1.3 GHz SRF CAVITY TESTS FOR ARIEL AT TRIUMF

P. Kolb, P. Harmer, D. Kishi, A. Koveshnikov, C. Laforge, D. Lang, R.E. Laxdal, Y. Ma, B.S. Wairach, Z. Yao, V. Zvyagintsev, TRIUMF, 4004 Wesbrook Mall, V6T 2A3 Vancouver, BC, Canada

Abstract

The 1.3 GHz cavity test program at TRIUMF for the ARIEL eLINAC is progressing into its next stage: Going from single cell cavity tests to demonstrate the operating Q and gradient for ARIEL can be reached at TRIUMF to nine cell cavity tests for production cavities.
Single cell cavity tests at TRIUMF showed a comparable performance to a characterization done on the same cavity at FNAL last year. These single cell tests show that the operating point for ARIEL of $Q_0 > 10^{10}$ at 10 MV/m during 2 K operation can be reached and exceeded at TRIUMF.
To prepare for the first ARIEL nine cell cavity, a test with a TESLA nine cell cavity was done. This includes frequency and field tuning, etching via BCP[1], HPR[2] and assembly in a class 10 clean environment as well as modifications to the cryo assembly and upgrades to the 2 K pumping system. The performance of this TESLA cavity and the performance of first ARIEL nine cell cavity produced by PAVAC will be shown.

INTRODUCTION

The ARIEL LINAC [1] is a electron LINAC based on 1.3 GHz TESLA technology. Five cavities accelerate a 10 mA electron beam to 50 MeV. The goal for each nine-cell cavity is a gradient of 10 MV/m with a Q of 10^{10} or higher while being cooled with liquid helium to 2 K.
Single cell testing is done to qualify processing and assembly protocols prior to nine cell processing. The processing includes HPR, etching via BCP and clean room assembly.
The TRIUMF nine cell cavity has been designed with HOM[3] in mind. Future upgrade plans include a recirculating beam line to either further accelerate the beam or excite an FEL on the back beam line. Two 50 kW power couplers provide 100 kW of beam-loaded RF power for each cavity. HOM damping is done exclusively with beam line absorbers [2, 3]. The shape of the cavity variies from the TESLA design in its end groups [4]. For a nine cell cavity additional steps include warm field flatness tuning.

SINGLE CELL TESTS

Single cell cavity tests are being pursued to facilitate fundamental SRF studies to investigate the effectiveness of cavity treatments such as etching and baking. For this it has to be shown that the conventional cavity treatments provide a reliable and good performance. For that purpose a single cell cavity was sent to FNAL to be tested there to get a reference performance of a TRIUMF single cell cavity. Treatments at FNAL (and ANL) included 5 μm BCP to clean off stains on the surface and 35 μm EP, followed by 1 h HPR before assembly. The cavity performed up to 25 MV/m with a Q between 1 and $2 \cdot 10^{10}$ with a modest slope and after 25 MV/m with a typical HFQS. Surface treatments at TRIUMF after this only include ultrasonic cleaning (1 h in LPS solution, 1 h in DI water), 1 h HPR followed by assembly in a Class 10 environment. As can be seen in fig. 1 the performance at 2 K was very comparable. No X-rays or quenches were detected and the limiting factor was the pressure control of the 2 K LHe bath. After 12-15 W the regulating valve is fully open and the helium pressure rises. With this reproduction of the FNAL result, it is proven that cavity handling inside the clean rooms including HPR is on a competitive level. Further tests could include removal of 20 μm via BCP at TRIUMF to qualify the procedures with respect to etching.
After baking the cavity at 120 C for 48 h the cavity developed a leak to the super fluid helium and the effect of baking on the HFQS could not be observed. However, Q vs T measurements at fixed gradient taken during both cooldowns show a small increase in residual resistance, from 5 to 17 nΩ as can be seen in fig. 2. After this test, single cell testing was further postponed and the cryostat modified to fit nine cell cavities.

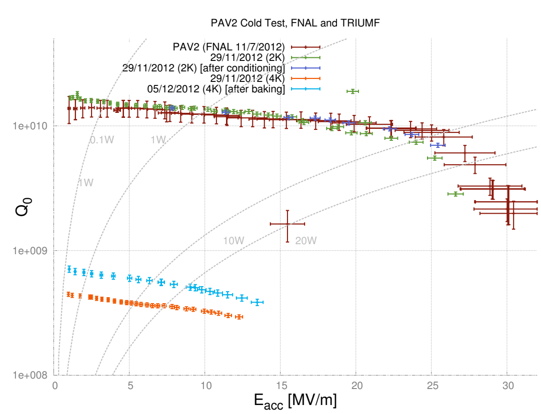

Figure 1: Q vs E_{acc} measurements of PAV2 cavity at 4 K (TRIUMF only) and 2 K (TRIUMF and FNAL). The smaller errorbars are due to a movable coupler at TRIUMF vs fixed coupling at FNAL.

