TRIUMF ARIEL E-LINAC READY FOR 30 MeV

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Abstract

The ARIEL electron linear acccelerator (e-linac) in its present configuration has a 10 mA electron gun, a single-cavity 10 MeV injector cryomodule and the accelerator cryomodule (EACA) housing two 10 MeV capable SRF cavities. There are momentum analysis stations at 10 MeV and 30 MeV. In October 2014, using a total of two cavities, the e-linac demonstrated 22.9 MeV acceleration. The second EACA cavity was installed in March 2017, thereby completing its designed 30 MeV capability. An unusual feature of the module is the power feed of two cavities by one klystron through a wave-guide type power divider, and closed-loop control of the combined voltage from the cavities. Initial operation of the two-cavity control, include power and phase balancing, is reported.

INTRODUCTION

The realization of ARIEL [1,2] (the Advanced Rare IsotopE Laboratory) is a decade-long project whose objective is the provision of three simultaneous rare isotope beams (RIB) to the three experimental areas in the ISAC facility. ARIEL-I (2010-2015) was dedicated to the construction of the e-linac and a new target hall, mass separator room, and laboratory space. ARIEL-II (2016-2021) is centred around construction of a 100 kW capable electron target station, mass separators, RIB transport to ISAC and the CANREB [3] beamline. This paper is focused on the build out of the electron-driver-beam linac to 30 MeV.

CAVITY QUALITY FACTOR

The e-linac 9-cell 1.3 GHz cavities are a variant of the DESY TESLA type, modified for cw operation and recirculation; with modified end groups to support high cw power input couplers and HOMs damping. The cavity specification is a bare quality factor Q_0 of 10^{10} at an accelerating gradient of 10 MV/m – as may be obtained by chemical etch of the niobium surfaces. The performance (see Fig. 1) of the second SRF cavity for EACA was measured in a vertical test prior to the cold-mass assembly. Performance when mounted horizontal is expected to be superior.

CRYOMODULE COLD MASS

The cold mass shown in Fig. 2, is suspended from the cryomodule [4] lid and includes a stainless steel (SS) strong back, a 2 K phase separator pipe, cavity support posts, and the cavity hermetic unit which consists of the two niobium cavities and their enclosing 2 K LHe jackets, an inter-cavity transition with a SS HOM damper, the four input coupler cold parts and two rf pick-ups. The end assemblies include the CESIC HOM damping tubes. Fig. 3 shows the cold mass assembly in the clean room.

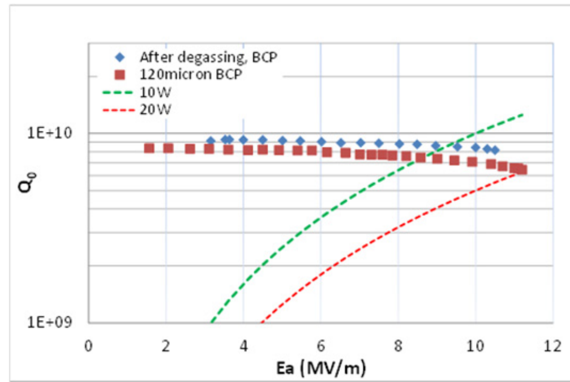

Figure 1: EACA:CAV2 performance in vertical test.

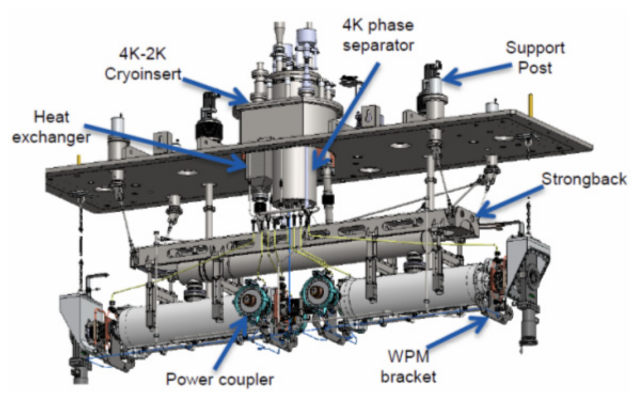

Figure 2: EACA cold mass, strong back and 4K-2K insert suspended from cryomodule top plate.

