

## CELL SHORT CIRCUIT, PRESHORT SIGNATURE

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TRW

(Figure 4-85)

TRW has been running ground test simulations of DSCS-3 missions for some time now. During the flight 7 simulation, several short-circuit events were observed.

In the process of our looking at what happened, we took a very, very close look at the cell level data preceding each of the short-circuit events. In the process of this investigation, we discovered that there was a voltage signature appearing anywhere from days to weeks prior to this short-circuit event. What I would like to discuss is what we saw and what we think it means.

(Figure 4-86)

It is necessary to describe this system just a bit. The ground test that we ran is a simulation of geosynchronous orbit cycling. It is the familiar 45 eclipses per season. We run real-time eclipses. There is no attempt to accelerate that part of the test. Mid-season maximum DOD is 40 percent, and that is at 72-minute discharge.

We reconditioned after each season. Reconditioning discharges into a 44-ohm load to a 1-volt per cell cutoff. The solstice period is accelerated to the extent that the 135 days is cut back to the time necessary for reconditioning only, which is approximately 1 to 2 weeks.

We have completed six seasons and the test is continuing. The test battery is a 22-cell battery with the indicated 12-ampere hour GE cells with nylon separator. The negatives are not teflonated.

(Figure 4-87)

The battery is mounted on a thermal electric baseplate. The battery baseplate interface is adjusted to give us a thermal profile equivalent to the actual orbital mission. The battery is hooked into the battery lab digital data acquisition system which gave us sufficient data on a continuing basis to perform this analysis.

The battery is switched between trickle charge and full charge based on temperature as indicated on the right. As the battery goes up, it switches down to trickle charge at about 76 degrees. On temperature fall it goes to approximately 70 degrees.

(Figure 4-88)

This rather busy looking curve is a summary of a typical mid-season profile showing battery voltage, battery current, and temperature.

This portion of the curve is the discharge. We come out of discharge, the temperature drops, and the voltage goes up. When the temperature drops sufficiently, we go into full charge. In full charge the temperature increases. While this is happening, the battery voltage goes up and reaches the voltage limit.

As we come off this because of temperature rise, the battery is about fully charged. It has taken about as much as it can. After this, everything you see is overcharge. We have what amounts to a series of overcharged pulses. This gives rise to what amounts to a battery voltage response to these current voltages, which looks very much like a series of square waves. And if you keep that in mind, that is what the signature turned out to be.

(Figure 4-89)

We saw a number of different types of short circuits. Hard shorts, of course, are very easy to define and see. The battery voltage goes to zero.

I don't want to, as part of this discussion, get into a discussion of what a soft short is, so we chose a simple working definition which I think is valid for what we have observed. Let me just say any time we saw anomalous voltage decrease that wasn't trivial, was greater than 100 millivolts, we called it a soft short. There should be a sense of time there. This usually occurred in minutes to hours, rather than hours to days.

Now, if you recall the voltage response to the current pulses for a nominal cell, it is about what this solid line looks like. The voltage ramps up. We have an initial square wave which is charging. We have a number of ensuing square waves which, in fact, are overcharge pulses.

However, in all instances the cells which exhibited hard or soft shorts, what we saw at some time prior to the short was something that looks like this dotted line. Where the voltage was depressed and coming into the charge region, we saw a feature of some kind at the beginning and a ramping up. In each of the subsequent overcharge pulses, instead of being squared, it ramped up. We defined our signature in terms of a degraded overall voltage, a ramping of the charge and discharge pulses and this feature which appeared at the beginning of this charge pulse.

(Figure 4-90)

Now, some specific data is information taken during cycle 24 of the third season. We plotted six different cell voltages in pairs to show the superposition of the data. In other words, the individual cells tracked one another. If they were nominal, they tracked very, very well. We didn't attempt to superimpose all six, because it wouldn't be readable.

You can see that one cell, cell number 14, is showing some very, very slight indication of ramping, and slightly depressed voltage.

(Figure 4-91)

Now moving to cycle 34 of the same season, in other words, ten 24-hour cycles later, three of these cells exhibit the signature as indicated, a generally depressed voltage feature at the beginning of the chart, falls, and this ramping.

I should point out during these 10 days battery help as we would normally judge it, based on the kind of information we would have from a battery in orbit, battery help would have been excellent. There would have been no indication that anything was wrong or about to be wrong, based on the normal battery telemetry. In fact, at this point the battery was still behaving fine, accomplishing its mission. We did have the signature.

