R&D OF PKU SINGLE SPOKE CAVITY

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Abstract

The R&D program of PKU single spoke cavity is based on the HI-13 Tandem. The maximum kinetic energy of proton is 26MeV, and the frequency of the chopper for superconducting is 150MHz. It leads us to choose a 450MHz and β=0.2 single spoke cavity.

In this paper, the RF design, mechanical study, fabrication arts, and room temperature RF test is presented. The cold RF test results will be obtained soon.

INTRODUCTION

Spoke cavities have been developed and have apparent advantages for high current proton accelerator based on superconductivity at low and medium energy region [1]. As the research and the technical reserve, Peking University has started the R&D program of single spoke cavity. The cavity is proposed to achieve a high accelerating gradient, and the beam load experiment is planned on the HI-13 Tandem at CIAE.

RF DESIGN

The main criteria of the cavity RF design are to minimize the peak surface electric and magnetic field ratios E_{peak}/E_{acc} and B_{peak}/E_{acc}. As the performance limitation in a spoke cavity is almost the thermal-magnetic quench with little or no field emission [2], to minimize B_{peak}/E_{acc} becomes the key point.

The beam dynamics considerations lead us to choose β=0.2 and the aperture diameter is 30 mm. The length from iris to iris is chosen 2/3βλ.

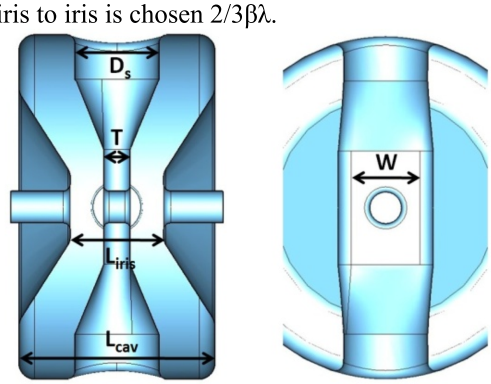

Figure 1: Cross section of the PKU SSC with the main parameters used in the optimization.

The optimization process of PKU SSC is described in details in reference [3]. To increase the probability of improving maximum accelerating gradient, a further optimization at magnetic field storage energy region has also been done based on the PKU SSC. The PKU SSC Mark II still minimizes B_{peak}/E_{acc} at the expense of E_{peak}/E_{acc}. The main comparison parameters are listed in Table 1.

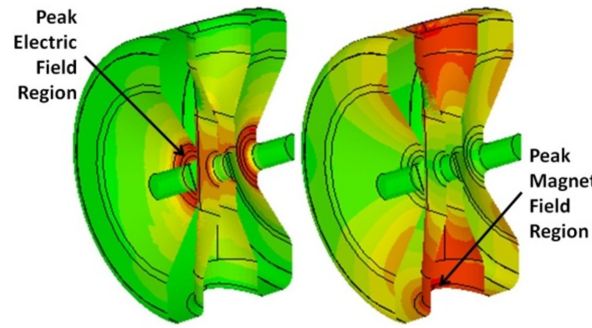

Figure 2: Surface electric (left) and magnetic (right) fields in PKU SSC. The field strength increases as the color changes from green to red.

Table 1: Main Parameters of PKU SSC and Mark II

	PKU SSC	PKU SSC Mark II
Frequency [MHz]	450	450
Beam pipe diameter [mm]	30	30
Geometrical beta	0.2	0.2
Transit time factor	0.80	0.80
G [Ω]	73	88
R/Q_0 [Ω]	179	211
E_{peak}/E_{acc}	2.65	2.86
B_{peak}/E_{acc} [mT/(MV/m)]	5.22	3.90

MECHANICAL STUDY

Mechanical structures have been studied to control the impacts of the various mechanical deformations. They are required to stiffen the cavity to withstand the vacuum load, and to reduce the frequency shifts caused by mechanical resonance. It also provides a uniform tuning deformation. Material properties of Niobium [4] are used as following:

Density=8560kg/m^3;

Young's modulus=107000MPa;

Poisson ratio=0.359.

Six radial niobium stiffening ribs are added to the re-entrant region, and four niobium stiffening ribs are presented on the cylindrical portion of the cavity, shown in Figure 6. The thickness of all the stiffening ribs is 4mm, while the cavity wall is 3mm.

