



US006137269A

United States Patent [19]
Champlin

[11] Patent Number: 6,137,269
[45] Date of Patent: Oct. 24, 2000

[54] METHOD AND APPARATUS FOR ELECTRONICALLY EVALUATING THE INTERNAL TEMPERATURE OF AN ELECTROCHEMICAL CELL OR BATTERY

[76] Inventor: Keith S. Champlin, 5437 Elliot Ave. South, Minneapolis, Minn. 55417

[21] Appl. No.: 09/388,276

[22] Filed: Sep. 1, 1999

[51] Int. Cl.⁷ H02J 7/00; G01N 27/416

[52] U.S. Cl. 320/150; 320/134; 324/431

[58] Field of Search 320/150, 132, 320/134; 324/430, 431, 432

[56] References Cited

U.S. PATENT DOCUMENTS

2,514,745 7/1950 Dalzell 171/95
3,356,936 12/1967 Smith 324/29.5
3,593,099 7/1971 Scholl 320/13

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

0 022 450 A1 1/1981 European Pat. Off. .
0 637 754 A1 2/1995 European Pat. Off. .
0 772 056 A1 5/1997 European Pat. Off. .
29 26 716 B1 1/1981 Germany .
59-017894 1/1984 Japan .
59-17892 1/1984 Japan .
59-17893 1/1984 Japan .
59-17894 1/1984 Japan .
60-225078 11/1985 Japan .
03274479 12/1991 Japan .
03282276 12/1991 Japan .
04131779 5/1992 Japan .
04372536 12/1992 Japan .
5216550 8/1993 Japan .
2 088 159 6/1982 United Kingdom .
WO 93/22666 11/1993 WIPO .
WO 98/58270 12/1998 WIPO .

OTHER PUBLICATIONS

R. Graf, "Radio Shack Dictionary of Electronics", 1975, p. 116.

"The Impedance of Electrical Storage Cells", by N.A. Hampson et al., *Journal of Applied Electrochemistry*, 1980, pp. 3-11.

"A Package for Impedance/Admittance Data Analysis", by B. Boukamp, *Solid State Ionics*, 1986, pp. 136-140.

"Precision of Impedance Spectroscopy Estimates of Bulk, Reaction Rate, and Diffusion Parameters", by J. Macdonald et al., *J. Electroanal. Chem.*, 1991, pp. 1-11.

"Electrochemical Impedance Spectroscopy in Battery Development and Testing", *Batteries International*, Apr. 1997, pp. 59 and 62-63.

"Battery Impedance", by E. Willihnganz et al., *Electrical Engineering*, Sep. 1959, pp. 922-925.

"Determining The End of Battery Life", by S. DeBardelaben, IEEE, 1986, pp. 365-368.

(List continued on next page.)

Primary Examiner—Shawn Riley

Assistant Examiner—Gregory J. Toatley

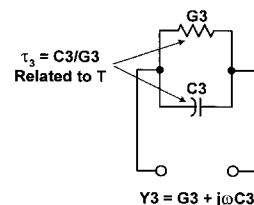
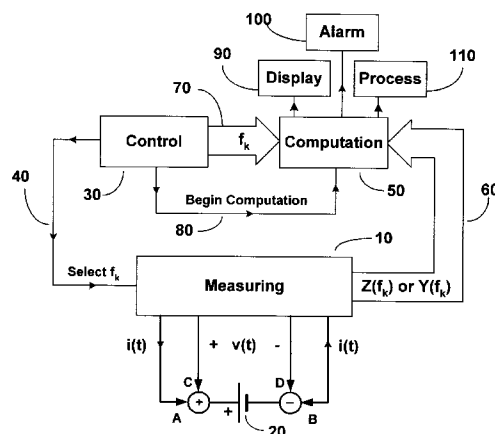
Attorney, Agent, or Firm—Westman, Champlin & Kelly, P.A.

[57]

ABSTRACT

A testing device applies time-varying electrical excitation to a cell or battery and senses the resulting time-varying electrical response. Computation circuitry within the device uses voltage and current signals derived from the excitation and response signals as inputs and computes values of elements of an equivalent circuit representation of the cell or battery. The internal temperature of the cell or battery is calculated from the value of the time constant of a particular parallel G-C subcircuit of the equivalent circuit. The battery's internal temperature is then either displayed to the user, used to apply appropriate temperature corrections to other computed quantities, used to detect thermal runaway, and/or used to control an external process such as charging of the battery.

