THE EUROTeV CONFOCAL RESONATOR MONITOR TASK *

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Abstract

We describe the progress in the analysis of the confocal resonator monitor, which is part of the diagnostics work package of EUROTeV. The initial (purely confocal) design was investigated experimentally on a test-bench. We found limitations and thus digressed from strict confocality. We report on S-parameter measurements of a modified (nearly-confocal) prototype. Moreover, we discuss the mechanical design needed for planned tests with beam in CTF3, which requires integration of the monitor into the vacuum pipe, damping of trapped modes, and frequency tunability.

INTRODUCTION

Diagnostic devices aimed at measuring beam position, intensity or time profiles in high intensity accelerators are often perturbed by microwave fields that are generated by the beam itself upstream of the detection device and that propagate in the vacuum pipe, in the wake of the bunches. In previous reports [1, 2], we discussed the design of a monitor based on a resonator with spherical mirrors, which is situated transversely to the direction of propagation of the beam and which picks up electromagnetic fields in the multi-GHz region, even at several wavelengths from a highly relativistic beam. In cylindrical coordinates, the paraxial solution of the wave equation between the mirrors is described by gaussian beams modulated with associated Laguerre polynomials [3]. Such a resonator can have a high quality factor for the diffraction losses. As a result, reciprocity [4] suggests that it couples weakly to external TE or TM fields, while keeping anyway a significant coupling to the direct, quasi-TEM, fields of the beam.

In this paper, we report on experimental investigations of such a resonator pick-up (for both its confocal and nearly-confocal configurations), designed for a frequency of 15 GHz. Also, we discuss the mechanical design of a next prototype, which will be tested with beam in CTF3.

LIMITATIONS OF THE CONFOCAL RESONATOR PICK-UP

The resonator pick-up that we aim at designing shall be installed in the CLIC Test Facility CTF3 [5] at CERN to measure the bunch frequency multiplication [6]. For this purpose, we need a monitor operating at 15 GHz and with dimensions that allow to fit the cavity into the CTF3 beam pipe, which has a fixed height d of 3.7 cm. Since the diffraction losses are smallest when the mirror distance is equal to their curvature radius, we first proposed to use a confocal resonator pick-up, with $D = R = 7.5$ cm for a resonance to occur at 15 GHz. The elevation of the zenith of the mirror domes above their edges and the mirror radius were thus $h = 1.9$ cm and $A = 4.99$ cm, see Figure 1.

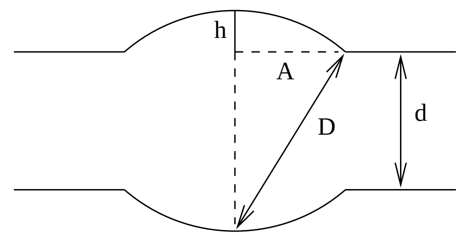

Figure 1: Schematic layout of a confocal resonator [1].

In order to experimentally test the confocal resonator, a simple prototype was built. It consists of two Aluminium plates facing each other, from which a spherical cavity with a radius 7.5 cm and a depth 1.9 cm was carved out. The mirror distance could be changed by inserting plastic legs of different heights between the plates. Microwave signals were generated with a network analyzer and injected into a waveguide connected to the upper mirror of the resonator, through a small circular hole, with a diameter of 5 mm and a depth of 2 mm. The S_{11} parameter was measured as a function of frequency and a resonance was clearly observed at 15 GHz, see Figure 2.

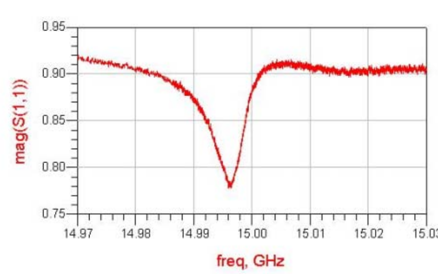

Figure 2: S_{11} versus frequency for the confocal resonator under-critically coupled to a waveguide. The input port is the coaxial transition to the waveguide.

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Note that the calibration of the network analyzer was done without the waveguide and its coaxial transition. Hence, the baseline of S_{11} in Figure 2 lies below 0 dB. The unloaded quality factor was derived by using the method described in Ref. [7]. It was found to be much smaller than the theoretical value. More measurements were therefore performed to better understand this discrepancy. In particular, the unloaded quality factor was measured as a function of the mirror distance and was found to be much worse in the confocal case than in the nearly-confocal ones. Meanwhile, the good agreement between the measured and expected values of the resonant frequency suggests that the theoretical description of the electromagnetic field between the mirrors is correct.

