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(54)【発明の名称】電池を充電するシステムおよび方法

(57)【要約】
鉛蓄電池の寿命を有利に延長するように鉛蓄電池を充電する方法が説明される。充電プロセスの終了が、印加される充電電圧の第１の導関数（ｄｖ／ｄｔ）と第２の導関数（ｄ２ｖ／ｄｔ２）との評価に基づいている。充電基準として第１の導関数（ｄｖ／ｄｔ）と第２の導関数（ｄ２ｖ／ｄｔ２）とを使用することによって、電池から以前に取り除かれたアンペア時の正確な量を計算に入れる過充電の量が電池に印加される。本発明の充電プロセスを実行する充電器構成も説明される。

【特許請求の範囲】
【請求項１】
ディープサイクル鉛蓄電池を充電する方法であって、
こうした電池に充電エネルギーを印加することと、
充電プロセスにおける９８％充電点を識別することと、
アンペア時を単位として供給される充電を監視することと、
前記電池を完全充電のほぼ１１０％に過充電するように印加されるべき残りの充電エネルギーを求めることと、
前記電池に前記残りの充電エネルギーを印加することと、
を含む方法。
【請求項２】
前記９８％充電点を求める段階は、
「印加された充電電圧」対「時間」の変化の速度（ｄｖ／ｄｔ）が最大値である時点を求めることと、
時間に対する電圧の加速度（$ｄ^2ｖ／ｄｔ^2$）がゼロである時点を求めることと、
を含む、ディープサイクル鉛蓄電池を充電する、請求項１に記載の方法。
【請求項３】
前記残りの充電エネルギーを求める段階は、
０．９８と、前記電池の充電容量の９８％に前記電池を充電するために印加される前記充電エネルギーとの積を、所望の過充電のパーセント値に等しい小数で割り算すること、
を含む、ディープサイクル鉛蓄電池を充電する、請求項１に記載の方法。
【請求項４】
前記残りの充電エネルギーを印加する段階は、さらに、
充電エネルギーの印加の終了の前に電池セル電圧を監視することと、
「充電電圧」対「時間」の変化の速度（ｄＶ／ｄｔ）がゼロであるまで前記充電プロセスを延長することと、
を含む、ディープサイクル鉛蓄電池を充電する、請求項１に記載の方法。
【請求項５】
前記充電プロセスを延長する段階は、さらに、予め決められた時間が超えられると直ぐに前記充電を終了させることを含む、ディープサイクル鉛蓄電池を充電する、請求項４に記載の方法。
【請求項６】
前記予め決められた時間が約１６時間である、ディープサイクル鉛蓄電池を充電する、請求項５に記載の方法。
【請求項７】
開回路電池電圧を監視する段階と、
前記開回路電圧が所望レベルよりも低下する場合に充電を開始する段階と、
をさらに含む、ディープサイクル鉛蓄電池を充電する、請求項１に記載の方法。
【請求項８】
最も最近の充電シーケンス以来の予め決められた時間の後に充電を開始する段階をさらに含む、ディープサイクル鉛蓄電池を充電する、請求項１に記載の方法。
【請求項９】
開放型ディープサイクル鉛蓄電池を充電する方法であって、選択された充電プロファイルにしたがってこうした電池に充電エネルギーを印加する段階と、前記電池の状態が前記電池の完全充電状態に対する既知の関係を有する前記プロセス中の時点を識別し、および、前記プロセスの開始からその時点までに前記電池に供給される充電エネルギーの第１の量を求める段階と、前記第１の量に関係付けられている選択された量だけ前記電池が過充電されることを引き起こすために前記電池に印加される時に適切である更なる充電エネルギーの第２の量を求める段階と、前記第２の量の充電エネルギーを前記電池に印加する段階と、を含む方法。

【請求項１０】
開放型ディープサイクル鉛蓄電池を充電する方法であって、
こうした電池に充電エネルギーを印加する段階と、
前記電池に供給される量とそのｄｖ／ｄｔおよび$ｄ^2ｖ／ｄｔ^2$の様相とに関して、ｄｖ／ｄｔが最大でありかつ$ｄ^2ｖ／ｄｔ^2$＝０である前記プロセス中の時点における前記電池に供給される充電エネルギーの量に関する情報を使用することによって、前記充電エネルギーを監視し、および、前記量に関係付けられている予め決められた度合いに前記電池を過充電するために適切な前記量に対して付加される設定された量の充電エネルギーをその時点を超えて求めて前記電池に供給する段階と、
を含む方法。
【請求項１１】
開放型ディープサイクル鉛蓄電池を充電する方法であって、
前記電池の初期充電不足量に等しい量の充電エネルギーをこうした電池に印加する段階と、
前記充電不足量の選択されたパーセント値として予め決められた度合いに前記電池を過充電するために適切な充電エネルギーのさらに別の増分を前記電池に印加する段階と、
を含む方法。
【請求項１２】
ディープサイクル鉛蓄電池を充電する電池充電装置であって、
直流電流源と、
電圧計と、
電流計と、
タイマと、
ｄｖ／ｄｔ測定回路と、
$ｄ^2ｖ／ｄｔ^2$測定回路と、
を備える電池充電装置。
【請求項１３】
前記直流電流源と前記電流計と前記タイマと前記ｄｖ／ｄｔ測定回路と前記$ｄ^2ｖ／ｄｔ^2$測定回路とに接続されている制御装置を含み、前記制御装置は、電池がおおむね完全充電の設定されたパーセント値にある電池再充電事象中の時点を求めるように、および、関係$Ｑ_Ｓ／ｐ＝Ｑ_Ｄ／（１＋ｘ^2）$から$Ｑ_Ｄ$の値を求めるように構成されており、ここで$Ｑ_Ｓ$は、前記再充電事象の開始から前記電池が前記完全充電の設定されたパーセント値をおおむね有する時点までの時間期間中に前記電池に供給される充電エネルギーのアンペア時であり、ｐは前記設定されたパーセント値に等しい小数であり、ｘは、過充電量として前記電池に供給されるべき補充充電の所望のパーセント値の量に等しい小数であり、および、$Ｑ_Ｄ$は、前記過充電の量に達するために前記再充電事象の開始から前記電池に供給されるべきアンペア時である、請求項１に記載の装置。
【請求項１４】
前記ｐの値がおおむね０．９８である、請求項２に記載の装置。
【請求項１５】
ｘは約０．０８から約０．１２の範囲内である、請求項２に記載の装置。
【請求項１６】
ディープサイクル鉛蓄電池を充電する装置であって、電圧測定装置と、電流測定装置と、タイマと、この装置によって充電されている電池が、完全充電かまたはそれよりも少ない状態である予め決められた充電状態を電池が有する充電事象中の時点に何時あるかを判定するように、および、その充電事象中のその時点に前記電池に供給される充電エネルギーの量の選択されたパーセント値だけ前記電池を過充電するのに有効な充電エネルギーの量の、その時点を超えた前記電池に対する印加を求めて制御するように動作する機構と、を含む組合せを具備することを特徴とする装置。
【発明の詳細な説明】

【技術分野】
【０００１】
本発明は、開放型ディープサイクル鉛蓄電池の再充電プロセスの終了を制御する方法に関する。さらに特に、本発明は、最も最近の先行の電池充電事象の後に放電されたエネルギーの量に直接的に関係付けられている再充電エネルギーの量をこうした電池に供給する手順に関する。本発明は、さらに、こうした手順を具体化する装置にも関する。
【背景技術】
【０００２】
ニッケルカドミウム電池、ニッケル水素電池、ニッケル鉄電池、リチウム電池、銀カドミウム電池、および、ディープサイクル鉛蓄電池のような様々な異なる種類の再充電可能な蓄電池が知られている。ディープサイクル鉛蓄電池は、例えば従来の自動車に使用されている電池のようなＳＬＩ（始動（starting）、照明（lighting）、点火（ignition））鉛蓄電池とは異なっている。ＳＬＩ電池は、大幅な充電と再充電との反復サイクルに耐えるように設計も構成もされておらず、したがって本発明の意味では再充電可能な電池ではない。
【０００３】
米国特許第4,392,101号および第4,503,378号のような特許から、電池が完全充電状態にあるということ、または、電池が完全充電状態には達していないが完全充電状態に近い比較的予測可能な局面にあるということを示す仕方で電池の再充電中に変化する再充電可能電池の特定の特徴が、電池の種類に係わらずに存在するということが公知である。これらの特許と他の刊行物は、この特徴を監視するための、および、この特徴の特定の事象や条件や状態を検出し、電池充電プロセスを終了させるように、または、事前設定された時間にわたってもしくは事前設定された仕方で充電を継続させるようにこの検出を使用するための装置および方法を説明する。こうした事前設定された仕方は、典型的には、検出された事象の時点で使用されている充電プロセスとは異なる充電プロセスを使用する。こうした充電事象検出方法は変曲分析法（inflection analysis method）として知られているが、これは、この方法が、例えば充電プロセス中の、電池電圧または電池電流の変化を示す時間ベースの曲線における特定の変曲点の検出に基づいているからである。現在までに説明されている変曲分析は、大半の種類の再充電可能電池の再充電を制御する上で有効であるが、上述したような変曲分析は、電池電解質がゲルのような何らかの支持マトリックスの中に拘束されてはいない液体（典型的には硫酸）である開放型ディープサイクル鉛蓄電池の再充電を制御するのには、あまり適切には役立たないということが判明している。
【０００４】
開放型ディープサイクル鉛蓄電池は、ゴルフカー、フォークリフトトラック、および、シザーリフト車両のような電動車両のためのエネルギー源として広く使用されている。この鉛蓄電池は、さらに、病院や他の建物と施設とにおける無停電電源の中で使用され、および、光発電電力設備の構成要素として使用されている。上述したような変曲分析法が開放型ディープサイクル鉛蓄電池の再充電を制御するためにはあまり役立たない理由が、一例としての電気ゴルフカーのこうした電池の使用から理解されることが可能である。
【０００５】
電気ゴルフカーは、４個または６個等の開放型ディープサイクル鉛蓄電池の組によって給電される。どのゴルフコースにも、ゴルファーによって利用可能なこうしたゴルフカーの集団がある。この集団の中の個々のゴルフカーは、その集団の中の他のゴルフカーよりも古い電池を有することがある。特定のゴルフカーが他のゴルフカーよりも頻繁に使用されることがある。幾台かのゴルフカーが、日によって他のゴルフカーよりも長時間にわたって使用されることがある。幾台かのゴルフカーが、それを使用するゴルファーの状況や走行した地形の違いや他の理由に応じて、日によって他のゴルフカーよりも過酷な使用条件を被ることがある。さらに、ゴルフカー集団中のすべての電池が同一の製造業者からのものであり、かつ、同一の公称上の古さである場合にさえ、電池の性能と寿命に影響を与える可能性があり、および、重要なことであるが再充電プロセスに電池が応答する仕方に影

響を与える可能性がある種類の、電池相互間の著しい差異がなお存在するということが知られている。したがって、その集団内のゴルフカーが再充電されることになっている１日の最後には、ゴルフカーごとに電池の放電状態の間に大きな差異がある可能性があり、したがって、電池がどのように充電される必要があるかに関してゴルフカーごとに当然の大きな差異がある可能性がある。集団全体にわたる均等な再充電手続きが、幾つかの電池が不十分にしか再充電されないこと、または、この方がさらに可能性が高いが、電池の大半が著しく過充電されることを引き起こすだろう。こうした電池の著しい過充電は電池寿命を低減させる。一般的に、ゴルフカー集団を再充電するために雇われている人間は、こうした著しい過充電の影響と、過充電が生じている時点を判定する方法とを理解していない。したがって、電気ゴルフカーで使用される電池が、著しい過充電を回避する装置およびプロセスによって再充電され、および、放電状態、古さ、製造上のばらつき等を原因とする電池相互間の差異を本来的に吸収し処理する仕方で再充電されることが望ましい。

【０００６】

ディープサイクル鉛蓄電池は、完全充電状態からの多量の放電と、放電状態から完全充電状態への再充電との反復サイクルに耐えるように設計されている。液体電解質を使用しない他種の再充電可能な電池に比較して、開放型ディープサイクル鉛蓄電池の液体酸電解質（liquid acid electrolyte）は、特定の電池、または、互いに組み合わされて繰り返し使用される少数の電池の特定の組が、再充電事象が開始される時点の電池の状態にその度合いが関係付けられている、制御された過充電を実現する仕方で再充電されることを必要とする特別な条件をもたらす。言い換えると、開放型ディープサイクル鉛蓄電池の効果的な再充電は、理想的には、電池の最も最近の先行デューティサイクル（最も最近の先行充電事象以来の使用期間）中に電池から取り除かれた（放電された）エネルギーの量によって決定される、制御された過充電を含まなければならない。この理由は、先行のデューティサイクルとそれに続く再充電事象との最中に液体電解質に生じるものに関係している。

【０００７】

鉛蓄電池のセルが放電すると、電解質中の酸イオンがセル電極に移動し、および、酸素原子がセルの活物質から電解質の中に移動し、電解質の水素イオンと共に水を形成する。したがって、電解質の酸が漸進的に希釈され、その比重がより高い開始比重から漸進的に１．０に近づく。セルが再充電される時には、そのイオン交換プロセスが、電解質の酸と活物質との再生を生じさせるために逆転させられる。電解質が、ゲルマトリックス中に存在している場合とは反対に、自由な液体としてセル中に存在している（すなわち、セルが開放型である）ならば、その再生された酸は、希薄な電解質よりも重いので、その生成時にセルの底に沈む。再充電プロセスが進行するにつれて、ますます高濃度になる再生された酸がセルの底に集まる。セルの活物質が完全に再生され終わった時点で、理論的にはセルはクーロンベースで完全に充電されている。しかし、このセルは、電解質の層状化のせいで、蓄積されたエネルギーを供給するために使用することには適した状態ではない。電解質はセル全体にわたって均一な酸性度になく、したがって、再生された酸電解質は、再生された活物質に対してその再生活物質の全面積にわたって均一に有効な接触状態にあるわけではない。セルがこの時点で放電することを求められる場合には、放電の電気化学的プロセスが、主として、電解質の酸が過剰に高濃度になっているセルの下部部分で生じることになる。セルは、所望のレベルでエネルギーを放出することがなく、および、セルの底部内の過剰に濃縮された酸が、隣接した活物質が過剰に早く劣化することを引き起こすことになる。この結果として、電池寿命を著しく短縮させる形でのセルの性能不足が生じる。

【０００８】

活物質の完全な再生的回復の直前に生じる鉛蓄電池セルの再充電プロセスの一部分において、再充電プロセスの通常の一部分として気体がセル内で発生する。この気体の気泡が電解質中を通ってセルの最上部に上昇し、このプロセスの中でセル内の電解質の循環（攪拌）を誘発する。しかし、再充電プロセスが活物質の完全な再生の時点で終了させられる場合には、生じている気体発生の量は、電解質を適切に攪拌してセル全体にわたって均一な

酸濃度（均一な比重）を電解質にもたらすには不十分だろう。この理由から、開放型ディープサイクル鉛蓄電池の再充電プロセスを完全充電の時点を超えて継続すること、すなわち、再生された電解質の適切な攪拌を得るために一定の時間にわたって気体発生プロセスを延長することが一般的な慣習である。すなわち、セルは意図的に過充電される。

【０００９】

現在の慣習は、最大限の攪拌を必要とする１つまたは複数のセルの内の電解質を十分に攪拌するのに適切であるように設定された予め決められた量だけ、幾つかのセルを含むこうした電池を過充電することである。この過充電の予め決められた量の設定は、セルがその先行のデューティサイクル中に最大限に放電され終わっており、かつ、そのセルが古さと条件と温度とに関する特定の属性を有するという仮定に基づいている。しかし、電気ゴルフカー集団の運用の説明において上記で示したように、この仮定は、再充電を必要とする電池の大半に関しては適切ではない。この結果として、開放型ディープサイクル鉛蓄電池の再充電の最終段階において印加される過充電の量に関してこの仮定に依存することは、（大半ではなくとも）相当数のこうした電池が極めて大幅に過充電されることの原因となる。こうした電池の極めて大幅な過充電は、特に数回を超えて反復される場合に、こうした電池の有効寿命を著しく減少させる。

【００１０】

上述の説明は、電池の再充電プロセスを制御するための変曲分析方法の従来の説明が、開放型ディープサイクル鉛蓄電池の再充電に適用される場合にどれほど不十分であるかを理解するための基礎を提供する。

【００１１】

米国特許第4,392,101号は、再充電可能な電池の再充電の制御における変曲分析の使用の初期の説明である。この特許は、再充電可能な電池が再充電プロセスに大まかに類似している応答特性を一般的に有するということを教示する。この特許は、電池の電圧または電流が例えば再充電中の時間に対比してグラフの形でプロットされる場合に、その結果としての電圧／時間曲線または電流／時間曲線が大まかな類似性を有するだろうということを教示する。充電プロセスの開始後に、電池セルを画定するために使用される個々の材料には無関係に、これらの曲線は、グラフの線がその湾曲を反転させる、すなわち、変曲させられる、少なくとも１対の変曲点を示すだろう。これら変曲点が、印加された充電エネルギーに対する電池の反応の様々な段階を示しすなわち表すということと、各々のセルのタイプに関して、この変曲が、電池が完全充電状態に達する前に、または、完全充電状態に達する時点で、充電プロセス中の比較的に予測可能な時点で生じるということが明らかにされている。変曲点の発生が予測可能であることは、一般的に、電池の実際電圧、個々のセルの特性、個別の充電履歴、または、実際の周囲温度条件といった要因によっては影響されない（これらの要因に無関係に生じる）ということが明らかにされている。この特許は、監視されている電池特性（電圧または電流）の時間に対する第１または第２の導関数の状態または特徴を観察することによって、変曲点が識別可能であるということを明らかにする。さらに明確に述べると、この特許は、第２の導関数のグラフが充電プロセス中に少なくとも２回はゼロ軸を横断し（この導関数の符号が、正から負に、または、これとは逆に変化し）、および、その導関数の第２のゼロ軸横断が、電池が完全充電状態に達する時に生じるか、または、完全充電が得られる直前のわずかな時間期間中に生じるだろうということを教示する。しかし、その特許は、鉛蓄電池の例では、電圧の第２の時間ベースの導関数がどの時点で完全充電に関して生じるかを説明することを試みていない。その特許の主要な説明は、その導関数の第２のゼロ軸横断が検出された時点から予め決められた時間を経過した後に再充電が終了させられるニッケルカドミウム電池に関するものである。ニッケルカドミウム電池は、化学プロセスの一部分として存在している可変濃度の電解質を使用せず、したがって、こうした電池は、過充電処理から何の利益も得ないか、または、過充電処理を全く必要としない。

【００１２】

米国特許第4,503,378号が、変曲分析による再充電の制御をニッケル亜鉛電池に適用し、

および、このタイプの電池の場合に、再充電が、時間に対する電池電圧の第２の導関数の符号変化（ゼロ軸横断）の第２の事例の発生時に終了させられることになるということを開示する。さらに、この特許は、第２の導関数が正から負にゼロ軸を横断するのと同時に、時間に対する電池電圧の第１の導関数の値が最大値すなわちピーク値にあり、この事実が、第２の導関数のゼロ横断が確認されることを可能にすると述べている。

【００１３】

「電圧変曲点を検出することによって１５分以内で電池を安全に充電する」という表題の記事がＥＤＭ　Ｍａｇａｚｉｎｅの１９９４年9月１日号に掲載された。この記事は主としてニッケルカドミウム電池の高速充電に焦点を当てている。この記事は、変曲分析が鉛蓄電池にも当てはまると注釈している。この関連において、この記事は、「鉛蓄電池では、第２のｄＶ／ｄｔ変曲が、電池が完全充電に達する前の予測可能な時間期間において生じるが、電池のアンペア時の容量定格から、完全充電を得るために必要とされる増分充電の持続時間を容易に導き出すことが可能である。」と述べている。この記述は、電池の真の再充電の必要性という点から見て極めて大幅に過充電することなしに、どのようにして開放型ディープサイクル鉛蓄電池を効率的に確実にかつ効果的に充電するかという問題の解決に対しては、少なくとも２つの理由から寄与しない。第１に、鉛蓄電池のＡｈｒ（アンペア時）容量定格は、工学的な情報から正確に求めることが可能な精確な値ではない。むしろ、このアンペア時容量定格は、マーケティング上の目標や保証方針等の要因のような製造業者に特有のビジネス上の要因の結果として、製造業者が電池のモデルまたはタイプに割り当てる値である。電池の「アンペア時」容量定格は、その種類またはタイプの平均的な電池の、おそらくは明記されていない条件下における、予想可能な性能に関する製造業者の言明であるにすぎない。この「アンペア時」容量定格は、特定のデューティサイクルの完了後の特定の電池の充電の必要性、すなわち、再充電事象を受ける前の電池の放電の深さに対して、確実な関係を持たない。第２に、この「アンペア時」容量定格は、電池自体以外のソースから得られることが必要とされている値である。必要とされているものは、電池の放電状態を示しており、かつ、再生電解質を適切に撹拌するのに必要な量だけ電池を過充電するために使用可能である、電池自体から導き出された情報を使用して、開放型ディープサイクル鉛蓄電池を充電する方法である。

【００１４】

上述の特許とＥＤＮ　Ｍａｇａｚｉｎｅの記事は両方とも、再充電プロセスが開始される前の電池放電の状態を考慮していない。これらは、放電状態に関する情報がその電池の再充電を制御するためにどのように使用可能であるかについての知識を与えない。しかし、これらの説明とは別に、常に電池と共に移動する一体型の電流計（アンペア時メータ）を、ゴルフカー内の電池のような電池に物理的に取り付けることが知られている。電池が電池デューティサイクル後に充電器に接続されると、最も最近のデューティサイクル中に電池から取り除かれたアンペア時の値を「オンボード」アンペア時メータがその充電器に通信することができるように、そのアンペア時メータが充電器に接続される。その情報は、電解質中で十分な撹拌を生じさせることが発見されている所望の係数（例えば１．１０すなわち１１０％）をアンペア時の測定値に乗算することによって電池に供給されるべき総充電を計算する計算／制御装置に充電器内において送られる。その次に、充電器内の計算／制御装置は、充電器によって電池に戻されるアンペア時を監視する。充電の戻り（charge return）に関する計算値に達すると、計算／制御装置は充電プロセスを終了させるように充電器に指示する。このアプローチは効果的であるが、電池に関連付けられているアンペア時メータから充電器にデータを通信することによる複雑さの増大という欠点を有する。このアプローチは、さらに、電池環境内での使用に耐えるように特別な構造にされなければならない電池自体の専用アンペア時メータを各々の電池または電池の各運用セットに装備するために、費用が増大するという欠点も有する。このアプローチは変曲分析とは無関係であり、この分野において明らかな実際的な問題点を有する。

【００１５】

したがって、どれか１つまたは小グループの開放型ディープサイクル鉛蓄電池を極めて大

幅に過充電することなしに開放型ディープサイクル鉛蓄電池を適切に再充電するために、電池技術の知識をわずかしか持たないか全く持たない人間によって効果的に効率的にかつ確実に使用されることが可能な装置および手順を使用できることが必要とされているということが明らかである。こうした装置および手順は、この必要性を満たすために、１つの電池または限定された小グループの電池の実際の再充電と電解質攪拌との必要性に効果的に対処し、かつ、これに適合しなければならない。術語「限定された小グループ」は、おそらくは同一の古さであり、同一の使用履歴を有し、および、グループとして最も最近に再充電を受けた時点と問題の再充電事象との間の時間期間中に同一のデューティサイクルを共有しているであろう、特定の電気ゴルフカー内に設置された幾つかの電池のような幾つかの電池を意味する。

【発明の開示】

【発明が解決しようとする課題】

【００１６】

上述の説明に照らして、本発明は、開放型ディープサイクル鉛蓄電池が実際の再充電要件と最小過充電プロセスとの点から個別にまたは限定された小グループの形で再充電可能である手順と装置とを提供するために、当業ではこれまで解決されていない問題状況に対処する。本発明は、新規の計算／制御装置を含む充電器のための、電池または電池セットの必要に対して各々の電池充電事象をカスタマイズする新しい仕方の変曲分析原理を適用する。この利益と利点は、電池の製造方法と使用方法とにおける変更を全く必要とせずに、効果的かつ確実に提供され実現される。修理整備担当者は充電器を電池に接続することと電池から取り外すことだけしか必要とされない。再充電要件に関する情報は、電池に取り付けられたアンペア時メータに依存することなしに、充電プロセスの過程中に電池自体から充電器によって得られる。すなわち、充電器は、再充電プロセスが開始される前の電池の放電状態を知らないし、それを知る必要もない。本発明は電池自体を最大限に保護すると共に、電池寿命の延長を実現することが可能である。

【課題を解決するための手段】

【００１７】

手順に関して、本発明は鉛蓄電池を充電するための方法を提供する。この方法は、充電プロセスの実行中に電池電圧を監視することと、充電時間を記録することと、アンペア時を単位として電池に供給される電荷を監視することとを含む。この方法は、さらに、完全充電状態に対する既知の関係を有する充電状態を電池が有する充電プロセス中の時点を判定することと、充電プロセスの開始と電池が完全充電される時点との間に供給可能なエネルギーの所望の部分に等しい、完全充電時点を超えて電池に供給可能な充電エネルギーの量を決定することとを含む。

【００１８】

本発明の構造的側面に関して、本発明は、鉛蓄電池、好ましくはディープサイクル鉛蓄電池を充電する充電器を提供する。この充電器は、直流電流源と、電圧計と、電流計と、タイマと、ｄｖ／ｄｔ測定回路と、d^2v/dt^2測定回路とを含む。