11 Claims, 2 Drawing Sheets



U.S. PATENT DOCUMENTS

3,607,673	9/1971	Seyl	204/1	5,140,269	8/1992	Champlin	324/433
3,676,770	7/1972	Sharaf et al.	324/29.5	5,144,248	9/1992	Alexandres et al.	324/428
3,729,989	5/1973	Little	73/133	5,170,124	12/1992	Blair et al.	324/434
3,753,094	8/1973	Furuishi et al.	324/29.5	5,204,611	4/1993	Nor et al.	320/21
3,808,522	4/1974	Sharaf	324/29.5	5,214,370	5/1993	Harm et al.	320/35
3,811,089	5/1974	Strezelewicz	324/170	5,214,385	5/1993	Gabriel et al.	324/434
3,873,911	3/1975	Champlin	324/29.5	5,241,275	8/1993	Fang	324/430
3,886,443	5/1975	Miyakawa et al.	324/29.5	5,254,952	10/1993	Salley et al.	324/429
3,889,248	6/1975	Ritter	340/249	5,281,919	1/1994	Palnisamy	324/427
3,906,329	9/1975	Bader	320/44	5,281,920	1/1994	Wurst	324/430
3,909,708	9/1975	Champlin	324/29.5	5,295,078	3/1994	Stich et al.	364/483
3,936,744	2/1976	Perlmutter	324/158	5,298,797	3/1994	Redl	307/246
3,946,299	3/1976	Christianson et al.	320/43	5,300,874	4/1994	Shimamoto et al.	320/15
3,947,757	3/1976	Grube et al.	324/28	5,302,902	4/1994	Groehl	324/434
3,969,667	7/1976	McWilliams	324/29.5	5,331,268	7/1994	Patino et al.	320/20
3,979,664	9/1976	Harris	324/17	5,336,993	8/1994	Thomas et al.	324/158.1
3,984,762	10/1976	Dowgiallo, Jr.	324/29.5	5,343,380	8/1994	Champlin	363/46
3,984,768	10/1976	Staples	324/62	5,352,968	10/1994	Reni et al.	320/35
4,008,619	2/1977	Alcaide et al.	73/398	5,365,160	11/1994	Leppo et al.	320/22
4,053,824	10/1977	Dupuis et al.	324/29.5	5,365,453	11/1994	Startup et al.	364/481
4,070,624	1/1978	Taylor	327/158	5,381,096	1/1995	Hirzel	324/427
4,086,531	4/1978	Bernier	324/158	5,426,371	6/1995	Salley et al.	324/429
4,112,351	9/1978	Back et al.	324/16	5,432,426	7/1995	Yoshida	320/20
4,114,083	9/1978	Benham et al.	320/39	5,434,495	7/1995	Toko	320/44
4,126,874	11/1978	Suzuki et al.	354/60	5,442,274	8/1995	Tamai	320/23
4,178,546	12/1979	Hulls et al.	324/158	5,449,996	9/1995	Matsumoto et al.	320/20
4,193,025	3/1980	Frailing et al.	324/427	5,449,997	9/1995	Gilmore et al.	320/39
4,207,611	6/1980	Gordon	364/580	5,457,377	10/1995	Jonsson	320/5
4,315,204	2/1982	Sievers et al.	322/28	5,485,090	1/1996	Stephens	324/433
4,316,185	2/1982	Watrous et al.	340/636	5,488,300	1/1996	Jamieson	324/432
4,322,685	3/1982	Frailing et al.	324/429	5,519,383	5/1996	De La Rosa	340/636
4,363,407	12/1982	Barkler et al.	209/3.3	5,528,149	6/1996	Rogers	324/426
4,369,407	1/1983	Korbell	324/416	5,550,485	8/1996	Falk	324/772
4,390,828	6/1983	Converse et al.	320/32	5,561,380	10/1996	Sway-Tin et al.	324/509
4,392,101	7/1983	Saar et al.	320/20	5,562,501	10/1996	Kinoshita et al.	439/852
4,396,880	8/1983	Windebank	320/21	5,572,136	11/1996	Champlin	324/426
4,408,157	10/1983	Beaubien	324/62	5,574,355	11/1996	McShane et al.	320/39
4,412,169	10/1983	Dell'Orto	320/64	5,585,728	12/1996	Champlin	324/427
4,423,378	12/1983	Marino et al.	324/427	5,592,093	1/1997	Klingbiel	324/426
4,423,379	12/1983	Jacobs et al.	324/429	5,596,260	1/1997	Moravec et al.	320/30
4,424,491	1/1984	Bobbett et al.	324/433	5,598,098	1/1997	Champlin	324/430
4,432,378	2/1984	Marino et al.	327/470	5,602,462	2/1997	Stich et al.	323/258
4,459,548	7/1984	Lentz et al.	324/158	5,606,242	2/1997	Hull et al.	320/48
4,514,694	4/1985	Finger	324/429	5,621,298	4/1997	Harvey	320/5
4,520,353	5/1985	McAuliffe	340/636	5,642,031	6/1997	Brotto	320/21
4,667,279	5/1987	Maier	363/46	5,650,937	7/1997	Bounaga	364/483
4,678,998	7/1987	Muramatsu	324/427	5,652,501	7/1997	McClure et al.	320/17
4,679,000	7/1987	Clark	324/428	5,675,234	10/1997	Greene	320/15
4,697,134	9/1987	Burkum et al.	320/48	5,677,077	10/1997	Faulk	429/90
4,707,795	11/1987	Alber et al.	364/550	5,699,050	12/1997	Kanazawa	340/636
4,709,202	11/1987	Koenck et al.	320/43	5,701,089	12/1997	Perkins	327/772
4,710,861	12/1987	Kanner	363/46	5,717,336	2/1998	Basell et al.	324/430
4,719,428	1/1988	Liebermann	324/436	5,757,192	5/1998	McShane et al.	324/427
4,743,855	5/1988	Randin et al.	324/430	5,773,978	6/1998	Becker	324/430
4,816,768	3/1989	Champlin	324/428	5,789,899	8/1998	van Phuoc et al.	320/30
4,820,966	4/1989	Fridman	320/32	5,793,359	8/1998	Ushikubo	345/169
4,825,170	4/1989	Champlin	324/436	5,821,756	10/1998	McShane et al.	324/430
4,849,700	7/1989	Morioka et al.	324/427	5,831,435	11/1998	Troy	324/426
4,881,038	11/1989	Champlin	324/426	5,872,443	2/1999	Williamson	320/21
4,912,416	3/1990	Champlin	324/430	5,914,605	6/1999	Bertness	324/430
4,929,931	5/1990	McCuen	340/636	5,945,829	8/1999	Bertness	324/430
4,931,738	6/1990	MacIntyre et al.	324/435	6,002,238	12/1999	Champlin	320/134
4,947,124	8/1990	Hauser	324/430	6,037,777	3/2000	Champlin	324/430
4,956,597	9/1990	Heavvvvey et al.	320/14				
4,968,941	11/1990	Rogers	324/428				
5,004,979	4/1991	Marino et al.	324/160				
5,032,825	7/1991	Xuznicki	340/636				
5,047,722	9/1991	Wurst et al.	324/430				
5,087,881	2/1992	Peacock	324/378				
5,126,675	6/1992	Yang	324/435				

