N92-22749

RISE TIME AND RESPONSE MEASUREMENTS ON A $LiSOCl_2$ CELL

[C. BASTIEN (SAFT) - E. LECOMTE (ETCA)]

ABSTRACT

Dynamic impedance tests have been performed on a 180Ah $LiSOCl_2$ cell in the frame of a short term work contract awarded by Aerospatiale as part of the Hermes space plane development work. These tests consisted of Rise Time and Response Measurements.

The Rise Time Test was performed to show the ability to deliver 4KW, in the nominal voltage range (75 - 115V), within less than 100 microseconds, and after a period at rest of 13 days.

The Response Measurements Test consisted of Step Response and Frequency Response tests.

The Frequency Response test allowed to determine the "small signal" impedance of the $LiSOCl_2$ cell. The cell impedance was measured for various frequencies, temperatures, intensities and depths of discharge.

The Step Response test was performed to characterize the response of the $LiSOCl_2$ cell to a positive or negative load step of 10A starting from various currents. The test was performed for various depths of discharge and various temperatures.

The test results were used to build a mathematical, electrical model of the $LiSOCl_2$ cell which are also presented.

Slides 5 to 17 give the test description and test results. Slides 18 to 25 give the electrical modelization description (for which additional comments are given hereafter). Slide 26 gives the conclusions of the presentation.

MATHEMATICAL MODEL OF THE $LiSOCl_2$ CELL (Slides 18 to 25)

Three models of increasing complexity are presented. Their validity is limited to the conditions of the tests presented :

- Frequency : 5 to 100 000Hz
- Temperature : 10 to 70°C (50 to 160°F)
- Depth of Discharge : 25 to 75%
- Bias Currents : 0 to 80A

The Frequency Response Tests directly give the impedance versus the frequency. The model is built on the basis of the Frequency Tests and validated and refined to match the measured Step Response.

The first model accounts for the Frequency Response when the temperature is greater or equal to 40°C (104°F) while the second one is a refinement valid also for low temperatures. Model 2 was validated by simulating its response to the Step Response Test and by comparing it to the experimental response. The validity proved to be good except for low DC currents.

MODEL 1 (Slides 18 to 19)

At temperatures greater than 40°C (104°F), all frequency responses are similar : a plateau at low frequencies and a resonance at 76 KHz.

The plateau is modelized by a Series Resistance (6mΩ) and the resonance by an R-L-C parallel cell.

R_2 of the R-L-C cell is given by the impedance at the resonance frequency : $R_2 = 41 - 6 = 35m\Omega$. The resonance frequency F_0 is equal to $1/2\pi\sqrt{LC}$ and the ratio $\Delta F/F_0$ is equal to $R\sqrt{C/L}$. This allows to determine L and C where L = 32nH and C = 137μF.

R_1 varies slightly with T° and I_{DC} = as I or T° increase, R_1 decreases.

MODEL 2 (Slides 20 to 22)

At low temperatures (10°C, 50°F), the impedance is higher for the low frequencies (below 2KHz), while the response is identical above 2KHz. This phenomenon is modelized by an RC parallel cell, added to Model 1.

R_3 is given by the value of the plateau : R3 = 30 - 6 = 24mΩ.
C_2 is given by the value of the impedance at F = 2KHz.

Model 2 also applies at high temperatures, with R_3 = 0mΩ (Model 1).

Model 2 is validated by comparing the experimental results of the Step Response Test to the simulated results. Slide N° 22 shows a good matching when the initial DC current is greater or equal to 10A for positive or negative steps.

MODEL 3 (Slides 23 to 24)

Slide N° 23 shows that for a DC current smaller than 10A, positive and negative responses are not symetrical.

Model 3 is similar to Model 2 (RC cell, series resistance and R-L-C cell) except that the resistance of the R-L-C cell is increased when the current measured before the application of the current step is smaller than 10A. The simulated Step Response is similar to the experimental Step Response, as shown in slide N° 24, which validates Model 3.

BATTERY MODEL (Slide 24)

The equivalent electrical model of 28 cells in a series is the electrical model of a cell with resistors and inductor values multiplied by 28 and capacitor values divided by 28.

An additional series resistance (R_4) and inductance (L_2) must be added in order to take into account the influence of the cabling between cells.

R_4 = 4.3mΩ
L2 = 1.2μH
As $R_4 << R_1$, R_4 can be neglected

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RISE TIME AND RESPONSE MEASUREMENTS ON A $LiSOCl_2$ CELL

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RISE TIME AND RESPONSE MEASUREMENTS ON A $LiSOCl_2$ CELL

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INTRODUCTION

* THE ELECTRICAL POWER GENERATION OF THE HERMES SPACE PLANE COMPRISES :

  - THE MAIN ELECTRICAL POWER GENERATION :

    2 FUEL CELL POWER PLANTS TO PROVIDE ELECTRICAL ENERGY FOR THE COMPLETE MISSION

  - THE SECONDARY ELECTRICAL POWER GENERATION :

    2 LITHIUM BATTERIES TO PROVIDE ELECTRICAL ENERGY AS AUXILARY SOURCES IN NOMINAL MODES AND BACK-UP SOURCES FOR EMERGENCY RE-ENTRY

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INTRODUCTION

* A SHORT TERM WORK CONTRACT WAS AWARDED BY AEROSPATIALE TO SAFT TO DEMONSTRATE THE FEASIBILITY OF A $LiSOCl_2$ BATTERY DESIGN, AS PART OF THE HERMES SPACE PLANE PRELIMINARY DEVELOPMENT WORK.