【００１９】

さらに明確に述べると、この充電器は、さらに、直流電流源と電流計と電圧計とタイマとｄｖ／ｄｔ測定回路とd^2v/dt^2測定回路とに接続されている制御装置を含む。この制御装置は、電池が大体において完全充電状態の予め決められたパーセント値にある電池再充電事象中の時点を求めるように、および、関係$(Q_S/p)=[Q_D/(1+x)]$からQ_Dの値を求めるように構成され、この関係において、Q_Sは、充電事象の開始から$d^2v/dt^2=0$かつｄｖ／ｄｔが最大値である時点までの時間期間中に電池に供給される充電エネルギーのアンペア時であり、ｐは、$d2_v/dt^2=0$である時に電池に供給される補充充電のパーセント値に等しい小数であり、ｘは、過充電量として電池に供給されるべき補充充電の所望のパーセント値量に等しい小数であり、および、Q_Dは、過充電量に達するために充電事象の開始時から電池に供給されるべきアンペア時である。完全充電の予め決められたパーセント値が９８％ならば、ｐ＝０．９８である。

【００２０】
本発明のこれらの特徴および利点と他の特徴および利点とが、添付図面を参照して理解される以下の詳細な説明からより適切に理解されるだろう。
【００２１】
用語の解説
完全充電Q_F：
電池が完全充電容量にあり、かつ、充電エネルギーの連続印加が電極または電極活物質に対して有益な効果を全く持たない電池の状態
初期充電状態Q_i：
電池の再充電事象または再充電プロセスの開始時点において電池が有する残存充電量
補充充電Q_R：
電池を完全充電状態に戻すために、初期充電状態を有する電池によって吸収される、アンペア時を単位として測定される充電エネルギーの量。$Q_R = G_F - Q_i$
充電不足量：
電池の完全充電と初期充電状態との間の差。これは補充充電Q_Rに等しい。
過充電Q_0：
再充電事象または再充電プロセスの終了まで、電池が完全充電を得た後に再充電事象または再充電プロセスの過程中に電池に供給される、アンペア時を単位として測定された充電エネルギーの量。これは、その次のデューティサイクル中の良好な性能のために電池をコンディショニングするために電池に供給される余分のエネルギーである。本発明の実施においては、過充電の大きさは補充充電の大きさに直接的に関係付けられる。
デューティサイクル：
電池が完全充電され終わった後に、その電池が中に配置されているか接続されている物品の使用中にその電池がエネルギーを供給する期間。デューティサイクルの終わりにおける電池の充電が、後続の電池の再充電事象または再充電プロセス中のその電池の初期充電状態である。
クーロン充電Q_C：
対象となるあらゆる時点において電池が有する充電量。
供給充電Q_D：
電池の再充電事象または再充電プロセスの開始と終了との間の時間期間中に電池に供給されるエネルギーのアンペア時。本発明の実施においては、これは補充アンペア時と過充電アンペア時との組合せであり、すなわち、$Q_D = Q_R + Q_0$である。
信号充電Q_S：
再充電プロセスの開始において始まり、電池充電レベルが完全充電に対して明確な関係を有することを示す検出可能な条件をその電池がその電池の特定の電気化学のために有する再充電プロセス中のより後の時点において終わる時間期間の期間中に、電池に供給されるアンペア時単位で測定された電荷の量。鉛蓄電池の電気化学に関係する本発明の文脈においては、その検出可能な条件は、電池電圧の第１の時間ベースの導関数の最大値と共に共存する電池電圧の第２の時間ベースの導関数のゼロ値である。
【発明を実施するための最良の形態】
【００２２】
図１Ａは、典型的な充電サイクル中の時間に対してグラフ化された、従来の鉄共振型充電器によって充電されている鉛蓄電池の端子における電圧と電流の様相のグラフである。このグラフ化された様相は電圧と、電流と、時間に対する電圧の第１および第２の導関数とである。こうした充電特性は、典型的には、鉛蓄電池を鉄共振型電池充電器で充電するときに観察される。鉄共振型充電器は、典型的には、電流１２８と電圧１０１が電池充電事象中に変化する仕方を記述する曲線の明確な形状を与える変圧器／整流器回路を含む。充電サイクルを実現する際に、充電サイクルの持続時間と、再充電エネルギーが電池に与えられる速度とが、電池に戻される充電量を決定する。開放型鉛蓄電池を完全充電するために、使用される典型的な方法は、電池に流れ込む充電電流が大きく減少した状態にその電

池が達した後にも、その電池に充電し続けること、すなわち、過充電することである。
【００２３】
直前のデューティサイクル中に鉛蓄電池から取り除かれたアンペア時の固定パーセント値にその鉛蓄電池の過充電を制御することが、典型的には、電池の寿命を著しく増大させる傾向がある。過充電パラメータは、典型的には、当業者に公知の様々な基準に基づいて選択される。このように先行のデューティサイクル中に取り除かれたアンペア時の固定パーセント値に充電される電池は、電池の総充電容量の固定パーセント値として設定された量の過充電を充電毎に受ける類似の電池よりも長い有効寿命を有するだろう。したがって、再充電開始時の初期電池放電状態の知識と使用は、最適な形で電池に供給される過充電の量の決定に役立つ。
【００２４】
鉛蓄電池の充電中の電圧応答１０１が図１Ａに時間の関数として示されている。測定された電圧は、充電サイクル中の様々な時点における電池の両端子間の電圧である。印加された充電電流１２８の特定の値に応答した電池の各充電サイクルに関する特有の電圧応答１０１が、その電池の温度と、通常は電池の古さの関数である内部条件とに応じて変化する。電池の温度と古さは両方とも、典型的な充電装置によっては認識されない。したがって、充電器に接続された電池の充電不足量を判断するための基礎は、確実な形で電圧の絶対値に基づいていることはないだろう。
【００２５】
電池の充電不足量のアンペア時の判定は、より確実性が高い形で開放型鉛蓄電池の特有の電圧－時間特性に基づいている。使用されることが好ましいこの特有の電圧－時間特性（図１Ａを参照されたい）は、時間の関数としての電圧Ｖ（ｔ）（曲線１０１）と、時間に対する電圧の変化の速度ｄｖ／ｄｔ（曲線１０４）と、時間に対する電圧の加速度$ｄ^2ｖ／ｄｔ^2$（曲線１０６）である。
【００２６】
電池の両外部端子の間で測定される電池電圧Ｖ（ｔ）（図１Ａの曲線１２８）は、印加される充電電流Ｉ（ｔ）に応答して充電サイクル中に変化する。充電中の電池の両端子間の電圧と、電池の中に流れ込む充電電流は、充電サイクル中に通常は変化する電池の内部抵抗と逆起電力（開回路電圧）とに関係付けられている。
【００２７】
特定の時点において、電池の内部抵抗が、電池の電解質中に配置されている電池のセル構造を構成する一連の導電性要素によって決定される。充電サイクルの開始時に、すなわち、ｔ＝０（図１Ａの点１１６を参照されたい）において、初期電池電圧$Ｖ_i$は開回路電圧である。充電サイクルの開始時には、充電器によって供給される電流は、典型的には、充電サイクル中のその最高値$Ｉ_i$（点１２６）にある。
【００２８】
典型的な充電プロセス中は、電池電圧１０１は最初は低い値$Ｖ_i$にあり、急速に中間の電圧に上昇して、この中間の電圧から一定の時間期間にわたってゆっくりと上昇し続け、その後に、次第に傾きを増大させながら再び急速に上昇し、最後には最終的な完全充電電圧$Ｖ_t$に達する。電池が充電されるにつれて、充電プロセス中に発生させられる熱と、電解質の比重の増大とのために、電池の逆起電力が大きくなる。電池が充電されるにつれて、充電器によって供給される電流１２８が、電池電圧１０１が電池インピーダンスの増大に伴って増大するのに応じて減少する。
【００２９】
充電の最終段階では、与えられたエネルギーに応答して電解質が分解することに応じて、水素気体と酸素気体の電解生成によって電池の逆起電力のさらなる増大が引き起こされる。この現象は「ガス放出」と呼ばれている。電池が完全充電状態に近づいて、この状態に達する時に、ガス放出が起こり、その電池の構成要素は再生の形で再充電エネルギーを受け入れることができなくなる。ガス放出プロセスが安定化すると、電池の両端子間の電圧が本質的に一定不変の状態のままとなり、その最終値に近づく。

【００３０】
充電の最終段階では、電解質攪拌効果のために、電池端子電圧１０１のわずかな増大が見られる。この電解質攪拌効果は、ガス放出プロセスによって引き起こされる。この攪拌効果は、電池内の一連のセルの各セルの中の電解質が実質的に均質になること、すなわち、均一な比重（酸濃度）になることを引き起こし、各セル内の電池逆起電力を安定させる。多くの場合、所望の充電プロセスを実現するために電池の内部構造と充電プロセスとを考慮に入れる電池充電システムを設計することが望ましい。
【００３１】
電池充電器は、様々なタイプの回路設計を使用して構成される。充電器の回路設計は強磁性技術およびスイッチング技術を含む。電池充電器の回路設計に適合した「プロファイル」または「アルゴリズム」と呼ばれる１つまたは複数の充電プロセスを提供するために、様々なタイプの電池充電器も設計されている。さらに、プロファイルは、電池寿命を延長する試みとして充電中の電池内の内部変化を利用するために選択されることが多い。
【００３２】
ｄｖ／ｄｔ＝０に合わせられた終了方式を有する充電器は、典型的には、電池から以前に取り出された電荷の１１８％から１２４％を供給する。
【００３３】
続けて図１Ａを参照すると、時間に対する電圧の第１の導関数１０４と第２の導関数１０６が、電池の所望の充電要件に関する追加の情報を提供する。さらに、第１と第２の電圧導関数は、容易に検出される明確な状態の遷移を与える。この第１と第２の導関数によって提供される情報は、個々の電池に特有の信頼性の高い基準を提供し、したがって充電プロファイルがその特定の電池に合わせて調整されることも可能である。電圧応答１０１曲線の第１の導関数１０４と第２の導関数１０６との選択された様相に電池の充電プロセスを基づかせることによって、特定の充電事象中における特定の電池に適合した過充電量を与えるために電池の固有かつ個別の充電要件を計算に入れる充電プロセスが実現できる。
【００３４】
図１Ａでは、従来の鉄共振型充電プロセスによって制御される充電サイクルを受ける開放型ディープサイクル鉛蓄電池の一例の電圧特性Ｖ（ｔ）が、曲線１０１によって示されている。充電サイクルの終わりには、電圧曲線１０１とその第１の導関数（ｄｖ／ｄｔ）１０４と第２の導関数（d^2v/dt^2）１０６との間の相互関係が、電池が完全充電状態に匹敵する特定の状態にある時点の有用な表示を提供することが可能である。開放型鉛蓄電池に関するこの特定の状態とは、電池が完全充電の約９８％にある状態である。図１Ａでは、この状態はグラフの水平な時間基線上の点１０８によって示されている。
【００３５】
電圧曲線１０１では、電圧は充電サイクルの終わりまで時間経過に応じて増大する。充電サイクルの終了の前に、この電圧曲線は頭打ちになって減少するまで急速に上昇する。この急速な増大の最中に、曲線１０１は、電圧が加速を止めて減速し始める変曲点１１５を有する。Ｖ（ｔ）の第１の導関数をプロットする対応する曲線１０４では、Ｖ（ｔ）の第１の導関数の最大値１１４が、Ｖ（ｔ）の変曲点１１５の発生と同時に生じる。電圧曲線１０１の第１の導関数（ｄＶ／ｄｔ）は再びピークに上昇することはない。ｄＶ／ｄｔのこの最大値１１４は、電圧変曲点１１５の場合よりも正確な９８％充電点１０８の表示を与える。
【００３６】
鉄共振型充電を受ける鉛蓄電池の第１の導関数（ｄｖ／ｄｔ）における変化、すなわち、「電圧」対「時間」の変化の速度を表す曲線１０４は、２つの応答ピークを有する曲線１０６によって特徴付けられている。最初に、第１の導関数１０４は、急激に変化する電池電圧に対応する高い値を有する。その次に、変化が小さい期間を電圧曲線１０１が通過するときに、電池電圧の変化の速度の曲線１０４が減少する。変化の速度の小さな値の後に、１１４でピークに達してから低下する変化の速度の第２の急激な減少が続く。ピーク１１４は電圧曲線１０１の変曲点１１５に対応し、この変曲点において最大の傾きが測定さ

れる。電圧が最も急速に変化している「電圧」対「時間」曲線１０１における変曲点１１５は、第１の導関数の曲線１０４上に対応する最大値１１４を有する。第１の導関数が最大値に達した後に、電圧１０１の変化速度１０４が減少する。

【００３７】

鉄共振型充電を受ける鉛蓄電池の「電圧」対「時間」関数の第２の導関数（d^2v/dt^2）が曲線１０６によって示されている。この第２の導関数は曲線１０４の変化の速度を表し、一方、この曲線１０４は電圧変化の速度を表す。したがって、曲線１０６は、電池端子に加えられる電圧の値が電池充電プロセス中にどのように加速したり減速したりするかを表す。第２の導関数１０６から分かるように、第１の導関数の曲線１０４が上述の最大値１１４のようなその曲線の傾きが瞬間的にゼロに等しい点に達するときに、第２の導関数はゼロである。

【００３８】

第１の導関数が最大値に達しかつ第２の導関数がゼロの値を有する時間上の点が、電池から以前に取り出されたアンペア時の９８％がその電池に戻され終わった時間上の点１０８を非常に正確に識別する。正値から負値への第２の導関数（d^2v/dt^2）の急激な変化は、第１の導関数の値における漸進的変化よりも容易に識別される。

【００３９】

曲線１０６上の点１０８は、この特徴が個々の電池の初期放電状態と古さと温度との特性に関係しているので、異なる電池において異なる時間（ｔ）に発生する。しかし、点１０８は、印加された電流１２８のほぼ全部が気体を発生させるのために使用されている充電プロセス中の時点に相当する。この時点は本発明の実施において信号として使用され、および、当該の再充電事象の開始から測定された、その点において電池に戻され終わっている充電が、信号充電Q_Sと呼ばれる。Q_Sの大きさと電池完全充電Q_Fに対するその関係との知識が、所望の過充電量Q_0と共に、供給可能な（供給される）総充電Q_Dが求められることを可能にし、および、これにしたがって充電プロセスが制御されることを可能にする。電池が８０°Ｆにおける開放型鉛蓄電池である場合には、$Q_S=0.98Q_F$である。電池が何らかの他の温度である場合には、Q_S対Q_Fの関係は異なっている可能性があるが、電池温度が室温よりも著しく低い温度ではないならば、関係$Q_S=0.98Q_F$の使用が実行可能であり、かつ、大きな改善をもたらすことが発見されている。

【００４０】

電池に供給される充電はアンペア時（「amp-hours」）単位で測定されることが可能である。１アンペア時は、１アンペア電流によって１時間で電池に供給される充電の量である。したがって、アンペア時単位で指定された充電容量を有する完全に放電された電池は、１アンペアの充電電流において、容量に対する完全充電状態または完全充電の所望の部分に電池を戻すために、その指定されたアンペア時容量に等しい時間数を要するだろう。

【００４１】

完全充電Q_Fを超えた指定された過充電量Q_0が、電池寿命の増大を実現するために選択される。一例としての実施形態では、この過充電量は補充充電Q_Rの１０８％として選択される。すなわち、図１Ａでは、Ｘが、補充充電よりも８％多い充電が電池に供給され終わった時点であり、および、この電池に関する再充電事象が終了させられる時点である。

【００４２】

所望のコンディショニングを実現するために有効に電池に戻される充電量が、次の関係によって得られるだろう。

（指定された過充電％）（充電開始から完全充電の９８％までのアンペア時）＝（指定された過充電に達するための初期充電からのアンペア時）（９８％））。

上記で定義した術語を使用して別の形で表現すると、

$$Q_S/0.98=Q_D/(1+x) \quad (式１)$$

ここでｘは、過充電量として電池に供給されるべき補充充電Q_Rのパーセント値に等しい小数である。ｘの使用可能で好ましい値は０．１０である。

【００４３】

図１Ａの時間Ｔ、すなわち、点１１２が、電池が完全充電されている、すなわち、電池が充電レベルQ_Fを有する時間上の点である。充電量Q_Sは、第２の導関数のゼロ横断を求めることから得られる。したがって、充電特性曲線の動的な様相の分析によってQ_Sが求められれば、再充電事象中に供給されるべき総充電Q_Dが得られるだろう。

【００４４】

この液体電解質の気体攪拌によって所望の度合いのコンディショニングを得るために電池に供給されるべき過充電の量は、好ましくは約８％から約１２％の範囲内であり、最も好ましくは約１０％である。

【００４５】

図１Ｂと図１Ｃはそれぞれにカ氏８０度とカ氏１２２度における電池の充電プロファイルに関するグラフである。所望のあらゆるプロファイルが使用可能であるが、好ましいプロファイルは定電力プロファイル（constant power profile）である。これらのグラフの場合には、電池は、それぞれの充電事象の開始前に１３５アンペア時または１３６アンペア時を供給した。充電不足量の９８％または他のパーセント値が電池に戻され終わった時間上の点が、各グラフ上に記されている。カ氏１２２度の温度を有する高温の電池が、充電電圧の第２の導関数がゼロの値になる時よりも時間的に早く、０．９８Q_F信号点に達する。しかし、完全充電の９８％に対する$d^2v/dt^2=0$の発生における温度ベースのずれはわずかである。こうした非常に高温の電池に関して$Q_S=0.98Q_F$を使用することが、そうでない場合に生じるであろう電池の過充電よりも著しく少ない電池の過充電を結果的に生じさせる。

【００４６】

図１Ｄと図１Ｅはそれぞれにカ氏８０度とカ氏４８度とにおける電池の充電プロファイルに関するグラフである。これらのグラフの場合には、電池は充電事象の開始前に８１アンペア時と８２アンペア時とを供給した。$Q_C=0.98Q_R$と$Q_C=1.09Q_R$である時間上の点が各グラフに記されている。これらのグラフから分かるように、低温の電池の信号点は電圧曲線に沿って右にずれている。例えば、低温の電池は、充電電圧の第２の導関数がゼロの値である時間上の点において完全充電の９８％未満であるだろう。この低温の電池に関する電圧の第２の導関数がゼロの値であるときには、完全充電の８２％だけしか電池に戻されていない。こうした状況では、関係$Q_S=0.98Q_F$の使用は電池に対するある程度の充電不足量を生じさせるが、電池を著しく損なうことはない。典型的な工業用の温度範囲に関して、$d^2v/dt^2=0$の時点において電池に戻される充電のパーセント値は、典型的には、その総充電容量Q_Fの８４％から１０２％まで変化するだろう。

【００４７】

温度をプロセスに要因として含める（factor）簡単な方法が、温度を直接測定してプロセス中の要因としてそれを含むことである。しかし、電池の内部温度を測定するのに効果的である温度センサを追加することは高コストであり、向上した信頼性を有する低コストの充電システムを生産する上で望ましくない別のレベルの複雑性を典型的な充電システムに付加する。

【００４８】

図２が、鉛蓄電池のための充電プロセスの一例の流れ図である。電池の９８％充電点に対応する第１および第２の導関数の情報を求めて利用するために、適切な情報を求めるためのプロセスが実行される。こうしたプロセスは、例えば、電池充電システムを備えておりかつ好ましくは電池充電器の一部分であるコンピュータやマイクロプロセッサや他の制御装置を駆動するプログラム命令セットとして具体化される。この命令は揮発性または不揮発性メモリ内に記憶されるか、または、大容量記憶媒体上に記憶されることが可能である。

【００４９】

この充電プロセスの開始時には、充電プロセスを開始させるためにコマンドが始動される２０２。その次のステップ２０４では、タイマ回路が始動される。代案のプロセスでは、タイマ回路が、動作または動作シーケンスを計時するようにマイクロプロセッサに指示す

るために使用されるソフトウェアのようなソフトウェアの形で具体化されることが可能である。所望の電圧条件に達した時に経過時間が分かるように、時間がステップ２０６で記録される。その次に、電圧の第１の導関数と電圧の第２の導関数との監視がステップ２０８で起動される。第２の導関数の値がステップ２１０で評価される。第２の導関数がゼロに等しくない場合には、そのプロセスが、ステップ２０８において、第２の導関数を監視し続ける。第２の導関数がゼロに等しい場合には、そのプロセスはステップ２１２で行われる評価に進む。ステップ２１２では、電圧の第１の導関数が、その導関数が最大値に達しているかどうかを判定するために監視される。第１の導関数が最大値に達していない場合には、ステップ２０８においてその第１の導関数が続けて監視される。ステップ２１２でｄｖ／ｄｔが最大値であると判定される場合には、プロセスの流れが分岐してステップ２１４に進む。ステップ２１４では、完全充電の９８％に達するための測定された時間が適用され、および、追加の充電時間が、所望のパーセント値の過充電が電池に加えられるように計算される。ステップ２１４の実行は、Q_Sを計算するために、および、上述の関係と、ｘ（過充電パーセント値）および$Q_S／Q_F$の所望の値を定義するプログラムパラメータとを使用してQ_Dを計算するために、タイマからの情報と、電池に供給された合計アンペア時に関する情報とを使用することを含む。

【００５０】

本発明の実施形態では、ステップ２１０、２１２で行われる評価は、その充電プロセスの結果に影響を与えることなしに相互交換されてもよい。さらに、一例としてのステップ２１２で行われる電圧の第１の導関数の最大値の判定が連続的に行われてもよく、または、当業者に公知のサンプリング方法を使用して行われてもよい。

【００５１】

充電サイクルの開始から$d^2v／dt^2$＝０までの初期充電時間が求められ終わり、および、ステップ２１４で所望の過充電を与えるための追加の時間量が計算された後に、プロセス（ステップ２１６）は、所望の過充電を与えるための追加の時間量にわたって電池が充電されるようにする。追加の充電時間が経過し終わった後に、充電サイクルがステップ２１８で停止される。

【００５２】

本発明による電池再充電プロセスが終了されなければならない時点を判定するのに有用な関係は次の通りである。

$$\frac{Q_S}{.98} = \frac{Q_D}{1+X}$$

ここで、Q_SとQ_Dは上記定義の通りであり（用語解説を参照されたい）、ｘは、電池の所望のコンディショニング（電解質攪拌）を得るために完全充電後に電池に加えられるべき補充充電Q_Rのパーセント値に等しい小数である。

【００５３】

電池の完全充電が１０００であり、および、所望の過充電パーセント値が８％であると仮定する。電池が再充電事象の開始時に５０％放電されている場合には、Q_S＝０．９８（１０００－５００）＝４９０であり、したがってQ_D＝５４０である。Q_i＋Q_D＝５００＋５４０＝１０４０であり、したがって再充電事象の終了時における実際の過充電の量は４０である。

【００５４】

再充電が始まるときに容量の２５％（Q_i＝２５０）である電池に同じ仮定を適用すると、Q_S＝０．９８（１０００－２５０）＝７３５、Q_D＝８１０、および、Q_i＋Q_D＝２５０＋８１０＝１０６０であり、したがって供給される過充電は６０である。同様に、再充電が始まるときに電池が容量の７０％である場合には、Q_S＝０．９８（１０００－７００）＝２９４、Q_D＝３２４、および、Q_i＋Q_D＝７００＋３２４＝１０２４であり、したがって供給される過充電は２４である。

【００５５】

電池の再充電事象が始まる時に電池が非常に深く放電されている場合には、酸電解質の高

度に希釈された状態のせいで酸電解質の比重が低い（１．００付近）ということが想起されるだろう。再充電が始まる時に電解質が希薄であればあるほど、完全充電時の電解質の密度の層状化が著しいだろうし、したがって、電池セル全体にわたって電解質を実質的に均質にすることによって電池を適正にコンディショニングするために、電解質がガス発生によって攪拌される必要が増すだろう。これとは逆に、電池の再充電事象が始まる時に電池が比較的浅く放電されている場合には、酸電解質はより高い開始比重を有し、完全充電時の密度の層状化がより小さく、および、電池を適切にコンディショニングするための電解質攪拌の必要性はより低いだろう。上述の例は、本発明が、適正なコンディショニングのために必要であると判定されておりかつ電池を極めて大幅に過充電しない量の過充電だけを、再充電される電池に供給するということを示す。電池の過充電の量は、再充電が始まる時の電池の放電状態の関数である。再充電プロセスが終了する時点は、電池自体から得られる情報から決定される。それは、図２－７に示されている電池再充電プロセスの特性である。

【００５６】

図３Ａと図３Ｂは、セル電圧を監視する充電プロセスの流れ図である。ステップ３０２－３１６がステップ２０２－２１６と同じであることが可能である。しかし、このプロセスでは、特定の最低条件が満たされなければ充電が終了させられない。一例としての実施形態では、セル電圧がこうした最低条件の１つである。ステップ３１８では、セル電圧が監視される。セル電圧が例えばセル１つ当たり２．４５ボルトに達すると、充電アルゴリズムがステップ３２０で終了させられる。この代わりに、他のセル電圧が他のタイプの電池のために使用されてもよい。

【００５７】

セル電圧がセル１つ当たり２．４５ボルトに達していない場合には、このプロセスが図３Ｂの文字Ａに分岐する。このプロセスでは、充電は、デフォルトとして、第１の導関数電圧がゼロになるまで充電プロセスを終了させない状態になる。したがって、充電はステップ３２２で継続する。充電中には、第１の導関数がステップ３２４で評価され続ける。第１の導関数がゼロに達する場合には、充電プロセスがステップ３２６で終了させられる。第１の導関数がゼロに達しない場合には、第１の導関数がゼロに達して充電プロセスが終了させられるまで、充電プロセスが続く。