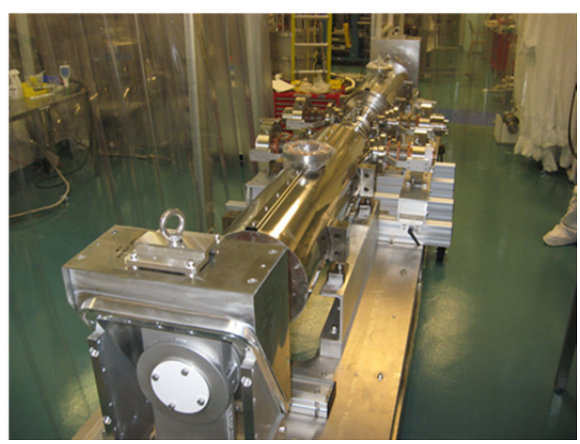

Figure 3: EACA cold mass assembly in the clean room.

Power Coupler Assembly

The CPI-produced fundamental power coupler [5] developed with Cornell for the ERL Injector Cryomodule is rated for use up to 65 kW cw. The design is typified by variable coupling in the range from Qext = 5-6×105, two cylindrical windows, one warm and one operating near

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the 80 K intercept, a 60 Ohm coaxial line in the cold section, and a shaped antenna tip for stronger coupling.

The e-linac adopts two CPI couplers per cavity delivering 100 kW of beam loaded rf power. The two EACA cavities together lead to a cluster of four couplers (see Fig. 4) passing through the isolation vacuum (and intercepted at 80 K) and mated to cavity end groups which are oriented back to back in the middle of the cryomodule.

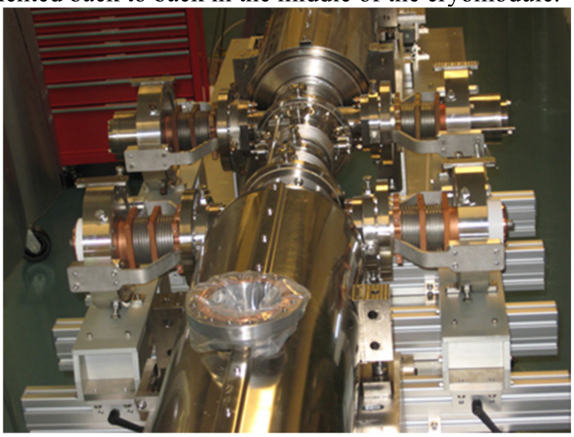

Figure 4: Attachment of the four FPC cold parts (4K).

HIGH POWER RF

The requirements and design of the e-linac HPRF are described at length in Refs. [6,7]. Two CPI 290 kW cw 1.3 GHz klystrons, each powered from an Ampegon 600 kW 65 kV DC supply form the heart of the system. Each cryomodule (EINJ & EACA) is driven by one rf power source. The EACA rf power feed is split to drive each of the cavities equally. A further splitting is required to feed each of the power couplers, while a motorized phase shifter achieves the proper phase. Thus, the rf distribution, shown in Fig. 5, terminates in a base unit comprised of 1 cavity, 2 input couplers, 1 phase shifter and a hybrid that splits power between the couplers.

There is one LLRF system used for each cryomodule. For EACA, the control includes a vector sum compensation of voltage and phase drifts.

Power Splitting

A variable power divider is used for EACA to vary the power delivered to each of the two accelerating cavities for the purpose of rf conditioning the cavities individually. During normal operation of the EACA, the variable power divider is set to equal power output.

