Experimental Investigation of the Heat transfer Performance of a Newly Designed Heat Pipe Cold Plate

Zheshu Ma, Shouguang Yao
School of Mechanical and Power Engineering
Jiangsu University of Science and Technology
2nd , Mengxi Road, Zhenjiang City，Jiangsu Province, 212003
The People's Republic of China

ABSTRACT: To deal with multi-heat-source and high-heat-flux heat transfer problem in the confined space within electronic equipments, cold plate equipment employing heat pipe technology is designed. Acetone-aluminum heat pipe construction composed of eight vertical pipes with their upper condensation section and lower evaporation section connected to let the working liquid and vapor flow through each other when the equipment works. The evaporation section of the connective heat pipe construction is embedded in the aluminum-made cold plate and the condensation section of the construction is cooled by cooling water flowing through the water jacket. Sixteen electronic-heating heat sources are evenly arranged on the two bigger vertical surfaces of the cold plate to simulate heat generation of the real array antennas and heat is eventually transferred to cooling water and then to outer environment. The startup performance and temperature evenness performance of the newly-designed heat pipe cold plate equipment are tested under different heat loads, different heat load means, different flow rates of cooling water. Experimental study indicates that the heat pipe cold plate equipment possesses excellent heat-transfer performance, startup performance and temperature evenness and it can solve the high heat-flux problem determining the working reliability of array antennas effectively.

Key-Words: Electronics cooling; Heat pipe cold plate; Experimental study; Heat transfer; Startup performance

1 Introduction

With the integration of electronic circuits and greatly increased power capacity of power appliances, cooling arrangements owing higher and higher heat transfer performance to provide electronic equipments suitable thermal environments are required as electronic devices have been becoming smaller and smaller. Today, how to solve cooling problems within electronic appliances effectively has been developed to one of the key technology of the design of electronic equipments[1-3].

Cooling of array antennas of shipborne radar equipment is a multi-heat-source and high-heat-flux heat transfer problem in confined space. In current employed forced-convection water-cooling cold plate equipment, cold plate is the main part of the heat exchanger and its two big vertical surfaces are the assembly surfaces of array antennas. Long-time application indicates that heat-transfer performance of the cold plate equipment is difficult to meet the cooling requirement. On the other hand, uneven plastic deformation of the surfaces of the cold plate caused by uneven temperature distribution further affects the effective running of antennas greatly and cooling effect. To deal with it, cold plate equipment employing acetone- aluminum heat pipe is designed and tested. Experimental study shows that the heat pipe cold plate equipment possesses excellent heat transfer performance and can afford more effective cooling to array antennas.

2 Design of the Heat Pipe Cold Plate Equipment

Based on the thermal environment wherein array antennas of shipborne radar equipment works well, constraints of the design of heat pipe cold plate equipment are as follows:

(1) total power of heat transfer of the equipment must be more than 12kW;

(2) maximum heat flux are more than 24W/cm^2;

(3) the maximum temperature of the equipment surface must be lower than 70℃;

(4) the temperature difference on equipment surface must be lower than 10℃ under different working conditions.

