Cryogenic Coefficient of Thermal Expansion Measurements of Type 440 and 630 Stainless Steel

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Abstract. The Dark Energy Camera is now installed on the Blanco 4m telescope at the Cerro Tololo Inter-American Observatory in Chile. The camera is cooled to 170K using a closed loop two-phase liquid nitrogen system. A submerged centrifugal pump is used to circulate the liquid from the base of the telescope to the camera in the prime focus cage. As part of the pump maintenance schedule, the rotor shaft bearings are periodically replaced. Common bearing and shaft materials are type 440 and 630 (17-4 PH) stainless steel. The coefficient of thermal expansion of the materials used is needed to predict the shaft and bearing housing dimensional changes at the 77K pump operating temperature. The thermal expansion from room temperature to 77K of type 440 and 630 stainless steel is presented . Measurements are performed using the ASTM E228 standard with a quartz push-rod dilatometer test stand. Aluminum 6061-T6 is used to calibrate the test stand.

Keywords: Cryogenic, Thermal Expansion, Martensitic Stainless Steel
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INTRODUCTION

The Dark Energy Camera (DECam)[1], is the primary instrument used in the Dark Energy Survey[2]. DECam is a 3 sq. deg. mosaic camera mounted at the prime focus of the Blanco 4m telescope at the Cerro-Tololo International Observatory (CTIO). The liquid nitrogen system used to cool the CCD camera is a closed loop, two-phase circulation system [3]. Liquid is pumped using a centrifugal pump from the liquid nitrogen process vessel and circulated continuously to the cameral heat exchanger. The centrifugal pump is constructed using components consisting of an aluminum housing, type 440 stainless steel bearing races, and type 630 stainless steel (17-4 PH) shaft material. Both stainless steels are martensitic, which typically are not advised for use in cryogenic applications due to their elevated ductile to brittle transition temperature compared to austenitic stainless steels. Since the material structure for austenitic 300 series stainless steels is different than the martensitic steels, it is anticipated that the thermal expansion is different also. The thermal expansion value is needed for these materials to appropriately quantify the bearing fits in the pump housing and shaft. The thermal expansion from room temperature to 77K for type 440C and type 630 stainless steel and the measurement technique is presented here.

TEST DESCRIPTION

The thermal expansion from room temperature to 77K is measured using the ASTM E228 standard with a quartz push-rod dilatometer test stand. The cryogenic dewar with the push rod assembly installed, and data logging system is shown in figure 1. The quartz push-rod assembly and mounted sample is shown in figure 2. The length of the quartz rods is approximately 12 inches, allowing for thermal isolation between the sample at the cold end and the warm end where the expansion is measured. Each sample measured is approximately 0.75 inches long in order to properly fit inside the dilatometer assembly. At the warm end of the push rods, a Linear Variable Differential Transformer (LVDT) is used to measure the expansion of the sample. The calibration for LVDT is performed by measuring a standard sample. The output of the LVDT is in units of mVolts per inch of displacement. For calibration, the standard sample is aluminum 6061-T6. The aluminum measurement is then compared to the standard published measurements. The mV/inch as recorded on the LVDT is then fit to the standard published thermal expansion curve[4]. The measured aluminum thermal expansion fitted to the reference aluminum is plotted in figure 3.

