Experiment on Heat Transfer Performance of Space Science Experiment Rack Thermal Control System

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Abstract
Thermal control system (TCS) performance test setup was established based on space science experiment rack design indexes by ground modeling experiments. The experiment scheme and measurement method can be suitable for performance tests of the TCS. Experiment rack TCS steady state results indicate that the setup is conducted to verify design index requirements. Heat transfer performance curves and flow distribution curves of the air to water heat exchanger (H/X) which is one of the main heat dissipation equipments were obtained based on the analysis of performance test results. The conclusion provides guidelines for the space science experiment rack TCS.

1. Introduction

The continuous development of Chinese space station program is undergoing several design iterations from its inception in some scientific fields, such as the microgravity science, space life science, space material science, space physics science and space application of new technology trials science. Considering development demands of Chinese space science researches and long-term strategic plans, it is necessary to design space experiment racks which integrate machinery, energy, electronics, communication and thermal control systems. The experiment racks provide a suitable space experiment environment and resources for all the research platform[1-2]. The thermal control system (TCS) is a very critical subsystem of experiment racks. TCS will charge and discharge the heat which were generated by experiment racks and various science modules, then to keep their temperature within the specified range and ensure the normal operation of all experiments and thermal payloads. the suitable thermal design scheme and thermal control measures must be taken[3].

Experiment equipment arranged in spacelab, space station and experimental cabin are used the standard experiment rack layout scheme. The thermal control methods mainly include forced air cooling and water cooling for local heating emitting equipment[4-5]. Experiment rack air cooling system drove the heated air into the air to water heat exchanger (H/X) by the fan. The cooled air was transferred into each experiment unit to achieve thermal control of experiment instruments and equipments[6-7]. Some high power thermal loads have to set the coldplates, such as experiment rack electronic system and other experiment units. The liquid-cooling loop was drove by pump to absorb and dissipate heat generated by experiment units. Then the heat collected by air cooling system and liquid cooling system is transferred to moderate water loop through a water to water H/X. The cooled liquid processed by spaceport was introduced again to the racks to achieve the continuous thermal control. As shown in figure1, the experiment rack water loop have heat exchange with the International Space Station moderate temperature loop, which then entered into experiment payloads. The low temperature water loop was divided into three branches after entering into the experiment rack. Flowing through the air cooling components of electronic equipment, one branch has heat exchange with air loop, and then flowed into avionics air assembly. Another two branches respectively flowed into two coldplates which dissipate high thermal loads. Finally three braches converged together and then flowed into the moderate temperature loop to complete the closed-loop thermal control of experiment racks[10].

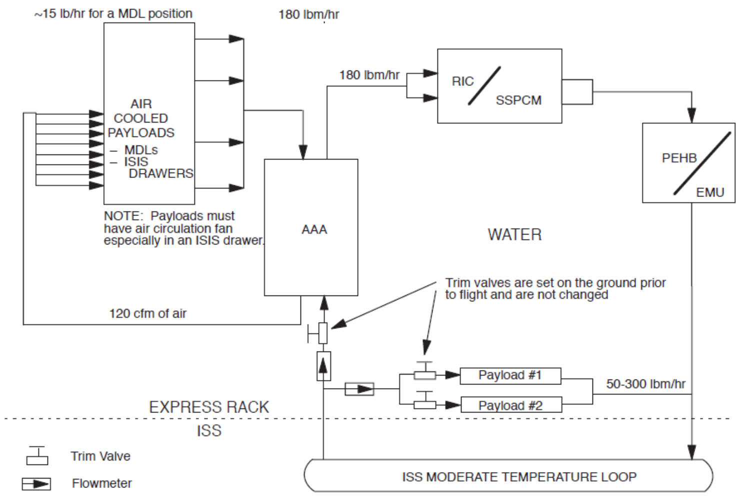

Figure 1: Expedite the processing of experiments to space station (EXPRESS) rack thermal schematic diagram

This paper has obtained the steady performance test results of experiment rack thermal control system, which based on the main test indicators of space experiment rack thermal control system. Besides, air to water H/X is a main cooling equipment of experiment rack thermal control system, analysis of the relationship between heat exchanger's performance, distribution of air and water flow rates and heat dissipated by air cooling is conducted in the paper.

