REALISATION OF THE 1.5 GHz SINGLE-MODE-CAVITY FOR PETRA IV

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Abstract

A third harmonic system is planned for PETRA IV. One possible option for the third harmonic cavity is a novel single-mode cavity based on the choke-mode principle. The DESY device developed on this basis offers the following advantages over alternative designs: a) Very strong suppression of all unwanted modes. b) Coupling factor adjustable during operation. c) The wall currents induced by the fundamental mode are not disturbed by weld seams. This has a favourable effect on the shunt impedance and quality factor. d) The simple geometry of the cavity results in the smallest possible number of independent cooling circuits. The paper describes the development work, introduces the design and highlights some of the cavity's outstanding features. It also discusses the current construction of the cavity.

THE RF SYSTEM FOR PETRA IV

A third-harmonic system is planned for the RF system. This will be used to lengthen the electron bunches in thus increasing their lifetime in the PETRA IV accelerator [1]. 24 cavities are planned for both the 500 MHz (fundamental) and 1.5 GHz (3rd harmonic) systems. The 500 MHz system will utilise EU-HOM cavities [2]. The baseline design for the PETRA IV harmonic cavity is a scaled version of the 500 MHz cavity [3]. However, there are a number of good reasons – which will be discussed later – for using a different design. The choice fell on a single-mode cavity based on the choke-mode principle [4].

DEVELOPMENT

Once the project idea had been conceived, a development concept was drawn up and a project team was put together.

Project Team

The project team consists of a project manager, a physicist, an RF engineer, a mechanical engineer, a product designer and a production planner.

Concept

Care was taken to ensure that the RF and mechanical engineering experts developed the cavity together from the outset. This prevented the RF design from heading in a direction that was mechanically unfeasible. Even the initial designs for the resonator, in various configurations, were discussed with the mechanical engineers. Designs that were difficult or impossible to implement were discarded. Conversely, mechanical requirements were integrated into the CST model and their effects on the RF were investigated. In this way, the RF design and the mechanical design were harmonised.

Review

Once the design had reached a stage of maturity where discussions about production could be held with manufacturers, a review was carried out with a recognised expert [5]. The expert was given access to the comprehensive project documentation. The review concluded that the design was highly likely to work in practice. Practical advice on manufacturing was also provided.

THE CAVITY

The basic principle of the choke-mode cavity is that the choke (Fig. 1) reflects and thus maintains the fundamental mode TM-010, whilst the excitation of all higher-order modes (HOM) is suppressed by the absorber. In theory, this means that, in our case, only 1.5 GHz thereof can be excited by the electron beam. In practice, this is not quite so perfect, but it does result in very strong HOM suppression [6, 7].

Absorber

The absorber is ring-shaped and made of silicon carbide (SiC). In the simulations, we have assumed a dielectric constant $\varepsilon_r = 20 - j5$. The SiC ring is held in position by a spring [8]. This has two key advantages.

The spring makes contact with the ring and the cavity only over very small areas. This results in very low thermal conductivity through the material. Consequently, heat is dissipated mainly via thermal radiation. This prevents a hotspot forming in the adjacent copper. The heat from the absorber ring is dissipated over a large area via thermal radiation to the surrounding copper and heats the cavity very evenly, as simulations have shown. The spring and SiC ring can be operated at very high temperatures. The spring is made of Hastelloy and was heated to 900°C. After cooling, no change in the mechanical properties was observed. The SiC ring can withstand even higher temperatures [9]. The thermal simulations showed that the absorber ring does not exceed 300°C in the PETRA IV operational mode with cavity voltage around 100 kV.

The second advantage is that the mechanical stress on the cavity body generated by expansion of the absorber material is greatly reduced by the spring, which can easily cope with this. If the absorber material were soldered in place, the different coefficients of thermal expansion of SiC and copper would lead to significant mechanical stresses in both the ring and the cavity body.

