THE LDEF HEAT PIPE EXPERIMENT POWER SYSTEM

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(Figure 3-83)

Future space shuttles are used for transporting a long duration exposure facility, LDEF spacecraft, to and from the near-Earth gravity orbit. The spacecraft was designed to house mobile experiments for long-time exposure duration to space and later retrieval by one of the space shuttles. After retrieval, each unit will be returned to the experimenter for test and evaluation.

One of the experiments that will go on the LDEF is a low-temperature heat pipe experiment designated HEPPS. For the HEPPS experiment, we have designed and fabricated a power system that is located on the top surface of the spacecraft directly above the heat pipe experiment on the side. The location was determined because the power system has solar panels on it, and the heat pipe requires at times to seek cold space.

(Figure 3-84)

This is a functional diagram of the HEPPS pipe experiment power system. The triangle to the left represents four solar array panels. They are miniature panels. The next unit over represents a 12-ampere hour, 18-cell nickel-cadmium battery. And the remaining components within the system comprise an electronic controller.

I would like to point out some of the features of the controller and the battery. Since the spacecraft will be carried by the shuttle in the forward compartment, we have designed some safety features that I would like to point out.

The main bus of the battery is fused to prevent catastrophical failure in case of a dead short on the main bus. During launch and retrieval, the LF spacecraft will enable the load relay only after the spacecraft is placed out in orbit away from the space shuttle. The battery will be launched in the discharge condition. After launch, when we acquire the Sun, the battery will start into a charge phase.

The load relay to the HEPPS experiment will remain open until one of two electrodes indicates that the battery is approximately 100 percent charged and turns on the relay to the HEPPS experiment. If the battery is in a cold condition of minus 10 degrees or less, we have a redundant turnon system that works through the shunt dump regulator.

If the battery voltage reaches 27 volts and the shunt dump circuit starts dumping approximately 100 milliamperes, this circuit can also turn on the relay to the HEPPS experiment.

If at any time the battery voltage drops below 18 volts, or a 0.5-volt delta that is exactly between the two halves of the battery, this would automatically turn it off. The battery will stay, or the relay will stay, in the off-condition until the cycle is again repeated and is turned on again by one of the third electrodes or the shunt dump circuit.

When the shunt dump circuit is active in the cold condition, we use the excess heat and transfer it back to the battery through resistors mounted at the baseplate of the battery.

(Figure 3-85)

Here we see the relative state of charge in the battery during two test cycles of the HEPPS experiment. This is calculated under worst-case conditions during the testing of the HEPPS experiment through two data cycles. After the completion of the second data cycle, the system automatically is clocked off for approximately 10 days to allow time for battery recharging.

(Figure 3-86)

Availability of battery charge current during orbit life is determined by calculating effect of solar array output versus the pseudo angle using data derived from tests of the four solar panels at a one-sun angle.

The data was plotted relative to the two extreme beta angles that they expect the spacecraft to acquire. It was also plotted to a battery voltage of 27 volts. The voltage that the shunt dump regulator will cut off at is approximately 25 volts and gives us an indication of the available power.

(Figure 3-87)

Again, using worst-case conditions, we plotted the predicted battery temperature versus orbit time, using computer calculations from the calculations of the thermal model. However, we expect the battery temperature to be somewhat less than the range that we have predicted here.

I believe the expected range is about plus 35 degrees down to minus 17 degrees. These curves show the battery voltage characteristics during capacity tests conducted at the extreme temperature range of minus 30 to plus 35 degrees.

Now, the capacity curves aren't true overcharge capacity curves. They are the capacity curves that we expect to see in the actual duty cycle generated by the control of the power electronic unit.

(Figure 3-88)

This is a typical example of one of the recharge curves with the battery in a flat condition. We go through approximately 17 orbits before the third-electrode signal will turn on the relay to provide power to the HEPPS system.

(Figure 3-89)

You will notice at 35°C that we acquire no load current, because the battery voltage is low at this time.

(Figure 3-90)

This vugraph is at the other extreme, or at minus 30°C. In this case we see that the dump circuit becomes active after approximately 14 orbits, and the third electrodes are out around 32 orbits or so before the second or third electrode would activate the load relay to the HEPPS experiment.

(Figure 3-91)

One ting I would like to point out on that last vugraph is the fact that during this charge, we simulated the expected solar array, instead of using a constant current or type charge of that nature.

Four photographs were taken of the system during the final assembly process. The first photograph shows a structure within a structure. This is the tray of the LDEF, and our structure is inside of the tray. This was done because directives specify that we mount to the tray using the bottom mounting surface only for equal load distributions and thermal design.