OTHER PUBLICATIONS

"A Look at the Impedance of a Cell", by S. Debardelaben, IEEE, 1988, pp. 394-397.

Internal Resistance: Harbinger of Capacity Loss in Starved Electrolyte Sealed Lead Acid Batteries, by Vaccaro, F.J. et al., AT&T Bell Laboratories, 1987 IEEE, Ch. 2477, pp. 128-131.

IEEE Recommended Practice For Maintenance, Testings, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations, *The Institute of Electrical and Electronics Engineers, Inc., ANSI/IEEE Std. 450-1987*, Mar. 9, 1987, pp. 7-15.

"Field and Laboratory Studies to Assess the State of Health of Valve-Regulated Lead Acid Batteries: Part I Conductance/Capacity Correlation Studies", by D. Feder et al., *IEEE*, Aug. 1992, pp. 218-233.

"Battery Impedance", by E. Willihnganz et al., *Electrical Engineering*, Sep. 1959, pp. 922-925.

"JIS Japanese Industrial Standard-Lead Acid Batteries for Automobiles", *Japanese Standards Association UDC*, 621.355.2:629.113.006, Nov. 1995.

"Performance of Dry Cells", by C. Hambuechen, Preprint of *Am. Electrochem. Soc.*, Apr. 18-20, 1912, paper No. 19, pp. 1-5.

"A Bridge for Measuring Storage Battery Resistance", by E. Willihnganz, *The Electrochemical Society*, preprint 79-20, Apr. 1941, pp. 253-258.