External Vacuum Load

The cavity has been evaluated for an external load of 1atm, while the flanges on both beam pipes are fixed. The stiffening ribs reduce the stresses and deformations of the structure. The comparison results are shown in Figure3 and Table 2.

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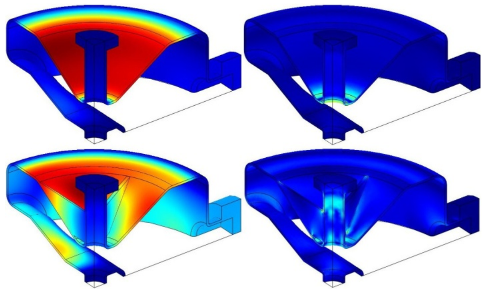

Figure 3: The SSC deformation and von mises stress under 1atm external vacuum load. (left) deformation; (right) von mises stress;(top) without stiffening ribs; (bottom) with stiffening ribs.

Table 2: The Comparison Parameters with and without Stiffeners

	With Stiffeners	Without Stiffeners
Max. Deformation [mm]	0.035	0.122
Max. von Mises stress [MPa]	56.0	161
Frequency Shift [kHz]	23.8	172

The stiffening significantly ribs reduce the stress at iris, and move the maximum stress point from the cavity body to the stiffening ribs. It also leaves enough places for cavity tuning.

Tuning

The cavity tuning is to change the capacitance at the view of equivalent circuit by pushing or pulling the end beam pipe flanges. The stiffening ribs control a uniform deformation at the tuning regions, which are the color changing region shown in Figure 4. The frequency response obtained by simulation and perturbation theory are listed in Table 3.

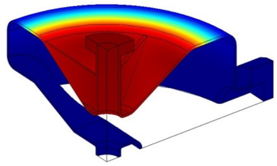

Figure 4: The displacements of cavity tuning. All the deformation occurs at color changing region.

Table 3: The Frequency Response by Simulation and Perturbation Theory

	Simulation	Perturbation
Frequency Shift [MHz/mm]	1.28	1.70

Mechanical Resonance

The study of the mechanical resonance modes is simulated by fixing the ends of both beam pipe flanges. The deformations of the first six modes are shown in Figure 5, and the frequencies are listed in Table 4.

The first mode seems not to be dangerous. As the torsion is around the beam axis, this mode does not cause the frequency shift. All other modes have longitudinal components, and are deleterious.

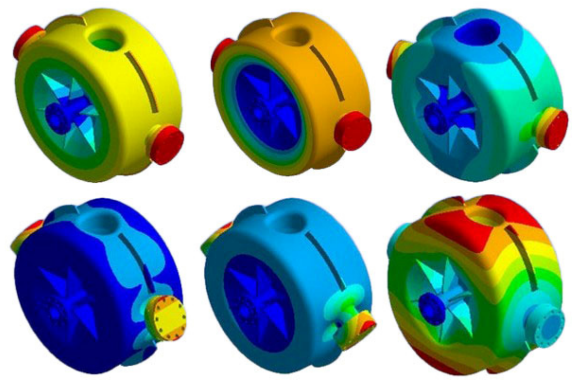

Figure 5: The total deformations of the lowest six mechanical resonance modes. The deformation is increased with the colour changing from blue to red.

Table 4: The Lowest Six Mechanical Resonance Frequency of PKU SSC

Mode	Frequency [Hz]
1	92
2	213
3	335
4	375
5	452
6	483

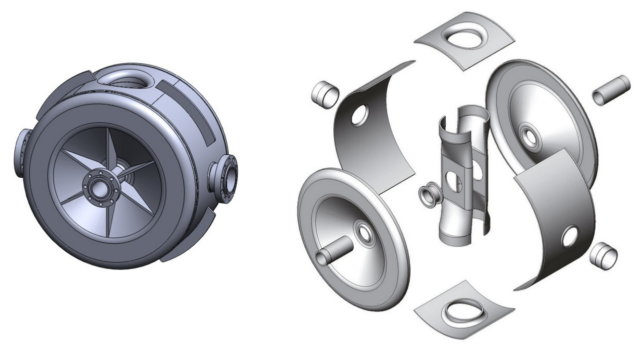

Figure 6: The stiffening ribs structures of PKU SSC, and the divided components without stiffening ribs and flanges.

