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Investigation the effectiveness of using heat pipe on the temperature uniformity distribution over the SC equipment panel

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Abstract. The heat pipe is a thermal device which allows an efficient transport of thermal energy. In this paper parametric study has been achieved to investigate the importance of using heat pipes about the uniformity of the temperature distribution over the equipment panel of the spacecraft (SC), which is a part of a real thermal control subsystem. Heat pipe analytical solution is used as a guide for design and geometrical parameters selection. The design of SC equipment panel radiator and a parametric study of the heat pipe are obtained numerically using Thermal desk top program (TDT). The space environment and the spacecraft operational conditions have been simulated by TDT program. Heat pipe prevents the hot spots which can be occurred due to the different equipment heat dissipation. The selected heat pipe design approach incorporates a conservative reliability philosophy and provides maximum operational flexibility

Keywords: Heat pipe, SC thermal control

1. Introduction

Spacecraft operates in specific environment, which is significantly different from Earth environment. Space environment is ultrahigh vacuum. SC operates with external heat flows fluctuations depending upon diurnal, orbital and other modes. Spacecraft hardware can operate in duty or session modes. Thermal control subsystem is used in spacecraft to maintain the temperature of the SC equipment in the operating temperature range. Passive thermal control system is used to reduce the consuming power of the SC. There are many components of SC thermal control system operates passively. [1]Materials and coatings, Shield-vacuum thermal insulation, Thermostats, Cold plates, Space radiators and heat pipes (HP) are passive thermal control components. Heat pipe is an appropriate passive device for space applications which does not consume electrical power. The HP is filled with a small amount of a working fluid by such a way that liquid completely soaks into the wick, whereas vapor occupies the central core. The idea of the heat pipe time constant is introduced in this work to describe the transient characteristics of the HP. Operation principal can be illustrated briefly as follow for aluminum/ammonia heat pipe with a sintered wick structure[6].

After applying heat on one end of the HP, the liquid evaporates, flows to the colder and the temperature of the evaporator will rise and sequentially the corresponding pressure will rise to move the



working fluid to the condenser side due to the potential difference. Under capillary action liquid returns through the wick to the evaporation section, closing the heat and mass transfer cycle. Due to the high value of the latent heat of the fluid, the mass flow rate, needed to transport the heat to a specified distance, is small enough to be pumped only by capillary tension forces at 0-gravity (0g) conditions. In this paper the effect of heat pipe on the panel temperature distribution is represented by constructing an equipment panel without heat pipe and with electrical heaters and study the temperature distribution over the equipment panel. Then assemble the equipment panel with adding the heat pipe and study the effect of adding the heat pipe on the panel temperature distribution at the same external and internal conditions and missions.[2] The assembly consists of the heat pipe itself, an evaporator and a radiator. The internal HP geometry and the dimensions of the radiator panel are the variables to be optimized. Operational and structural constraints are considered and the assembly is optimized for different operational modes

2. Mathematical analysis

The design of a heat pipe or thermos-syphon to fulfill a particular duty involves four broad processes:

- Selection of appropriate type and geometry
- Selection of candidate materials
- Evaluation of performance limits
- Evaluation of the actual performance

The design procedure for a heat pipe is outlined in Fig. 1. As with any design process, many of the decisions that must be taken are interrelated and the process is iterative. For example, many candidate working fluids, often including water, due to compatibility constraints. If the design then proves inadequate with the available fluids, it is necessary to reconsider the choice of construction materials. Two aspects of practical design, which must also be taken into consideration, are the fluid inventory and performance at off-design conditions, particularly during the start-up of the heat pipe. HP cross-sectional view is shown in Fig.2. This section describes a mathematical analysis under the following assumptions:

- Heat transfer from the heat pipe condenser surface is by radiation only.
- Heat fluxes into the evaporator and the condenser are uniform.
- Heat pipe condenser has a constant temperature distribution along the heat pipe axis.
- Heat flow in the heat pipe is one dimensional.
- Vapor flow in the heat pipe is laminar and incompressible.
- Heat pipe radiator is exposed to deep space.

2.1. Heat balance equation

2.1.1. Heat pipe section

The HP primary heat transfer mechanisms[1] for the low temperature are:

- Heat conduction across the container wall and the liquid-saturated wick at the evaporator section
- Convective transport of latent heat by vapor from the evaporator to the condenser.
- Heat conduction across the liquid-saturated wick and the container wall at the condenser section.
- The heat conduction in the pipe wall and in the liquid-saturated wick can be described by where ΔT is the temperature drop through the wall and R is the thermal resistance, which can be evaluated from expressions for the cylinder wall:

$$R = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi.L.K} \quad (1)$$

where, R is the thermal resistance, L is the pipe length, K is the thermal conductivity and r_1, r_2 are the outer and inner pipe radius sequentially

$$T_1 - T_2 = \frac{T_v(P_2 - P_1)}{\rho_v \cdot h_{fg}} \quad (2)$$

where, T_1 is the condenser external surface temperature, T_2 is the evaporator external surface temperature, T_v is the vapor temperature, P_1 the condenser pressure, P_2 is the evaporator pressure, ρ_v is the vapor pressure and h_{fg} is the latent heat of vaporization