(Figure 4-92)

At the end of that season, in other words, almost 2 weeks later during reconditioning, two of the cells which exhibited the signature dropped out of the reconditioning discharge very, very early. Cell number 14 and cell number 17 dropped out at about 2 and about 6 or 7 ampere-hours in. Cell number 19 was just included, as an example of a cell which did not exhibit a short-circuit signature.

(Figure 4-93)

If we move to cycle 24 of season 5, or approximately 100 days later, cell number 14 dropped out. Let me explain what we have here. We have plotted six cells, and we have displaced the scales so the data would be readable on the six cells.

Cell number 14 started out low but was remaining parallel to the remaining cells. At this point an inflection occurred. At this point the second inflection occurred, and we associate some physical process with the presence of the inflection.

Then, the cell dropped off fairly rapidly and, in fact, went into reverse, and reversed for about 1 ampere-hour or so. Then, again immediately prior to this reversal, battery health had been good. The only reason we would have expected something was wrong was the presence of the signature which persisted through this time.

(Figure 4-94)

So, what do we think the signature means? Probably the depressed voltage is some kind of a high impedance shorting that exists. What is interesting and perhaps a little difficult to explain is that it appears, whatever it is, to be stable, to be capable of being stable for long periods of time. In fact, that seems to be unpredictable. When we see the signature, the cell may go out in hours, or it may go out in weeks. But it is capable of being stable.

The ramping is probably the easiest part to explain. If there is this partial short you go into that pulse, charge pulse not fully charged so the voltage isn't going to jump up immediately, it is going to go up gradually.

That little feature that we saw at the beginning of the charge pulse is perhaps the most mysterious part. But it may suggest that the signature itself is charge dependent and that we are at the lowest state of charge. Whatever its manifestation, it behaves differently once the battery goes past its first stage of charge. But that is purely speculation.

Are there any applications of this possible? I think the question that has to precede that is, how general is the phenomenon? Will we be able to use it in other similar situations? That is something we are talking about.

If we can and if it is reasonably general, perhaps this could develop into short circuit early warning system if we had some microprocessor capability, an algorithm to sense the curve shape.

What we are doing at present is some extensive DPA autopsy work on these cells to try and correlate the degree of problem that we think we are having with physical observations during teardown analysis. We hope that will tell us a little bit more about what we are seeing.

## DISCUSSION

FORD: I couldn't tell from the back of the room, what is the rise time of the pulse?

LURIE: The rise time is rapid. I don't know.

FORD: What was the width of the pulse?

LURIE: This is a 24-hour charge.

So that's on the order of what? Half an hour? 45 minutes? That's a function of the thermal characteristics of the system.

LURIE: As soon as it heats up, it is going to drop off.

HENDEE: I find that very interesting. There are several other preshort signatures, though, that one could probably observe. It depends on whether it is a short on charge — there is that type which may give you problems. You may see that in your subsequent reconditioning.

Then, there may be the continuous type of short. I have seen signatures that start out with, when you are recharging your normal voltage peaking, and then decrease, you just start seeing, instead of going up to a nice peak and then levelling back off, it goes up and just keep smoothing out, smoothing out until you are just approaching it.

I have seen other ones starting to go up and then there's a clamp. I have seen cells on slow charge which I will have a plot of tomorrow on my presentation. But you do see an oscillation in the ampere per hour voltage. There are many of them.

SCHULMAN: Did you try to correlate in any particular cell, where you found a signature of a soft short with a test that is being used in battery acceptance testing, cell acceptance testing, that charge retention-type test which is supposed to indicate a short?

LURIE: What we did correlate with very successfully was capacity, voltage decay in a fully charged state.

We charged the battery up and let it sit for a period of 7 days. When we did a statistical analysis, we found that all the cells except two were very, very close, around the three sigma limit. Two cells dropped out of the three sigma limit, and the cell that was furthest away from the three sigma limit failed first. And the cell that was closer to the three sigma limit but out of it failed second. So we did get very, very good correlation with a more classical test.

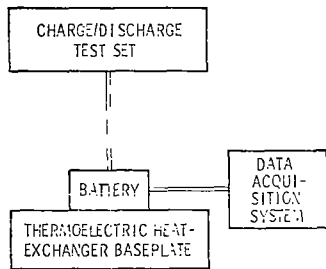
- SEVERAL CELL SHORT CIRCUIT EVENTS WERE OBSERVED DURING A GROUND TEST SIMULATION OF DSCS II F7 BATTERY OPERATIONS.
- CELL LEVEL DATA FOR THE PERIOD PRECEDING THE SHORT CIRCUIT EVENTS WAS INSPECTED FOR ANOMALIES.
- THE RESULTS OF THIS INVESTIGATION SUGGEST THAT CANDIDATE CELLS DEVELOP A CHARACTERISTIC SIGNATURE ANYWHERE FROM HOURS TO DAYS PRIOR TO A SHORTING EVENT.

