A NEW FAST TUNING SYSTEM FOR ATLAS INTENSITY UPGRADE CRYOMODULE

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Abstract

An upgrade project is underway at the ATLAS superconducting RF (SRF) heavy-ion linac at Argonne National Laboratory to dramatically increase the intensity of both stable beams and short-lived isotopes from the CARIBU fission source. The upgrade includes a new normal conducting RFQ injector and an SRF cryomodule consisting of seven high-performance 72.75 MHz quarter-wave cavities optimized for ions with velocity of 0.077c. The module will deliver more than 17.5 MV of accelerating potential over 5 meters and replace three existing split-ring cryomodules. Key to this performance will be a new cavity fast tuning system that replaces the voltage-controlled-reactance (VCX) fast tuner. The recently completed ATLAS upgrade cryomodule installed in June 2009 has a real estate gradient of 14.5 MV over 4.6 meters, the highest for any low-beta cryomodule, however, performance is 40% less than could be achieved without the VCX. As such, the VCX is being replaced with a high-power rf coupler and a fast piezoelectric-based tuner to be used together to control the cavity phase. Initial cold test results of a prototype power coupler and piezo-tuner are discussed here.

INTRODUCTION

Due to the intrinsically narrow bandwidth (~1 Hz or less) of SRF cavities, it is usually necessary to provide a means of correcting for microphonic- or vibration-induced frequency shifts to maintain a constant phase between cavities. In CW operation where the beam removes a large amount of power relative to losses into the cavity wall (Q_{loaded}<<Qo), the microphonic induced frequency shifts may be much smaller than the loaded cavity bandwidth and no additional compensation is necessary. For the majority of existing and proposed SRF linacs, the beam loading is relatively small. In this case, a solution is to position the rf power coupler so that Q_{EXT}~$Q_{LOADEDt}$<<Qo. Another is to match the coupler position to the required (modest) beam power and then rapidly adjust the rf power in the presence of microphonics. In both cases excess rf power is required and is eventually dumped into a load via an rf circulator. Another solution is to directly shift the cavity rf frequency to compensate for microphonics. The VCX tuner is one such device. Here an inductive coupling loop is rapidly cycled into and out of conduction switching the cavity frequency between two states. The relative duty cycle for the two states determines the average cavity frequency and phase. Yet, another solution is to induce a deformation in the cavity wall to cancel the effect of microphonics. This has the benefit of being

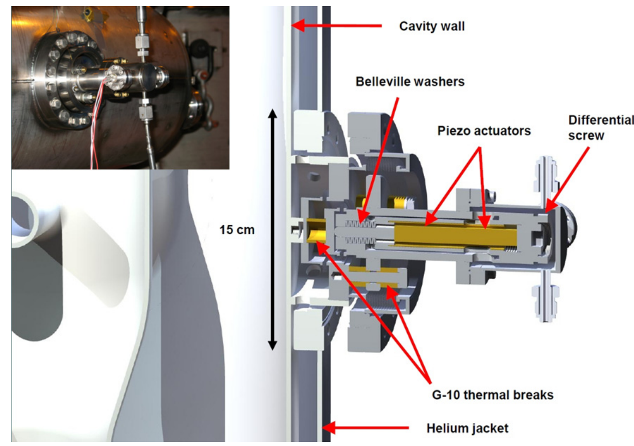

Figure 1: Prototype piezo-electric fast tuner.

insensitive to the cavity field level and stored energy. For the new ATLAS Intensity Upgrade project [1], ANL is using a combination of a fast piezoelectric based tuner (See Fig. 1) to move the cavity wall and a high-power coupler (see Fig. 2) in order to compensate for the frequency detuning from microphonics.

