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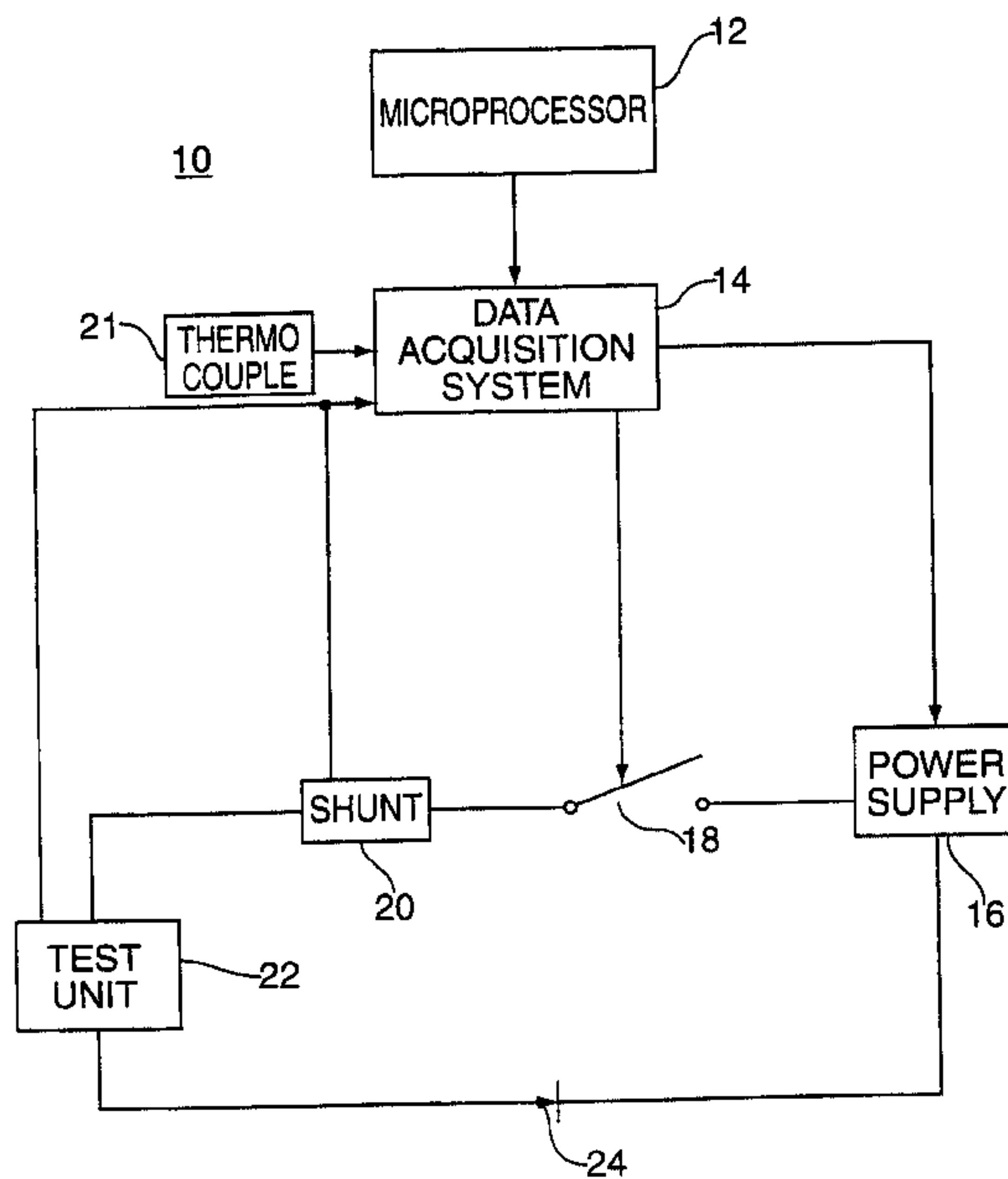
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(30) 1998/09/15 (09/153,606) US

(54) **DISPOSITIF ET PROCEDE DE DETERMINATION DE LA CAPACITE D'UNE BATTERIE NICKEL-CADMIUM**

(54) **APPARATUS AND METHOD FOR DETERMINING THE CAPACITY OF A NICKEL-CADMIUM BATTERY**



(57) The invention provides for a timesaving method of determining the capacity of a nickel cadmium (NiCd) (22). A fully charged NiCd battery (22) under test is subjected to a positive sloped current charge ramp (42) and then a negative sloped current charge ramp (46) while continuously monitoring the battery terminal voltage. The voltage is plotted and the maximum slope of the measure terminal voltage determines  $I_{gas}$ . The value of  $I_{gas}$  is compared to a temperature calibration curve to determine the capacity of the battery (22) under test.

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(54) Title: APPARATUS AND METHOD FOR DETERMINING THE CAPACITY OF A NICKEL-CADMIUM BATTERY			
(57) Abstract			
<p>The invention provides for a timesaving method of determining the capacity of a nickel cadmium (NiCd) (22). A fully charged NiCd battery (22) under test is subjected to a positive sloped current charge ramp (42) and then a negative sloped current charge ramp (46) while continuously monitoring the battery terminal voltage. The voltage is plotted and the maximum slope of the measure terminal voltage determines <math>I_{gas}</math>. The value of <math>I_{gas}</math> is compared to a temperature calibration curve to determine the capacity of the battery (22) under test.</p>			
<pre> graph TD     12[MICROPROCESSOR] --&gt; 14[DATA ACQUISITION SYSTEM]     14 --&gt; 21[THERMO COUPLE]     14 --&gt; 20[SHUNT]     20 --&gt; 22[TEST UNIT]     22 --&gt; 16[POWER SUPPLY]     16 --&gt; 14   </pre>			

5 APPARATUS AND METHOD FOR DETERMINING THE  
CAPACITY OF A NICKEL-CADMIUM BATTERY

Government Statement

10 All or part of this invention was developed with Government support  
for the United States Navy under Government Contract No. N00164-96-C-  
0045. The Government has certain rights to this invention under the terms  
of the contract.