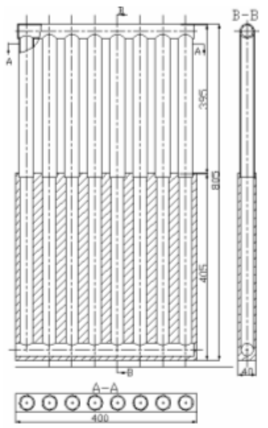

Fig.1 construction of heat pipe cold plate equipment

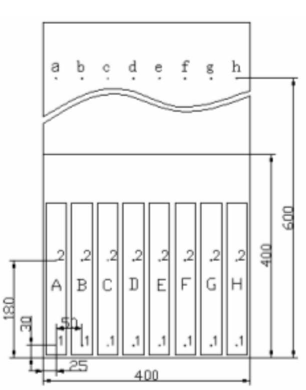

Fig.2 distribution of thermocouples

The newly designed heat pipe cold plate is shown in Fig.1. Acetone-aluminum heat pipe construction composed of eight vertical pipes with their upper end and lower end connected to let working liquid flow through each other is embedded in the aluminum-made cold plate. Eight electronic - heating heat sources are evenly arranged on each of the two bigger vertical surfaces to simulate heat generation of the array antennas and heat is eventually transferred to cooling water surrounding the condensation segment and then to outer environment. Under this construction, for branches of the heat pipe is connected through with each other, different temperature and pressure in the branches caused by different antennas' working combinations can be effectively reduced and quickly maintain to a new balanced temperature and pressure level and thus the equipment can quickly works stably. Thus, temperature evenness performance of the equipment under different heating conditions becomes better. To gain good weldability, water jacket used for cooling employed aluminum alloy plate also. The inlet and outlet of cooling water are on the opposite side of the cooling water jacket and there is a hole on the top of the jacket to allow the thermocouples measuring temperatures of condensation segment through.

3 Design and Working Principle of the Experimental System

Pure aluminum blocks, which shapes are just the same as the real array antennas, are employed to simulate the heat generation of real array antennas. Each block is machined with one groove to embed the electronic heating piece generating heat. Heating conditions of the experiment are realized by electronic heating pieces employing different coil densities in different heat-generation areas. Pure aluminum blocks contact closely with the surface of the cold plate and are stuck solidly with conductive silicon glue. Further, a pair of iron clamps designed by us is employed to ensure better fixation.

The two big vertical surfaces of the cold plate are marked "positive" and "negative". Eight Simulative antennas on the "positive" and the "negative" surface are marked "A", "B", "C", "D", "E", "F", and "G", "H". Thermocouples employed to measure temperatures of high heat flux areas are marked "1" and thermocouples employed to measure temperatures of low heat flux areas are marked "2". Thus, measuring point under the "A" simulative antenna and on the high flux area of "positive" surface can be nominated "positive A1". At the same time, eight thermocouples, marked "a", "b", "c", "d", "e", "f", "g", "h", are welded at the middle of the condensation segment on each branch heat pipes. Thus there are 40 thermocouples in the experimental system. The arrangement of thermocouples is shown on Fig.2.

To realize dynamic data acquisition and graphic display, data acquisition and processing system is employed. The hardware system is set up based on a "PCL-812PG" A/D card and three serial "PCLD-789D" cards and the software system is developed based on Kingview6.01 desktop. The data acquisition and processing system can acquire dynamic data from each channel and display the data varying curves. In addition, data acquired are stored as Access2000 database to be convenient for analysis.

4 Experimental Contents and Results Analysis

The startup performance and temperature evenness performance of the heat pipe cold plate are tested under full heat load condition and partial heat load conditions. The full load condition is the condition under which all simulative antennas work and under partial load conditions more than one antenna doesn't work. The startup performance includes the startup time and how other factors affect the startup time. In this paper, experiments under different cooling water flow rate with the same heat generation power and different heat generation power with the same cooling water flow rate are processed and reported. In all the following result figures, temperatures of thermocouples "1" and thermocouples "2" are the average temperatures of the 8 branches at the same height.