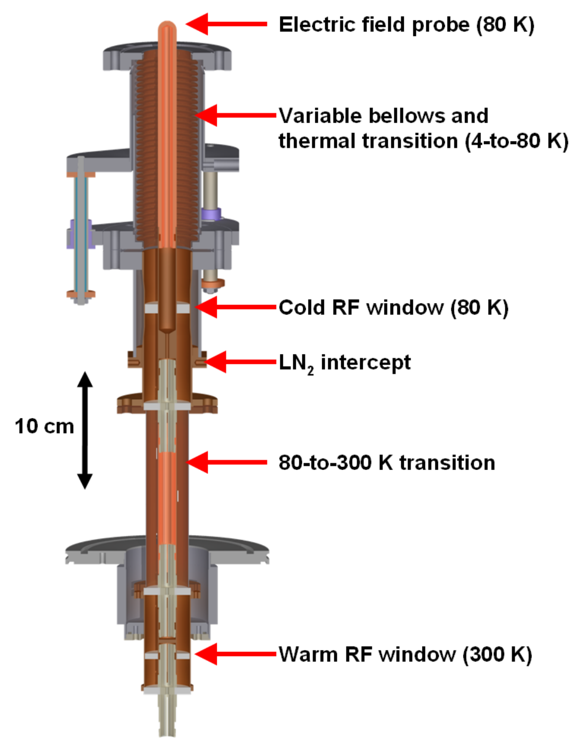

Figure 2: Variable coupler for 4 kW CW operation with a 72 MHz quarter-wave cavity.

DESIGN AND FABRICATION

Piezoelectric Fast Tuner

A fast mechanical tuner based a device such as a small piezo-electric transducer is attractive because it, in principle, provides a low cost (relative to rf power) and general solution to the problem of cavity microphonics compensation [2]. At Argonne, a tuner based on a pair of Noliac SCMAP09 stacks has been prototyped and mounted on a 170 MHz SC half-wave cavity for testing. The intended use is for the new β=0.077, 72.75 MHz quarter-wave cavities for the ATLAS Intensity Upgrade project.

The square stacks are loaded one on top of the other, as in Fig. 1. Each has dimensions of 10 mm by 10 mm by 40 mm long. Piezo-electric stacks require a preload for long-term operation. Here a constant 360 pound preload is provided by compressing 14 Belleville washers stacked in series each with a spring constant of 4×10^4 lb/inch.

The piezo transducer presses on a small niobium button electron-beam welded directly to the cavity wall and reacts against a 3 inch diameter niobium ring also welded to the cavity wall. In this way the cavity helium vessel is essentially removed from the tuner mechanical system. The 80 K piezoelectric stacks are directly cooled by liquid nitrogen and separated from the 4 K niobium by G-10 thermal breaks. Hysteresis curves were measured for each of the stacks at 80 K and room temperature and found to be similarly shaped, however, as expected at 80 K, the total stroke is reduced by about a factor of three to 0.0015 inches per stack. The required force to displace the cavity wall by this amount is typically much smaller (~100 N) than the 'blocking' force for the piezoelectric stacks of 4000 N so that force is not generally a critical parameter.

The problem of differential thermal contraction of the tuner components relative to the cavity wall during cool down has been overcome as follows; the stack is first adjusted by means of an integral precision differential screw (0.0013 inches per turn) at room temperature such that it presses 0.005 inches into the cavity wall. During cool down the position of the piezo-tuner shifts by only about 0.001 inches due to the strategic choice of materials with known ΔL/ΔT. Materials used in the fabrication of the tuner and the contribution to ΔL are shown in Fig. 3. The small overall shift on cool down of about 0.001 inches has been verified in direct measurements by cooling the tuner in a bench top vacuum chamber to 80 K.

The first measurement of the 4 Kelvin cavity frequency response to a sinusoidal drive signal of 0-200 V applied to one of the two piezoelectric stacks is shown in Fig. 4. The test was repeated for sweep times of up to 5 minutes. Each showed the 20 Hz peak-to-peak response to be linear with no resonances over the indicated frequency range from 0-50 Hz. Based on simulations the corresponding total frequency shift in the quarter-wave cavity is expected to be more than double that of the half-wave cavity.

It is noted that these tuner measurements with a 170 MHz half-wave cavity are for initial testing only. Detailed testing on a complete prototype 72 MHz quarter-wave cavity including a full transfer function will be performed when the prototype is available.

