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# RF DEFLECTORS DESIGN FOR TESLA DAMPING RING

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## Abstract

The paper illustrates some considerations concerning the design of RF Deflectors for TESLA Damping Ring. Scaling laws are applied to investigate the RF Deflector properties in term of length, filling time and dissipated power as a function of the iris diameter. Two optimized cells operating on the $p/3$ and $p/2$ modes are finally shown.

## 1. Introduction

An injection/extraction scheme for the TESLA Damping Ring (DR) using RF deflectors is described in [1]. If $\Delta L_L$ is the bunch spacing in the LINAC and the ring circumference is $(N_B * \Delta L_L + \Delta L_L)/F$ ($N_B$ is the number of bunches and F is the recombination factor [1]), the distance between two adjacent bunches stored in the ring results $\Delta L_L/F$. Higher recombination factor (F) can be obtained if the deflecting voltage results either from two or three RF kickers working at slightly different frequencies or from the same RF kicker fed by a combined source of the same frequencies [1]. Below we describe the design of the deflectors.

The RF deflectors characteristics of main interest for the DR are the filling time and the length of the structure. The shorter is the filling time, the smaller is number of empty bucket in the ring and the ring circumference itself, as a consequence. Minimizing the structure length and the filling time is important to reduce its beam coupling impedance and to maximize its efficiency in case of multi frequency excitation [1]. In Section 2 three different modes ($p/2$, $2p/3$ and $4p/5$) of traveling wave structures will be compared looking in particular at these requirements. In Section 3, finally, the single cell of the deflector has been completely characterized from the electromagnetic (e.m.) point of view by using the simulation codes HFSS and MAFIA and considering two different modes: $p/2$ and $p/3$.

## 2. Comparative characterization of different traveling wave modes in deflecting structures

TW disc loaded waveguides have been studied as deflecting structures in 1968 [2]. Examples of structures tuned at the same RF frequency (2.855GHz) and working in three different modes ($p/2$, $2p/3$ and $4p/5$) were completely characterized as a function of the cell dimensions.

A typical dispersion curve of a Lengeler-type deflecting structure is plotted in Fig. 1. The three modes considered by the Lengeler analysis are pointed out in the figure. The $p/2$ mode presents the highest group velocity $v_g$ (highest tangent slope).

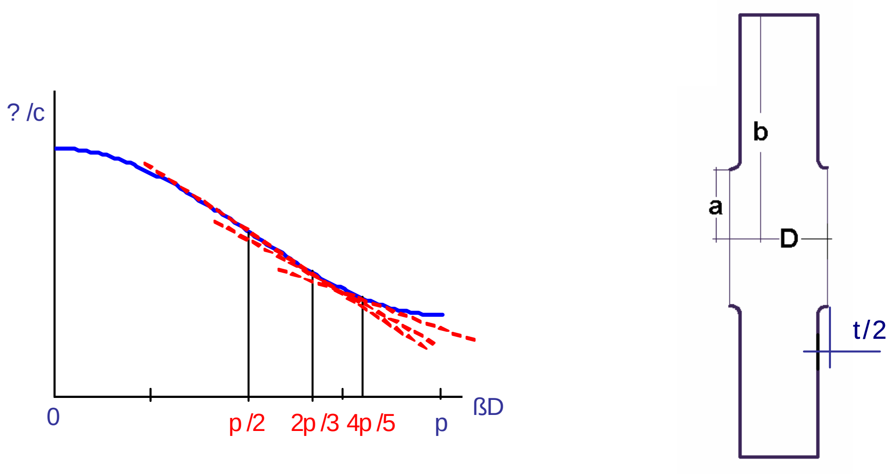


**Figure1 - Typical dispersion curve of a disk loaded structure (left) and single cell dimensional parameter (right)**

For the TDR RF Deflector, the same kind of analysis has been performed by scaling the Lengeler results at the frequency of 1.3 GHz. The choice of the 1.3 GHz derives from the availability of existing klystrons at this frequency [3].

For each considered mode we have fixed the energy of the beam (E=2.5 GeV), the angle of deflection (0.6 mrad) and the RF power feeding the structure ($P_{RF}$=9 MW and 5 MW[1]) according to the calculations developed in [2].

The length of the structure (*L*) and the filling time ($t_f$) are reported in Fig.2 and 3 as a function of the iris radius (a). *L* and $t_f$ are linked by the formula:

$$t_f = \frac{L}{v_g} \tag{1}$$

where $v_g$ is the group velocity.

The power dissipated along the deflector due to resistive losses is reported in Fig.4 for copper devices.

Finally, it is pointed out in Fig. 5 the reduction of the effective kick when the deflector is fed by a 3 MHz detuned excitation. This happens when a double or triple frequency RF input feeds the same deflector [2].

