Initial Test Performance of a Closed-Cycle Continuous Hydrogen Sorption Cooler, the Planck Sorption Breadboard Cooler

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ABSTRACT

The Jet Propulsion Laboratory (JPL) is developing a continuous hydrogen sorption cryocooler for the ESA Planck mission, which will measure the anisotropy in the cosmic microwave background. The sorption cooler is the only active cooling for one of the instruments and it is the first of a chain of three coolers for the other instrument on Planck. The cooler has been designed to provide a cooling capacity of 1.1 W at a temperature below 20 K with a temperature stability requirement of 100 mK over a compressor cycle (667 s). The performance of these coolers depends on many operating parameters (such as the temperatures of pre-cooling thermals shield and the warm radiator and their fluctuations) and compliance can only be assessed through a detailed testing of the whole cooler and its interfaces. A breadboard sorption cooler (EBB) is undergoing testing to verify the flight cooler design performance in terms of input power, cooling power, cold end temperature and cold end temperature fluctuations, heat load on the pre-cooling stages, and heat flow to the warm radiator. We present initial test data compared to predictions based on previously performed component tests.

INTRODUCTION

Planck is a European Space Agency (ESA) mission, whose main objective is to image the temperature anisotropy of the Cosmic Microwave Background (CMB) at high angular resolution. Planck will produce high sensitivity maps over 95% of the sky in a wide range of frequencies that have never before been studied at such high resolutions and sensitivities. The telescope will measure temperature fluctuations in the CMB with a precision of ~ 2 parts per million and an angular resolution ~ 10 arc-min. The analysis of these fluctuations will determine to a precision of few percent the fundamental cosmological parameters (Hubble constant, density of the Universe, cosmological constant etc.). Planck will carry two instruments: the High Frequency Instrument (HFI) and the Low Frequency Instrument (LFI). Together these instruments will observe and image the full sky in nine spectral bands between 30 and 857 GHz. Both the LFI and the HFI instrument sensors need to be cooled to cryogenic temperatures to optimize their signal to noise ratio. The detector cooling system has also to minimize the mechanical vibration to reduce the spurious signal generation on the ultra-sensitive detectors.

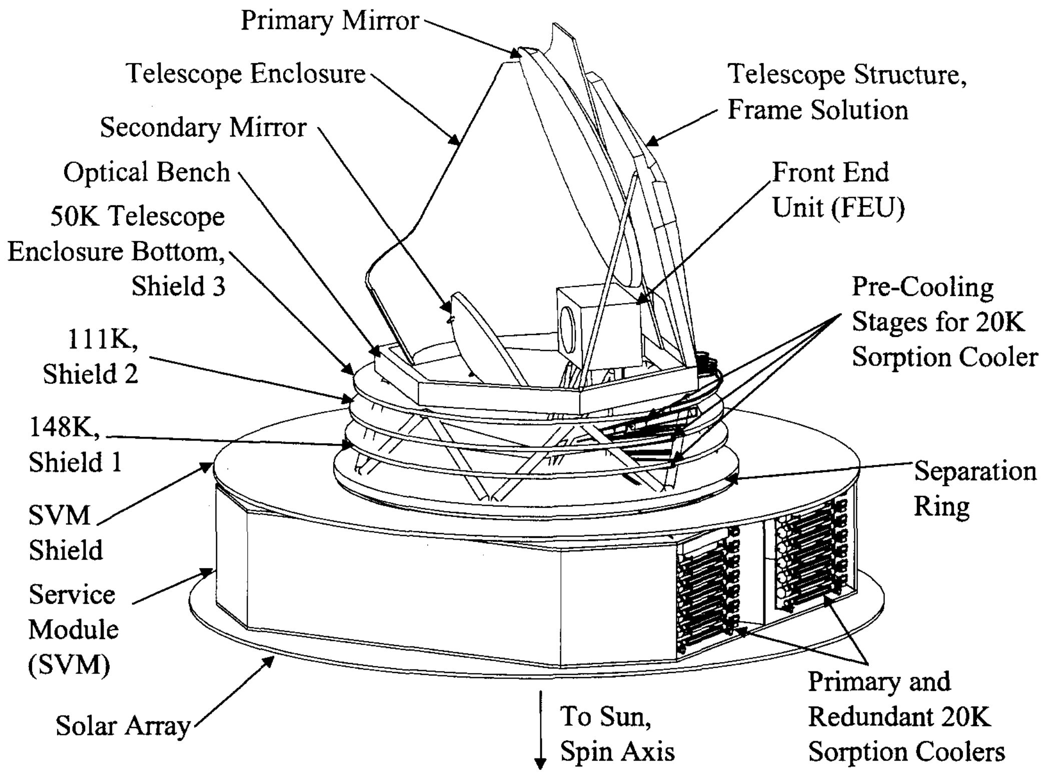

Figure 1. Schematic of the mounting of the Planck sorption cooler on the whole spacecraft[2]. The three shields temperature are the nominal values within the spacecraft specifications. The radiator temperature on which the compressor is mounted is at temperature of 270 K.

