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TEMPERATURE CONTROL OF MAN-MADE SATELLITE,(U)
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by

Wu Ling-yao

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Temperature Control of Man-made Satellite

Wu Ling-yao

This article attempts in the form of dialogue to discuss why does a man-made satellite need temperature control, and the methods and principles of temperature control.

A: Today we would like to ask you to talk about the problems of temperature control in a man-made satellite.

B: What should we begin with?

A: Please, first of all, tell us why does a man-made satellite need temperature control.

B: The reason is obvious. In a satellite, there are various kinds of equipment which can function normally only under a certain kind of temperature. The situation is just like how we treat our daily used instruments. In the hot summer, we use fans to cool the room where the instruments are located, and in the winter, we heat the room in order to have appropriate temperature required for the instruments. Some delicate and fine instrument must be put in a workshop of constant temperature to work. Otherwise, the property of the instrument will change, its life will be short and the instrument itself may become totally dysfunctional. It is even more so in a man-made satellite. An instrument made of germanium semiconductor, for example, requires working temperature no higher than 50°C. A photoconductive photographic tube cannot work normally when the temperature is above 40°C. The increase of temperature by every 10°, the electricity generated from the solar battery will be lower by 5%. When the temperature is above 100°C, the generation of the battery will drastically reduce. The nickel-cadmium battery will shorten its life if it continuously works under high temperature, and if it is charged under low temperature, the internal pressure of the battery will cause the battery crack, and its voltage will become low when the temperature reaches a certain degree. Generally speaking, the equipment in a satellite permits the environmental temperature to stay at + and - 40°C, namely, the highest degree is not over 40°C. and the lowest is not 40 below zero. The nickel-cadmium battery, secondary energy source and emitters all have strict temperature requirement, so the environmental temperature must be guaranteedto be 5-40°C..

A: This kind of environmental temperature requirement, I think, is easy to be met, because the changes of outdoor temperature in a whole year cannot go beyond the limit of + and - 40°C.. And there should be no difficulty to have indoor temperature at 5-40°C.

B: What you are saying is the situation on the earth. The environment in the air is very much different from that on the earth. The environmental temperature on the earth is known as "air temperature" that is the temperature of air. The temperature difference between daytime and night is only about several degrees or ten some degrees, and even following the seasonal changes, the difference cannot be more than a few tens of degrees. Moreover, air can have the function to regulate the temperature of instruments and equipment. By artificial ventilation, the instrument and equipment temperature can be made almost same as that of the air. But, in the sky high above, there is almost no air, and the temperature equals to 4° of absolute temperature, that is a dark space where the temperature is 269°C. below zero. So there are tremendous changes of temperature in a satellite when it is in such an environment. If there is no measure for temperature control, when the sun shines upon the satellite, the temperature on its shell can be as high as 100 or 200°C. When the satellite enters into the shade of the earth, the temperature in it can become as low as 100 or 200°C. below zero. On the side of a satellite, which is facing the sun, the water can become boiling and turn into steam, and on the side, which is in the shade, the water can freeze into ice (see Figure 1). The temperature difference on two different sides of a satellite may reach 200°. In order to maintain a suitable temperature for the equipment in a satellite, a temperature control system is indispensable.

A: The temperature control system in a satellite, I suppose, is composed of temperature testing components, electronic outfits, and temperature adjusting devices. The temperature testing components can be used to test the temperature in the satellite and its equipment. The temperature and the temperature adjusting devices are all controlled by the electronic instrumnets. If the temperature is too high, a cooler is used to cool it down, and if it is too low, a heater is used to heat it up. So in a satellite, there can be a temperature as required.