* THE PROPOSED $LiSOCl_2$ BATTERY CONSISTS OF 28 CELLS OF 180 AH CONNECTED IN SERIES

  TOTAL ENERGY = 16.6 KWH

  TOTAL MASS = 60 KG (132 LB)

  TOTAL VOLUME : 54 L

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INTRODUCTION

* SUMMARY OF THE ELECTRICAL CHARACTERISTICS OF EACH BATTERY

  - OUTPUT POWER : 0 TO 6 KW
  - OUTPUT VOLTAGE : 75 V < u < 115 V
  - REQUIRED ENERGY : 16 KWH
  - RISE TIME : EACH BATTERY SHALL BE ABLE TO START DELIVERING 4 KW WITHIN LESS THAN 100 MICROSECONDS AND WITH U IN THE SPECIFIED RANGE, AFTER A PERIOD AT REST OF 13 DAYS, AT T BETWEEN 15 AND 40°C (59 AND 104°F).

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INTRODUCTION

* DYNAMIC IMPEDANCE TESTS HAVE BEEN PERFORMED ON A 180 AH $LiSOCl_2$ CELL :
  - A RISE TIME TEST WAS PERFORMED TO SHOW THE ABILITY OF THE CELL TO MEET THE RISE TIME REQUIREMENT
  - RESPONSE TESTS WERE PERFORMED IN ORDER TO BUILD A MATHEMATICAL ELECTRICAL MODEL OF THE $LiSOCl_2$ BATTERY

THE TESTS HAVE BEEN PERFORMED AT SAFT BY ETCA (BELGIUM) WHO ALSO PROPOSED THE MATHEMATICAL MODEL.

ETCA IS INVOLVED IN THE HERMES PROGRAM AS THE POWER SYSTEM CONTRACTOR.

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RISE TIME AND RESPONSE MEASUREMENTS ON A $LiSOCl_2$ CELL

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TEST DESCRIPTIONS

* RISE TIME TEST :

- DISCHARGE AT 40A, VOLTAGE MEASUREMENT DURING THE FIRST 200 µs OF THE DISCHARGE.
- 13 DAYS REST PERIOD, DURING WHICH A 50mA DISCHARGE CURRENT IS IMPOSED IN ORDER TO AVOID THE PASSIVATION EFFECT.
- DISCHARGE AT 40A, VOLTAGE MEASUREMENT DURING THE FIRST 200 µs OF THE DISCHARGE.

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TEST DESCRIPTIONS

* **RESPONSE TESTS**

THEY CONSISTED OF STEP RESPONSE AND FREQUENCY RESPONSE TESTS

- STEP RESPONSE TEST : THE CELL VOLTAGE TO A NEGATIVE AND POSITIVE 10A STEP WAS MEASURED STARTING FROM VARIOUS CURRENTS, AT VARIOUS DOD's AND CELL TEMPERATURES.

25% DOD		75% DOD	
T = 43°C	T = 11°C	T = 11°C	T=72°C
I = 0, 1, 2, 5, 10, 20, 40, 70 A.	I = 0, 10, 40, 70 A.	I = 0, 10, 40, 70 A.	I = 0, 10, 40, 70 A.

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TEST DESCRIPTIONS

★ **RESPONSE TESTS**

- FREQUENCY RESPONSE TEST : A SMALL SINUSOIDAL CURRENT WAS SUPERIMPOSED ON A GIVEN CURRENT AND THE VOLTAGE RESPONSE WAS MEASURED FOR VARIOUS FREQUENCIES, TEMPERATURES, INITIAL CURRENTS AND DOD's. THIS TEST ALLOWED TO DETERMINE THE "SMALL SIGNAL" IMPEDANCE OF THE $LiSOCl_2$ CELL.

25% DOD		75% DOD	
T = 43°C	T = 11°C	T = 11°C	T=72°C
I = 0, 1, 2, 5, 10, 20, 30, 40, 60, 78 A.	I = 1, 2, 5, 10, 20, 40, 78 A.	I = 1, 2, 78, 5, 40, 10, 20 A.	I = 1, 2, 78, 5, 40, 10, 20 A.

FOR EACH CASE, THE FREQUENCY VARIED BETWEEN 5 Hz and 100 kHz

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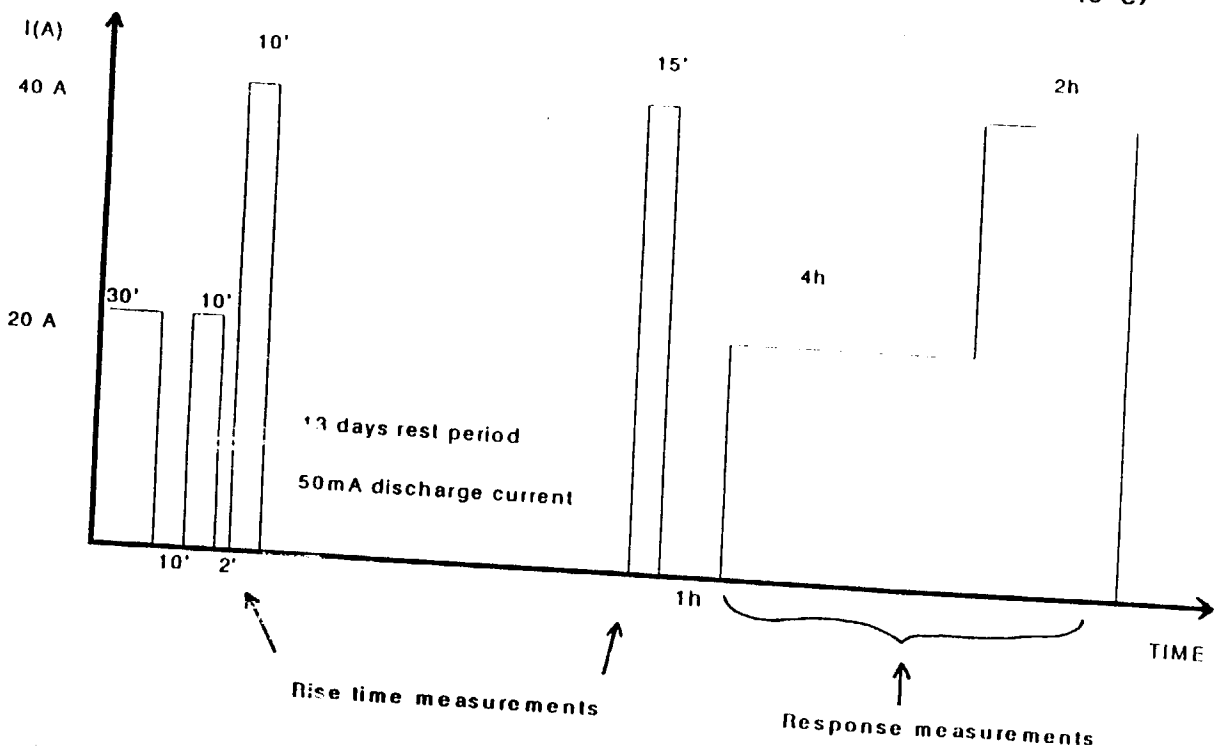
TEST SEQUENCE