The LFI radiometers need a temperature of 20 K reached through a combination of passive cooling to about 50 K and active cooling using a hydrogen sorption cooler to reach lower temperatures. The HFI uses bolometers cooled to 100 mK through a combination of passive cooling (radiator at 50 K), the 20 K sorption cooler, a 4.5 K Mechanical Joule-Thomson cooler and a Benoit style open cycle dilution cooler (^3He-^4He). The use of an open cycle dilution cooler will limit the mission life to 1.5 years for the HFI. The description of the whole cooling chain has been previously provided by Collaudin et al.[1] and by Wade[2].

The sorption cooler operates by compressing the refrigerant hydrogen through the compressor to the high pressure stabilization tanks which are maintained at 50 ATM. The refrigerant than travels from the tanks through a series of heat exchangers and radiators, which provide pre-cooling to approximately 50 K (see Fig. 1), through the JT expander at the Front End Unit (FEU). When the refrigerant (H_2) expands through the JT flow restriction valve, hydrogen forms liquid droplets whose evaporation provides the cooling power in the liquid reservoirs. Each of the reservoirs is filled with a wicking material in order to retain the liquid in the reservoirs without gravity. The third reservoir is maintained above the hydrogen saturated vapor temperature, to wick and then evaporate any liquid that reaches it, thus providing an even gas flow back to the sorbent bed.

The functional requirements of the Planck Sorption Cooler are summarized in Table 1.

Table 1. Functional requirements of Planck Sorption Cooler

Cooler Total Power	<520 W
Cooling capacity when Shield 3 is at 50 K	1600 mW
Cooling capacity when Shield 3 is at 60 K	1102 mW
Cold end temperature	<24 K
Cold end temperature fluctuations	<100 mK
Heat load on the Shield 3	<1390 mW

FACILITY FOR THE EBB COOLER TEST

The flight sorption cooler design is currently being validated by operating an Engineering Bread Board unit (EBB) over the whole parameter space defined by the thermal, mechanical and electric interfaces provided by the spacecraft to the cooler. The EBB cooler sub-components, such as the compressor elements[3,5], gas gap heat switches[6,7], the check valves and the filters[8], the JT valve and the liquid reservoirs[9] have been previously tested to validate the component design but EBB operation is the first test of the whole cooler as a unit. Hence, it is providing information on the mutual interaction of the components and a validation of the cooler subsystem flow-down requirements assumed in the design[2,10]. It should be observed that, contrary to the case for the Planck flight coolers which will be thoroughly integrated using only weld joints, all the subsystems of the EBB cooler could be interchanged with similar units in case of a component failure or of a substantial redesign.

The EBB cooler compressor is composed of six compressor elements with their own gas gap actuator as shown in Fig. 2. To verify the effect of the high pressure stabilization tank size on the performance a system with multiple tanks was built to possibly connect to the high pressure manifold a 2, 3, 4, 5 liter volume. For the same reason two identical low pressure stabilization beds were connected to the low pressure manifold. Each compressor element is chilled by attaching it to