Background of the Invention

15 This invention relates to rechargeable batteries, and more  
particularly to determining the capacity of a nickel cadmium (NiCd) battery.  
The battery capacity of NiCd batteries are determined by charging the  
battery to 100% state of charge and then discharging the battery at a  
constant current. The time required for the battery to discharge to a  
20 specified voltage is measured. The battery capacity in ampere-hour (A-  
hr.) is then calculated by multiplying the time in hours to discharge the  
battery by the constant discharge current. This method takes several  
hours of charging and discharging.

25 At the present time, there is no method for determining the capacity  
of a NiCd battery without discharging the battery.

There is, therefore, a need for a method to determine the capacity  
of a NiCd battery without discharging the battery.

Brief Description of the Drawings

FIGURE 1 is a schematic of a battery charging and analyzing circuit;

FIGURE 2 is a graphical representation of the voltage and current

5 curves during battery charging at room temperature;

FIGURE 3a is a graphical representation of the voltage and current

curves in the evaluation cycle of the invention;

FIGURE 3b is an alternate current charging curve;

FIGURE 4 is a graphical representation of the capacity-temperature

10 calibration curve at room temperature;

FIGURE 5 is a graphical representation of the capacity-temperature

calibration curve at -30°C;

FIGURE 6 is a graphical representation of the voltage and current

curves of a 20 Ah, 24 V NiCd battery under test in accordance with the

15 invention; and

FIGURE 7 is a graphical representation of the voltage and current

curves of a A 30 Ah, 24V NiCd battery under test in accordance with the

invention.

20 Description of the Invention

This invention provides for a time-saving method for determining the capacity of a nickel cadmium battery, without discharging the battery.

An exemplary charging system is shown in Figure 1. A NiCd battery charging system 10 comprises a microprocessor 12 in combination with a data acquisition system 14, such as a National Instruments SCXI data acquisition system. The components of the data acquisition system 14 are Labview 4.0 software, a signal conditioning unit, such as a National Instruments signal conditioning system with digital to analog converters and analog to digital converters and thermocouple modules. System 10 further comprises a

programmable power supply 16, a relay 18, a 50A, 50mV shunt 20 to measure current, a thermocouple 21 to measure temperature, a unit under test 22, in this case, a 24V NiCd battery, and a diode 24 to protect the power supply. In 5 operation, the microprocessor is programmed using Labview 4.0 to control the current output of the power supply 16 and to close/open the relay 18 to electrically connect/disconnect the battery 22. The microprocessor 12 stores the voltage, current and temperature data acquired by the data acquisition hardware.

Once attached to the charging system 10, the battery 22 is charged to 10 full capacity, i.e. 100% state of charge, as graphically shown in Figure 2. This is achieved by applying a constant current 26 to the battery. As the battery is subjected to this constant current charge, the voltage goes through three 15 phases: gradual voltage rise indicating charge reaction, as indicated by time period 28; a sharp voltage rise indicating initiation of gas reaction, as indicated by time period 30; and a plateau region showing simultaneous gas reaction and charge reaction, as indicated by time period 32. During time period 28, the battery voltage gradually rises until the cumulative charge delivered to the battery is about 80 to 90% of the battery's charge capacity. At this point, 75% of the battery's capacity is normally available upon discharge. On further 20 charging during time period 30, the battery voltage quickly increases as the battery starts evolving gas towards the end of the charge process. The battery voltage tends to stabilize until the battery is fully charged at the end of time period 32. At time period 34, the battery voltage gradually decreases in the overcharge portion of the charge. After a decrease of 15mV has been detected 25 in the overcharge, the current charge is terminated at point 36 and the battery is left in open circuit, time period 38 and is fully charged.

After the battery 22 comes to a stabilized status in terms of temperature and open circuit voltage, it is subjected to a test cycle. Before starting the test cycle, safe voltage and current limits are established from the known

characteristics of the battery as would be published by the battery manufacturer. During the test cycle, an increasing charge current 42 is applied to the battery. Preferably, the charge current is started from zero and increases linearly up to the maximum current the charging system can output or 5 to the identified safe battery voltage and current limits, whichever is lower. In actual practice, the charge current will be as shown in Fig. 3a due to the output lag time of the power supply compared with the programmed value. The increasing current charge does not have to be linear, as long as it increases as a known function of time. Alternatively, consecutive pulses with an increasing 10 current amplitude can also be used during the ramp test as shown in Fig. 3b.

The current charge ramp is then decreased at any negative slope 46 until the current reaches zero. Preferably, the slope of the decreasing current charge is the same slope as the current charge 42. During the current charge phases 42 and 46, the battery terminal voltage 44 is continuously measured 15 and recorded. The slope of the voltage curve is also calculated. When the slope goes through a maximum it indicates the transition from charge reaction to gas reaction. The current at this transition point is referred to as the gas current ( $I_{gas}$ ). We have demonstrated that  $I_{gas}$  correlates with the battery capacity. Further,  $I_{gas}$  is a function of ambient battery temperature and 20 accordingly, the correlation between  $I_{gas}$  and battery capacity must be performed at a given temperature for fully charged nickel-cadmium batteries. Calibrations for nickel cadmium batteries at 21°C and -30° C are shown in Figures 4 and 5.

