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THE STIFFENING STRUCTURE OF THE $\beta = 0.12$ HWR CAVITY AT RISP

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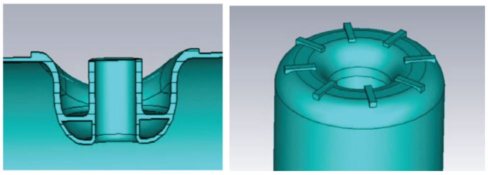
Abstract

We report out progress in developing halfwave resonator (HWR) in RISP. HWR development in Rare Isotope Science Project(RISP) is in its early stage with much effort focused on the cavity design. It aims to deliver various kinds of ions in high current, which requires a large beam pipe aperture ($r = 2$ cm), tolerant time transit factor, and the small pressure sensitivity. We present the design of HWR that satisfies above conditions with the optimal performance, including the simulation results on RF design, elctromechanical design, tuning system, and multipaction.

INTRODUCTION

At RISP, a driver linac has a section SCL1-2 consisting of the HWR's that accelerates the low-medium velocity ions. Earlier study on beam dynamics [1] determined the operation condition of the HWR as $\beta = 0.12, f = 162.5$ MHz. For uranium $U^{+33}_{235}, U^{+34}_{235}$, it is designed to accelerate from 2.5 MeV/u to 18.52 MeV/u, requiring about 120 HWR's with the accelerating voltage $V_{acc} \sim 1$ MV.

In this paper, we present our final design of the HWR with the stiffeners and the helium vessel. The vessel provides the realistic boundary condition to the cavity and the stiffeners are optimized under this boundary condition for the helium pressure fluctuations. Fig.1 shows the stiffeners as developed at Argonne national lab, whose general features are adopted in our design.



(a) Front view (b) Side view

Figure 1: The sectional view of the HWR.

In particular, we realized the self-compensation design against the pressure for the HWR, which was first done in [2] for the single spoke cavities. Subsequently, we performed the simulations to evaluate the frequency shifts from the remaining deformations, i.e., the Lorentz detuning, the cool down, and the polishing to predict the target frequency for the trimming before the final welding.

Our EM design appeared in [2] and has not been modified since. Its dimensions and optimized figures of merit are listed in Table.1.

Table 1,2 list the specifications of EM design obtained with the simulations by 3D solver CST-MWS.

Table 1: The Optimized Geometrical Parameters of the HWR

Geometrical parameters	value (mm)
Total height h	948
Outer radius R	120
Inner top radius r_t	50
Neck size r_n	22
Beam port inner radius r_b	20
Beam port outer radius r_o	60
Gap distance g	35
Gap-to-gap distance d	100

Table 2: Optimized Figures of Merit

figures of merit	value
β	0.12
U(J)	3.93
$G(\Omega)$	4.98
R/Q_0	314.1
V_{acc} (MV)	1.09
E_{peak}(MV/m)	30
B_{peak}(mT)	38.47
P(W)	1.8

U is the stored energy by the electromagnetic field inside the cavity, $G = R_s Q_0$ a geometrical factor with R_s resistivity of the Nb, Q_0 unloaded quality factor, R shunt impedance, V_{acc} the effective accelerating voltage with the time transit factor accounted, E_{peak} the peak electric field, B_{peak} peak magnetic field, and P is power loss at the cavity wall.

HELIUM VESSEL DESIGN

The helium vessel was designed to be stainless steel L316 (non-magnetized after the welding) with the thickness of 3 mm and encloses the 10 mm outside the bare cavity. Since the stainless thermally contracts more than the niobium in cool down, it could deform the cavity. So we introduced the bellows to the coupling ports at the upper and lower toroids where the contraction difference is large. See Fig.2. The stainless flange and bellow are welded while the niobium port will be brazed to the flange [3].

Near the beam ports the contraction difference is not so large and the simple bending of the vessel would suffice to overcome the difference.

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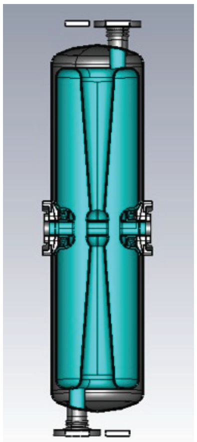
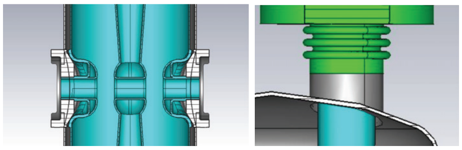


(a) Overview of the helium vessel



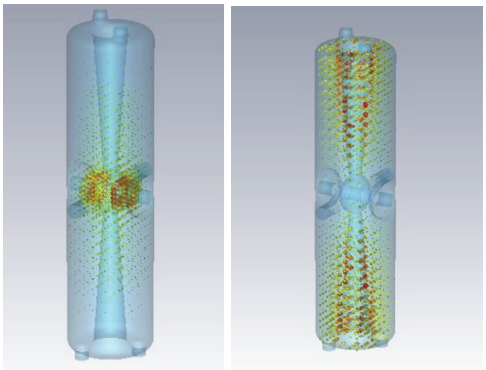
(b) Beam port flange design (c) Coupling port bellow design

Figure 2: The helium vessel design.

