

Canada's national laboratory for particle and nuclear physics and accelerator-based science

# BALLOON SINGLE SPOKE RESONATOR

Z. Yao, R.E. Laxdal, B. Matheson, B.S. Waraich, V. Zvyagintsev, TRIUMF, Canada June 26, 2018

TESLA Technology Collaboration Meeting







- Balloon Concept
- RISP SSR1 Cavity
- Cavity Fabrication
- Processing
- Cold test results
- Summary





# What is the Balloon SSR?

#### MULTIPACTING IN SPOKE CAVITIES





### **RIUMF**

## **BALLOON CONCEPT**





Multipacting areas are spoke bases for 1st order barrier, and equator for higher order ones.

Balloon shaped outer conductor and local geometry of spoke bases narrow these barriers and push them to lower gradient by changing local EM field.





#### Balloon + Spoke





Z.YAO, Balloon Single Spoke Resonator, TTC, RIKEN



# **RISP SSR1 Cavity**

June 26, 2018

#### **RIUMF**

#### **RISP SSR1 CAVITY**



TRIUMF was commissioned to design, fabricate, and test a balloon variant prototype for RISP SSR1.

RISP SSR1 Specifications				
Operating frequency	325 MHz			
Geometry β	0.30			
Operating temperature	2K			
Q <sub>0</sub>	>5X10 <sup>9</sup>			
Epeak	35 MV/m			
V <sub>acc</sub>	>2.5 MV			
df/dp	<10 Hz/mbar			
Frequency tuning range	±100 kHz			
Q <sub>ext</sub>	8X10 <sup>6</sup>			
RF bandwidth	40 Hz			
Beam aperture	50 mm			
Pressure envelop at 300K	2 bar			
Pressure envelop at 2K	5 bar			

## RIUMF SSR1 Traditional Design (RISP) vs Balloon Design (TRIUMF)

- Very similar rf performance in terms of basic parameters with balloon having slightly higher effective voltage for same peak electric field and slightly lower peak magnetic field
- Main difference MP barriers pushed to low fields away from operating gradient

	SSR1 RISP	SSR1 TRIUMF
Design	Traditional	Balloon
RF Freq (MHz)	325	325
beta	0.3	0.3
<b>G</b> (Ω)	93	93
<b>R/Q (</b> Ω)	229	233
Ep/Ea	3.96	3.84
Ep (MV/m)	35	35
Bp/Ea (mT/(MV/m))	6.46	6.07
Bp (mT)	57.1	55.3
Veff (MV)	2.45	2.52
Diameter (mm)	525	570







- The Bare Balloon cavity is inherently more rigid mechanically (sphere vs drum)
  - Lower natural df/dp easier to reduce
  - fewer stiffeners are required cheaper fabrication costs

Parameters	Beam Pipes C.	Baseline	Balloon	Unit
Internal Stress	Fixed	323	49	Maa
@1bar pressure	Free	150	99	Тира
df/dp	Fixed	-145	-16.5	Uz/mbar
	Free	-1718	-1289	H2/MDar
LFD	Fixed	-4.5	-2.1	$H_{\tau}/(M)/(m)^2$
Tuning	N/A	300	545	kHz/mm
	N/A	2.1	3.3	kN/mm
	N/A	67.3	85.5	MPa/mm



The deformations of both designs under 1bar external pressure load. The color ranges are shown in the same scale.



- Design complies with ASME guidelines
  - Only requires spoke reinforcing plates and two stiffener rings on shell
- To minimize pressure sensitivity
  - -ring stiffeners are attached to jacket on only one side
  - End shell geometry of helium jacket adds compensation



Beam Tube	Value	
free	-1.6	
fixed	+1.5	
free	-8.7	
fixed	-1.4	
	467 kHz/mm	
	32.7 kHz/kN	
	Beam Tube free fixed free fixed	



#### **ENGINEERING DESIGN**





# **Cavity Fabrication**



### SPOKE FORMING

- Forming die was developed at TRIUMF.
- Deep drawing was tested in copper before moving to Nb.
  - Die shape was good. No modification required.
  - Blank sheet was optimized.
- Niobium half spokes were then punched and machined.
  - No significant material thinning.













#### SHELL SPINNING

- Due to the size of the shell and hence the size of the required forming dies TRIUMF opted to form the shells by spinning
- 2-steps spinning for shell.
  - Spin nose cone
  - Spin outer shell
- Two Cu shells spun then moved to Nb shells.