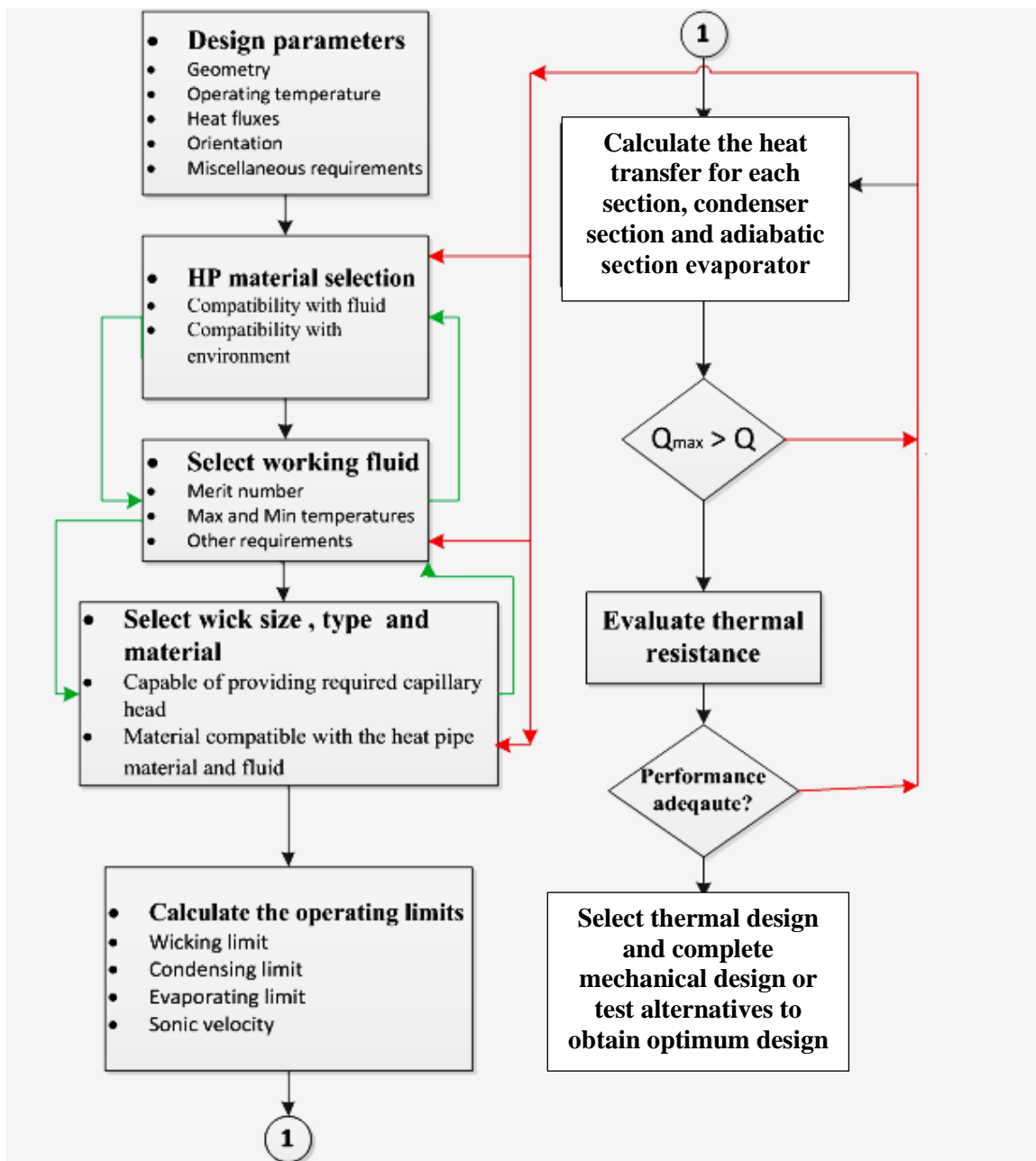


Figure 1. The HP design methodology flow chart

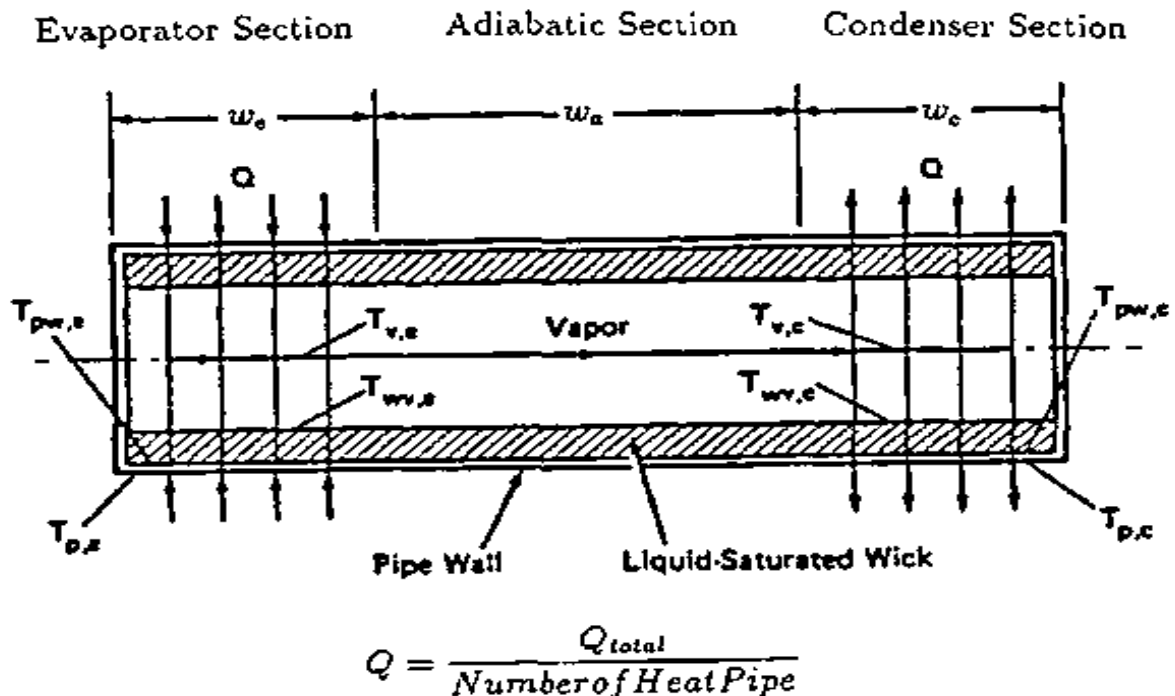


Figure 2. A section of the heat pipe

In figure 2, w_e is the evaporator section length, w_a is the adiabatic section length and w_c is the condenser section length.

