MECHANICAL AND THERMAL PROTOTYPE TESTING FOR A ROTATABLE COLLIMATOR FOR THE LHC PHASE II COLLIMATION UPGRADE*

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Abstract

The Phase II upgrade to the LHC collimation system calls for complementing the robust Phase I graphite collimators with high Z, low impedance Phase II collimators. The design for the collimation upgrade has not been finalized. One option is to use metallic rotatable collimators and testing of this design will be discussed here.

The Phase II collimators must be robust in various operating conditions and accident scenarios. A prototype collimator jaw has been tested for both mechanical and thermal compliance with the design goals. Thermal expansion bench-top tests are compared to ANSYS simulation results.

MECHANICAL DESIGN

Details of the overall mechanical design of the rotatable collimator are found in a different paper [1]. The most critical issue in the design of the collimator is the thermal deflection of the jaws due to beam heat load. A variety of materials were investigated to determine which had the appropriate thermal and Z properties to sufficiently absorb the beam, yet not rise above the melting or fatigue point of the material. Ultimately, copper was chosen as a balance between collimation efficiency, thermal deflection and manufacturability. Studies of the energy deposition along the collimator are presented at this conference by Lari [2]

Each jaw consists of a molybdenum shaft and concentric glidcop jaw joined only at the center via a glidcop hub as illustrated in figure 1. This layout was dubbed the jaw-hub-shaft concept. It allows the jaw ends to deflect mostly away from the beam, reducing the jaw deflection toward the beam to below 25 microns relative to the 7σ initial aperture.

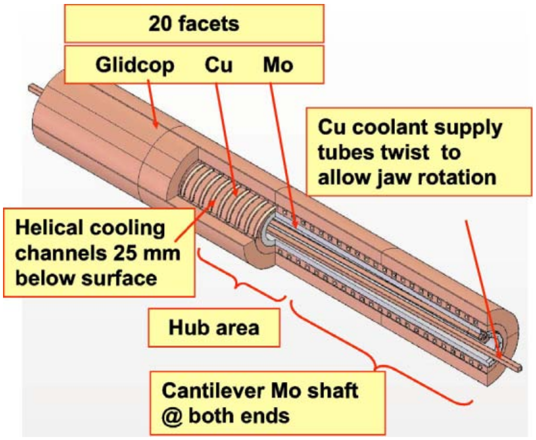

Figure 1: Cutaway of jaw showing outer jaw surfaces, cooling tube and inner moly shaft. The outer jaw is only supported by the moly shaft near the center in the “hub” area.

ANSYS SIMULATIONS

Extensive simulations were performed in FLUKA [3] and ANSYS [4] to simulate the realistic heating of the jaw due to the beam in both the steady state and transient beam conditions. A summary of those results is shown in table 1

Table 1: Jaw heating and deflection characteristics for Steady State (SS) and Transient (TR) beam conditions

Component	**SS**	**TR**	**units**
Max jaw temp	70.6	224	C
Max deflection toward beam	105	365	μ m
Surface sagitta	226	880	μ m
Effective length	0.67	0.33	m
Water temp rise	20.3		C
Water pressure drop	2.4		bar

According to these simulations, the collimator jaw will withstand the beam heating and still function within the specified tolerances. The ultimate test of performance is to place the collimator in an accelerator and test the collimation in real world conditions, however there would be no way to directly measure the jaw deflection. Bench-top measurements are therefore called for to test the ANSYS predictions for thermal deflections. Unfortunately, there is no way to accurately simulate the beam heating within the jaw without placing the jaw within the path of an actual high energy beam. A substitute must therefore be used. In our case, we chose to use two commercial 5 kW cartridge heaters embedded in the test jaw and illustrated in figures 2 and 3. This setup can approximate the expected steady state heat input of 11.5 kW. To directly compare the bench-top measurements, new ANSYS simulations were performed that accurately represented the heating due to the embedded heaters, accounting for material properties and points of contact between the heaters and the jaw surface. The heaters were embedded in a copper bar which in turn was placed within a slot cut into the jaw surface. Thermal paste was then used to make good thermal contact between the

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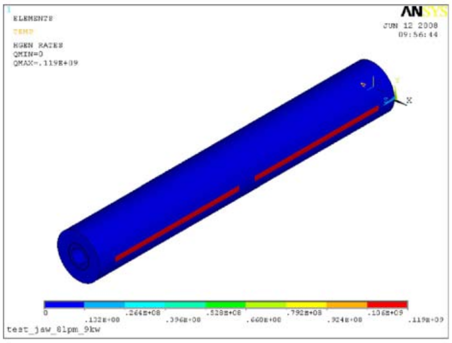

Figure 2: ANSYS output showing the location of the two cartridge heaters embedded in the jaw surface to simulate beam heating.