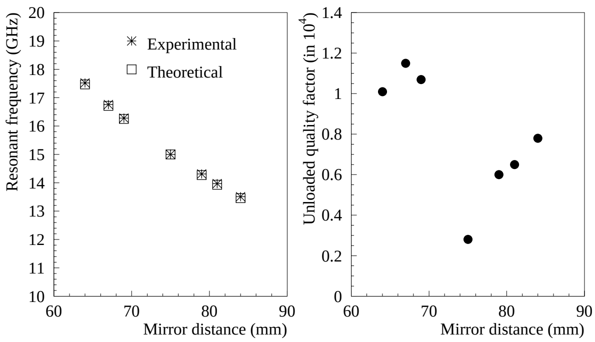

Figure 3: Resonant frequency (left) and unloaded quality factor (right), as a function of the distance between the spherical mirrors of the open resonator prototype.

In the nearly-confocal configurations, the resonance condition is usually satisfied by only one eigen-mode. On the other hand, in our confocal resonator, 28 different eigenmodes are found at 15 GHz. Because of their mixing, the total quality factor is likely to be significantly diminished as compared to the nearly-confocal cases.

INVESTIGATION OF NEARLY-CONFOCAL CONFIGURATIONS

Two nearly-confocal resonator prototypes were built. With $D = 5.345$ cm and $R = 8.908$ cm, only one eigenmode is found in the resonator at 15 GHz. The elevation of the zenith of the mirror domes above their edges and the mirror radius are now $h = 0.823$ cm and $A = 3.739$ cm.

The first prototype is an open resonator, made of two carved Aluminium plates facing each other, separated by plastic legs, as shown in Figure 4. Similarly to the purely confocal resonator prototype, the unloaded quality factor was derived from the S_{11}-spectrum and it was found to be 1.2×10^4 when the mirror distance is set to $D = 5.345$ cm. Note that the major contribution to this quality factor comes from the scattering losses at the small coupling iris, which acts as a single magnetic dipole. In Ref. [3], it is assumed that all electromagnetic power scattered by the small hole leaves the resonator. However, when the mirrors are close to each other, as in our case, a fraction of the scattered power can hit one of the mirrors and stay in the resonator, thus leading a larger quality factor. On the other hand, if one moves the two Aluminium plates further apart, then the measured quality factor agrees very well with the one derived from the equations of Ref. [3].

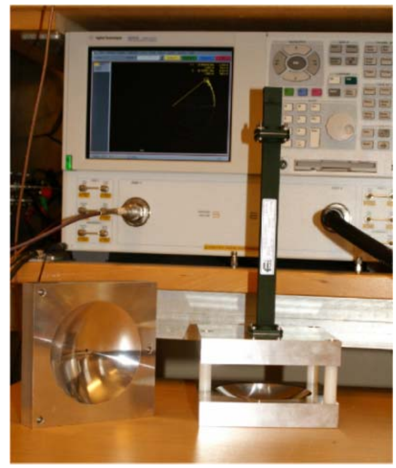

Figure 4: Open nearly-confocal resonator prototype with its extraction waveguide. One Aluminium plate with its mirror cavity is also shown.

In the second prototype, the two mirrors are inserted in a rectangular piece of Aluminium pipe with an inner vertical dimension of 3.7 cm. Its unloaded quality factor is about 20% larger than for the open resonator prototype. Because of the surrounding pipe, a larger fraction of the electromagnetic power scattered by the small coupling hole is likely to stay inside the resonator, leading to a somewhat larger quality factor than for the open configuration. As for the resonant frequency, it is almost the same for both prototypes, with only a small discrepancy due to slightly different mirror distances.

With the second prototype, transmission measurements were also performed, by sending microwave signals into the pipe with a horn at one of its ends and measuring the signal in the waveguide, which is under-critically coupled to the resonator through a small iris. The corresponding S_{12}-spectrum is shown in Figure 5. One clearly observes a decrease of S_{12} at the resonant frequency, as expected from the large quality factor for the diffraction losses of the nearly-confocal resonator at 15 GHz. But, an increase of S_{12} is also visible in the same frequency region. This is presumably due to the presence of a coupling iris in one mirror. Indeed, S_{11} measurements show that some electromagnetic power can be scattered out of the resonator by this small hole. So, by reciprocity, external fields may couple to it. At 15 GHz, a fraction of the electromagnetic power radiated by the iris is trapped between the mirrors and then transmitted to the waveguide, thus leading to the observed increase of S_{12}.

