Development and testing of a novel thermal switch

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ABSTRACT

A novel thermal switch, named as Double Driving Devices-based Thermal Switch (DDDTSW) will be described. Some details will be focus on the structure and the work principle of this device, as well as something about experiment for the device's work performance and the test result from it will be introduced. In ground testing of using LN2 as cold resource, the DDDTSW demonstrated an "Off" resistance of 2450K/W and an "On" resistance of 6.0K/W. Finally, it is proposed to advance the DDDTSW design to increase the heat conduction, and it's also pointed out this kind of thermal switch has the potential feasibility used in the space cooling system.

INTRODUCTION

With the development of infrared remote sensing system, there are more requirements in space cryogenic technology, such as better reliability and longer lifetime of the cryogenic cooling systems using mechanical cryocoolers. One of the feasible approach is to incorporate redundant cryocoolers in the cooling system to protect against individual cryocooler failures.
(see Figure 1)

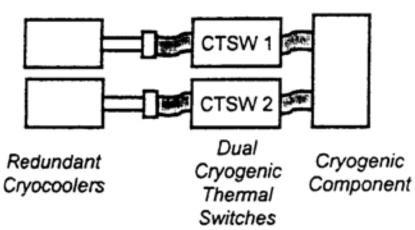


Figure 1. Dual CTSW System.

In applications, the non-operating standby cooler presents an added parasitic load to the operating cooler. So the non-operating cooler needs to be thermally isolated from the focal plane array, while the active cooler is thermally connected to the system. For typical space cryocoolers operating without a thermal switch device, the parasitic load stem primarily from conduction through the non-operating cryocooler expander. The thermal resistance of this conductive path is generally 400-500 K/W for space cryocoolers. As a result, the parasitic load due to the non-operating cryocooler is approximately 0.5W at 60K.[1]

In order to minimize cooling and input power requirements, a reliable cryogenic thermal switch is desirable. A properly designed heat switch increases the thermal isolation between the instrument and expander body of the non-operating crycooler and reduces the parasitic load from the non-operating cryocooler by 65-80% [1].As a result, cryocooler cooling and input power requirements are reduced. [2]

CRYOGENIC THERMAL SWITCH PERFORMANCE REQUIREMENTS

The development of the cryogenic thermal switches presented in this paper was funded by National Innovation Project to improve the reliability and lifetime of space cooling system, which requires consecutive work for 3 years. The design of the DDDTSW is driven by the following performance requirements, outlined in Table 1.

Table 1. DDDTSW Performance Requirements

Operating Temperature	<150K
"Off" Thermal Resistance	>1000K/W
"On" Thermal Resistance	<4K/W
Displacement	>1mm

DOUBLE DRIVING DEVICES-BASED THERMAL SWITCH(DDDTSW) DESIGN

In order to meet the above requirement, a high reliable thermal switch with good performance is needed. So it's very important to invent a novel and promising concept for this purpose. DDDTSW is mainly made up of five parts, which are Shape Memory Alloy Spring(SMAS), small assistant spring, copper strap, link for connecting DDDTSW to cold head, link for connecting DDDTSW to focal plane. (see Figure 2)

