FREQUENCY TUNING FOR A DQW CRAB CAVITY*

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Abstract

The nominal operating frequency for the LHC crab cavities is 400.79 MHz within a bandwidth of ±60 kHz. Attaining the required cavity tune implies a good understanding of all the processes that influence the cavity frequency from the moment when the cavity parts are being fabricated until the cavity is installed and under operation. Different tuning options will be available for the DQW crab cavity of LHC. This paper details the different steps in the cavity fabrication and preparation that may introduce a shift in the cavity frequency and introduces the different tuning methods foreseen to bring the cavity frequency to meet the specifications.

INTRODUCTION

In the framework of the HL-LHC project, two DQW crab cavity prototypes are currently being fabricated at CERN for their test with beam in SPS [1]. The goal frequency for a fully equipped cavity at 2K and delivering 3.34 MV deflecting voltage to the 450 GeV beam of SPS is 400.79 MHz.

The cavity will follow different procedures from the moment its parts are welded together until the fully dressed cavity is at 2 K and in operation with beam. Whereas some frequency shifts can be pretty well estimated from coupled thermo-mechanical and RF simulations, others processes are difficult to quantify. Thus, the design of an SRF cavity must be accompanied by the development of tuning mechanisms.

MAIN FREQUENCY SHIFTS

The main frequency shifts during fabrication will be due to the last weld sagging and shrinkage - that can be compensated upstream in the process if needed - and surface thickness removal from the Buffer Chemical Polishing (BCP).

During assembly, another frequency shift is expected when couplers are inserted. The assembly of the helium tank around the cavity may also introduce some detuning, as explained later in the paper.

The cavity will experience additional frequency shifts when being evacuated (from the pressure change but also from the difference in permittivity between air and vacuum) and due to cooldown. When operational, the cavity will suffer the so-called Lorentz force detuning. Beam loading is negligible for the SPS beam.

The frequency shifts expected for some of these processes are summarized in Table 1. Other processes that could shift the cavity frequency are the high-temperature baking and the cavity transportation (if the cavity is not protected and handled appropriately).

Table 1: Expected Frequency Shifts for DQW Crab Cavity

Process	Δf [kHz]
Last weld (sagging)	+70
BCP (210 μm)	-170
Couplers insertion (out → in)	-89
Welding of helium tank	-148
Evacuation ($\varepsilon_{air} \rightarrow \varepsilon_{vacuum}$)	+133.3
Evacuation (pressure change)	-0.103
Cooldown (300 K → 2 K)	+573
Lorentz detuning (off → on)	-0.4

POSSIBLE DETUNING SOURCES

The frequency shifts associated to the welding of the cavity parts and the assembly of the helium tank are discussed next.

Welding the Cavity Subassemblies Together

The niobium parts of the DQW crab cavity will be Electron Beam Welded (EBW). The welds must be full penetration, butt welds. These welds may however show some sagging, which can have an associated frequency shift. CST MWS simulations [2] were used to study the shift introduced by welds with a sag depth of 0.5 mm and underbead thickness of 5 mm (see Fig. 1).

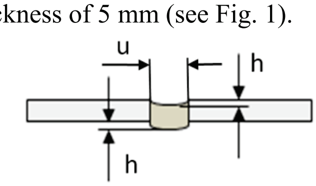

Figure 1: Sagging parameters in a weld: sag depth (h) and underbead thickness (u).

The full assembly of the cavity requires 2 welds of type A, 2 welds of type B and 4 welds of type C. The location of these welds is illustrated in Fig. 2. The frequency shift due to B-type welds for is about +100 kHz per weld with respect to ideal cavity frequency. Weld B is the most critical as it is in the highest magnetic field area. Weld A and C give a frequency shift of +70 kHz each, respectively, for the same weld sagging dimensions as used for the Weld B study. The frequency shift resulting from summing up the contribution of all cavity welds is about 670 kHz.

The values here discussed represent the worst-case scenario. In any case, the frequency shift introduced by the welds is not negligible and will be taken into account in

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the tuning strategy and compensated before the last weld of the cavity assembly or during pre-tuning. An option is to grind the welds to reduce the sagging. This operation requires special care to avoid the insertion of particles. The cavity will later go through a series of chemical polishing procedures that will smooth down the weld sagging among other surface features. Note that grinding will only be possible for all welds but the last one (weld A).