4.1 Startup Performance and Temperature Evenness Performance of the Heat Pipe Cold Plate under Full Load Conditions

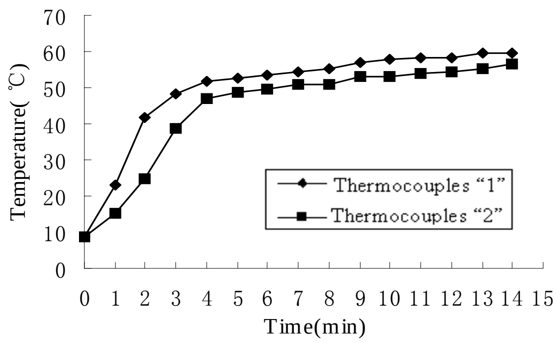

Fig.3a Startup performance of heat pipe cold plate
P=4000W，m=200L/h

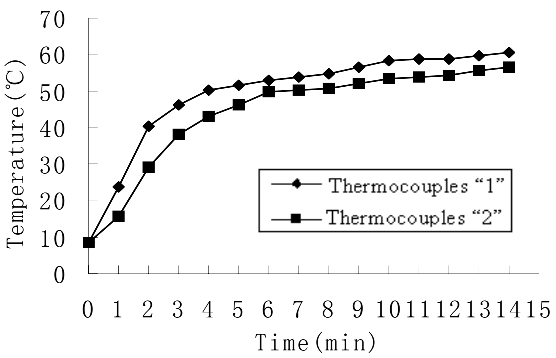

Fig.3b Startup performance of heat pipe cold plate
P=4000W，m=300L/h

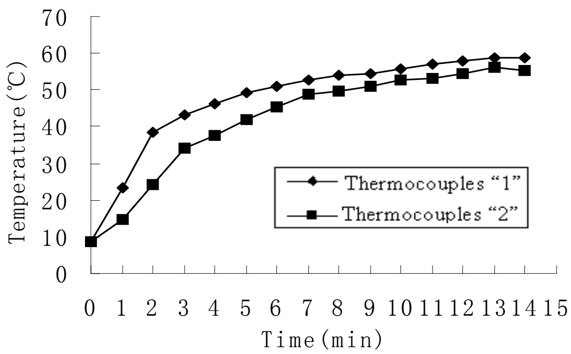

Fig.3c Startup performance of heat pipe cold plate
P=4000W，m=400L/h

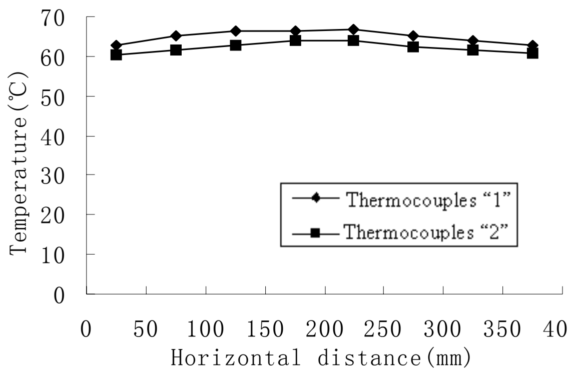

Fig.4a Temperature evenness of heat pipe cold plate
P=4000W，m=200L/h

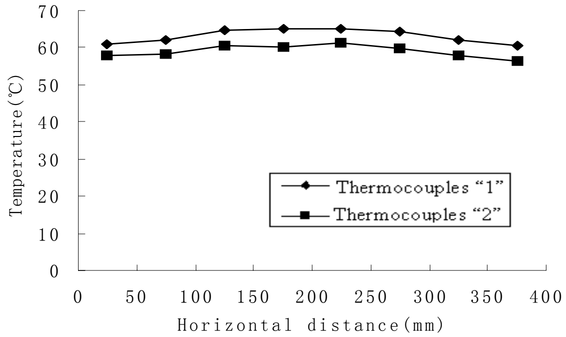

Fig.4b Temperature evenness of heat pipe cold plate
P=4000W，m=300L/h

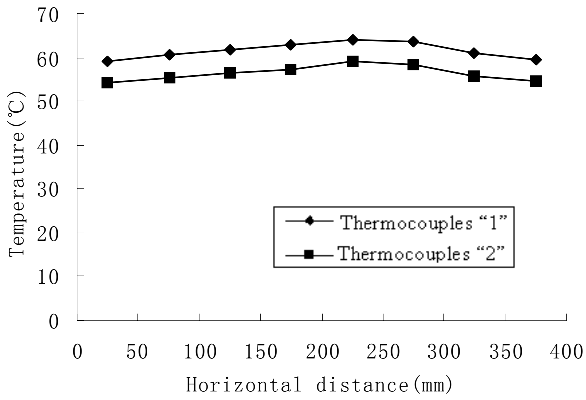

Fig.4c Temperature evenness of heat pipe cold plate
P=4000W，m=400L/h

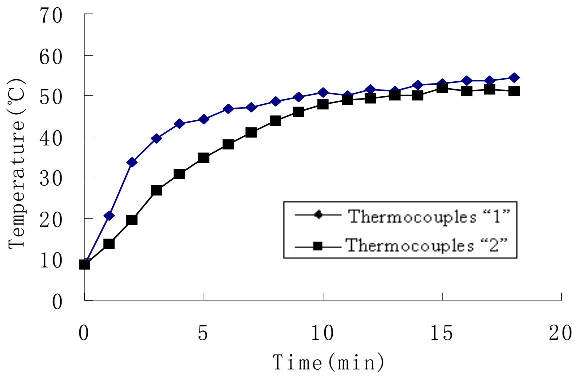

Fig.5a Startup performance of heat pipe cold plate
P=2000W，m=200L/h

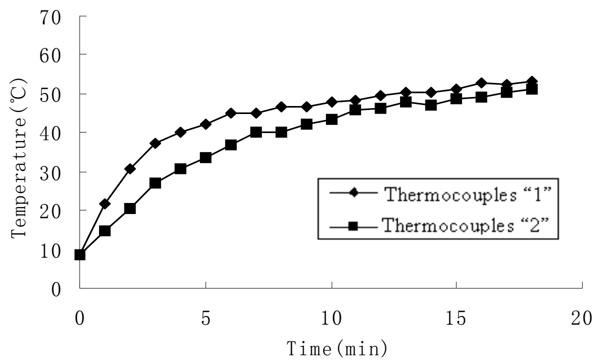

Fig.5b Startup performance of heat pipe cold plate
P=2000W，m=300L/h

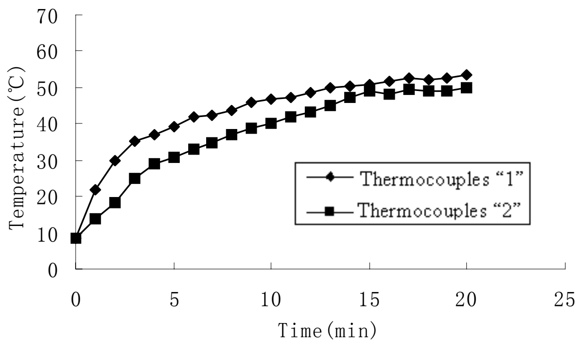

Fig.5c Startup performance of heat pipe cold plate
P=2000W，m=400L/h

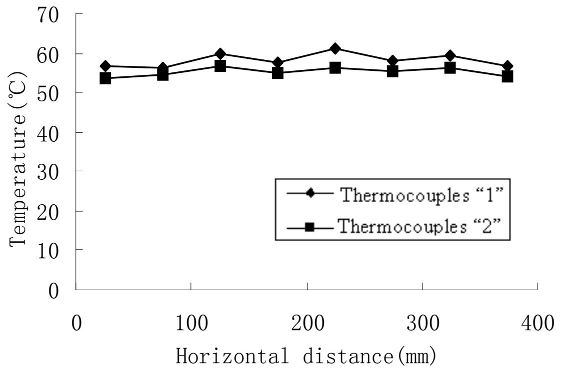

Fig.6a Temperature evenness of heat pipe cold plate
P=2000W，m=200L/h

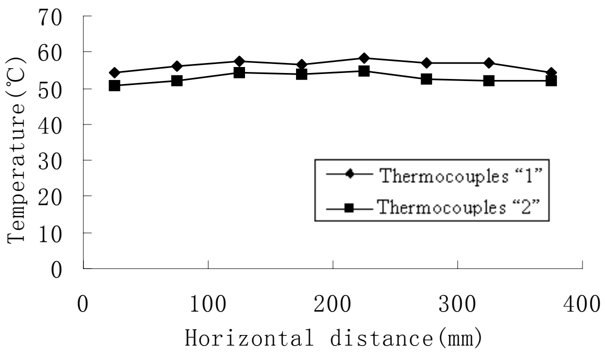

Fig.6b Temperature evenness of heat pipe cold plate
P=2000W，m=300L/h

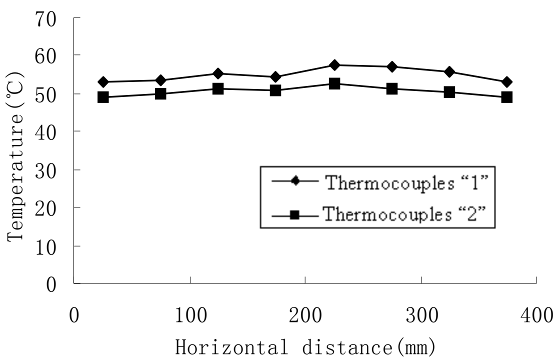

Fig.6c Temperature evenness of heat pipe cold plate
P=2000W，m=400L/h

Fig.3a, Fig.3b and Fig.3c are startup curves of heating power P=4000W and cooling water flow rate m=200L/h, 300L/h and 400L/h alternately. Fig.3a shows that temperatures of “1” are higher than that of “2”. For “1” locates on high heat flux area while “2” locates on the low heat flux area, temperatures of “1” increase more quickly than that of “2”, as the slopes of the start segment of the curves shows. After four minutes, difference of temperatures of “1” and “2” is coming to a stable value and temperatures are beyond 50℃. It can be concluded that the heat pipe cold plate equipment has already been startup. Contrast to Fig.3a, Fig.3b and Fig.3c, startup performances under same heating power but different cooling water flow rate are similar to each other: the working temperature of the equipment is about 60℃ and the startup time becomes longer with the increase of cooling water flow rate.

