STUDY OF BALLOON SPOKE CAVITIES

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Abstract

A balloon geometry has been proposed to suppress multipacting for single spoke resonators. The design may find a useful application for proton and ion accelerator projects. TRIUMF has completed initial RF, mechanical studies on this special geometry for both low (β=0.12) and medium (β=0.3) β geometries. The RF properties are comparable with that of traditional spoke cavities but with improved RF efficiency in addition to the reduced multipacting. The results of electro-magnetic and structural design studies comparing the balloon geometry with traditional spoke geometries will be presented. We will also present optimization studies of the mechanical design, such as decreasing df/dp by EM field compensation.

INTRODUCTION

A balloon geometry has been proposed to suppress multipacting for single spoke resonators [1]. The name derives from the spherical geometry and big volume at the periphery of cavity. Since a number of proton and ion accelerator projects have been proposed to use spoke resonators for different energy sections, such as Project-X [2], Europe Spallation Source [3], Chinese ADS [4], and Rare Isotope Science Project (RISP) [5], this design may find a useful application.

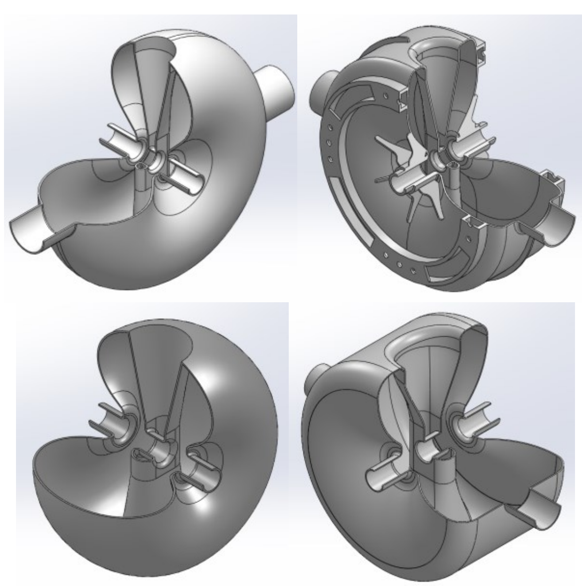

Figure 1: Geometry comparison of 0.12 balloon resonator (top left) and CADS spoke012 (top right), and that of 0.3 balloon resonator (bottom left) and RISP SSR1 (bottom right).

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325MHz β=0.12 and β=0.3 balloon spoke resonators have been studied at TRIUMF. They were respectively proposed as the alternative candidates of the Spoke012 [6] of CADS and the SSR1 [7] of RISP. TRIUMF has completed initial RF, mechanical, and fabrication studies for low β balloon cavities. The comparison of resonator's geometry between the β=0.12 balloon resonator and the Spoke012 of the preliminary design of CADS is shown in Fig. 1. The SSR1 cavity of RISP is still in the design stage. The β=0.3 balloon cavity is also shown in conceptual design in Fig. 1. There are no power coupler ports or cleaning ports added as yet.

ELECTRO-MAGNETIC PROPERTIES

The balloon variant is proposed to suppress multipacting, while maintaining good RF performance. For the initial design of the balloon variant of PKU-I spoke cavity, the requirements on RF parameters are well satisfied [1]. The comparison of RF parameters are shown in Table 1 for β=0.12 and β=0.3 spoke resonators. The simulation is done using the CST code. The parameters are defined for a maximal effective voltage of 0.78 MV per cavity for β=0.12 resonator, which is the requirement of CADS beam dynamic design. In the case of the β=0.3 spoke resonator the fields are defined with respect to a maximal peak electric field of 35 MV/m in consideration of stable cavity operation. For most RF parameters, the results show that the balloon variants have similar values as the mainstream designs.

Table 1: RF parameters comparison of original spoke and balloon variants at low and medium β region.

Parameters	Unit	CADS Spoke012	Balloon 0.12	RISP SSR1	Balloon 0.3
E_p/E_{acc}	1	4.5	4.8	4.7	4.4
B_p/E_{acc}	mT/(MV/m)	6.4	7.5	6.4	6.8
R/Q_0	Ω	142	161	234	272
G	Ω	61	63	94	98
E_{acc}	MV/m	7.1	7.1	7.5	8.0
E_p	MV/m	32	34	35	35
B_p	mT	44	53	48	54

The β=0.12 balloon resonator has a 17% higher B_p/E_{acc}, due to the circular rather than elliptical spoke base used in the Spoke012 [8]. However, the peak magnetic field at the operational gradient is acceptable in both cases. The β=0.3 balloon resonator also has a higher B_p at operational gradient, but is also acceptable while

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delivering a higher accelerating gradient.