2. Experiments

2.1 Experiment rack TCS design indexes

The experiment rack thermal control subsystem has been designed to verify whether the thermal control performances of the rack payloads meet the design requirements. The design indexes of ground performance test setup of the TCS is mainly depend on the design indexes of the space science experiment rack TCS. The experiment setup was built to study the heat transfer performances of air and water cooling loop of the payloads. The setup would realize the temperature predication and evaluate the overall temperature control level of the TCS[11].

(1) Experiment setup heat dissipation capacity
    The experiment rack TCS performance test platform can dissipate heat loads up to 1500 watts.

(2) Temperature of fluid in experiment units
    Table 1 shows the design indexes of air and water loop of experiment rack TCS test setup.

(3) Fluid flow of experiment setup
    The maximum flow rate of air cooling loop should be 204m3/h, the maximum flow of water cooling loop should be 170kg/h.

Table 1: Design indexes of fluid circuit temperature

water inlet temperature/℃	**water outlet temperature/℃**	**air inlet temperature/℃**	**air outlet temperature/℃**
17～21	≯29	19～30	≯45

2.2 Experiment rack thermal control system performance testing

A schematic of the experiment rack TCS performance test fluid layout was depicted in figure 2. The experiment system consists of two main loops: water loop and air loop. The experiment setup of the water loops was pumped by the low-temperature loop water tank. The outlet temperature was controlled by refrigerator of the water tank. The cooling water flow from the tank to the experiment rack TCS was divided to three branches, which were all equipped with solenoid valves and turbine flowmeters. The water flow states of three branches were controlled by the valves and monitored by the flowmeters. One of three branches flowed through a cross-counterflow air-to-water H/X. The branch flowed into an electronic coldplate for cooling electronic modules. The maximum flow of the water cooling loop from the heat exchanger to the electronic coldplate was 80kg/h. The other two branches flowed into two coldplates which controlled the temperature of payloads, respectively. The maximum flow of the water cooling loops

was 45kg/h. Three branches converged into the low-temperature loop water tank and then started the next water cooling loop. Electronic heating films which attached the coldplates could be used to simulate heat flux of payloads. In order to reduce heat loss of the heating films, rubber insulation cotton could be used to equip with all the heat transfer equipments such as heat exchanger, coldplates, etc.
Air cooling of the TCS performance test was carried out by the air cooling section. The air cooling and loop functions combine with the TCS and intermodule ventilation to provide element thermal management. A fan drove the exhausted air from the air heater. After the fan, the air flow passed through the air to water H/X to dissipate to all the collected heat which simulated experiment thermal loads to the air. Air loop, in conjunction with the air cooling minimized hot spots and reduced the possibility of overheating non-coldplate equipment. Pt100 temperature sensors within the uncertainty of ±0.1℃ were used to measure the inlet and outlet temperatures of water and air loop. The data acquisition unit was linked to the computer to record the time-temperature history of each Pt100.

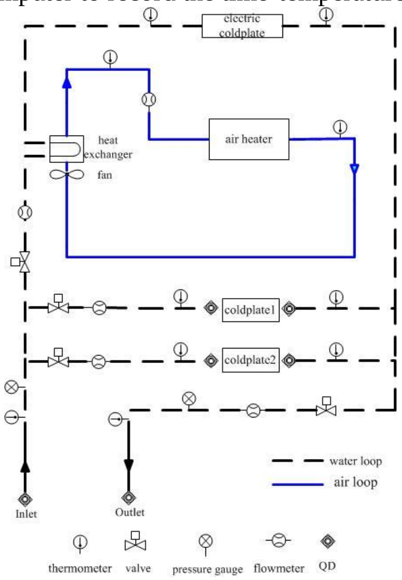

Figure 2: Experiment rack thermal control system performance test schematic diagram