B: Well, what you are saying is the way that can be very good and useful on the earth, but it is difficult in a satellite. Because an automatic control system will consume energy, especially a temperature adjusting device consumes a great amount of electricity. An electric resistance heater or

Figue 1 The temperature difference is very great in a satellite between the side facing the sun and the side opposing the sun

a cooling fan, for example, will use several tens of volts of electricity. They can increase the weight and complicate the working system in the satellite. Thus the reliability of the satellite can become low. So this so-called initiative or active temperature control method is not serviceavle to a satellite. The temperature control method often used in a satellite is a passive temperature control method. This method has proved to be a useful and simple control method through many times of practical uses. One of its characteristics is that it can make change within a limit permitted by the environmental temperature in a satellite. The reason that this method is called "passive model" is because that it uses no temperature testing component nor temperature adjusting device, so it cannot initiatively or actively go to control. It consumes no energy nor will increase any weight. It controls the temperature only by means of the painted layer on both external and internal surface of the instrument cabin and the satellite, and by the installed insulating materials.

A: Please tell us more in detail about the passive temperature control system.

B: Certainly. The essence of a passive temperature control system is that it scientifically organizes the process of heat absorbing and heat releasing of a satellite. It enables the temperature in the satellite to change within a required limit. The work of a passive temperature control system can be briefly summarized as follows: "absorbing less and releasing more"; "sharing the burden evenly"; "isolating inside from outside" ; and "discharging the surplus heat".

The temperature change in a satellite is the result of heat absorbing and heat releasing. The heat that a satellite can absorb comes from four different sources. The first one is the sun. The heat that the sun radiates to the satellite is about 1,400 watts per square meter. Under the condition of large orbit inclination and high altitude, the satellite will be shone by the sun in the whole cycle of orbiting. This situation sometimes can continue for a few days, weeks and even one month. Generally, in each cycle, the satellite passes the shadow of the earth once, which constitutes 30-40% of the time for orbiting one cycle. The time for an equatorial synchronous satellite in the shade constitutes only 5% of that for one cycle. So it can be said that most of the time a satellite is exposed to the sun. The second source is that while a satellite is being heated directly by th sun, it also at the same time receives the solar heat reflected back from the earth. Heat from these two sources constitutes more than 90% of the total quantity of heat the satellite received, and more than 60% of the heat the satellite absorbed. The third source is the earth, which is a low temperature heat source and send out radiant heat, and the satellite constantly receives this kind of radiant heat from the earth. The strenght of earth radiant heat is about 190 watts per sqare meter. The fourth source is that the instruments in the satellite radiate heat when they are working, and the heat is about several tens of watts per sqare meter. At the time when a satellite receives heat from these four different sources, by way of its shell surface, the satellite discharges heat into the cold space. The situation of how a satellite receives heat is illustrated in Figure 2. From the heat sources mentioned above, it can be known that the main force that regulates the temperature in a satellite is the absorption of heat and that the major heat source is the sun. So the primary task of temperature control is to limit the absoption of solar heat by the satellite. The principle of controlling the satellite is " absorbing less and releasing more".

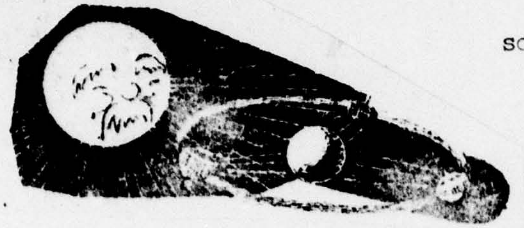

Figure 2 Diagram of a satellite receiving heat

A: What do you mean by "absorbing less and releasing more"?

B: Don't you know why people wear white or light color clothes in summer?

A: Because the white or light color clothes can reject most of the sun shine and absorb only a small part of it. So it makes people feel cool to wear white or light color clothes in summer (see Figure 3).