$T_{p,e}$ is the external pipe evaporator section temperature, $T_{pw,e}$ is the pipe wick structure evaporator section temperature, $T_{p,c}$ is the external pipe temperature of the condenser, $T_{pw,c}$ is the pipe wick structure condenser section temperature, $T_{wv,e}$ the internal temperature of the wick of the evaporator section, $T_{wv,c}$ the internal temperature of the wick of the condenser section, $T_{v,e}$ is the vapor temperature of the evaporator section and $T_{v,c}$ is the vapor temperature of the condenser section, Q is the heat load of the heat pipe

The HP balance equations for the three HP sections are presented as following:

Evaporator section

- Heat transfer between external and internal pipe surface

$$T_{Pe} - T_{PW_e} = Q \left[\frac{\ln(r_o - r_i)}{2\pi \cdot W_e \cdot K_p} \right] \quad (3)$$

where K_p is the pipe material thermal conductivity

- Heat transfer between external and internal wick surface

$$T_{PW_e} - T_{WV_e} = Q \left[\frac{\ln(r_i - r_v)}{2\pi \cdot W_e \cdot K_{e_e}} \right] \quad (4)$$

where K_{e_e} is the wick effective thermal conductivity

- Heat transfer between Evaporator and condenser by axial convection

$$T_{v_e} - T_{v_c} = \frac{T_v(P_v - P_c)}{\rho_v \cdot h_{fg}} \quad (5)$$

- Heat transfer at condenser section

$$T_{w_{vc}} - T_{p_{wc}} = Q \left[\frac{\ln(r_i - r_v)}{2\pi \cdot W_c \cdot K_{e_e}} \right] \quad (6)$$

where K_{e_c} is the thermal conductivity of the

$$T_{p_{wc}} - T_{p_c} = Q \left[\frac{\ln(r_i - r_v)}{2\pi \cdot W_c \cdot K_p} \right] \quad (7)$$

Combining all the previous equations, the temperature difference between the condenser and evaporator will be defined as the follows;

$$T_{p_e} - T_{p_c} = Q \left[\frac{\ln(r_o - r_i)}{2\pi \cdot W_e \cdot K_p} + \frac{\ln(r_i - r_v)}{2\pi \cdot W_e \cdot K_{e_e}} + \frac{T_v(P_{v_e} - P_{v_c})}{\rho_v \cdot h_{fg} \cdot Q} + \frac{\ln(r_o - r_i)}{2\pi \cdot W_c \cdot K_p} + \frac{\ln(r_i - r_v)}{2\pi \cdot W_c \cdot K_{e_e}} \right] \quad (8)$$

And the total heat transfer of the heat pipe is defined as

$$Q = A \cdot U_{HP} \cdot (T_{p_e} - T_{p_c}) \quad (9)$$

$$AU_{HP} = A_p U_{HPp} = A_e U_{HP,e} = A_c \cdot U_{HPc} \quad (10)$$

Choosing the cross-sectional area for this area

$$Q = A \cdot U_{HP} \cdot (T_{p_e} - T_{p_c}) \quad (11)$$

where T_{p_e} is the outer surface temperature of the evaporator, T_{p_c} is the outer surface temperature of the condenser, U_{HP} is the overall heat transfer coefficient based on an arbitrary area, A .

Note that A may be the cross-sectional area of the pipe A_p , the surface area of the evaporator A_e , the surface area of the condenser A_c , or any other area. By nature of the definition for U_{HP} , it follows that

$$AU_{HP} = A_p U_{HPp} = A_e U_{HP,e} = A_c \cdot U_{HPc} \quad (12)$$

Choosing the cross-sectional area for this area

$$Q = A_p \cdot U_{HP} \cdot (T_{p_e} - T_{p_c}) \quad (13)$$

$$U_{HP,p} = \left[\frac{r_o^2}{2 \cdot W_e \cdot K_p} \ln \left(\frac{r_o}{r_i} \right) + \frac{r_o^2}{2 \cdot W_e \cdot K_{e_e}} \ln \left(\frac{r_i}{r_v} \right) + \frac{\pi r_o^2 T_v (P_{v_e} - P_{v_c})}{\rho_v \cdot h_{fg} \cdot Q} + \frac{r_o^2}{2 \cdot W_c \cdot K_{e_c}} \ln \left(\frac{r_i}{r_v} \right) + \frac{r_o^2}{2 \cdot W_c \cdot K_p} \ln \left(\frac{r_o}{r_i} \right) \right]^{-1} \quad (14)$$

The vapor pressure drop, $P_{v_e} - P_{v_c}$ is the sum of the average vapor pressure drops in the evaporator, the adiabatic section, and the condenser.

$$P_{v_e} - P_{v_c} = \Delta P_{v,e} + \Delta P_{v,a} + \Delta P_{v,c} \quad (15)$$

The average pressure drop through each section can be expressed as follows:

$$\Delta P_{v,e} = \frac{F_v \cdot w_e \cdot Q}{6} \quad (16)$$

$$\Delta P_{v,a} = F_v \cdot w_a \cdot Q \quad (17)$$

$$\Delta P_{v,c} = \frac{F_v \cdot w_c \cdot Q}{6} \quad (18)$$

$$P_{v_e} - P_{v_c} = F_v \cdot Q \left(\frac{w_e}{6} + w_a + \frac{w_c}{6} \right) \quad (19)$$

The design equation of heat pipe will be as follows

$$T_{p_e} - T_{p_c} = Q \left[\frac{\ln(r_o - r_i)}{2\pi \cdot W_e \cdot K_p} + \frac{\ln(r_i - r_v)}{2\pi \cdot W_e \cdot K_{e_e}} + \frac{T_v F_v \cdot \left(\frac{w_e}{6} + w_a + \frac{w_c}{6}\right)}{\rho_v \cdot h_{fg}} + \frac{\ln(r_o - r_i)}{2\pi \cdot W_c \cdot K_p} + \frac{\ln(r_i - r_v)}{2\pi \cdot W_c \cdot K_{e_c}} \right] \quad (20)$$

Considering the temperature difference equation (20) between the evaporator and condenser depends on the following;

- Geometrical parameters
HP length, internal and external diameters,
HP material wick structure
- Fluid parameters
Working fluid type
- Flow parameters
Transient phase change flow, incompressible fluid flow

There are some constrains parameters which effect on the design as follows

Geometrical parameters Length of the panel and honeycomb thickness which will be translate into the external diameter of the heat pipe, the heat load which is one of the main parameter of the heat pipe design.

The design of the heat pipe depends mainly on the heat energy which will be transferred from the evaporator section to the condenser.