In the plots the thickness (*t*) of the iris is 11.53 mm.

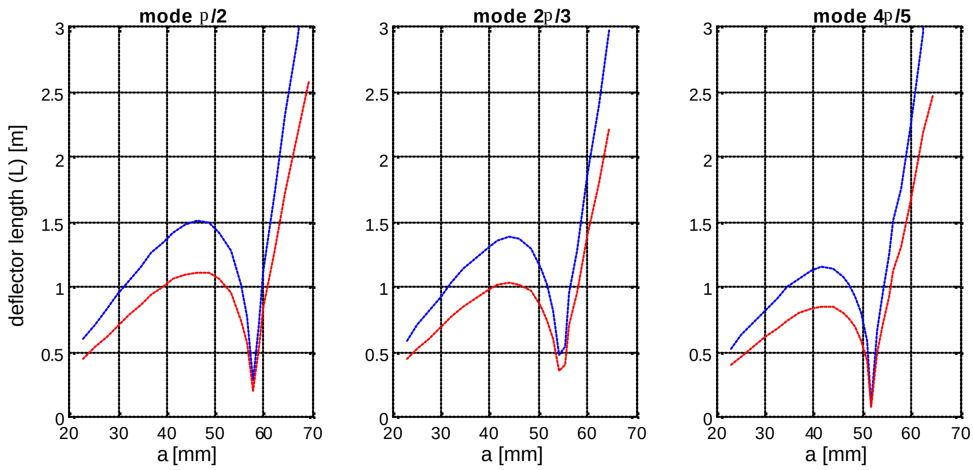


**Figure 2 - deflector length vs. iris radius (red: 9MW input power, blue: 5MW)**

[1] 9 MW is the maximum output power of the klystrons developed for TESLA.