FABRICATION ARTS AND MECHANICAL ERRORS ANALYSIS

All the components, shown in Figure 6, are formed by deep drawing and machining, and connected by electron-beam welding (EBW).

The cavity barrel is divided into four parts to prevent welding on the saddle-face and to decreases the number of welding seals across the peak magnetic field region. It also reduces the challenges of the EBW between spoke bar and cavity barrel.

In fabrication process, mechanical errors cannot be avoided. The mechanical tolerance has been studied to ensure the performances of the cavity, which are mainly the resonant frequency and the field flatness. As the cavity is proposed to be reshaped by dies and the edges connecting cavity barrel and end-walls are planned to be machined just before the final EBW. All mechanical errors, including the cavity total length, the asymmetry of both accelerating gaps, the parallelism of both end-walls, and the shrinkage due to the EBW, occur at these edges, shown in Figure 7.

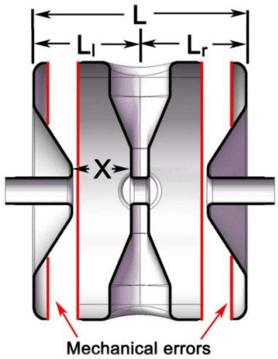

Figure 7: The major mechanical errors in the considered region of PKU SSC.

As the magnitudes of mechanical errors are several orders smaller than geometry size of the cavity, the impacts can be considered by the first order perturbations theory. The systematically analysis of the influences on the RF performance of PKU SSC is described in reference [5]. It obtains that only the cavity total length has an obvious effect on the frequency shift, and the mechanical tolerance should be less than 0.2mm, including machining errors and welding shrinkage. Others can be ignored for typical fabrication errors. On the other hand, the SSC is robust, even tuning in order to obtain a flat field profile is not necessary.

The PKU SSC after fabrication and welding is shown in Figure 8.

Figure 8: The PKU SSC.

RF TEST AT ROOM TEMPERATURE

RF Test after the Final EBW

The room temperature RF test has been done by HP8753d. The antennas of feed through and pickup are separately fixed at each cleaning port. The signal S21 is used to obtain frequency and field profile.

The frequency of PKU SSC after the final EBW is 459.793MHz, which is nearly 10MHz higher than the design frequency. It may be caused by not strictly controlling the machining quality, and not considering the influence of stiffening ribs welding. However, the field profile is much better. The initial field flatness is 99.3%, which also proves the conclusion of previous section.

Tuning

As the frequency is higher, tuning must have been done by pushing both beam pipe flanges. The frequency response is tested, while the tuning amount can be controlled by 0.02mm. The data accords with the linear fitting nicely at the initial statue, but it deviates more obvious from that as the tuning magnitude increases. The initial frequency response is 1.73MHz/mm, which agrees with the evaluation by perturbation.

Vacuum

The vertical test of this cavity will be done at 4K. The interior of the cavity will be vacuum, while the exterior will be 1atm pressure of 4K liquid helium. The beam pipe flanges will not be fixed, which is different with the mechanical study. The experiment of vacuum test is done under these conditions. The frequency shift is -1.76MHz when the frequency is around 452MHz, and the vacuum is 1.2×10^{-3}mbar.

Final Statue

Considering the shrink of cooling down to 4K, the frequency will be changed by +0.62MHz. Adding the effect of vacuum, the target frequency of RT tuning is 451.14MHz. After the tuning process, the frequency is 451.27MHz, and the field flatness is still above 98% without special tuning for field profile.

The PKU SSC is proposed to be tested at Jefferson Lab. Thanks to Jefferson Lab, and especially to Peter. As the cavity will be shipped to Jefferson Lab, the further tuning has not been done yet.

CONCLUSION

The PKU SSC has been fabricated at Peking University. The RF design gives a low value of peak field ratio, which may allow a good performance in cold test. The mechanical structures are used to offer a credible mechanical stability. The mechanical tolerant analysis has shows that single spoke cavity is robust with respect to mechanical errors, and gives directions for fabrication. The room temperature test obtains RF parameters of the initial state, and some mechanical properties. The SSC is finally tuned to the target frequency for cold test.

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