3. Numerical simulation

In this paper a numerical solution is provided to simulate the space conditions and the SC several missions in the designed orbit. [2]The effect of heat pipes effect on the temperatures distributions over the equipment panel is studied. The results of numerical predictions and the corresponding analysis are presented in this paper. A complete design of the thermal control subsystem which includes the MLI , electrical heaters , sensors, solar reflectors and heat pipes is also presented. Calculations of radiator area and electrical heaters power used to tune the thermal desk top analysis are modeled. External solar fluxes radiations are simulated in cold and hot cases. Panel emission rate depends on average panel's temperatures, panel's area, and optical characteristics of the surface. External absorbed heat fluxes of the interested panel are (solar fluxes, albedo, reflected solar fluxes from the earth and heat dissipation from equipment panel's)

3.1. Problem formulation

Satellite model in Low earth orbit, at 700 km is created using thermal desk top program to study the effect of heat pipe on the equipment panel temperatures distribution. temperatures field calculations for an equipment panel are performed to ensure the maximum and minimum temperatures of the lower sheet of the equipment panel from 0°C to 40°C and optimize the selection of the heaters power. Heat pipes are designed to prevent formulation of hot spots and distribute heat uniformly over the equipment panel.

3.2. Thermal desktop assumptions

Energy and continuity equation are solved in transient conditions

Maximum solar fluxes intensity is 1423W/m²

Calculation of the maximum heat fluxes power are calculated at the minimum values of heat fluxes at the shadow cold case

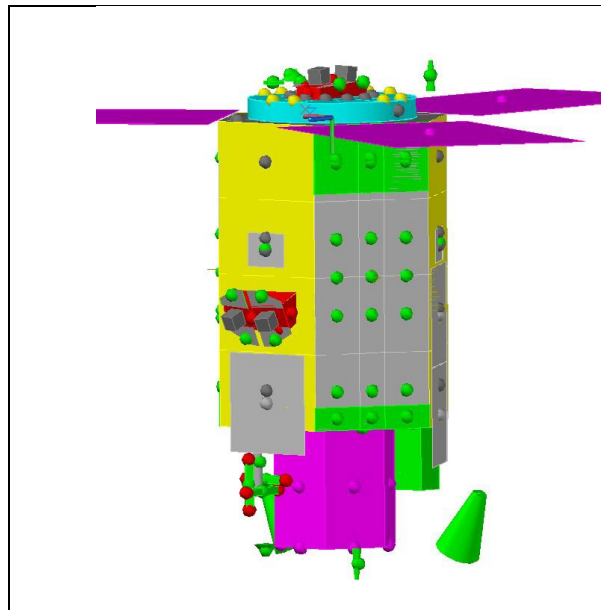


Figure 3. The complete structure for the SC with all the equipment

3.3. Calculations Steps:

- Draw SC by Thermal Desktop.
- Calculate Solar and Planet Heat Fluxes at Beta angles (angle between solar vector and plane of orbit) = (-75,-60,-45,-30,-15,0,15,30,45,60,75) for Inertial Orientation.
- Calculate Solar and Planet Heat Fluxes at Beta angles (angle between solar vector and plane of orbit) = (-75,-60,-45,-30,-15,0,15,30,45,60,75) for Orbital Orientation.
- Choose Max Heat Fluxes for Inertial and Orbital Orientation from all Angles.
- Calculate Solar Battery Fluxes.
- Substitute by the Value of Equipment Heat Dissipations To Calculate Radiators Area and Power of Heaters.
- According to the geometrical constrains and limitations of the panel, the heat pipe design parameters are chosen to match the panel requirements
- Design the SC equipment panel without heat pipes and another design adding the heat pipes to the panel to compare the valuable effect of the heat pipe on the panel temperature distribution
- Result analysis and conclusion

3.3.1. Heat fluxes

For the radiator area calculation, its necessary to calculate the external heat fluxes and the internal heat dissipation at the hot case which can cause an overheating of the SC equipment. [3]presented an optimization of a heat pipe radiator applied to a practical engineering design application. For this study, a communications satellite payload panel was considered. Four radiator areas were defined instead of a centralized one in order to improve the heat rejection into space; the radiator's dimensions were determined considering worst hot scenario, solar fluxes, heat dissipation and the component' s design temperature upper limit. Dimensions, thermal properties of the structural panel, optical properties and degradation/contamination on thermal control coatings were also considered. A thermal model was constructed for thermal analysis and two heat pipe network designs were evaluated and compared. In our analysis for the electrical heaters power, the calculation is executed by considering the minimum heat dissipation of the SC equipment at cold case for the surviving mode, few equipment in operation. Figure 4 represents the external heat fluxes which affects on the SC at the hot case. The heat fluxes includes the solar fluxes, reflected solar fluxes from the earth and the albedo.