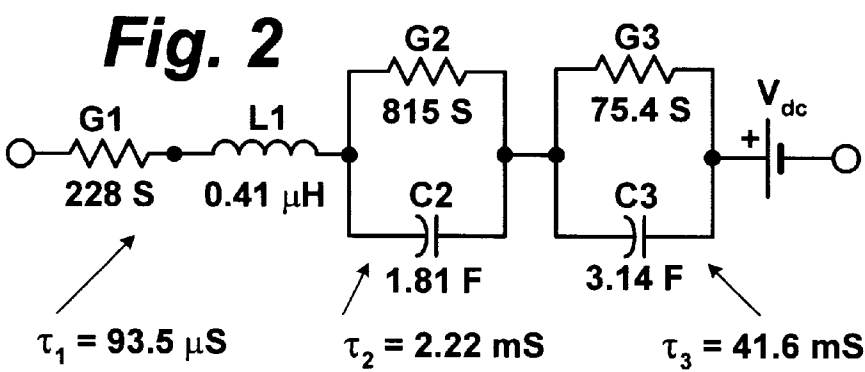
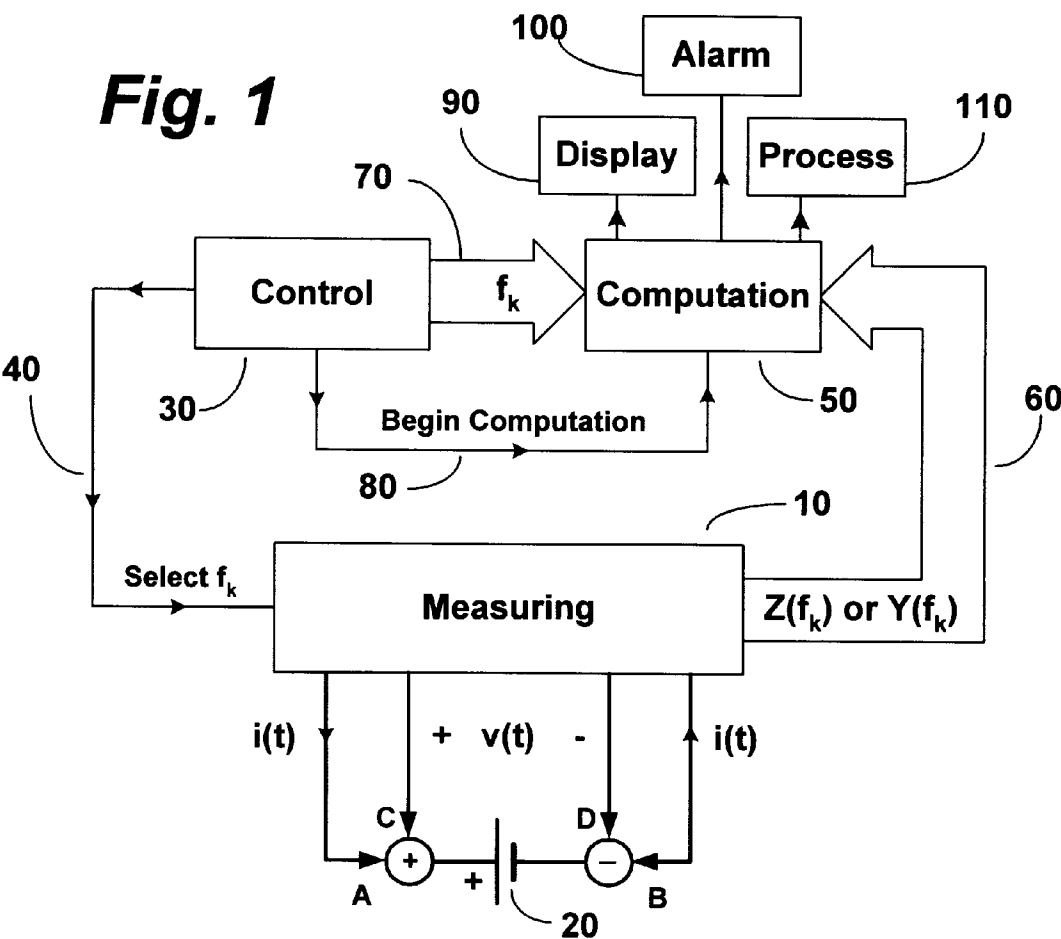