THE CELL WAS DISCHARGED UNDER THE FOLLOWING PROFILE (T = 40°C)



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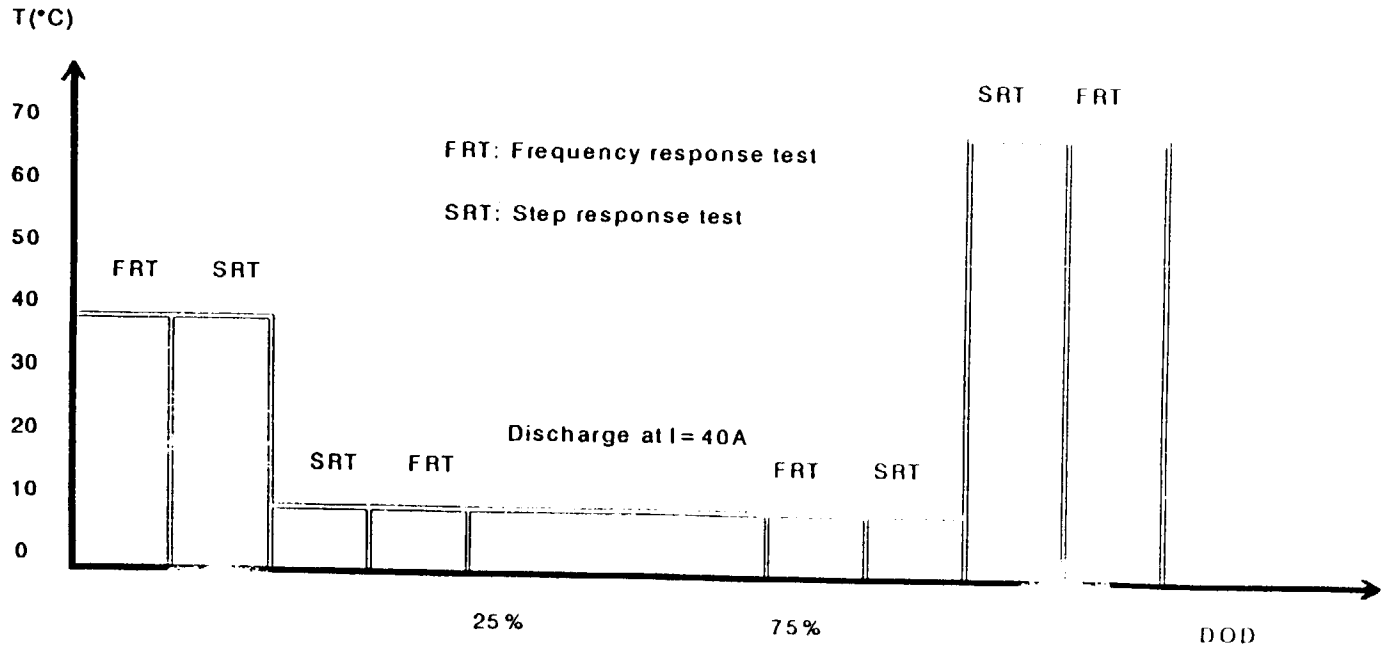
TEST SEQUENCE

RESPONSE TESTS SEQUENCE



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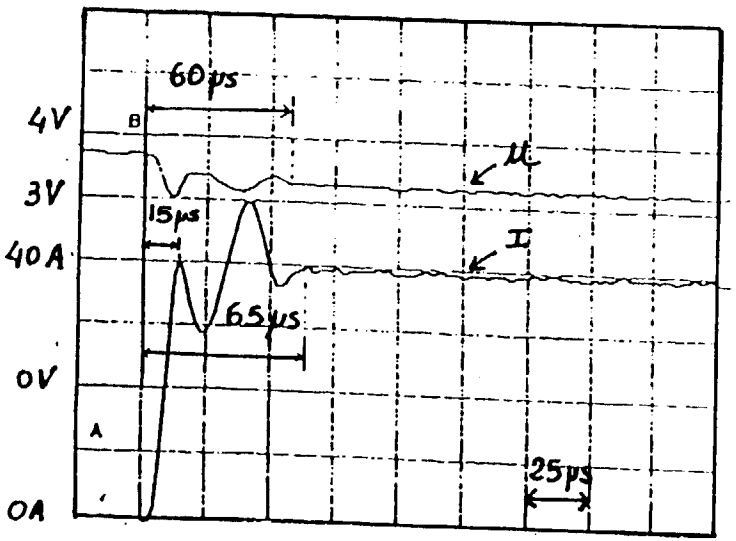
TEST RESULTS

RISE TIME TEST

RISE TIME MEASUREMENT AT T = 40 °C, DOD ≃ 20%. AFTER 13 DAYS WITH A 50MA DISCHARGE CURRENT (LOAD VARIATION 40A).



