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LCLS-II AVERAGE CURRENT MONITOR

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Abstract

The LCLS-II project at SLAC is a high power upgrade to the existing free electron laser facility. The LCLS-II Accelerator System will include a new 4 GeV continuous-wave superconducting linear accelerator in the first kilometer of the SLAC linear accelerator tunnel and supplements the existing low power pulsed linac [1]. Average Current Monitors (ACMs) are needed to protect against excessive beam power which might otherwise cause damage to the beam dumps [2]. The ACM units are pillbox-shaped, stainless steel RF cavities with two radial probe ports with couplers, one radial test port with a coupler, and a mechanism for mechanically fine tuning the cavity resonant frequency. The ACM RF cavities will be located at points of known or constrained beam energy and will monitor the beam current; a safety system will trip off the beam if the beam power exceeds the allowed value.

INTRODUCTION

The LCLS-II project at SLAC is a high power upgrade to the existing free electron laser facility that will include a new 4 GeV continuous-wave superconducting linear accelerator. Average Current Monitors (ACMs) are needed to protect against damage that might be caused by excessive beam power. The ACMs will be located at points of known or constrained beam energy; a safety system will trip off the beam if the measured currents exceeds the allowed value. The ACM require a resonant frequency of 1.3 GHz and ±1°C temperature stability. RF, thermal and structural analyses of the ACMs were performed in the development process for design optimization. A thermal management system was devised to allow for thermal frequency tuning and provide the required probe signal stability. Performance validation was provided by RF and thermal testing of the ACMs.

MECHANICAL DESIGN

The ACM unit (Fig. 1) is a pillbox-shaped stainless steel RF cavity with two beam ports and two flanges on the axis, two radial probe ports with couplers, one radial test port with a coupler, and four tuner inserts.

The ACM cavity is required to operate under vacuum at a temperature of 45 °C and required the design of a thermal insulation assembly to accommodate the temperature requirement. The mechanical design of the ACM cavities was performed taking these operating parameters into inconsideration.

The cavity structure is fabricated from 304 L stainless steel piece parts and copper tuner inserts. These parts are joined in a high temperature braze process using a copper-gold alloy. The cavity seal assembly features three feedthrus with RF coupling loops. The RF coupling loops are welded to feedthrus mounted on rotatable, 2 ¾ inch conflat flanges. By rotation of the feedthrus, the cavity RF parameter can be adjusted for the application. The vacuum joint between the cavity body and feedthrus is a bolted connection with the vacuum sealing being provided by OFE copper gaskets.

After the cavity has been brazed and the feedthrus have been installed, the unit is enclosed in the thermal management system (Fig. 2). There are four thermal insulation assemblies per cavity, each composed of an aluminum shell with a thin film heater attached to the interior surface and a rigid, low thermal conductivity, polyurethane foam insulation piece bonded to the exterior. The custom heaters wrap around the cavity end faces and were designed to be capable of providing 50 W of total power to allow for fast warm-up capability when paired with a PID temperature controller.

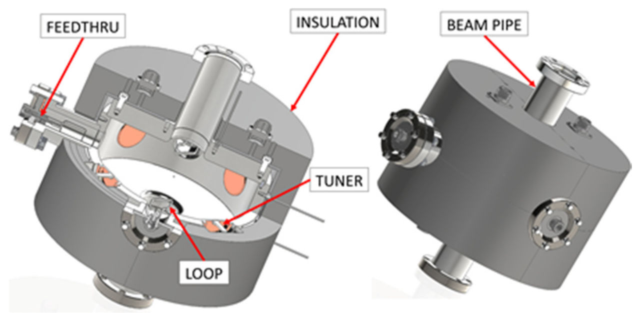

Figure 1: ACM cavity final assembly views.

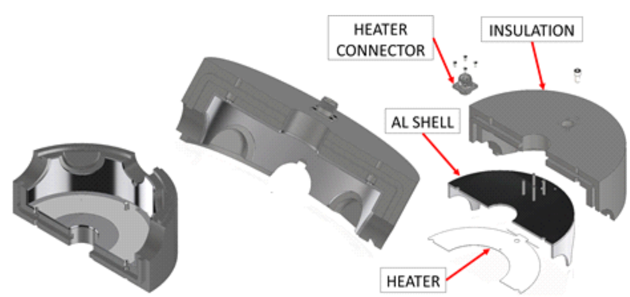

Figure 2: ACM thermal management system. The left and center views are assembled while the right is exploded.