Determination of the slope of the voltage curve is accomplished by 25 calculating the difference in successive voltage values over a small interval. This data is then subjected to a five point moving averaging technique that was found to provide a reliable method to suppress noise caused by the electronics circuitry. As is known to those skilled in the art, any digital filtering technique to suppress noise may be used. Averaging methods using less than 5 data points

did not suppress the noise adequately; hence did not provide satisfactory results. Using more than 5 points in the average reduces the peak intensity severely. Peak detection was accomplished by comparing each voltage difference point with an average of two voltage difference points before and 5 after the point. The point should be greater than both the averages by a predetermined margin in order to indicate a maximum in slope. The current at this point is determined to be the  $I_{gas}$  for the battery. The battery's capacity is calculated using this  $I_{gas}$  and a temperature calibrated curve.

A temperature-calibrated curve is determined as follows. Nickel 10 cadmium batteries of various capacities were subjected to the charge regime as described above. Once the battery was completely charged, it was left in open circuit until the temperature and voltage stabilized. Once the battery was in an equilibrium state, it was subjected to test cycle outlined above and the  $I_{gas}$  value was noted. Next, the battery was completely discharged. This was 15 accomplished by drawing a constant current from the battery. The discharge was terminated when the battery voltage dropped to 0.95 volts per cell. The capacity value was calculated by multiplying the discharge current by the amount of time required to reach 0.95 volts per cell. The calibration curve was generated using the capacity and  $I_{gas}$  values from numerous iterations to the 20 above procedure with different nickel cadmium batteries.

The safe voltage and current limits imposed on the system during the ramp test cycle significantly affect the gas current,  $I_{gas}$ . Therefore it is important to remember that one can set these limits at different values within a range for nickel cadmium batteries and generate different calibration curves. As long as 25 the battery whose capacity has to be determined is subjected to the same conditions as the calibration curve batteries, the results should be satisfactory. For example the safe voltage limit for nickel-cadmium batteries can be set at in the range 1.3 to 1.65 volts per cell.

Example 1

Referring to Fig. 6, a 20 Ah, 24 V NiCd battery was completely charged, following the charge regime described above. Once at an equilibrium state, the battery was subjected to a test cycle. Voltage and current data from the test cycle are shown in figure 6. In the figure, the maximum slope and the corresponding current are indicated by the arrows. It was determined, via the methods described above, that the battery had 28.1 Ah available capacity.

Upon a complete discharge, the battery was found to provide 27.8 Ah.

Example 2

With reference to Fig. 7, a 30 Ah, 24V NiCd battery was placed in a temperature-control chamber that was set to -30° Celcius. After the battery temperature reached this ambient temperature, it was completely charged, following the charge regime described above. Once at an equilibrium state, the battery was subjected to a test cycle. Voltage and current data from the test cycle are shown in figure 7. In the figure, the maximum slope and the corresponding current are indicated by the arrows. It was determined, via the methods described above, that the battery had 43.1 Ah available capacity.

Upon a complete discharge, the battery was found to provide 44.9 Ah.

AMENDED SHEET

SUPERSEDED SHEET

We claim:

1. A method for determining the capacity of a battery comprising the steps of:

5 a) measuring the temperature of said battery;

b) subjecting said battery to an increasing current charge and then a decreasing current charge;

10 c) measuring the battery terminal voltage during said step (b); and

d) determining the maximum slope of the measured battery terminal voltage;

characterized in that said method determines the capacity of a nickel cadmium battery and further comprises the steps of

15 e) calculating the current charge value  $I_{gas}$  associated with said maximum

slope for said nickel cadmium battery; and

ascertaining the capacity of said nickel cadmium battery by comparing said  $I_{gas}$  value of step (e) against a known determination of cadmium battery capacity for 20 different  $I_{gas}$  values at said measured temperature.

2. The method of claim 1 further characterized in that said increasing current charge is current pulses with each subsequent current pulse having a higher current magnitude than the preceding current pulse.

AMENDED SHEET

SLIPSTYLLE SHEET

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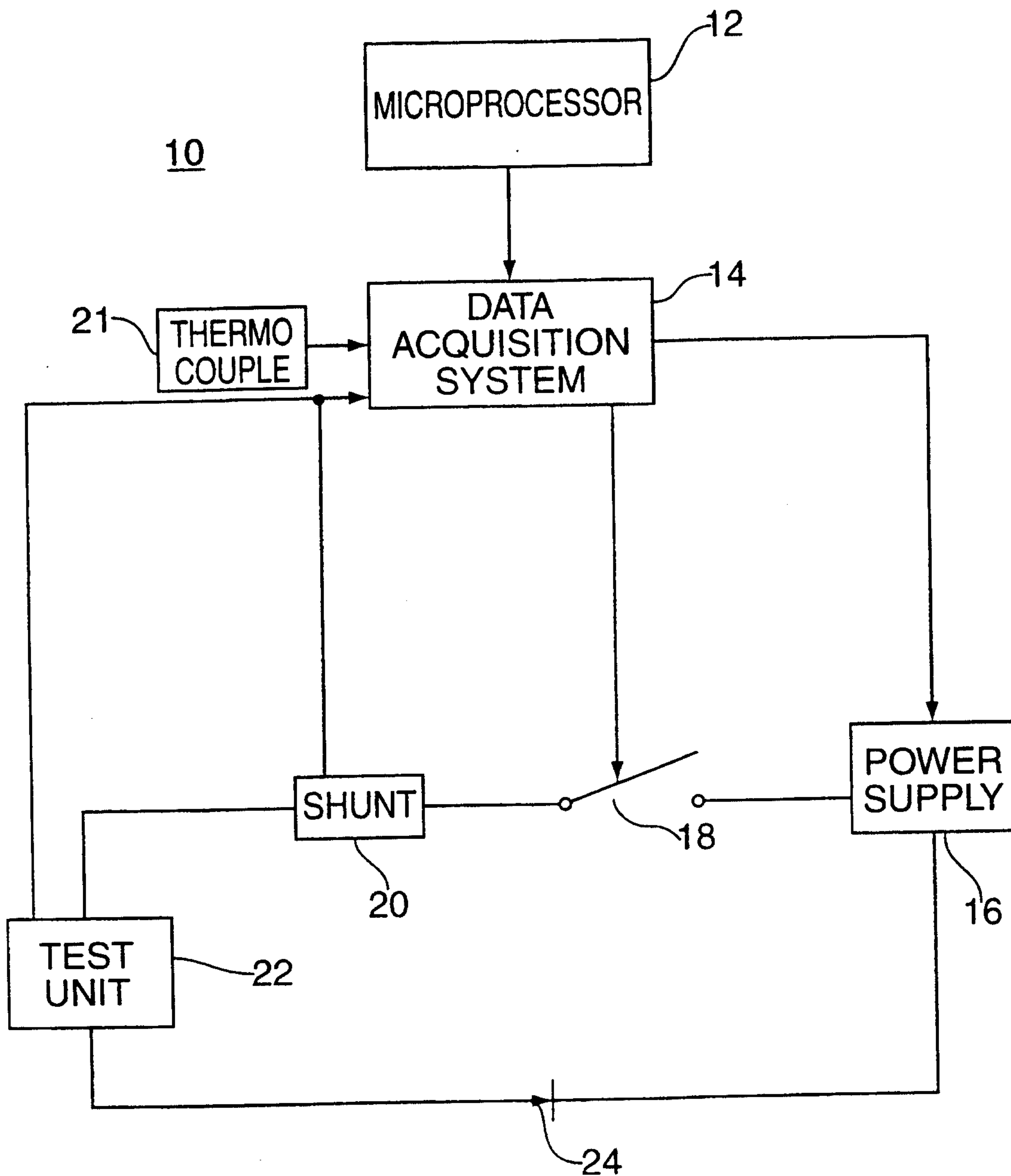