* RISE TIME MEASUREMENTS ARE THE SAME BEFORE AND AFTER THE 13 DAY REST PERIOD
* THE VOLTAGE RESPONSE STABILIZED AFTER 60µS AND ALWAYS STAYED SUPERIOR TO 3V (U BATTERY ≥ 84V)
* NO DELAY EFFECT

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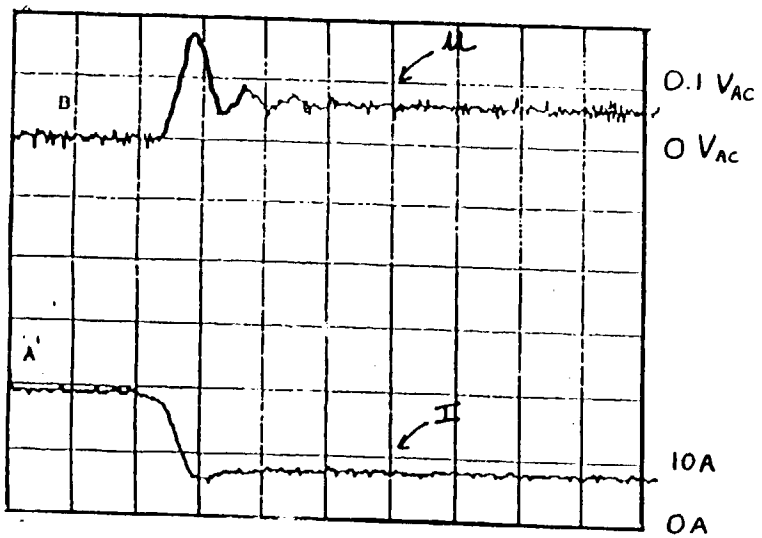
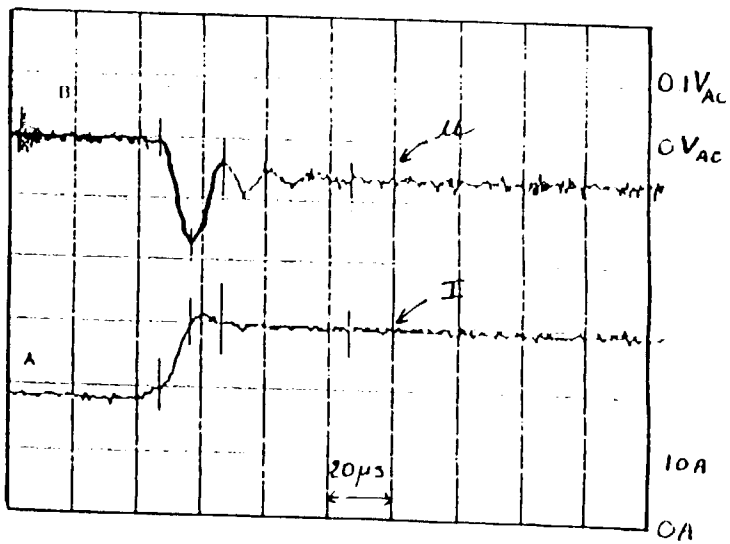
TEST RESULTS

STEP RESPONSE TEST

AT T = 43°C, DOD = 25%, I = 20A





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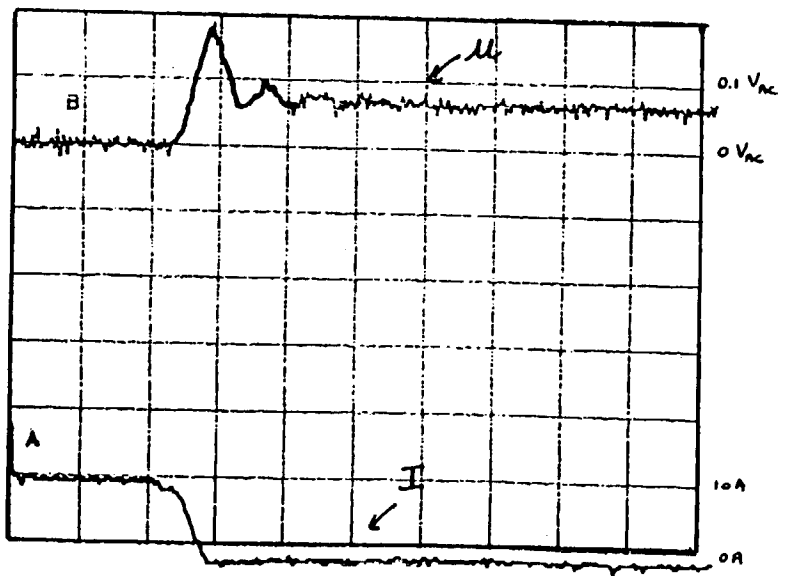
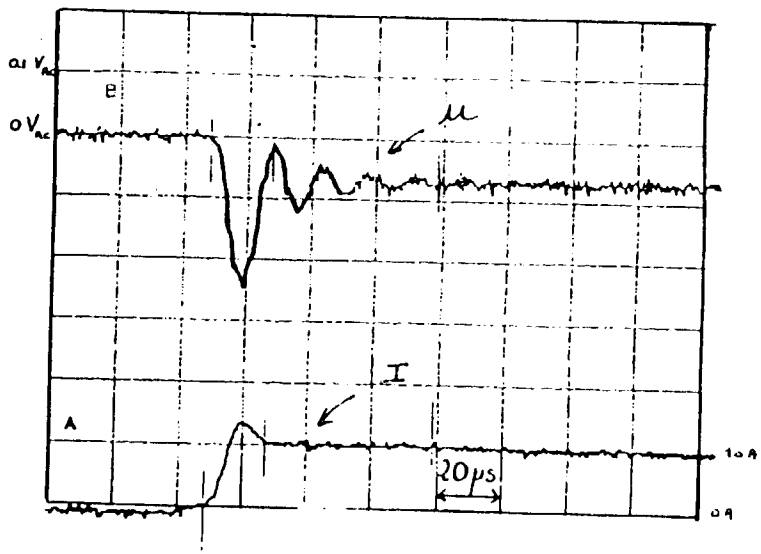
TEST RESULTS

STEP RESPONSE TEST

AT T = 43°C , DOD = 25%, I = 0A





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TEST RESULTS

STEP RESPONSE TESTS

- DYNAMIC RESPONSE (0 TO 70 µs) :

  * WHEN 40 < T < 70°C, NEGATIVE STEP RESPONSE IS IDENTICAL FOR ALL CURRENT AND DOD.