【００５８】

図４Ａと図４Ｂは、所望の過充電を生じさせるためにセル電圧と充電時間とを監視する充電プロセスの流れ図である。このプロセスは、図３のプロセスの代案の実施形態である。図４Ａに示されているプロセスは図３Ａのプロセスと類似しており、ステップ４０２－４２６はステップ３０２－３２６と同じであることが可能である。しかし、このプロセスでは、充電は、特定の最低条件が満たされなければ終了させられない。セル電圧がこうした最低条件の１つであることが可能である。ステップ４１８では、セル電圧が監視される。

【００５９】

図４Ａと図４Ｂとに示されているプロセスは、特定の用途で望ましいと考えられるように、充電が特定の時間数の内に完了させられていない場合に充電サイクルを終了させるというさらに別の代替策を提供する。ここで説明している実施形態では、１６時間が完全充電を完了させるための最大時間数であると考えられている。この代案として、電池に対するダメージを防止するのに適した任意の時間期間が代わりに採用されてもよい。

【００６０】

図４Ｂを続けて参照すると、充電プロセスがステップ４２２で継続し、一方、第１の電圧導関数がステップ４２４で監視される。第１の導関数がゼロに達すると、充電プロセスがステップ４２６で終了させられる。第１の電圧導関数がゼロに達していない場合には、充電プロセスが、経過した充電時間を設定時間（この場合には１６時間）と比較する評価ステップ４２８に分岐する。一実施形態では、任意の適切な時間期間が設定時間として選択されてよい。

【００６１】

予め決められた充電時間を超えた場合には、警報信号または警報メッセージが視覚的に、音声によって、または、他の方法で、電池充電プロセスを担当しているか監視している係員に送られることが可能である（ステップ４３０）。このメッセージは、ゴルフカー集団内の各ゴルフカーの電池が同時に再充電されているときのように、存在している可能性がある他の充電器から当該の充電器を区別するために、当該の充電器の識別属性に関する情報を含むことが可能である。ステップ４３０における警報信号の発動時には、充電サイクルがステップ４３２で終了させられる。ステップ４２８において、予め決められた時間が未だ経過し終わっていない場合には、充電サイクルが継続する。

【００６２】

図５は、リフレッシュ充電を提供する充電プロセスの流れ図である。ステップ５０２－５１６がステップ４０２－４１６と同じであることが可能である。充電プロセスはステップ５１８で終了させられることが可能である。

【００６３】

電池がまだ充電器に接続されている状態で、ステップ５２０で電池の開回路電圧が監視される。電池の電圧が事前設定された最小値V_{Min}よりも低下する場合には、充電プロセスが繰り返されることが引き起こされる。電圧V_{Min}は、充電器が電池がその閾値よりも低下することを許可しない所望の低い方の電圧閾値を与えるために選択される。充電器は電池上の電荷をV_{Min}よりも高いように保つ。しかし、電池が低い電圧閾値V_{Min}よりも高いままである限りは、充電プロセスは再開されず、充電プロセス全体がステップ５２２で停止させられる。V_{Min}のために選択される値は、ユーザによって選択可能である許容可能な残存充電の量、または、その代案として、充電操作プログラムにおける事前設定値としてプログラミング可能な許容可能な残存充電の量に基づいている。

【００６４】

図６は、電池の充電終了時から経過した時間と電池の開回路電圧とを監視する充電プロセスの流れ図である。ステップ６０２－６１８はステップ５０２－５１８と同じであることが可能である。電池の充電終了時から経過した時間と電池の開回路電圧とを監視するこの充電プロセスでは、電池充電プロセスの終了時から経過した時間がステップ６２２で監視される。予め決められた量の時間が充電プロセスの終了時点から経過し終わっており、かつ、電池が充電器装置に接続され続けている場合には、充電プロセスが再開される。経過した時間が予め決められた量の時間を超えていない場合には、充電プロセスがステップ６２４に進む。開回路電圧がその予め決められた値V_{Min}よりも低い場合には、充電が再開される。電池開回路電圧がV_{Min}よりも高いままである場合には、充電プロセスがステップ６２６で終了させられる。

【００６５】

代案のプロセスでは、開回路電圧が、充電プロセスの終了時点から経過した時間を評価する前に監視されることが可能である。さらに別の代案のプロセスでは、充電プロセスの終了時点からの時間が、電池の開回路電圧の監視と同時に監視されることが可能である。

【００６６】

図７は、様々な充電プロファイルの選択を可能にする本発明の一形態の流れ図である。ステップ７０２で充電プロセスが開始される。その次に、充電プロファイルが選択される７０４。採用可能な充電プロファイルは、定電位、変更された定電位、定電流、鉄および鉄共振（ferro and ferro resonant）、定電流－定電位－定電流（ＩＥＩ）、定電力－定電位－定電流（ＰＥＩ）、並びに、好ましくは定電力を含む。この異なるプロファイルを記述し定義する情報が、充電器の制御様相に関連して充電器内に含まれたアドレス可能メモリ内に格納されることが可能である。

【００６７】

充電プロファイルが選択され終わると、タイマ回路が初期値にセットされ、その選択されたプロファイルを使用する充電プロセスがステップ７０６で開始される。その次に、ステップ７０８で充電プロセスが経過時間を記録し始める。ステップ７１０において、充電プロセスは電圧の第１と第２の導関数を監視する。第２の導関数がゼロに等しく（ステップ

７１２）かつ第１の導関数が最大値に達している（ステップ７１４）場合には、充電プロセスが継続する。第２の導関数がゼロに達しておらずかつ第１の導関数が最大値に達していない場合には、これらの値がその所望の値に達するまで、これらの値が連続的に監視される。

【００６８】

所望の導関数値に達すると、所望の過充電のための追加の充電時間がステップ７１６で計算され、電池が所望の過充電を得るために追加の充電時間にわたって充電される（ステップ７１８）。この追加の充電時間は、以前に選択された充電プロファイルまたは別の充電プロファイルを使用してもよい。所望の過充電のための追加の充電時間が経過し終わると、充電プロセスがステップ７２０で終了させられる。

【００６９】

図８は、充電制御アルゴリズム装置ＩＣと、適切にプログラミングされたマイクロプロセッサのような「測定／計算／制御装置」（ＭＣＣＤ）とを使用する、電池充電システムの一例のブロック図である。整流器８０４に対する交流入力８０２が、充電プロセス制御装置集積回路８０８を通して電池８１０に印加される充電電流を所望の電圧において発生させる。この充電プロセス制御装置集積回路８０８は、電池８１０に対する充電エネルギーの印加を制御する。

【００７０】

充電制御装置ＩＣ　８０８は、１つまたは複数の充電プロファイルまたは充電プロセスを含む充電信号を印加するために、ＭＣＣＤと共に機能する。図２から図７に示されているプロセスの１つまたは複数を実施するための命令がＭＣＣＤ　８０６内に記憶されることが可能である。典型的には、この記憶は、充電プロセスを記述する１組のプログラム命令をＭＣＣＤ内にロードすることによって実現される。この代案として、充電プロセスは、集積回路８０８の特徴と機能とを含むことが可能な専用の充電プロセス制御集積回路の形に統合されてもよい。

【００７１】

図９は、電池を充電するための本発明の充電プロセスの１つまたは複数を実施することが可能な電池充電システムのブロック図である。交流入力９０２がリレー９１２によって制御される。リップル成分を有する直流電圧を生じさせるために、交流電力が整流器９０４に供給される。電圧調整器９０６が直流電圧の変動を減少させる。調整された直流電圧が、リレー９１４の接点を通して電池９１６に所望の電流と電圧を供給するために、従来通りに構成された電流制限装置９１０と共に働く従来通りに構成された直列通過素子（series pass element）９０８に印加される。電池に印加される電流は従来通りの電流計９１８によって監視される。この電流計は導体内を流れる電流の瞬間値を監視する。代案の構成では、従来の平均電流計が、導体を通過する平均電荷を表示するために使用されることが可能である。さらに別の代案の構成では、従来の総合電流計が、導体を通過する総電荷の表示を与えるために使用されることが可能である。電池の両端子間の電圧が電圧計９２０によって監視される。電流計と電圧計とから得られた情報がＭＣＣＤ　８０６に与えられることが可能である。

【００７２】

電池９１６の両端子間の電圧は、さらに、電圧の第１の導関数を計算する微分器回路９２２にも供給される。こうした回路は、９３０に示されているように従来通りに構成されていることが可能である。微分器は、典型的には、微分器を構成するように当業者に公知の通りに接続されている演算増幅器Ａと抵抗器Ｒとコンデンサ Ｃとを備える。電圧V_iが微分器の入力に印加される。信号出力V_0は－ＲＣ（ｄＶ／ｄｔ）に等しい。

【００７３】

第１の導関数回路９２２の出力がピーク検出器９２８に送り込まれる。最大の第１の導関数の信号が検出されると、その表示がＭＣＣＤ　８０６に与えられる。第１の導関数の処理回路の出力は、第２の導関数の処理回路９２４にも供給される。この回路は単純に９２２の回路の複製である。第２の導関数の回路９２４の出力がゼロ横断検出器９２６に送り

込まれる。ゼロ横断検出器は、電圧が正から負へ変化し必然的にゼロボルトの値を通過する時のような信号極性の遷移を検出する回路である。図１の電圧曲線１０１における変曲点１１５の検出に対応するゼロ横断の検出が求められる。ゼロ横断検出の表示がＭＣＣＤ　８０６に与えられる。本発明の実施形態を含むプロセスの制御によって、ＭＣＣＤは充電電流と充電電圧とがリレー９１４を通して印加されるようにその充電電流と充電電圧とを送り出す。ＭＣＣＤは、さらに、リレー９１２によって交流入力の動作を制御することもできる。

【００７４】

図９に示されている充電システムの構成要素が共通の充電器ハウジングの中に収容されていることが好ましい。充電器は、一般的に、電池、または、電池が中に配置されている物品（例えばゴルフカー）から分離していることが可能であり、一般的に分離している。しかし、必要に応じて、充電システムの構成要素の一部または全部が、例えばゴルフカーの要素のような要素として電池に物理的に付随させられることが可能である。

【００７５】

本発明が、電池寿命を低減させるほど電池を過剰に充電することなしに電池を効果的に充電する仕方でディープサイクルタイプの開放型鉛蓄電池を充電するための装置と手順を提供するということが理解されるだろう。この電池は、電池の最も最近の先行デューティサイクルの完了の後に電池を完全充電状態にするのに必要とされる充電エネルギーの選択されたパーセント値である量だけ過充電される。本発明の実施において実現される再充電事象は、本質的に、電池の古さと、充電の有効性と効率とに影響を与える電池内部特性とのような要因を考慮し計算に入れる。

【００７６】

本発明が電池の再充電に関して上記で説明されてきたが、本発明が、電気ゴルフカーもしくは何らかの他の電動車両または装置において必要となる可能性がある１組の電池の再充電、または、例えば、光起電力システムと共に使用される１組の電池の再充電にも適用されるということが理解されるだろう。

【００７７】

本発明の好ましい具体例および形態と他の具体例および形態との上述の説明が、本発明が有利に実現または使用されることが可能な装置または手順のすべての形態のカタログとしてではなく、一例として示されてきた。本発明が関わる分野の専門家は、上述の装置およびプロセスの変形と変更とが本発明の範囲から逸脱することなしに有益に使用されることが可能であるということを理解するだろう。

【図面の簡単な説明】

【００７８】

【図１Ａ】典型的な充電サイクル中の時間に対してグラフ化された、従来の鉄共振型充電器を用いて充電される鉛蓄電池の端子における電圧と電流の様相のグラフである。

【図１Ｂ】約１３５アンペア時のデューティサイクル放電の後の、カ氏８０度における同様の電池の充電プロファイルに関するグラフである。

【図１Ｃ】約１３５アンペア時のデューティサイクル放電の後の、カ氏１２２度における同様の電池の充電プロファイルに関するグラフである。

【図１Ｄ】約８１アンペア時のデューティサイクル放電の後の、カ氏８０度における同様の電池の充電プロファイルに関するグラフである。

【図１Ｅ】約８１アンペア時のデューティサイクル放電の後の、カ氏４８度における同様の電池の充電プロファイルに関するグラフである。

【図２】開放型ディープサイクル鉛蓄電池に関する充電プロセスの実施形態の流れ図である。

【図３Ａ】セル電圧を監視する充電プロセスの実施形態の流れ図である。

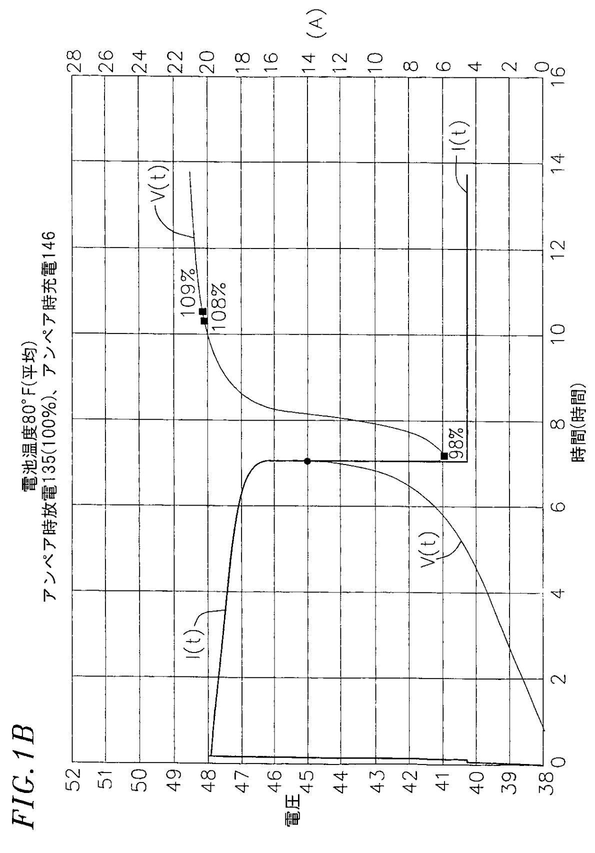
【図３Ｂ】セル電圧を監視する充電プロセスの実施形態の流れ図である。

【図４Ａ】セル電圧と充電時間を監視する充電プロセスの実施形態の流れ図である。

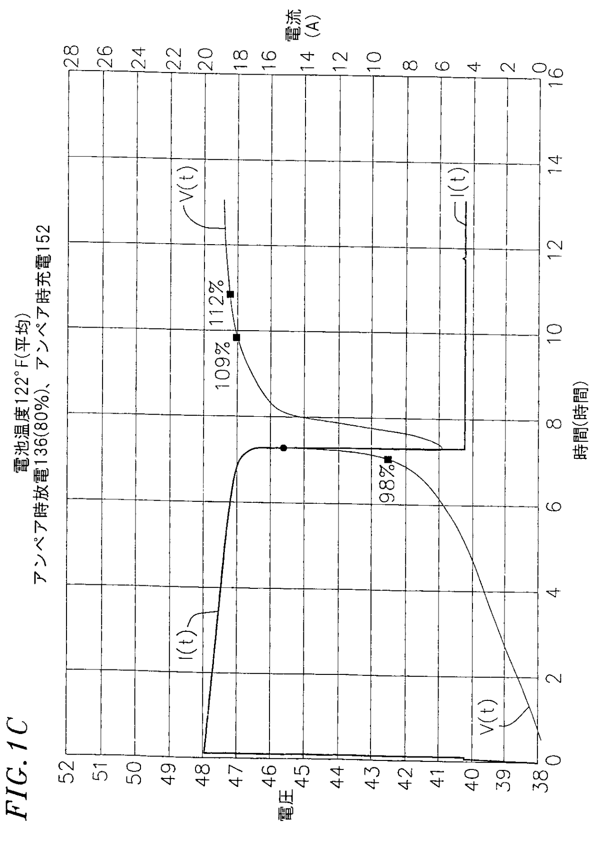
【図４Ｂ】セル電圧と充電時間を監視する充電プロセスの実施形態の流れ図である。

【図５】リフレッシュ充電を実現する充電プロセスの実施形態の流れ図である。
【図６】充電終了時からの経過時間と電池開回路電圧とを監視する充電プロセスの実施形態の流れ図である。
【図７】様々な充電プロファイルの選択を可能にする本発明の実施形態の流れ図である。
【図８】充電プロセス制御装置ＩＣと測定／計算／制御装置（「ＭＣＣＤ」）とを使用する電池充電システムの実施形態のシステムブロック図である。
【図９】電池を充電するために本発明のプロセスの実施形態を使用する電池充電器の実施形態のブロック図である。

【図１Ｂ】



【図１Ｃ】



【図１Ｄ】

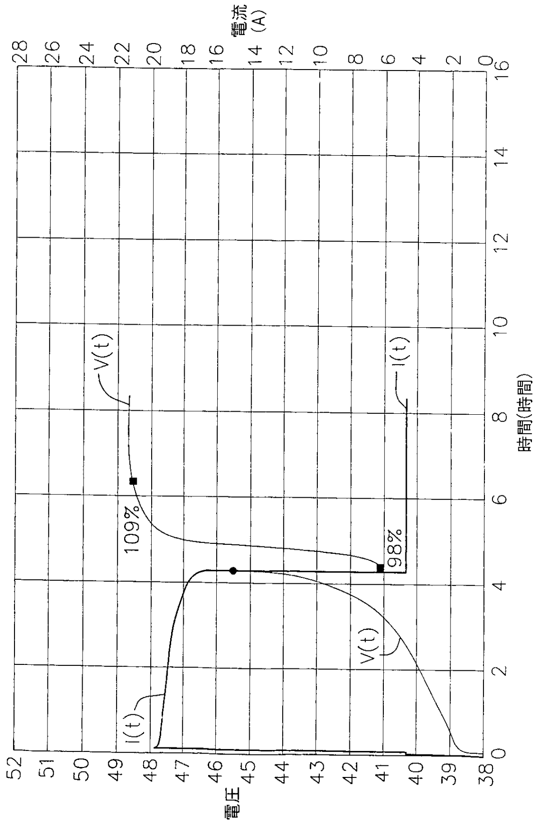


FIG. 1D

【図１Ｅ】

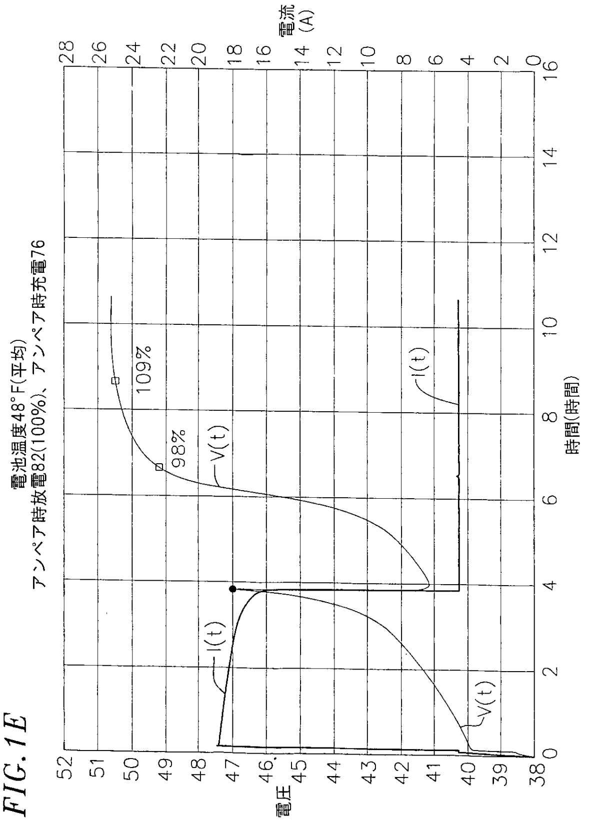
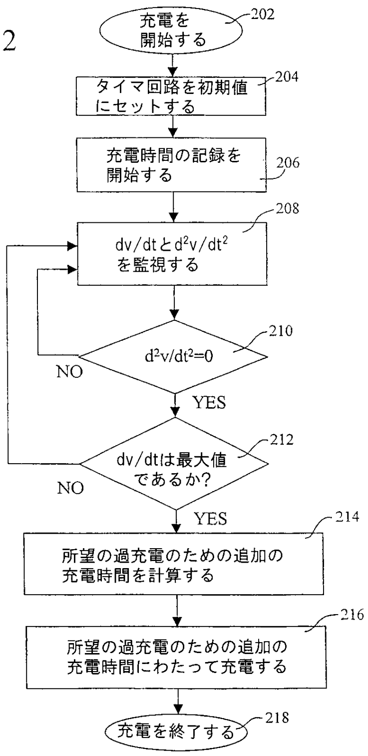