Spanning the beta range from 0.12 to 0.3 (including β=0.2 [1]), the big dome and big volume in the higher magnetic region of the balloon variants will offer about 15% higher R/Q_0*G compared with traditional single spoke cavities. It increases the accelerating efficiency and reduces the power loss at the same operational gradient, and saves cryogenic power as well. The higher R/Q_0*G is an advantage of the balloon variant resonators.

The simulation results of multipacting for the balloon resonators are shown in Fig. 2. They are done with the ACE3P and CST codes. The multipacting barriers of the 1st and 2nd order will appear at 1 MV/m and 3 MV/m in the β=0.12 resonator, and around 1 MV/m and 2 MV/m in the β=0.3 resonator. The key point is that there are no stable secondary electron resonating trajectories at the operational accelerating gradient.

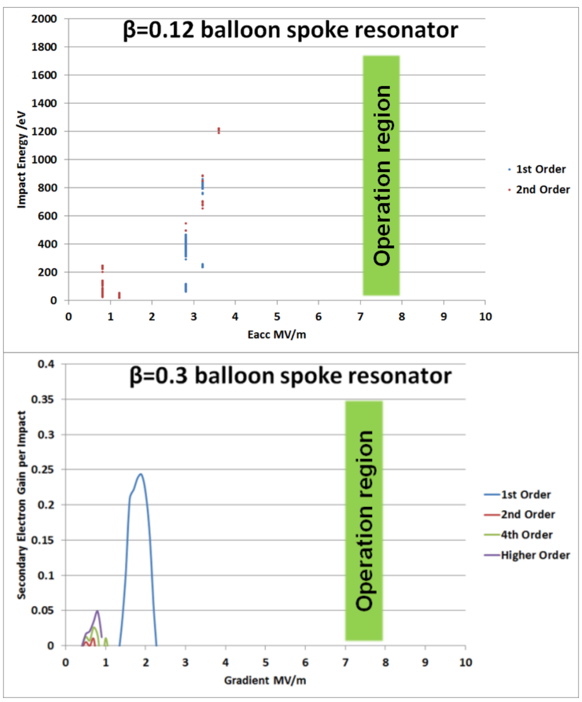

Figure 2: Simulation results of multipacting of balloon spoke resonators. The result of the 0.12 resonator is obtained with ACE3P code, while that of 0.3 with CST code.

MECHANICAL PROPERTIES

A mechanical study has been done on the β=0.12 balloon resonator. The design of the mechanical stiffeners and a comparison of mechanical parameters with respect to the Spoke012 will be presented.

Due to the higher frequency of the spoke resonator compared to typical quarter wave or half wave resonators, the accelerating gap of very low β (β=0.1) spokes is short. The increased capacitance in the beam gap makes the resonant frequency highly sensitive to the variation of the gap length. On one hand the sensitivity allows a broad tuning range for a small movement, but while on the other hand, the sensitivity puts challenging requirements on mechanical stability during operation due to the helium pressure fluctuation demanding complex stiffeners configurations.

Recently, the geometry of end walls of single spoke resonators has changed from the flat form to the dome shape [8, 9]. This feature made the unjacketed cavities stronger, and helped to remove the expensive donut stiffeners. The CADS Spoke012 chose this new concept, using an elliptical curve as the profile of the end walls. Compared to the Spoke012 end wall, the profile of the balloon resonator is most like an elliptical cavity, which offers a superior mechanical strength. The comparison of the mechanical parameters of each bare cavity is shown in Table 2. The maximal displacement and stress is calculated under 1bar pressure on the outer surface of resonator.

Table 2: Mechanical parameters comparison of bare cavities of 0.12 balloon resonator and CADS Spoke012.