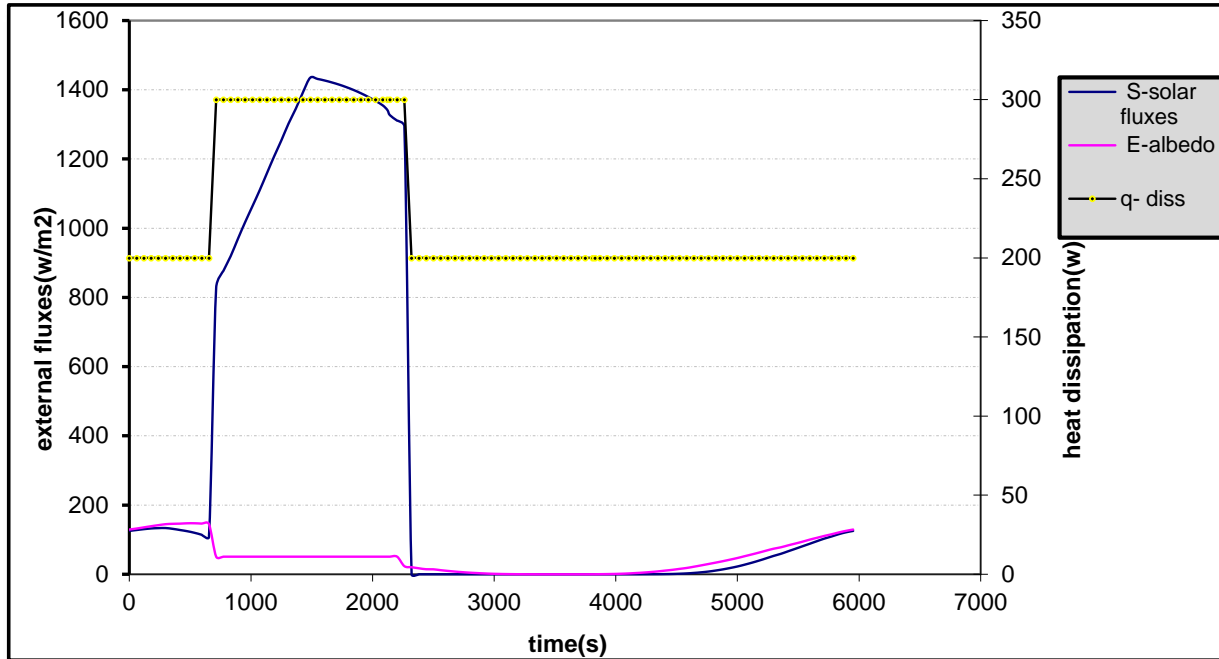


Figure 4. External heat fluxes and heat dissipation affect on the SC

Table 1 The external and internal heat fluxes affect on the equipment panel during the thermal cycle of the SC

Panel No.	q- Solar	q- Earth	q- SB	q- diss
1	368.7	48.6	96.4	227.2

For panel (1) thermal desktop program according to the input heat load which affect on the SC, calculate the heat fluxes over panel (1) .

3.3.2. Calculations of Radiators Area

Calculation of radiator area using the energy balance equation at the hot case conditions

$$q_S A_s F_{rad} + q_E \epsilon F_{rad} + q_{SB} \epsilon F_{rad} + q_{diss} - \epsilon \sigma T^4 F_{rad} = 0$$

where:

$$q_S = q_{Solar} + q_{Albedo}$$

$$A_s = 0.1 : 0.17 \quad \epsilon = 0.85 \quad T = 20 \text{ C}^0 = 293 \text{ k}$$

$$q_{SB} = \epsilon_{SB} \sigma T_{SB}^4 F_{SB} \phi_{SB-Panel i} (1 / F_{Panel i})$$

$$q_{SB Panel} = (\sum q_{SBi} / 4)$$

To Calculate T_{SB} :

$$q_S A_{s-front} F_{SB} - \epsilon_{front} \sigma T_{SB}^4 F_{SB} - \epsilon_{back} \sigma T^4 F_{rad} = 0$$

where:

$$A_{s-front} = 0.78 \epsilon_{front} = 0.92 \quad \epsilon_{back} = 0.9$$

3.3.3. Calculations of Heaters Power

$$q_{\text{diss-min}} + q_{\text{Heater}} - \varepsilon \sigma T^4 F_{\text{rad}} = 0$$

where:

$$\varepsilon = 0.85 \quad T = -5 \text{ } ^\circ\text{C} = 268 \text{ K}$$

Table (2) The calculated radiator area and electrical power heaters for panel

Panel No.	Radiator Area (m ²)	Power of Heaters (w)
	1.2	180

The calculated radiator area of the panel (1) is used to distribute the MLI and solar reflector over the panel. Electrical heaters power is used to grantee the optimum usage of the electrical power of the heaters, to avoid the high power consumption

3.4. SC panel at hot and cold case conditions

The SC and thermal control subsystem design are mainly depends on the external n internal effective conditions. The SC has to survive [4] and the SC equipment have to operate efficiently during the different modes and conditions. Cold and hot cases are studied to stand on the main requirements of the thermal control system.

Figure 5 shows the equipment panel assembled with the solar panel and equipment without adding the heat pipes. All the other thermal control components (electrical heaters , sensors MLI solar reflectors and thermal contact) are added to the equipment designed panel, and after adding the HP.

3.4.1. Creation of Heaters and Sensors

- Each heat pipe has three heaters: main1 & main 2 and reserve.
- Power of each heater is 30 W.
- Activation temperature of main 1 group is 8 °C, while deactivation temperature is 13 °C.
- Activation temperature of main 2 group is 5 °C, while deactivation temperature is 10 °C.
- Activation temperature of reserve group is 2 °C, while deactivation temperature is 7 °C.
- Two sensors in each zone (for two heat pipes) are used to take readings.

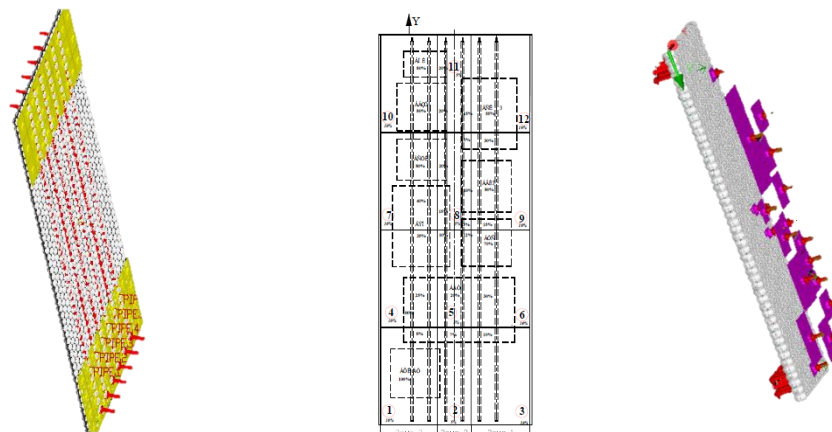


Figure 5 The equipment panel assembled by heat pipes, Equipment, electrical heaters, MLI and sensors

3.4.2. Cold case and hot case specifications

Three orbits are created to perform the calculations as follows :

Orbital position is the shooting mode position of the SC which the payload camera is pointing to the earth during the shooting session. Inertial position is the charging mode position of the SC which the SC solar panels are pointed to the sun. Orbital position and Inertial position at beta angle -60° as shown in figure 6 (a,b) which both of them represents the hot case.

Inertia position at beta angel 0° represents the cold case.