Fig. 3

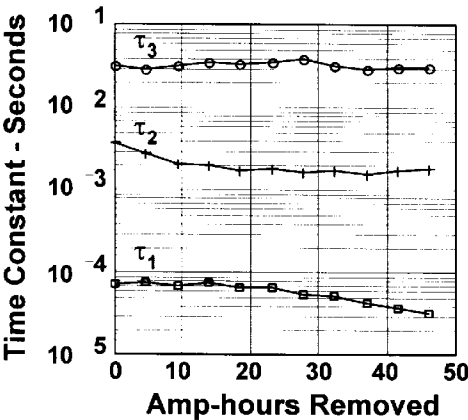


Fig. 4

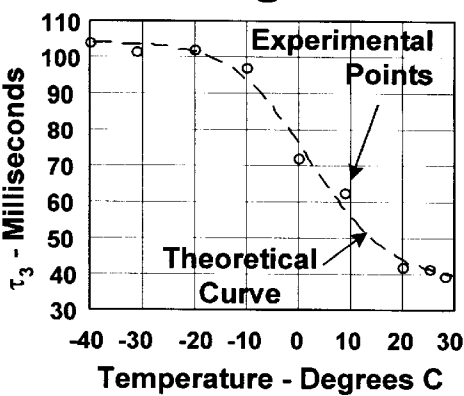


Fig. 5

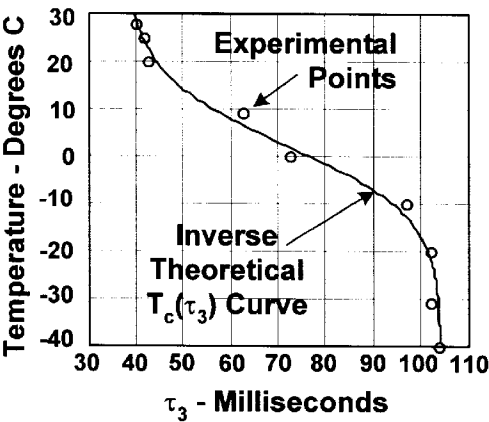
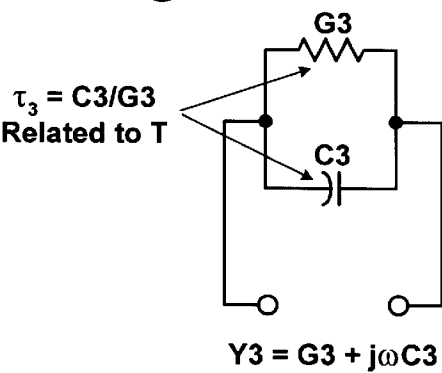


Fig. 6



1

METHOD AND APPARATUS FOR ELECTRONICALLY EVALUATING THE INTERNAL TEMPERATURE OF AN ELECTROCHEMICAL CELL OR BATTERY

BACKGROUND OF THE INVENTION

The present invention relates to testing of storage batteries. More specifically, the invention relates to measuring temperature of an electrochemical cell or battery.

When testing or evaluating the performance of cells and batteries, it is desirable to accurately know battery temperature in order to apply appropriate temperature corrections to the measured results. For example Champlin, in U.S. Pat. No. 3,909,708, describes setting a dial on the tester to the battery's temperature in order to cause the measured dynamic conductance to comport with that of a battery at room temperature. However, exactly how this battery temperature information is to be obtained is not discussed. Others employ a very rough correction by instructing the user to push a button when the ambient temperature is, e.g., "below 0° C.". Marino et al., in U.S. Pat. No. 4,423,378 refer to a battery temperature "probe" whose output is inputted to a microprocessor for the purpose of correcting load-test results. Similar temperature probes are described by Alber et al. in U.S. Pat. No. 4,707,795. Other workers have attached thermistors to test clips so that they would be in thermal contact with a battery terminal, or have placed them in thermal contact with the battery's case. Even infrared techniques have been used to determine battery case temperature.

All of these prior art techniques have measured either the battery's ambient temperature or its external case temperature. Unfortunately however, these quantities can be very different from the actual internal temperature of the battery—the truly desired quantity. These temperature differences come about from localized internal heating caused by currents flowing through the battery, from the large thermal mass of the battery, and from the poor thermal contact between the battery and its environment. For example, an automobile engine compartment will warm up rapidly with the engine running. If the battery is cold, however, its internal temperature will remain low for a very long period of time.