In addition, welding can lead to some shrinkage of the sheets. The effect of weld shrinkage is not accounted in this study. The shrinkage experienced when welding the last circular weld that joins the body subassembly with the dome subassembly will be estimated in following tests.

Welding could be thought as an alternative method to correct the cavity frequency. A welded joint which shows enough sensitivity could be re-welded in a controlled manner to provide further tuning once the cavity has been welded.

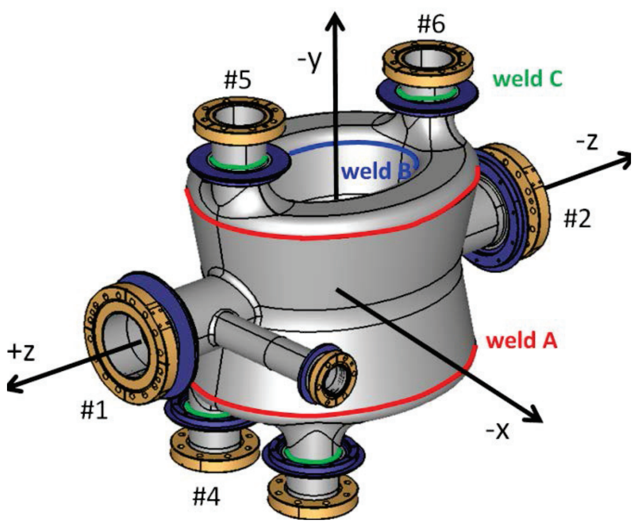

Figure 2: DQW crab cavity weld joints and port identifiers (#1 - #6) for study of detuning due to tank assembly.

Assembly of Helium Tank

A dummy tank has been built to evaluate the stiffness and response to thermal shock of the helium tank designed for such cavities [1]. A displacement of the dummy tank plates in the order of few tenths of mm was measured after mounting and welding [3]. Coupled ACE3P simulations were performed in order to determine the detuning experienced by the cavity resulting from the deformation of the tank during its assembly.

When the displacements of the tank plates were measured, there was no cavity inside the tank. Here we are assuming that the cavity will present no resistance to the tank deformation. Thus simulations were performed using the bare cavity model, and applying the corresponding displacement to each cavity port. First, the TEM3P solver of ACE3P [4] was used to obtain the deformed cavity model resulting from applying the measured displacements. Then, Omega3P simulations were run to evaluate the frequency difference between nominal and deformed cavity models.

The total detuning from all displaced ports can be described by a single expression that considers the contribution of each displaced port as an independent term:

$$\Delta f = 140(d_1 - d_2) + 580(d_3 + d_4) - 800d_5 - 380d_6,$$

where Δf is given in MHz and d_i is the displacement in mm for port i, following the nomenclature in Fig. 2. The pickup port is not included because it will be connected to the helium vessel by a bellow. For $d_1 = -d_2 = d_5 = d_6 = 0.1$ mm and $d_3 = d_4 = -0.05$ mm (realistic values from measurements), the expected detuning is -148 kHz.

TUNING METHODS

Three main methods will be implemented for the tuning of the DQW cavity, each designed for a different stage of the cavity (fabrication, integration and operation). A comprehensive description of the pre-tuning and push-pull tuning systems was provided in Ref. [5].

Trimming

The DQW cavity is subdivided in three main subassemblies. An over-length is left at the edges of the two dome subassemblies, where the A-type welds will be later performed. The ends can be trimmed to adjust the cavity frequency. The frequency decreases by 0.98 MHz when trimming (reducing the length of extra material) in only one side of a single weld line by 1 mm. Note that the position of the port interfaces could vary from nominal value due to this trimming.

For the DQW cavity, about 2.7 mm will be available for the trimming process before the nominal cavity shape is reached. From that point on, the edge can still be trimmed for about 1.3 mm more if the cavity frequency needs to be further increased.

This tuning method will be used to compensate frequency shifts associated to machining and assembly tolerances before the last weld is performed.

Pre-tuning for Cavity in Helium Tank

This tuning method is intended to counteract any possible frequency shift due to cavity deformation as result of helium vessel assembly. The cavity pre-tuning is foreseen after the cavity has been assembled to the helium vessel.