  * WHEN T < 40°C, THE VOLTAGE VARIATION DUE TO THE 10A STEP INCREASES AND VARIES WITH THE DOD.

  * THE POSITIVE STEP RESPONSE IS THE OPPOSITE OF THE NEGATIVE STEP RESPONSE FOR I > 10 A.

  * FOR I ≤ 10 A, THE VOLTAGE VARIATION DUE TO THE POSITIVE 10 A LOAD STEP, IS HIGHER

  * THE VOLTAGE ALWAYS STABILIZED WITHIN 70 µs WITH ΔV ALWAYS INFERIOR TO 0.13V.

- STATIC RESPONSE :

  * AFTER τ = 70µs, THE VOLTAGE SLOWLY VARIES WITH TIME BEFORE REACHING ITS NOMINAL VALUE

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TEST RESULTS

GENERAL OBSERVATIONS ON DYNAMIC RESPONSES OF $LiSOCl_2$ CELLS :

- THE HIGHER THE STARTING CURRENT, THE LOWER THE VOLTAGE VARIATION DUE TO THE 10A STEP
- THE HIGHER THE TEMPERATURE, THE LOWER THE VOLTAGE VARIATION DUE TO THE 10A STEP
- THE LOWER THE DEPTH OF DISCHARGE, THE LOWER THE VOLTAGE VARIATION DUE TO THE 10A STEP

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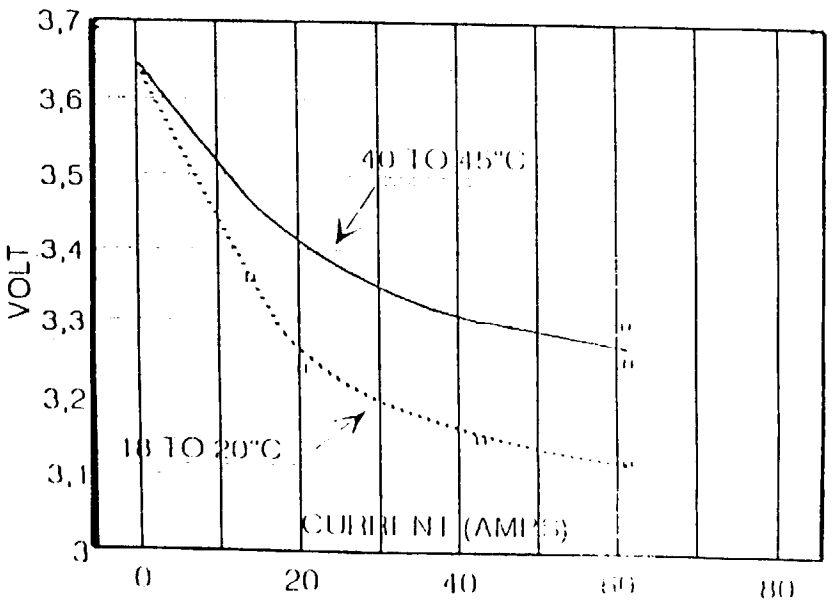
TEST RESULTS

STATIC RESPONSES OF $LiSOCl_2$ CELLS

VLS 250 AM AVERAGE VOLTAGE Vs CURRENT FOR VARIOUS TEMPERATURES



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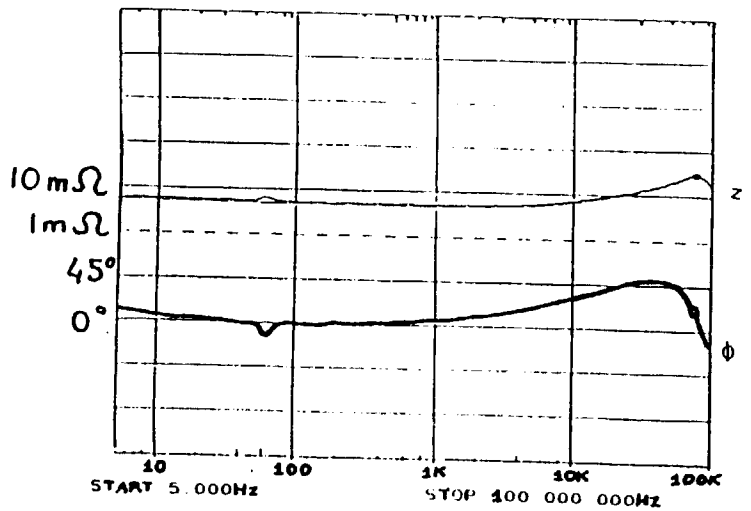
TEST RESULTS

FREQUENCY RESPONSE TEST

AT T = 43°C, DOD = 25%, I = 40 , 60, 78 A



* THE MAXIMUM CELL IMPEDANCE IS 41 m Ω ALWAYS MEASURED AT 76000 Hz INDEPENDENTLY OF T°, DOD, I.

* OVER 50 KHz, THE FREQUENCY RESPONSE CURVES ARE IDENTICAL FOR ALL T°, DOD, I.