Our input to the spacecraft is through the slots located up to the top right for connector mounting.

(Figure 3-92)

This is the next step in the process where we have mounted a thermal blanket completely to the inside. We have some rigid requirements not to pull heat from the spacecraft and not to dump any heat into the spacecraft. I think they are working in the range of 5 to 10 watts. So we mounted a thermal blanket over the entire inside of the surface.

(Figure 3-93)

The third photo was taken on the top plate of the power system which contains all the electronic components. In the center we see the battery. We have a feeder flow mounted directly to the battery that I mentioned previously.

The power electronic unit is mounted to its right with the cabling actually going through the plate to interface with the solar panels on the other side. This plate is made out of 3/4-inch aluminum and is approximately 30 by 30 inches. This type plate was used to provide the thermal control that we need plus the thermal – I mean the structural strength that we needed in the verification.

Eight 1/2-inch square fiberglass spacers, G-10 spacers, are used to mount this plate on to the internal structure, again, for the thermal isolation required of our experiment.

(Figure 3-94)

This last photo was taken of the completed system in which case you can now see the four solar panels to the right to the top of the tray. The top surface has been painted green. This is a special thermal paint to allow for the best thermal conductivity throughout the plate.

The goal of the design was to provide a power system that would provide sufficient power to the HEPPS experiment. A system that would operate completely automatic from time of launch to time of retrieval. And a system that would operate in the near-Earth gravity gradient orbit without detrimental degradation due to the temperature environment.

DISCUSSION

NAPOLI: In one of the first vugraphs, you had an indication that the main battery system for the LDEF was discharged, and then was subsequently charged after being released from the shuttle. Is that some sort of a safety requirement that was imposed upon you by the shuttle operation people? Or, was that something that you elected to do?

TILLER: Because the astronauts were on board the shuttle, they would desire the battery to be in the discharged condition both during launch and retrieval.

During launch it was very easy for us to start with a discharged battery and let the battery charge once it obtained its orbital position.

During retrieval it was a lot harder to discharge a battery. So we have to live with the fact that the HEPPS experiment will be removed from the main bus during retrieval by the LDEF spacecraft itself.

NAPOLI: Is there some sort of general safety requirement for all shuttle payloads that you may be aware of that requires this?

TILLER: I am not sure what the requirements were. What we tried to do was provide as much safety as possible with our experiment. I am not familiar with what the real requirements are, except the fact that during our design review, they bought the fact that we would launch in that condition. It just provides adequate safety. I am not familiar with other experiments on the LDEF for future shuttle missions.

FORD: Joe, if I might add to that, there is another driver here, and that's launching in the condition we are in. This LDEF configuration has quite a long time period in which you don't have access to it prior to launch, and I don't know whether it is like 4 to 6 months. But once delivered, we have no way to get back into it.

So this mode of launch in the discharge condition was chosen to minimize the unknown effects of that long exposure in this environment. That was the main driver.

TILLER: They gave us a maximum time period of 10 weeks, up to 6 months.

HARKNESS: Sid, did your tests at -30°C immediately follow those at 35°C?

TILLER: I don't remember the exact sequence of the four tests we ran at minus 30, minus 15; I believe it was zero and plus 35. I think once we were cold, we probably ran the cold tests and then the hot. But I don't remember offhand which sequence we went through.