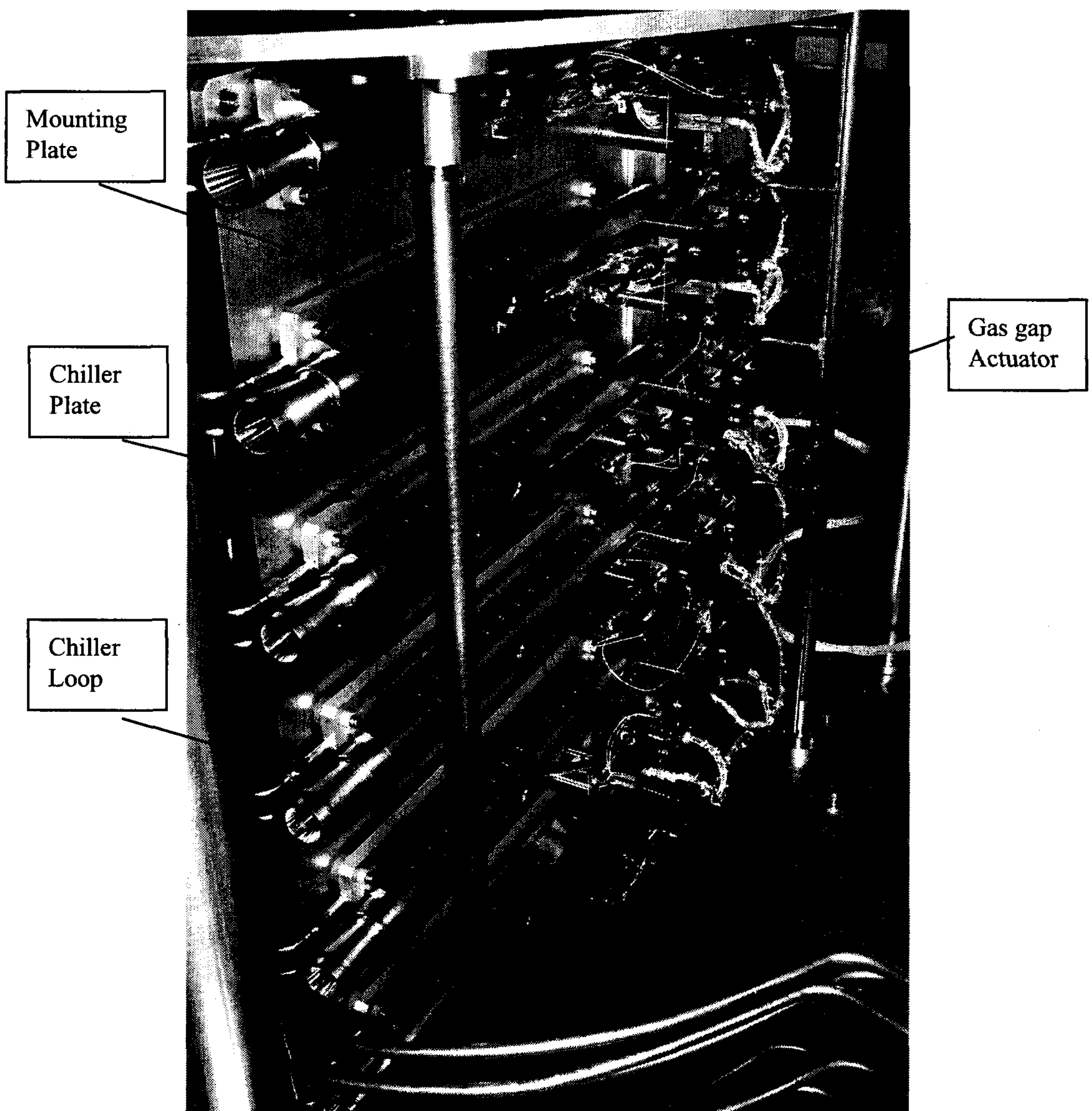

Figure 2. View of the compressor elements of the EBB sorption compressor. The six compressor elements are mounted on chiller plates thermally isolated from the support structure on which they are mechanically mounted.

a plate cooled independently by an external chiller. The chiller provides a 3-4 gpm (gallon per minute) flow to a common manifold inside the chamber from which the feed lines to the individual chiller plate leave (see Fig. 2). The chiller plate temperature fluctuations during cooler operation are within the present requirements based on a simulation of the spacecraft radiator.

The whole sorption cooler was placed into a thermal vacuum chamber for the test, also providing a verification of the test facilities required to operate the sorption cooler. As previously described[2], the sorption cooler has complicated mechanical and thermal interfaces with the spacecraft V-Groove shields (see Fig. 1) needed to efficiently pre-cool the high pressure hydrogen gas below its inversion temperature. The 100 K and 50 K pre-coolers designed for the EBB tests are shown in Fig. 3, where the two 50 K and the 100 K pre-coolers can be observed below the facility radiative shield containing the cold end. Each thermal interface where the cooler attached has been designed to provide a heat flow measurement at the interface. The cold end assembly is the part above the interface "50 K shield" and is composed of the JT valve, two liquid reservoirs, a particle filter, a continuous tube-in-tube heat exchanger and a discrete heat exchanger (reported by Sirbi et al.[9]) that stabilizes the liquid-vapor interface in the cold-end assembly. The cold end assembly flight design is not complete and a separate design validation is currently ongoing at JPL.