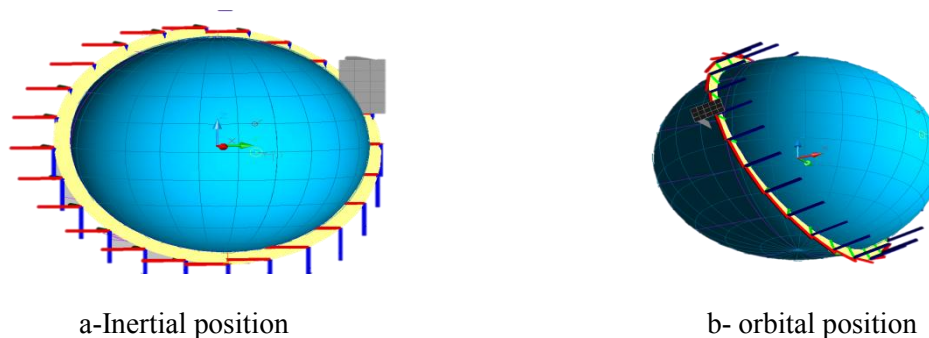


Figure 6 The hot case, inertial and orbital positions sequentially, at beta angle -60°

3.4.3. Creation of case set

The hot case calculations are performed in steady and transient conditions together Inertial and orbital positions at Beta angel 60° , Altitude 700

Planet data

- Radius of planet 6378.14 and Albedo = 0.35
- The hot case set includes 23 orbits as follows:
- 10 orbits with inertial orientation only.
- 3 consecutive orbits having orbital orientation for 25 min. for the first two orbits and 15 min. for the last one.
- 10 orbits with inertial orientation only.

The cold case set includes 10 orbits as follows:

10 orbits with inertial orientation only.

10 labs in the orbit needs 59515seconds

Calculations re performed in steady and transient conditions together

Inertial positions at Beta angle 0, Albedo = 0.35, Radius of planet 6378.14Altitude 500

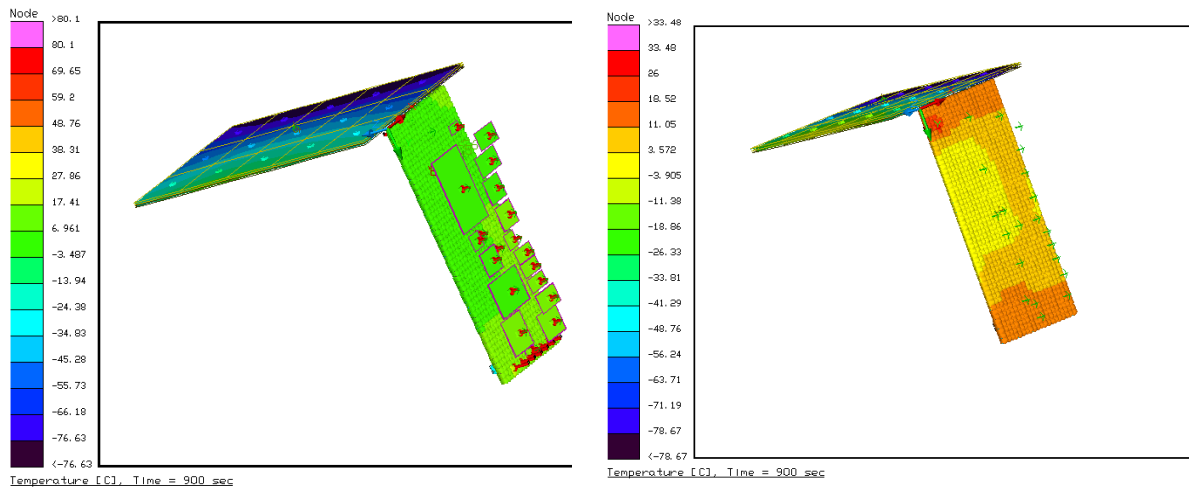
4. Results and Analysis

Temperature field calculations of an equipment panel with and without adding HP between the upper and lower sheet are created. Figure 7 a shows the main role of haet pipes for the uniform temprature field distribution over the equipmnet panel surfaces in cold case conditions. The maximum and mininum tempratures differences are so close between the two cases (using heat pipes and without using heat pipes). [4] The main reason for the two case to have the same temprature differences is use of the electrical heaters. Electrical heaters at the case of non using heat pipes is operating longer time to over come the cooling conditions which occurred due to non using the heat dissipation energy from the hot equipmnet to heat the other parts and equipmnet from the equipment panel. The hot spots and non uniformty of tempratures cause the thermal stresses and cracks which leads to mission faileur. The equipment panel without heat pipes has higher temprature differences between the upper and lower parts of the equipment panel due the apscence of HP

Table 3. The time intervals and the different positions of the SC during the two cases (cold and hot cases)

Time Intervals	Orientation	Explanation
0 S - 59515.1 S	Inertial	starts at 0 S
		ends at HR-period * 10 turns
59516 S - 61016.1 S	Orbital	starts at 0 S HR-period * 10 turns + 1 S
		ends at 0 S HR-period * 10 turns + 25 * 60 S
61017.1 S - 65466 S	Inertial	starts at 0 S HR-period * 10 turns + 25 * 60 + 1 S
		ends at HR-period * 11 turns
65467 S - 66967 S	Orbital	starts at HR-period * 11 turns + 1
		ends at HR-period * 11 turns + 25 * 60 S
66968 S - 71418 S	Inertial	starts at HR-period * 11 turns + 25 * 60 + 1 S
		ends at HR-period * 12 turns
71419 S - 72319 S	orbital	starts at HR-period * 12 turns + 1
		ends at HR-period * 12 turns + 15 * 60 S
72320 S - 136884 S	Inertial	starts at HR-period * 12 turns + 15 * 60 + 1 S
		ends at HR-period * 23 turns

