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STUDY AND COMPARISON OF MODE DAMPING STRATEGIES FOR THE UA9 CHERENKOV DETECTOR TANK

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Abstract

In the framework of the UA9 experiment, the Cherenkov detector is useful to measure the amount of particles deflected by a bent crystal, proving the crystal collimation principle. The tank used to host this device is taken as a case study for an in-depth analysis of different damping strategies for electromagnetic modes which otherwise would give rise to important beam-coupling impedance contributions. Such strategies involve the use of ferrite, damping resistors and a mode-coupler, a solution which intercepts the modes inside the cavity but damps the related power outside the vacuum tank (potentially avoiding heating). Such solutions are discussed through experimental measurements and the relative quality factor is taken as a figure of merit.

INTRODUCTION

The UA9 experiment aims at the use of bent crystals instead of carbon jaws to achieve beam collimation. The UA9 experimental layout [1] includes many critical devices such as precision piezo-goniometers for crystal positioning, beam-loss monitors and Cherenkov detectors. The Cherenkov detector is installed using a special vacuum tank with four apertures.

From the beam-coupling impedance viewpoint, these apertures can give rise to resonances which could de-stabilize the beam. Many techniques are available to date [2]-[4] in order to decrease the quality factor of unwanted cavity resonances. This paper takes the UA9 Cherenkov detector (CD) as a case study for investigation on different damping techniques, based on ferrite insertions, damping ceramic resistors and mode couplers. The study is performed with experimental measurements carried out on a 1:1 scale replica of the Cherenkov vacuum tank.

THE CASE STUDY

The UA9 CD vacuum tank for use in the SPS is depicted in Fig. 1. It can be seen as a central cylindrical cavity with four smaller cylindrical cavities (ends), disposed on two perpendicular directions. Along the z direction, instead, is the beam path.

The vacuum tank is made of 316 LN steel and does not present any object in the central cavity. The detector bar is mounted on one of the four ends [5], whereas the other three ends remain available for diagnostic equipment.

A fast simulation of the UA9 CD tank using Microwave Studio has shown that two particular modes are of interest when considering the beam-coupling impedance issues of this device: the first one is at about 922 MHz and the second one is at about 1.32 GHz. Both are TM modes associated with the central cavity and are characterized by the quality factors listed in Table 1 (void cavity).

A way of decreasing or even vanishing the quality factors and shunt impedances of parasitic cavity resonances is to re-design the structure, so as to avoid the occurrence of such resonances (e.g. use of uniform-diameter sectors, RF shielding, elimination of unused empty spaces). When this step is not possible due to other design issues, i.e., when the re-design for impedance-related issues leads to unacceptable changes, passive countermeasures have to be considered.

EXPERIMENTAL RESULTS

Measurements Setup

Measurements have been carried out in transmission. The two beam pipe outputs and the four apertures of the vacuum tank have been sealed with aluminium flanges. Two small antennas mounted on coaxial assemblies, have been inserted axially and connected to a Vector Network Analyser (VNA) for the measurement of the S_{21} scattering parameter (Fig. 2).

Given the excitation scheme (axial linear antenna), mostly TM modes will be excited. The two probes are largely undercoupled so as not to perturb the configuration of the electromagnetic fields in the original uncoupled vessel. [6].

For each resonance peak measured on the S_{21} parameter, a preliminary check (through the Smith chart) has been done in order to maintain under-coupling conditions of the probes. Successively, the quality factor [4], [6] has been measured directly with the VNA.

Different damping strategies have been tested for this

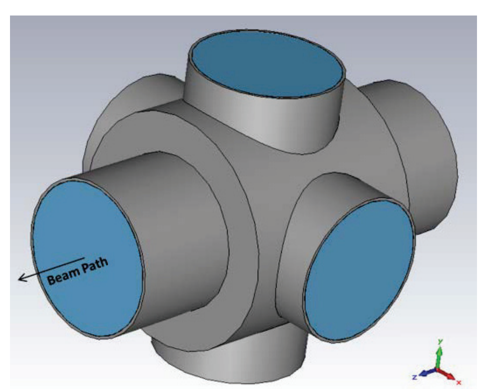

Figure 1: UA9 Cherenkov detector vacuum tank adopted as a case study.

