RF CAVITY PERFORMANCE AND RF INFRASTRUCTURE FOR THE ISAC-II SUPERCONDUCTING LINAC

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Abstract

The ISAC-II superconducting linac is presently being commissioned. Twenty cavities have been prepared and characterized in single cavity tests before mounting in the on-line cryomodules. The cavities are specified to operate at a challenging peak surface field of 30 MV/m to supply an accelerating voltage of 1.1 MV/cavity. An overview of the rf systems will be given. We will describe the early operating experience and compare the cavity on-line performance with the single cavity characterizations.

INTRODUCTION

TRIUMF has installed a new heavy ion superconducting linac as an extension to the ISAC facility [1], to add ∼20 MV of accelerating voltage to the existing room temperature linac capability of 1.5 MeV/u for ions with $A/q \leq 6$. The superconducting linac is composed of twenty bulk niobium, quarter wave, rf cavities, for acceleration, and superconducting solenoids, for periodic transverse focussing, housed in five cryomodules. The first eight have a design velocity of $\beta_o = 5.7\%$ while the remaining twelve have a design velocity of $\beta_o = 7.1\%$(Fig. 1).

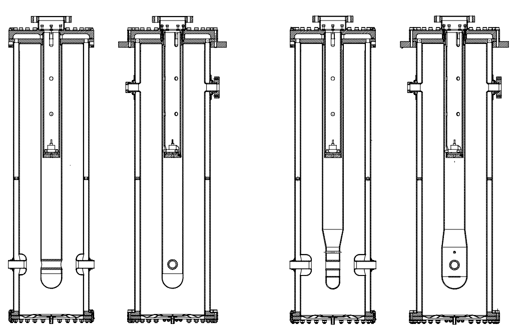

Figure 1: The two medium beta quarter wave cavities for the ISAC-II linac.

The ISAC-II medium beta cavity design goal is to operate up to 6 MV/m across an 18 cm effective length with $P_{cav} \leq 7$ W. The gradient corresponds to an acceleration voltage of 1.1 MV, a challenging peak surface field of $E_p = 30$ MV/m and a stored energy of $U_o = 3.2$ J and is a significant increase over other operating heavy ion facilities.

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RF SYSTEMS

The large stored energy requires an rf system capable of achieving stable performance. To achieve stable phase and amplitude control the cavity natural bandwidth of ±0.1 Hz is broadened by overcoupling to accomodate detuning by microphonic noise. The required forward power on resonance is given by $P_f(W) \simeq \pi U_o \Delta f_{\frac{1}{2}}$ for overcoupled systems. The chosen tuning bandwidth of ±20 Hz demands a cw forward power of ∼200 W and peak power capability of ∼400 W to be delivered to the coupling loop.

RF Controls

The RF Control system [2] for the superconducting cavities is a hybrid analogue/digital design based on self-excited phase-locking mode of operation. Homodyne detection is used as the amplitude detector while a high speed Field Programmable Gate Array is used for the two phase detectors. The FPGA also contains two 32-bit frequency counters for cold tuner alignment. Amplitude and phase regulating loops are controlled by embedded digital signal processors, while slow tuner loop, power-up sequencing control, supervisory control and an EPICS IOC are provided by an Intel-based PC. A total of twenty individual systems are housed within five VXI mainframes.

LN2 Cooled Coupling Loop

Starting with a design from INFN-Legnaro a new LN2 cooled coupler has been developed[3] that reduces the helium load to less than 0.5 W at the design gradient of 6 MV/m and $P_f = 200$ W. The coupler has a stainless steel body for thermal isolation and a copper outer conductor and rf feed line cooled with LN2. Cooling of the inner conductor is achieved by adopting a thermally conducting Aluminum Nitride dielectric localized in the coupling loop. Thermal radiation from the uncooled rf drive cable is intercepted by an LN2 cooled copper tube.