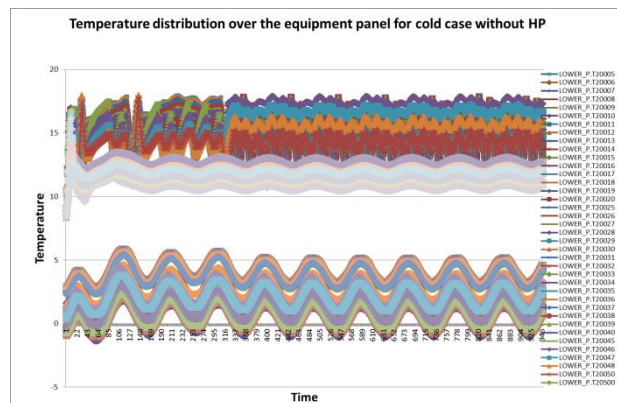
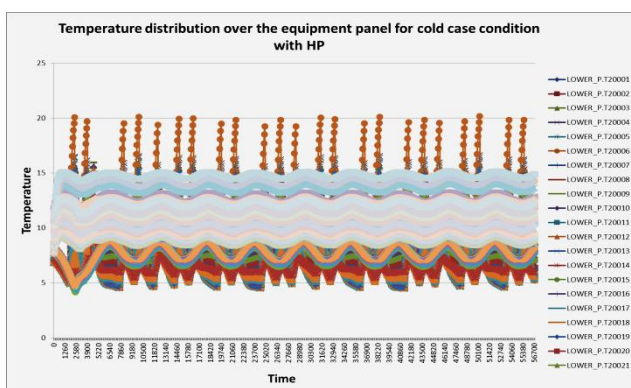
Figure 8a shows temperature distribution of the equipment panel in cold case condition, the equipment panel is assembled by heat pipes. The minimum and maximum temperature are 5°C and 15°C sequentially which in the operating temperature ranges for the equipment operation -10°C to 40°C. The heat pipes guarantee the uniformity of the temperature over the equipment panel. The electrical heaters main1, main2 and reserve were operated partially for short time because of the heat pipes which cause a low power consumption of the SC. Figure 8b shows the cold case but the equipment panel is assembled without heat pipes. The maximum and minimum temperatures ranges are 12°C and -2°C sequentially. The reason of being in the design temperature ranges is the electrical heaters. The electrical heaters raise the temperatures of the condenser and evaporator together to save the SC from the cold conditions. The electrical heaters [5] are operating for long time to guarantee the operating temperature ranges of the equipment. In spite of saving the SC panel equipment from under cooling conditions but the absence of heat pipes cause hot spots and thermal stresses of the SC panel material.



- a. with heat pipe

b. without heat pipe

Figure 7. The uniformity of temperature by using HP for cold case

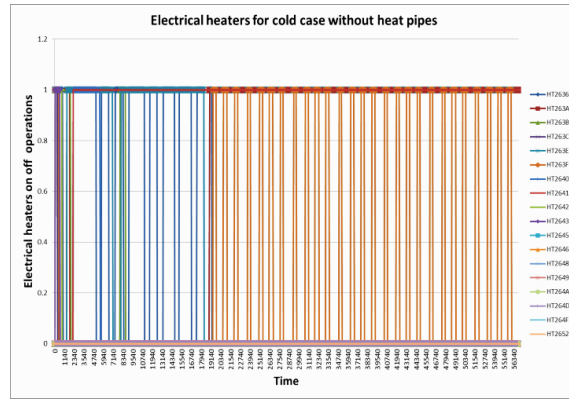
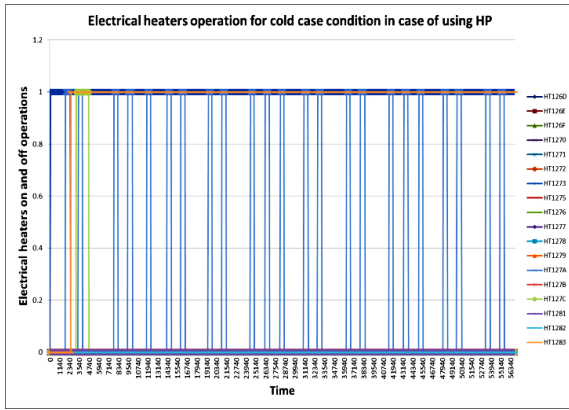


a. Temperature distribution over panel with HP

b. Temperature distribution over panel without HP

Figure 8 (a,b) Cold case temperature distribution over the equipment panel with and without heat pipes sequentially

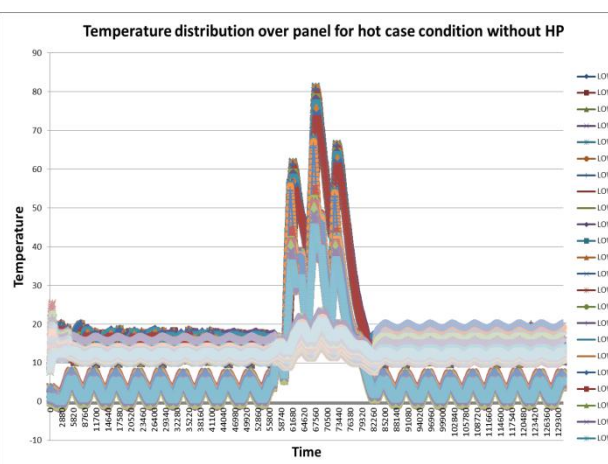
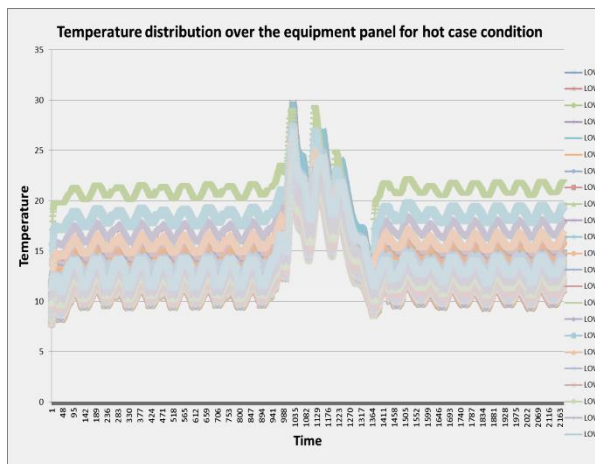
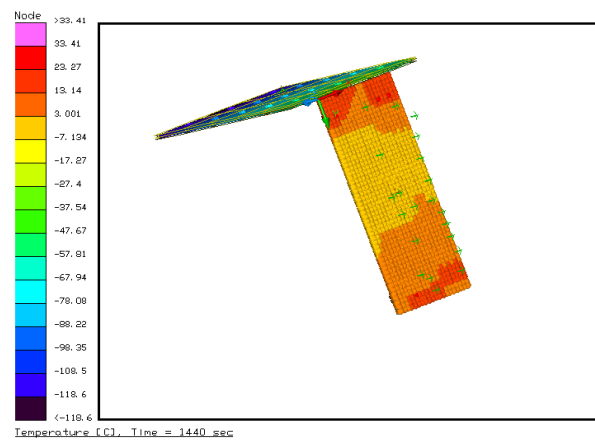
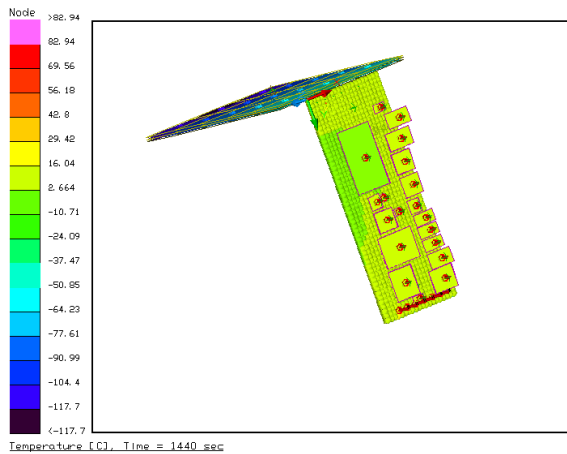
Figure (9a) shows the switching on and off conditions of the electrical heaters at the cold case for the equipment panel with heat pipes. The electrical heaters power consumption in the cold case condition is 50 W in 10 consequence inertial orbits. The electrical heater main2 is not operating because the electrical heaters main1 and reserve keeping the panel in the operating temperature range. The electrical heaters main1 and reserve are operating within the schedule plan. Figure (9b) shows the continuation of the three electrical heaters main1, main2, reserve to keep the panel equipment in the operating temperature ranges. The 10 inertial orbits without using heat pipes costs high electrical heaters power consumption 180W



