RF Coupler and Tuner Design for the Rare Isotope Accelerator Superconducting Cavities

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Abstract

The low-beta cavities proposed for the Rare Isotope Accelerator (RIA) driver linac require RF power couplers and both slow and fast tuning systems. This paper discusses several methods for tuning and phase stabilization, the use of passive vibration damping, and a variable power coupler suitable for the low beta cavities required for RIA. Because of the relatively small beam loading characteristic of the RIA accelerator, the loaded cavity bandwidth may be too narrow to accommodate microphonic-induced frequency noise, and a fast-tuning system is likely to be necessary to phase-stabilize the low-beta cavities. There are several possible choices of fast-tuning system. For cavities operating at and below 150 MHz, the variable reactance tuner which has been developed for the existing ATLAS accelerator has ample tuning range, is cost-effective, and has demonstrated high reliability over many millions of unit-hours of operation. We also discuss the design of a variable power coupler for CW operation at 20 kW, a prototype of which has successfully operated in tests with a 345 MHz double-spoke cavity.

RF Power Coupler

An RF power coupler suitable for the low to medium beta cavities does not presently exist. The RF power coupler should be capable of delivering 20kW CW power as determined by the beam loading power and the power for phase stabilization. It must also span a frequency range from 57 to 350 MHz. To achieve the high accelerating gradients required for RIA, it has been demonstrated that interior cavity cleanliness plays a large role. Therefore, any probe that is inserted into the cavity must be clean. This has led to a design that provides separate vacuum systems for the cavity interior and the cryostat insulating vacuum. The coupler should be adjustable from the cryostat exterior and provide thermal isolation from 80k to 4.5k.

A prototype coupler has been designed in collaboration with Porcellato (INFN Legnaro) to meet the required goals. (Figure 1.)

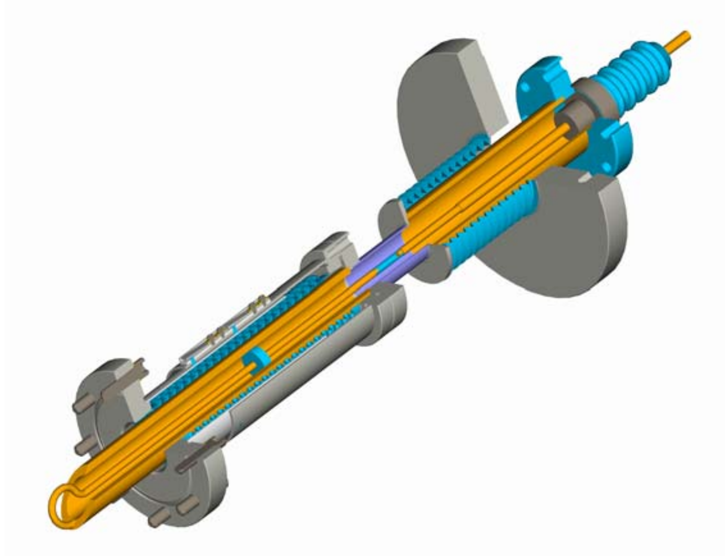

Figure 1 Prototype 20 kW RF coupling probe

The initial design has been tested on the ANL 350 MHZ two-cell-spoke cavity. It has operated at 7kW pulsed power with a 3 inch stroke and is adjustable via a stepping motor. This first version will be used to phase stabilize a double-spoke cavity operating under realistic conditions. An updated design is also under construction.

Slow Tuners

Several methods have been successfully employed to compensate for slow frequency drifts due to changes in the helium system pressure all based on a mechanical force to deform the cavity. Some include stepping motors and compression screws while others use a pneumatic system operated with helium gas and a bellows to compress the cavity wall. Also under development is a pre-loaded magneto-strictive tuner. [1]

Many of these existing methods should be applicable to RIA.