FIG. 1

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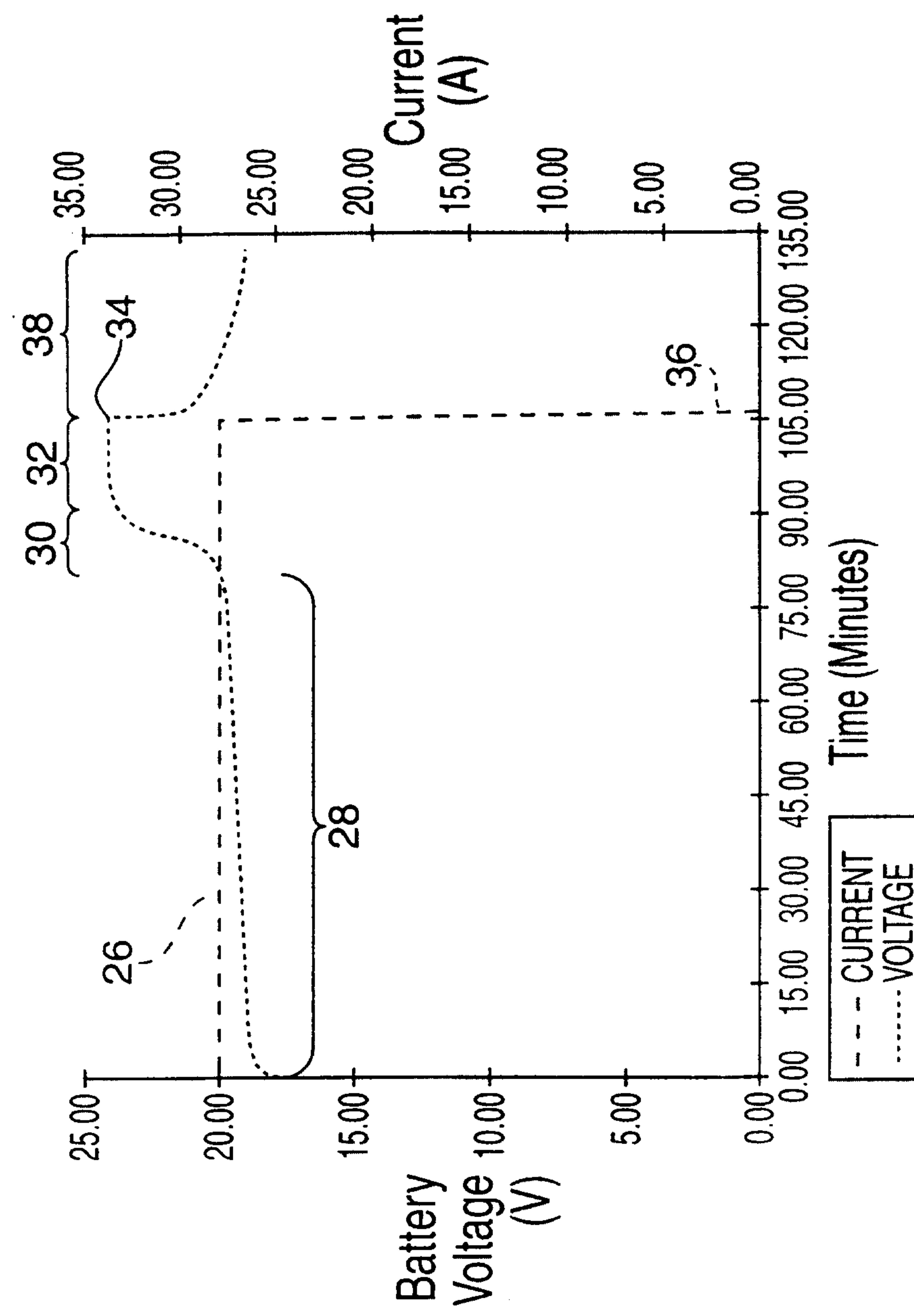