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case study: ferrite insertions, damping resistors and finally a mode coupler, meant to intercept the resonant modes and carry the related power to an external load, avoiding the dissipation in vacuum conditions. Therefore, the measurement procedure described above has been repeated for all these cases.

Ferrite and Damping Resistors Insertions

The measurement results regarding the first two modes for the empty CD vessel are shown in Fig. 3 and the related quality factors listed in Table 1. The two different possible damping strategies have been tested, namely the insertion of ferrite blocks or damping resistors.

TT2111R grade samples have been used to test the effectiveness of ferrite dampers for this case. They provide dispersive regions where there can be significant energy dissipation. The configuration which has shown to be the most effective is with the ferrite blocks placed on the sides of the main cavity, in high-magnetic-field regions. The quality factors decrease significantly.

Damping resistors are hollow cylindrical insertions made of composite materials (e.g. alumina and nickel [7]) and can be placed in a relatively easy way (with clamps and supports, just as ferrite blocks) in the vacuum vessel. They provide resistive dissipation. The results using these resistors are shown in Table 1 and again in Fig. 3. In this case the decrease of the quality factor of the resonances is also remarkable, but less significant than in the case of ferrite blocks.

In this case too, different configurations have been tested and the most convenient has been found to be the one with a single resistor, better if hanged from one of the apertures. The effect of adding a second damping resistor is not dramatic (see Table 1).

Mode Coupler

A mode coupler can be the ideal solution when dissipation of energy in vacuum conditions is to be avoided (e.g. resonances with potential heating issues). This solution entails the use of a probe (e.g. with the shape depicted in Fig. 4) which can couple to the fields associated with specific modes. The coupled electromagnetic field is propagated in a line connected to

Table 1: Measured Quality Factors

Condition	920 MHz	1320 MHz
Void	2500	750
Ferrite (Top-Bottom)	132	380
Ferrite (Sides)	62	30
Damping resistor	554	125
2 Damping resistors	228	215
Hanged damping resistor	383	110
Mode coupler (0 deg)	20	150
Mode coupler (45 deg)	44	27
Mode coupler (90 deg)	2300	39

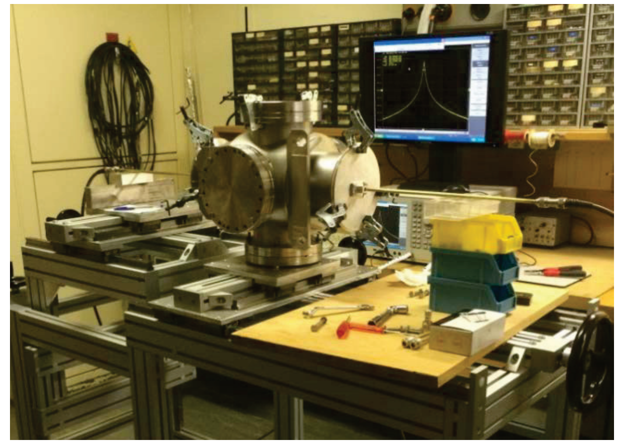

Figure 2: Measurement setup with aluminium flanges and probes already inserted in the beam pipe sectors.

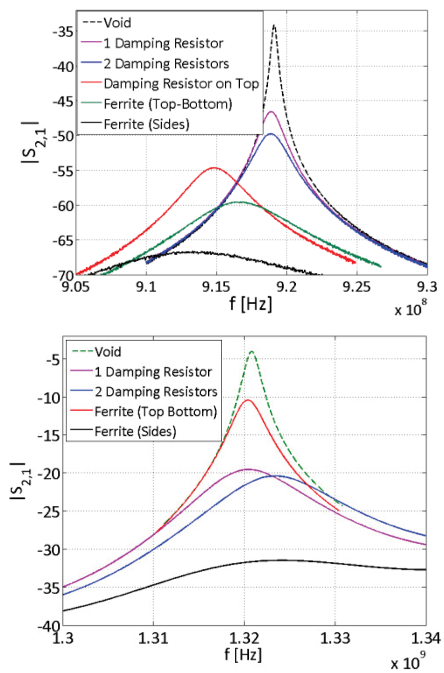

Figure 3: Measurement results in transmission for (Top) first mode and (Bottom) second mode adopting ferrite blocks and damping resistors as strategies. The first graph also shows the effect of a single damping resistor when it is hanged on top of the cavity, instead of being clamped.

the coupler and damped in an external load, placed outside the vacuum. The length of the transmission line can be tuned so to optimize the matching and improve adaptation of the coupler to a particular mode.