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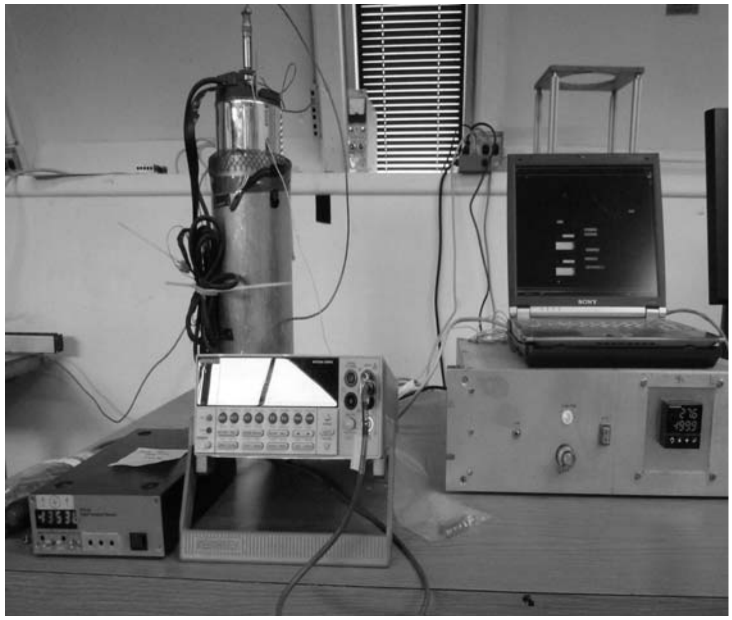

FIGURE 1. Thermal Expansion measurement stand.

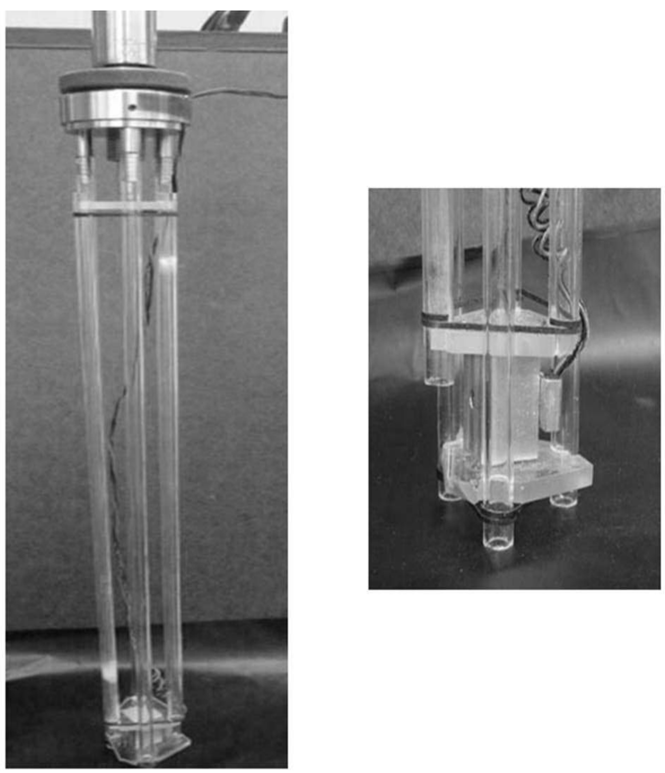

FIGURE 2. Left: Quartz Push-rod assembly. Right: Mounted sample with bolt on temperature sensor.

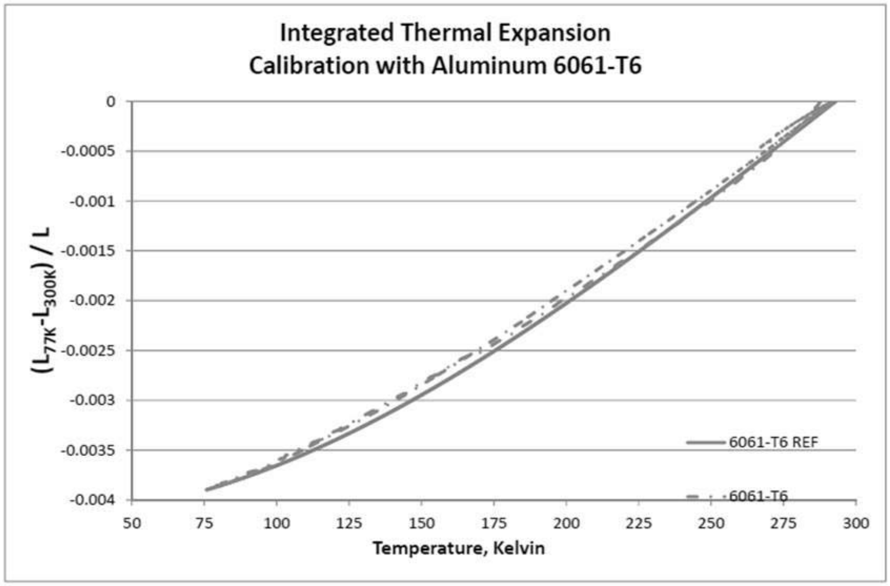

FIGURE 3. Integrated aluminum thermal expansion between 77K and room temperature.