FIG. 2

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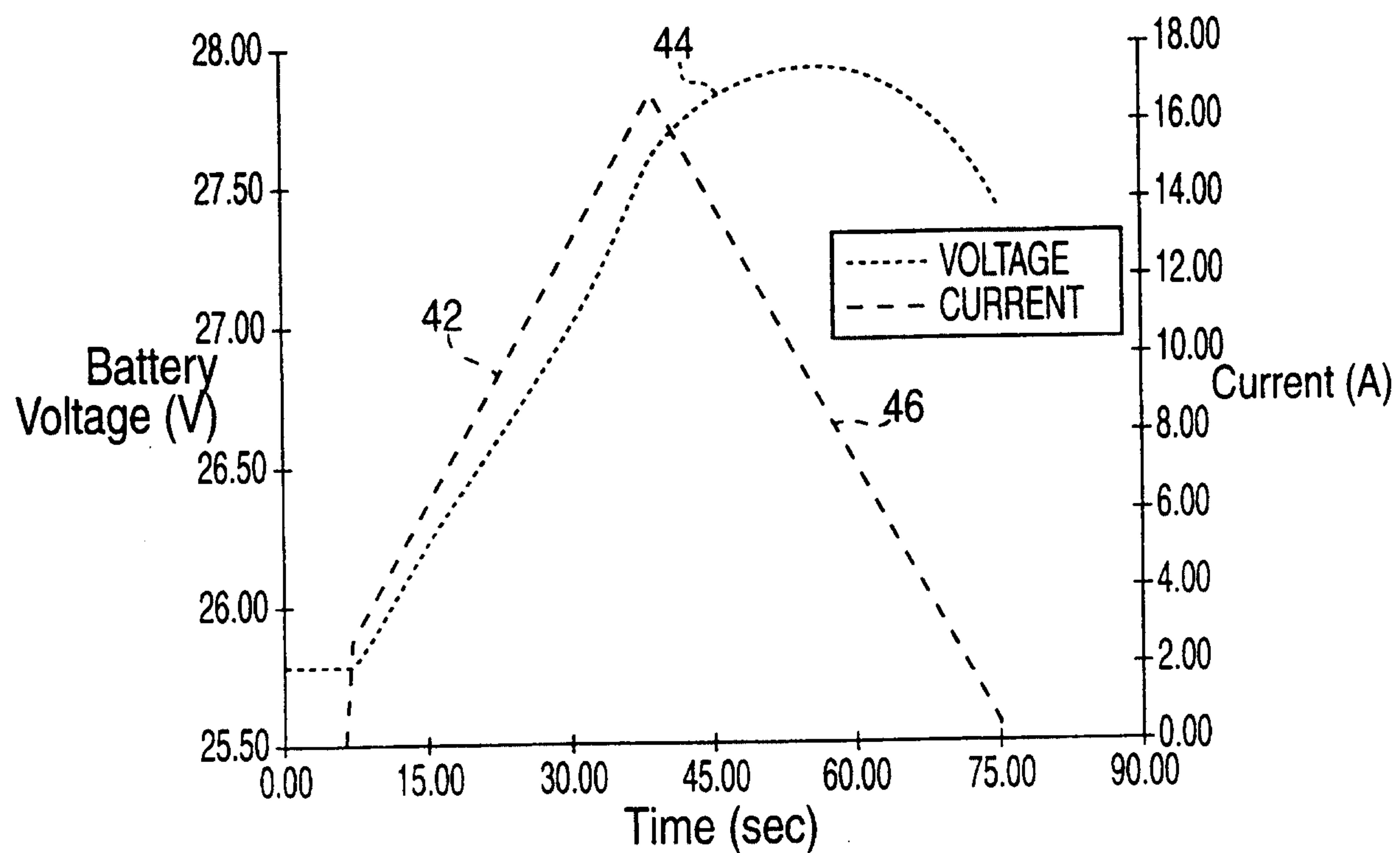