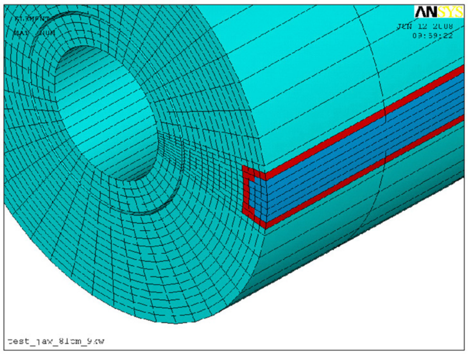

Figure 3: ANSYS output showing the heating rod embedded in a copper bar placed in a slot cut in the jaw surface using thermal paste for contact.

copper bar and jaw and all components were simulated in ANSYS. Water flow was simulated using the model shown in figure 4 which also shows the change in temperature of the water as it passes through the jaw. The overall experimental parameters as simulated in ANSYS, reflecting the real world experimental conditions, are given in table 2

Table 2: Jaw heating and cooling parameters as simulated in ANSYS.

Component	Value	units
Incoming water temp.	20	C
Outgoing water temp.	36.65	C
Water flow	8.3	l/m
water incoming pressure	170	psi
water outgoing pressure	19.5	psi
Heater 1 power	4500	kW
Heater 2 power	4500	kW

The two principal parameters to be measured are the sagitta, or curvature, along the jaw face and the temperature increase. The ANSYS simulation results are given in figure 5. The predicted sagitta is 100 microns.

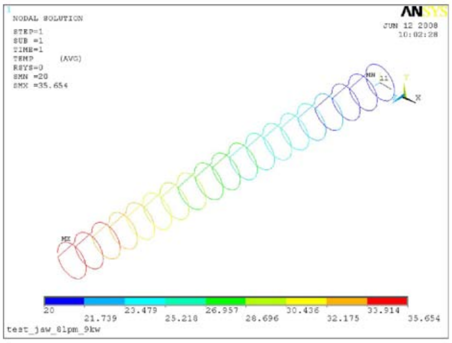

Figure 4: Jaw water flow simulated in the jaw showing water temperature change along jaw.

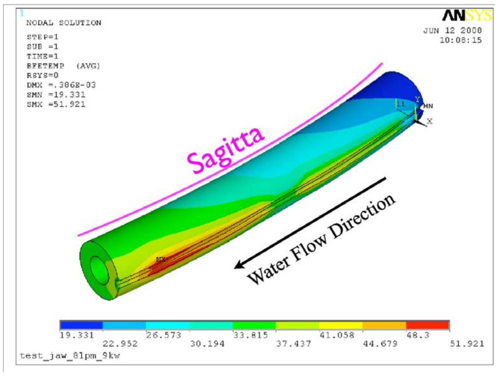

Figure 5: Jaw sagitta and temperature distribution under 9 kW heat load.

EXPERIMENTAL SETUP

The prototype jaw was mounted on the support structure as shown in figure 6. Not shown in the photograph are the two 5 kW heater power supplies and the 16 kW water chiller. The jaw sagitta was measured with three Capacitec [5] HPT-150 capacitive distance sensors which were calibrated for ±5μm accuracy and a precision well

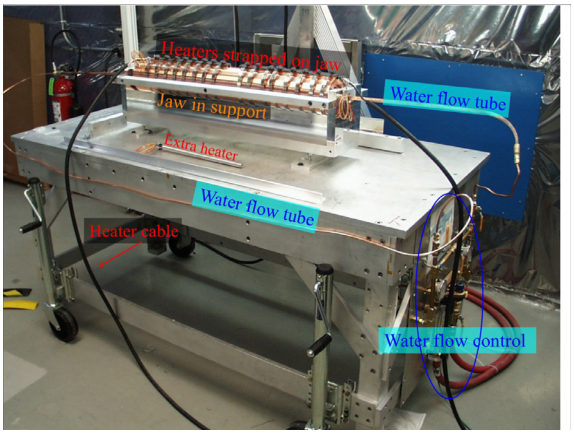

Figure 6: Experimental setup with heaters and cooling attached to jaw prototype.