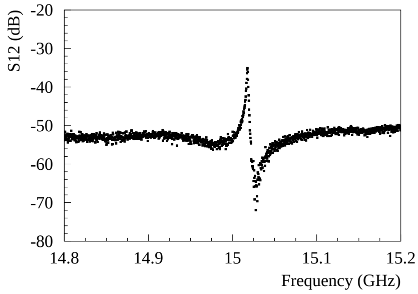

Figure 5: S_{12} parameter versus frequency for a nearly-confocal resonator installed on a pipe and under-critically coupled to a waveguide through a small iris. The input port is a microwave horn at one end of the pipe and the output port is the coaxial transition to the waveguide.

This effect disappears where there is no coupling iris in the mirror, i.e. when the waveguide goes directly into the nearly-confocal resonator, see Figure 6. The rejection of parasitic external fields by the nearly-confocal resonator prototype was thus demonstrated experimentally. But, only the case of a large coupling hole between the waveguide and the resonator allows a clear proof of principle, because the presence of a small iris in one mirror may result in a worse rejection efficiency.

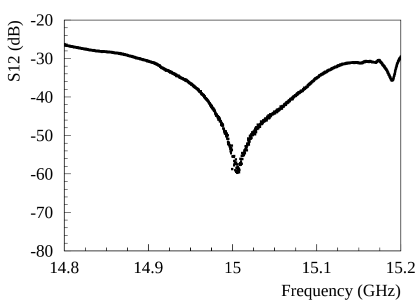

Figure 6: Same as Figure 5, but there is no coupling iris between the waveguide and the nearly-confocal resonator.

CONCLUSION AND OUTLOOKS

We have presented experimental results obtained with various confocal resonator prototypes on a test-bench. As a result of these tests, we moved away from the initial strictly confocal resonator design to a nearly-confocal configuration, since it turned out that the purely confocal version is overmoded and thereby too unstable for our application. Apart from having gained a considerable amount of measurement experience on the device discussed above, we are now ready to prepare the final layout to be installed in CTF3 or any other suitable machine. This final layout shall contain some ultra-high vacuum compatible absorbers for the suppression of undesired modes, as well as a coupling hole and a waveguide attached on each of the two mirrors. While we are aiming at a near critical coupling on one of the spherical mirrors for maximal signal sensitivity, the other side shall provide a very weak coupling, since it is only used for diagnostic and adjustment purposes (without beam) via transmission and/or reflection S-measurements. In-situ adjustments of the mirror spacing and inclination by remotely controlled actuators is also mandatory for a proper operation of the pick-up, e.g. in order to compensate for atmospheric pressure and/or temperature variations that may lead to small changes of the geometry, see Figure 7.

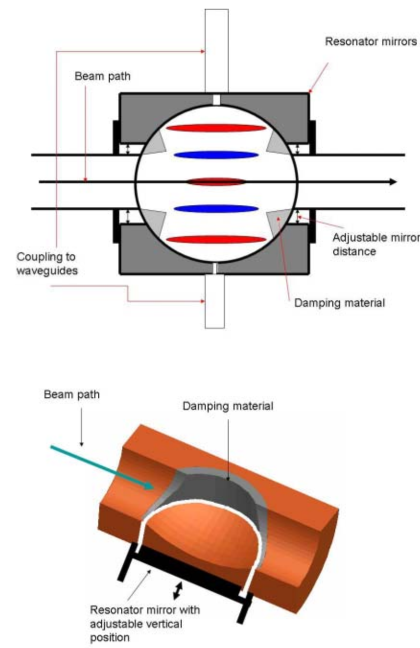

Figure 7: Artistic views of the nearly-confocal resonator pick-up to be installed in CTF3.

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REFERENCES

[1] F. Caspers, A. Ferrari, T. Lofnes, I. Syratchev, V. Ziemann, CERN-AB-2004-053, EPAC 2004, Lucerne, Switzerland.

[2] T. Ekelöf, A. Ferrari, M. Johnson, A. Rydberg, V. Ziemann, E. Öjefors, EUROTeV-Report-2005-018.

[3] N. Klein, External Report, Bergische Universität, Wuppertal, February 1987.

[4] F. Caspers, G. Dome, Proceedings of PAC 1994, London, United Kingdom.

[5] G. Geschonke, A. Ghigo (ed.), "CTF3 Design Report", CERN/PS 2002-008 (RF), LNF-02/008 (IR).

[6] F. Tecker *et al.*, CLIC note 565, CERN-AB-2003-042-OP, Proceedings of PAC 2003, Portland, USA.

[7] J.R. Bray, L. Roy, IEE Proc. Microw. Antennas Propag., Vol 151, No 4, 2004.