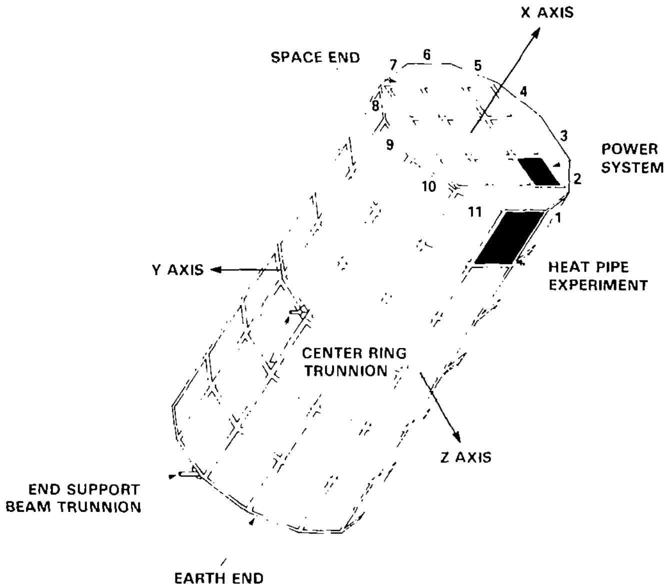

Figure 3-83

HEAT PIPE EXPERIMENT POWER SYSTEM FUNCTIONAL DIAGRAM

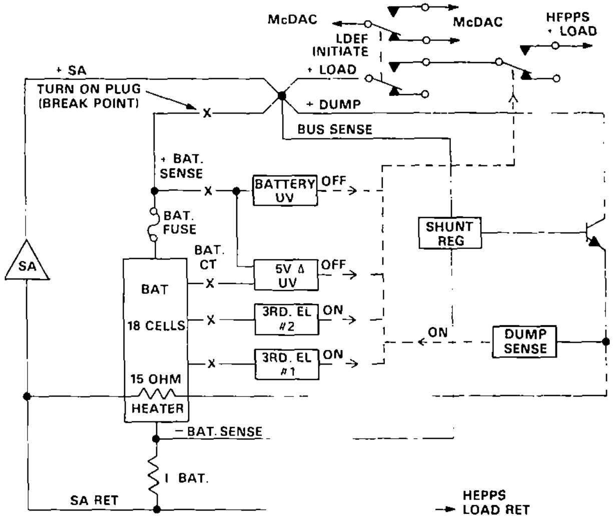

Figure 3-84

BATTERY CHARGE/DISCHARGE CHARACTERISTICS VS EXPERIMENT DUTY CYCLE

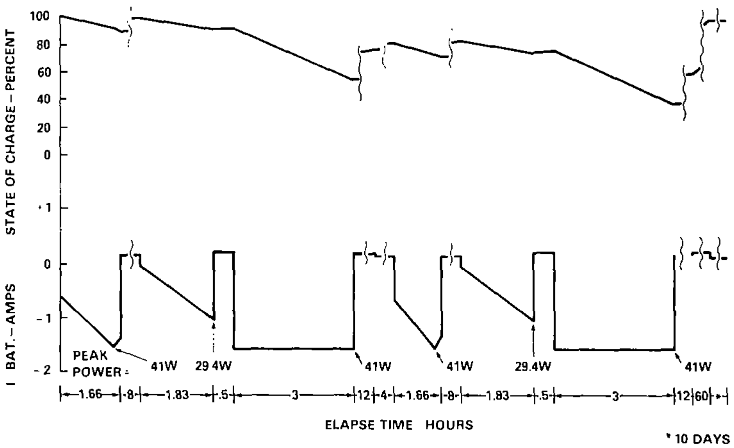

Figure 3-85

AVAILABLE BATTERY CHARGE CURRENT VS PSEUDO LATITUDE

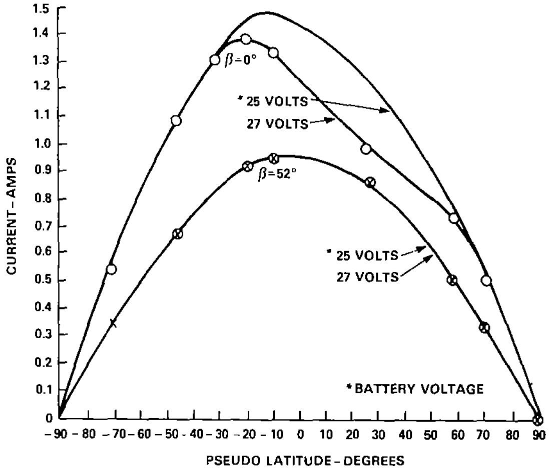

Figure 3-86

BATTERY TEMPERATURE VS ORBIT TIME

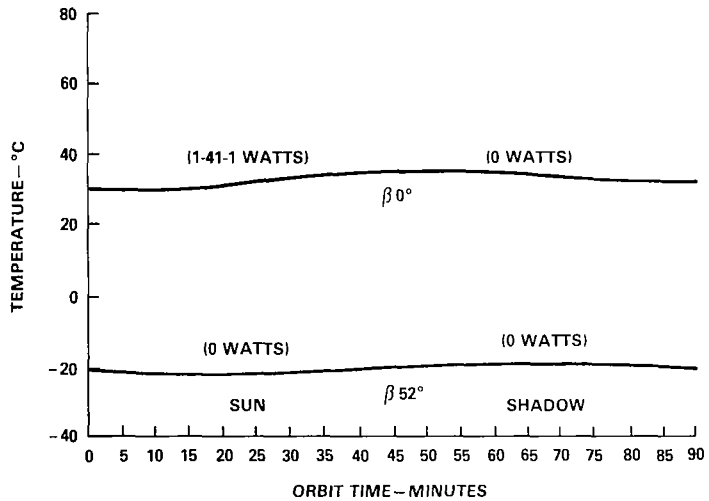

Figure 3-87

BATTERY VOLTAGE CHARACTERISTICS VS CAPACITY (2 AMP DISCHARGE RATE)