THERMAL ANALYSIS

Extensive thermal modeling of steady state and transient operation was performed using the ANSYS Mechanical FEA simulation tool. Figure 3 shows the ANSYS model utilized in the thermal simulations which was a quarter of the full cavity geometry, utilizing the cavity mid-plane and

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the axial plane as planes of symmetry. The simulation included a fixed temperature boundary condition at the conflat flange end face, natural convection on the exterior of the insulation, the protruding beam pipes and connector, and thermal radiation losses from the exterior of the insulation.

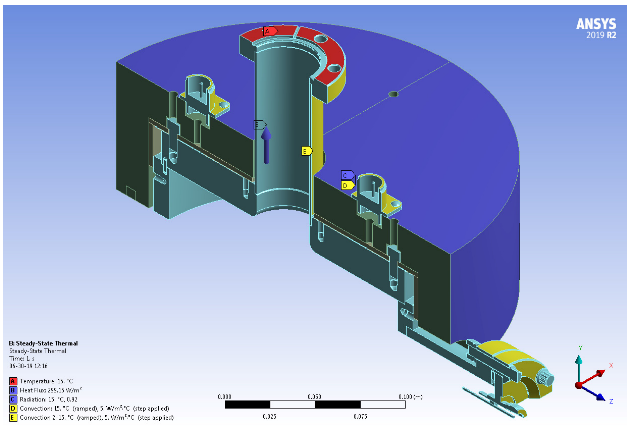

Figure 3: ANSYS Mechanical Cavity Thermal Model.

Due to the required operating temperature of 45 °C, steady state thermal analyses were performed to determine the required operating power of the cavity. Figure 4 shows the results of the steady state thermal analysis with 12 W of heater power applied to the cavity. With the 12 W of heater power, the vacuum wall of the cavity reaches the nominal temperature of 45 °C. Additionally, the temperature gradient over the interior cavity vacuum wall is less than 1.2 °C, showing the effectiveness of the insulation assemblies.

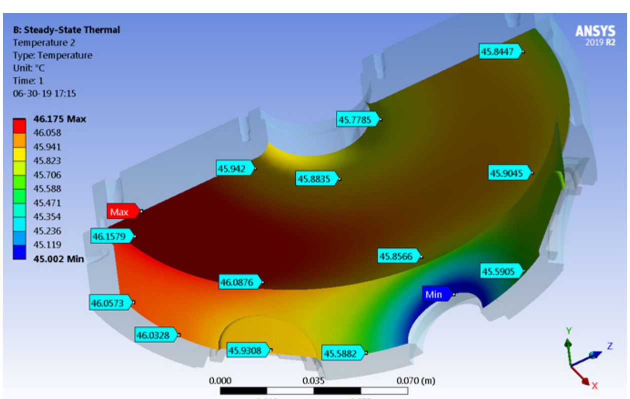

Figure 4: ANSYS Thermal Analysis Temperature Result.

STRUCTURAL ANALYSIS

Structural analyses of the cavity assembly were performed to ensure the frequency stability of the cavity during operation and to minimize frequency shift due to vacuum cycling. The thickness of the end flanges of the cavity were chosen so that the deflection is less than 2 microns under a vacuum to provide frequency stability over repeated vacuum cycles and to facilitate tuning of the cavity by minimizing frequency shift under vacuum conditions.

The cavity frequency change due to operating temperature thermal expansion is approximately 639 kHz. This frequency change is calculated by taking the average radial thermal expansion of cavity body (0.044 mm) as shown in Fig. 5 and calculating the corresponding frequency change in the cavity body. With an ambient temperature of 15 °C ($\Delta T = 30$ °C) a cavity thermal tuning rate 21.2 kHz/°C was predicted.