The capacitive plate of the cavity and surroundings can be displaced by adjusting the relative position of the cavity plate to the helium vessel top-plate. A hollow tube piston connects cavity plate and helium vessel top-plate. The base of the piston is fixed close to the borders of the cavity plate. Some bolts on the helium vessel top-plate allow adjusting the distance between cavity and helium vessel plates. The relative movement not only displaces the cavity plate (thus changing the capacitance of the cavity) but it also deforms the inductive region between the plates and the port openings.

The tuning sensitivity for this tuning method is $\Delta f/\Delta Ø_{gap}$ =0.802 MHz/mm distance between plates.

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Push-pull Tuning

Designed for frequency tuning after cavity installation, the push-pull tuning system is meant to make the cavity transparent to the beam, for suppression of coupled bunch instabilities or to counteract the frequency drift due to the different SPS energy beams. The tuner must be able to change the cavity frequency from 400.79 MHz (450 GeV beam –nominal operation for SPS test) to 400.73 MHz (120 MeV beam).

A push-pull rod is fixed to the center of each central plate. The relative displacement of piston-like tube and rod deforms the region of the central plate that falls in the interior of the piston base. A scissor-jack frame connects push-pull systems of both central plates, so that deformation is equal at both sides. The asymmetry of the cavity introduces some difference on the actuation of the tuner.

The tuning sensitivity for the push-pull mechanism is $\Delta f/\Delta Ø_{gap}$ =186 kHz/mm distance between plates. The maximum frequency shift achievable with fine tuning is about ±300 kHz defined by a maximum displacement of the plates of 1.6 mm each. Figure 3 sketches the pre-tuning and push-pull systems designed for the DQW cavity.

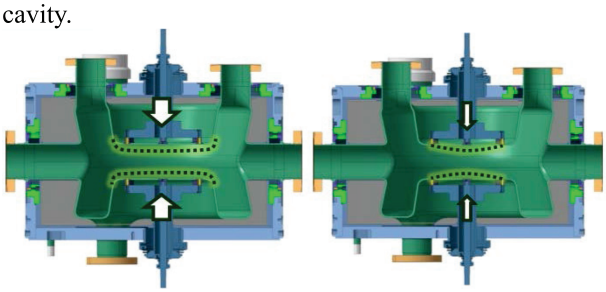

Figure 3: Pre-tuning (left) and push-pull tuning (right) for a DQW cavity into its helium tank.

Alternative Tuning Methods

An intuitive way to find large tuning sensitivity in a DQW cavity is to deform the cavity central plates, where the largest electric stored energy is found. Both the pre-tuning and the push-pull tuning systems exploit this feature. Alternative methods were also considered in search for additional tuning before the cavity is assembled into the helium tank. In that phase of the cavity production, the tuning could compensate any difference between the frequency expected after bulk BCP and the last weld and the value that actually the cavity shows once these processes have taken place.

One first method consisted in squeezing the cavity waist. For a peak deformation of 1 mm, the frequency of the cavity would increase a maximum of 115 kHz.

A second method pressed on the interior of the cavity bowl. The third method evaluated the frequency shift after clamping one of the sides of the cavity dome. In both cases, the frequency increased only about 80 kHz for a peak deformation of at least 3 mm.

Figure 4 sketches the three methods here presented. These alternative methods do not provide a large tuning range. Structural-mechanical properties should be also evaluated if finally these methods want to be used.

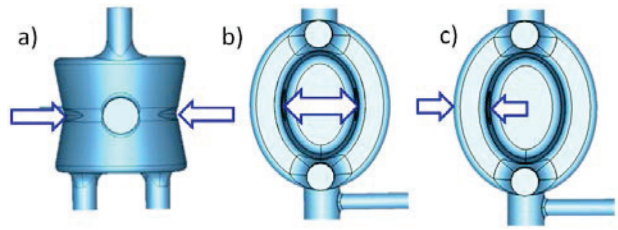

Figure 4: Alternative tuning methods for DQW cavity: a) squeezing cavity waist; b) pressing bowl interior and, c) clamping one side of the cavity dome.

OVERVIEW

According to the current schedule, the cavity parts in preparation by CERN will be ready in Autumn 2016. By that time, a detailed procedure should have been put in place to describe and guide the tuning of the cavity during its different phases of fabrication, assembly and operation. More information should be available about the weld features and shrinkage.

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