FIG. 1E

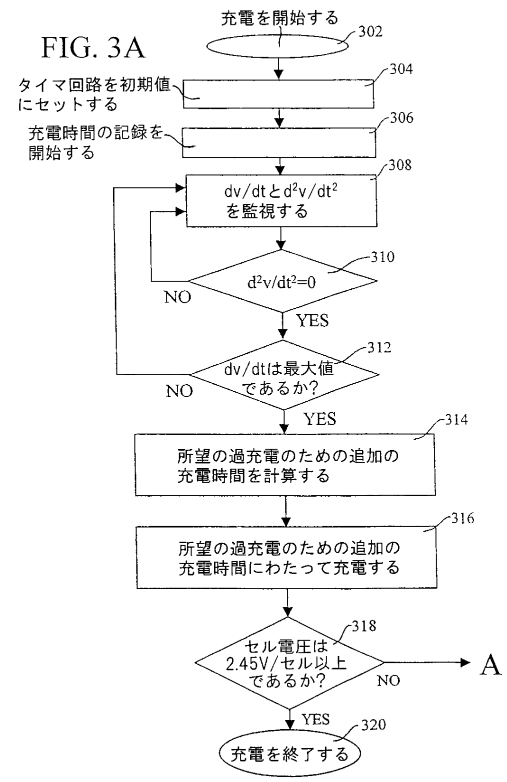
【図２】

FIG. 2



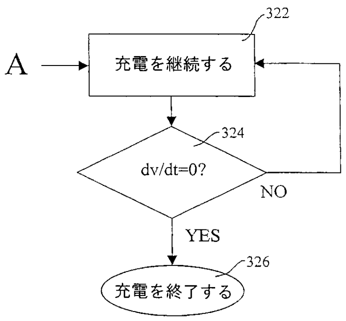
【図３Ａ】

FIG. 3A



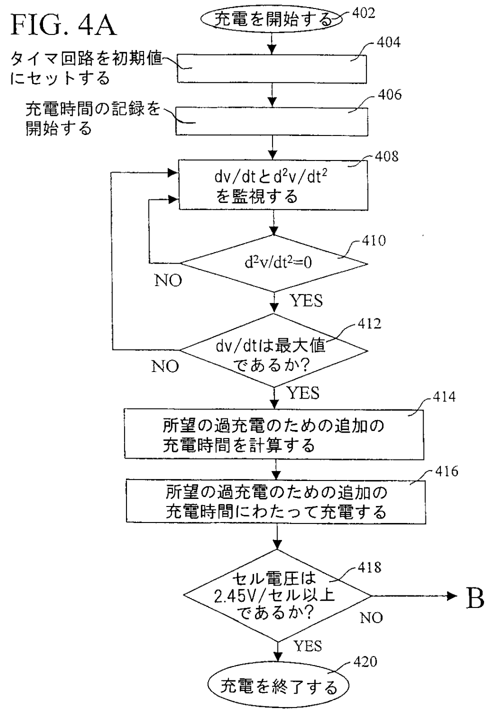
【図３Ｂ】

FIG. 3B



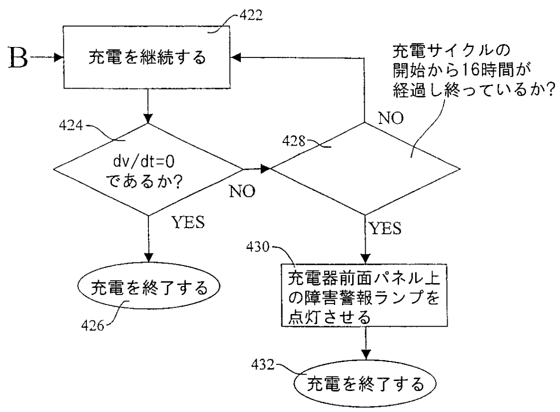
【図４Ａ】

FIG. 4A



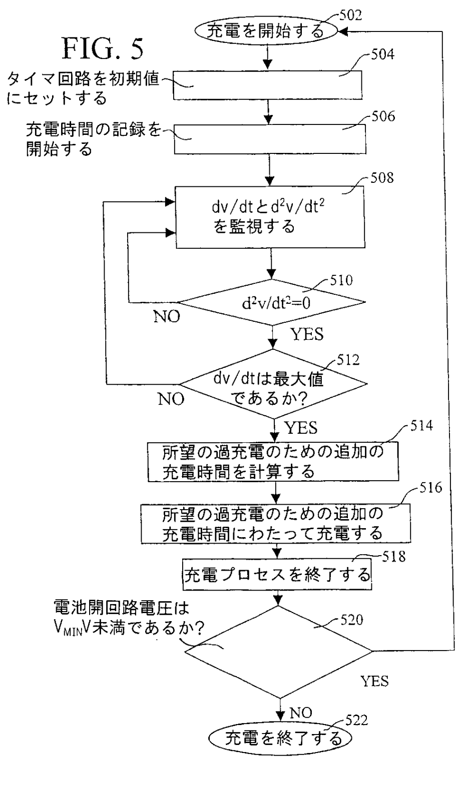
【図４Ｂ】

FIG. 4B



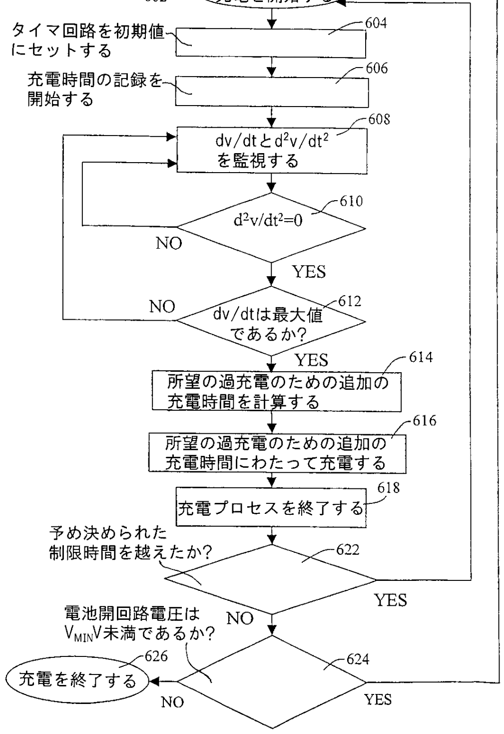
【図５】

FIG. 5



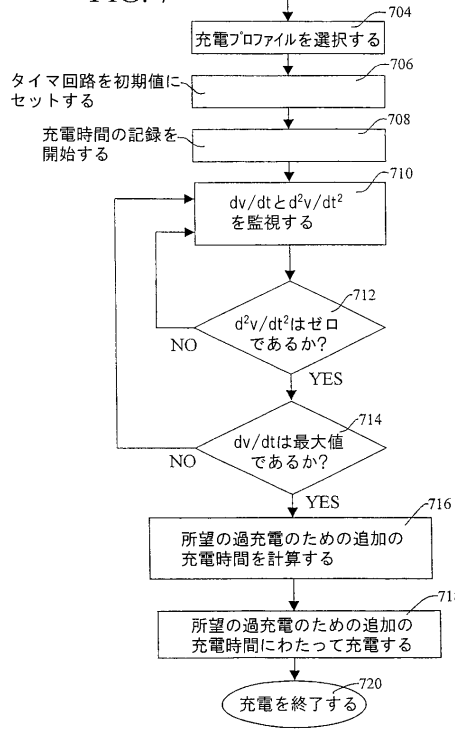
【図６】

FIG. 6



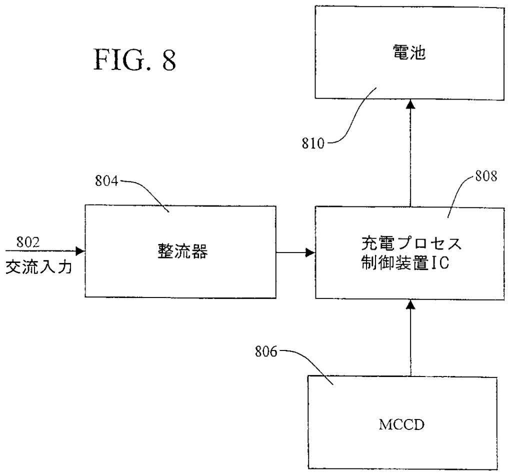
【図７】

FIG. 7



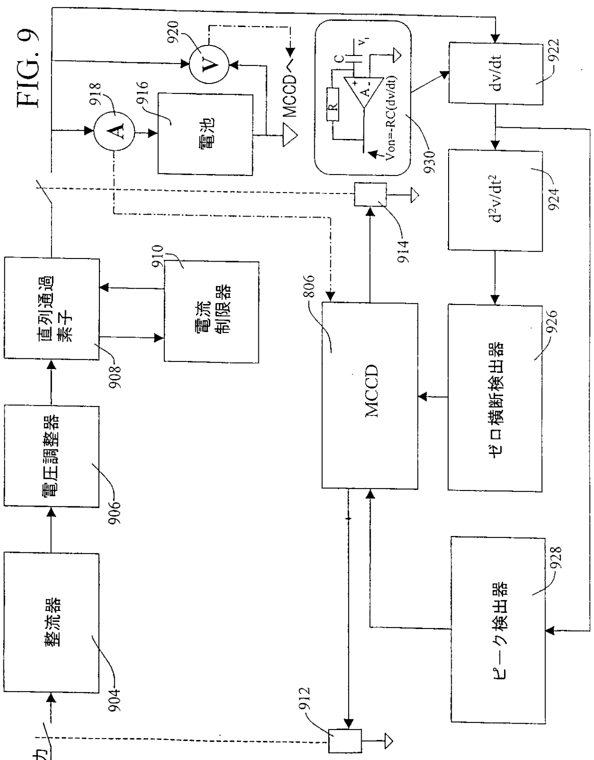
【図８】

FIG. 8



【図９】

FIG. 9



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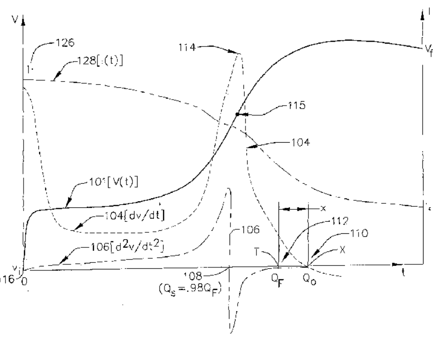
(54) Title: SYSTEM AND METHOD FOR BATTERY CHARGING



(57) Abstract: A method for charging a lead acid storage battery to advantageously extend its life is described. The termination of a charging process is based upon an evaluation of the first derivative (dv/dt) and second derivative (d2v/dt2) of the applied charging voltage. By utilizing the first derivative (dv/dt) and second derivative (d2v/dt2) as charging criteria, an amount of overcharge is applied to the battery that takes into account the precise amount of amp-hours previously removed from the battery. A charger arrangement for performing a charging process of the invention also is described.

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1 SYSTEM AND METHOD FOR BATTERY CHARGING

FIELD OF THE INVENTION

This invention pertains to a method for controlling the termination of a recharging process for flooded deep-cycle lead acid electric storage batteries. More particularly, it pertains to procedures which supply to such batteries a quantity of recharge energy which is directly related to the amount of energy discharged following the last preceding battery charge event. It also pertains to equipment for implementing such procedures.

BACKGROUND OF THE INVENTION

Rechargeable electric storage batteries of many different kinds are known, such as nickel-cadmium, nickel metal hydride, nickel-iron, lithium, silver-cadmium and deep-cycle lead acid batteries. Deep-cycle lead acid batteries differ from SLI (starting, lighting, ignition) lead acid batteries used, e.g., in conventional automobiles; SLI batteries are not designed or constructed to withstand repeated cycles of substantial discharge and recharge, and so are not rechargeable batteries in the sense of this invention.

It is known, such as from U.S. Patents 4,392,101 and 4,503,378, that there are certain characteristics of a rechargeable battery, regardless of kind, which change during recharging of the battery in ways which signal either that the battery is fully charged or that it is at a relatively predictable point short of but near a state of full charge. Those patents, as well as other publications, describe equipment and techniques for monitoring those characteristics and for detecting certain events, conditions or states of them, and using such detections either to terminate the battery charging process or to continue charging for preset times or in preset ways. Those preset ways typically use charging processes different from those in use at the time of the detected event. Those charging event detection techniques are known as inflection analysis methods because they rely on the detection of certain inflection points in time-based curves which describe the change in battery voltage or battery current, e.g., during the charging process. While inflection analysis as described to date works well to control recharging of most kinds of rechargeable batteries, inflection analysis as heretofore described has been found not to serve satisfactorily for controlling recharging of flooded deep-cycle lead acid batteries in which the battery electrolyte is a liquid (typically sulfuric acid) unconfined in any supporting matrix such as a gel.

Flooded deep-cycle lead acid batteries are widely used as energy sources for electrically powered vehicles such as golf cars, fork lift trucks, and scissor lift vehicles. They also are used in uninterruptible power supplies in hospitals and other buildings and facilities, and as components of photovoltaic power installations. The reasons why inflection analysis techniques as heretofore described are not satisfactory for controlling recharging of flooded deep-cycle lead acid batteries can be understood from the use of such batteries in electric golf cars, as an example.

Electric golf cars are powered by sets of 4, 6 or so flooded deep-cycle lead acid electric batteries. At a given golf course, there is a fleet of such golf cars available for use by golfers. Different cars in the fleet may have older batteries in them than other cars in the fleet. Certain cars may be used more frequently than others. Some cars may be used longer on a given day than others. Some cars may be subjected to more strenuous usage conditions on a given day than others, depending on the circumstances of the using golfers or differences in traversed terrain, among other reasons. Also, it is well known that even if all batteries in the fleet are from the same manufacturer and are of the same nominal age, there still will be meaningful variations between batteries of kinds which can affect battery performance, life and, importantly, how they respond to recharging processes. As a consequence, at the end of a day when the golf cars in that fleet are to be recharged, there can be significant differences between the discharge states of the batteries from car to car, and consequent meaningful differences from car to car in how the batteries need to be charged. Fleet- wide uniform recharging procedures either will cause some batteries to be insufficiently recharged or, more likely, substantial numbers of the batteries will be materially overcharged. Material overcharge of such a battery reduces battery life. Very commonly, the persons employed to recharge fleets of golf cars have no understanding of the effects of substantial overcharge and how to determine when it is occurring. Therefore, it is desirable that the batteries used in electric golf cars be recharged by equipment and processes which avoid substantial overcharge and do so in ways which inherently accommodate and deal with differences between batteries due to discharge state, age, and manufacturing variations, among other factors.

Deep-cycle lead acid batteries are designed to withstand repeated cycles of substantial discharge from a fully charged state and of recharge from a discharged state to a state of full charge. As compared to other kinds of rechargeable batteries which do not use liquid electrolytes, the liquid acid electrolyte of flooded deep-cycle lead acid batteries presents special conditions which require that a given battery, or a given set of a small number of batteries repeatedly used in combination with each other, be recharged in a way which provides a controlled overcharge related in extent to the state of the battery at the time a recharge event is commenced. Stated differently, effective recharge of a flooded deep-cycle lead acid battery ideally should include a controlled overcharge determined by the amount of energy removed from (discharged by) the battery during its last preceding duty cycle (period of use following the last prior charging event). The reason is related to what happens to the liquid electrolyte during the prior duty cycle and the following recharge event.

As a cell of a lead acid battery discharges, the acid ions in the electrolyte move to the cell electrodes and oxygen atoms move from the active material of the cell into the electrolyte to form water with the electrolyte hydrogen ions. As a consequence, the electrolyte acid becomes progressively more diluted and its specific gravity progressively approaches 1.0 from a higher starting specific gravity. As the cell is recharged, that ion exchange process is reversed to produce regeneration of the electrolyte acid and the active material. If the electrolyte is present in the cell as a free liquid (i.e., the cell is flooded), as opposed to being present in a gel matrix, the regenerated acid, being heavier than the dilute electrolyte, sinks to the bottom of the cell as it is created. As the recharging process continues, more and more concentrated regenerated acid collects in the bottom of the cell. At the point at which the cell active material has been fully regenerated, the cell is theoretically fully recharged on a Coulombic basis. However, the cell is not in good condition for use to deliver stored electrical energy because of the stratification of the electrolyte. The electrolyte is not of uniform acidity throughout the cell and so the regenerated acid electrolyte is not in uniformly effective contact with the regenerated active material over the full area of the regenerated active material; if the cell were to be called upon to discharge at that point, the discharging electrochemical process will occur predominantly in the lower part of the cell where the electrolyte acid is overly concentrated. The cell will not discharge energy at the levels desired, and the over concentrated acid in the bottom of the cell will cause overly rapid degradation of the adjacent active material. The consequence is under performance of the cell in a manner which materially reduces cell life.

In the portion of the recharge process for a lead acid battery cell which immediately precedes full regenerative restoration of the active material, gas is generated in the cell as a normal part of the recharge process. The gas bubbles rise through the electrolyte to the top of the cell and, in the process, induce circulation (stirring) of the electrolyte in the cell. However, if the recharge process is terminated at the point of full regeneration of the active material, the amount of gas generation which will have occurred will be insufficient to stir the electrolyte adequately to cause it to be of uniform acid concentration (uniform specific gravity) throughout the cell. For that reason, it is common practice to continue the process of recharging a flooded deep-cycle lead acid battery beyond the point of full recharge, i.e., to extend the gas generation process for a time to achieve adequate stirring of the regenerated electrolyte. That is, the cell is intentionally overcharged.

Current practice is to overcharge such batteries, which include a number of cells, by a predetermined amount which is defined to be adequate to fully stir the electrolyte in the cell or cells which need the most stirring; that definition of the predetermined amount of overcharge is based on the assumption that the cell has been maximally discharged in its previous duty cycle and that the cell has certain properties of age, condition and temperature. However, as shown above in the discussion of the operation of a fleet of electric golf cars, that assumption is not apt for a substantial portion of batteries requiring recharge. As a result, reliance upon that assumption about the amount of overcharge to be applied in the terminal stages of recharging flooded deep-cycle lead acid storage batteries causes a substantial number, if not the majority, of such batteries to be meaningfully overcharged. Meaningful overcharge of such a battery, especially if repeated more than a few times, substantially reduces the effective life of such a battery.

The foregoing description provides a foundation for understanding how existing descriptions of inflection analysis techniques for controlling battery recharge processes are deficient when applied to the recharging of flooded deep-cycle lead acid storage batteries.

U.S. Patent 4,392,101 is an early description of the use of inflection analysis in controlling recharging of rechargeable batteries. It teaches that rechargeable batteries in general have broadly similar response characteristics to recharging processes. It teaches that if battery voltage or current, e.g., is plotted graphically against time during recharge, the resulting voltage/time or current/time curves will have broad similarities. After initiation of the charge process, irrespective of the particular materials used to define a battery cell, those curves will manifest at least a pair of inflection points in which the graph line reverses curvature, i.e., is inflected. It is disclosed that those inflection points signal or denote different phases of the battery's response to applied charging energy and, for each type of cell, those inflections occur at relatively predictable times in the process, either before or at the time of the battery reaching a state of full charge. It is disclosed that the predictability of the inflection point occurrences is generally unaffected by (happens without regard to) factors such as the actual voltage of the battery, individual cell characteristics, individual charging history, or actual ambient temperature conditions. That patent discloses that the inflection points can be identified by observing the state or character of the first or second derivative with respect to time of the battery characteristic (voltage or current) being monitored. More particularly, it teaches that a graph of the second derivative will cross the zero axis (the sign of the derivative will change from positive to negative, or vice versa)at least twice during the charging process, and the second zero axis crossing of that derivative either will occur at the time the battery reaches full charge or will occur at some interval shortly before full charge is achieved. However, in the instance of lead acid batteries, that patent does not attempt to describe when the second time-based derivative of voltage occurs relative to full charge. The principal descriptions of that patent are in the context of nickel-cadmium batteries where recharging is terminated a preset time after that second zero-axis crossing of that derivative has been detected. Nickel-cadmium batteries do not use a variable density electrolyte which is present as a part of the chemical process and so such batteries do not benefit from or require any measure of overcharge.

U.S. Patent 4,503,378 applies inflection analysis recharging controls to nickel-zinc batteries and discloses that, for that type of battery, recharging is to be terminated upon the occurrence of the second instance of sign change (zero axis crossing) of the second derivative of battery voltage with respect to time. It also observes that, at the same time as the second derivative crosses the zero axis from positive to negative, the value of the first derivative of battery voltage with respect to time is at a maximum or peak value, a fact which enables the second derivative's zero crossing to be confirmed.

The article titled "Charge batteries safely in 15 minutes by detecting voltage inflection points" appeared in the September 1,1994,issue of EDN Magazine. That article focuses principally upon fast recharging of nickel-cadmium batteries. It comments that inflection analysis also applies to lead acid batteries. In that connection, it states "In lead-acid batteries, the second dV/dt inflection occurs at a predictable interval before the batteries reach full charge, but from the battery's Ahr capacity rating, you can easily derive the duration of the incremental charging needed to achieve full charge." That statement does not contribute, for at least two reasons, to a solution to the problem of how to efficiently, reliably and effectively charge a flooded deep-cycle lead acid battery, without meaningfully overcharging it, in terms of the battery's true need for recharge. First, a lead acid battery's Ahr (ampere-hour) capacity rating is not a precise value which can be determined accurately from engineering information. Rather, it is a value which a battery manufacturer assigns to a model or type of battery as a result of business factors peculiar to the manufacturer, such as marketing objectives, warranty policies, and other factors. A battery's ampere-hour capacity rating is merely a manufacturer's statement of the expectable performance, perhaps under unspecified conditions, of an average battery of that kind or type. It has no reliable relation to the charging needs of a particular battery after completion of a particular duty cycle, i.e., its depth of discharge before experiencing a recharging event. Second, the ampere-hour capacity rating is a value which needs to be known from a source other than the battery itself. What is needed is a way to charge a flooded deep-cycle lead acid battery using information, derived from the battery itself, which describes the battery's discharge state and which is usable to overcharge the battery only enough to stir the regenerated electrolyte adequately.

Neither of the patents cited above nor the EDN Magazine article consider the state of battery discharge before a recharging process is commenced. They impart no knowledge about how information about that discharge state can be used to control recharge of that battery. However, apart from those descriptions it is known to physically attach to a battery, such as a battery in a golf car, an integrating ampere meter (ampere hour meter) which travels with the battery at all times. When the battery is connected to a charger following the battery duty cycle, the "on board" ampere hour meter is connected to the charger so it can communicate to the charger the value of ampere hours removed from the battery during that last duty cycle. That information is applied in the charger to a computing and control device which computes the total charge to be delivered to the battery by multiplying the metered value of ampere hours by the desired factor (for example 1.10 or 110%)that has been found to produce sufficient stirring in the electrolyte. A computing and control device in the charger then monitors the ampere hours returned to the battery by the charger. When the calculated value for the charge return is reached, that computing and control device instructs the charger to terminate the charging process. While this approach is effective, it suffers from the added complexity of communicating data to the charger from the ampere hour meter which is associated with the battery. That approach also suffers from the added expense of equipping every battery, or every operational set of batteries, with its own captive ampere hour meter which must be specially constructed to survive in the environment of the battery. That approach is independent of inflection analysis and has apparent practical problems in the field.

It is apparent, therefore, that a need exists for the availability of equipment and procedures which can be used effectively, efficiently and reliably by persons having little or no knowledge of battery technology to adequately recharge flooded deep-cycle lead acid batteries without meaningfully overcharging any one or small group of batteries. Such equipment and procedures, to satisfy that need, should effectively address and conform to the actual recharge and electrolyte stirring needs of a battery or of a defined small group of batteries. The term "defined small group" means a number of batteries, such as those installed in a given electric golf car, which most probably will be of the same age, will have experienced the same usage history, and will have shared the same duty cycle in the interval between last being recharged as a group and the recharge event of interest.

SUMMARY OF THE INVENTION

In light of the foregoing, this invention addresses problem situations not heretofore resolved in the art to provide procedures and equipment by which flooded deep-cycle lead acid batteries, individually or in defined small groups, are rechargeable in terms of actual recharge requirements and minimal overcharge processes. The invention applies inflection analysis principles in new ways to customize each battery charging event to the needs of the battery, or battery set, presented to the charger which includes a novel computing and control device. These benefits and advantages are provided and achieved effectively and reliably without calling for any change in how the battery is made or used. Service personnel are required only to connect and to disconnect the charger to and from the battery.

Information about recharge requirements is obtained by the charger from the battery itself in the course of the charging process, without reliance upon an ampere hour meter matched to the battery. That is, the charger does not know, and does not need to know, the discharge state of the battery before the recharging process is commenced. The invention is maximally protective of the batteries themselves and can lead to extended battery life.

In terms of procedure, the invention provides a method for charging lead acid batteries. The method includes monitoring the battery voltage during the performance of the process, recording the charging time, and monitoring the charge provided to the battery in ampere hours. The method also includes determining a point in the charging process at which the battery has a charge state having a known relation to a full charge state, and determining the quantity of charging energy deliverable to the battery beyond a point of full charge which is equal to a desired portion of the energy deliverable between commencement of the process and the point at which the battery is fully charged.

In terms of its structural aspects, the invention provides a charger for charging lead acid batteries, preferably deep cycle lead acid batteries. The charger includes a DC current source, a voltmeter, an ammeter, a timer, a dv/dt measurement circuit, and a d^2v/dt^2 measurement circuit.

More specifically, the charger also includes a controller coupled to the DC current source, the ammeter, the voltmeter, the timer and the dv/dt and d^2v/dt^2 measurement circuits. The controller is configured to determine the time in a battery recharge event when a battery is at substantially a predetermined percentage of full charge and to determine the value of Q_D from the relation $(Q_s/p) = [Q_D/(1+x)]$ in which Q_s is the ampere-hours of charging energy delivered to the battery in the interval from the beginning of the event to the time at which $d^2v/dt^2 = 0$ and dv/dt is maximum, p is the decimal equivalent of the percentage of replenishment charge delivered to the battery when $d2_v/dt^2 = 0$, x is the decimal equivalent of a desired percentage amount of replenishment charge to be delivered to the battery as an overcharge amount, and Q_D is the ampere hours to be delivered to the battery from the beginning of the event to reach the overcharge amount. If the predetermined percentage of full charge is 98%, then p = .98.

DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be better understood from the following detailed description read in light of the accompanying drawings, wherein:

FIG. 1A is a graph of aspects of voltage and current at the terminals of a lead acid storage battery being charged with a conventional ferroresonant charger, graphed over time during a typical charging cycle;

FIG. 1B and 1C are graphs for the charging profile of similar batteries at 80 degrees Fahrenheit and 122 degrees Fahrenheit respectively following a duty cycle discharge of about 135 ampere-hours;

FIG. 1D and 1E are graphs for the charging profile of similar batteries at 80 degrees

Fahrenheit and 48 degrees Fahrenheit respectively following a duty cycle discharge of about 81 ampere hours;

FIG. 2 is a flow diagram of an embodiment of a charging process for a flooded deep cycle lead acid storage battery;

FIGS. 3A and 3B are flow diagrams of an embodiment of a charging process that monitors cell voltage;

FIG. 4A and 4B are a flow diagram of an embodiment of a charging process that monitors cell voltage and charging time;

FIG. 5 is a flow diagram of an embodiment of a charging process that provides refresh charging;

FIG. 6 is a flow diagram of an embodiment of a charging process that monitors time since the termination of charging and battery open circuit voltage;

FIG. 7 is a flow diagram of an embodiment of the invention that allows selection of different charging profiles;

FIG. 8 is a system block diagram of an embodiment of a battery charging system utilizing a charge process control device IC and a measuring computing and control device ("MCCD"); and

FIG. 9 is a block diagram of an embodiment of a battery charger utilizing an embodiment of the invention's process to charge a battery.

Glossary

Full charge Q_F:	the state of a battery at which it is at full charge capacity and continued application of charging energy has no beneficial effect upon the electrodes or upon electrode active materials;
Initial state of charge Q_i:	the amount of residual charge possessed by a battery at the commencement of a battery recharge event or process;
Replenishment charge Q_R:	the amount of charging energy, measured in ampere-hours, absorbed by the battery having an initial state of charge to return the battery to a state of full charge; $Q_R = Q_F - Q_i$
Charge deficiency:	the difference between a battery's full charge and initial state of charge; it is equal to the replenishment charge Q_R
Overcharge Q_o:	the amount of charging energy, measured in ampere-hours,

delivered to a battery in the course of a recharge event or process after the time the battery achieves full charge until the termination of the event or process; it is extra energy delivered to the battery to condition the battery for good performance during its next duty cycle; in the practice of this invention, its magnitude is directly related to the magnitude of the replenishment charge;

Duty cycle: the period after a battery has been fully recharged during which the battery delivers energy during use of the thing in which the battery is located or to which it is connected; the battery charge at the end of a duty cycle is the battery's initial state of charge in the following battery recharge event or process;

Coulombic charge Q_C: the amount of charge possessed by a battery at any time of interest;

Delivered charge Q_D: the ampere hours of energy delivered to a battery during the interval between commencement and termination of a battery recharge event or process; in the practice of this invention it is the combination of the replenishment and overcharge ampere hours, i.e., $Q_D = Q_R + Q_O$;

Signal charge Q_S: the amount of charge, measured in ampere hours, delivered to a battery during the interval beginning with the commencement of the recharging process and ending at that later point in the process at which the battery, due to its particular electrochemistry, has a detectable condition indicative that the battery charge level has a definite relation to full charge; in the context of this invention which pertains to lead acid battery electrochemistry, the detectable condition is a zero value of the second time-based derivative of battery voltage coexisting with a maximum value of the first time-based derivative of battery voltage.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1A is a graph of aspects of the voltage and the current at the terminals of a lead acid storage battery being charged with a conventional ferroresonant charger graphed over time during a typical charging cycle; the graphed aspects are voltage, current, and the first and second derivatives of the voltage with respect to time. Such a charging characteristic is typically observed when charging a lead acid battery with a ferroresonant battery charger. A ferroresonant charger typically includes a transformer and rectifier circuit that contributes to the distinctive shapes of the curves describing the way the current 128 and voltage 101 vary during a battery charging event. In implementing a charging cycle the duration of the charging cycle and the rate at which recharging energy is applied to the battery determines the amount of charge returned to the battery. To fully charge a flooded lead acid battery, a typical method utilized is to continue to charge, i.e., to overcharge, the battery after it has reached a state where charging current flowing into the battery has decreased significantly.