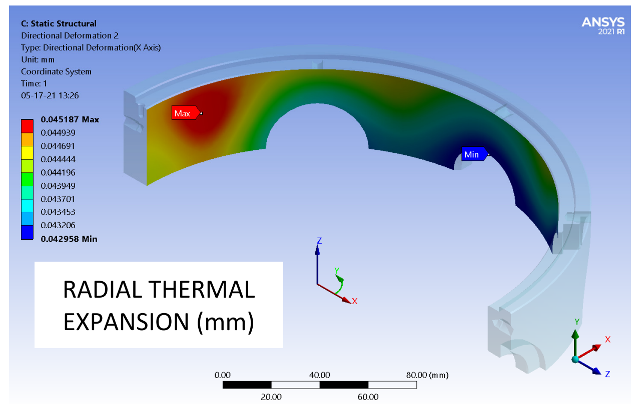

Figure 5: Radial Expansion at 45 °C.

Structural analysis of the cavity assembly showed only minimal deflections when the cavity assembly is mechanically loaded at the beam pipe ends. The maximum deflection of the vacuum wall for a 2,000 N transverse load on the beam pipe flanges is 4 microns as seen in Fig. 6. Such a small, localized, deflection would only result in minimal frequency shifts.

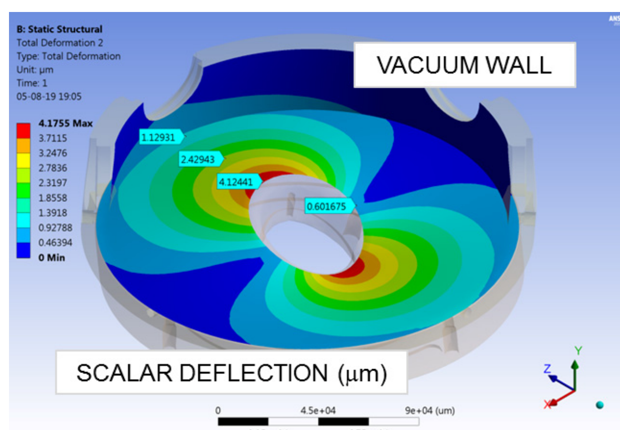

Figure 6: Deflection of vacuum wall due to transverse loading.

The frequency tuning range of each of the tuners built into the cavity was analyzed by simulating an applied force to the stud attached to the copper tuning insert [3]. The re-

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sults of this simulation, performed with different forces applied to the tuning stud, can be seen in the plots shown in Fig. 7.

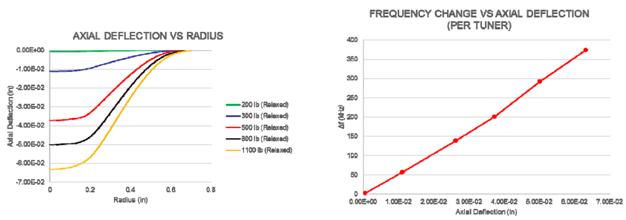

Figure 7: Axial deflection profiles of the tuner and frequency change vs axial deflection.

Based on these results, the expected tuning range of each tuner was found to be approximately ± 370 kHz. Additionally, the deflection of the tuners under vacuum was analyzed. The tuners were found to be insensitive to vacuum cycling with an expected frequency change under vacuum of less than 1 kHz.

RESULTS

To validate the thermal design of the ACM cavities, a 24 hour stability test was performed, measuring the temperature at various points on the cavity. The results can be seen in Fig. 8 and show that the cavity body was held at a stable temperature of approximately 45 °C for a period of 24 hours. Additionally, the fast heating capability of the heater design, combined with the PID controller, can be seen as the cavity heats up to the operating temperature in approximately 95 minutes. The cavity cools back to ambient temperature in roughly eight hours, demonstrating the thermal efficiency of the thermal management system.

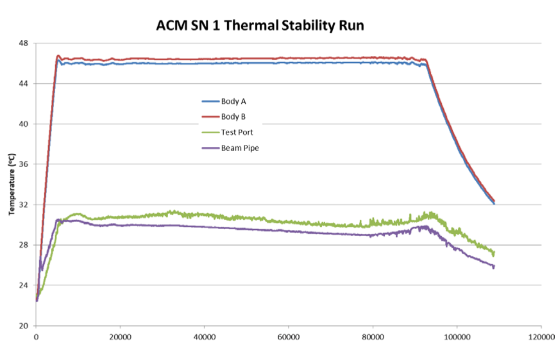

Figure 8: Thermal stability plots for ACM serial number one.