a. Electrical heaters operation using HP

b. Electrical heaters operation without HP

Figure 9 (a,b) operation of electrical heaters during the cold case the panel with and without heat pipes



(a)

(b)

Figure 10 (a,b) cold case temperature distribution over the equipment panel with and without heat pipes

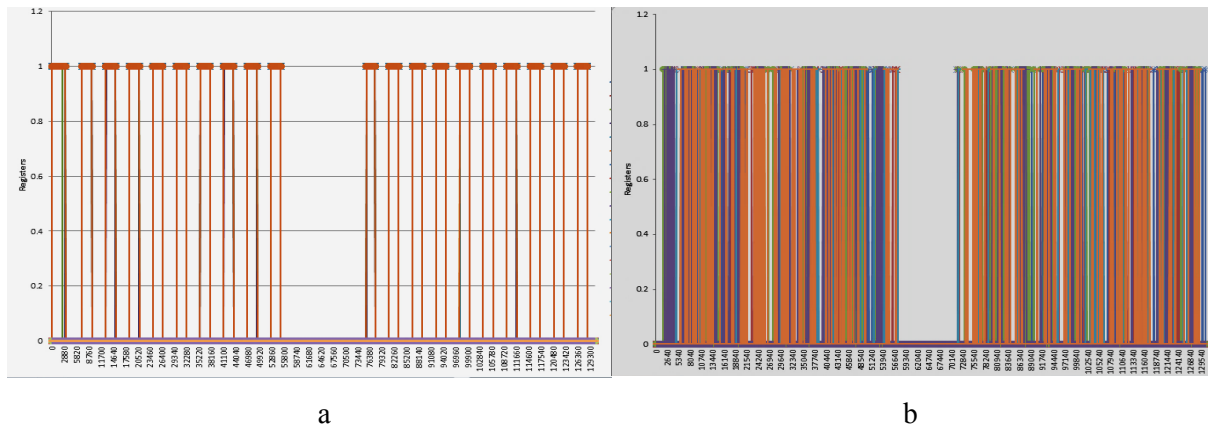


Figure 11 (a,b) the operation of electrical heaters during the cold case, the panel with and without heat pipes

Aspects of comparison			Using heat pipes	Without using heat pipes
Cold case	Temperature field distribution (uniformity)		Uniform temperature field distribution all over the equipment panel	Non uniform temperature field distribution all over the equipment panel (hot spot formation)
	Electrical power consumed by electrical heaters		Maximum and minimum temperatures	Min =0°C Max=15°C
	Electrical power consumed by electrical heaters	Main 1	60 w	Min =-2°C Max=12°C
		Main 2	20 w	180 w
		Reserve	0 w	60 w
Temperature field distribution (uniformity)	Uniform temperature field distribution all over the equipment panel	Non uniform temperature field distribution all over the equipment panel (hot spot formation)	0 w	
Hot case	Maximum and minimum temperatures		Min =3°C Max=22°C	Min =-1.5°C Max=33°C
	Electrical power consumed by electrical heaters		Main 1	70 w
	Electrical power consumed by electrical heaters	Main 2	0 w	140 w
				40 w

Figure 10-a shows the hot case of equipment panel with heat pipes. The heat pipes guarantee the designed operating temperature ranges of the equipment with maximum temperature 27.5 °C and minimum temperature 0°C. Figure 10-b shows the temperature operating ranges of the equipment panel at the hot case without using heat pipes. The electrical heaters operate during all the inertial orbits and during the sun orbits (orbital position) are switched off. The maximum temperature is 32°C and the minimum temperature is -1 °C

Figure 11 a shows the interval of switching on and off of the electrical heaters in the hot case. Electrical heater main 2 did not operate and electrical heaters main 1 and reserve operate according to the designed plane. Hot case takes 129540 seconds between orbital and inertial positions to be achieved. Figure 11 b shows the high consumed electrical power by the three electrical heaters main1, main2, reserve in 129540 seconds. The power consumed to guarantee the designed operating temperature range for the SC equipment. Only during the orbital position, the SC is exposed to higher thermal energy from the sun solar fluxes. Which makes the electrical heaters switched off and save energy.

5. Conclusion

Heat pipes remove the heat dissipation from the high temperature equipment and reuse it to heat the cold temperature equipment which required a certain operating temperature range to operate efficiently.

Using of heat pipes improves the heat distribution over the equipment panel, avoid the formation of hot spots between the high and low temperature equipment over the SC panels.

The more saving from the heat dissipation of the high temperature equipment, the lower consuming of the electrical power energy.

In case of using heat pipes electrical heaters operate time less than if not using heat pipes and saving more electrical power

Heat pipes is used to handle the heat between the equipment and the excessive heat is removed by the condenser section outside the SC through the radiator area.

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