Fig.4a, Fig.4b and Fig.4c show temperature difference of “1” and “2” on different simulative antenna under heating power P=4000W and cooling water flow rate m=200L/h, 300L/h and 400L/h alternately. In these curves, distance direction is the horizontal direction of the cold plate, temperature values are temperatures of “1” and “2” on different simulative antennas. In Fig.4a, the maximum surface temperature is 66.75℃ and the minimum is 60.44℃. The difference of the two is 6.31 ℃ (lower than 10 ℃). The surface temperature in the middle is higher than that of the two sides. It may be that the vapor pressure in the middle branch is higher than that of the other branches and thus the acetone liquid in it is less than that of the others. With the increase of cooling water flow rate, the working temperature lowers a little and difference between “1” and “2” becomes a little bigger, as is shown in fig.4a, fig.4b and fig.4c.

4.2 Startup Performance and Temperature Evenness Performance of the Heat Pipe Cold Plate under Partial Load Conditions

Fig.5a, Fig.5b and Fig.5c are startup curves of heating power P=2000W (simulative antennas marked “A”, “C”, “E” and “G” on both surfaces work while other simulative antennas don’t work) and cooling water flow rate m=200L/h, 300L/h and 400L/h alternately. Contrast Fig.5a, Fig.5b and Fig.5c with Fig.3a, Fig.3b and Fig.3c, startup performances and variation of working temperature of the cold plate equipment under partial load conditions (with same heating power but different cooling water flow rate) are similar. The startup time becomes longer with the increase of cooling water flow rate.