B: Your answer has fully explained the meaning of "absorbing less and releasing more". "Absorbing less" means to absorb less solar heat from the sunshine, and "releasing more" means to release more of its own radiant heat. This is carried out in a satellite by the paint layer on the external surface of its shell, and the paint layer has low heat absorbance . The amount of solar heat absorbed by the paint layer can be indicated by absorbance. The energy of emitting radiation heat of the paint layer equals to that of absoring radiation heat and the magnitude

Figure 3

can be indicated by radiativity. The ratio of absorbance and radiativity is called absorption-radiation ratio. When the absorption-radiation ratio is low, it means that the ability of the paint layer to absorb solar heat is small and the ability of emitting heat is great. After the external surface of the satellite shell having been painted a paint layer, it will absorb less solar heat and release more radiation heat when the satellite is in the sunshine zone, so the temperature cannot become too high (see Figure 4).

A: Then, what is " sharing the burden evenly"?

B: As we know that the difference is very great between the high temperature on the side of a satellite facing the sun and the low temperature on the side which is in the shade. If the internal surface of the satellite shell is painted a paint layer of high radiativity, such as black lacquer, it can help the exchange of radiation heat in the satellite, and makes the high temperature part release more heat and the low temperature part absorb more heat. Thus every part of the whole shell will share equal quantity of heat, and the temperature difference is thereby much lessened. This is the so-called " sharing the burden evenly" (see Figure 5).

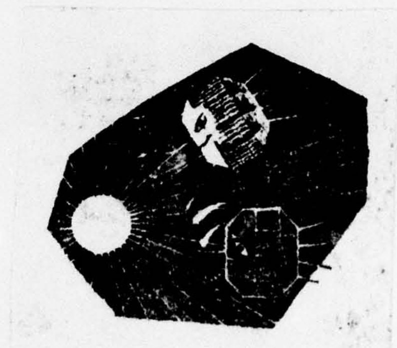

Figure 4 Diagram of "absorbibg less and releasing more!' The upper temperature control paint layer absorbs less heat but releases more. The lower part without a paint layer absorbs more heat but releases less.

A: After the practice of "absorbibg less and releasing more" and "sharing the burden evenly", the temperature cannot become too high when the satellite is in the sunshine zone. Won't the temperature become too low when the satellite is in the shady zone?

B: In the shady zone, because of the absence of the sun, a main heat source, the temperature will definitely become low. But because the radiation heat of the earth is always there, the instruments in the satellite can also generate some heat, and the shell of the satellite can maintain some solar heat as the time of being in the shady zone is not long, so the temperature cannot become too low. Of course, this requires careful calculation and analysis in advance. If the temperature in the shady zone is lower than the regulated lower limit, it will change to use the paint layer of higher absorption radiation ratio or to change the size of the paint layer. Thus the temperature in the sunshine zone will correspondingly become higher, but it will be all right if the temperature is not above the permitted upper limit. The temperature on the external surface of the satellite shell is not only determined by the absorption radiation ratio of the paint layer and the size of the layer, it is also related to such factors as the length of time in the sunshine zone and the shady zone, the direction of sun shining and the attitude of the satellite. With respect to such problems as what is the proper absorption radiation ratio and what is the proper size of the paint layer, it requires comprehensive calculation and analysis. It also needs experiments in environmental simulation experiment field where the simulation of sun shining is possible and can have high vacuum, hard low temperature and dark space. By careful design and careful processing of temperature control paint layer, it is possible to have the surface temperature of a satellite shell not over + and - 70-80° C.

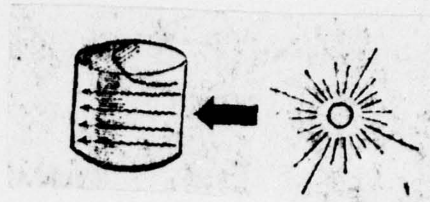

Figure 5 Diagram of "to share the burden evenly. The high temperature part on the surface of a satellite transfer heat to the low temperature part so as to even the temperature.

A: Of many man-made satellites, I know, the shell is attached with a solar battery, which can generate electricity by means of absorbing solar light, and the battery has strong solar light absorbing ability. As a result, the surface temperature must be very high. How to solve such a problem?

