

# PRODUCTION OF A 1.3 GHz NIOBIUM 9-CELL TRIUMF-PAVAC CAVITY FOR THE ARIEL PROJECT

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## Abstract

A nine-cell 1.3 GHz superconducting niobium cavity has been fabricated for the ARIEL project at TRIUMF. The cavity is intended to accelerate a beam current of 10 mA at an accelerating gradient of 10 MV/m. The beam loaded RF power of 100 kW is supplied through two opposed fundamental power couplers. The electromagnetic design was done by TRIUMF [1]. The cavity final design and fabrication procedure has been developed in collaboration between TRIUMF and PAVAC Industries Inc. [2]. Several innovations in the cavity fabrication process were developed at PAVAC. Since the most important weld is at the equator this weld is done first to form a 'smart-bell' as the basic unit as opposed to welding first at the iris to form 'dumb-bell' units. Each half cell is pressed with a male die into a plastic forming surface to produce half-cells with less shape distortion and material dislocations. Since the 'smart-bell' concept is novel the cavity fabrication sequence including the frequency tuning steps and RF frequency modelling methods will be discussed.

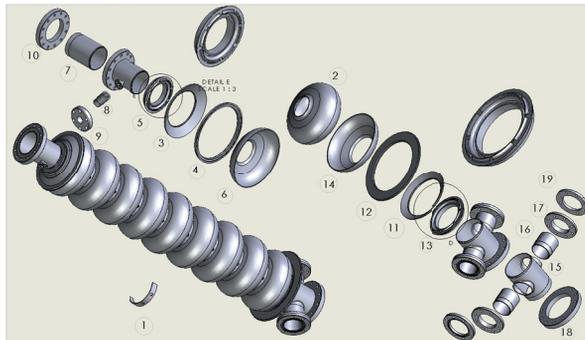


Figure 1: Design of the TRIUMF-PAVAC 9-cell cavity.

## INTRODUCTION

The development of superconducting cavity for the ARIEL project has been started at TRIUMF. It was decided to fabricate and install five 1.3 GHz 9-cell elliptical Nb cavities (Fig. 1) operating at 2 K in CW regime to accelerate an electron beam current of 10 mA up to an energy of 50 MeV [1]. In such a way each cavity will require 100kW of beam loaded RF power and operate at a relatively modest accelerating gradient of 10 MV/m.

## MANUFACTURING PREPARATION

The ARIEL cavity fabrication was granted to PAVAC. The preparation of 9-cell cavity manufacturing procedures was started with the production of a 7-cell copper model. At this stage we developed cavity fabrication and tuning concepts, prepared RF jigs and

fixtures, and developed experience with cavity tuning. The cavity final fabrication has been developed in collaboration between TRIUMF and PAVAC.

## 'Smart-bell' Concept

It is typical in elliptical cavity production to form 'half-cells' by deep drawing and weld the half-cells at the iris to form, so called, 'dumb-bells' [3] as the basic fabrication unit. In developing the ARIEL cavities we decided to explore an alternate variant. Since the cavity will only be required to hold modest gradients due to the high beam loading we concentrated efforts on optimizing the equator weld where the magnetic field is a maximum. Here we decided to develop a new 'smart-bell' concept, where the 'half-cells' are first welded at the equator to form the basic fabrication unit (see Fig. 2). In this variant there is access from both the inside as well as the outside for the electron beam during welding and there is better access for visual inspection post-weld. The 'half-cells' are prepared with a male and female equator detailing to enable interleaving of equator edges. This serves to self-fixture the parts for welding and reduces handling of the etched surfaces.



Figure 2: 'Smart-bells' and sub-assemblies.

## New Cell Forming Die Set

Another PAVAC innovation for the fabrication was the development of a cell forming die set utilizing a plastic female. It provides forming with less stress on the niobium and results in a very reproducible shape of the cell (Fig. 3).



Figure 3: New cell forming die set.

### BCP for EB Welding

Each ‘half-cell’ was given an initial 20µm etch after forming. In addition the edges of the Nb parts for all welding were cleaned by means of BCP etching of ~20 µm (Fig. 4). Chemical etching procedures and fixtures were developed at TRIUMF.



Figure 4: BCP for EB welding of the cavity sub-assembly at TRIUMF

### RF Jigs and Fixtures

Several RF jigs and fixtures were developed in the TRIUMF-PAVAC collaboration for network analyser frequency measurements during the cavity fabrication. Accuracy of measurements ±0.1 MHz was achieved.