Constant phase shift between input and output ports is not needed for rf conditioning of the cavities; so, a variable divider without constant phase shift was chosen. The device [6] consists of three hybrid couplers, one sliding short and a dummy load on the remaining port.

The attenuation of the variable divider versus DC control voltage is non-linear (see Fig. 6), whereas the phase varition is linear throughout the range of the attenuation and is 72.5 degree /volt. This phase shift is compensated

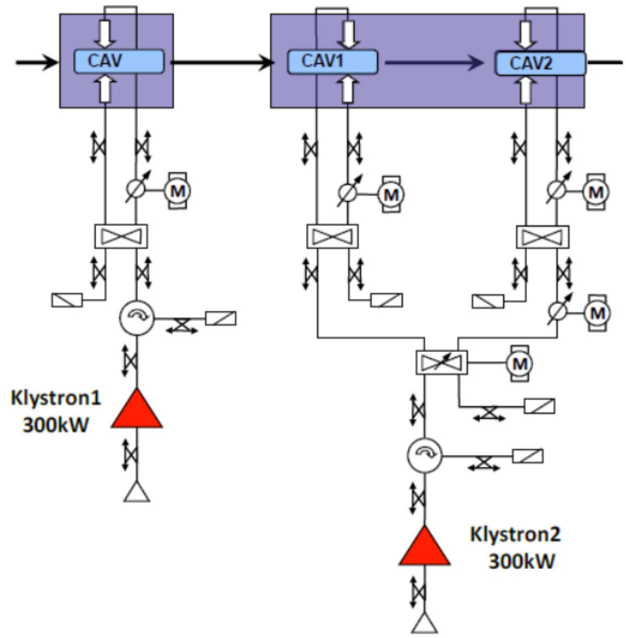

Figure 5: HPRF distribution system for e-linac.

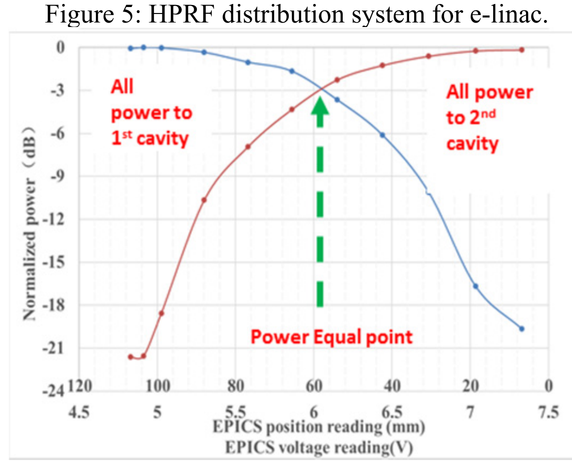

Figure 6: Test or rf power splitting between cavities.

by the motor controlled phase shifter (Fig. 7) located after the variable power divider (see Fig. 5).

Phase Adjustment

The phase shifters have to accommodate the overall phase shift (through waveguides) between the HPRF source and the cavity; and balance the phase shifts between the final hybrid and the two input couplers feeding the cavity. Hybrid-coupler-based (rather than 2- or 3-stub) phase shifters were chosen because they provide excellent phase shift characteristic [8,9] and use only one motor controlled stub. The phase shift is 22.5 degrees for 10 mm travel of the waveguide short.

The phase balance for EACA is further complicated since two cavities are driven by a single rf generator. An additional motorized phase shifter (see Fig. 7) cancels the phase shift through the divider and the phase advance

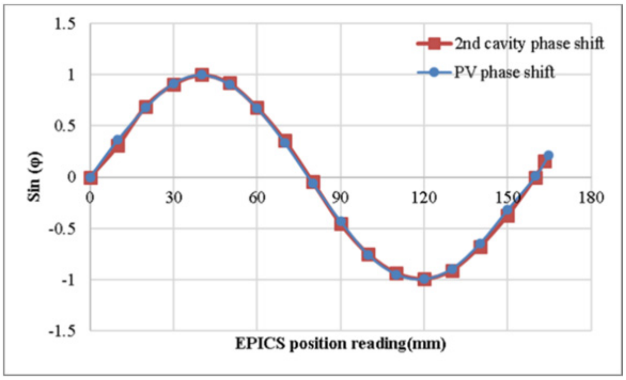

Figure 7: Test of hybrid-type phase shifter.

between the two 9-cell cavities; due to its upstream location, the power handling is 150 kW cw with water flow at 5 litre/min.