The main difference between the EBB and the flight sorption cooler is the flow allowed by the JT porous plug. The JT valve used for these tests was not characterized at operating temperatures and it was observed that the flow was reduced to 5.1 mg/s compared to the design value of 6.5 mg/s. Based on this, different system performance is expected as shown in Table 2. The expected cooling power has been obtained by simply scaling the design cooling power by the ratio of the measured and design hydrogen flow. Total cooler power for this reduced flow does not scale with the flow since more than half of the power supplied to the compressor is used to pressurize the compressor element to 50 ATM while the rest of the power is used to supply the mass flow. For this reason the estimated power for the EBB cooler is not linearly increased, as for the cooling power, but is obtained by adding the heat up power, the gas gap actuator power (that did not change), and the new

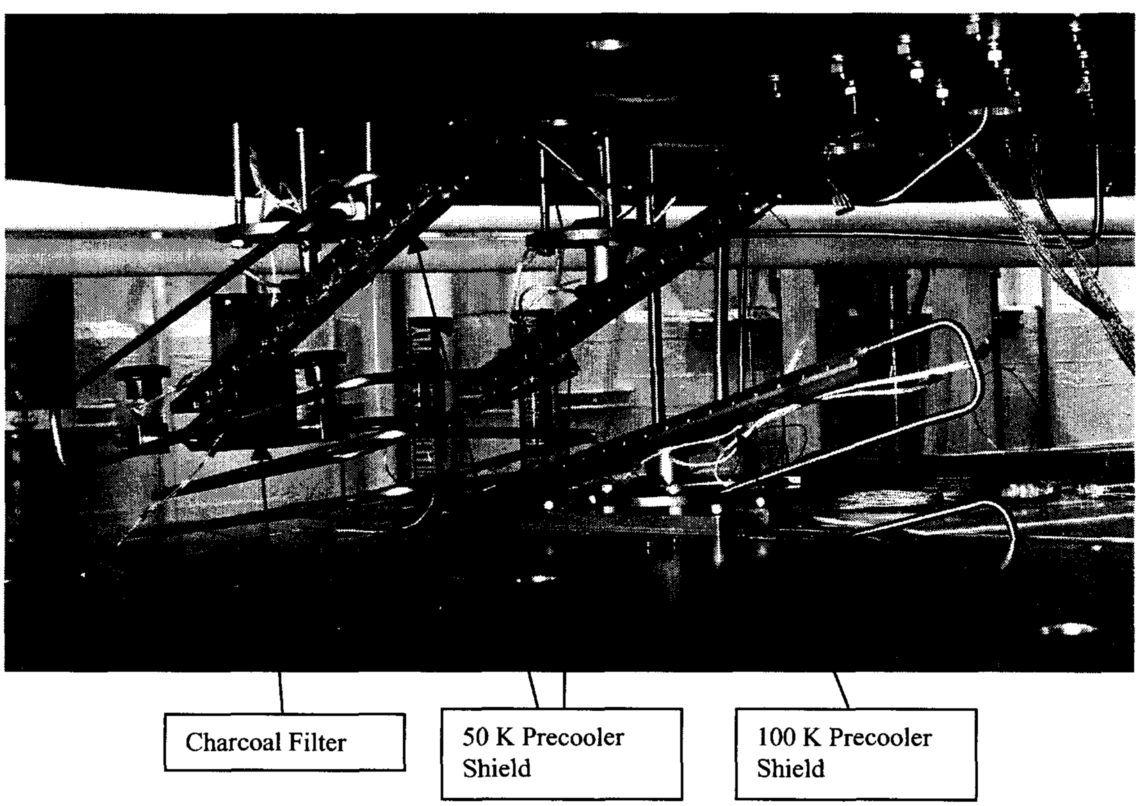

Figure 3 View of the 50 K and the 100 K precooling stages. The precoolers are attached to mounting plates simulating the V-Groove shields of the spacecraft. The attachments are thermally stood off from the radiative shield to measure the heat load on the three different radiators.

desorption power for a total of 390 W.

Table 2. Performance predictions for EBB cooler for Hydrogen mass flow of 5.1 mg/s

Cooling capacity when Shield 3 is at 50 K	1255 mW
Cooling capacity when Shield 3 is at 60 K	864 mW
Cold end temperature	<100 K
Heat load on the Shield 3	<1090 mW

INITIAL TEST RESULTS

Initial testing of the EBB sorption cooler was performed in January 2002. This testing demonstrated a continuous sorption cooler capable of producing liquid hydrogen at a temperature less than 20 K with a cooing power greater than 1 W for a 50 K pre-cooling temperature. The tests conducted were also the first for the test facility and some uncertainty in the measurements are due to improper calibration of some instruments and by thermal design limitations of the facility during these first tests.