Controlling overcharge of a lead acid storage battery to a fixed percentage of ampere hours removed from the battery during an immediately previous duty cycle typically tends to greatly increase a battery's lifetime. Overcharge parameters are typically selected based upon varying criteria known to those skilled in the art. A battery thus charged to a fixed percentage of ampere hours removed in the prior duty cycle typically may have a longer useful life than a comparable battery which receives, each time it is recharged, an amount of overcharge defined as a fixed percentage of the total charge capacity of the battery. Thus, knowledge and use of the initial battery discharge state when recharging begins aids in determination of the amount of overcharge best delivered to the battery.

A voltage response 101 during charging of a lead acid storage battery is shown as a function of time in FIG. 1A. The voltage measured is that present across the battery's terminals at various times during the charging cycle. A particular voltage response 101 for each charging cycle of a battery, in response to a given value of an impressed charging current 128, changes as a function of the battery's temperature and internal conditions, which normally are a function of a battery's age. Neither the temperature nor the age of a battery are known by a typical charging device. Thus, the basis for judging the charge deficiency of a battery connected to a charger may not be reliably based on an absolute value of voltage.

A determination of the ampere hours of battery charge deficiency is more reliably based upon inherent voltage-time characteristics of flooded lead acid storage batteries. The inherent voltage-time characteristics preferably utilized (see FIG. 1A) are voltage as a function of time V(t) (curve 101), the rate of change of voltage over time dv/dt (curve 104), and the acceleration of the voltage over time d^2v/dt^2 (curve 106).

A battery's voltage V(t), as measured across its external terminals, varies during a charging cycle in response to an impressed charging current I(t) (curve 128 in FIG. 1A). A voltage across the terminals of a battery being charged and a charging current into the battery are related by a battery's internal resistance and back EMF (open circuit voltage) that typically varies during a charging cycle.

At a given time, a battery's internal resistance is determined by a series of conductive elements that make up a battery's cell structure disposed in the battery's electrolyte. At initiation of a charging cycle, or t=0 (see point 116 in FIG.1A), the initial battery voltage V_i is the open circuit voltage. At initiation of the charging cycle, the current supplied by a charger typically is at its highest value I_i (point 126) during a charging cycle.

During a typical charging process, battery voltage 101 is initially at a low value V_i, rises rapidly to an intermediate voltage from which the voltage continues to rise slowly for a period of time, after which the voltage rises rapidly again with an increasing slope where it finally levels to a final fully charged voltage V_t. As the battery is charged, the battery back EMF rises due to heat generated in the charging process and due to rising specific gravity of the electrolyte. As the battery charges, current 128 supplied by a charger decreases as the battery voltage 101 increases in step with the increasing battery impedance.

In the final stages of charging, a further increase in battery back EMF is caused by the electrolytic generation of hydrogen and oxygen gas as the electrolyte decomposes in response to the applied energy; that phenomenon is called "out gassing". Out gassing occurs as the battery nears and reaches a state of full charge, and its components can no longer accept recharging energy in a regenerative way. As the out gassing process stabilizes, the voltage across the battery's terminals remains essentially constant and approaches its final value.

In the final stages of charging, a slight increase in battery terminal voltage 101 appears due to an electrolyte stirring effect. The electrolyte stirring effect is caused by the out gassing process. The stirring effect causes the electrolyte within each of a series of cells in the battery to become substantially homogeneous, i.e., of uniform specific gravity (acid concentration), stabilizing the battery back EMF within each cell. It is often desirable to design a battery charging system that takes a battery's internal construction, and the charging process into consideration in order to provide a desirable charging process.

Battery chargers are constructed utilizing various types of circuit designs. Circuit designs of chargers include ferromagnetic and switching techniques. The various types of battery chargers are also designed to provide one or more charging processes called "profiles" or "algorithms" that are compatible with the circuit design of the charger. Profiles are also often selected to take advantage of the internal changes in the battery during charging in an attempt to extend battery life.

A charger which has a termination scheme keyed to dv/dt=0 typically provides 118% to 124% of the charge previously taken out of the battery.

Continuing with reference to FIG. 1A, the first derivative 104 and the second derivative 106 of voltage with respect to time provide additional information concerning a battery's desired charging requirements. In addition, the first and second voltage derivatives provide distinct transitions of state that are easily detected. The information provided by those first and second derivatives provides reliable criteria that are unique to an individual battery, so that the charging profile may be tailored to that particular battery. By basing a battery's charging process on selected aspects of the first 104 and second 106 derivatives of the voltage response 101 curve, a charging process may be implemented that takes into account a battery's unique and individual charging requirements to provide an amount of overcharge that is appropriate for a particular battery during a particular charging event.

In FIG. 1A, a voltage characteristic V(t) of an exemplary flooded deep cycle lead acid storage battery undergoing a charging cycle, controlled by a conventional ferroresonant charging process, is depicted by curve 101. At the end of the charging cycle, the interrelation between the voltage curve 101 and its first (dv/dt) 104 and second (d^2v/dt^2) 106 derivatives can provide a useful indication of the time that at which the battery actually is at a certain state compared to a state of full charge. That certain state for a flooded lead acid battery is the state at which the battery is at about 98% of full charge. In FIG. 1A, that state is identified by point 108 on the horizontal time base of the graph.

In the voltage curve 101, the voltage increases over time until the end of the charging cycle. Prior to the end of the charging cycle, the voltage curve begins to rise rapidly before topping out and decreasing. During the rapid increase, curve 101 has an inflection point 115 at which the voltage ceases to accelerate and begins to decelerate. In the corresponding curve 104 plotting the first derivative of V(t), a maximum value 114 of the first derivative of V(t) occurs at the same time as the occurrence of the inflection point 115 of V(t). The first derivative (dv/dt) of the voltage curve 101 does not again rise to a peak. This maximum 114 of dV/dt provides a more accurate indication of the 98% charging point 108 than does voltage inflection point 115.

The curve 104 depicting the changes in the first derivative (dv/dt), or rate of change of the voltage versus time, of a lead acid battery undergoing ferroresonant charging, is characterized by a curve 106 having two response peaks. Initially, the first derivative 104 has a high value corresponding to a swiftly changing battery voltage. Next the curve 104 of rate of change of the battery voltage decreases as the voltage curve 101 goes through a period of slight change. The small values of rate of change are followed by a second rapid increase in the rate of change that peaks at 114 and then falls off. The peak 114 corresponds to the voltage curve 101 inflection point 115, where a maximum slope is measured. The inflection point 115 in the voltage verses time curve 101 where the voltage is changing the fastest has a corresponding maximum 114 on the first derivative curve 104. After the first derivative maximum has been reached, the rate of change 104 of the voltage 101 decreases.

The second derivative (d^2v/dt^2) of the voltage versus time function of the lead acid battery undergoing ferroresonant charging is shown by curve 106. The second derivative describes the rate of change of curve 104, which in turn describes rate of voltage change. Thus, curve 106 describes how the value of voltage applied to the battery terminals accelerates and decelerates during the battery charging process. As can be seen from the second derivative curve 106, the second derivative is zero when the first derivative curve 104 reaches a point where its slope is instantaneously equal to zero, such as at the previously described maximum 114.

The point in time at which the first derivative reaches a maximum value and the second derivative has a value of zero very accurately identifies the point 108 in time when 98% of the ampere-hours previously withdrawn from the battery have been returned to it. The abrupt change of the second derivative (d^2v/dt^2) from a positive to a negative value is easier to accurately identify than the gradual change in value of the first derivative.

Point 108 on curve 106 occurs at different times (t) for different batteries because this characteristic is related to the initial state of discharge, age and temperature characteristics of an individual battery. However, point 108 corresponds to the time in the charging process where an impressed current 128 is nearly all being used to produce gas. That point is used as a signal in the practice of this invention, and the charge which has been returned to the battery at that point, measured from the beginning of the pertinent recharge event, is denominated as the as the signal charge Q_S. Knowledge of the magnitude of Q_s and of its relation to battery full charge Q_F, together with the amount of overcharge Q_o desired, enables the total deliverable (delivered) charge Q_D to be determined and enables the charging process to be controlled accordingly. If the battery is a flooded lead acid battery at 80°F, Q_s = .98 Q_F. If the battery is at some other temperature, the relation of Q_s to Q_F can be different, but if the battery temperature is not a temperature significantly below room temperature, then use of the relation Q_s = .98 Q_F has been found to be workable and to produce significant improvements.

Charge delivered to a battery can be measured in ampere-hours ("amp-hours"). One ampere-hour is the quantity of charge delivered to the battery in one hour by a one ampere current. Thus, a completely drained battery having a charge capacity specified in ampere hours will take a number of hours equal to the specified ampere-hour capacity to return the battery to a fully charged state to capacity, or a desired fraction of full charge, at a one ampere charging current.

The specified amount of overcharge Q_O beyond full charge Q_F is selected to provide an increased battery life. In an exemplary embodiment the overcharge quantity is chosen to be 108%

of the replenishment charge Q_R. That is, in FIG. 1A, X is the time when 8% more than the replenishment charge has been delivered to the battery and is the time when the recharge event for that battery is terminated.

The amount of charge usefully returned to a battery to achieve the desired conditioning may be found by the following relation:

(specified % overcharge) (ampere-hours from start of charge to 98% of full charge)
= (ampere-hours from initial charge to reach specified overcharge)(98%)).

Stated differently using the terms defined above,

$$Q_S/.98 = Q_D/(1+x) \qquad \text{(Equation 1)}$$

where x is the decimal equivalent of a percentage of the replenishment charge Q_R to be delivered to the battery as an overcharge amount. A workable and preferred value of x is .10.

Time T, point 112 in FIG. 1A, is the point in time at which the battery is fully charged, i.e., has charge level Q_F. Charge amount Q_s is found from determining the second derivative's zero crossing. Thus, the total charge Q_D to be delivered during the recharge event may be found once Q_s has been found by analysis of the dynamic aspects of the charging characteristic curves.

The amount of overcharge to be delivered to the battery to obtain the desired degree of conditioning by gaseous stirring of this liquid electrolyte preferably is in the range of from about 8% to about 12%, and most preferably is about 10%.

FIG. 1B and 1C are graphs for the charging profile of a battery at 80 degrees Fahrenheit and 122 degrees Fahrenheit, respectively; while any profile desired can be used, the peferred profile is a constant power profile. In these cases, the battery delivered 135 or 136 ampere-hours before the commencement of the respective recharge events. The points in time where 98% and other percentages of the charge deficiency has been returned to the battery are marked on each graph. A hot battery having a temperature of 122 degrees Fahrenheit reaches the .98 Q_F signal point earlier in time than when the second derivative of the charging voltage is zero valued. However, the temperature-based shift in the occurance of $d^2v/dt^2=0$ relative to 98% of full charge is slight. Use of Q_s= .98 Q_F for such a very hot battery results in far less overcharge of the battery than would otherwise occur.

FIG. 1D and 1E are graphs for the charging profile of a battery at 80 degrees Fahrenheit and 48 degrees Fahrenheit respectively. In these cases, the battery delivered 81 and 82 ampere-hours before commencement of the charging events. The points in time where Q_C=.98 Q_F and Q_C=1.09 Q_R are marked on each graph. As can be seen from those graphs, the cold battery's signal point is shifted to the right along the voltage curve. For example, a cold battery will be at less than 98% of full charge at the point in time when the second derivative of the charging voltage is zero valued. When the second voltage derivative for the cold battery is zero valued, only 82% of the full charge has been returned to the battery. In such a situation, use of the relation Q_S=.98 Q_F produces a measure of undercharge to the battery but does not meaningfully harm the battery. Over a typical industrial temperature range, the percent of charge returned to a battery at the time $d^2v/dt^2=0$ will typically vary from 84% to 102% of its total charge capacity Q_F.

A straightforward way to factor temperature into a process is to directly measure it and include it as a factor in the process. However, adding a temperature sensor which is effective to measure a battery's internal temperature is expensive and adds to a typical charging system another level of complexity that is undesirable in producing a low cost charging system that possesses an increased reliability.

FIG. 2 is a flow diagram of an exemplary charging process for a lead acid storage battery. In order to determine and utilize first and second derivative information corresponding to the 98% charge point of a battery, a process to determine the relevant information is executed. Such a process is implemented, for example, as a program set of instructions that drive a computer, microprocessor or other controlling device that comprises a battery charging system and preferably is part of the battery charger. The instructions may be stored in volatile or non-volatile memory or on a mass storage medium.

At the beginning of the process, a command 202 is initiated to start the charging process. In the next step, a timer circuit is initialized 204. In an alternative process, the timer circuit can be implemented in software, such as would be used to direct a microprocessor to time an operation, or sequence of operations. The time is recorded at step 206 so that when the desired voltage conditions are reached, an elapsed time will be known. Next, monitoring of the first derivative of the voltage and the second derivative of the voltage is initiated at step 208. The value of the second derivative is evaluated at step 210. If the second derivative is not equal to zero, the process continues to monitor the second derivative at step 208. If the second derivative is equal to zero, the process continues to the evaluation made in step 212. At step 212, the first derivative of the voltage is monitored to determine if it has reached a maximum value. If it has not, it is continued to be monitored at step 208. If dv/dt is determined to be a maximum value at step 212, process flow branches to step 214. At step 214, the measured time to reach 98% of full charge is applied and an additional charging time is computed so that a desired percent of overcharge may be added to the battery. Performance of step 214 includes use of information from the timer and information about total amperes delivered to the battery to compute Q_S, and to compute Q_D using the relations described above and program parameters defining the desired value of x (percentage overcharge) and Q_S/Q_F.

In an embodiment of the invention, the evaluations performed at steps 210 and 212 may be interchanged without affecting the outcome of the process. Additionally, determination of the maximum of the first derivative of the voltage performed in exemplary step 212 may be done continuously or by utilizing sampling methods known to those skilled in the art.

After the initial charging time, from initiation of the charging cycle until $d^2v/dt^2=0$, has been determined and the additional amount of time to provide a desired overcharge is calculated at step 214, the process (step 216) directs the battery to be charged for an additional amount of time to provide the desired overcharge. After the additional charging time has elapsed, the charging cycle is stopped at step 218.

A relation which is useful to determine when a battery recharging process according to this invention is to be terminated is as follows:

$$\frac{Q_S}{.98} = \frac{Q_D}{1+x}$$

in which Q_S and Q_D are as defined above (see Glossary), and x is the decimal equivalent of the percentage of the replenishment charge Q_R to be applied to the battery, after it is fully charged, to achieve the desired conditioning (electrolyte stirring) of the battery.

Assume that the full charge of a battery is 1000, and the desired overcharge percentage is 8%. If a battery is 50% discharged at the beginning of a recharge event, $Q_S = .98\ (1000\text{-}500) = 490$, and so $Q_D = 540$. $Q_i + Q_D = 500 + 540 = 1040$, and so the actual amount of overcharge at termination of the recharge event is 40.

Applying the same assumptions to a battery which is at 25% capacity ($Q_i = 250$) when recharging begins, $Q_S = .98\ (1000\text{-}250) = 735$, $Q_D = 810$, $Q_i + Q_D = 250 + 810 = 1060$, and so the delivered overcharge is 60. Similarly, if the battery is at 70% of capacity when recharging begins, $Q_S = .98\ (1000 - 700) = 294$, $Q_D = 324$, $Q_i + Q_D = 700 + 324 = 1024$, and so the delivered overcharge is 24.

It will be recalled that if a battery is very deeply discharged when its recharging event begins, the specific gravity of the acid electrolyte is low (near 1.00) due to the highly diluted state of the electrolyte. The more dilute the electrolyte when recharging begins, the greater will be the density stratification of the electrolyte at full charge, and so the more the electrolyte needs to be stirred by gas generation to properly condition the battery by making the electrolyte substantially homogenous through the battery cells. Conversely, if a battery is relatively lightly discharged when its recharging event begins, the acid electrolyte will have a higher starting specific gravity, a lower density stratification at full charge, and a lower need for electrolyte stirring to properly condition the battery. The foregoing examples show that this invention delivers to a recharged battery only that amount of overcharge which is determined to be needed for proper conditioning and does not excessively overcharge the battery. The amount by which the battery is overcharged is a function of the discharge state of the battery when recharging begins. The point at which the recharging process is ended is determined from information obtained from the battery itself. That is a characteristic of the battery recharge processes illustrated in Figs. 2-7.

FIGS. 3A and 3B are flow diagrams of a charging process that monitors cell voltage. Steps 302-316 can be the same as steps 202-216. However, in this process charging is not terminated unless certain minimum conditions are satisfied. In the exemplary embodiment, cell voltage is one such minimum condition. At step 318, the cell voltage is monitored. If the cell voltages have reached, say, 2.45 volts per cell, the charging algorithm is terminated at step 320. Alternatively other cell voltages may be utilized for other types of batteries.

If the cell voltage has not reached 2.45 volts per cell, the process branches to letter A in FIG. 3B. In this process, charging defaults to a state that does not terminate the charging process until the first derivative voltage equals zero. Thus, charging continues at step 322. While charging, the first derivative continues to be evaluated at step 324. If the first derivative reaches zero, the charging process is then ended at step 326. If the first derivative does not reach zero, the charging process continues until the first derivative reaches zero and the process is ended.

FIG. 4A and 4B are a flow diagram of a charging process that monitors cell voltage and charging time to produce a desired overcharge. This process is an alternative embodiment of the process of FIG. 3. The process shown in FIG. 4A is analogous to the process of FIG. 3A, and steps 402-426 can be the same as steps 302-326. However, in this process, charging is not terminated unless certain minimum conditions are satisfied. Cell voltage can be one such minimum condition. At step 418, the cell voltage is monitored.

The process shown in Figs 4A and 4B provides a further back-up of terminating the charging cycle if charging has not been accomplished in a certain number of hours, as may be deemed desirable in a particular application. In the embodiment described, 16 hours is deemed the maximum number of hours to accomplish a full charge. Alternatively, any time period suitable to prevent damage to a battery may be substituted.

Continuing with FIG. 4B, the charging process continues in step 422 while the first voltage derivative is monitored at step 424. If the first derivative reaches zero, the charging process is ended at step 426. If the first voltage derivative has not reached zero, the process branches to an evaluation step 428 that compares the elapsed charging time to a set time, in this case 16 hours. In an embodiment any suitable time period may be selected as the set time.

If the predetermined charging time has been exceeded, an alarm signal or message may be sent (step 430) visibly, audibly or otherwise to the person in charge of or overseeing the battery recharging process. The message can include information on the identity of the charger of interest, to distinguish it from other chargers which may be present, as when batteries in each of the golf cars in a fleet are being recharged at the same time. Upon activation of the alarm signal by step 430, the charging cycle is terminated at step 432. If at step 428 the predetermined time has not been exceeded, the charging cycle continues.

FIG. 5 is a flow diagram of a charging process that provides refresh charging. Steps 502-

516 can be the same as steps 402-416. The charging process can be terminated at step 518.

While the battery is still connected to the charger, the open circuit voltage of the battery is monitored at step 520. If the battery's voltage falls below a preset minimum value V_{Min}, the charging process is caused to be repeated. The voltage V_{Min} is selected to provide a desired lower threshold of voltage that the charger will not allow the battery to drop below. The charger keeps a charge on the battery to keep it above V_{Min}. However, as long as the battery remains above the low voltage threshold V_{Min}, the charging process will not be reinitiated, and the overall process is stopped at step 522. The value selected for V_{Min} is based upon an amount of acceptable remaining charge that is user selectable, or alternatively programable as a preset value in the charges operating program.

FIG. 6 is a flow diagram of a charging process that monitors an elapsed time since termination of charging of a battery, and the battery open circuit voltage. Steps 602-618 can be the same as steps 502-518. In this charging process which monitors an elapsed time since termination of charging of a battery, and the battery open circuit voltage, the time elapsed since termination of the charging process is monitored at step 622. If a predetermined amount of time has elapsed since the charging process was terminated and the battery continues to be connected to the charger equipment, then the charging process is reinitiated. If the elapsed time has not exceeded the predetermined amount of time the process proceeds to step 624. If the open circuit voltage is less than its predetermined value V_{Min} then charging is reinitiated. If the battery open circuit voltage remains above V_{Min} then the process is terminated at step 626.

In an alternative process, the open circuit voltage can be monitored prior to evaluating time since termination of the charging process. In a further alternative process, time since termination of the charging process can be monitored simultaneously with monitoring of the battery open circuit voltage.

FIG. 7 is a flow diagram of a form of the invention that allows the selection of various charging profiles. At step 702 the charging process is initiated. Next, a charging profile is selected 704. Possible charging profiles comprise: constant potential; modified constant potential; constant current; ferro and ferro resonant; constant current-constant potential-constant current (IEI); constant power-constant potential-constant current (PEI); and, preferably, constant power. Information describing and defining the different profiles can be contained in an addressable memory included in the charger in association with the control aspects of the charger.

Once a charging profile has been selected, a timer circuit is initialized and the process is at step 706 started utilizing the selected profile. Next, the process begins recording an elapsed time at step 708. The process monitors the first and second derivatives of the voltage at step 710. If the second derivative is equal to zero (step 712) and the first derivative has reached a maximum (step 714), the charging process continues. If the second derivative has not reached zero and the first derivative has not reached the maximum, their values are continuously monitored until they reach the desired values.

Once the desired derivative values have been reached, an additional charging time for a desired overcharge is calculated at step 716, and the battery is charged for an additional charging time for the desired overcharge (step 718). The additional charging time may utilize the previously selected charging profile or another charging profile. Once the additional charging time for the desired overcharge has elapsed, the process is terminated at step 720.

FIG. 8 is a block diagram of an exemplary battery charging system utilizing a charge control algorithm device IC and a "measuring computing and control device" (MCCD) such as a suitably programmed microprocessor. An AC input 802 to rectifier 804 creates a charging current, at a desired voltage, that is applied to battery 810 through a charge process control device integrated circuit 808. The charge process control device integrated circuit 808 controls application of the charging energy to the battery 810.

The charge control device IC 808 functions in conjunction with the MCCD to apply a charging signal comprising one or more charging profiles or processes. Instructions to implement one or more of the processes described in FIGS. 2 through 7 can be stored in the MCCD 806. Typically storage is achieved by loading a set of program instructions describing the process into the MCCD. Alternatively, the process may be integrated into a custom charge process control integrated circuit which may include the features and functions of integrated circuit 808.

FIG. 9 is a block diagram of a battery charging system capable of implementing one or more of the invention's charging processes to charge a battery. An AC input 902 is controlled by relay 912. The AC power is applied to rectifier 904 to produce a DC voltage having a ripple component. Voltage regulator 906 reduces the variations in the DC voltage. The regulated DC voltage is applied to a conventionally constructed series pass element 908 that works in conjunction with a conventionally constructed current limiting device 910 to supply a desired current and voltage through the contacts of a relay 914 to battery 916. Current applied to the battery is monitored by a conventional ampere meter 918. The ampere meter monitors the instantaneous value of current flowing in a conductor. In an alternative arrangement, a conventional averaging ampere meter can be used to indicate an average charge passing through the conductor. In a further alternative arrangement a conventional totalizing ampere meter can be used to provide an indication of the total charge passing through the conductor. Voltage across the battery terminals is monitored by volt meter 920. Information obtained from the ampere meter and the volt meter can be supplied to MCCD 806.

The voltage across the battery 916 is also supplied to a differentiator circuit 922 that computes the first derivative of the voltage. Such a circuit may be conventionally constructed as shown at 930. A differentiator typically comprises an operational amplifier A, a resistor R and a capacitor C, connected as known by those skilled into the art to produce a differentiator. A voltage V_i is applied to the input of the differentiator. The signal output V_o is equal to -RC(dV/dt).

The output of the first derivative circuit 922 is fed into a peak detector 928. When a maximum first derivative signal is detected, an indication is provided to MCCD 806. The output of the first derivative processing circuit is also fed to a second derivative processing circuit 924. This circuit is simply a replica of the circuit in 922. The output of the second derivative circuit 924 is fed to a zero crossing detector 926. A zero crossing detector is a circuit that detects a transition in signal polarity, such as when a voltage goes from positive to negative and by necessity crosses through a value of zero volts. Detection of a zero crossing corresponding to the detection of inflection point 115 in voltage curve 101 of FIG.1 is sought. An indication of the detection of a zero crossing is provided to the MCCD 806. Under control of the process comprising an embodiment of the invention, the MCCD directs a charging current and voltage to be applied through relay 914. The MCCD also can control the operation of the AC input through relay 912.

It is preferred that the components of the charging system depicted in Fig. 9 be housed in a common charger housing. The charger can be, usually is, separate from the battery or thing (e.g., golf car) in which the battery is located. However, if desired, some or all of the components of the charging system can be physically associated with the battery as elements of, e.g., a golf car.

It will be seen that this invention provides equipment and procedures for charging a flooded lead acid battery of the deep cycle type in ways which charge the battery effectively yet without overly charging the battery to extents which reduce battery life. The battery is overcharged by an amount which is a selected percentage of the charging energy required to place the battery in a state of full charge following completion of its last preceding duty cycle. A recharging event achieved in the practice of this invention inherently allows for and takes into consideration factors such as the battery, age and internal characteristics which impact charging effectiveness and efficiency.

While the invention has been described above with reference to recharging a battery, it will be understood that the invention also applies to the recharging of a set of batteries which may be encountered in an electric golf car or some other electrically powered vehicle or device, or with a set of batteries used in connection with a photovoltaic electrical power system, for example.