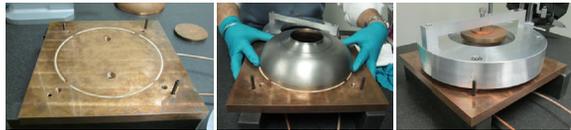


Figure 5: RF jig for half-cell frequency measurement

Figure 5 presents the RF jig for half-cell measurements in an electric boundary configuration. For the equator a copper plate with a groove feature to capture a silver plated balseal [4] is used with a fixture to hold the ‘half-cell’ on the plate. Two RF probes are mounted on the panel in a position where the density of the electric and magnetic field is the same to provide minimum frequency perturbation. The iris edge, with less magnetic field, is closed with a flat copper blank under small pressure.



Figure 6: RF jig for ‘smart-bell’ frequency measurement

Inner and end ‘smart-bell’ frequency measurement setups are shown in Fig. 6. Smart-bells are closed with flat copper disks assembled with RF probes. To provide

reliable RF contact the ‘smart-bell’ is loaded with a weight of ~3 kg.

### GOAL AND RESULTS OF FABRICATION

We manufactured two 9-cell cavities (ARIEL 1 and 2) and two (ARIEL 3 and 4) are in fabrication. ARIEL 1 went through leak check, BCP, tuning, US and HPR cleaning and superconducting vertical test [5]. During the vertical test the cavity had the right operating frequency of 1300.0 MHz at 2 K but a quality factor below specification and is being reprocessed. Here we will discuss the goals and results for fabrication and tuning steps.

#### Fabrication Frequency Goal

The fabrication frequency goal corresponds to the room temperature and atmospheric pressure pi-mode frequency before processing that is required to reach the operating frequency. Since our cavity design is similar to the TESLA 9-cell, we use the TESLA tuning data [6] in our initial estimates. A comparison of assumed frequency shifts and those measured with ARIEL 1 values are given in Table 1.

Table 1: Measured (ARIEL1) Compared to Expected (TESLA) Frequency Shifts for Various Procedures

Detuning step	Δf (MHz)	
	TESLA	ARIEL1
Vacuum and cooldown	+2.34	+2.6
BCP 130 µm	-1.3	-1.17
Stretching 0.5 mm	+0.15	+0.15

The expected total frequency shift is 1.19 MHz while the measured shift is 1.58 MHz so that the assumed and corrected fabrication goals are within the tuning range of ~2 MHz.

#### 9-cell RF Cavity Model

A Comsol [7] 2D RF parametric cavity model was developed (Fig. 7) to provide simulation results for resonant frequencies and sensitivities of half-cells and sub-assemblies that allows activating and deactivating sub-domains and changing boundary conditions. For calculation of goal frequencies we take into account weld shrinkage and change of boundary conditions during assembly. A list of the goal frequencies for various steps of fabrication is given in Table 2 along with the assumed total weld shrinkage (half from each side).

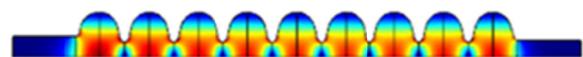


Figure 7: Comsol 2D RF model of the cavity; E-field distribution for operating mode.

Table 2: Goal Frequencies as Measured with Electric Boundary for Various Stages of ‘Smart-bell’ Fabrication

Step	Goal Freq. (MHz)	Weld shrinkage (mm)
Half cell	1272.49	0.45
Smart bell (inner)	1274.50	0.30
Smart bell with pipe (power)	1287.19	0.30
Smart bell with pipe (tuner)	1286.73	0.30
2x inner cells ( $\pi$ )	1286.50	0.30
3x inner cells ( $\pi$ )	1292.59	0.30
4x inner cells ( $\pi$ )	1295.13	0.30
5x inner cells ( $\pi$ )	1296.39	0.30
6x inner cells ( $\pi$ )	1297.09	0.30
7x inner cells ( $\pi$ )	1297.53	0.30
Completed cavity ( $\pi$ )	1298.81	N/A

### Manufacturing and Frequency Tuning Steps

There are three kinds of ‘half-cells’ in the 9-cell cavity: 16 inner ‘half-cells’, one for ‘power’ (coupler) end and one for ‘tuner’ (opposite to coupler) end. They are formed to have excess length on both the iris and equator for trimming, both to true the surface and to adjust the frequency. Machining allowances of 1.5 mm and 1.05 mm are used for each of the irises and equators respectively. The fabrication tuning strategy is to measure the ‘half-cell’ frequency with the RF jig (Fig. 5), compare the measured value with the goal frequency and trim the equator to reach the frequency goal assuming some weld shrinkage.