SUMMARY OF THE INVENTION

A testing device applies time-varying electrical excitation to a cell or battery and senses the resulting time-varying electrical response. Computation circuitry within the device uses voltage and current signals derived from the excitation and response signals as inputs and computes values of elements of an equivalent circuit representation of the cell or battery. The internal temperature of the cell or battery is calculated from the value of the time constant of a particular parallel G-C subcircuit of the equivalent circuit. In various aspects, the battery's internal temperature is then displayed to the user, used to apply appropriate temperature corrections to other computed quantities, used to detect thermal runaway, and/or used to control an external process such as charging of the battery.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a device for measuring the internal temperature of an electrochemical cell or battery according to the present invention.

FIG. 2 depicts a six-element small signal equivalent circuit representation of a particular automotive storage battery.

2

FIG. 3 is a plot of the variation of the three subcircuit time-constants defined in FIG. 2 as functions of the charge removed from the battery.

FIG. 4 is a plot of measured and theoretical values of time constant τ_3 defined in FIG. 2 as functions of the internal temperature of the battery.

FIG. 5 is a plot of the inverse of the relationship plotted in FIG. 4.

FIG. 6 is a circuit representation of the parallel G3-C3 subcircuit showing its admittance Y3.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Clearly, a method and apparatus for electronically determining the true internal temperature of a cell/battery would be of great value. The present invention addresses this need.

A very important application of the method taught herein is in the detection of "thermal runaway"—a phenomenon in which the internal temperature of a battery undergoing charging rises catastrophically (see, e.g., McShane et al., U.S. Pat. No. 5,574,355). Using the technique disclosed below, a runaway condition can be quickly detected by a precipitous internal temperature rise, which, in turn could be used to shut off the charger or reduce its charging voltage.

FIG. 1 discloses a block diagram of apparatus for evaluating a battery's internal temperature according to the present invention. Apparatus of this type is fully disclosed in pending U.S. patent application Ser. No. 09/152,219, filed Sep. 11, 1998 and entitled "METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES" and pending U.S. patent application Ser. No. 09/151,324, filed Sep. 11, 1998, entitled "METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE ADMITTANCE" which are incorporated herein by reference. Measuring circuitry 10 electrically couples to cell/battery 20 by means of current-carrying contacts A and B and voltage-sensing contacts C and D. Measuring circuitry 10 passes a periodic time-varying current $i(t)$ through contacts A and B and senses a periodic time-varying voltage $v(t)$ across contacts C and D. By appropriately processing and combining $i(t)$ and $v(t)$, measuring circuitry 10 determines real and imaginary parts of a complex parameter, either impedance Z or admittance Y, at a measuring frequency f_k ; where f_k is a discrete frequency contained in the periodic waveforms of both $i(t)$ and $v(t)$.

Control circuitry 30 couples to measuring circuitry 10 via command path 40 and commands measuring circuitry 10 to determine the complex parameter of cell/battery 20 at each one of n discrete measuring frequencies, where n is an integer number. This action defines 3n experimental quantities: the values of the n measuring frequencies and the values of the n imaginary parts and n real parts of the complex parameter at the n measuring frequencies.

Computation circuitry 50 couples to measuring circuitry 10 and to control circuitry 30 via data paths 60 and 70, respectively, and accepts the 2n experimental values from measuring circuitry 10 and the values of the n measuring frequencies from control circuitry 30. Upon a "Begin Computation" command from control circuitry 30 via command path 80, computation circuitry 50 uses algorithms disclosed in U.S. patent application Ser. No. 09/151,324 to combine these 3n quantities numerically to evaluate 2n elements of an equivalent circuit representation of the cell/battery. Computation circuitry 50 then calculates the internal temperature of the cell/battery from values of particular elements of this

circuit representation. Finally, computation circuitry 50 outputs the computed result to the user on display 90 and/or uses the result to activate an alarm 100 or to control a process 110 such as a battery charger.

In practice, a microprocessor or microcontroller running an appropriate software program can perform the functions of both control circuitry 30 and computation circuitry 50.

FIG. 2 discloses a six-element equivalent circuit representation of a typical automotive storage battery. This circuit representation was evaluated using apparatus of the type disclosed in FIG. 1 with $n=3$ by employing algorithms disclosed in U.S. patent application Ser. No. 09/151,324. The three measurement frequencies were 5 Hz, 70 Hz, and 1000 Hz. One notes that the $n=3$ equivalent circuit comprises three subcircuits:

A series G1-L1 subcircuit.