• Significant thinning was noticed on both Cu and Nb spun shells





- Mechanical polishing was done at vendor
- Salt water soak
- Nitric acid clean (X2)
- Ultrasound
- 10um BCP both sides
- Salt water soak
- Ultrasound

#### Rust appears after salt water soak





#### Post-BCP salt water soak

June 26, 2018



#### **OTHER PARTS**

#### **Collar forming**















Nb-SS Brazing Follow recipe from CERN, ATLAS and FNAL. [1] J.P. Bacher, CERN/EF/RF 87-7. [2] J.D. Fuerst, TUP11, SRF2003. [3] L. Ristori, WEPPC058, IPAC2012.

## Nb-Cu TIG welding



RF tubes Beam tubes SS flanges



#### EB WELDING



June 26, 2018



#### FREQUENCY CONTROL



#### FREQUENCY MEASUREMENT



	Conditions	Target Freq. /MHz	Freq. Shift /MHz
Operational	2К	325.000	-
	Pre-tune	N/A	±100kHz
Jacketed Cavity	2К	325.000	-
	R.T. and atm.	324.683	-213kHz-104kHz
	Pre 30µm etch	324.723	+40kHz
	Tuning	324.723	As needed
	Weld Jacket	N/A	±160kHz* (PAVAC)
Bare Cavity	4K/2K w/ support	325.293	+466kHz+104kHz
	R.T. and atm.	324.723	-
	Tuning	324.723	As needed
	Pre 150µm etch	324.921	+198kHz
	Tuning	324.921	As needed
Weld	Final weld	-	-
	Collar weld	-	±72kHz/mm*
	RF Tubes weld		-
	Equator weld shrinkage	324.974	+88x0.6*=+53kHz





@  $S_{21}$  -75dB and  $Q_L(Q_0)$  3000.



#### Unjacketed cavity and test frame







## **Processing and Cold Test**



#### Cavity Processing and Cryogenic Tests





June 26, 2018



#### Cold test – Jan. 12, 2018





11



#### Unjacketed cold test - notes



- There were four cold tests with etching depths of 60, 140, 200 micron pre-degassing and 220micron after degassing
- Degassing records indicated high H levels
- After degassing the base residual resistance is 4.9nΩ with an ambient magnetic field of 35mG -4K BCS resistance is 25.1nΩ after 120°C bake.
- Cavity quench limits the cavity gradient at 10.3 MV/m, corresponding to a nominal peak magnetic field of 63 mT,
- Surface defects in the form of either geometry or foreign material are suspected
- We were battling the background field in our new cryostat B~35-50mG





#### BCS Fit – Surface Resistance

2K Q curve has a pronounced Qslope in the medium field range due to a significant field dependence on the residual

Base residual is high due to large base field in our new cryostat





There is excellent agreement between MP simulations and cold test data

No multipacting barriers near the operational gradient or below 0.1 MV/m.

The barriers only exist between 0.2 MV/m and 1.8 MV/m.





## Jacketing at TRIUMF

- Measured warm frequency (324.6MHz), spring constant (10Nt/micron), tuning sensitivity – within warm goals
- Cold frequency excellent
  - 4.3K 324.978 MHz
  - 2.1K 324.995 MHZ
- df/dp = 15Hz/mbar
- Multipacting takes about 1.5 hour to pass through and then does not reappear







#### Jacketed Cold Test Result

Cavity performance declined after jacketing – suspect that the etch after jacketing opened up one or more inclusions

See some signs of defects and uneven surface finish with camera







- Evidence of bubble trace on shell near rf port
- Small geometric defects on shell
- Imperfect welds at the spoke collar















- Balloon SSR variant is proposed to mitigate multipacting around operational field level.
- The first balloon variant of single spoke resonator has been designed, fabricated and tested at TRIUMF.
- The cold tests demonstrate the principle of the balloon concept and achieved the design goals.
  - There is no multipacting barrier around the operational gradient and low levels are easily managable.
  - Cavity geometry achieves high R/Q and G, and high  $V_{acc}$  @ 35MV/m  $E_{peak}$  with low  $B_{peak} Q=4e9$  at 9.1MV/m in unjacketed test
  - Mechanical design complies ASME guidelines and minimizes pressure sensitivity for CW operation.
  - Fabrication is simplified with less reinforcing ribs required



# • RISP

- Xu Ting, Jie Wei (FRIB)
- TRIUMF machine shop (machining and forming)
- Vector Aerospace (brazing),
- AMS Industries Ltd. (spinning)
- ROARK (EB welding)

#### ACKNOWLEDGEMENTS





Canada's national laboratory for particle and nuclear physics and accelerator-based science

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McGill | McMaster | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York

# Thank you! Merci!

Follow us at TRIUMFLab

f 🖸 🏏