* BELOW 50 KHz, AND WHEN T < 40°C, TEMPERATURE IMPACT IS NOTICEABLE : WHEN T DECREASES, IMPEDANCE INCREASES

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TEST RESULTS

CELL DISCHARGE

DELIVERED ENERGY : 612.1 WH (400 WH/KG)

DELIVERED CAPACITY : 204.8 AH

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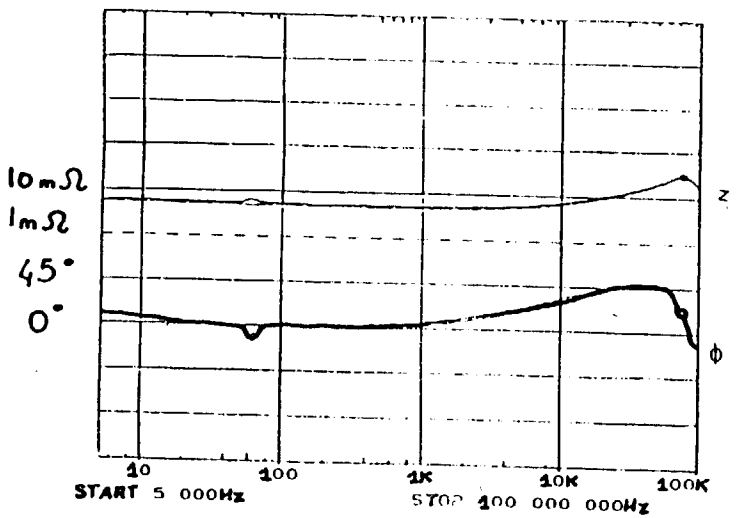
ELECTRICAL MODELIZATION

CELL ELECTRICAL MODELIZATION BASED ON FREQUENCY RESPONSE TEST

MODEL 1 : T ≥ 40°C



* PLATEAU AT 6 mΩ

  → SERIES RESISTANCE : R_1

* RESONANCE AT 76 KHz, 41 mΩ

  → RLC PARALLEL CIRCUIT : R_2 = 35 mΩ

  $1/2\pi\sqrt{LC}$ = 76 KHz

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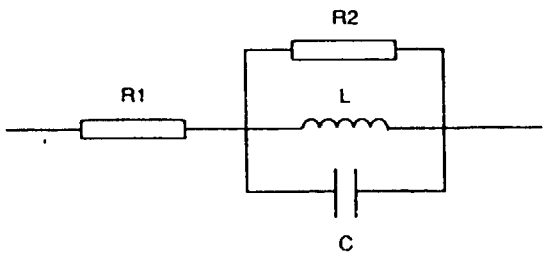
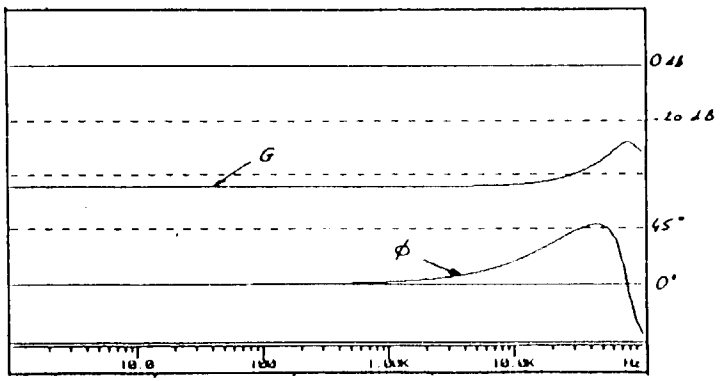
ELECTRICAL MODELIZATION

MODEL 1 : T ≥ 40°C



SIMULATION RESULT



R_1 = 6 mΩ TO 10 mΩ
(R_1 INCREASES AS T° AND/OR DC CURRENT DECREASES)

R_2 = 35 mΩ
L = 32 µH
C = 137 µF

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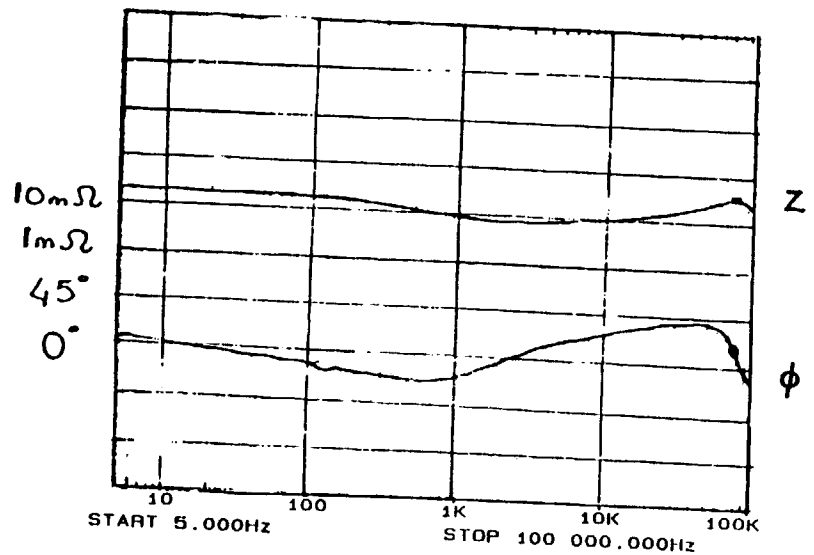
ELECTRICAL MODELIZATION

CELL ELECTRICAL MODELIZATION BASED ON FREQUENCY RESPONSE TEST

MODEL 2 : T < 40°C



* HIGHER IMPEDANCE AT LOW FREQUENCIES
* SAME AS MODEL 1 ABOVE 2KHz

→ ADD A RC PARALLEL CIRCUIT TO MODEL 1

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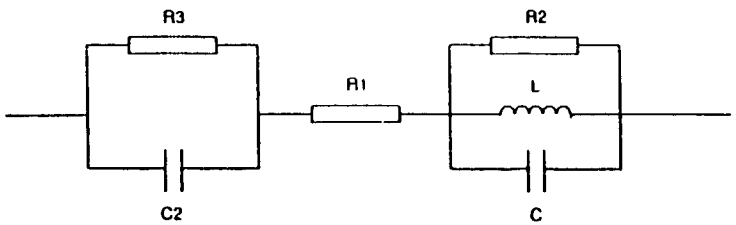
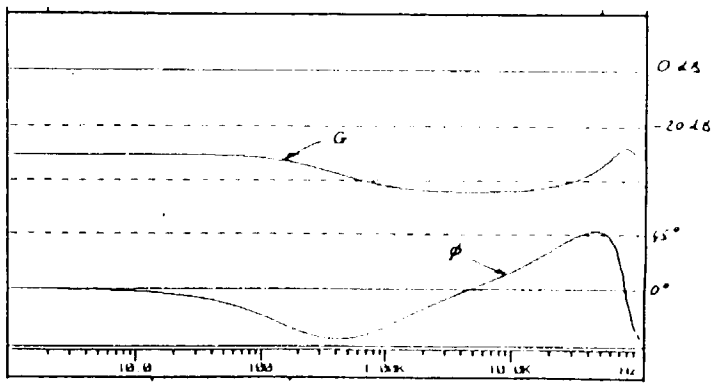
ELECTRICAL MODELIZATION