	Compression		
PART	OPERATING TEMP	LENGTH (INCH)	ΔL(inches)
MOUNTING RING (Nb)	4K	1.230	1.75E-03
CARTRIDGE GUIDE TUBE (INVAR-36)	80K	3.880	1.36E-03
WASHER STACK (G-10 NORMAL DIRECTION)	4K	0.313	2.09E-03
SHOULDER WASHER (G-10 FILL DIRECTION)	4K	0.125	3.11E-04
BELLOWS FLANGE (STAINLESS STEEL)	4K	0.250	7.43E-04
DIFFERENTIAL SCREW (SILICON BRONZE)	80k	0.110	3.84E-04
TOTAL			6.64E-03
	Decompression		
PART	OPERATING TEMP	LENGTH (INCH)	ΔL(inches)
PIEZO PLUNGER (INVAR-36)	80K	1.538	5.38E-04
SM. BELLOWS DISK (INVAR-36)	80K	0.213	7.44E-05
CYLINDER (G-10 FILL DIRECTION)	4K	0.500	1.25E-03
LG. BELLOWS DISK (INVAR-36)	4K	0.088	3.24E-05
BOSS (Nb)	4K	0.313	4.44E-04
PIEZO STACKS (PZT)	80K	3.150	2.96E-03
PIEZO THRUST PLATE (STAINLESS STEEL)	80K	0.125	3.51E-04
TOTAL			5.65E-03

Figure 3: Length changes in the piezoelectric tuner on cool down. The total effective change is 0.001 inches.

Coupler

Primary considerations in the design of a new coupler included the possibility to run with up to several kilowatts of rf power for frequencies between 72-350 MHz, compatibility with clean room assembly and the ability to vary the coupler position to allow for the possibility of operating under a variety of conditions.

The main components of a new prototype coupler

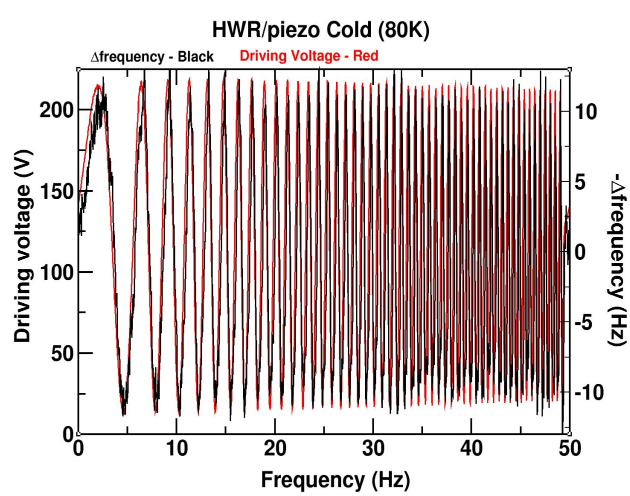

Figure 4: First measurement at 4 Kelvin of cavity frequency response to a piezoelectric tuner driving voltage.

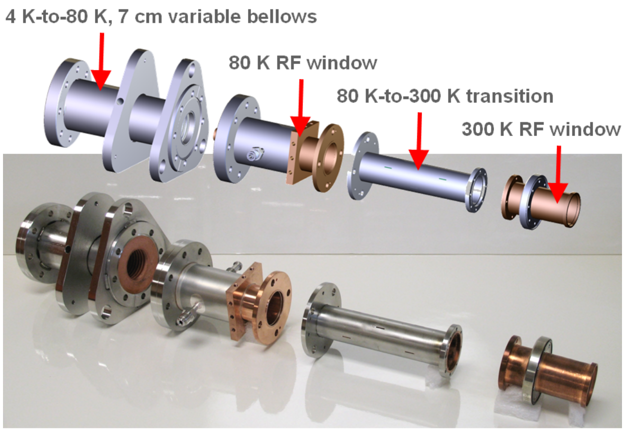

Figure 5: Primary coupler components fabricated for prototype testing.

shown in Figs. 1 and 5 are:

- A capacitive antenna terminating a 1-5/8 inch 50 ohm coaxial line (at 80 K) inserted into the SC cavity coupling port at 4 K.
- The physical connection between the 80 K antenna and the 4 K cavity is through a formed stainless-steel bellows with 1-5/8 inch ID and 3 inches of travel. The bellows is plated on the ID with 20 μm of copper.
- A cold rf and vacuum window consisting of a 96-97% alumina disc brazed to the inner and outer conductor
- A thin-walled stainless steel thermal transition plated on the ID with 20 μm of copper
- A warm rf and vacuum window similar in construction to the cold window.