within 1 micron. Jaw temperature was monitored using 24 Type K thermocouples with an accuracy of better than ±1 F. The mounting of the Capacitec sensors and thermocouples is shown in figure 7. With three Capacitec sensors, one placed at each jaw end and another in the middle, the sagitta can be measured. The jaw is rotatable so sagitta measurements can be performed at any azimuthal angle except near the heaters where the heaters and straps block the view of the Capacitec sensors. In figures 6 and 7 the heaters are located on the bottom of the jaw and the Capacitec sensors are measuring the sagitta 180 degrees away from the heaters. The thermocouples were placed longitudinally along the jaw at three azimuthal angles 90, 180 and 270 degrees with respect to the heater location. A total of 27 temperature and Capacitec channels were recorded in real time using a National Instruments Corporation [6] TC-2095 terminal block read by a NI SCXI-1102B amplifier. An extra 7 channels were recorded manually including water flow, water temperature in and out and the power supply voltages and currents. All data was collected using Labview [6].

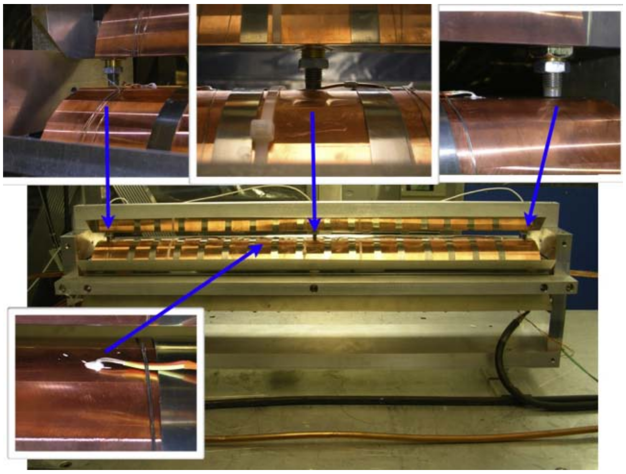

Figure 7: Capacitec Sensors mounted on Jaw support. Shown are zooms onto the location of each sensor plus one thermocouple

EXPERIMENTAL RESULTS

The measured sagitta at six azimuthal locations around the jaw are shown compared to the ANSYS predicted curve in figure 8. The thermocouple readings compared to the ANSYS predictions are shown in figure 9. As can be seen, the measured sagitta at 180 degrees is slightly greater than expected at 112 microns. The temperature along the jaw is also consistently about 3 degrees higher than the ANSYS results. One source of discrepancy is the actual incoming water temperature was about 21.5 C whereas the ANSYS model used 20 C. This can account for about half the temperature disagreement and brings the results in close agreement. The sagitta measurement disagreement of 12% is small and gives us confidence that our ANSYS simulations are accurately giving the jaw deformation due to realistic beam heating.

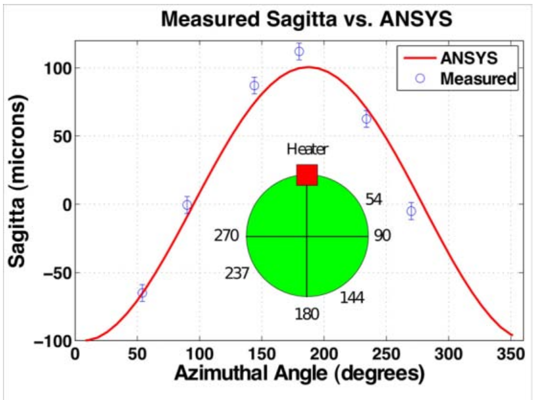

Figure 8: Measured sagitta at six azimuthal location compared to the ANSYS curve,.

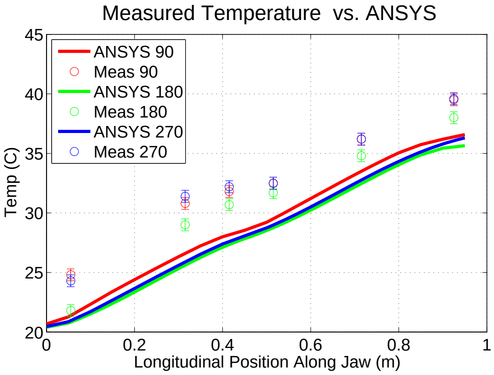

Figure 9: Measured temperature along the jaw at three azimuthal locations compared to the ANSYS predictions.

ACKNOWLEDGMENTS

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REFERENCES

[1] Smith, J. *et al.*, “Design of a Rotatable Copper Collimator for the LHC Phase II Collimation Upgrade,” Proceedings EPAC08 **MOPC096** (2008)

[2] Lari, L., “Evaluation of Beam Loss and Energy Deposition for One Possible Phase II Design for LHC Collimation,” Proceedings EPAC08 **WEPP072** (2008)

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