MODEL 2 : T < 40°C



SIMULATION RESULT



R_3 = 0 mΩ TO 24 mΩ
(R_3 INCREASES AS T° AND/OR DC CURRENT DECREASES)

C_2 = 35.4 mF

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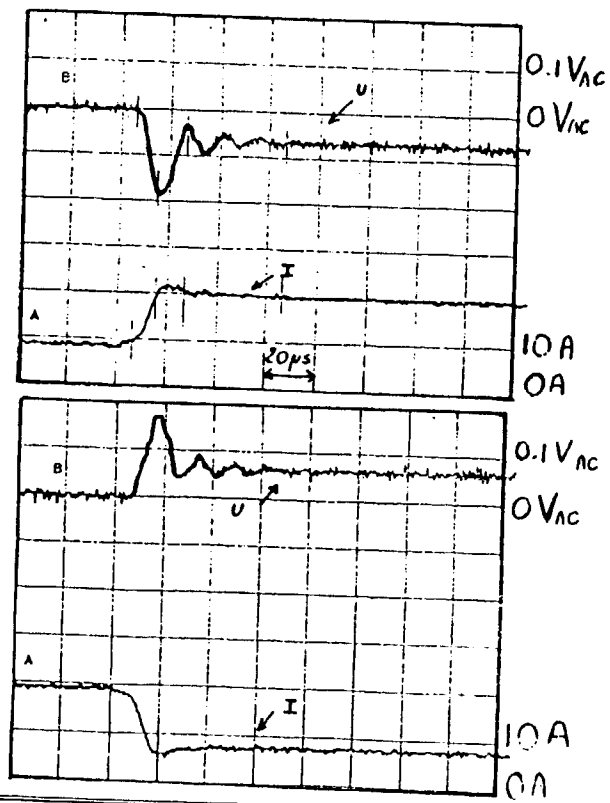
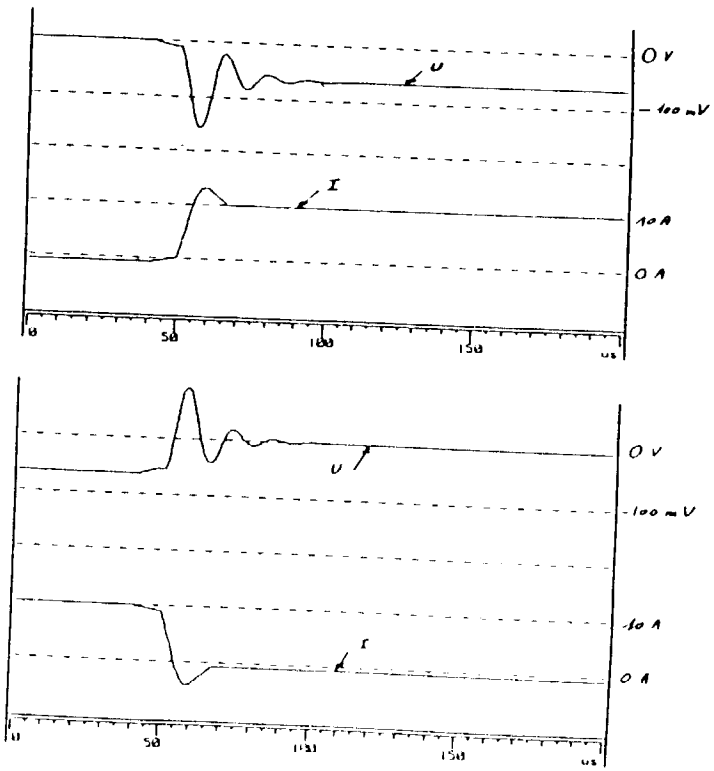
ELECTRICAL MODELIZATION

MODEL VALIDATION WITH STEP RESPONSE RESULTS ($I_{DC} \geq 10A$)





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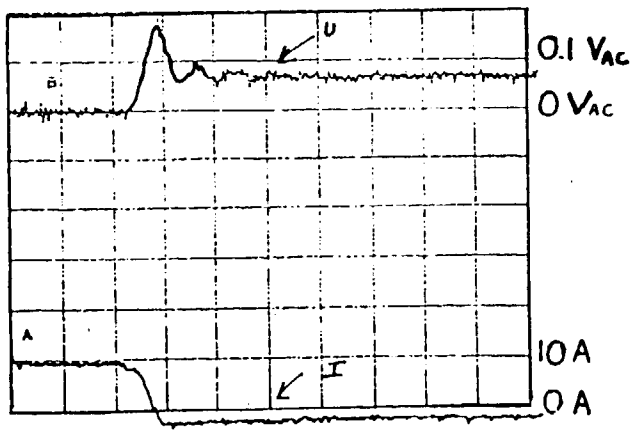
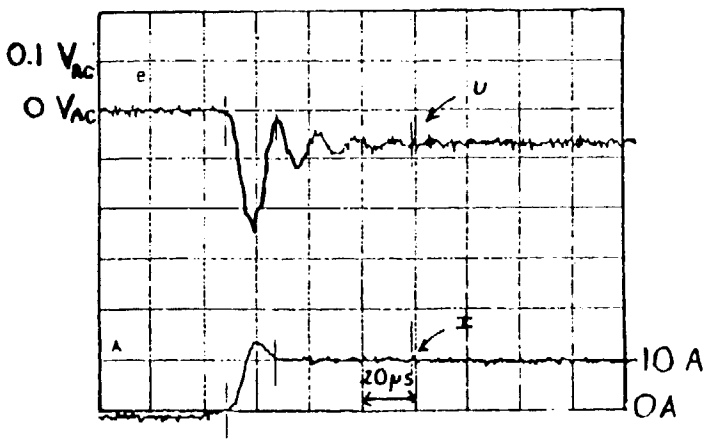
ELECTRICAL MODELIZATION

MODEL VALIDATION WITH STEP RESPONSE RESULTS (I_{DC} < 10A)

FOR I < 10A, THE POSITIVE AND NEGATIVE STEP RESPONSES ARE NOT SYMETRICAL.THE CELL VOLTAGE VARIATION DUE TO THE POSITIVE STEP IS HIGHER.