OPTIMIZATION OF THE STIFFENERS

To minimize the frequency shifts and also relieve the mechanical stresses in the cavity, the stiffeners are introduced to the appropriate parts of the cavity. The optimization of the stiffeners was done against the helium pressure fluctuation, which is ever-present during the operation and affects the RF power required to maintain the constant accelerating voltage. [4], [5] The corresponding frequency shift, characterized by the helium pressure sensitivity $|df/dp|$, can not be tuned by the slow tuner and cause a significant cavity control implication if the sensitivity of the cavity is too high. (the threshold sensitivity is set to be $|df/dp| \leq 1.5$ Hz/mbar) Thus the HWR cavity must be designed with the sensitivity less than the threshold.

The most common method is to design the cavity so that the contribution to the frequency sensitivity from the deformations of the various parts of the cavity compensate each other, making an overall sensitivity nearly zero. To achieve this compensation, we first identify the frequency shift sensitive spots (i.e., strong electric or magnetic region) and then try to control their displacements under the unit pressure by adding the stiffeners whose dimensions are parameter swept.-Unlike the spoke cavities, the coaxial cavities have the correlated interaction between the sensitive spots, which makes impossible to analyze the frequency shift with the separate degrees of freedom. In the HWR, the sensitive spots are the beam ports (electric region) and the upper and lower toroids.(magnetic region) See Fig.3(a) and 3(b).



(a) Strong electric field region (b) Strong magnetic field region

Figure 3: The frequency sensitive regions.

Using the stiffeners in Fig.1, with the parameters of the length a, the width b, the height c of the gussets, and the depth of the doubler d, we sweep for each parameter to determine the frequency shift dependence. The boundary condition for the cavity is approximately the beam ports fixed. Then the contribution from each parameter is given as

$$df_k = \alpha_k \Delta x_k + \beta_k, \tag{1}$$

here Δx_k is the k-th parameter change and α_k is the one obtained by fixing all the other parameters except for k-th parameter. The total frequency shift is given as a sum

$$df = \sum_k df_k, \tag{2}$$

We determine α_k by multiphysics simulation. The reference point common to all the lines is provided by the “residual" frequency shift, obtained with all the spots fixed, i.e., $\Delta_k = 0$ for all k. Assuming the linear behavior, one determines the frequency sensitivity (under the pressure) via the displacements at each spot as follows. The sensitivity is conveniently determined by reading off the slope of the straight line determined by the “reference point" and the free point.-This can be corroborated by connecting multiple points, i.e., assuming the linear behavior, we control the displacement via the pressure. where α is the residual frequency shift. We determine α_i's and α by multiphysics simulations. Then to minimize the frequency shift, we have

$$0 = df = \sum_k \alpha_k \Delta x_k + \beta_k, \tag{3}$$

for any combinations of Δx_i's that satisfies (3), the frequency shift becomes close to 0. This can be done by mechanical simulation for the displacement.

Finally, the mechanical resonant modes were obtained to check they are well above 60 Hz, an upper limit of the various microphonics of the cavity.

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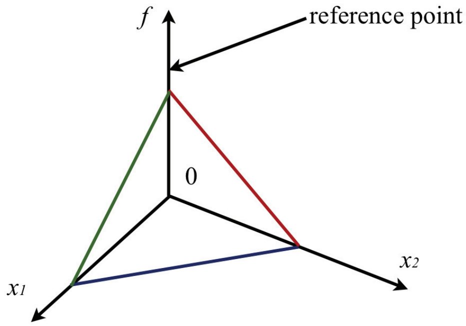

Figure 4: The diagram of the frequency shift.

Interface to the Tuning System

One related issue to the stiffening structure, the doubler in particular, is the tuning ability of the tuner. If the stiffening is too strong, too much tuning force is needed. Therefore in principle one would have to find the optimal stiffening structure taking into account also the tuning ability. In reality, we simply checked the required tuning force after the stiffening structure is determined.

The slow tuner is implemented so that the tuning force is applied on the flange in the beam port. As the tuning force is applied, the frequency is tuned satisfying the following relation.

$$R = \frac{s}{k} F, \tag{4}$$

where the tuning range R and the tuning force F are related by the stiffness k and the (tuning) sensitivity s. The simulation determines $k = 5.08$ kN/mm, $s = -0.4288$ MHz/mm and we would need ~ 1.2 kN to have 100 kHz tuning range.

SUBSEQUENT SIMULATIONS

Once the stiffening structure is determined, the remaining deformation simulations are done with their results listed in Table.3.

Table 3: The Target Frequency Table

Procedure	Frequency shift	Target frequency
Clamp-up	-	162.092 MHz
Final welding	163.2 kHz	162.255 MHz
Polishing	72.6 kHz	162.328 MHz
Evacuation	-4 kHz	162.324
Cool down	222 kHz	162.55
Tuner installation	-50 kHz	162.5

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