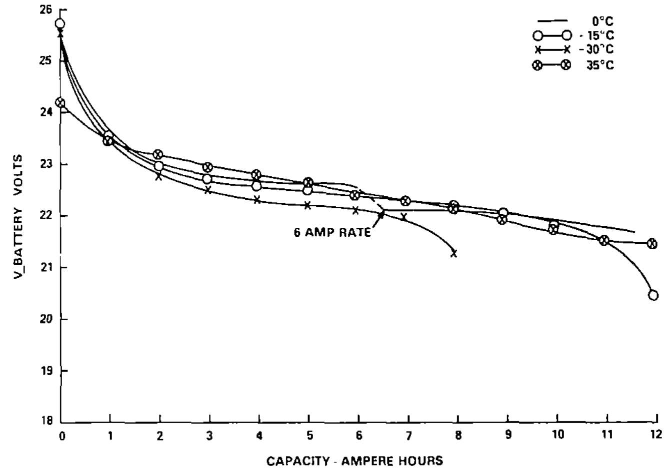

Figure 3-88

POWER SYSTEM BATTERY CHARGE CHARACTERISTICS AT 35°C

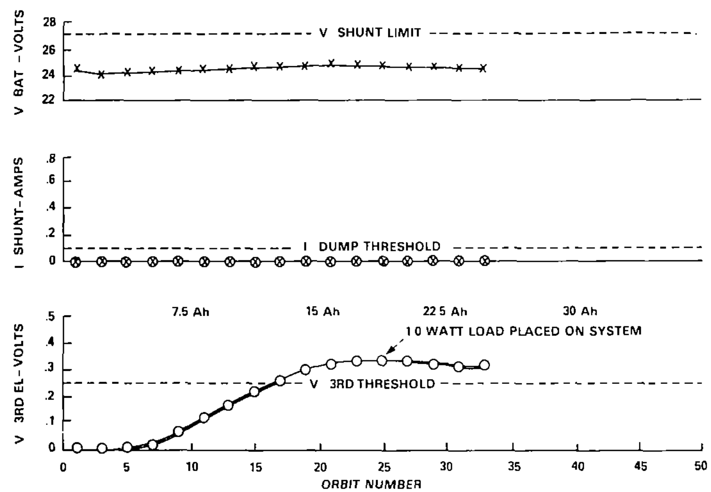

Figure 3-89

POWER SYSTEM BATTERY CHARGE CHARACTERISTICS AT -30°C

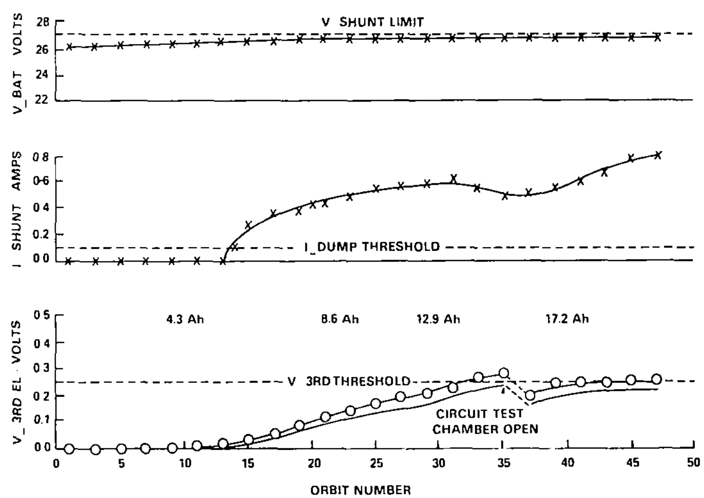