THE MODEL MUST INCLUDE A VARIABLE RESISTOR (R) WHICH WILL BE A FUNCTION OF THE CURRENT DELIVERED BY THE CELL.

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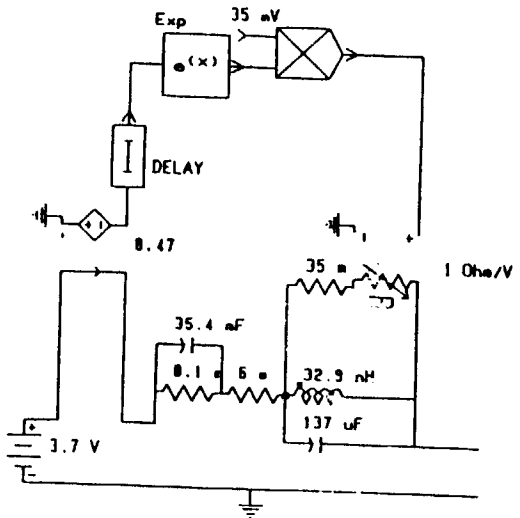
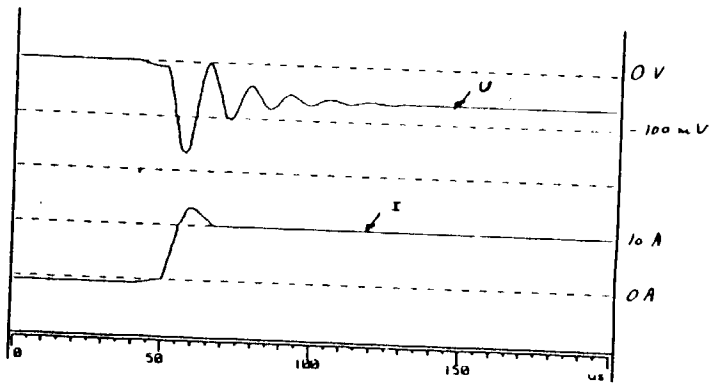
ELECTRICAL MODELIZATION

MODEL 3 : MODEL2 + RESISTOR (R)



SIMULATION RESULT



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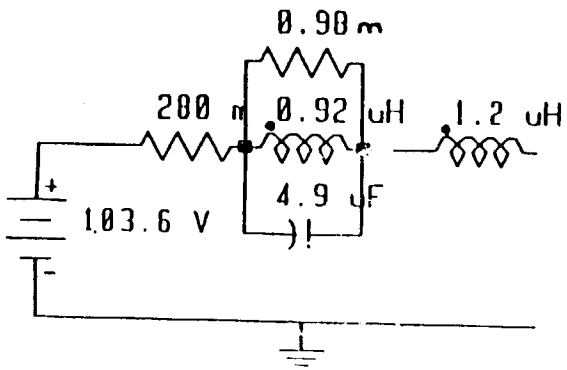
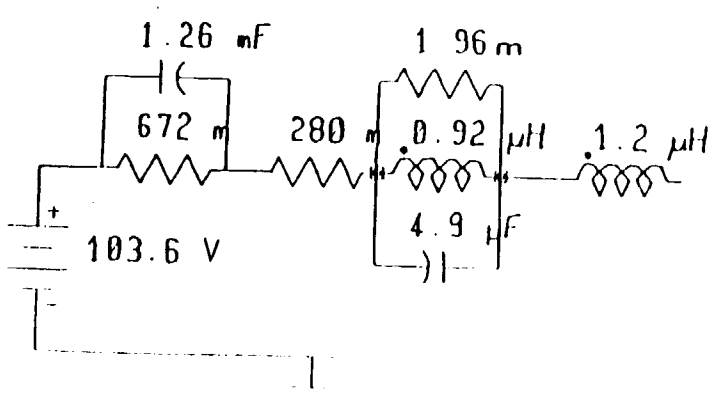
ELECTRICAL MODELIZATION

BATTERY ELECTRICAL MODELIZATION

T > 40°C



WORST CASE
(LOW CURRENT, LOW TEMPERATURE, HIGH DOD)



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CONCLUSION

* THE 180 Ah $LiSOCl_2$ CELL HAS SHOWN THE ABILITY TO DELIVER 40A WITHIN LESS THAN 60 µs IN THE SPECIFIED VOLTAGE RANGE (> 3 VOLTS).

* NO DELAY EFFECT WAS NOTICED AFTER 13 DAYS DURING WHICH A 50mA PERMANENT CURRENT WAS DISCHARGED.

* SEVERAL ELECTRICAL MODELS HAVE BEEN PRESENTED WHICH SIMULATE THE DYNAMIC BEHAVIOUR OF THE CELL FOR DIFFERENT CONDITIONS OF TEMPERATURE, CURRENT AND DOD.

* TWO MODELS OF THE 28 $LiSOCl_2$ CELL BATTERY ARE PROPOSED TO BE USED FOR THE MATHEMATICAL ANALYSIS OF THE HERMES POWER SYSTEM AND FOR AN ELECTRICAL SIMULATOR SPECIFICATION.