Phase Stabilization

Beam power for the low and medium beta RIA cavities will be on the order of 500 to 1500 watts resulting in beam-loaded cavity bandwidths of 50 to 250 Hz. Microphonic-induced frequency noise in many cases may exceed the beam-loaded bandwidth. Though phase stabilization is not a fundamental technical problem for drift-tube cavities, it will have a large impact on RF power requirements. Presently there are three methods available for phase stabilization. They are: over-coupling, electro-mechanical tuners and reactive tuners. (ATLAS) [2] Some combination of the methods will most likely be used for RIA.

Electro-mechanical tuners

Electro-mechanical tuners are attractive for the 345 (two-cell and three-cell spoke) and 172.5 MHz (half-wave) cavities since the intrinsic cavity mechanical modes lie relatively high in frequency (~500Hz).

Microphonics measurements on the ANL β=0.4 two-cell spoke cavity have been performed, many at high fields using a new "cavity resonance monitor" device developed in collaboration with JLAB. Tests on a cold two-cell spoke are the first ever on a multi-cell spoke geometry. The design is essentially a production model with an integral stainless steel housing to hold the liquid helium bath. [3] The results have shown that the first mechanical vibration frequency is about 500Hz. The total microphonic induced frequency noise is on the order of 2 to 5Hz rms. Developments to phase stabilize this cavity using a piezo-electric tuner are underway and is being performed in collaboration with Delayan (TJNAF), Simrock (DESY), and Rusnak (LLNL). Also Energen (Joshi), as part of an SBIR grant, will provide a magneto-restrictive tuner to ANL.

The overwhelming advantage of electro-mechanical tuners is that it is not affected by the stored energy of the cavity. There is no RF power dissipation in the electro-mechanical tuner.

Over-coupling

Increasing the cavity bandwidth by over-coupling the drive probe is also an option. The amount of RF power required for this method is determined by beam loading and the amplitude of the microphonic-induced noise. This second factor can only be tested in production cavities in a realistic accelerator environment. ANL measurements on the 350 MHz two-cell spoke cavity and experience with ATLAS 48.5 MHz cavities, (similar to the RIA 57.5 MHz class cavity) find reasonable tuning windows to be on the order of 100 to 200 Hz. Given these parameters, Table 1 shows the power requirements to phase stabilize by over-coupling.

			Over-coupling Tuning window					Fast Tuner	
Freq (MHz)	Beta	Emax	50 Hz	100 Hz	200 Hz	BmPWR	Bm/Win 50 Hz	ReactivePwr 200Hz	LN2 Dissap.
57.5	0.02	16	368	735	1471	431	58.56	5883	58.827
57.5	0.03	16	744	1487	2974	530	28.96	11897	118.97
57.5	0.06	20	1538	3075	6151	557	14.00	24602	246.02
115	0.15	20	2168	4337	8674	794	9.93	34696	346.96
172.5	0.26	20	5120	10240	20480	1052	4.21		
345	0.38	20	1615	3229	6459	1150	13.33		
805	0.47	27.5	6964	13927	27855	2161	3.09		
805	0.61	27.5	10670	21340	42681	3530	2.02		
805	0.81	27.5	16636	33272	66544	5800	1.29		
345	0.50	27.5	11366	22732	45463	3175	1.89		
345	0.63	27.5	15614	31228	62455	3819	1.38		

Table 1 Shows the RF power required for the beam and tuning windows of 50, 100 and 200 Hz and for the low-beta cavities the real dissipated power using the variable reactance fast tuner to phase stabilize.

Mechanical Damping

For quarter-wave cavity designs, a passive damping device, developed by Facco (INFN Legnaro) [4], will certainly be installed to reduce the amount of mechanical vibration. This reduction will proportionately lower the amount of RF Power needed to phase stabilize the cavity. At ANL a modified design of the vibration damper was installed in three low beta cavities. The results are shown in figure 2.