The first test started with the coldest pre-cooler temperature at 86 K and cooling at a rate of 0.5 K/hour. This is shown in Figure 4., where the pre-cooler and cold-end temperatures are displayed as a function of time. After 6 hours, the pressure in the high pressure tanks reached the operating value of 50 ATM. The first accumulated liquid hydrogen in the liquid reservoir was observed 49 hours after the beginning of the test. The cold-end temperature stabilized at17.7 K with an applied power of 900 mW. After six hours the sorption cooler was shutdown to allow for the pre-cooler to reach 50 K. The large amount of noise observed in the pre-cooler temperature is due to faulty read-out electronics.

When 50 K was reached on the pre-cooler, a second test was started. During this test the JT valve plugged when it reached a temperature of 37 K due to what we believe to be methane contamination. The plug was removed by heating the JT to a temperature of 80 K. During this period, the temperature of LR1 reached 50 K while the temperature of LR2 did not change. When the temperature of the JT reached 48 K the sorption compressor was restarted. Liquid was observed in the liquid reservoirs 5 hours and 20 minutes after the JT was observed to be plugged. The cooler produced 1.2 W (pre-cooling shield at 50 K) of cooling power at a temperature of 17.7 K on both LR1 (the HFI interface) and LR2 (the LFI interface). The temperature between the two liquid reservoirs differed by less than 40 mK.

CONCLUSIONS

The EBB sorption cooler has provided first demonstrations of the design of the Planck 20 K sorption cooler by operation of a closed loop hydrogen sorption cycle. The results reported in the present paper are only the initial test and a fully detailed description of the EBB test results will be reported at the end of the complete test program.

Expected contamination problems were observed during the test when the JT plugged before running smoothly probably due to a residual methane gas component generated by the compressor elements (Bowman et al.[5]). Currently, the cooler has been operated for almost a 750 hours and these tests are providing essential information for the full validation of the flight design.

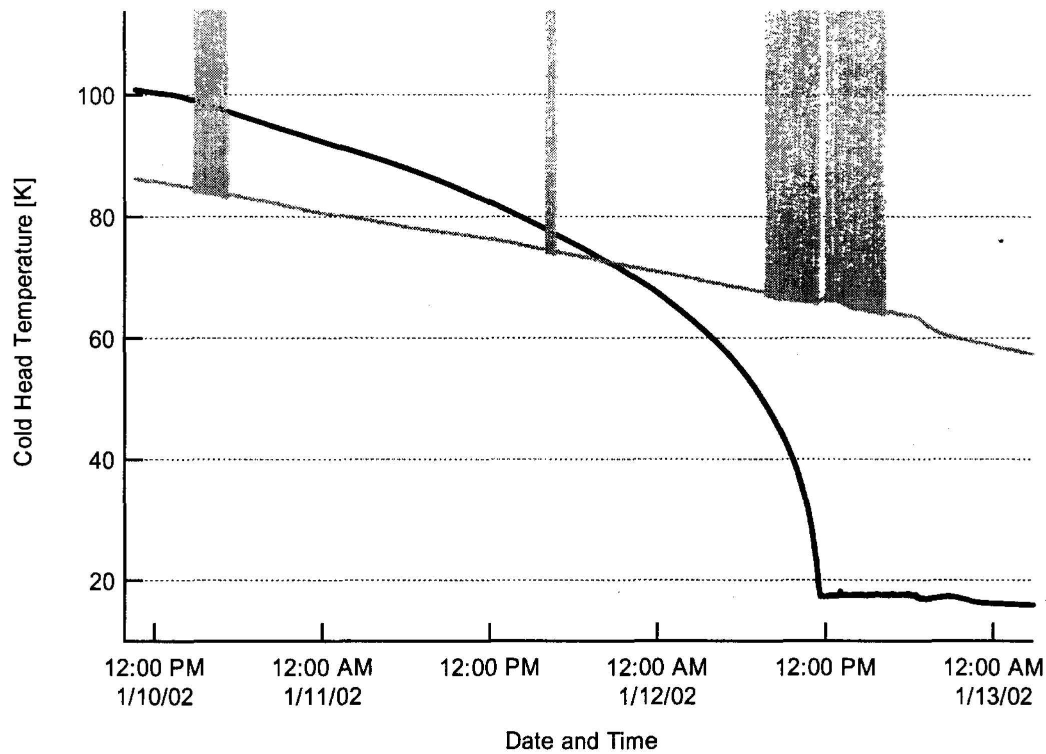

Figure 4 Cold end temperature and last radiator temperature during the first cool down of the EBB cooler. In gray is temperature of the last precooler while the black line is the temperature of the cold end.

ACKNOWLEDGMENTS

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