FIG. 3a

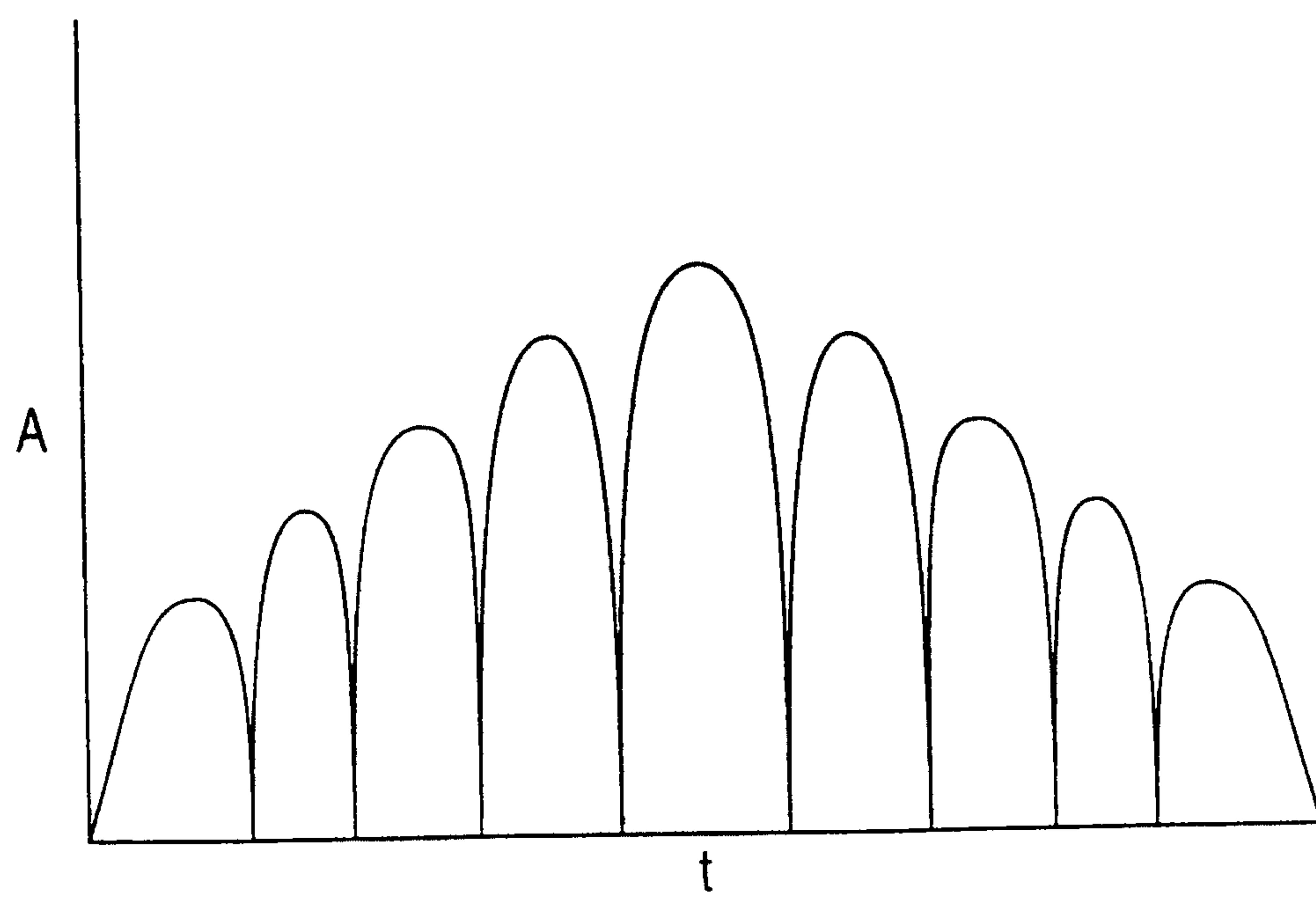


FIG. 3b

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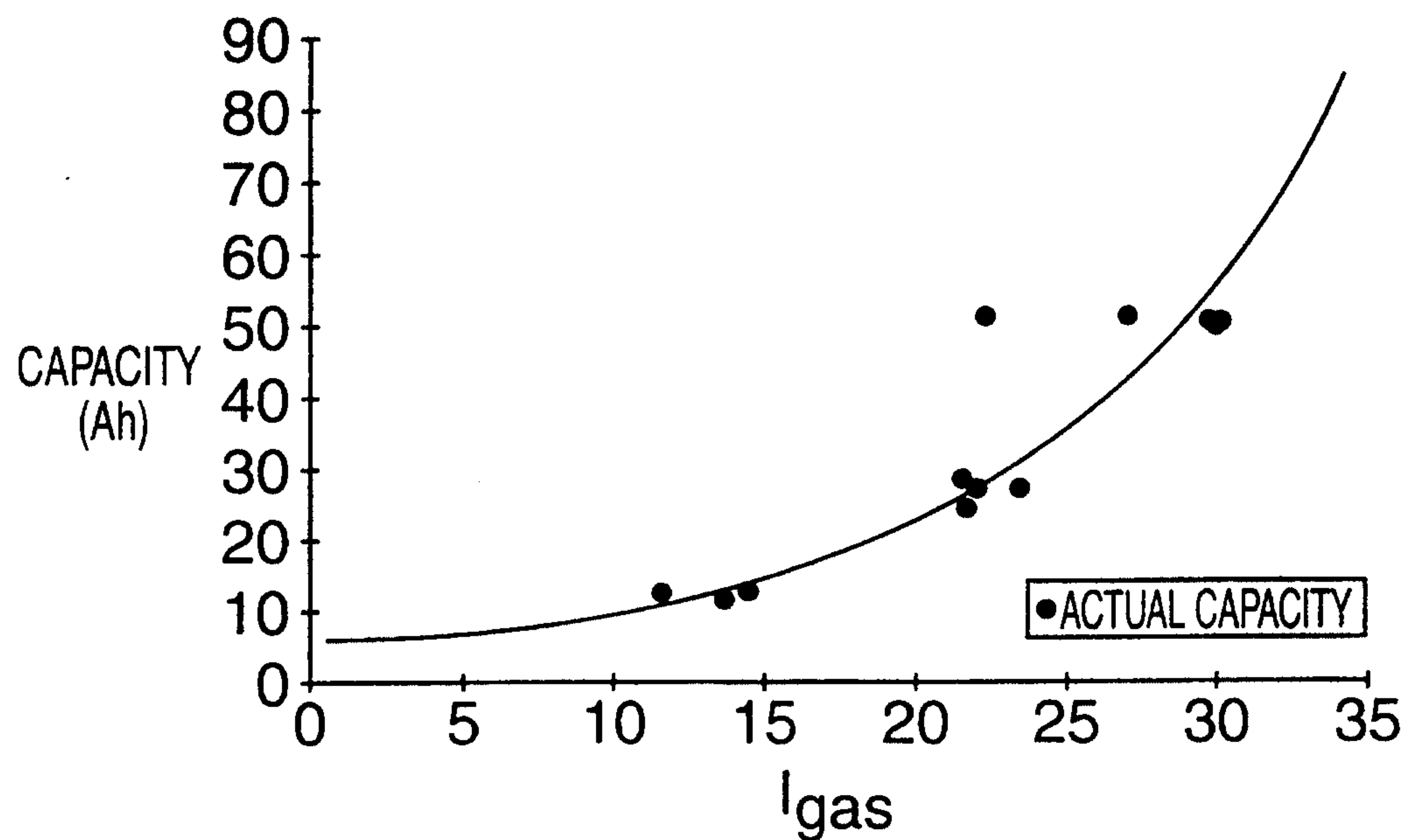