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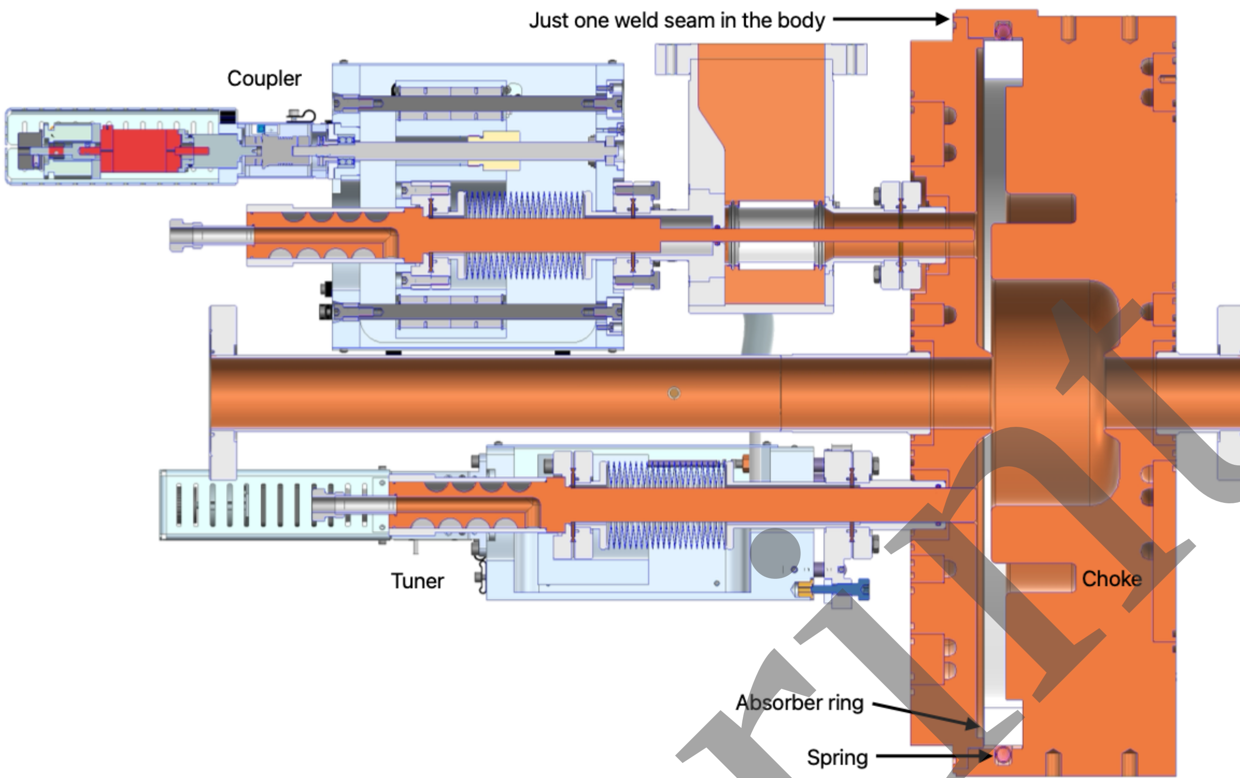

Figure 1: The single mode cavity. The coupling factor can be adjusted during operation.

RF Sensors and HOMs

All HOMs in the range from 1.5 to 5 GHz were determined using the CST eigenmode solver on the simulation model. A detailed mode discussion was then carried out and verified by [5]. The result is that only three HOMs in the range from 3.5 to 5 GHz could be excited by the electron beam and thus also be detectable. These would be TM-020, TM-212 and TM-021. The TM-110 mode, which is critical for the electron beam, is completely suppressed in the simulation.

To verify this in practice, at least two sensors are required, arranged at an angle of 150° to each other. One at 9 o'clock and one at 2 o'clock. If only one sensor is used, the field pattern of an existing dipole, quadrupole, hexapole or octupole mode may be such that the sensor is located at the zero-crossing line of the electric field and the mode is not measured.

To further increase the chances of HOM detection, we have two sensors at each of these positions: one coupled to the actual cavity and another mounted beyond the choke. Beyond the choke, the fundamental mode is barely present, and detecting HOMs becomes easier as the fundamental mode does not dominate here.

Position of Coupler and Tuner

During development, every possible position for the coupler and tuner was tested in the simulation programme. Due to the choke, a conventional arrangement of the coupler and tuner perpendicular to the beam direction is only possible if the orientation of the choke is reversed. However, this would have significantly complicated the design. In collaboration with the mechanical design team, we concluded that the arrangement shown in Fig. 1 is an excellent solution for balancing the requirements of manufacturing, cooling, coupling and tuning. The effectiveness of the coupler and tuner depends heavily on their positioning. During an optimisation process, the positions offering maximum effectiveness were identified and chosen for the design (Fig. 1).

Coupler

Originally, there was no requirement for the coupler to be adjustable during operation, but during the design of the tuner, the idea arose to construct the coupler in a similar way. As a remote control was planned for the tuner, it seemed logical to include this feature in the coupler as well. It became apparent in subsequent discussions that this brings significant operational benefits and thus represents an outstanding feature of this cavity [10]. The coupling factor can be adjusted during operation within a very wide range of 0.2 to 5.

Tuner

The tuner can be adjusted within a range of ±1.2 MHz.

MANUFACTURING

The original plan was to solder the individual parts of the cavity body together (Fig. 1). This plan was abandoned because the copper would have been soft-annealed as a result, and the smooth inner surfaces of the cavity would have been degraded.