The foregoing description of preferred and other embodiments and forms of the invention has been presented by way of example, not as a catalog of all forms which equipment or procedures in which the invention can be manifested or used to advantage. Workers skilled in the art to which the invention pertains will understand that variations and modifications of the described equipment and processes can be used beneficially without departing from the scope of the invention.

CLAIMS

1. A method for charging deep cycle lead acid batteries comprising:

applying charging energy to such a battery;

identifying a 98% charge point in the charging process;

monitoring the charge provided in amp hours;

determining the remaining charging energy to be applied to overcharge the battery to substantially 110% of full charge;

applying the remaining charging energy to the battery.

2. The method of claim 1 for charging a deep cycle lead acid battery wherein the step of determining the 98% charge point comprises:

determining when the rate of change of an applied charging voltage verses time (dv/dt) is a maximum; and

determining when the acceleration of the voltage with respect to time (d^2v/dt^2) is zero.

3. The method of claim 1 for charging a deep cycle lead acid battery wherein the step of determining the remaining charging energy comprises:

dividing the product of .98 and the charging energy applied to charge the battery to 98% of its charge capacity by a decimal equivalent of the percent of overcharge desired.

4. The method of claim 1 for charging a deep cycle lead acid battery wherein the step of determining the remaining charging energy further comprises:

monitoring a battery cell charge voltage prior to termination of the calculated overcharge desired;

extending the charging period until the rate of change of the charging voltage verses time (dV/dt) is zero.

5. The method of claim 4 for charging a deep cycle lead acid battery wherein the step of extending the charging period further comprises terminating the charging once a predetermined time has been exceeded.

6. The method of claim 5 for charging a deep cycle lead acid battery wherein the predetermined time is about 16 hours.

7. The method of claim 1 for charging a deep cycle lead acid battery further comprising the steps of

monitoring the open circuit battery voltage;

initiating charging if the open circuit voltage falls below a desired level.

8. The method of claim 1 for charging a deep cycle lead acid battery further comprising the step of initiating charging after a predetermined time since the last charging sequence.

9. A method for charging flooded deep cycle lead acid batteries comprising the steps of applying charging energy to such a battery according to a selected charging profile; identifying the point in the process at which the battery state has a known relation to a state of full charge of the battery and determining a first amount of charging energy delivered to the battery from the inception of the process to that point; determining a second amount of further charging energy, adequate when applied to the battery to cause the battery to be overcharged by a selected amount related to the first amount; and applying the second amount of charging energy to the battery.

10. A method for charging flooded deep cycle lead acid batteries comprising the steps of:

applying charging energy to the battery;

monitoring the charging energy as to quantity delivered to the battery and its dv/dt and d^2v/dt^2 aspects, by use of information about the amount of charging energy delivered to the battery at a point in the process when dv/dt is a maximum and $d^2v/dt^2=0$, determining and delivering to the battery beyond that point a defined quantity of charging energy additive to said amount adequate to overcharge the battery to a predetermined extent related to said amount.

11. A method for charging flooded deep cycle lead acid batteries comprising the steps of:

applying to such a battery an amount of charging energy equal to the initial charge deficiency of the battery, and

applying to the battery a further increment of charging energy adequate to overcharge the battery to an extent predetermined as a selected percentage of the charge deficiency.

12. A battery charging apparatus for charging deep cycle lead acid batteries comprising:

a DC current source

a voltmeter;

an ammeter;
a timer;
a dv/dt measurement circuit; and
a d^2v/dt^2 measurement circuit

13. Apparatus according to claim 1 including a controller coupled to the DC current source, the ammeter, the timer, and the dv/dt and d^2v/dt^2 measurement circuit, the controller being configured for determining the point in a battery recharge event when a battery is at substantially a defined percentage of full charge, and for determining the value of Q_D from the relation $Q_S/p = Q_d/(1+x)$in which Q_S is the ampere-hours of charging energy delivered to the battery in the interval from the beginning of the recharge event to the point at which the battery has substantially the defined percentage of full charge, p is the decimal equivalent of the defined percentage, x is the decimal equivalent of a desired percentage amount of replenishment charge to be delivered to the battery as an overcharge amount, and Q_D is the ampere-hours to be delivered to the battery from the beginning of the recharge event to reach the overcharge amount.

14. Apparatus according to claim 2 in which the value of p is substantially .98.

15. Apparatus according to claim 2 in which x is in the range of from about .08 to about 12.

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(54) Title: SYSTEM AND METHOD FOR BATTERY CHARGING

(57) Abstract: A method for charging a lead acid storage battery to advantageously extend its life is described. The termination of a charging process is based upon an evaluation of the first derivative (dv/dt) and second derivative (d2v/dt2) of the applied charging voltage. By utilizing the first derivative (dv/dt) and second derivative (d2v/dt2) as charging criteria, an amount of overcharge is applied to the battery that takes into account the precise amount of amp-hours previously removed from the battery. A charger arrangement for performing a charging process of the invention also is described.

SYSTEM AND METHOD FOR BATTERY CHARGING

FIELD OF THE INVENTION

This invention pertains to a method for controlling the termination of a recharging process for flooded deep-cycle lead acid electric storage batteries. More particularly, it pertains to procedures which supply to such batteries a quantity of recharge energy which is directly related to the amount of energy discharged following the last preceding battery charge event. It also pertains to equipment for implementing such procedures.

BACKGROUND OF THE INVENTION

Rechargeable electric storage batteries of many different kinds are known, such as nickel-cadmium, nickel metal hydride, nickel-iron, lithium, silver-cadmium and deep-cycle lead acid batteries. Deep-cycle lead acid batteries differ from SLI (starting, lighting, ignition) lead acid batteries used, e.g., in conventional automobiles; SLI batteries are not designed or constructed to withstand repeated cycles of substantial discharge and recharge, and so are not rechargeable batteries in the sense of this invention.

It is known, such as from U.S. Patents 4,392,101 and 4,503,378, that there are certain characteristics of a rechargeable battery, regardless of kind, which change during recharging of the battery in ways which signal either that the battery is fully charged or that it is at a relatively predictable point short of but near a state of full charge. Those patents, as well as other publications, describe equipment and techniques for monitoring those characteristics and for detecting certain events, conditions or states of them, and using such detections either to terminate the battery charging process or to continue charging for preset times or in preset ways. Those preset ways typically use charging processes different from those in use at the time of the detected event. Those charging event detection techniques are known as inflection analysis methods because they rely on the detection of certain inflection points in time-based curves which describe the change in battery voltage or battery current, e.g., during the charging process. While inflection analysis as described to date works well to control recharging of most kinds of rechargeable batteries, inflection analysis as heretofore described has been found not to serve satisfactorily for controlling recharging of flooded deep-cycle lead acid batteries in which the battery electrolyte is a liquid (typically sulfuric acid) unconfined in any supporting matrix such as a gel.

Flooded deep-cycle lead acid batteries are widely used as energy sources for electrically powered vehicles such as golf cars, fork lift trucks, and scissor lift vehicles. They also are used in uninterruptible power supplies in hospitals and other buildings and facilities, and as components of photovoltaic power installations. The reasons why inflection analysis techniques as heretofore described are not satisfactory for controlling recharging of flooded deep-cycle lead acid batteries can be understood from the use of such batteries in electric golf cars, as an example.

Electric golf cars are powered by sets of 4, 6 or so flooded deep-cycle lead acid electric batteries. At a given golf course, there is a fleet of such golf cars available for use by golfers. Different cars in the fleet may have older batteries in them than other cars in the fleet. Certain cars may be used more frequently than others. Some cars may be used longer on a given day than others. Some cars may be subjected to more strenuous usage conditions on a given day than others, depending on the circumstances of the using golfers or differences in traversed terrain, among other reasons. Also, it is well known that even if all batteries in the fleet are from the same manufacturer and are of the same nominal age, there still will be meaningful variations between batteries of kinds which can affect battery performance, life and, importantly, how they respond to recharging processes. As a consequence, at the end of a day when the golf cars in that fleet are to be recharged, there can be significant differences between the discharge states of the batteries from car to car, and consequent meaningful differences from car to car in how the batteries need to be charged. Fleet- wide uniform recharging procedures either will cause some batteries to be insufficiently recharged or, more likely, substantial numbers of the batteries will be materially overcharged. Material overcharge of such a battery reduces battery life. Very commonly, the persons employed to recharge fleets of golf cars have no understanding of the effects of substantial overcharge and how to determine when it is occurring. Therefore, it is desirable that the batteries used in electric golf cars be recharged by equipment and processes which avoid substantial overcharge and do so in ways which inherently accommodate and deal with differences between batteries due to discharge state, age, and manufacturing variations, among other factors.

Deep-cycle lead acid batteries are designed to withstand repeated cycles of substantial discharge from a fully charged state and of recharge from a discharged state to a state of full charge. As compared to other kinds of rechargeable batteries which do not use liquid electrolytes, the liquid acid electrolyte of flooded deep-cycle lead acid batteries presents special conditions which require that a given battery, or a given set of a small number of batteries repeatedly used in combination with each other, be recharged in a way which provides a controlled overcharge related in extent to the state of the battery at the time a recharge event is commenced. Stated differently, effective recharge of a flooded deep-cycle lead acid battery ideally should include a controlled overcharge determined by the amount of energy removed from (discharged by) the battery during its last preceding duty cycle (period of use following the last prior charging event). The reason is related to what happens to the liquid electrolyte during the prior duty cycle and the following recharge event.

As a cell of a lead acid battery discharges, the acid ions in the electrolyte move to the cell electrodes and oxygen atoms move from the active material of the cell into the electrolyte to form water with the electrolyte hydrogen ions. As a consequence, the electrolyte acid becomes progressively more diluted and its specific gravity progressively approaches 1.0 from a higher starting specific gravity. As the cell is recharged, that ion exchange process is reversed to produce regeneration of the electrolyte acid and the active material. If the electrolyte is present in the cell as a free liquid (i.e., the cell is flooded), as opposed to being present in a gel matrix, the regenerated acid, being heavier than the dilute electrolyte, sinks to the bottom of the cell as it is created. As the recharging process continues, more and more concentrated regenerated acid collects in the bottom of the cell. At the point at which the cell active material has been fully regenerated, the cell is theoretically fully recharged on a Coulombic basis. However, the cell is not in good condition for use to deliver stored electrical energy because of the stratification of the electrolyte. The electrolyte is not of uniform acidity throughout the cell and so the regenerated acid electrolyte is not in uniformly effective contact with the regenerated active material over the full area of the regenerated active material; if the cell were to be called upon to discharge at that point, the discharging electrochemical process will occur predominantly in the lower part of the cell where the electrolyte acid is overly concentrated. The cell will not discharge energy at the levels desired, and the over concentrated acid in the bottom of the cell will cause overly rapid degradation of the adjacent active material. The consequence is under performance of the cell in a manner which materially reduces cell life.

In the portion of the recharge process for a lead acid battery cell which immediately precedes full regenerative restoration of the active material, gas is generated in the cell as a normal part of the recharge process. The gas bubbles rise through the electrolyte to the top of the cell and, in the process, induce circulation (stirring) of the electrolyte in the cell. However, if the recharge process is terminated at the point of full regeneration of the active material, the amount of gas generation which will have occurred will be insufficient to stir the electrolyte adequately to cause it to be of uniform acid concentration (uniform specific gravity) throughout the cell. For that reason, it is common practice to continue the process of recharging a flooded deep-cycle lead acid battery beyond the point of full recharge, i.e., to extend the gas generation process for a time to achieve adequate stirring of the regenerated electrolyte. That is, the cell is intentionally overcharged.

Current practice is to overcharge such batteries, which include a number of cells, by a predetermined amount which is defined to be adequate to fully stir the electrolyte in the cell or cells which need the most stirring; that definition of the predetermined amount of overcharge is based on the assumption that the cell has been maximally discharged in its previous duty cycle and that the cell has certain properties of age, condition and temperature. However, as shown above in the discussion of the operation of a fleet of electric golf cars, that assumption is not apt for a substantial portion of batteries requiring recharge. As a result, reliance upon that assumption about the amount of overcharge to be applied in the terminal stages of recharging flooded deep-cycle lead acid storage batteries causes a substantial number, if not the majority, of such batteries to be meaningfully overcharged. Meaningful overcharge of such a battery, especially if repeated more than a few times, substantially reduces the effective life of such a battery.

The foregoing description provides a foundation for understanding how existing descriptions of inflection analysis techniques for controlling battery recharge processes are deficient when applied to the recharging of flooded deep-cycle lead acid storage batteries.

U.S. Patent 4,392,101 is an early description of the use of inflection analysis in controlling recharging of rechargeable batteries. It teaches that rechargeable batteries in general have broadly similar response characteristics to recharging processes. It teaches that if battery voltage or current, e.g., is plotted graphically against time during recharge, the resulting voltage/time or current/time curves will have broad similarities. After initiation of the charge process, irrespective of the particular materials used to define a battery cell, those curves will manifest at least a pair of inflection points in which the graph line reverses curvature, i.e., is inflected. It is disclosed that those inflection points signal or denote different phases of the battery's response to applied charging energy and, for each type of cell, those inflections occur at relatively predictable times in the process, either before or at the time of the battery reaching a state of full charge. It is disclosed that the predictability of the inflection point occurrences is generally unaffected by (happens without regard to) factors such as the actual voltage of the battery, individual cell characteristics, individual charging history, or actual ambient temperature conditions. That patent discloses that the inflection points can be identified by observing the state or character of the first or second derivative with respect to time of the battery characteristic (voltage or current) being monitored. More particularly, it teaches that a graph of the second derivative will cross the zero axis (the sign of the derivative will change from positive to negative, or vice versa)at least twice during the charging process, and the second zero axis crossing of that derivative either will occur at the time the battery reaches full charge or will occur at some interval shortly before full charge is achieved. However, in the instance of lead acid batteries, that patent does not attempt to describe when the second time-based derivative of voltage occurs relative to full charge. The principal descriptions of that patent are in the context of nickel-cadmium batteries where recharging is terminated a preset time after that second zero-axis crossing of that derivative has been detected. Nickel-cadmium batteries do not use a variable density electrolyte which is present as a part of the chemical process and so such batteries do not benefit from or require any measure of overcharge.

U.S. Patent 4,503,378 applies inflection analysis recharging controls to nickel-zinc batteries and discloses that, for that type of battery, recharging is to be terminated upon the occurrence of the second instance of sign change (zero axis crossing) of the second derivative of battery voltage with respect to time. It also observes that, at the same time as the second derivative crosses the zero axis from positive to negative, the value of the first derivative of battery voltage with respect to time is at a maximum or peak value, a fact which enables the second derivative's zero crossing to be confirmed.

The article titled "Charge batteries safely in 15 minutes by detecting voltage inflection points" appeared in the September 1,1994,issue of EDN Magazine. That article focuses principally upon fast recharging of nickel-cadmium batteries. It comments that inflection analysis also applies to lead acid batteries. In that connection, it states "In lead-acid batteries, the second dV/dt inflection occurs at a predictable interval before the batteries reach full charge, but from the battery's Ahr capacity rating, you can easily derive the duration of the incremental charging needed to achieve full charge." That statement does not contribute, for at least two reasons, to a solution to the problem of how to efficiently, reliably and effectively charge a flooded deep-cycle lead acid battery, without meaningfully overcharging it, in terms of the battery's true need for recharge. First, a lead acid battery's Ahr (ampere-hour) capacity rating is not a precise value which can be determined accurately from engineering information. Rather, it is a value which a battery manufacturer assigns to a model or type of battery as a result of business factors peculiar to the manufacturer, such as marketing objectives, warranty policies, and other factors. A battery's ampere-hour capacity rating is merely a manufacturer's statement of the expectable performance, perhaps under unspecified conditions, of an average battery of that kind or type. It has no reliable relation to the charging needs of a particular battery after completion of a particular duty cycle, i.e., its depth of discharge before experiencing a recharging event. Second, the ampere-hour capacity rating is a value which needs to be known from a source other than the battery itself. What is needed is a way to charge a flooded deep-cycle lead acid battery using information, derived from the battery itself, which describes the battery's discharge state and which is usable to overcharge the battery only enough to stir the regenerated electrolyte adequately.

Neither of the patents cited above nor the EDN Magazine article consider the state of battery discharge before a recharging process is commenced. They impart no knowledge about how information about that discharge state can be used to control recharge of that battery. However, apart from those descriptions it is known to physically attach to a battery, such as a battery in a golf car, an integrating ampere meter (ampere hour meter) which travels with the battery at all times. When the battery is connected to a charger following the battery duty cycle, the "on board" ampere hour meter is connected to the charger so it can communicate to the charger the value of ampere hours removed from the battery during that last duty cycle. That information is applied in the charger to a computing and control device which computes the total charge to be delivered to the battery by multiplying the metered value of ampere hours by the desired factor (for example 1.10 or 110%)that has been found to produce sufficient stirring in the electrolyte. A computing and control device in the charger then monitors the ampere hours returned to the battery by the charger. When the calculated value for the charge return is reached, that computing and control device instructs the charger to terminate the charging process. While this approach is effective, it suffers from the added complexity of communicating data to the charger from the ampere hour meter which is associated with the battery. That approach also suffers from the added expense of equipping every battery, or every operational set of batteries, with its own captive ampere hour meter which must be specially constructed to survive in the environment of the battery. That approach is independent of inflection analysis and has apparent practical problems in the field.

It is apparent, therefore, that a need exists for the availability of equipment and procedures which can be used effectively, efficiently and reliably by persons having little or no knowledge of battery technology to adequately recharge flooded deep-cycle lead acid batteries without meaningfully overcharging any one or small group of batteries. Such equipment and procedures, to satisfy that need, should effectively address and conform to the actual recharge and electrolyte stirring needs of a battery or of a defined small group of batteries. The term "defined small group" means a number of batteries, such as those installed in a given electric golf car, which most probably will be of the same age, will have experienced the same usage history, and will have shared the same duty cycle in the interval between last being recharged as a group and the recharge event of interest.

SUMMARY OF THE INVENTION

In light of the foregoing, this invention addresses problem situations not heretofore resolved in the art to provide procedures and equipment by which flooded deep-cycle lead acid batteries, individually or in defined small groups, are rechargeable in terms of actual recharge requirements and minimal overcharge processes. The invention applies inflection analysis principles in new ways to customize each battery charging event to the needs of the battery, or battery set, presented to the charger which includes a novel computing and control device. These benefits and advantages are provided and achieved effectively and reliably without calling for any change in how the battery is made or used. Service personnel are required only to connect and to disconnect the charger to and from the battery.

Information about recharge requirements is obtained by the charger from the battery itself in the course of the charging process, without reliance upon an ampere hour meter matched to the battery. That is, the charger does not know, and does not need to know, the discharge state of the battery before the recharging process is commenced. The invention is maximally protective of the batteries themselves and can lead to extended battery life.

In terms of procedure, the invention provides a method for charging lead acid batteries. The method includes monitoring the battery voltage during the performance of the process, recording the charging time, and monitoring the charge provided to the battery in ampere hours. The method also includes determining a point in the charging process at which the battery has a charge state having a known relation to a full charge state, and determining the quantity of charging energy deliverable to the battery beyond a point of full charge which is equal to a desired portion of the energy deliverable between commencement of the process and the point at which the battery is fully charged.

In terms of its structural aspects, the invention provides a charger for charging lead acid batteries, preferably deep cycle lead acid batteries. The charger includes a DC current source, a voltmeter, an ammeter, a timer, a dv/dt measurement circuit, and a d^2v/dt^2 measurement circuit.

More specifically, the charger also includes a controller coupled to the DC current source, the ammeter, the voltmeter, the timer and the dv/dt and d^2v/dt^2 measurement circuits. The controller is configured to determine the time in a battery recharge event when a battery is at substantially a predetermined percentage of full charge and to determine the value of Q_D from the relation $(Q_s/p) = [Q_D/(1+x)]$ in which Q_s is the ampere-hours of charging energy delivered to the battery in the interval from the beginning of the event to the time at which $d^2v/dt^2 = 0$ and dv/dt is maximum, p is the decimal equivalent of the percentage of replenishment charge delivered to the battery when $d2_v/dt^2 = 0$, x is the decimal equivalent of a desired percentage amount of replenishment charge to be delivered to the battery as an overcharge amount, and Q_D is the ampere hours to be delivered to the battery from the beginning of the event to reach the overcharge amount. If the predetermined percentage of full charge is 98%, then p = .98.

DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be better understood from the following detailed description read in light of the accompanying drawings, wherein:

FIG. 1A is a graph of aspects of voltage and current at the terminals of a lead acid storage battery being charged with a conventional ferroresonant charger, graphed over time during a typical charging cycle;

FIG. 1B and 1C are graphs for the charging profile of similar batteries at 80 degrees Fahrenheit and 122 degrees Fahrenheit respectively following a duty cycle discharge of about 135 ampere-hours;

FIG. 1D and 1E are graphs for the charging profile of similar batteries at 80 degrees

Fahrenheit and 48 degrees Fahrenheit respectively following a duty cycle discharge of about 81 ampere hours;

FIG. 2 is a flow diagram of an embodiment of a charging process for a flooded deep cycle lead acid storage battery;

FIGS. 3A and 3B are flow diagrams of an embodiment of a charging process that monitors cell voltage;

FIG. 4A and 4B are a flow diagram of an embodiment of a charging process that monitors cell voltage and charging time;

FIG. 5 is a flow diagram of an embodiment of a charging process that provides refresh charging;

FIG. 6 is a flow diagram of an embodiment of a charging process that monitors time since the termination of charging and battery open circuit voltage;

FIG. 7 is a flow diagram of an embodiment of the invention that allows selection of different charging profiles;

FIG. 8 is a system block diagram of an embodiment of a battery charging system utilizing a charge process control device IC and a measuring computing and control device ("MCCD"); and

FIG. 9 is a block diagram of an embodiment of a battery charger utilizing an embodiment of the invention's process to charge a battery.

Glossary

Full charge Q_F: the state of a battery at which it is at full charge capacity and continued application of charging energy has no beneficial effect upon the electrodes or upon electrode active materials;

Initial state of charge Q_i: the amount of residual charge possessed by a battery at the commencement of a battery recharge event or process;

Replenishment charge Q_R: the amount of charging energy, measured in ampere-hours, absorbed by the battery having an initial state of charge to return the battery to a state of full charge; $Q_R = Q_F - Q_i$

Charge deficiency: the difference between a battery's full charge and initial state of charge; it is equal to the replenishment charge Q_R

Overcharge Q_o: the amount of charging energy, measured in ampere-hours, delivered to a battery in the course of a recharge event or process after the time the battery achieves full charge until the termination of the event or process; it is extra energy delivered to the battery to condition the battery for good performance during its next duty cycle; in the practice of this invention, its magnitude is directly related to the magnitude of the replenishment charge;

Duty cycle: the period after a battery has been fully recharged during which the battery delivers energy during use of the thing in which the battery is located or to which it is connected; the battery charge at the end of a duty cycle is the battery's initial state of charge in the following battery recharge event or process;

Coulombic charge Q_C: the amount of charge possessed by a battery at any time of interest;

Delivered charge Q_D: the ampere hours of energy delivered to a battery during the interval between commencement and termination of a battery recharge event or process; in the practice of this invention it is the combination of the replenishment and overcharge ampere hours, i.e., $Q_D = Q_R + Q_O$;

Signal charge Q_S: the amount of charge, measured in ampere hours, delivered to a battery during the interval beginning with the commencement of the recharging process and ending at that later point in the process at which the battery, due to its particular electrochemistry, has a detectable condition indicative that the battery charge level has a definite relation to full charge; in the context of this invention which pertains to lead acid battery electrochemistry, the detectable condition is a zero value of the second time-based derivative of battery voltage coexisting with a maximum value of the first time-based derivative of battery voltage.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1A is a graph of aspects of the voltage and the current at the terminals of a lead acid storage battery being charged with a conventional ferroresonant charger graphed over time during a typical charging cycle; the graphed aspects are voltage, current, and the first and second derivatives of the voltage with respect to time. Such a charging characteristic is typically observed when charging a lead acid battery with a ferroresonant battery charger. A ferroresonant charger typically includes a transformer and rectifier circuit that contributes to the distinctive shapes of the curves describing the way the current 128 and voltage 101 vary during a battery charging event. In implementing a charging cycle the duration of the charging cycle and the rate at which recharging energy is applied to the battery determines the amount of charge returned to the battery. To fully charge a flooded lead acid battery, a typical method utilized is to continue to charge, i.e., to overcharge, the battery after it has reached a state where charging current flowing into the battery has decreased significantly.

Controlling overcharge of a lead acid storage battery to a fixed percentage of ampere hours removed from the battery during an immediately previous duty cycle typically tends to greatly increase a battery's lifetime. Overcharge parameters are typically selected based upon varying criteria known to those skilled in the art. A battery thus charged to a fixed percentage of ampere hours removed in the prior duty cycle typically may have a longer useful life than a comparable battery which receives, each time it is recharged, an amount of overcharge defined as a fixed percentage of the total charge capacity of the battery. Thus, knowledge and use of the initial battery discharge state when recharging begins aids in determination of the amount of overcharge best delivered to the battery.

A voltage response 101 during charging of a lead acid storage battery is shown as a function of time in FIG. 1A. The voltage measured is that present across the battery's terminals at various times during the charging cycle. A particular voltage response 101 for each charging cycle of a battery, in response to a given value of an impressed charging current 128, changes as a function of the battery's temperature and internal conditions, which normally are a function of a battery's age. Neither the temperature nor the age of a battery are known by a typical charging device. Thus, the basis for judging the charge deficiency of a battery connected to a charger may not be reliably based on an absolute value of voltage.