FIG. 4

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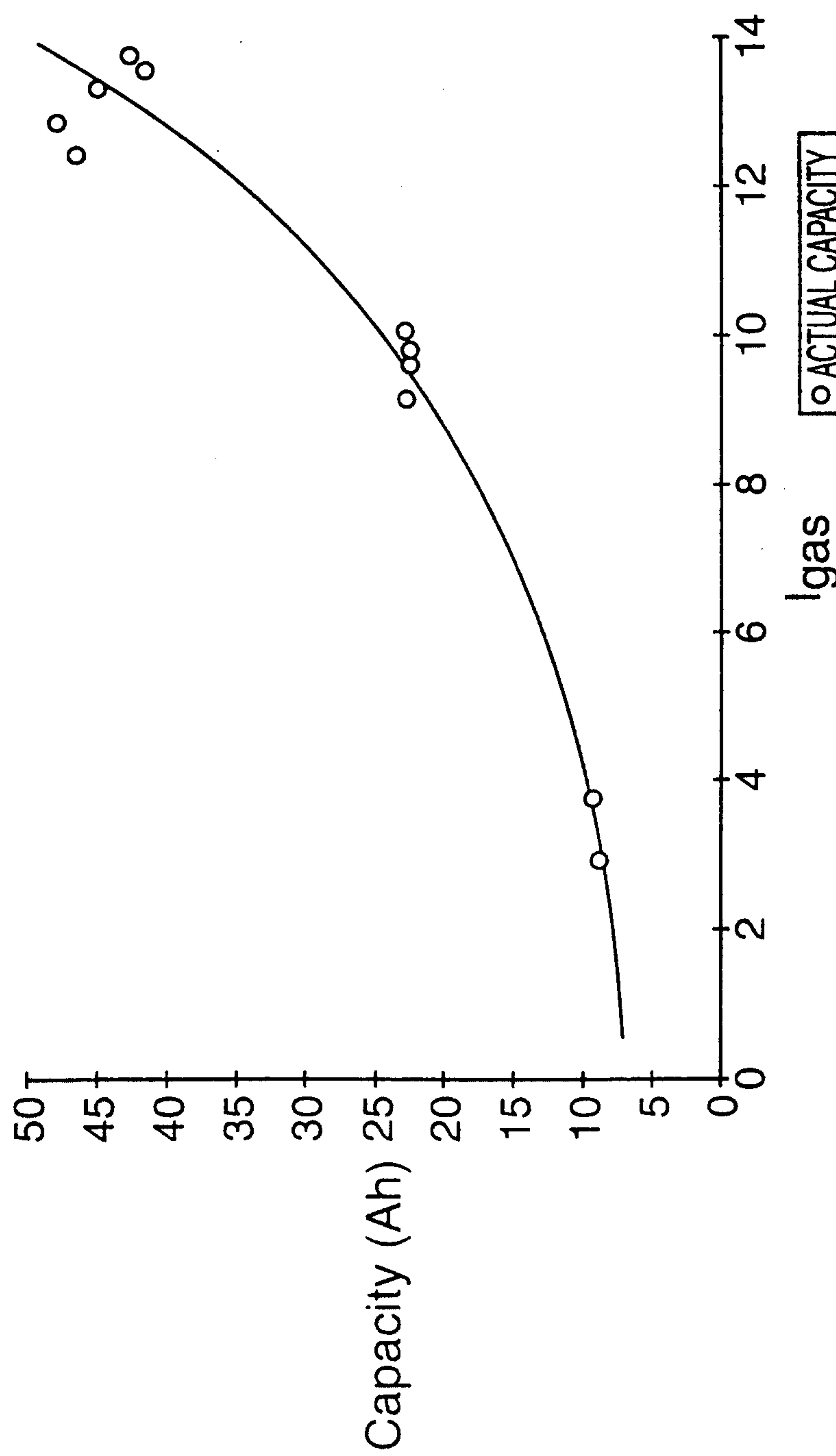


FIG. 5

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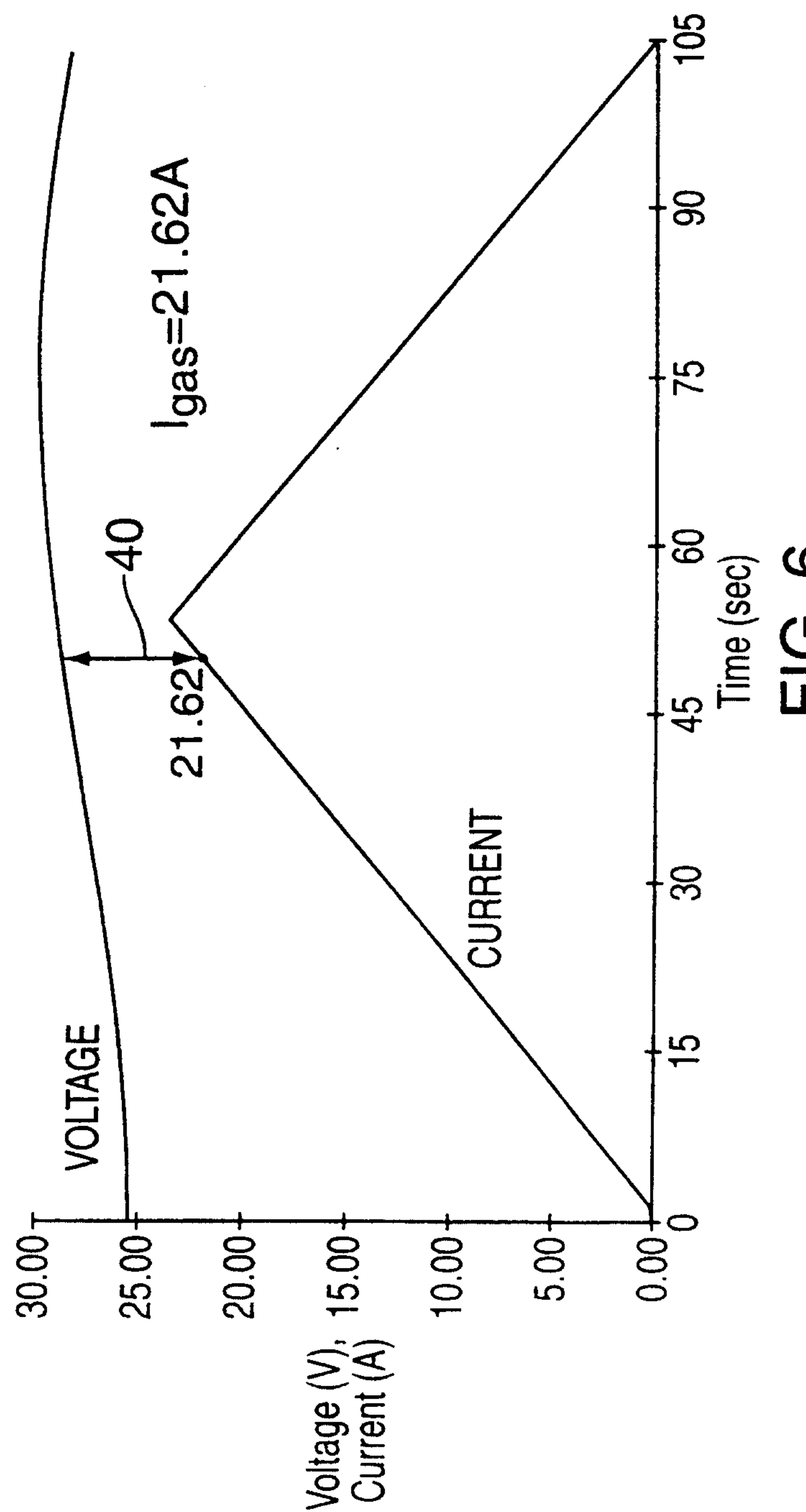


