PHASE CONTROL TESTING OF TWO SUPERCONDUCTING CRAB CAVITIES IN A VERTICAL CRYOSTAT

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Abstract

The ILC crab cavities require very tight phase control in order to achieve the desired luminosity increase at the interaction point. In order to test the performance of the phase control system designed to lock the cavities, two single-cell superconducting cavities were built and tested in a liquid helium cryostat. The preparation of the cavities, and design of the cryostat support structure are detailed in this paper, as is the performance of the phase control system.

EXPERIMENTAL SET-UP

The experimental set-up was described in a previous report [1]. Briefly, it consists of a magnetically shielded vertical helium vessel containing both cavities. A Labview interface allows us to monitor and log temperature, helium level and gas flows. A pump allows us to cool the system to 2K when required.

Cavities

The cavities used are single-cell 3.9GHz superconducting dipole mode cavities, manufactured by Niowave Inc. Coupling into the cavities is done by antennae penetrating through the beam-pipes. Two cavities were used, designated C1 and C3.

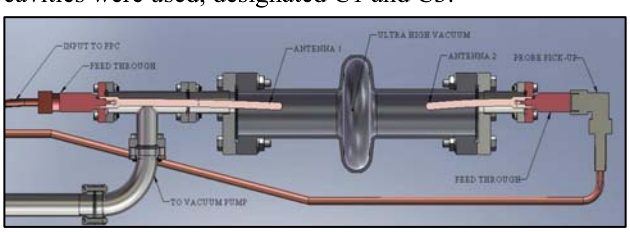

Figure 1: Cavity and coupler configuration.

The coupler lengths were determined by simulation and improved after taking transmission parameter measurements. The coupling factors were fine-tuned by careful adjustment of the flanges in the cleanroom in order to achieve the desired external Q values. This operation was quite time-consuming due to the sensitivity of the relationship between the position and the coupling.

Frequency Tuning

The cavity frequencies were pre-tuned by stretching them in a purpose built rig. The target warm frequency was 3.8941GHz, which was chosen to account for the frequency shift that occurs due to vacuum and operation at 4K. The desired cold frequency was 3.9003GHz, which gives some margin for the cold tuners to operate.

Figure 2: Cavity in its tuning jig.

Early measurements emphasised the need to carefully control the frequencies of the cavities during measurements. As such, the design was improved upon subsequently to the initial tests. The tuners can only compress the cavity (thereby shifting the dipole mode frequency downwards), and care must be taken during the experiment not to exceed the elastic limit of the cavities to avoid any plastic deformation beyond the operating frequency of 3.9GHz. The tuners were designed to apply up to 2000N of force on the load-cells, which allow a frequency shift of up to 10MHz and a fine-tuning accuracy down to 10Hz by the addition of grams of weight on the lever arms. Once the correct frequency was found, it was stable over extended periods of time.

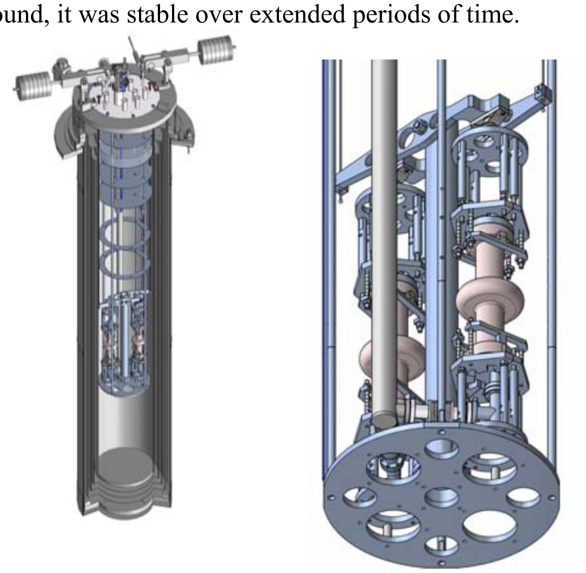

Figure 3: View of the cells in the cryostat and detail of the cavities, tuner arms and load-cells.

Table 1: Cavity parameters for C1 and C3

	C1	C3
Frequency, warm (GHz)	3.894125	3.89425
Qe input, warm	3.91 x10^6	7.83 x10^6
Qe output, warm	3.59 x10^7	5.94 x10^7
Frequency, 4.2K (GHz)	3.9	3.9
Qe input, 4.2K	4.14 x10^6	5.33 x10^6
Qe output, 4.2K	1.94 x10^8	1.88 x10^8

Cryogenics

The cryostat used for the experiment can be pumped down in order to bring the interior temperature to 2K. Thermocouples mounted on the cavity equator allow us to monitor the temperature at all times.