[1]Buffered Chemical Polishing
[2]High Pressure Rinsing
[3]Higher Order Modes

ISBN 978-3-95450-143-4

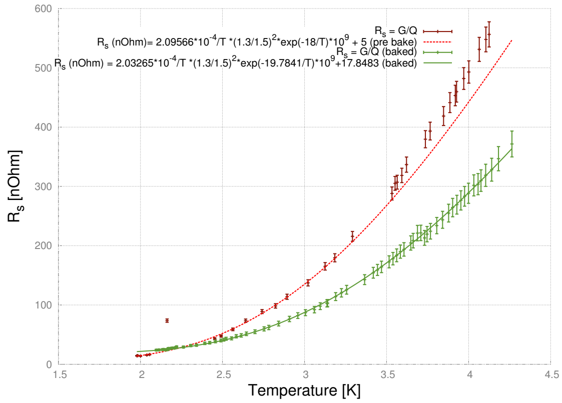

Figure 2: R_s vs T measurements of PAV2 cavity at fixed gradient.

NINE CELL TESTS

The first cold test at TRIUMF of a nine cell 1.3 GHz cavity was done in April 2013. A TESLA-type cavity, was prepared and tested to show that all the preparation steps of cell tuning, etching, US degreasing, HPR, assembly and and the upgraded vertical cryostat function correctly. A adjustable horizonal coupler was developed for vertical cavity tests. As can be seen in figure 3 the coupler provides Q_C in the range of $1.5 \cdot 10^7$ to $1.5 \cdot 10^{11}$ in its full travel range. This covers a wide range of Qs suitable for the expected cavity Q_0 during 4 K (around $3 - 4 \cdot 10^8$) and 2 K (around $1 \cdot 10^{10}$) tests.

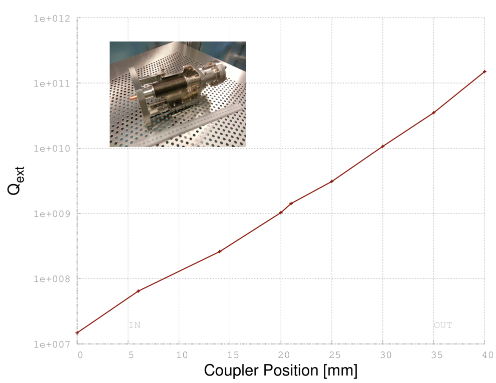

Figure 3: Coupling range of the new horizontal multicell coupler. The total travel is about 5 cm and reaches from 10^7 to 10^{12}.

Etching of the cavity is done via BCP. The TESLA cavity was etched (20+20) μm (flipping the cavity upside down between etches to provide an even etch). Right after each etch the cavity is flushed out with DI water to rinse out any residual acid and stop the etching process. Before the etching the cavity was tuned for field flatness on the warm tuning stand by plastic deformation of individual cells. After the etching the cavity was again mounted on the tuning stand and a small re-tuning step was found to be necessary as the flatness degraded from 98 % to 78 %. After the re-tuning to 95 %, the cavity is cleaned via ultrasound, 1 h in a liquinox solution and 1 h in DI water, then 3 h of high pressure rinsing in a separated room inside a class 100 cleanroom. Drying and assembly is done in a class 10 environment. The assembly is done in two steps: after the first HPR all flanges except the coupler and the bottom beam port are closed off, then a second HPR (again 3 h), followed by the final assembly of the coupler and bottom flange. During assembly the cavity can be rotated so that flanges are always attached from below the cavity and no work has to be done on top of it. Evacuating the cavity is done over a clean pumping and venting system which allows slow evacuation (1 Torr/s).

The cryostat is filled with 300 liters of LHe, supplied and recycled by the Phase I cryosystem of ISAC-II on site. For single cell tests at 2 K one set of sub-atmospheric pumps had been installed previously. Those pumps are sufficient for the smaller single cell cryostat (around 100 liters), but not for the much bigger multicell cryostat. The first test had to be aborted at around 300 Torr due to overheating of the pumps. A new set of pumps was installed and commissioned, providing a mass flow of up to 1.1 g/s (up from 0.5 g/s). With those additional pumps cooldown of a multicell cavity in the bigger cryostat is successful.

Using a pressure rise technique the static load of the cryostat was measured. By measuring the time it takes for the Helium temperature to increase from 2.0 K to 2.1 K at various heater loads with closed off pumping valves it is possible to determine a static load of 4.8 W.