FIG. 6

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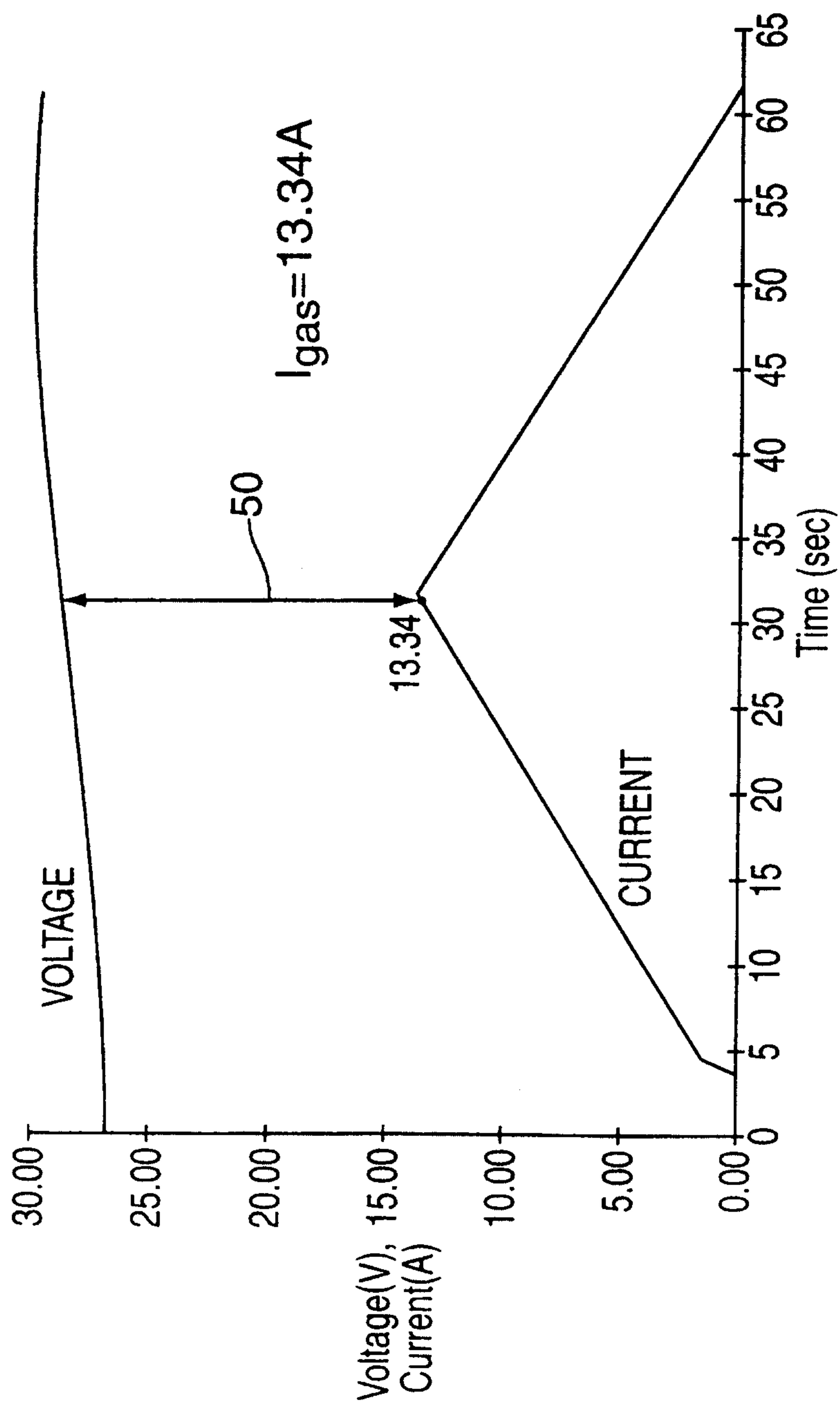


FIG. 7