B: This problem can be solved by using "absorbing less and releasing more". On the one hand, the surface of the solar battery is covered by a piece of glass lid, which has high radiativity. This glass lid will not affect the penetration of solar light, but it can help to promote the heat-absorbing ability. On the other hand, some part of the surface around the solar battery is painted a paint layer, of which the absorption radiation ratio is low, and this paint layer is used as a heat-diffusion plane. Thus the temperature of the solar battery can maintain low. The guide board of the solar battery, which is used to show the direction of the sun, is painted a paint layer of high radiativity at its back. It can thereby help to expand the heat-diffusion plane realizing the principle of "releasing more". Thus the temperature of the solar battery is controlled not over 70-80°C..

A: The temperature control paint layer sounds very useful in a passive temperature control system, but I don't know what kind of paint layer is used the most now?

B: The paint layer of low absorption radiation ratio used now in space temperature control system includes silver-polytetrafluoroethylene, aluminum-polytetrafluoroethylene, zinc oxide, silicate white lacquar. Their strong points are that they can last long in the space environment and that under the action of radiation of solar ultravoilet ray and space charged particles, their property has not much negative change. The paint layer of high radiativity includes propylene black lacquer and silcon oxide white lacquer, and that of low radiativity is usually made of aluminum plated film or highly polished metal surface made of aluminum, copper or stainless steel.

Now we shall continue to discuss " isolating inside from ouside" and " discharging the surplus heat".

A: About "isolating inside from outside", I think I know something. That we wear cotton-padded jacket in winter, for example, is to isolate the internal warmth from going out. In summer the ice-bar peddlers using blanket cover their ice-bar box to isolate the outside heat from from coming inside their box. Again in a cave or a cellar, we always feel "warm in winter and cool in summer", this is because the action of "isolation" cuts off the effect of the outside temperature. So when the outside temperature is 30-40°C., inside the cave or cellar, it can only be 20°C. or so; when the outside temperature becomes 10 or 20°C. below zero, inside there it can only be in the vinicity of 0°C.

B: The method of"isolating inside from outside" in a satellite temperature control system is using multi-layer insulating material to wrap up the satellite or the instrument cabin in it. This method is mostly used in the temperature control of the instrument cabin. In order to have proper environmental temperature for the instruments, it often collects the instruments in one room and installs an independent temperature control system there. The insulating material is made of 20 layers of doubled-face aluminumized tylon film and 19 layers of glass fabric paper (see Figure 6).

The surface radiativity of the double-face aluminized tylon film is very low. This material does not absorb heat nor releases heat. The insulating ability of glass fabric paper is high, so it is not easy to conduct heat. The environmental temperature outside the instrument cabin is the temperature of the internal surface of the satellite.

After the satellite shell being painted a paint layer, the temperature limit has pressed to be + and - 70-80°C.. If the satellite shell is wrapped with insulating materials, the temperature scale of the internal surface will be smaller than that of the external surface. When the instrument cabin is wrapped with many layers of insulating material, the scale of temperature change within the cabin will be far smaller than the temperature scale of the internal surface of the shell. In addition, within the cabin there can be full of inertial air to even the temperature of different parts of the cabin so as to realize sharing the temperature evenly.

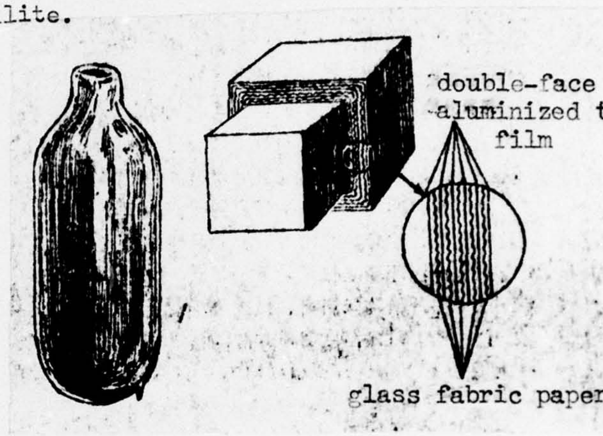

Figure 6 Diagram of isolating inside from outside. A vacuum thermal sustaining device of a thermos bottle (right) made of two mercury plated layers. Thermal sustaining device of an instrument cabin (left) made of glass fabric paper sandwiched by double-face aluminized tylon film.

