Præcis Application Case Study
Temperature Control for NASA

NASA: Temperature Control of a Metrology Station for Next Generation X-Ray Optics Mirror Elements.

NASA Goddard Space Flight Center is conducting a program to develop enabling technologies for the manufacture of the next generation of orbiting X-ray telescope. The metrology of individual elements of the telescope required an environment stable to +/- 0.1 °C.

Praecis assisted NASA with the design of an appropriate enclosure and provided an air temperature control unit (ATCU) that met NASA's specifications by a factor of 2. Subsequently NASA purchased a second unit that was modified to improve thermal stability; its performance (+/-0.009 °C) exceeded specifications by a factor greater than 10.

Background—NASA Next Generation X-Ray Optics

The NASA Goddard Space Flight Center is developing and demonstrating technologies essential to the success of the next generation of orbiting X-Ray telescope. The optical assembly for a representative telesope design, illustrated in Figure 1, is composed of almost 14,000 individual glass off-axis aspheric elements, each with dimensions of approximately 200 mm x 200 mm and a thickness of 400 μm. The figure accuracy specification for each element is 100 nm p-v.

Manufacturing and Metrology

The strategy being developed for the manufacture of individual elements calls for creating precision convex mandrels of the same profile as the optical surface to be produced, and then slumping glass sheets over the mandrels in an oven to create the concave optical surface. Individual elements are subsequently inspected using a Hartmann test apparatus designed and built at NASA Goddard. Meeting metrology accuracy requirements requires that the temperature of the instrument and the element under inspection be maintained within ± 0.1 °C.

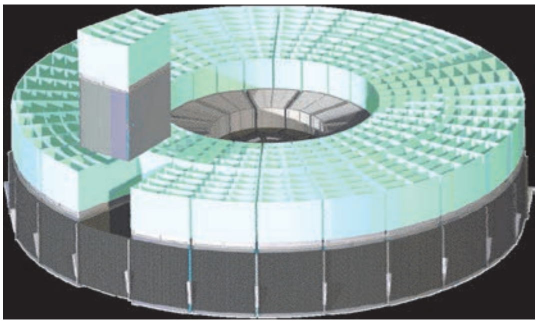

Figure 1: A conceptual example of a next-generation X-ray telescope. The overall diameter of the optic is approximately 3.2 meters.

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Sensitivity of the Metrology Process to Temperature Variations

NASA conducted a detailed finite element analysis to determine the dimensional sensitivity of individual elements under test to different boundary conditions. The results of the analysis indicated that the temperature of the environment surrounding the test apparatus and the element under test must be maintained to within +/-0.1 °C. The room environment, however, typically varies by +/-1.0 °C.

Air Shower Temperature-Controlled Enclosure

NASA concluded that the preferred solution to their problem was to provide a local enclosure around the instrument, and control the temperature inside the chamber to the required level. In this instance, however, the design of the instrument precluded the use of the solution typically preferred by Praecis, whereby air enters the chamber via a plenum atop the enclosure, and evenly distributes air flow through a matrix of small (6-mm diameter) holes in the plenum floor. This design minimizes gradients and 'dead zones' within the enclosure.

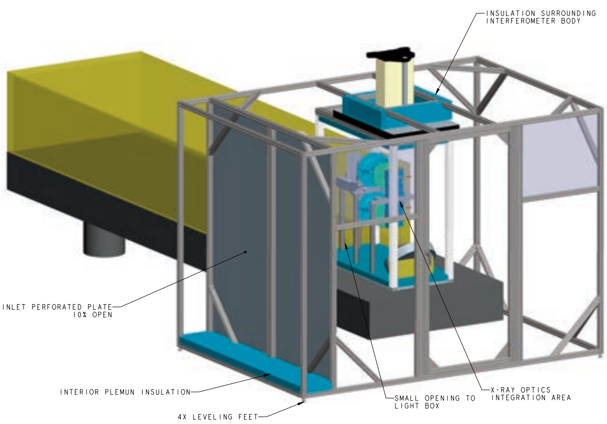

Figure 2. Drawings of the NASA Goddard enclosure.

Because NASA chose to use a horizontal flow design, Praecis suggested an alternative configuration whereby the distribution of air flow through the chamber could be regulated by placing an array of 9 fans on the wall opposite the plenum. The speed of individual fans can be independently regulated, thus allowing reasonable uniformity in air-flow and temperature. The system is a one-pass design, with the air from the enclosure exiting directly into the surrounding room.