The vertical test can currently be shielded from three sides only, which limited the maximum cavity gradient to 2MV/m in order to preclude the risk of radiation escaping the cryostat. In the future we plan to relocate and expand the test facility, and place the cryostat into a pit, which will allow high power operation.

PHASE CONTROL RESULTS

Noise Reduction

One major challenge of the phase control system was to remove sources of noise in the electronics and the environment.

Microphonics in the cavity environment were a problem in the earlier tests, and were caused by such things as the vacuum pump being located on the cryostat's platform, as well as a pump in a nearby room that transmitted its microphonics through the building's beams. Careful surveys of the sources of vibrations have allowed us to isolate and minimise them where it was feasible. Additionally, later tests allowed much finer control over the cavity frequencies through improved tuner designs.

Figure 4: View of the cryostat and diagnostics.

The phase control system's incompressible noise floor was 70 milli-degrees r.m.s. due to the four phase detectors and the most significant contributor that could not be improved on with the available equipment was the reference oscillator. Our best results were taken with a Rhode and Schwarz signal generator.

Locking a Single Cavity

Phase jitter could be inferred from direct measurements with respect to the source using frequency dividers and a digital phase detector, or by examining the spectral output. The phase detector was calibrated by splitting a signal from the signal generator, shifting one leg with a calibrated manual phase shift and comparing the phases of the two legs in the phase detector after division of each. Calibration was dependent on the gain of the differential amplifiers used with the digital phase detectors. In this instance the calibration gave 7.5 mV per degree.

Measuring the phase jitter between the cavity and the source for the unlocked cavity and with a bandwidth of 500 kHz gave a peak to peak signal output of 225 mV corresponding to 30º peak to peak which is about 10º r.m.s.

When the cavity was locked the peak to peak noise was better than 3 mV on the same bandwidth. This implies a peak to peak jitter of 400 milli-degrees peak to peak or 140 millidegrees r.m.s.. This jitter includes source noise, ADC noise and some oscilloscope noise.

The source noise was measured to typically be 140 milli-degrees r.m.s. hence all we can say is that the locking performance was substantially better than that.

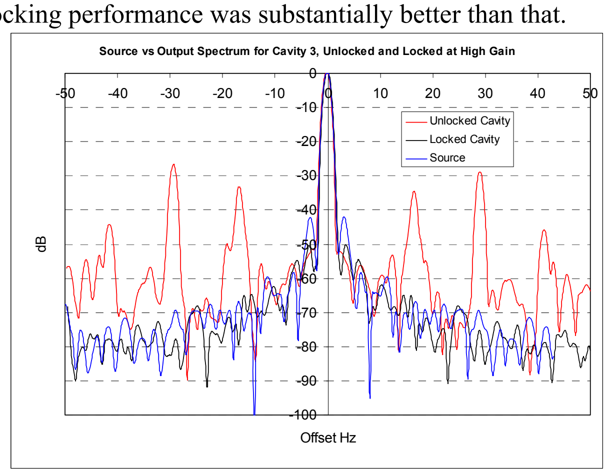

Figure 5: Source spectrum compared to the locked and unlocked spectra at high DSP gain.

Locking Both Cavities

The target phase control performance at 3.9 GHz was 120 milli-degrees r.m.s. Having demonstrated lock with each of the cavities separately it was necessary to bring them to the same natural frequency to lock them.

A double-balanced mixer comparing the cavity output signals was used to verify the quality of the lock. During the November test, the mixer was inserted into the cryostat in order to minimize the cable length between the mixer and the cavities. This however required keeping the mixer warm enough to avoid damage. For the latest test, that occurred late April 2009, it was decided not to have the mixer inside the cryostat in order to reduce the thermal load and negate the risk of components getting damaged in the event of a heater malfunction.