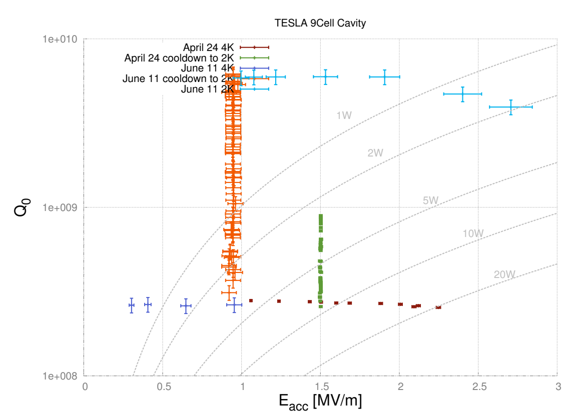

Figure 4: 4 K and 2 K performance of the TESLA cavity.

For the test with the TESLA cavity the new radiation shielding was not ready, so gradients were limited to make sure no harmful radiation was emitted. Data was only taken up to 2.25 MV/m with a Q around $5 \cdot 10^9$ (see fig. 4), which corresponds to a residual resistance of around 33 nΩ .

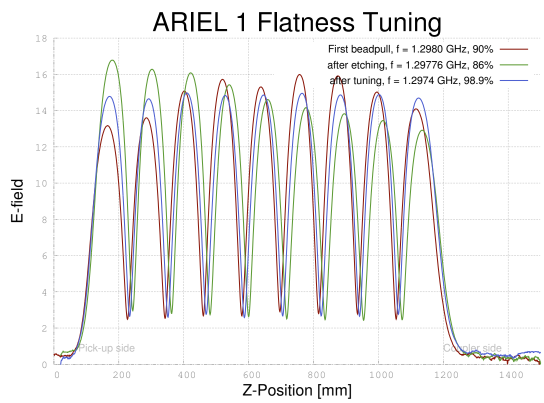

Figure 5: Flatness and frequency tuning of the ARIEL1 cavity. Received with only 0.8 MHz below goal and with a flatness of 90 % it was tuned after etching to 1.2974 GHz and 98 %.

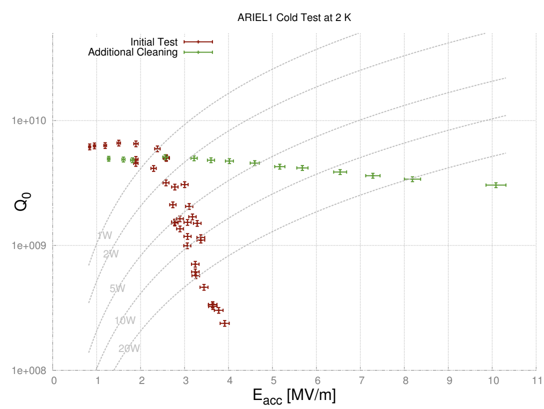

Figure 6: ARIEL1 2 K performance. The strong Q slope in the first test is due to field emitters that could be eliminated by additional cleaning of the cavity and the test coupler.

ARIEL1, the first cavity for ARIEL, got a similar treatment. After receiving the cavity the frequency was 1.2980 GHz, 0.8 MHz below the goal fabrication frequency, with a flatness of 90%. After 120 μm removal via BCP the flatness reduced to 86% and the frequency is 1.29776 GHz (goal 1.29751 GHz). A final re-tuning step, before the cavity gets into the clean room, achieved a flatness of 98% and within 100 kHz of the goal frequency as can be seen in fig. 5. This warm frequency tuning step facilitates a final frequency at 2 K within 10 kHz of 1.3 GHz. Details of the cavity fabrication steps can be found in [5].

Further processing steps include HPR for 4 h, assembly of blank flanges and pick-up on cavity, HPR 4 h, hermetic sealing with coupler and bottom flange. The first RF test showed a Q of $7 \cdot 10^9$ at low gradients with a strong slope at 3 MV/m. Further cleaning steps, including 6 h HPR before final assembly and extensive cleaning of the coupler, improved the test result (see fig 6). A gradient of 10 MV/m was reached with this additional cleaning. No multipacting or xrays were detected. The achieved gradient was limited only by the available cryopower. The Q of the cavity was low with a mild Q-slope and Q-disease is suspected. A retest of this cavity is planned after degassing at FNAL.

OUTLOOK

The first cavity for ARIEL has been successfully tested at 2 K. The frequency tuning steps have been qualified as well as all the new processing hardware including BCP, US cleaning, and HPR. The new vertical test cryostat and new helium pumps work well and provide the ability to test nine cell cavities. The performance of ARIEL1 is presently below goal (10^{10}) with a Q of only $3 \cdot 10^9$, but the goal gradient can be reached. The next step in treatment is a degassing step done at FNAL to increase the Q.

ARIEL2 is already fabricated and ready for cold testing. ARIEL3 and 4 are in fabrication. All individual cells have been fabricated and the multicell fabrication is under way at PAVAC.

ACKNOWLEDGMENTS

The author would like to thank the SRF group at FNAL for their support in testing one of our cavities.

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ISBN 978-3-95450-143-4