A parallel G2-C2 subcircuit.

A parallel G3-C3 subcircuit.

One notes further that the three subcircuits are characterized by having very different time constants. The shortest time constant, $\tau_1=L1 \cdot G1=93.5 \mu S$, belongs to the series G1-L1 subcircuit. The next longest time constant, $\tau_2=C2/G2=2.22 \text{ mS}$, belongs to the parallel G2-C2 subcircuit; and the longest time-constant, $\tau_3=C3/G3=41.6 \text{ mS}$, belongs to the parallel G3-C3 subcircuit. Accordingly, the three subcircuits represent quite different physical processes and can be differentiated from one another by their time constants.

FIG. 3 is a logarithmic plot of the three time constants defined above as functions of charge (ampere-hours) removed from the battery. One notes that the three time constants remain widely separated as charge is removed, and that the longest of the three, τ_3 , is nearly independent of state-of-charge. This result is important to the present invention.

FIG. 4 discloses the observed variation of time constant $\tau_3=C3/G3$ with internal battery temperature. One sees that τ_3 varies inversely with temperature. This variation is consistent with a theoretical model that associates the G3-C3 subcircuit with a linearized, small-signal, representation of the nonlinear electrochemical reaction occurring at the negative plates. For such a model, the RC product $\tau_3=C3/G3$ represents the reaction time for the process and therefore varies inversely with temperature. By empirically establishing this relationship between τ_3 and T , one can actually utilize measurements of τ_3 to determine the battery's internal temperature, T .

FIG. 4 shows experimental points compared with a theoretical $\tau_3(T_c)$ relationship. Note that the steepest slope, and hence the most accurate temperature determination, occurs in the most interesting region between -20° C. and $+20^\circ \text{ C.}$ The theoretical curve disclosed in FIG. 4 is a plot of the following equation:

$$\tau_3(T_c) = K_3 + \frac{1}{\frac{1}{K_2} + \frac{1}{K_1 \exp[qV_0/k(T_c + 273^\circ)]}} \quad (1)$$

where τ_3 is the time constant measured in milliseconds and T_c is the internal temperature measured in degrees Celsius. Physical parameters introduced in this equation are:

$k=1.38 \times 10^{-23} \text{ Joules/}^\circ \text{ K}$ (Boltzman's Constant)

$q=1.6 \times 10^{-19} \text{ Coulombs}$ (electronic charge)

$V_0=0.85 \text{ eV}$ (activation energy)

The three constants K_1 , K_2 , and K_3 were empirically determined to be

$$K_1=2.0 \times 10^{-14}$$

$$K_2=67.0 \text{ mS}$$

$$K_3=37.0 \text{ mS}$$

One notes excellent agreement between theory and experiment. Measurements show that τ_3 is virtually independent of battery size and state-of-charge (see FIG. 3). Thus, this empirical $\tau_3(T_c)$ relationship plotted in FIG. 4 appears to be quite universal.

In order to determine internal temperature from time constant measurements, one must mathematically invert the above $\tau_3(T_c)$ relationship to obtain a $T_c(\tau_3)$ relationship. The result is:

$$T_c(\tau_3) = \frac{(qV_0/k)}{\ln\left\{\frac{(K_2/K_1)(\tau_3 - K_3)}{(K_2 + K_3 - \tau_3)}\right\}} - 273^\circ \quad (2)$$

where the parameters and constants, q , V_0 , k , K_1 , K_2 , K_3 , are the same as those introduced in the $\tau_3(T_c)$ relationship.

The inverse theoretical $T_c(\tau_3)$ curve is plotted in FIG. 5. By employing this relationship, one can readily determine the battery's true internal temperature from measurements of τ_3 . This important temperature information can then be used to apply accurate temperature corrections to other measured quantities, such as CCA, state-of-charge, and amp-hour capacity. It can also be used to detect a thermal runaway condition, and to control an external process such as a battery charger.

This completes the disclosure of my invention. FIGS. 6, however, will place the true nature of the invention in greater perspective. FIG. 6 illustrates the G3-C3 subcircuit and shows that the complex admittance of this parallel subcircuit, $Y3=G3+j\omega C3$, explicitly contains the two quantities, $G3$ and $C3$, necessary to determine the battery's internal temperature. Thus, my discussion above actually discloses a relationship existing between the real and imaginary parts of $Y3$ and the internal temperature of the battery. Although it is true that complex Z and complex Y are reciprocals of one another, no simple relationship exists between the real and imaginary parts of impedance $Z3$ and time constant τ_3 . Accordingly, the results of any ac measurement must be expressed in complex admittance form—not complex impedance form—in order to observe the important relationship that I have disclosed herein. How this complex admittance is obtained, however, is relatively unimportant.