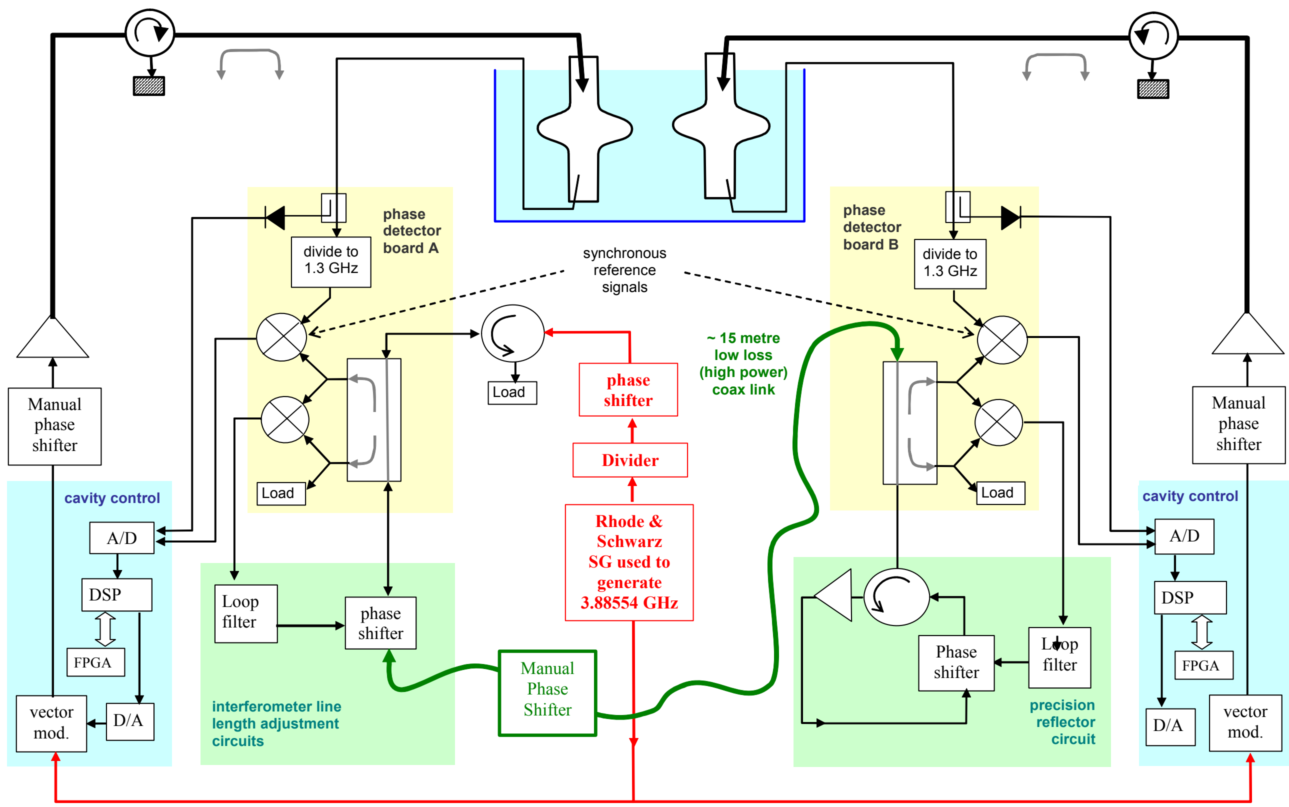

Figure 6: Schematic of the phase control system used for the vertical tests.

The performance of the control system can be seen in Figure 7.

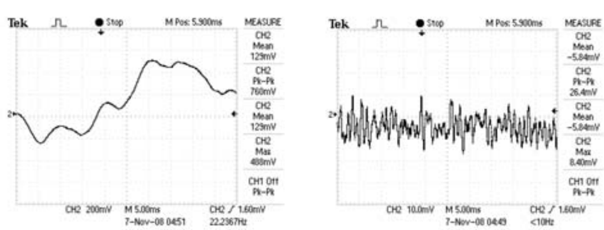

Figure 7: Phase jitter between C1 and C3 (unlocked, left, and locked, right), 1mV = 20 millidegree phase difference.

In order to verify the effectiveness of the control system at specific frequencies, a speaker was placed in contact with the cryostat walls and powered by a signal generator. The performance of the control system was found to be satisfactory at the studied ranges.

Further analysis of the results is ongoing and will be presented in a forthcoming publication.

CONCLUSION

The vertical cryostat facility allowed us to carry out low power tests on two superconducting cavities. Continual improvements to the tuning system and noise environment allowed us to achieve good conditions for the low level RF tests.

The tests allowed us to verify the performance of the phase control system on real cavities set with realistic values of the input and output external Q factors. The performance of the control system was shown to be able to meet the desired specifications.

The experience from this series of tests will also allow us to design the forthcoming improved high-power capable facility in the best conditions.

REFERENCES

[1] P. Corlett et al, A Superconducting RF Vertical Test Facility at Daresbury Laboratory, Proc. EPAC08, Genoa, 2008.

[2] A. Dexter et al, ILC Crab Cavity Phase Control System Development and Synchronisation Testing in a Vertical Cryostat Facility, EuroTeV-Report-2008-073, Dec 2008.