- THE GROUND TEST IS A SIMULATION OF GEOSYNCHRONOUS ORBIT CYCLING.
  - 45 REAL-TIME ECLIPSES PER SEASON: MAXIMUM DOD = 40%.
  - RECONDITIONING AFTER EACH SEASON: BATTERY IS DISCHARGED INTO A 44 Ω LOAD TO A 1V/CELL CUTOFF.
  - THE SOLSTICE PERIOD IS SHORTENED TO THE TIME REQUIRED FOR RECONDITIONING AND RECHARGE ONLY.
- SIX SEASONS HAVE BEEN COMPLETED AND THE TEST IS CONTINUING.
- THE TEST BATTERY CONTAINS 22 GE 12 AH CELLS, P/N 42B012AB20 WITH NYLON SEPARATOR. NEGATIVE PLATES CONTAIN SILVER BUT ARE NOT TEFLONATED.

Figure 4-86

GEOSYNCHRONOUS ORBITAL SIMULATION

TEST CONFIGURATION



SSTS SWITCH POINTS

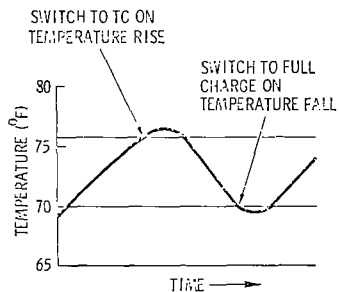
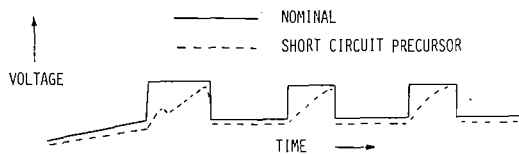


Figure 4-87

CELL SHORT CIRCUIT, PRESHORT SIGNATURE SHORT CIRCUIT EVENTS

- DESCRIPTION: HARD, SOFT, INTERMITTANT
- "SHORT" DEFINITION  
FOR PURPOSES OF THIS STUDY ANY ANOMALOUS VOLTAGE DECREASE GREATER THAN 100 mV WAS CONSIDERED TO BE EVIDENCE OF A SHORT.
- PRECURSOR OBSERVATION



- "SIGNATURE" DEFINITION
  - DEGRADED OVERALL VOLTAGE
  - "RAMPING" OF CHARGE AND DISCHARGE PULSES
  - "FEATURE" AT THE BEGINNING OF THE CHARGE PULSE