Parameters	Unit	Spoke012	Balloon	Beampipe
Max. displacement	mm	3.26	0.77	Free
		0.22	0.08	Fixed
Max. Stress	MPa	157	72	Free
		389	141	Fixed
df/dp	Hz/mbar	-8284	-1812	Free
		-211	-122	Fixed
LFD	$Hz/(MV/m)^2$	-15	-2.7	Fixed

As discussed above the mechanical stability due to the helium pressure fluctuation is an important issue in the mechanical design, especially for very low β spoke resonators. Two approaches will reduce the helium pressure sensitivity. One is stiffening the cavity with more and stronger ribs. This approach may lead the structure to be very complicated, and increase the expense. Another way is to optimize the structure to produce compensating volume variations in each of the electric and magnetic field domains for helium pressure variations. This will allow a relative larger deformation, but leave very little frequency shift, which can be negligible in the case of a good design.

The optimized design of stiffeners and helium jacket is shown in Fig. 3. There are two ring stiffeners on each side of the cavity, connecting the cavity and helium jacket. The helium jacket is separated into two aperture parts and a peripheral part by two bellows. The bellows are configured to tune the frequency at the flanges of the beam pipes. The positions of the two different ring stiffeners and the big fillets of helium jacket are optimized to supply suitable compensation of the cavity's deformation due to helium pressure variation, and minimize the value of df/dp.

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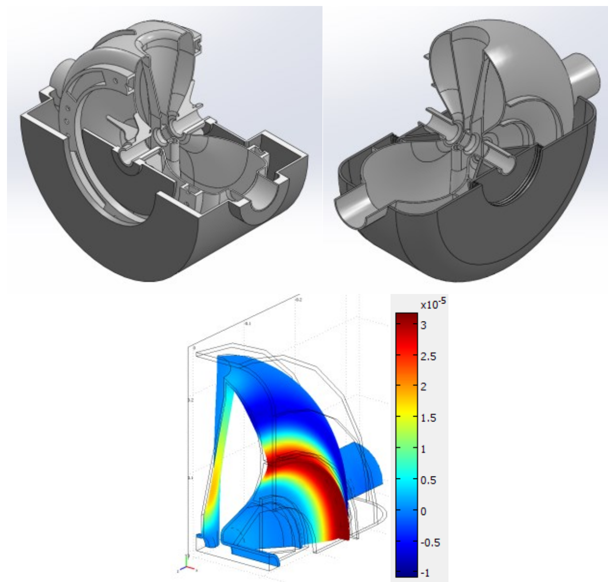

Figure 3: The mechanical design of CADS Spoke012 (topleft) and 0.12 balloon resonator (topright). The deformation of balloon resonator due to helium pressure (bottom).

The cavity deformation due to helium pressure variation is also shown in Fig. 3. The geometry comparison with the Spoke012 is shown in Fig. 3, while the mechanical parameters comparison is shown in Table 3. It shows the balloon variant requires fewer stiffeners, but offers better mechanical stability. The helium pressure sensitivity will be nearly zero if the tuner compresses on both ends of the beam pipe flanges. For a high beam intensity application, the operational bandwidth of this resonator will be around 400 Hz, which means that the df/dp is good enough at 2 K operation even in the condition where the beam pipe flanges are totally flexible.

Table 3: Mechanical parameters comparison of 0.12 balloon resonator and CADS Spoke012 with stiffeners and helium jackets.

Parameters	Unit	Spoke012	Balloon	Beampipe
Max. displacement	mm	0.20	0.04	Free
		0.07	0.03	Fixed
Max. Stress	MPa	83	23	Free
		86	23	Fixed
df/dp	Hz/mbar	-192	+43	Free
		+30	+0.3	Fixed
LFD	Hz/(MV/m)^2	-1.3	-1.5	Fixed

CONCLUSION

A balloon geometry has been proposed to suppress multipacting for single spoke resonators. TRIUMF has completed initial RF, mechanical studies on this special geometry for both low (β=0.12) and medium (β=0.3) β geometries. The RF properties are comparable with that of traditional spoke cavities but with improved RF efficiency in addition to the reduced multipacting. The balloon geometry supplies a better mechanical strength than the traditional bare spoke cavities. Good mechanical parameters are obtained by a compact stiffeners design based on the electro-magnetic and deformation compensation. The mechanical study on the β=0.3 balloon resonator will be done later. Comparison with the RISP SSR1 design will make an in-depth understanding of this new kind of geometry of single spoke resonators.

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