From the first batches of ‘half-cells’ it was determined that the resonant frequency is well correlated with length (Fig. 8); it means that the forming process has sufficient shape reproducibility (due to the new forming die). After the first series the ‘half-cell’ RF measurement was abandoned and equator of the ‘half-cell’ was trimmed to a length of 60.25 mm to get 1.5 mm allowance for iris.

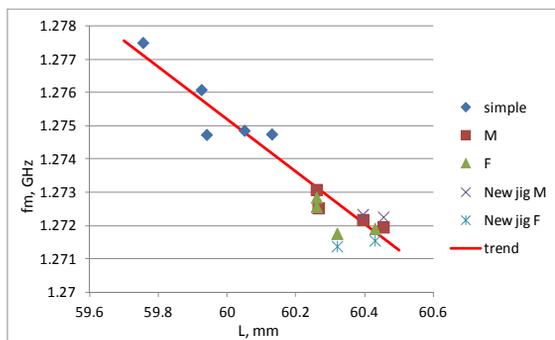


Figure 8: Frequency monitoring data for TRIUMF-PAVAC cavities production.

Next the inner ‘smart-bells’ are welded, the frequency measured (Fig. 6) and the two iris edges trimmed equally to reach the frequency goal. Our experience is that the weld shrinkage is so reproducible that typically a

common iris trim is requested for a batch of inner cells. The multi-cell is welded one cell at a time and the stiffening ring is added after each new cell. The iris weld is inspected and polished if required.

Iris edge machining allowance isn’t effective for ‘power’ and ‘tuner’ ‘smart-bells’ frequency tuning because the iris forms the start of a cut-off waveguide for the operating mode. In this case RF jigs (Fig. 5) are used for the end ‘half-cell’ and inner ‘half-cell’ measurements and then we are doing equator trims to reach the goal frequency. To provide better frequency measurements we assemble the iris with a cut-off beam pipe. After equator welding the end ‘smart-bell’ is tuned by trimming the inner iris.

Frequency data recorded during ARIEL1 and ARIEL2 cavity production is presented in Fig. 9 in comparison with frequency goals (pi-modes), calculated with Comsol 2D RF model. The horizontal axis shows production steps and sub-assemblies: steps 1, 2 and 3 correspond to power, tuner end and inner ‘smart-bells’; steps 4-9 correspond to sub-assemblies of inner ‘smart-bells’ of from two to seven cells; steps 10 and 11 corresponds to the final sub-assembly of 7 inner ‘smart-bells’ with tuner and power ‘smart-bells’. ARIEL 1 was delivered with a frequency just 0.8 MHz below the goal. ARIEL 2 was 1.75 MHz below the goal. Both cavities were tuned to the goal frequency and field flattened to better than 95% by plastic deformation on a warm tuning and bead pull stand. ARIEL 3 and 4 are now in production.

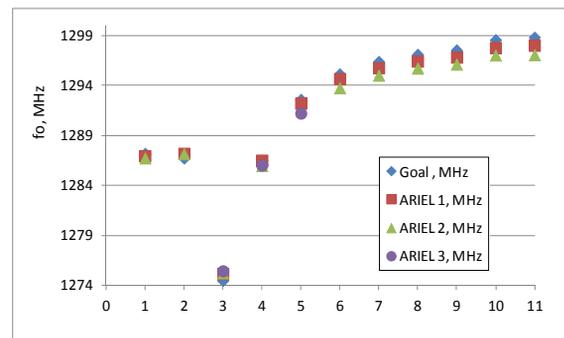


Figure 9: Frequency monitoring data for TRIUMF-PAVAC cavities production.

## CONCLUSIONS

The new ‘smart-bell’ concept of multi-cell cavity fabrication with interleaved equator edges has been developed with PAVAC with the goal to have better control over the equator weld. In addition a new forming die has been developed to achieve less stress in the material and more shape reproducibility. All fabrication procedures, including machining, forming, pre-weld etching, welding, and frequency tuning were completed for this new variant of nine-cell cavity fabrication. Two 9-cell TRIUMF-PAVAC Nb cavities are completed, and the next two cavities are in the process of fabrication.

**REFERENCES**

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