Figure 4-89

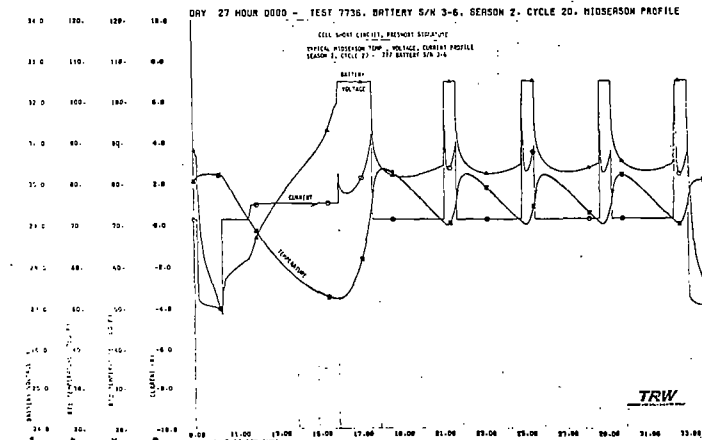


Figure 4-88

CELL SHORT CIRCUIT, PRESHORT SIGNATURE

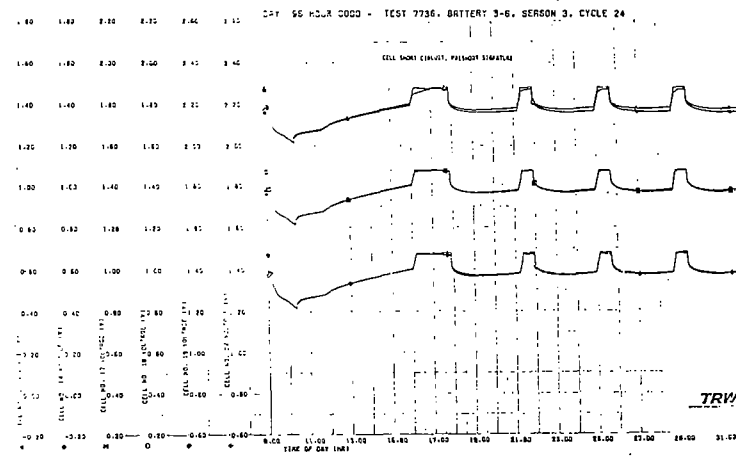


Figure 4-90



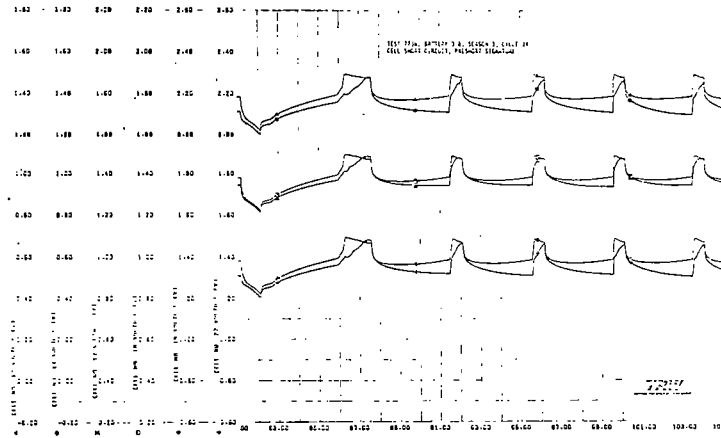


Figure 4-91

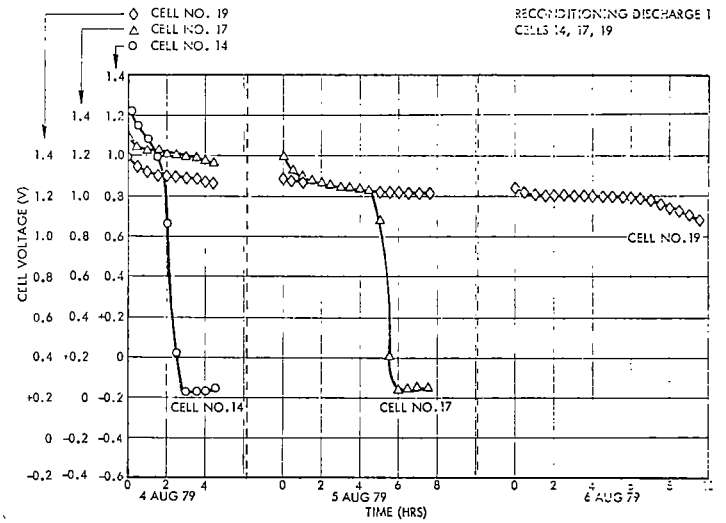


Figure 4-92

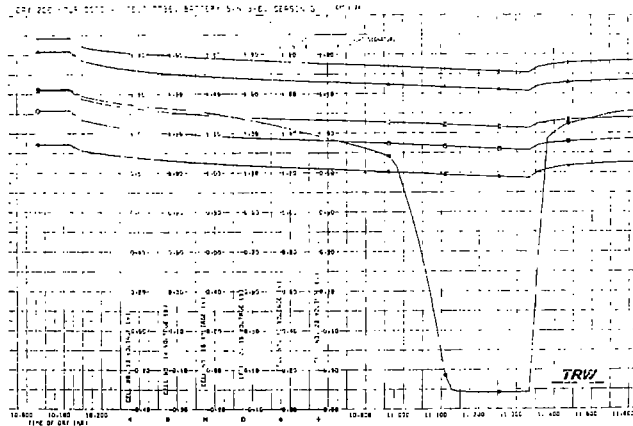


Figure 4-93

- PHYSICAL INTERPRETATION OF THE SIGNATURE
  - DEPRESSED VOLTAGE-----HIGH IMPEDANCE SHORTING PATH WHICH CAN BE STABLE FOR A PERIOD OF WEEKS.
  - "RAMPING"-----BATTERY IS PARTIALLY DISCHARGED AT THE BEGINNING OF THE PULSE.
  - ANOMALOUS CHARGE-----THE PHYSICAL SIGNIFICANCE IS NOT CLEAR AT PRESENT BUT IT MAY SUGGEST THAT THE NATURE OF THE SIGNATURE IS STATE OF CHARGE DEPENDENT.
- APPLICATIONS-----AS A SHORT CIRCUIT EARLY WARNING SYSTEM,
- WORK IN PROGRESS-----DPA TO CORRELATE TEARDOWN OBSERVATIONS WITH SIGNATURE/SHORTING EVENT HISTORY.

Figure 4-94