During the heating of each of the cavities, the frequency was measured at a number of temperatures to determine the thermal tuning rate. The measured cavity thermal tuning range for the five ACMs manufactured was found to be in the range of 23-24.4 kHz/°C as shown in Fig. 9 with an average thermal tuning rate of 23.3 kHz/°C. The slightly higher than predicted temperature tuning rate can be attributed to the simplified model used in the FEA thermal mechanical simulations, these did not include the effects of the coupling loops on the cavity frequency tuning rate.

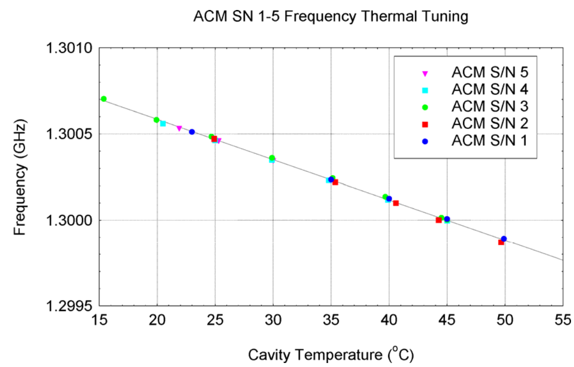

Figure 9: Thermal frequency tuning plot.

A network analyzer was utilized to take measurements of each of the ACM cavities. The parameters measured were: the frequency of the cavity, the Q parameter, and the coupling of the ports to the test port. Each of the cavities were also vacuum leak checked. Figure 10 shows a sample measurement taken from one probe port to the test port at operating temperature under vacuum. These results show that the ACM cavity was tuned to: a frequency of 1.3 GHz, a probe to test port coupling of -39.7 dB and a Q of 1282. These measurements were taken for each of the ACM cavities to verify that all met the required operating parameters. The value of probe coupling strength, β, was determined using the reflection type method [4]. Typical β values were 0.75 to 0.80 with a maximum probe coupling difference of less than 5%.

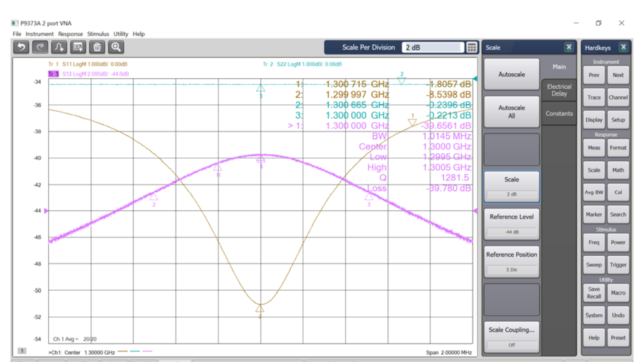

Figure 10: Sample network analyzer readings for ACM serial number three.

CONCLUSION

The ACM Unit was designed to allow for the measuring of the beam current of the LCLS-II Accelerator system. The mechanical design, supported by the use of thermal and structural analyses utilizing ANSYS Mechanical FEA software, provides an RF cavity that allows for the measurement of the beam current of the LCLS-II system while being robust through repeated vacuum cycles and maintains the required operating temperature. Subsequent tuning and testing of the completed units validated the design and manufacturing process of the ACM sensors.

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REFERENCES

[1] J. Welch *et al.*, "Average Current Monitor (ACM) Sensor," SLAC, Menlo Park, CA, Rep. LCLSII-2.4-SW-1284-R0, Feb. 2019

[2] J. Welch, "Average Current Monitor Beam Generated Signals," SLAC, Menlo Park, CA, Rep. LCLS-II-TN-19-01, Jan. 2019

[3] E. Jongewaard, "BCS Preliminary Design Review," SLAC, Menlo Park, CA, Rep. LCLSII-2.7-EN-1349-R0, Nov. 2018

[4] D. Kajfez, "Reflection-type Q factor measurement of transmission-type cavities," in *Proc. 2000 Asia-Pacific Microwave Conference*, Sydney, NSW, Australia, Dec. 2000, paper 00TH8522, pp. 449-452. doi:10.1109/APMC.2000.925855.