Figure 3-90

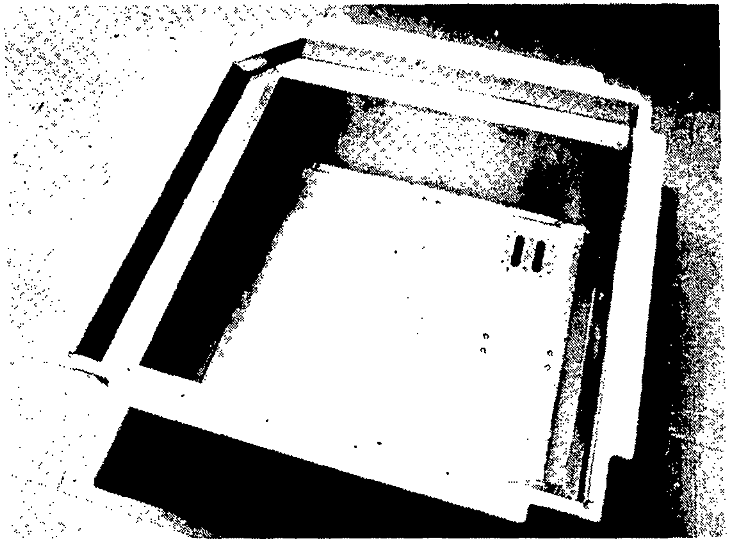

Figure 3-91

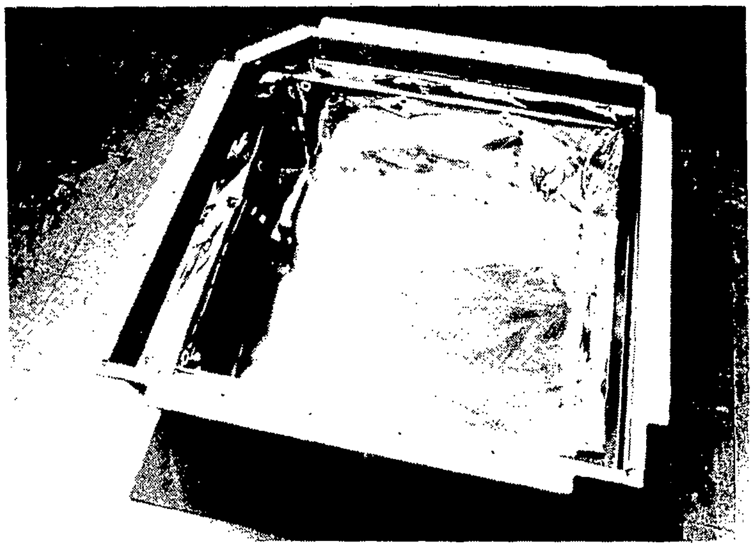

Figure 3-92

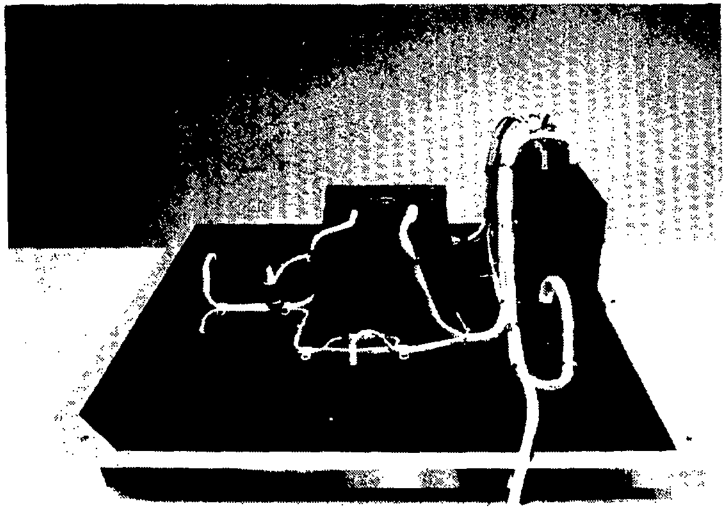

Figure 3-93

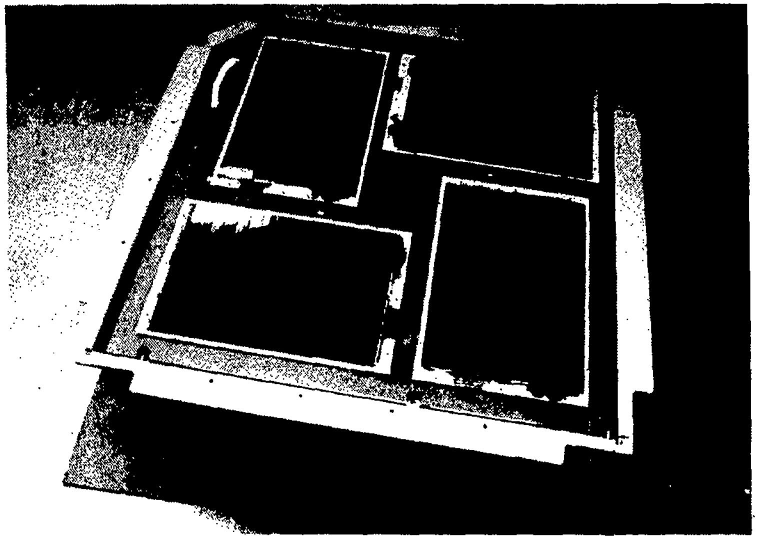

Figure 3-94