Low-Heat Input Cryogenic Temperature Control with Recuperative Heat-Exchanger in a Joule-Thomson cryocooler.

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The control of cryogenic temperatures is a constantly developing field that has achieved unprecedented results in terms of stability.
Stability is usually accomplished in two ways: a passive stage, exploiting the combined effect of a thermal mass connected to a thermal resistance; or an active control, often of a PID type, based on the combination of a dedicated sensor, a heater and a controller.
The efficiency of a passive controller depends on the ratio of the thermal time constant of the passive stage and the time period of the raw fluctuations. A thermal passive control stage is, generically speaking, efficient in terms of damping high frequencies from the raw oscillations but not very effective in filtering the low frequencies.
An actively controlled stage, on the other hand, is more effective in damping low frequency fluctuations, and is useful if the source of the oscillations has significant energies associated with low frequencies. Such a system typically uses a controlled stage that is isolated from the source of the fluctuations by a thermal isolator. Controlled insertion of heat into this stage counters the temperature fluctuations reaching the stage. Inherent to this type of system is the insertion of heat into the controlled stage that eventually reaches the cold end of the cooler, reducing the net heat lift available. The larger the thermal isolation, the smaller the reduction of this heat lift, but with the attendant increase in the interface temperature. Hence, the design of this system requires a tradeoff of these two negative effects. Any scheme that can reduce the penalty associated with the loss of heat lift or the temperature offset would be attractive in terms of cooler performance.
If the cooler system has a recuperative heat exchanger between the coldest heat sink and a higher temperature precooler, a different approach can be used. In this paper we describe a novel approach for cryogenic temperature control capable of passively damping low frequency fluctuations, requiring minimal reduction of cooler heat lift and minimal temperature increase of the cold end interface. This alternative scheme is based on the idea of controlling the temperature of a section of the recuperative heat exchanger between the coldest precooler and the cold end of the cooler.
The control scheme has been tested on a 20 K hydrogen cryocooler with recuperative heat exchanger, demonstrating that reduction in heat lift is considerably smaller, and the corresponding cold end interface temperature increase is substantially lower, than that corresponding to typical proportional-integral control schemes utilized under the same conditions. In this paper are reported the operating principles as well as the test results associated with this innovative control scheme during implementation in this 20 K cooler.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.