3. Results and discussion

3.1 Experiment rack TCS steady-state performance test analysis

Steady-state performance tests took use of the design indexes of experiment rack TCS platform to inspect thermal control capacity of the setup. Electrically insulated film heaters were attached below each coldplate using a thin layer of thermal conducting paste. An adjustable DC power supply was connected to the heaters. The heaters can provide constant heating for the TCS. The input heat power of three coldplates are 300W (coldplate1), 300W (coldplate2), 200W (electric coldplate). The ambient temperature of experiment tests was 22.5℃. The air flow rate of the experiment tests was 204m^3/h and the water flow rate was 170kg/h. The outlet air temperature of the air heater was 43℃ and the outlet water temperature of the low-temperature tank was 21℃. Based on a lot of TCS performance tests, the changes of TCS test parameters became stable after half an hour time. Therefore, those parameters can be considered as the reasonable data. Figure 3 shows the steady state parameters of the experiment rack TCS. The inlet and outlet water temperature of coldplate 1 were 21.22℃ and 26.43℃, respectively. The inlet and outlet water temperature difference was 5.21℃. The heat absorption of the coldplate 1 was 278W. The inlet and outlet water temperature of coldplate 2 were 21.16℃ and 26.21℃, respectively. The inlet and outlet water temperature difference was 5.05℃. The heat absorption of the coldplate 2 was 270W. The inlet and outlet water temperature of electronic coldplate were 29.35℃ and 31.25℃, respectively. The inlet and outlet water temperature difference was 1.90℃. The heat absorption of the electronic coldplate was 178W. The inlet and outlet water temperature of air to water H/X were 21.14℃ and 29.35℃, respectively. The inlet and outlet water temperature difference was 8.21℃. The heat absorption of the air to water H/X was 772W. The inlet and outlet water temperature of TCS were 21.00℃ and 28.44℃, respectively. The inlet and outlet water temperature difference was 7.44℃. The heat absorption of the TCS was 1495W. The actual operating state of the TCS meet the design indexes mentioned in chapter 2.1, which showed that the design of the TCS performance test setup was reasonable. The heat transfer process of the experiment system was very stable. The inlet and outlet water temperature varied small. All of the testing methods and the collected parameters were accurate and reliable.

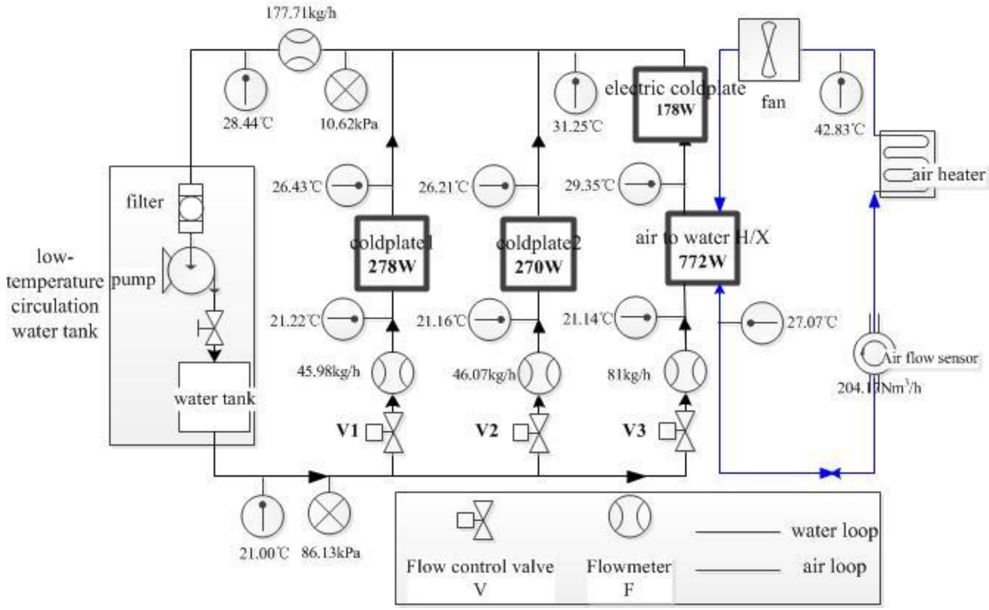

Figure 3: Experiment rack thermal control system steady-state performance operating parameters

3.2 Air to water H/X heat transfer performance analysis

In order to measure air to water H/X heat transfer performance and get the following experiment rack TCS flow distribution data, the experiment set the following initial conditions. The inlet water temperature of air to water H/X was 21℃. The temperature of inlet air, which came from the air heater, was 43℃. This design maintain effectiveness over an airflow range of 68 to 204 m^3/h and a coolant flow range of 45 to 80kg/h. Figure 4 shows heat transfer performance curves of air to water H/X for different air and water flow. With air and water flow increase, the heat transfer capacity of the air to water H/X increases in the conditions of certain inlet air and water temperatures. When the air flow rate increased from 68m^3/h to 136m^3/h, all of the slope of heat transfer performance curves got larger and the heat transfer amount were enhanced significantly. When the air flow rate increased from 136m^3/h to 204m^3/h, the slope of all the heat transfer performance curves were relatively small and the heat transfer amount were enhanced gently. According to the curve variation tendencies, with the air flow continually increase, the heat transfer amount will increase more gently. If the air flow rate is further increased, the heat transfer enhancement amount of the air to water H/X will not be quite as obvious.