A: Can the method of isolating inside from outside isolate the heat produced by the instruments from going out and make the temperature in the cabin become higher and higher?

B: this is just the problem which can be solved by using the fourth method--" discharging the surplus heat". The outside of the instrument cabin cannot be completely wrapped with insulating material, and there must be some part on the surface, which is painted a paint layer as a heat-diffusion plane. The surplus heat within the cabin can be then discharged through this plane. By selecting a proper size of heat-difussion plane and a paint layer with proper radiativity, the temperature in the cabin can be well controlled below 30-40°C..

A: If there are many instruments in the cabin and they are working intermittently, the fluctuation of heat-increasing will be great. If the permitted temperature scale in the cabin is narrow, for instance, it is 5-35°C. Under such condition, is the passive temperature control system still good?

B: Of course not. Every method has its limit. When the degree of rising and falling of the outside temperature is greater than the thermal fluctuation in the cabin, there can set a Venetian blind on the outside of the heat-diffusion plane. The slats of the blind must be printed with a paint layer of low radiativity. There is a double metal spring made of two different kinds of metals which have different expansion coefficiency. One end of the spring is connected the wall of the instrument cabin, and the other end is

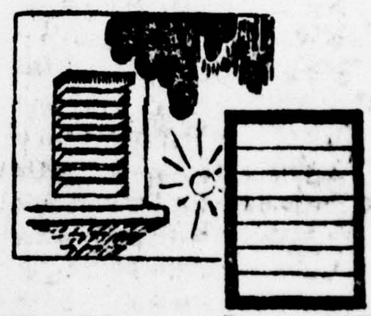

Figure 7 Diagram of discharging the surplus heat. When temperature is high, open the Venetian blind, the outward heat-radiation is more. When temperatureis low, close the blind, the outward heat-radiation is less.

connected with the slat of the blind. This double metal spring is a temperature sensing agent and also an executive agent. When the temperature in the cabin is changing, the spring will expand when hot and shrink when cold. Due to the fact that the two metals of which the spring was made do not change uniformly, the spring becomes bending and further develops a postion change.Thereby the slats of the blind are drived to make turn and change the radiativity of heat-diffusing. When the temperature is high, the set of slats of the blind will open to disclose the heat-diffusion plane which now has a high radiativity, so the heat diffusing is fast. When the temperature is low, the blind closes and the surface of the slats with a low radiativity is facing outward, so the quantity of heat-diffusing is small. This kind of control method can automatically regulate the quantity of heat diffusing, so it is initiative or active. It needs no energy source, it is therefore called "sourceless initiative or active temperature control".

A: The passive temperature control and sourceless initiative or active temperature control need no electricity, nor temperature regulation equipment. They really have the characteristics of being simple, economical and effective, so they represent an outstanding feature in the space temperature control technology. But I wonder whether or not the needs in satellite temperature control can be satisfied by only those two methods as you mentioned above?

B: No. Certainly not. Those two methods are only good for a man-made satellite, in which the change of heat quantity is small, and the permitted temperature scale is large, and they are good for other space crafts as well. Should the heat source in the satellite produce a great quantity of heat, and the changes are drastic, it requires a constant temperature control, and the passive temperature control or the sourceless initiative or active temperature control cannot satisfy the requirement of a satellite temperature control. Under such circumstances, the automatic temperature control system as you mentioned at the beginning should be used. Besides, some of the infrared probing instruments in a satellite requires specially low temperature environment (196°C. below zero). This kind of temperature can be obtained only through some special arrangement. Recently it has developed a new method, which uses "thermal tube" to regulate the temperature in a satellite. This new method can carry out the program of sharing the burden evenly and make the temperature even in every part of a satellite.

(Drawings by Li Chia)

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