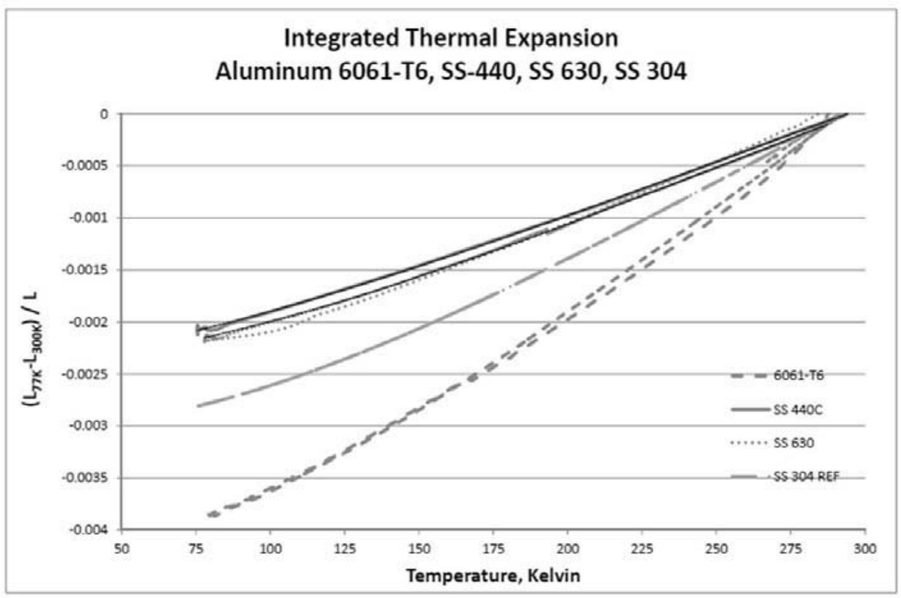

FIGURE 4. Thermal expansion type 440C stainless steel, type 630 stainless steel, type 304 stainless steel, aluminum 6061-T6.

RESULTS

The thermal expansion for type 440C stainless steel and type 630 stainless steel is measured from 77K to room temperature using the quartz push-rod dilatometer test stand. For comparison, the thermal expansion of the aluminum 6061-T6 sample used during callibration and also the published data [4] for type 304 stainless steel is shown on the same plot in figure 4. The two martensitic stainless steels have a similar thermal expansion. The integrated expansion

Integrated Thermal Expansion $\frac{(L_{77K} - L_{300K})}{L} = a + bT + cT^2 + dT^3 + eT^4$				
Coefficient	Type 440C S.S.	Type 630 S.S.	Type 330 S.S.*	6061-T6*
a	-2.5e-3	-2.5e-3	-2.9546e-3	-4.1272e-3
b	4.0e-06	2.0e-06	-4.0518e-6	-3.064e-6
c	3.0e-8	4.0e-8	9.4014e-9	8.7960e-8
d	-4.0e-11	-5.0e-11	-2.109e-10	-1.0055e-10
e	0	0	1.878e-13	0

* http://cryogenics.nist.gov/Papers/Cryo_Materials.pdf

FIGURE 5. Integrated thermal expansion coefficients for type 440C and 630 stainless steels with reference materials aluminum 6061 and type 304 stainless steel.

between room temperature and 77K for type 440C stainless steel is -0.00205 and -0.00215 for the type 630 stainless steel. For comparison, the value for type 304 stainless steel is -0.00281. The measurements are fitted to determine the integrated thermal expansion coefficients. The chart is shown in figure 5.

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4. `http://cryogenics.nist.gov/Papers/Cryo_Materials.pdf`