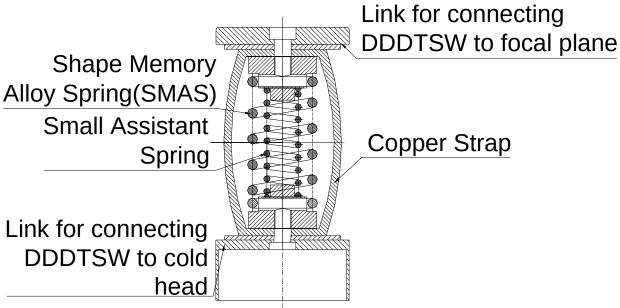


Figure 2. DDDTSW Design

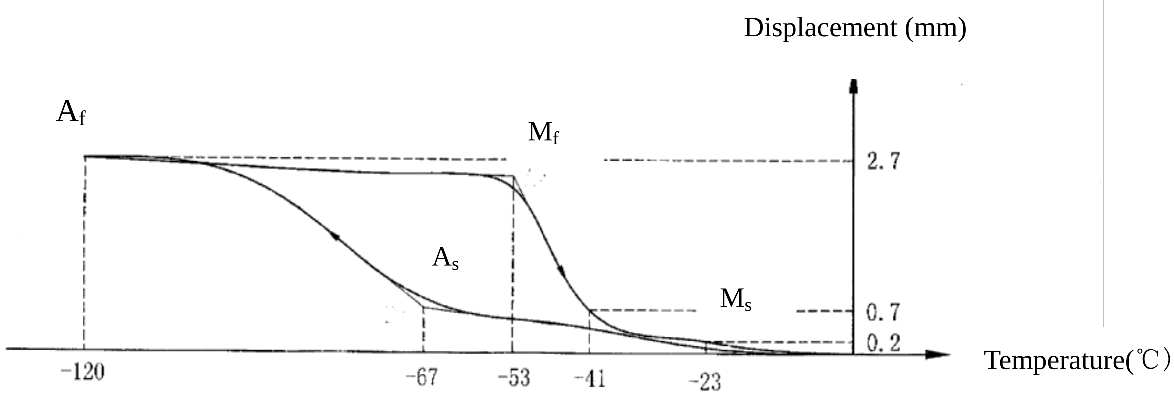
The key part of DDDTSW is SMAS, which is based on SMA effect, that means it can move when certain temperature reaches, and stay stable condition when the working temperature is lower or higher than the certain one. There are four special temperature points for SMA: Ms, the starting temperature of martensite transformation; M_f , the finishing temperature of martensite transformation ; As, the starting temperature of austenite transformation; A_f , the finishing temperature of austenite transformation. If these four special temperature points can be adjusted in line with our requirements, this SMAS will move at certain range of temperature that we need.

In term of DDDTSW, according to our requirements, these four temperature points should be respectively as following: Ms<220K;M_f>150K;As>200K;A_f<250K. These four temperature points can guarantee DDDTSW work effectively and reliably.

The other important part is the small assistant spring, just as its name implies, is to assistant to the move of SMAS. Because SMA we used only has the one-way shape memory effect, which means SMAS only can move towards single one direction, the force need for moving towards another direction should be provided by the small assistant spring. The heat conduction will be considered to resolve by using copper strap. The whole advice is fixed between the cooler's cold head and the focal plane with the link.

The process of DDDTSW is described as following: The temperature will begin to drop after the cryocooler start to work, and DDDTSW is expanded with the force of SMA. When the temperature drops to below Ms, DDDTSW starts to expand with the force provided by small assistant spring until the temperature is lower than M_f. At this moment, DDDTSW completely connects to the focal plane, which is "On" of DDDTSW. Correspondingly, when the cryocooler stop working, the temperature will rise. When the temperature rises to above As, DDDTSW starts to contract with the force of SMA until the temperature is higher than A_f. At this moment, DDDTSW completely disconnects to the focal plane, which is "Off" of DDDTSW. The maximal displacement for DDDTSW is designed to about 2mm.

DDDTSW TEST RESULTS



Graph 1 Relation Between the Displacement of SMAS and Temperature

temperature and to see what's the maximal displacement. After experiment, we get a graph showing the relation between the temperature and displacement (Graph 1).

From this graph, we can see clearly the maximal displacement is about 2.5mm. The four special temperature points, respectively, Ms=206K; M_f=153K; As=220K; A_f=250K, are nearly in the range the we require.

Another important purpose of the test is to get "on" and "off" performance of DDDTSW. In this experiment, LN_2 is used as the cold source, and the heater is to balance the cold of LN_2 to guarantee keep the temperatures in steady state. So the temperature difference (△T) across the switch is measured (△T=T_o-T_c, where T_o is the temperature of the warm end and T_c is the temperature of the cold end). And a known heater power Q is obtained. The "on" and "off" conductance is the heater power divided by the change in temperature difference. Eq. (1) provides the analytical relationship.[3]

$$R_{on,off} = Q \big/ \Delta T \tag{1}$$

After some calculation, we get the "On" performance is about 6.0K/W and the "Off" performance is about 2450K/W.

The result is not so satisfactory compared to the other heat switch. Specially, because of poor heat conduction of DDDTSW, the "On" performance is too big. Some measures can be taken to improve it, such as adding the copper thickness and improving the connect condition between DDDTSW and focal plane, and so on.

SUMMARY

The primary objective of this paper is to describe the design, operation, and test results of the Double Driving Devices-based Thermal Switch (DDDTSW). This type of thermal switch features simple construction and reliable work performance, repeatable actuating mechanism. After test, the "Off" performance is about 2450K/W and the "On" resistance is 6 K/W. With further development, this kind of thermal switch will meet the requirements of the space cooling system.

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