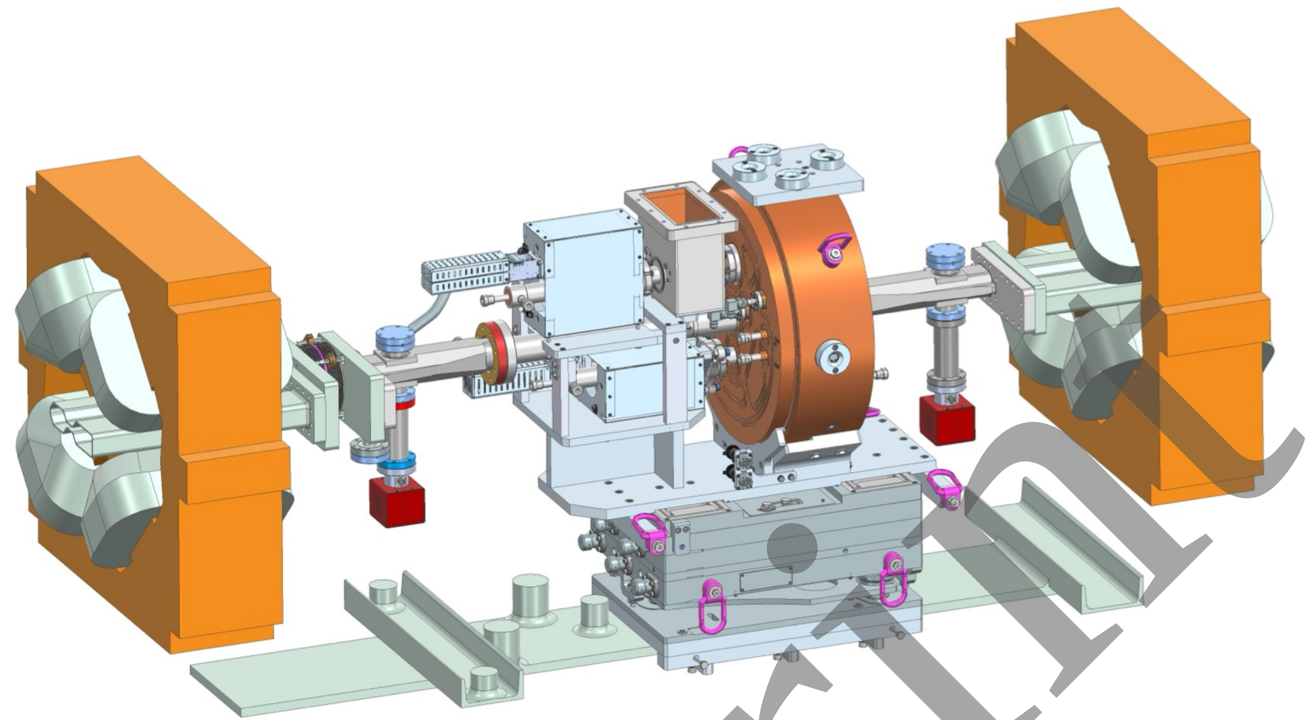

Figure 2: Test setup for the single mode cavity in DELTA.

Soft annealing would have led to significant deformation of the cavity as the vacuum was applied, thereby causing severe detuning. The degradation of the inner surface would reduce the cavity's Q-factor and shunt impedance. It was therefore decided to use electron beam welding. The heat input here is considerably lower than with soldering. However, as even this heat input can still cause deformation of the internal dimensions, the two cavity halves are first roughly milled on the inside. The cooling covers and pipe sockets are then welded to both cavity halves. The internal contours are subsequently milled to final dimensions. The spring and absorber are then inserted. Finally, both cavity halves are welded together. This weld seam will be just 2 mm deep and is located at the outer edge of the cavity. As a result, heat input is low and the risk of deformation is therefore minimal. Furthermore, the dimensions critical to the tuning process are located inside the cavity, i.e. well away from the final weld seam.

SUMMARY

A single-mode cavity has been developed for a light source. The basic principle of a choke-mode cavity was applied [4]. This offers several significant advantages over alternative cavity types [3]. The HOM damping is much better in the design shown here. In practice, this means that we do not expect to detect any HOMs between 1.5 and 3.5 GHz. In the range from 3.5 to 5 GHz, three strongly damped HOMs could occur. A negative influence of HOMs on the electron beam is therefore ruled out. The simple design of the cavity brings several advantages. Manufacturing is more cost-effective. The Q-factor and shunt impedance are higher because there are no welds that could impede surface currents. The only weld inside the cavity is located behind the absorber, where no fundamental mode wall current flows. The simulations yielded $Q_0 \approx 19{,}000$, an effective shunt impedance $R_S \approx 1.6\ \mathrm{M}\Omega$, and $R_S/Q_0 \approx 84$. Cooling is achieved with only 2 water circuits, as opposed to 6. The remotely adjustable coupling factor, which ranges from 0.2 to 5, offers great flexibility in the operation of the accelerator.

OUTLOOK

The production of the cavity is in full swing. The test setup with which the cavity will be tested in DELTA this year has already been designed and partially constructed (Fig. 2). The conditions here are ideal for studying the behavior of the cavity as a third-harmonic system. Furthermore, it will be possible to investigate whether any HOMs are excited and, if so, which ones.

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