The principle of having a higher-order-mode (HOM) coupler is derived from cavity design [4], where this countermeasure is adopted to reject the main cavity mode (used for beam acceleration) and absorb (as in a notch filter) potentially dangerous HOMs.

In the CD vessel however one does not need to preserve any mode for acceleration, giving more freedom for the design of the coupler.

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Figure 4: Example of mode coupler geometry mounted on a copper flange.

In this case, a copper bar connected to coaxial lines (Fig. 4) on an aluminium flange is chosen as mode coupler. The coaxial lines can then be easily connected to a hybrid coupler and the corresponding sum and difference ports can be connected to the line and load.

The coupler has been inserted from one of the four apertures of the CD vacuum tank and three different orientations have been tested: parallel/perpendicular to the beam and with an angle of 45 degrees.

The measured Qs are listed in Table 1 and the results depicted in Fig. 5. For each case, the length of the external line has been tuned to widen as much as possible the resonance peaks and therefore lower the quality factors. It is interesting to notice that the two orientations are mutually exclusive: when parallel to the beam, the coupler is more effective in damping the first mode,

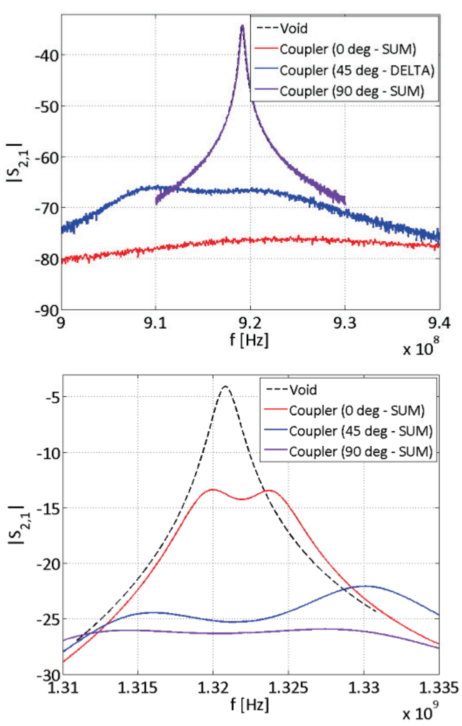

Figure 5: Measurement results in transmission for (Top) first mode and (Bottom) second mode adopting a mode coupler. DELTA and SUM indicate the port of the hybrid to which the tuning line has been connected.

whereas when perpendicular to the beam, the Q of the second mode is more significantly decreased. The 45 degrees orientation seems an optimal solution to guarantee significant damping for both modes.

Comparison and Discussion

These three strategies constitute different approaches to the damping of unwanted modes for beam-coupling impedance issues. The use of ferrite insertions is a classical solution, even though care should be taken in evaluating the heating of the blocks, which can be an issue for high-Q modes.

The damping resistors are a relatively straight-forward countermeasure, since very little hardware interventions are needed, which is sometimes crucial for devices already at the final production stage. They provide significant decrease of the quality factor.

The effectiveness of the mode coupler in reducing the quality factors has been demonstrated to be remarkable. This solution is advised for devices in which an unwanted high-Q mode is not avoidable in the design phase. Its use for beam-coupling impedance issues has to be foreseen in the design or prototyping phases, since it may demand mechanical adaptations (e.g. re-design of a flange).

For the CD case study, as the design has to be kept as is and only very little interventions on the mechanical assembly could be possible, a convenient choice would be a damping resistor.

CONCLUSIONS AND OUTLOOK

The effectiveness of three different damping strategies (ferrite, damping resistors and mode coupler) have been analysed in this paper on the UA9 Cherenkov detector tank, which has been adopted as a case study.

The effectiveness, mechanical integration and trade-offs of the three solution are addressed and guidelines on their applications are drawn.

More detailed studies on the mode coupler design (geometry, related transmission line design, simulations) are matter for future works.

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