A determination of the ampere hours of battery charge deficiency is more reliably based upon inherent voltage-time characteristics of flooded lead acid storage batteries. The inherent voltage-time characteristics preferably utilized (see FIG. 1A) are voltage as a function of time V(t) (curve 101), the rate of change of voltage over time dv/dt (curve 104), and the acceleration of the voltage over time d^2v/dt^2 (curve 106).

A battery's voltage V(t), as measured across its external terminals, varies during a charging cycle in response to an impressed charging current I(t) (curve 128 in FIG. 1A). A voltage across the terminals of a battery being charged and a charging current into the battery are related by a battery's internal resistance and back EMF (open circuit voltage) that typically varies during a charging cycle.

At a given time, a battery's internal resistance is determined by a series of conductive elements that make up a battery's cell structure disposed in the battery's electrolyte. At initiation of a charging cycle, or t=0 (see point 116 in FIG.1A), the initial battery voltage V_i is the open circuit voltage. At initiation of the charging cycle, the current supplied by a charger typically is at its highest value I_i (point 126) during a charging cycle.

During a typical charging process, battery voltage 101 is initially at a low value V_i, rises rapidly to an intermediate voltage from which the voltage continues to rise slowly for a period of time, after which the voltage rises rapidly again with an increasing slope where it finally levels to a final fully charged voltage V_t. As the battery is charged, the battery back EMF rises due to heat generated in the charging process and due to rising specific gravity of the electrolyte. As the battery charges, current 128 supplied by a charger decreases as the battery voltage 101 increases in step with the increasing battery impedance.

In the final stages of charging, a further increase in battery back EMF is caused by the electrolytic generation of hydrogen and oxygen gas as the electrolyte decomposes in response to the applied energy; that phenomenon is called "out gassing". Out gassing occurs as the battery nears and reaches a state of full charge, and its components can no longer accept recharging energy in a regenerative way. As the out gassing process stabilizes, the voltage across the battery's terminals remains essentially constant and approaches its final value.

In the final stages of charging, a slight increase in battery terminal voltage 101 appears due to an electrolyte stirring effect. The electrolyte stirring effect is caused by the out gassing process. The stirring effect causes the electrolyte within each of a series of cells in the battery to become substantially homogeneous, i.e., of uniform specific gravity (acid concentration), stabilizing the battery back EMF within each cell. It is often desirable to design a battery charging system that takes a battery's internal construction, and the charging process into consideration in order to provide a desirable charging process.

Battery chargers are constructed utilizing various types of circuit designs. Circuit designs of chargers include ferromagnetic and switching techniques. The various types of battery chargers are also designed to provide one or more charging processes called "profiles" or "algorithms" that are compatible with the circuit design of the charger. Profiles are also often selected to take advantage of the internal changes in the battery during charging in an attempt to extend battery life.

A charger which has a termination scheme keyed to dv/dt=0 typically provides 118% to 124% of the charge previously taken out of the battery.

Continuing with reference to FIG. 1A, the first derivative 104 and the second derivative 106 of voltage with respect to time provide additional information concerning a battery's desired charging requirements. In addition, the first and second voltage derivatives provide distinct transitions of state that are easily detected. The information provided by those first and second derivatives provides reliable criteria that are unique to an individual battery, so that the charging profile may be tailored to that particular battery. By basing a battery's charging process on selected aspects of the first 104 and second 106 derivatives of the voltage response 101 curve, a charging process may be implemented that takes into account a battery's unique and individual charging requirements to provide an amount of overcharge that is appropriate for a particular battery during a particular charging event.

In FIG. 1A, a voltage characteristic V(t) of an exemplary flooded deep cycle lead acid storage battery undergoing a charging cycle, controlled by a conventional ferroresonant charging process, is depicted by curve 101. At the end of the charging cycle, the interrelation between the voltage curve 101 and its first (dv/dt) 104 and second (d^2v/dt^2) 106 derivatives can provide a useful indication of the time that at which the battery actually is at a certain state compared to a state of full charge. That certain state for a flooded lead acid battery is the state at which the battery is at about 98% of full charge. In FIG. 1A, that state is identified by point 108 on the horizontal time base of the graph.

In the voltage curve 101, the voltage increases over time until the end of the charging cycle. Prior to the end of the charging cycle, the voltage curve begins to rise rapidly before topping out and decreasing. During the rapid increase, curve 101 has an inflection point 115 at which the voltage ceases to accelerate and begins to decelerate. In the corresponding curve 104 plotting the first derivative of V(t), a maximum value 114 of the first derivative of V(t) occurs at the same time as the occurrence of the inflection point 115 of V(t). The first derivative (dv/dt) of the voltage curve 101 does not again rise to a peak. This maximum 114 of dV/dt provides a more accurate indication of the 98% charging point 108 than does voltage inflection point 115.

The curve 104 depicting the changes in the first derivative (dv/dt), or rate of change of the voltage versus time, of a lead acid battery undergoing ferroresonant charging, is characterized by a curve 106 having two response peaks. Initially, the first derivative 104 has a high value corresponding to a swiftly changing battery voltage. Next the curve 104 of rate of change of the battery voltage decreases as the voltage curve 101 goes through a period of slight change. The small values of rate of change are followed by a second rapid increase in the rate of change that peaks at 114 and then falls off. The peak 114 corresponds to the voltage curve 101 inflection point 115, where a maximum slope is measured. The inflection point 115 in the voltage verses time curve 101 where the voltage is changing the fastest has a corresponding maximum 114 on the first derivative curve 104. After the first derivative maximum has been reached, the rate of change 104 of the voltage 101 decreases.

The second derivative (d^2v/dt^2) of the voltage versus time function of the lead acid battery undergoing ferroresonant charging is shown by curve 106. The second derivative describes the rate of change of curve 104, which in turn describes rate of voltage change. Thus, curve 106 describes how the value of voltage applied to the battery terminals accelerates and decelerates during the battery charging process. As can be seen from the second derivative curve 106, the second derivative is zero when the first derivative curve 104 reaches a point where its slope is instantaneously equal to zero, such as at the previously described maximum 114.

The point in time at which the first derivative reaches a maximum value and the second derivative has a value of zero very accurately identifies the point 108 in time when 98% of the ampere-hours previously withdrawn from the battery have been returned to it. The abrupt change of the second derivative (d^2v/dt^2) from a positive to a negative value is easier to accurately identify than the gradual change in value of the first derivative.

Point 108 on curve 106 occurs at different times (t) for different batteries because this characteristic is related to the initial state of discharge, age and temperature characteristics of an individual battery. However, point 108 corresponds to the time in the charging process where an impressed current 128 is nearly all being used to produce gas. That point is used as a signal in the practice of this invention, and the charge which has been returned to the battery at that point, measured from the beginning of the pertinent recharge event, is denominated as the as the signal charge Q_S. Knowledge of the magnitude of Q_s and of its relation to battery full charge Q_F, together with the amount of overcharge Q_o desired, enables the total deliverable (delivered) charge Q_D to be determined and enables the charging process to be controlled accordingly. If the battery is a flooded lead acid battery at 80°F, $Q_s = .98\ Q_F$. If the battery is at some other temperature, the relation of Q_s to Q_F can be different, but if the battery temperature is not a temperature significantly below room temperature, then use of the relation $Q_s = .98\ Q_F$ has been found to be workable and to produce significant improvements.

Charge delivered to a battery can be measured in ampere-hours ("amp-hours"). One ampere-hour is the quantity of charge delivered to the battery in one hour by a one ampere current. Thus, a completely drained battery having a charge capacity specified in ampere hours will take a number of hours equal to the specified ampere-hour capacity to return the battery to a fully charged state to capacity, or a desired fraction of full charge, at a one ampere charging current.

The specified amount of overcharge Q_O beyond full charge Q_F is selected to provide an increased battery life. In an exemplary embodiment the overcharge quantity is chosen to be 108%

of the replenishment charge Q_R. That is, in FIG. 1A, X is the time when 8% more than the replenishment charge has been delivered to the battery and is the time when the recharge event for that battery is terminated.

The amount of charge usefully returned to a battery to achieve the desired conditioning may be found by the following relation:

(specified % overcharge) (ampere-hours from start of charge to 98% of full charge)

= (ampere-hours from initial charge to reach specified overcharge)(98%)).

Stated differently using the terms defined above,

$Q_S/.98 = Q_D/(1+x)$ (Equation 1)

where x is the decimal equivalent of a percentage of the replenishment charge Q_R to be delivered to the battery as an overcharge amount. A workable and preferred value of x is .10.

Time T, point 112 in FIG. 1A, is the point in time at which the battery is fully charged, i.e., has charge level Q_F. Charge amount Q_s is found from determining the second derivative's zero crossing. Thus, the total charge Q_D to be delivered during the recharge event may be found once Q_s has been found by analysis of the dynamic aspects of the charging characteristic curves.

The amount of overcharge to be delivered to the battery to obtain the desired degree of conditioning by gaseous stirring of this liquid electrolyte preferably is in the range of from about 8% to about 12%, and most preferably is about 10%.

FIG. 1B and 1C are graphs for the charging profile of a battery at 80 degrees Fahrenheit and 122 degrees Fahrenheit, respectively; while any profile desired can be used, the peferred profile is a constant power profile. In these cases, the battery delivered 135 or 136 ampere-hours before the commencement of the respective recharge events. The points in time where 98% and other percentages of the charge deficiency has been returned to the battery are marked on each graph. A hot battery having a temperature of 122 degrees Fahrenheit reaches the .98 Q_F signal point earlier in time than when the second derivative of the charging voltage is zero valued. However, the temperature-based shift in the occurance of $d^2v/dt^2=0$ relative to 98% of full charge is slight. Use of Q_s= .98 Q_F for such a very hot battery results in far less overcharge of the battery than would otherwise occur.

FIG. 1D and 1E are graphs for the charging profile of a battery at 80 degrees Fahrenheit and 48 degrees Fahrenheit respectively. In these cases, the battery delivered 81 and 82 ampere-hours before commencement of the charging events. The points in time where Q_C=.98 Q_F and Q_C=1.09 Q_R are marked on each graph. As can be seen from those graphs, the cold battery's signal point is shifted to the right along the voltage curve. For example, a cold battery will be at less than 98% of full charge at the point in time when the second derivative of the charging voltage is zero valued. When the second voltage derivative for the cold battery is zero valued, only 82% of the full charge has been returned to the battery. In such a situation, use of the relation Q_S=.98 Q_F produces a measure of undercharge to the battery but does not meaningfully harm the battery. Over a typical industrial temperature range, the percent of charge returned to a battery at the time $d^2v/dt^2=0$ will typically vary from 84% to 102% of its total charge capacity Q_F.

A straightforward way to factor temperature into a process is to directly measure it and include it as a factor in the process. However, adding a temperature sensor which is effective to measure a battery's internal temperature is expensive and adds to a typical charging system another level of complexity that is undesirable in producing a low cost charging system that possesses an increased reliability.

FIG. 2 is a flow diagram of an exemplary charging process for a lead acid storage battery. In order to determine and utilize first and second derivative information corresponding to the 98% charge point of a battery, a process to determine the relevant information is executed. Such a process is implemented, for example, as a program set of instructions that drive a computer, microprocessor or other controlling device that comprises a battery charging system and preferably is part of the battery charger. The instructions may be stored in volatile or non-volatile memory or on a mass storage medium.

At the beginning of the process, a command 202 is initiated to start the charging process. In the next step, a timer circuit is initialized 204. In an alternative process, the timer circuit can be implemented in software, such as would be used to direct a microprocessor to time an operation, or sequence of operations. The time is recorded at step 206 so that when the desired voltage conditions are reached, an elapsed time will be known. Next, monitoring of the first derivative of the voltage and the second derivative of the voltage is initiated at step 208. The value of the second derivative is evaluated at step 210. If the second derivative is not equal to zero, the process continues to monitor the second derivative at step 208. If the second derivative is equal to zero, the process continues to the evaluation made in step 212. At step 212, the first derivative of the voltage is monitored to determine if it has reached a maximum value. If it has not, it is continued to be monitored at step 208. If dv/dt is determined to be a maximum value at step 212, process flow branches to step 214. At step 214, the measured time to reach 98% of full charge is applied and an additional charging time is computed so that a desired percent of overcharge may be added to the battery. Performance of step 214 includes use of information from the timer and information about total amperes delivered to the battery to compute Q_S, and to compute Q_D using the relations described above and program parameters defining the desired value of x (percentage overcharge) and Q_S/Q_F.

In an embodiment of the invention, the evaluations performed at steps 210 and 212 may be interchanged without affecting the outcome of the process. Additionally, determination of the maximum of the first derivative of the voltage performed in exemplary step 212 may be done continuously or by utilizing sampling methods known to those skilled in the art.

After the initial charging time, from initiation of the charging cycle until $d^2v/dt^2=0$, has been determined and the additional amount of time to provide a desired overcharge is calculated at step 214, the process (step 216) directs the battery to be charged for an additional amount of time to provide the desired overcharge. After the additional charging time has elapsed, the charging cycle is stopped at step 218.

A relation which is useful to determine when a battery recharging process according to this invention is to be terminated is as follows:

$$\frac{Q_S}{.98} = \frac{Q_D}{1+x}$$

in which Q_S and Q_D are as defined above (see Glossary), and x is the decimal equivalent of the percentage of the replenishment charge Q_R to be applied to the battery, after it is fully charged, to achieve the desired conditioning (electrolyte stirring) of the battery.

Assume that the full charge of a battery is 1000, and the desired overcharge percentage is 8%. If a battery is 50% discharged at the beginning of a recharge event, $Q_S = .98\ (1000\text{-}500) = 490$, and so $Q_D = 540$. $Q_i + Q_D = 500 + 540 = 1040$, and so the actual amount of overcharge at termination of the recharge event is 40.

Applying the same assumptions to a battery which is at 25% capacity ($Q_i = 250$) when recharging begins, $Q_S = .98\ (1000\text{-}250) = 735$, $Q_D = 810$, $Q_i + Q_D = 250 + 810 = 1060$, and so the delivered overcharge is 60. Similarly, if the battery is at 70% of capacity when recharging begins, $Q_S = .98\ (1000 - 700) = 294$, $Q_D = 324$, $Q_i + Q_D = 700 + 324 = 1024$, and so the delivered overcharge is 24.

It will be recalled that if a battery is very deeply discharged when its recharging event begins, the specific gravity of the acid electrolyte is low (near 1.00) due to the highly diluted state of the electrolyte. The more dilute the electrolyte when recharging begins, the greater will be the density stratification of the electrolyte at full charge, and so the more the electrolyte needs to be stirred by gas generation to properly condition the battery by making the electrolyte substantially homogenous through the battery cells. Conversely, if a battery is relatively lightly discharged when its recharging event begins, the acid electrolyte will have a higher starting specific gravity, a lower density stratification at full charge, and a lower need for electrolyte stirring to properly condition the battery. The foregoing examples show that this invention delivers to a recharged battery only that amount of overcharge which is determined to be needed for proper conditioning and does not excessively overcharge the battery. The amount by which the battery is overcharged is a function of the discharge state of the battery when recharging begins. The point at which the recharging process is ended is determined from information obtained from the battery itself. That is a characteristic of the battery recharge processes illustrated in Figs. 2-7.

FIGS. 3A and 3B are flow diagrams of a charging process that monitors cell voltage. Steps 302-316 can be the same as steps 202-216. However, in this process charging is not terminated unless certain minimum conditions are satisfied. In the exemplary embodiment, cell voltage is one such minimum condition. At step 318, the cell voltage is monitored. If the cell voltages have reached, say, 2.45 volts per cell, the charging algorithm is terminated at step 320. Alternatively other cell voltages may be utilized for other types of batteries.

If the cell voltage has not reached 2.45 volts per cell, the process branches to letter A in FIG. 3B. In this process, charging defaults to a state that does not terminate the charging process until the first derivative voltage equals zero. Thus, charging continues at step 322. While charging, the first derivative continues to be evaluated at step 324. If the first derivative reaches zero, the charging process is then ended at step 326. If the first derivative does not reach zero, the charging process continues until the first derivative reaches zero and the process is ended.

FIG. 4A and 4B are a flow diagram of a charging process that monitors cell voltage and charging time to produce a desired overcharge. This process is an alternative embodiment of the process of FIG. 3. The process shown in FIG. 4A is analogous to the process of FIG. 3A, and steps 402-426 can be the same as steps 302-326. However, in this process, charging is not terminated unless certain minimum conditions are satisfied. Cell voltage can be one such minimum condition. At step 418, the cell voltage is monitored.

The process shown in Figs 4A and 4B provides a further back-up of terminating the charging cycle if charging has not been accomplished in a certain number of hours, as may be deemed desirable in a particular application. In the embodiment described, 16 hours is deemed the maximum number of hours to accomplish a full charge. Alternatively, any time period suitable to prevent damage to a battery may be substituted.

Continuing with FIG. 4B, the charging process continues in step 422 while the first voltage derivative is monitored at step 424. If the first derivative reaches zero, the charging process is ended at step 426. If the first voltage derivative has not reached zero, the process branches to an evaluation step 428 that compares the elapsed charging time to a set time, in this case 16 hours. In an embodiment any suitable time period may be selected as the set time.

If the predetermined charging time has been exceeded, an alarm signal or message may be sent (step 430) visibly, audibly or otherwise to the person in charge of or overseeing the battery recharging process. The message can include information on the identity of the charger of interest, to distinguish it from other chargers which may be present, as when batteries in each of the golf cars in a fleet are being recharged at the same time. Upon activation of the alarm signal by step 430, the charging cycle is terminated at step 432. If at step 428 the predetermined time has not been exceeded, the charging cycle continues.

FIG. 5 is a flow diagram of a charging process that provides refresh charging. Steps 502-

516 can be the same as steps 402-416. The charging process can be terminated at step 518.

While the battery is still connected to the charger, the open circuit voltage of the battery is monitored at step 520. If the battery's voltage falls below a preset minimum value V_{Min}, the charging process is caused to be repeated. The voltage V_{Min} is selected to provide a desired lower threshold of voltage that the charger will not allow the battery to drop below. The charger keeps a charge on the battery to keep it above V_{Min}. However, as long as the battery remains above the low voltage threshold V_{Min}, the charging process will not be reinitiated, and the overall process is stopped at step 522. The value selected for V_{Min} is based upon an amount of acceptable remaining charge that is user selectable, or alternatively programable as a preset value in the charges operating program.

FIG. 6 is a flow diagram of a charging process that monitors an elapsed time since termination of charging of a battery, and the battery open circuit voltage. Steps 602-618 can be the same as steps 502-518. In this charging process which monitors an elapsed time since termination of charging of a battery, and the battery open circuit voltage, the time elapsed since termination of the charging process is monitored at step 622. If a predetermined amount of time has elapsed since the charging process was terminated and the battery continues to be connected to the charger equipment, then the charging process is reinitiated. If the elapsed time has not exceeded the predetermined amount of time the process proceeds to step 624. If the open circuit voltage is less than its predetermined value V_{Min} then charging is reinitiated. If the battery open circuit voltage remains above V_{Min} then the process is terminated at step 626.

In an alternative process, the open circuit voltage can be monitored prior to evaluating time since termination of the charging process. In a further alternative process, time since termination of the charging process can be monitored simultaneously with monitoring of the battery open circuit voltage.

FIG. 7 is a flow diagram of a form of the invention that allows the selection of various charging profiles. At step 702 the charging process is initiated. Next, a charging profile is selected 704. Possible charging profiles comprise: constant potential; modified constant potential; constant current; ferro and ferro resonant; constant current-constant potential-constant current (IEI); constant power-constant potential-constant current (PEI); and, preferably, constant power. Information describing and defining the different profiles can be contained in an addressable memory included in the charger in association with the control aspects of the charger.

Once a charging profile has been selected, a timer circuit is initialized and the process is at step 706 started utilizing the selected profile. Next, the process begins recording an elapsed time at step 708. The process monitors the first and second derivatives of the voltage at step 710. If the second derivative is equal to zero (step 712) and the first derivative has reached a maximum (step 714), the charging process continues. If the second derivative has not reached zero and the first derivative has not reached the maximum, their values are continuously monitored until they reach the desired values.

Once the desired derivative values have been reached, an additional charging time for a desired overcharge is calculated at step 716, and the battery is charged for an additional charging time for the desired overcharge (step 718). The additional charging time may utilize the previously selected charging profile or another charging profile. Once the additional charging time for the desired overcharge has elapsed, the process is terminated at step 720.

FIG. 8 is a block diagram of an exemplary battery charging system utilizing a charge control algorithm device IC and a "measuring computing and control device" (MCCD) such as a suitably programmed microprocessor. An AC input 802 to rectifier 804 creates a charging current, at a desired voltage, that is applied to battery 810 through a charge process control device integrated circuit 808. The charge process control device integrated circuit 808 controls application of the charging energy to the battery 810.

The charge control device IC 808 functions in conjunction with the MCCD to apply a charging signal comprising one or more charging profiles or processes. Instructions to implement one or more of the processes described in FIGS. 2 through 7 can be stored in the MCCD 806. Typically storage is achieved by loading a set of program instructions describing the process into the MCCD. Alternatively, the process may be integrated into a custom charge process control integrated circuit which may include the features and functions of integrated circuit 808.

FIG. 9 is a block diagram of a battery charging system capable of implementing one or more of the invention's charging processes to charge a battery. An AC input 902 is controlled by relay 912. The AC power is applied to rectifier 904 to produce a DC voltage having a ripple component. Voltage regulator 906 reduces the variations in the DC voltage. The regulated DC voltage is applied to a conventionally constructed series pass element 908 that works in conjunction with a conventionally constructed current limiting device 910 to supply a desired current and voltage through the contacts of a relay 914 to battery 916. Current applied to the battery is monitored by a conventional ampere meter 918. The ampere meter monitors the instantaneous value of current flowing in a conductor. In an alternative arrangement, a conventional averaging ampere meter can be used to indicate an average charge passing through the conductor. In a further alternative arrangement a conventional totalizing ampere meter can be used to provide an indication of the total charge passing through the conductor. Voltage across the battery terminals is monitored by volt meter 920. Information obtained from the ampere meter and the volt meter can be supplied to MCCD 806.

The voltage across the battery 916 is also supplied to a differentiator circuit 922 that computes the first derivative of the voltage. Such a circuit may be conventionally constructed as shown at 930. A differentiator typically comprises an operational amplifier A, a resistor R and a capacitor C, connected as known by those skilled into the art to produce a differentiator. A voltage V_i is applied to the input of the differentiator. The signal output V_o is equal to -RC(dV/dt).

The output of the first derivative circuit 922 is fed into a peak detector 928. When a maximum first derivative signal is detected, an indication is provided to MCCD 806. The output of the first derivative processing circuit is also fed to a second derivative processing circuit 924. This circuit is simply a replica of the circuit in 922. The output of the second derivative circuit 924 is fed to a zero crossing detector 926. A zero crossing detector is a circuit that detects a transition in signal polarity, such as when a voltage goes from positive to negative and by necessity crosses through a value of zero volts. Detection of a zero crossing corresponding to the detection of inflection point 115 in voltage curve 101 of FIG.1 is sought. An indication of the detection of a zero crossing is provided to the MCCD 806. Under control of the process comprising an embodiment of the invention, the MCCD directs a charging current and voltage to be applied through relay 914. The MCCD also can control the operation of the AC input through relay 912.

It is preferred that the components of the charging system depicted in Fig. 9 be housed in a common charger housing. The charger can be, usually is, separate from the battery or thing (e.g., golf car) in which the battery is located. However, if desired, some or all of the components of the charging system can be physically associated with the battery as elements of, e.g., a golf car.

It will be seen that this invention provides equipment and procedures for charging a flooded lead acid battery of the deep cycle type in ways which charge the battery effectively yet without overly charging the battery to extents which reduce battery life. The battery is overcharged by an amount which is a selected percentage of the charging energy required to place the battery in a state of full charge following completion of its last preceding duty cycle. A recharging event achieved in the practice of this invention inherently allows for and takes into consideration factors such as the battery, age and internal characteristics which impact charging effectiveness and efficiency.

While the invention has been described above with reference to recharging a battery, it will be understood that the invention also applies to the recharging of a set of batteries which may be encountered in an electric golf car or some other electrically powered vehicle or device, or with a set of batteries used in connection with a photovoltaic electrical power system, for example.

The foregoing description of preferred and other embodiments and forms of the invention has been presented by way of example, not as a catalog of all forms which equipment or procedures in which the invention can be manifested or used to advantage. Workers skilled in the art to which the invention pertains will understand that variations and modifications of the described equipment and processes can be used beneficially without departing from the scope of the invention.

CLAIMS

1. A method for charging deep cycle lead acid batteries comprising:

applying charging energy to such a battery;

identifying a 98% charge point in the charging process;

monitoring the charge provided in amp hours;

determining the remaining charging energy to be applied to overcharge the battery to substantially 110% of full charge;

applying the remaining charging energy to the battery.

2. The method of claim 1 for charging a deep cycle lead acid battery wherein the step of determining the 98% charge point comprises:

determining when the rate of change of an applied charging voltage verses time (dv/dt) is a maximum; and

determining when the acceleration of the voltage with respect to time (d^2v/dt^2) is zero.

3. The method of claim 1 for charging a deep cycle lead acid battery wherein the step of determining the remaining charging energy comprises:

dividing the product of .98 and the charging energy applied to charge the battery to 98% of its charge capacity by a decimal equivalent of the percent of overcharge desired.

