,\ y=0,\ z,\ \omega t=0)=E'(z)$ $\quad$ $B_x(x=0,\ y=0,\ z,\ \omega t=0)=B'(z)$

$E_y(x=0,\ y=0,\ z,\ \omega t=\pi/2)=E''(z)$ $\quad$ $B_x(x=0,\ y=0,\ z,\ \omega t=\pi/2)=B''(z)$

we can define:

$$E_y(z) = \left[E'^2(z) + E''^2(z)\right]^{1/2} \quad B_x(z) = \left[B'^2(z) + B''^2(z)\right]^{1/2}$$

$$\Phi_E(z) = \arctan\left[\frac{E''(z)}{E'(z)}\right] \qquad \Phi_B(z) = \arctan\left[\frac{B''(z)}{B'(z)}\right]$$

The two interesting transverse components of E and B are represented by the two phasors:

$$E_y(z,t) = \mathrm{Re}\left\{ E_y(z) e^{j[\omega t - \phi_E(z)]} \right\}$$

$$B_x(z,t) = \mathrm{Re}\left\{ B_x(z) e^{j[\omega t - \phi_B(z)]} \right\}$$

The maximum transverse deflecting voltage applied to the beam, at a given frequency, is then:

$$V_\perp(\omega) = \left| \int_0^l \left[E_y(z) e^{j\left[-\omega \frac{z}{c} - \phi_E(z)\right]} + c B_x(z) e^{j\left[-\omega \frac{z}{c} - \phi_B(z)\right]} \right] dz \right|$$

where l is the device length, the -ωz/c term accounts for the transit time factor and the absolute value of the integral is considered to yield directly the maximum transverse kick value corresponding to the best phasing between the bunch and the external generator. The comparison between analytical and numerical calculations of the transverse shunt impedance versus frequency is shown in Fig. 5.

A peak value larger than 2 KΩ together with a bandwidth wider than 300 MHz has been obtained. As a first estimate, a kicker driving power of ≈200 W seems enough to keep the machine transverse instabilities (coupled bunch and resistive wall) under control [7]. An updated assessment of the power budget will be carried out very soon.

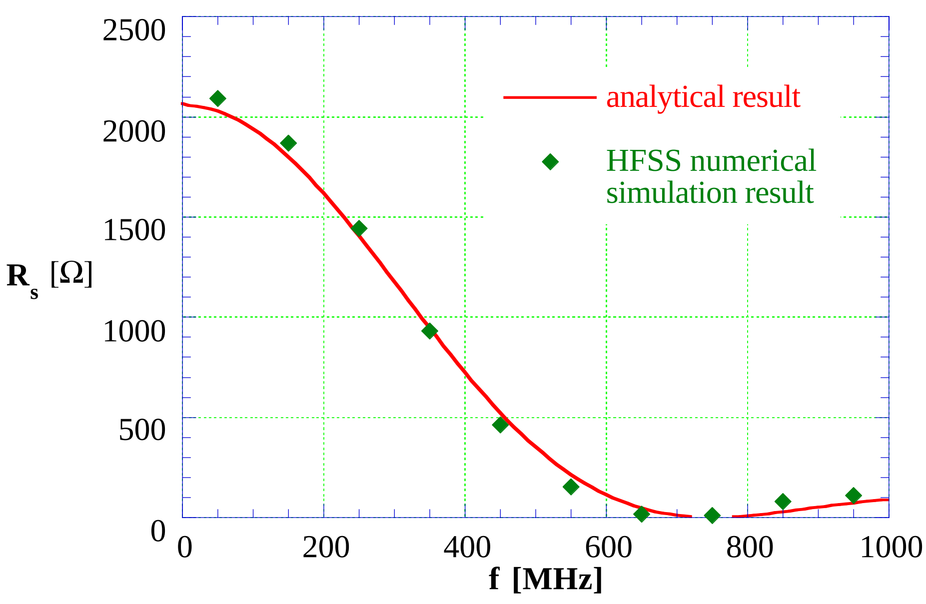

Fig. 5 - Transverse shunt impedance.

3.3 - High Order Modes

The beam passage through the kicker structure can excite HOMs that are potentially a source of coupled bunch instability.

The HOMs of the kicker together with the tapered vacuum chamber have been investigated in the frequency domain with the MAFIA code; the half-structure input geometry for MAFIA simulations is shown in Fig. 6.

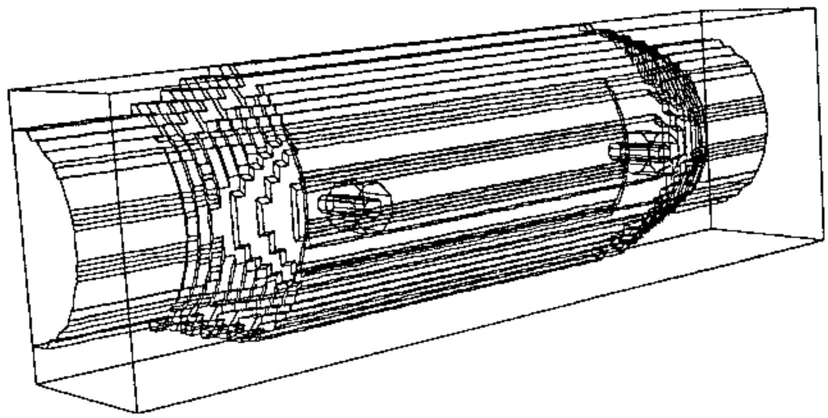

Fig. 6 - Input geometry for MAFIA simulation.