NASA constructed an enclosure per the attached drawings (Figure 2). Features of note are the plenum along one wall, the perforated entrance from the plenum to the enclosure, the nine fans distributed along the opposing wall, and insulation on all external surfaces.

Based on the volume of the enclosure, Praecis selected a model ATCU-7 air temperature control unit for the NASA application. The Praecis ATCU is a stand-alone temperature control unit that feeds temperature-controlled air to the enclosure plenum.

Praecis ATCUs typically achieve a level of temperature control at the enclosure "critical point" that is a factor of at least 50 or better than the ambient room temperature variation. This level of performance is achieved through the application of a digital two-loop PID temperature control system, whereby temperature is sensed at the "critical point" within the enclosure to generate a set-point feedback signal to the PID controller.

Praecis based the selection of an ATCU-7 on two criteria: A minimum exchange rate of 3 air changes per minute, and a minimum average air velocity in the enclosure of 0.1 m/sec. The ATCU-7 has a cooling capacity of 7 kW, and provides an air flow rate of 27 m^3/min.

—Præcis Achived NASA's Performance Goal by a Factor of ten.

Figure 3 is a photograph of the enclosure and the Praecis ATCU-7 as installed at NASA Goddard.

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Figure 3: Enclosure and Praecis ATCU-7 as installed at NASA Goddard.

Performance Testing and Results

The Praecis ATCU was specified by NASA to control the temperature at the enclosure critical point within +/-0.1 °C. NASA tested the performance of the system with a digital data acquisition system logging temperatures at various points inside and outside the enclosure. Figure 4 illustrates the performance of the temperature control system over a period of 13 hrs. Critical point and room temperatures are plotted, along with several others for diagnostic purposes.

The performance of the Praecis ATCU met NASA's specification by a factor of 2. It did not, however, meet Praecis' performance objective of maintaining temperature variations at the critical point to within +/-0.015 °C in the NASA +/- 0.75 °C environment. A closer examination of the NASA data revealed an anomalous cycle at the critical point with a period of 61 sec and an amplitude of +/-0.03 °C, as shown in Figure 5.

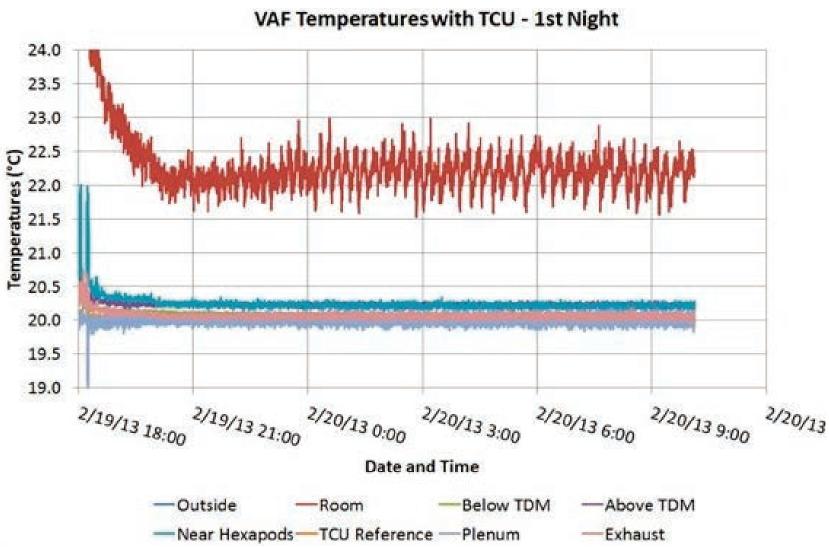

Figure 4: Results of testing of the performance of the temperature control system over 13 hrs. The red trace is of room temperature, and the pink (labeled as TCU reference) is of the critical point. The critical point varies by +/- 0.05 °C, while the room temperature varies by +/-0.75 °C.