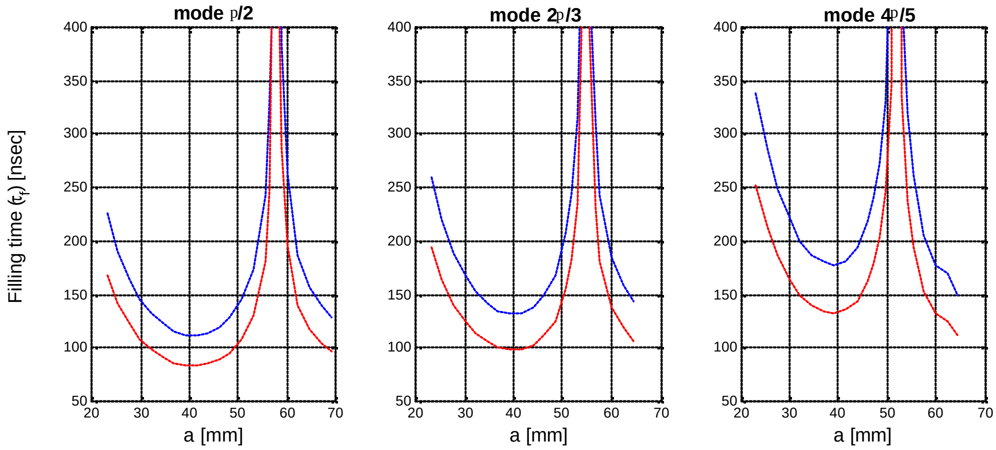


**Figure 3 - deflector filling time (red: 9MW input power, blue: 5MW)**

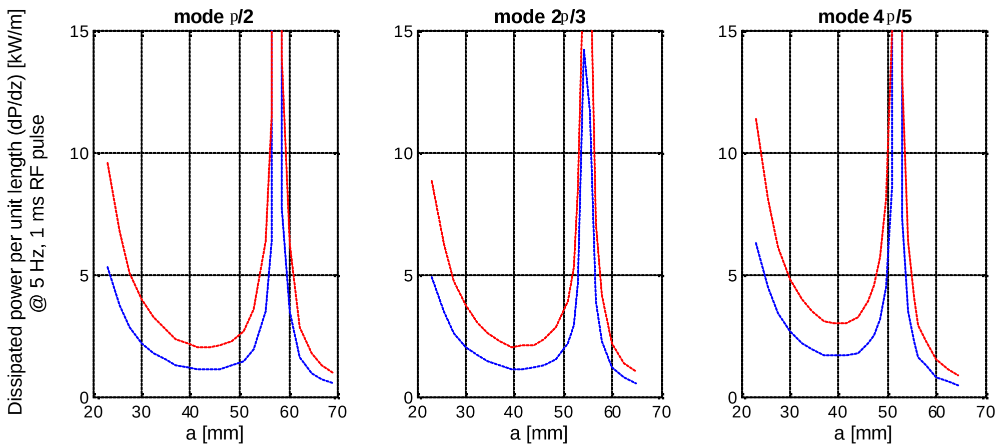


**Figure 4 - dissipated power per unit length (red: 9MW input power, blue: 5MW).**

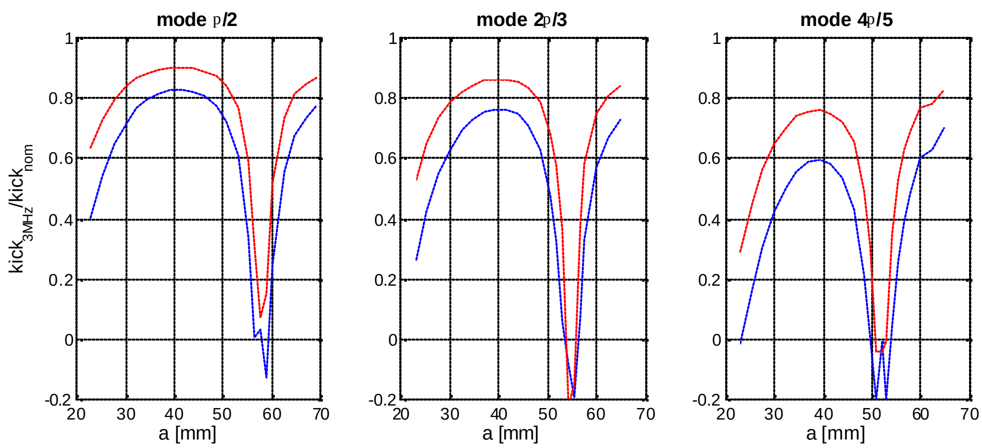


**Figure 5 - relative reduction of the effective kick when the deflector is fed by a 3 MHz detuned excitation (red: 9MW input power, blue: 5MW)**

For small values of *a* (low coupling between adjacent cells), the wave is backward and high shunt impedance can be obtained so the length of the deflector can be very short. On the contrary, the group velocity is very low and, consequently, the filling time is not the minimum possible. The group velocity reaches a maximum for a certain value of *a* and then decreases to 0 (pure standing wave). Beyond this value the group velocity change its sign and the wave becomes forward. With *a* around 40 mm the filling time is minimized and the shunt impedance per unit length is high enough so that the desired deflecting field can be reached with a reasonably short structure.

Comparing the different modes it can be seen that the $4p/5$ mode has the higher shunt impedance per unit length, but the $p/2$ mode is preferable for having the shorter filling time.

The power dissipated does not seem to be a parameter of great concern.

The loss of effectiveness due to a detuned excitation, depending on the phase difference between tuned and detuned wave along the deflector, is reduced if the filling time of the structure is short. Looking at the plots, p/2 mode is the less sensitive to this effect.

## 3. Single cell electromagnetic code simulations

From the analysis described in the previous section, $p/2$ mode results to have suitable characteristics for our requirements. So a complete electromagnetic characterization of the mode has been performed, simulating the single cell with the proper phase advance (90 deg) between the two periodic boundary planes. The application of this condition fixes the value of *D*, while *a* has been already chosen to minimize the filling time. With reference to the geometric parameter indicated in Fig. 1, it remains to choose *b* for tuning the frequency of resonance.

A second cell, designed to work in the $p/3$ mode, has been simulated as well, in order to explore the region on the left of $p/2$ in the dispersion diagram and because from that diagram also $p/3$ mode seems to have high group velocity.

The dimensions of the simulated cell for both the considered modes are listed in Table I (t=11.53 mm).

**Table I - dimensions of the cells for the p /2 and p /3 mode**

| | π/2 | π/3 |
|---|---|---|
| a [mm] | 41.8 | 41.8 |
| b [mm] | 133 | 133.5 |
| D [mm] | 58.06 | 38.70 |

**Table II - Single cell parameters from simulation results**

| **mode** | | p **/2** (f˜1.3GHz) | | p **/3** (f˜1.3GHz) | |
|---|---|---|---|---|---|
| code | | HFSS | MAFIA | HFSS | MAFIA |
| Series impedance | $Z = \frac{E_\perp^2}{P}\left[\frac{\mathrm{M\Omega}}{\mathrm{m}^2}\right]$ | 0.578 | 0.552 | 0.608 | 0.618 |
| Quality Factor | $Q = w\frac{w}{p_d}$ | 17000 | 17300 | 12400 | 12700 |
| | $R = \frac{E_\perp^2}{p_d}\left[\frac{\mathrm{M\,\Omega}}{\mathrm{m}}\right]$ | 16.07 | 15.95 | 12.03 | 11.97 |
| Attenuation | $a\left[\frac{1}{\mathrm{m}}\right]$ | 0.0180 | 0.0174 | 0.0254 | 0.026 |
| Group velocity | $v_g$ | 0.045*c | 0.045*c | 0.043*c | 0.041*c |

$E_\perp$ = Equivalent deflecting voltage
$P$ = RF power
$p_d$ = rms dissipated power per unit length
$w$ = rms stored energy per unit length

Solutions obtained independently with MAFIA and HFSS simulations yield the results shown in Table II, describing the main parameters characterizing the cell designed to work in both the $p/2$ and $p/3$ mode. The listed numbers are in good agreement.