CAVITY CONTROL

The two EACA cavities are driven by one power amplifier, and the field control loops are common to both cavities. The LLRF system will be operated with a combination of self-excited mode (SEM) and generator driven mode (GDM), depending on experience from phases of operation. SEM has the advantage that frequency seeking is not required. The "turn on" method is to set up the cavities individually, using the power divider. Power is first sent to the first cavity. The SEM is used to establish the π-mode and the tuner is used to reach the operating frequency and to establish phase lock; and then the tuner is fixed in position. Power is then diverted to the second cavity, leading to phase lock and frequency tuner locked. The LLRF is then switched to GDM and the power equalized between the cavities. Each cavity loop is tuned to establish the optimum phasing based on the individual pick-up signals. Each cavity can be tuned individually, so the two resonance control loops are separate. Automatic tuning is done by comparing the phases in each circuit.

I/Q modulation/demodulation is used in SEM and GDM, so the loop phases for each cavity must be kept to a multiple of 2π, irrespective of the actual phase between the cavities. Furthermore, they could be running at different gradients based on cavity performance. Thus, an additional attenuator and phase shifter is added to the second cavity feedback path before the two feedback paths are vector summed to form one feedback for the LLRF control. The actual phase relationship between the two cavities is determined in GDM from beam acceleration and optimized iteratively by adjustment of the phase shifter in the second cavity transmission line with compensation via the LLRF loop phase adjustment.

CAVITY POWER BALANCING

Data anticipated by 2017 May 31.

CAVITY PHASE BALANCING

Data anticipated by 2017 May 31.

OPTICAL TUNES TO 30 MeV

The e-linac has a gridded electron gun, operating at 300 keV, which injects into the 10 MeV EINJ via a solenoid focusing channel. Due to the low energy, there is significant rf focusing at the entrance to the first cell of the EINJ cavity. Quadrupole magnet focusing channels transport the beam from EINJ to the EACA, and afterward through a momentum analysis beam line to a low power beam dump. The relation between magnet excitation current and integrated strength is known for all elements. Optimized element strengths and beam envelopes shown in Fig. 8 for 30 MeV are determined using the TRANSOPTR code, which has proven very reliable [10, 11].

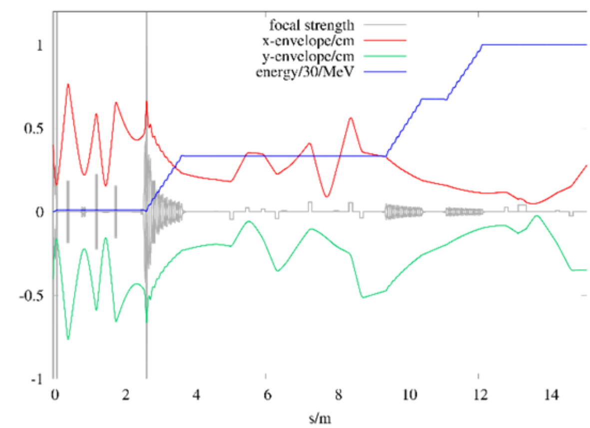

Figure 8: Beam envelope and energy, and optics focusing strength (H,V shown +ve,-ve respectively), for 30 MeV.

CONCLUSION

We have reported rf power and phase balancing results for the TRIUMF e-linac cryomodule containing two 9-cell SRF cavities driven from a single klystron rf source. The next step will be to accelerate electron beam to 30 MeV. It is anticipated this will be reported [12] in the coming months.

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