Fig.6a, Fig.6b and Fig.6c show temperature differ -ence of “1” and “2” on different simulative antenna under heating power P=2000W (simulative antennas marked “A”, “C”, “E” and “G” on both surfaces work while other simulative antennas don’t work) and cooling water flow rate m=200L/h, 300L/h and 400L/h alternately. Because “A”, “C”, “E” and “G” antennas on both surfaces work while other simulative antennas don’t work under this heating arrangement, the temperature curves fluctuate. On the other hand, for heat pipe branches are connected through with each other, heat pipe branches still work though simulative antennas on which don’t work. Pressure in the heat pipe construction goes to a new balanced value and thus the temperatures of “1” and “2” under simulative antenna marked “B”, “D”, “F” and “H” are still close to that of the appropriate others. It indicates that the heat pipe cold plate equipment evens the surface temperature well. With the increase of cooling water flow rate, working temperature of cold plate decreases and difference between “1” and “2” becomes a little bigger and thus the heat pipe cold plate equipment evens the surface temperature worse.

5 Conclusion

(1)Experiments of heat pipe cold plate equipment under full load conditions and partial load conditions shows that startup time becomes longer as cooling water flow rate increases and startup time becomes shorter as heat generation power increases;

(2)Under full load conditions and partial load conditions, the heat pipe cold plate equipment evens the surface temperature of cold plate well and meets the design requirements;

For electronic heating pieces can’t resist the required design value of partial heat flux value ($24W/cm^2$), experiments under design heating power are not carried out. But through the conclusion gained and real experiments, if the new heating means can afford design heat generation power and realize appropriate power distribution, the heat transfer performances (startup performance and temperature evenness performance) of the designed heat pipe cold plate will be even better. On the other hand, from the detailed numerical simulation of the liquid-vapor two-phase flow in the heat pipe cold plate [4,5], it can be concluded that the newly designed heat pipe cold plate can provide excellent cooling of array antennas.

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