More in detail, it is noteworthy that the series impedance values confirm the estimate obtained by scaling the Lengeler structure and used for the evaluation of the needed deflector length (Fig. 2).

Respect to the *p* / 2 mode, the *p* /3 mode has the series impedance slightly higher while the group velocity is a bit lower. The resulting filling time is about the same. On the other hand *p* / 2 is still preferable for having lower power losses as it can be seen looking at both attenuation and Q.

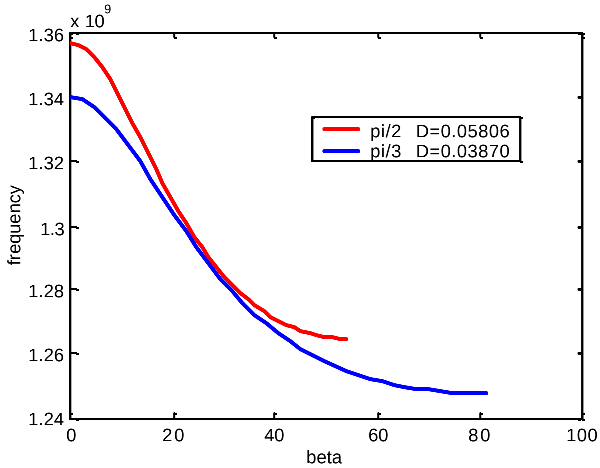


**Figure 6 - Dispersion curves calculated by MAFIA**

2D simulations have also been performed to evaluate the dispersion curve of both the considered TW modes (Fig.6). Their slopes at 1.3 GHz indicate that the group velocity is close to its maximum reachable value.

Field distribution in the volume of the cell has also been evaluated by HFSS simulations. In particular, the peak values for the electric field are localized in correspondence of the irises, as it is shown in the plot. The resulting values are listed in Table III for input power of both 9 MW (single frequency input case) and 27 MW (triple frequency input case).

**Table III - estimated peak values of electric field in the cell volume**

| **RF** **mode** **input power** | p **/2** | p **/3** |
|---|---|---|
| **9 MW** | 5.7 MV/m | 5.4 MV/m |
| **27 MW** | 10.0 MV/m | 9.3 MV/m |

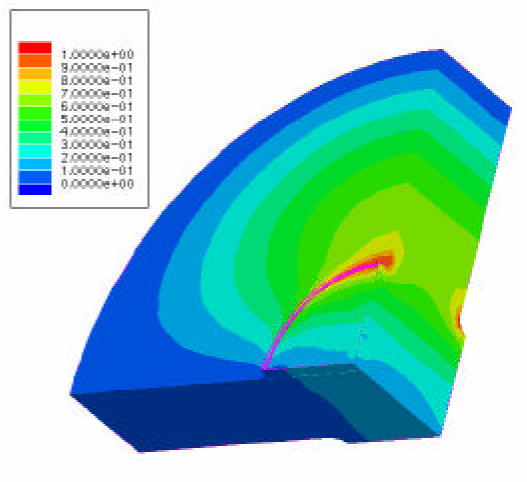


**Figure 7 - Magnitude of electric field**

## 4. Conclusions

Some considerations about the design of RF Deflectors for TESLA Damping Rings have been discussed in this paper. Scaling law have been applied to investigate the RF Deflector properties as structure length, filling time and dissipated power as a function of the iris diameter. The analysis of the $p/2$, $2p/3$ and $4p/5$ TW modes for beam deflection has pointed out that $p/2$ mode gives the minimum filling time with a reasonable total length of the structure.

An electromagnetic characterization of the single cell for both $p/2$, $p/3$ mode has been performed. Even if the filling time and the shunt impedance of the two modes are the same the $p/2$ mode give less power dissipation.

## 5. References

[1] D. Alesini, S. Guiducci, F. Marcellini and P. Raimondi, “ “, TESLA-LNF Technical Note 5, 2003

[2] P. Bernard and H. Lengeler, “On the design of disc-loaded waveguides for RF separators”, CERN 68-30, 1968.

[3] TESLA Technical Design Report, Desy, 2001.