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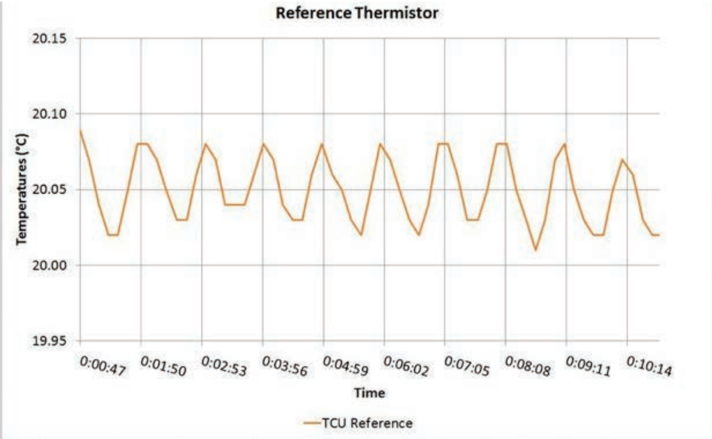

Figure 5: Critical point temperature over 30 min, revealing a cyclic error with a period of 61 sec and an amplitude of +/- 0.03 °C.

The cyclic error was traced to a hot gas bypass valve, and corrected by replacing the valve with an alternative design on a subsequent unit for NASA. Short-term stability can now be maintained at +/-0.005 °C in a +/-0.21 °C environment, and to +/-0.009 °C in a +/-0.4 °C environment. Figure 6 illustrates the performance of the modified system over a period of ten minutes and Figure 7 is a recording of the stability over 16.5 hours.

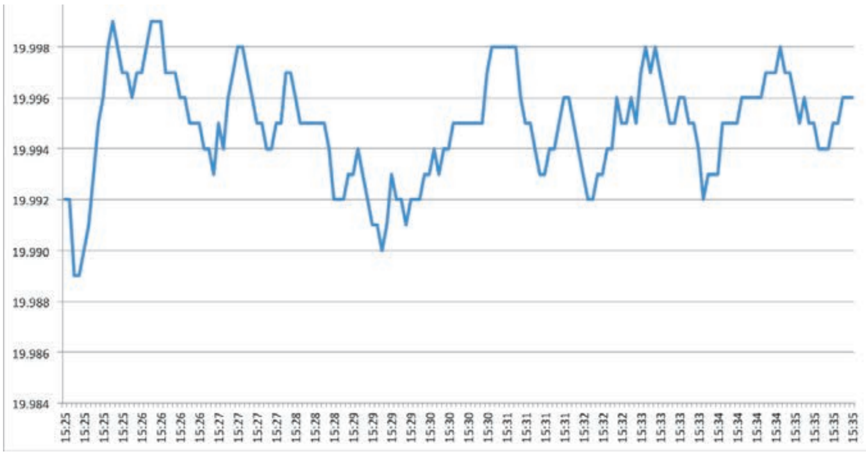

Figure 6: Temperature variation at the critical point is +/-0.005 °C in a +/- 0.21 °C environment over a period of 10 min.

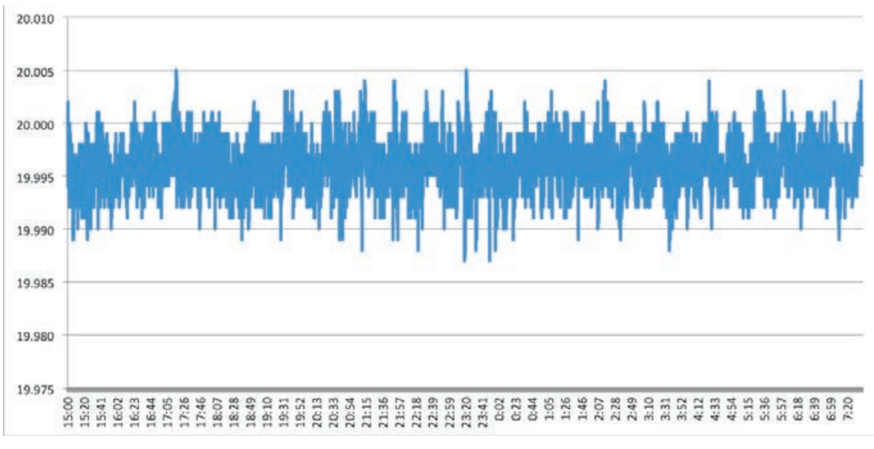

Figure 7: Temperature variation at the critical point is +/-0.009 °C in a +/- 0.4 °C environment over a period of 16.5 hrs.