The resonant mode frequencies and the relevant RF parameters, up to the beam pipe cut-off frequency, are listed in Table 1.

Table 1: HOM's e.m. characteristic parameters

MAFIA			Unloaded (HFSS)			Loop Loaded (HFSS)		
f[MHz]	Q	R/Q[Ω]	f[MHz]	Q	R/Q[Ω]	f[MHz]	Q	R/Q[Ω]
2285	23040	0.47	2275	3800	1.61	2291	65	1.73
2388	29190	0.75	2376	270	0.022			
2520	22750	2.17	2530	6750	2.84	2567	85	2.13

The results have been obtained by applying Neumann and Dirichelet boundary conditions, electrical and magnetic mirror wall respectively, on the midplane x=0. Moreover, metallic wall has been imposed at the end planes x-y. Our release of MAFIA can only solve closed problems and it is not possible to simulate the matching impedance on the coaxial ports. Anyhow, starting from the MAFIA output and adding the proper boundary conditions in the HFSS code input, the impedances of these apparently dangerous modes have been calculated. Only the modes having a resonant frequency below the beam pipe cut-off (≈2.6 GHz) are trapped. The simulation results show that only two trapped modes can be considered dangerous, one resonating at 2.275 GHz with Q=3800 and R/Q=1.61, the other resonating at 2.530 GHz with Q=6750 and R/Q=2.84.

4 - HOM damping

In order to damp the two dangerous trapped modes, two identical rectangular loops have been introduced in the vacuum chamber (see Fig. 1). The loops intercept the magnetic field lines of the two modes and the coupled power is dissipated on external 50 Ω loads, resulting in a strong damping of these modes.

The choice of the loop shape and position has been optimised with several HFSS runs. The values of the loaded Q and R/Q factors for the two mentioned modes, as reported in the two last columns of Tab. 1, are not considered dangerous anymore for the longitudinal beam dynamics.

The results of HOM's e.m. characterisation are summarised in Tab. 1: in the first column the HOM parameters found with MAFIA, in the second column the same parameters calculated with HFSS for the kicker without loops; in the last column the same parameters for the two more dangerous modes in the loaded structure.

5 - Simulations of the longitudinal impedance measurement.

A simulation of the measurement with a metallic wire placed along the kicker axis, simulating the beam, has been performed. The longitudinal coupling impedance of the kicker, used in order to estimate the power released by the beam to the structure, and the transfer impedances, defined as the ratio of the voltages at the output ports to the beam current [5], have been calculated.

Figure 7 shows the structure used in this simulation. Three different transfer impedances for the loop ports (#1), the downstream ports (#2) and the upstream (#3) ports, can be defined (the input port for the beam is #5).

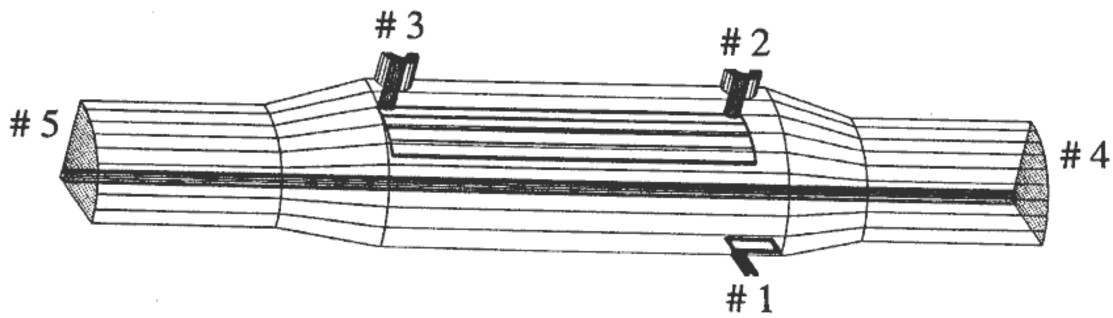

Fig. 7 - Input geometry for HFSS simulation of impedance measurements.

It must be noted that for an ideal, perfectly directional stripline device the transfer impedance, and the power flowing through the coaxial ports downstream the beam, should therefore vanish.