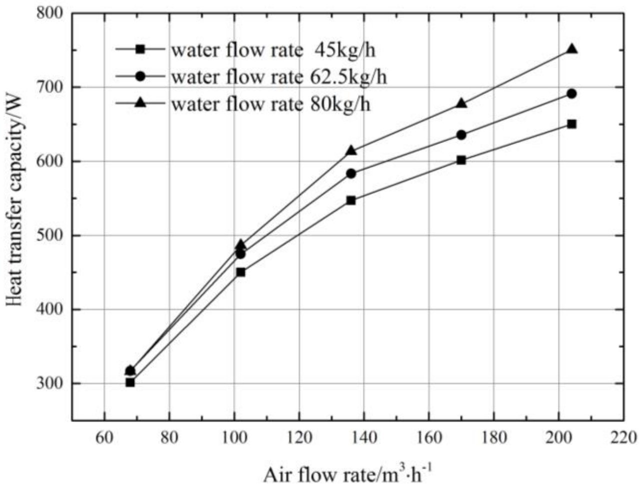

Figure 4: Heat transfer performance curves of the air to water H/X

The flow distribution design of air to water H/X is mainly based on payload air cooling heat transfer capacity and heat transfer performance curves. The water flow rate and air flow rate of the air to water H/X will be adjusted in the designed range. As shown in figure 5, the maximum air flow rate and water flow rate of the air to water H/X was $204m^3/h$ and 80kg/h, respectively. The maximum heat transfer amount of the H/X was 750W. $1m^3/h$ unit air flow rate and 1kg/h unit water flow rate can dissipate 3.68W and 9.375W payload heat transfer capacity under the operating pressure of 101kPa. If the air flow rate is more than $68m^3/h$ and the water flow rate is more than 45kg/h, air and water flow rate will be adjusted according to the payload heat transfer capacity. It can optimize the resource allocation. The cooled air will be supplied directly into each experiment payloads.

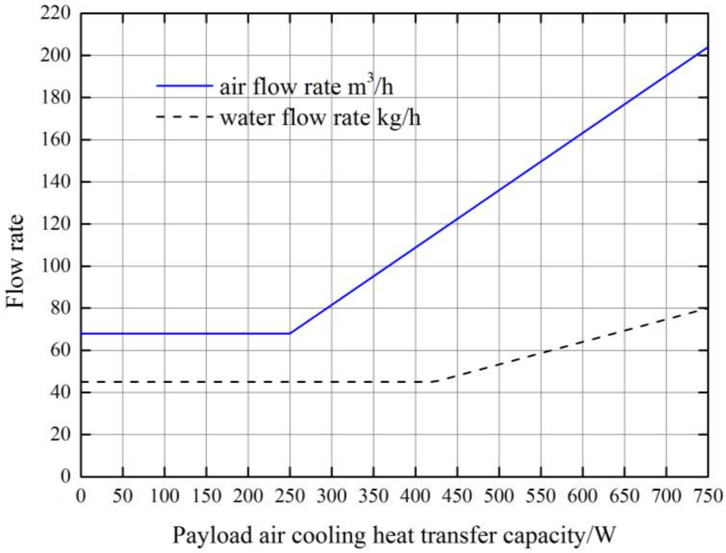

Figure 5: Flow distribution curves of the air to water H/X

4. Conclusion

The paper described the principle and design indexes of space science experiment rack thermal control system. The ground performance experiment setup of the TCS was built. By steady-state performance tests, the TCS was stable and the effective data were obtained after the test adjusted about half an hour. When air and water flow rate adopted the maximum design values, the operating state of the system will meet the design indexes of the experiment setup. According to the performance curves of the air to water H/X with different air and water flow rate, flow distribution curves between the payload air cooling curves of the TCS and the flow distribution of the H/X were obtained. The study provides guidelines for the air and water regulation of space science experiment rack thermal control system.

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