Mechanical Tuner

The tuning plate is actuated by a vertically mounted permanent magnet linear servo motor, at the top of the cryostat, using a ‘zero backlash’ lever and push rod configuration (Fig. 2) through a bellows feed-through[4]. The system resolution at the tuner plate center is $\sim 0.055\mu$m (0.3 Hz). The tuning plate is radially slotted and formed with an ‘oil can’ undulation to increase the flexibility. The demonstrated dynamic and coarse range of the tuner are ±4 kHz and 33 kHz respectively. The demonstrated mechanical response bandwidth is 30 Hz. Amplitude and phase regulation can be maintained for eigen-frequency changes of up to 60 Hz/sec.

Figure 2: Photo of tuning plate and tuning lever mechanism.

LINAC INSTALLATIONS

The controllers and supplies to service the linac cryomodules are installed in the power supply room adjacent to the ISAC-II accelerator vault on the second floor. The arrangements of the equipment racks are modular with one row, consisting of seven racks servicing one cryomodule. Hence five rows, one for each cryomodule, and a total of thirty-five racks are utilized for the medium beta section of the accelerator.

A BOP (break out panel), housing the EPICS controls interface, is installed at the end of each row. The ISAC-II controls VME crate and beam diagnostics exist in single racks not linked to a particular cryomodule. The cables from the racks to the cryomodules go through 'chase' openings at the north wall of the power supply room at floor level. All cables are labeled and documented as part of the pre-commissioning Q/A initiative. Fig. 3 shows the modular layout of racks and the installed equipments for the medium beta linac. Another five rows of racks have been kept reserved for the high beta part of the linac due for installation in 2008.

Twenty air cooled rf amplifiers operating at 106 MHz and packaged two per rack were procured from Amplifier Systems Inc, USA. The amplifiers have been tested for amplitude and phase response to a full rated cw power of 800 Watts prior to installation in the power supply room. Site safety requires that the rf amplifiers are interlocked such that rf can not be turned on when the ISAC vault exclusion area is open.

CAVITY PERFORMANCE

Single Cavity Tests

All cavities are characterized via cold test in a single cavity test cryostat prior to mounting in the cryomodule. Some cavities received repeated tests depending on the initial performance. The cavities are first baked at $\sim 90\,^{\circ}$C

Figure 3: Installation of the service racks in the power supply room.

for 48 hours. LN2 is then fed to a bath side-shield and the cold mass is cooled by radiation for at least 48 hours to bring the average temperature to about 200K before helium transfer. Studies have shown that at least some of the cavities are prone to Q-disease and so the early standard practise of pre-cooling the cold-mass with LN2 has been abandoned[5].

Prior to installation all twenty cavities met or exceeded ISAC-II specifications for frequency and performance. At 7 W rf power the average peak surface field for the cavities is 38 MV/m and corresponds to a gradient of 7.6 MV/m and a voltage gain per cavity of 1.4 MV. Conversely the cavities would consume an average of 3.3 W to each produce the design peak surface field of 30 MV/m.

In Situ Cavity Tests

Linac cooldown is done sequentially, one cryomodule at a time, to achieve a cavity cooling rate of $\sim$100K/hour to mitigate the effects of Q-disease.[5] This requires a LHe flow of $\sim$100-150 ltr/hr.

On two of the cryomodule cold tests we have had problems with one or more cavities having an open connection on the rf feed. These open connections close after warming. The hypothesis is that the thermal contraction on the LN2 cooldown of the side shields and coupling loops is responsible for the open circuit. The procedure now is to regulate the LN2 flow to slow the cooldown rate. This has been sufficient to eliminate the problem to date.

The rf cavities are initially pulsed conditioned to optimize performance where required, and base Q values are recorded. Prior to acceleration the cavities are set to the power limit of 7 W per cavity at critical coupling. The coupler is then moved to a position requiring a forward power of $\sim$160 W for a coupling $\beta \sim 100$ that has been determined to provide sufficient rf bandwidth to maintain lock. The cavities are initially locked and left for twenty-four hours to test the operational stability and tuner perfomance.