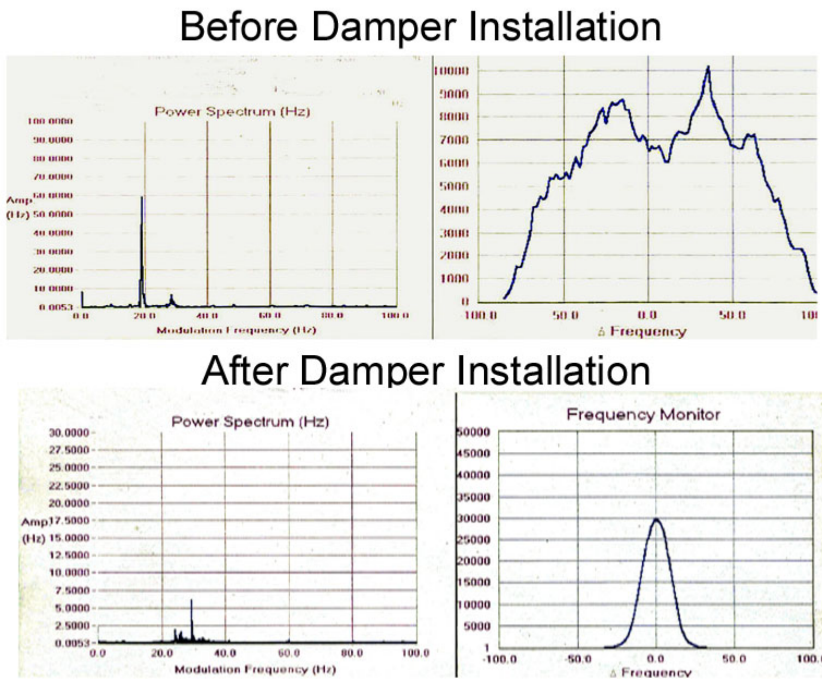

Figure 2 is observed after installation of a vibration damper. The microphonic noise level has been reduced by a factor of five.

Reactive Tuner

A fast tuner based on 80k PIN diode switching technology is in use at ATLAS. It has been used to phase stabilize cavities at ATLAS from 48 to 150 MHz. This technology is directly transferable to the RIA cavities from 57.5 MHz to 115 MHz**.** The present fast tuner design has successfully switched 35kVAR. To have an equivalent control capability using an over- coupled system would require approximately a 9 kW RF source.

The fast tuner in its present state has been proven at ATLAS with more than 1.3 million integrated resonator beam available hours of operation over the past seven years. Complete statistics show that over that same time period there have been only a total of 84 hours of lost time due to the fast tuner system. The system was fully functional 99.8% of the time on every ATLAS cavity for schedule beam runs.

The majority of the power to operate the fast tuner is dissipated into liquid nitrogen. For typical tuning windows of about 200 Hz, about 1% of the Pk-to-Pk reactive power is dissipated into LN2 and approximately 2 watts of power from the fast tuners is dissipated into the helium system.

Freq (MHz)	Beta	Emax	Fast Tuner Reactive Pk-Pk Pwr 200Hz	Real Pwr into LN2 (W)	Beam Power
57.5	0.02	16	9192	92	431
57.5	0.03	16	18589	186	531
57.5	0.06	20	24602	246	557
115	0.15	20	34696	347	794

The cost of the entire system fast tuner system is listed below.

80k Mechanical Unit	**$2.7k**
Electronic Units	
Pulser	$2.2k
Power supplies	$0.630k
RF control section	$1.25k
Assembly Cost	$0.90k
Total	**$7.68k**
LN2 Operating Cost	**$0.19 / cavity hr.**

Conclusion

Realistic tests on final form RIA cavities are necessary to get real data on microphonics and to make cost effective system design choices. The next prototype RF couple is in progress at ANL and tests will be done upon its completion. Present slow tuning technology is transferable to RIA. Also there is a choice of several methods for phase stabilizing cavities. The most appropriate method needs to be determined for each class of cavity.

Development on electro-mechanical fast tuners is underway.

For the RIA low-beta cavities, the PIN diode reactive fast tuner is a proven, highly reliable system, and is certainly one good option for fast tuning.

References:

[1] C. Joshi et al, Particle Accelerator Conference, (2003) May 12 -16

[2] N. Added et al, Proc. of the 16th International Linear Accelerator Conference (1992)

[3] M. P. Kelly et al, Particle Accelerator Conference, (2003) May 12 -16

[4} A. Facco et al, 9th Workshop on RF Superconductivity (1999) Vol. 1 pp 309-311