The components shown in Fig. 5 have been fabricated from left to right by the following; Argonne Central Shops, Societe Des Ceramiques, CMG Precision Machining Co., and MPF Products. MPF has also produced two cold window assemblies to be tested shortly.

The anticipated rf power required for the ATLAS Intensity Upgrade (AIU) quarter-wave cavities is 4 kW

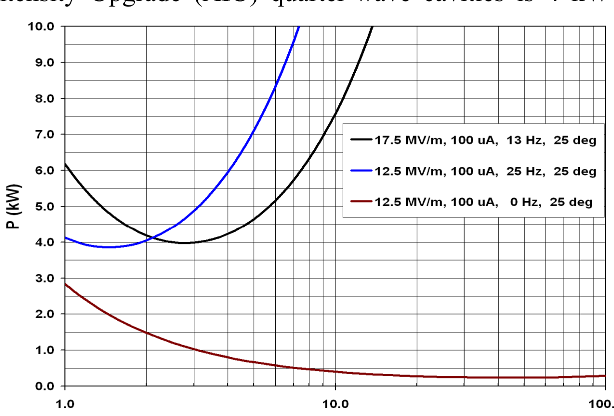

Figure 6: Required RF power versus coupling strength. The blue curve represents the nominal operation conditions.

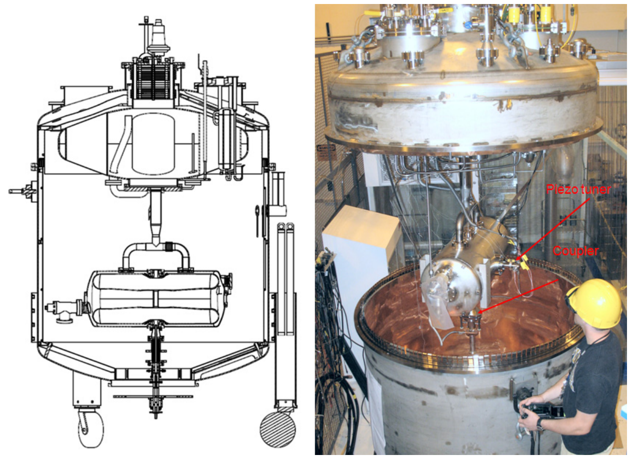

Figure 7: Coupler as mounted for initial testing with a 170 MHz half-wave cavity.

fully reflected in an overcoupled configuration. Curves in Fig. 6. shows forward power versus Qext for three sets of conditions. The blue curve represents the anticipated operating parameters for the AIU.

Initial measurements of heating were performed using the experimental test setup in Fig. 7. Silicon diodes were mounted at four different coupler locations and 1 kilowatt of RF power at 109 MHz was fully reflected and dissipated into a load via a circulator at the rf supply. At this power negligible heating was observed at the cavity flange, 80 K cold window, thermal transition and room temperature window. More realistic tests with 4 kW of rf power at 72 MHz together with a prototype quarter-wave cavity will be performed.

CONCLUSION

A 4 kW CW rf coupler designed to operate in full reflection and a fast piezoelectric-based tuner have been prototyped and are undergoing testing at Argonne for use with 72.75 MHz quarter-wave cavities for the ATLAS Intensity Upgrade Project. Initial tests of the coupler with up to 1 kW of rf power fully reflected show little or no heating on any of the basic components. The piezoelectric tuner performance in initial open-loop testing was also linear and without mechanical resonances up to at least 50 Hz.

ACKNOWLEDGEMENTS

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REFERENCES

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[2] S. Simrock, TUO09, Proc. of SRF 2003.