The average cavity gradients for each cavity for three different beam accelerations as calculated from the acceleration rate are shown in Fig. 4. The average gradient is 7.2 MV/m corresponding to an average peak surface field of 36 MV/m and an average voltage gain of 1.3 MV/cavity. Single cavity rf test results for each cavity are plotted for comparison. The gradients in general match well the gradients from initial single cavity tests. A few cavities have obviously been contaminated during assembly, namely 8, 12, 14 and 20. Of these three appear in the downstream location in the module and so may be victem to a systematic contamination. Others, 1 and 19, have improved perhaps during the final assembly rinse or through repeated conditioning. A distribution of the cavity gradients at 7 W for

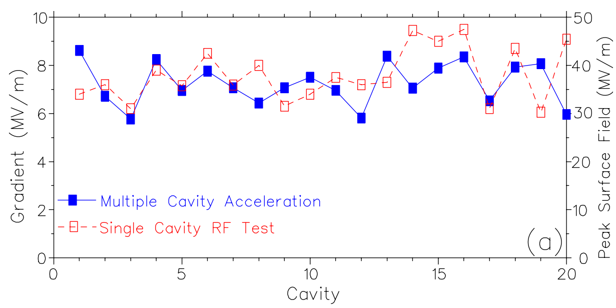

Figure 4: Average cavity gradients for the three A/q values and for 7 W cavity power. Results are inferred from the step energy gain per cavity during acceleration. Also shown are gradients from initial single cavity characterizations.

both the single cavity tests and the *in situ* tests are plotted in Fig. 5. The average operating gradient is down by only 5% from the single cavity result.

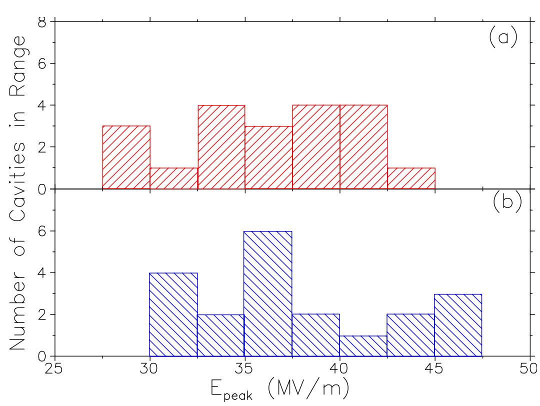

Figure 5: Distribution of cavity peak surface field for both the *in situ* cavities (a) and the single cavity tests (b).

Phase Noise Measurements

Any amplitude noise is suppressed by the low pass filter nature of the cavity response as well as the amplitude feedback controller in the LLRF. However phase noise is only suppressed by the phase feedback controller. Under this scheme phase noise is the dominant form of noise that affects beam stability.

Fig. 6 shows the phase noise of all the cavities under normal operating condition; i.e. high field gradient, amplitude and phase locked, and tuner loop closed. Note that most of the cavities have phase noise better than 0.2 degree rms. There are, however, three cavities in Cryomodule 2 (Cavities 5-8) that have phase noise that exceeds 0.4 degree rms, in particular Cavity 7, where the phase noise is more than 1 degree rms. Since this crymodule also has a cavity that has very stable phase performance, Cavity 8, it is improbable that the poor performance of the rest of the cavities is due to a mechanical problem within the cryomodule. We believe that the switching power supply in the driver amplifier is susceptible to RF interference. Future steps will involve stabilizing the power supplies.

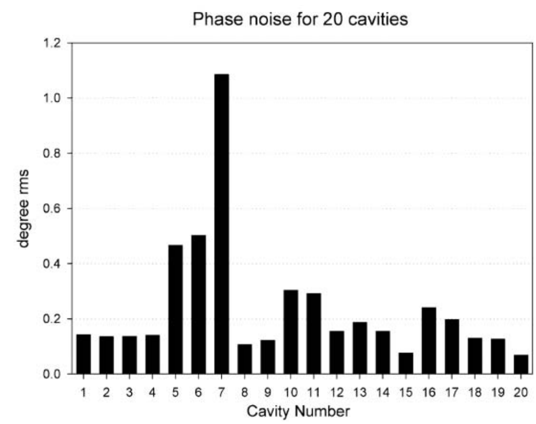

Figure 6: Phase noise measured for each cavity.

CONCLUSION

The performance of the *in situ* cavities at P_{cav}=7 W is down by only 5% from the measurements on single cavities during initial characterizations. The primary focus of rf investigations in the coming commissioning periods is to identify and reduce the phase error associated with some of the cavities to improve the overall beam stability and quality.

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