Although my disclosure has relied upon particular apparatus and algorithms previously disclosed in U.S. patent applications Ser. No. 09/152,219 and Ser. No. 09/151,324, other methods will be apparent to one skilled in the arts. For example, one can employ bridges or other types of apparatus to measure complex admittance (or its reciprocal, complex impedance). Furthermore, if accuracy is not a strict requirement, one can take advantage of the fact that the various time constants are widely separated from one another and simply assume that the subcircuits are not coupled. Within this approximation, C2 and C3 are treated as short circuits at frequencies near $f_{01}=1/2\pi\tau_1$, L1 and C3 are treated as short circuits at frequencies near $f_{02}=1/2\pi\tau_2$, and at frequencies near $f_{03}=1/2\pi\tau_3$, L1 is treated as a short circuit while C2 is treated as an open circuit. Thus, with some batteries, it is possible to obtain satisfactory results from a very simple analysis of measurements at two or three frequencies. With certain batteries, it is even possible to obtain useful approximations to $Y3$ from measurements of complex Y or $Z=1/Y$ obtained at a single, appropriately

5

chosen, frequency. Workers skilled in the art will recognize that these and other variations may be made in form and detail without departing from the true spirit and scope of my invention.

What is claimed is:

1. Apparatus for determining the internal temperature of an electrochemical cell or battery comprising:

electrical excitation circuitry adapted to apply time-varying electrical excitation to said cell or battery;

response sensing circuitry configured to sense time-varying electrical response of said cell or battery generated as a result of said time-varying electrical excitation; and

computation circuitry responsive to said time-varying excitation and to said time-varying response and adapted to calculate the time constant of a particular parallel G-C subcircuit comprising part of an electrical circuit representation of said cell or battery, said time constant characterized by varying inversely with internal temperature, said computation circuitry further adapted to evaluate said internal temperature from the computed value of said time constant.

2. The apparatus of claim 1 including a display device coupled to said computation circuitry and wherein the computation circuitry provides a temperature output on the display.

3. The apparatus of claim 1 wherein said computation circuitry couples to an external process device and said external process device is controlled by said computation circuitry in accordance with the computed value of said internal temperature.

4. The apparatus of claim 1 wherein said electrical circuit representation comprises at least three subcircuits having differing time constants and the time constant of said particular parallel subcircuit is longer than the time constants of at least two other subcircuits.

6

5. The apparatus of claim 1 wherein said electrical circuit representation comprises at least two subcircuits having different time constants and the time constant of said particular parallel subcircuit is longer than the time constant of at least one other subcircuit.

6. The apparatus of claim 1 including an output indicative of detect a thermal runaway condition, said condition characterized by a rapid rise in internal temperature while charging of the battery.

7. The apparatus of claim 6 including an alarm coupled to said computation circuitry and wherein the computation circuitry provides an alarm output in response to said thermal runaway condition.

8. The apparatus of claim 3 wherein said external process device is a battery charger.

9. A method for electronically evaluating the internal temperature an electrochemical cell or battery comprising:

applying time-varying electrical excitation to said cell or battery;

sensing time-varying electrical response to said electrical excitation;

evaluating the time constant of a particular parallel G-C subcircuit of an equivalent circuit representation of said cell or battery from said time-varying electrical excitation and said time-varying electrical response; and evaluating said internal temperature from the value of said time constant.

10. The method of claim 9 including the displaying said internal temperature to a user.

11. The method of claim 9 including the controlling an external process device in accordance with said internal temperature.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,137,269
DATED : October 24, 2000
INVENTOR(S) : Keith S. Champlin

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Page 2, under U.S. PATENT DOCUMENTS

Change "Heavvvvey et al." to --Heavy et al.--.

Change "5,528,149" to --5,528,148--.

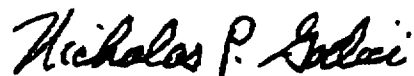
Col. 6, line 8, delete "detect".

Col. 6, line 18, after "temperature" insert
--of--.

Col. 6, line 32, after "controlling" insert
--of--.

Signed and Sealed this
Twenty-second Day of May, 2001

Attest:



NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office