Coupling and transfer impedances can be easily obtained from the scattering matrix yielded by HFSS simulations according to the following formulas:

$$Z_{coup} = 2Z_0'\left(\frac{1}{S_{54}} - 1\right) \quad Z_{tr,\,i} = \frac{S_{5i}}{S_{54}}\sqrt{Z_0 Z_0'} \quad , \quad i=1,2,3.$$

where Z_0 and Z_0' are respectively the characteristic impedance of the downstream ports (≈50 Ω) and of the wire-beam tube coaxial line (≈130 Ω)

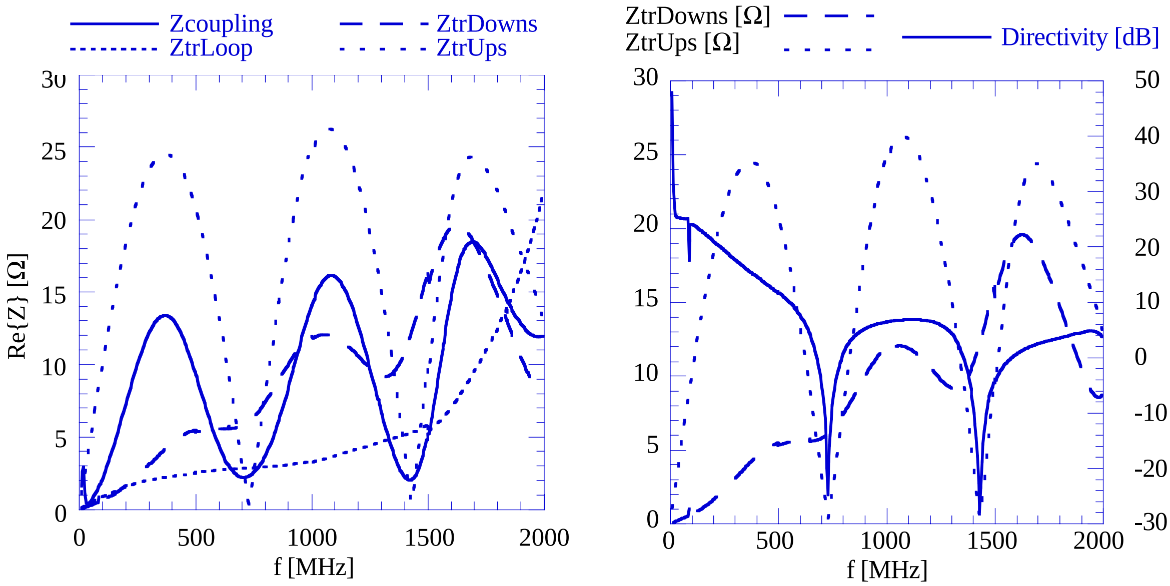

Fig. 8 - Transverse kicker coupling and transfer impedances (real part).

The real part of these functions versus frequency is shown in Fig. 8, together with the device directivity, defined as:

$$D[dB] = 20\log\frac{\Re e\{Z_{tr,\,3}\}}{\Re e\{Z_{tr,\,2}\}}.$$

With a defined beam current spectrum it is possible to estimate the total power P_b released by the beam to the structure:

$$P_b = \sum_n \frac{1}{2}\Re e\{Z_{coup}(\omega_n)\} I_n^2$$

as well as the power $P_{tr,i}$ flowing through the coaxial lines connected with loops and striplines:

$$P_{tr,i} = \sum_n \frac{1}{2Z_0}\Re e\{Z_{tr,i}(\omega_n)\}^2 I_n^2 \quad , \; i=1,2,3.$$

The power dissipated on the kicker metallic walls is:

$$P_d = P_b - \Sigma_i P_{tr,i}.$$

The wire method simulation results are reliable below 2 GHz, where no significant HOMs have been found. Therefore the HOM power coupled by loops has been estimated making use of the following formula:

$$P_{HOM} = \sum_k \sum_n \frac{1}{2} \frac{Q_{Lk} \left(\frac{R}{Q} \right)_k}{1 + Q_{Lk}^2 \left(\frac{\omega}{\omega_k} - \frac{\omega_k}{\omega} \right)^2} I_n^2$$

where the HOM parameters referring to the damped structure have been taken from Tab. 1.

Including the effect of the roll-off due to the 3 cm DAΦNE bunch length the previous formulas together yield the results summarised in Tab. 2 for two typical beam configurations:

Table 2: Estimated beam power distribution on transverse kicker parts.

Number of regularly spaced bunches	30	120
Total beam released power [W]	372+60*	1483+436*
Power flowing through each loop port [W]	9+30*	40+218*
Power flowing through each downstream port [W]	34	135
Power flowing through each upstream port [W]	143	555
Dissipated power on aluminium walls [W]	≈ 0	23
Power flowing from each downstream port to each upstream port due to amplifier [W]	100	100

*power due to HOMs impedance.

The chosen sizes of the striplines and feedthroughs are completely sufficient to withstand the power released by the beam together with the incoming power from the endstage amplifier of the transverse feedback system.

Conclusion

The design of a transverse kicker for the DAΦNE main rings within the machine space constraints has been completed. A good matching of the input lines, a satisfactory transverse impedance peak value and bandwidth, and a strong enough damping of the structure HOMs have been obtained.

The resulting structure is simple enough to decide to avoid the fabrication of a prototype, so that the next steps should be the final mechanical design and the realisation of a real, vacuum compatible device.

References

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