4. The method of claim 1 for charging a deep cycle lead acid battery wherein the step of determining the remaining charging energy further comprises:

monitoring a battery cell charge voltage prior to termination of the calculated overcharge desired;

extending the charging period until the rate of change of the charging voltage verses time (dV/dt) is zero.

5. The method of claim 4 for charging a deep cycle lead acid battery wherein the step of extending the charging period further comprises terminating the charging once a predetermined time has been exceeded.

6. The method of claim 5 for charging a deep cycle lead acid battery wherein the predetermined time is about 16 hours.

7. The method of claim 1 for charging a deep cycle lead acid battery further comprising the steps of

monitoring the open circuit battery voltage;

initiating charging if the open circuit voltage falls below a desired level.

8. The method of claim 1 for charging a deep cycle lead acid battery further comprising the step of initiating charging after a predetermined time since the last charging sequence.

9. A method for charging flooded deep cycle lead acid batteries comprising the steps of applying charging energy to such a battery according to a selected charging profile; identifying the point in the process at which the battery state has a known relation to a state of full charge of the battery and determining a first amount of charging energy delivered to the battery from the inception of the process to that point; determining a second amount of further charging energy, adequate when applied to the battery to cause the battery to be overcharged by a selected amount related to the first amount; and applying the second amount of charging energy to the battery.

10. A method for charging flooded deep cycle lead acid batteries comprising the steps of:

applying charging energy to the battery;

monitoring the charging energy as to quantity delivered to the battery and its dv/dt and d^2v/dt^2 aspects, by use of information about the amount of charging energy delivered to the battery at a point in the process when dv/dt is a maximum and $d^2v/dt^2=0$, determining and delivering to the battery beyond that point a defined quantity of charging energy additive to said amount adequate to overcharge the battery to a predetermined extent related to said amount.

11. A method for charging flooded deep cycle lead acid batteries comprising the steps of:

applying to such a battery an amount of charging energy equal to the initial charge deficiency of the battery, and

applying to the battery a further increment of charging energy adequate to overcharge the battery to an extent predetermined as a selected percentage of the charge deficiency.

12. A battery charging apparatus for charging deep cycle lead acid batteries comprising:

a DC current source

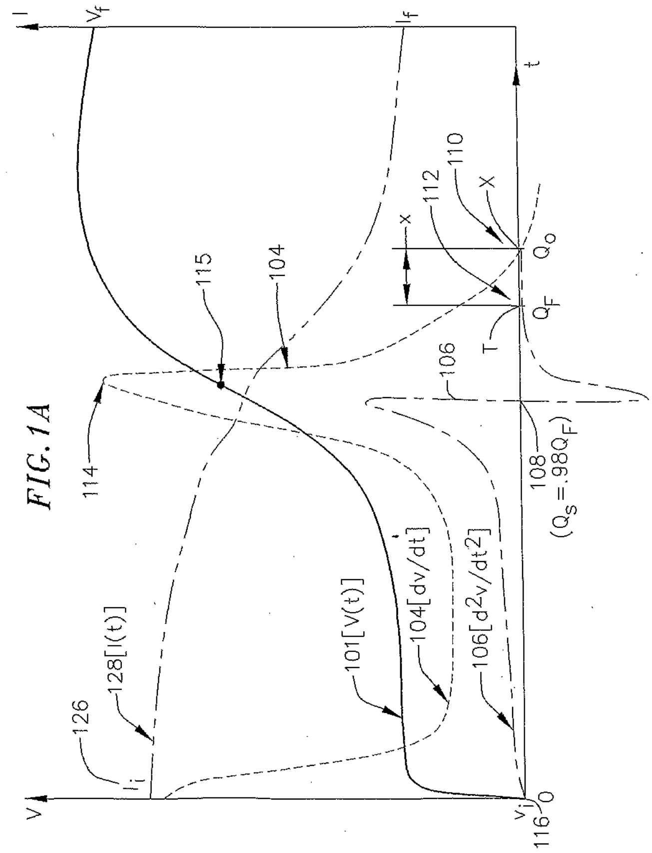
a voltmeter;

an ammeter;
a timer;
a dv/dt measurement circuit; and
a d^2v/dt^2 measurement circuit

13. Apparatus according to claim 1 including a controller coupled to the DC current source, the ammeter, the timer, and the dv/dt and d^2v/dt^2 measurement circuit, the controller being configured for determining the point in a battery recharge event when a battery is at substantially a defined percentage of full charge, and for determining the value of Q_D from the relation $Q_S/p = Q_d/(1+x)$in which Q_S is the ampere-hours of charging energy delivered to the battery in the interval from the beginning of the recharge event to the point at which the battery has substantially the defined percentage of full charge, p is the decimal equivalent of the defined percentage, x is the decimal equivalent of a desired percentage amount of replenishment charge to be delivered to the battery as an overcharge amount, and Q_D is the ampere-hours to be delivered to the battery from the beginning of the recharge event to reach the overcharge amount.

14. Apparatus according to claim 2 in which the value of p is substantially .98.

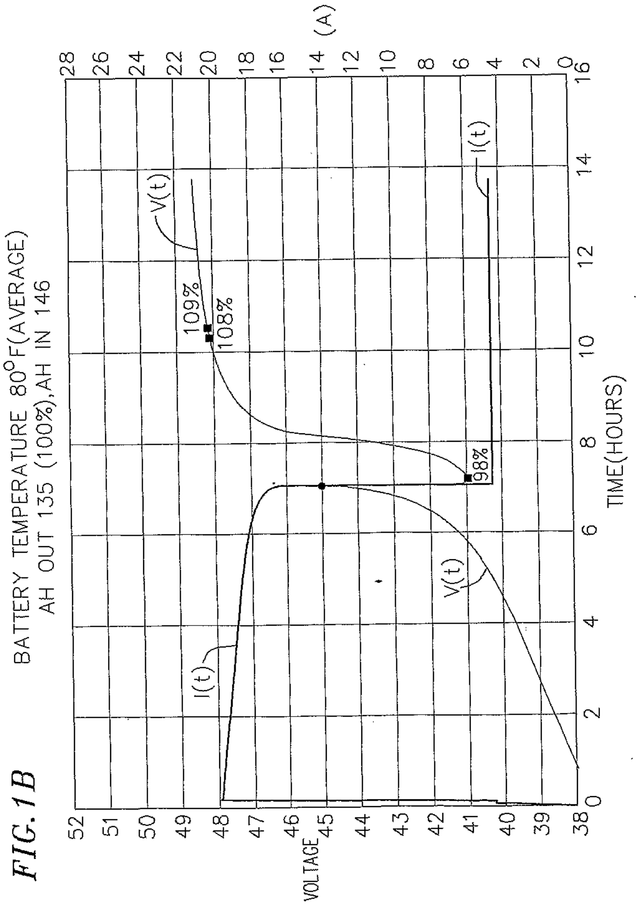
15. Apparatus according to claim 2 in which x is in the range of from about .08 to about .12.



I
V
t
V_f
I_f
I_i
V_i
0
116
126
128[I(t)]
101[V(t)]
104[dv/dt]
106[d²v/dt²]
104
106
108
(Q_s=.98Q_F)
110
112
114
115
X
x
T
Q_F
Q_o

FIG. 1A

FIG.1B


BATTERY TEMPERATURE 80°F(AVERAGE)
AH OUT 135 (100%),AH IN 146
V(t)
I(t)
109%
108%
98%
V(t)
I(t)
TIME(HOURS)
VOLTAGE
(A)
52 51 50 49 48 47 46 45 44 43 42 41 40 39 38
28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
0 2 4 6 8 10 12 14 16

3/15

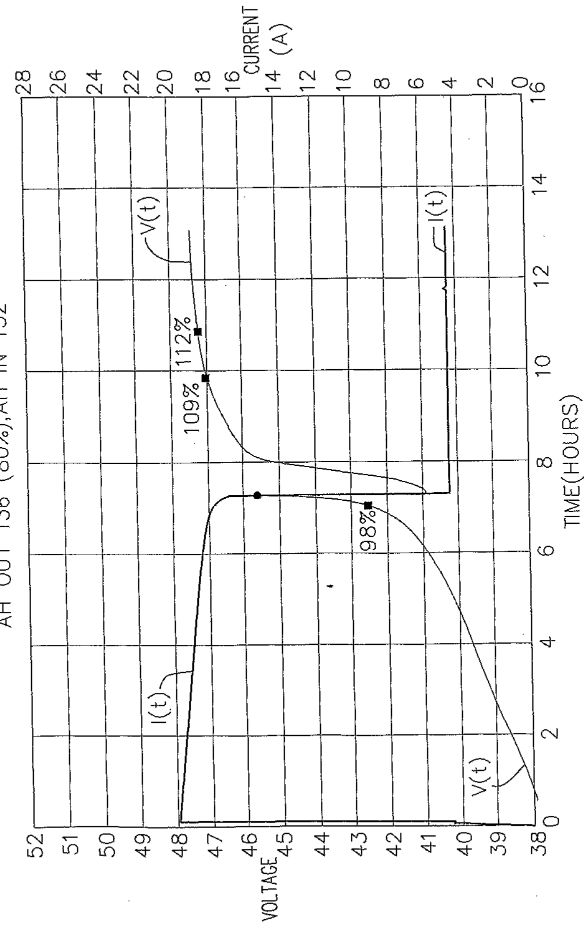
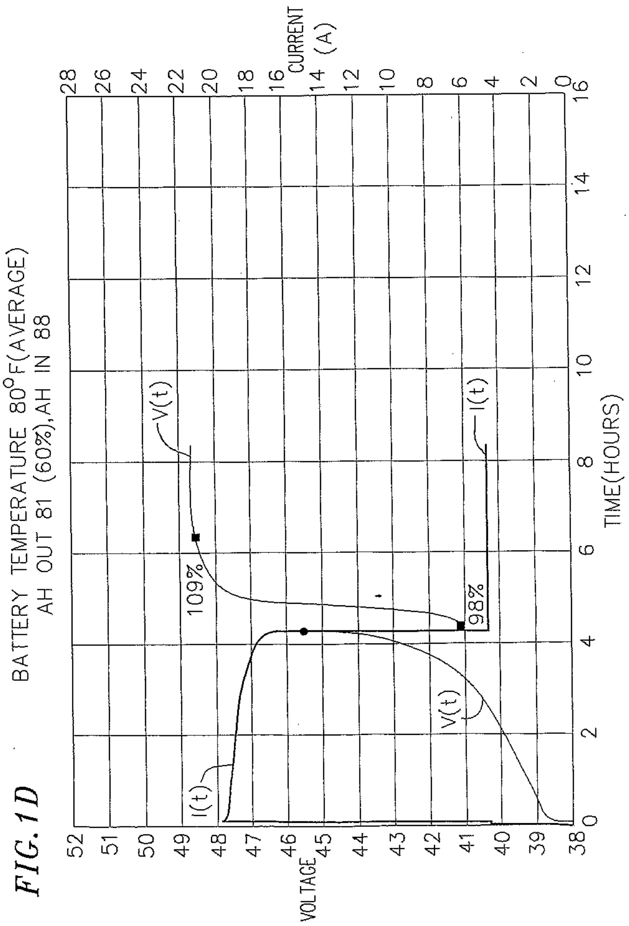

BATTERY TEMPERATURE 122°F(AVERAGE)
AH OUT 136 (80%),AH IN 152
CURRENT (A)
28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
VOLTAGE
52 51 50 49 48 47 46 45 44 43 42 41 40 39 38
TIME(HOURS)
0 2 4 6 8 10 12 14 16
V(t)
I(t)
112%
109%
98%

FIG. 1C

FIG.1D



BATTERY TEMPERATURE 80°F(AVERAGE)
AH OUT 81 (60%),AH IN 88
CURRENT (A)
VOLTAGE
TIME(HOURS)
V(t)
I(t)
109%
98%

FIG.1E

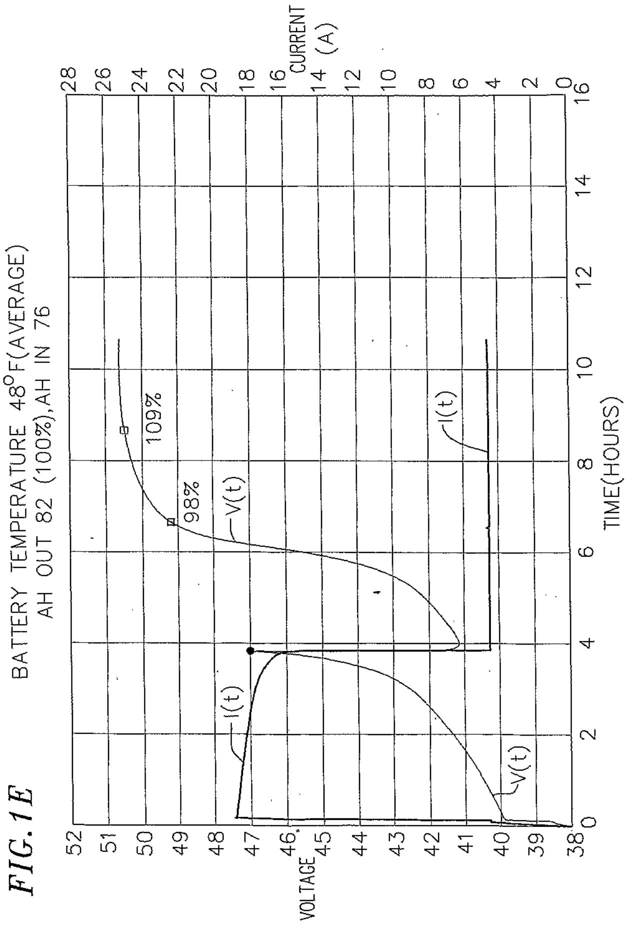
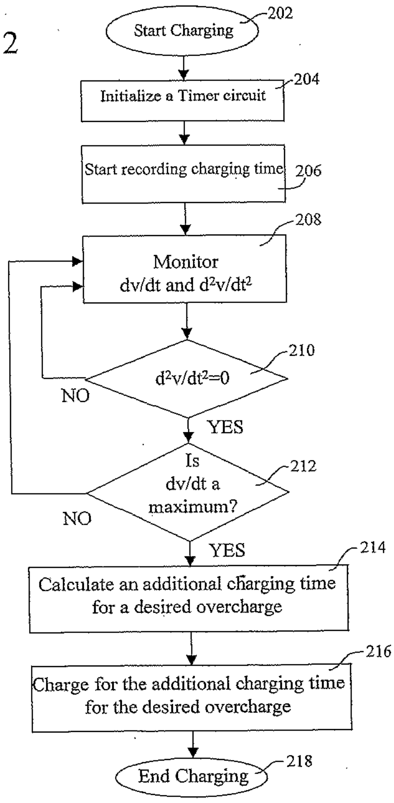

BATTERY TEMPERATURE 48°F(AVERAGE)
AH OUT 82 (100%),AH IN 76
CURRENT (A)
VOLTAGE
TIME(HOURS)
V(t)
I(t)
98%
109%

FIG. 2



Start Charging
202
Initialize a Timer circuit
204
Start recording charging time
206
208
Monitor
dv/dt and d²v/dt²
210
d²v/dt²=0
NO
YES
Is
dv/dt a
maximum?
212
NO
YES
214
Calculate an additional charging time
for a desired overcharge
216
Charge for the additional charging time
for the desired overcharge
End Charging
218

FIG. 3A

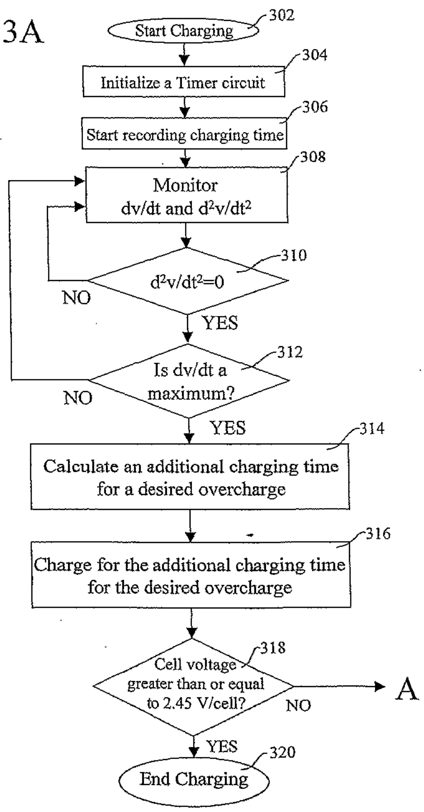

Start Charging
302
Initialize a Timer circuit
304
Start recording charging time
306
Monitor
dv/dt and d²v/dt²
308
d²v/dt²=0
310
NO
YES
Is dv/dt a maximum?
312
NO
YES
Calculate an additional charging time for a desired overcharge
314
Charge for the additional charging time for the desired overcharge
316
Cell voltage greater than or equal to 2.45 V/cell?
318
NO
A
YES
End Charging
320

FIG. 3B

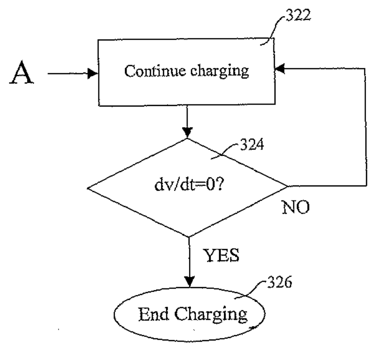


FIG. 4A

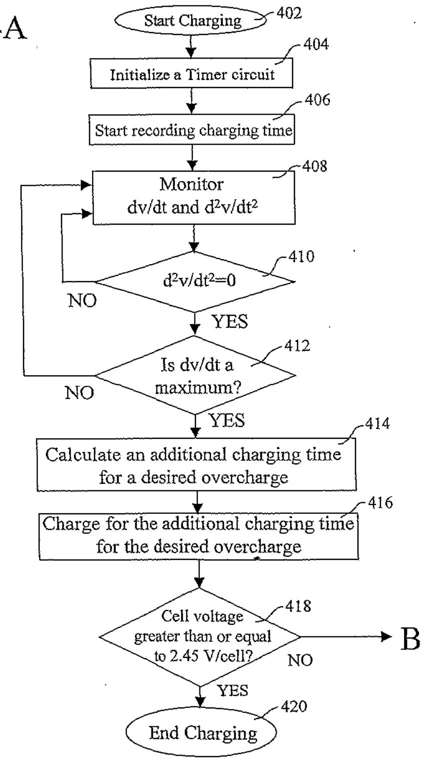

Start Charging
402
Initialize a Timer circuit
404
Start recording charging time
406
Monitor dv/dt and d²v/dt²
408
d²v/dt²=0
410
NO
YES
Is dv/dt a maximum?
412
NO
YES
Calculate an additional charging time for a desired overcharge
414
Charge for the additional charging time for the desired overcharge
416
Cell voltage greater than or equal to 2.45 V/cell?
418
NO
B
YES
End Charging
420

FIG. 4B

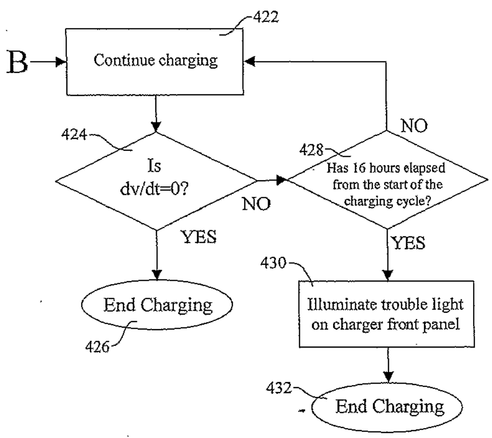
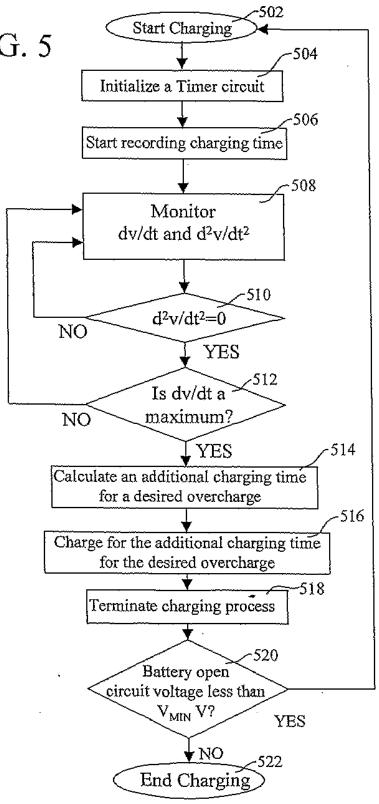
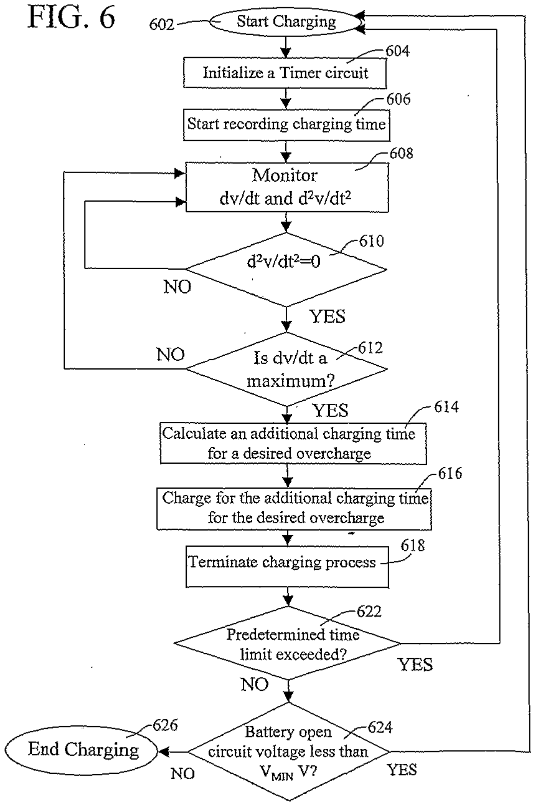

B
Continue charging
422
424
Is
dv/dt=0?
NO
YES
End Charging
426
428
Has 16 hours elapsed
from the start of the
charging cycle?
NO
YES
430
Illuminate trouble light
on charger front panel
432
End Charging

FIG. 5



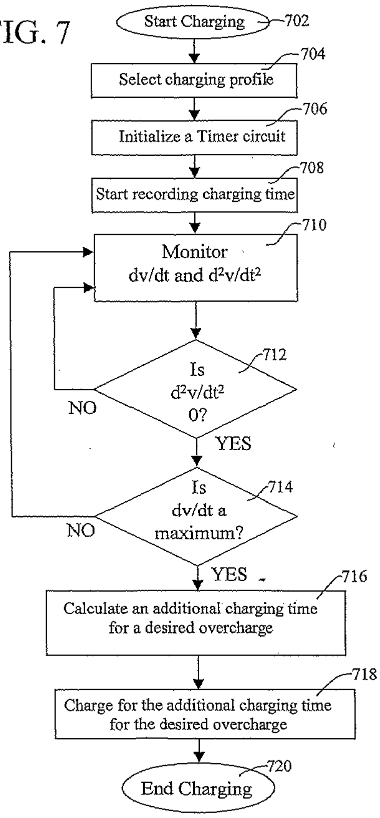
Start Charging
502
Initialize a Timer circuit
504
Start recording charging time
506
Monitor dv/dt and d²v/dt²
508
d²v/dt²=0
510
NO
YES
Is dv/dt a maximum?
512
NO
YES
Calculate an additional charging time for a desired overcharge
514
Charge for the additional charging time for the desired overcharge
516
Terminate charging process
518
Battery open circuit voltage less than V_MIN V?
520
YES
NO
End Charging
522

FIG. 6



602
Start Charging
604
Initialize a Timer circuit
606
Start recording charging time
608
Monitor dv/dt and d²v/dt²
610
d²v/dt²=0
NO
YES
612
Is dv/dt a maximum?
NO
YES
614
Calculate an additional charging time for a desired overcharge
616
Charge for the additional charging time for the desired overcharge
618
Terminate charging process
622
Predetermined time limit exceeded?
YES
NO
624
Battery open circuit voltage less than VMIN V?
YES
NO
626
End Charging

FIG. 7



Start Charging
702
Select charging profile
704
Initialize a Timer circuit
706
Start recording charging time
708
Monitor dv/dt and d²v/dt²
710
Is d²v/dt² 0?
712
NO
YES
Is dv/dt a maximum?
714
NO
YES
Calculate an additional charging time for a desired overcharge
716
Charge for the additional charging time for the desired overcharge
718
End Charging
720

FIG. 8

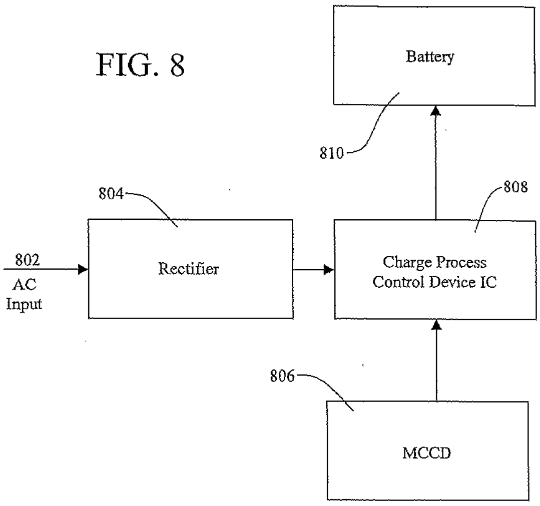
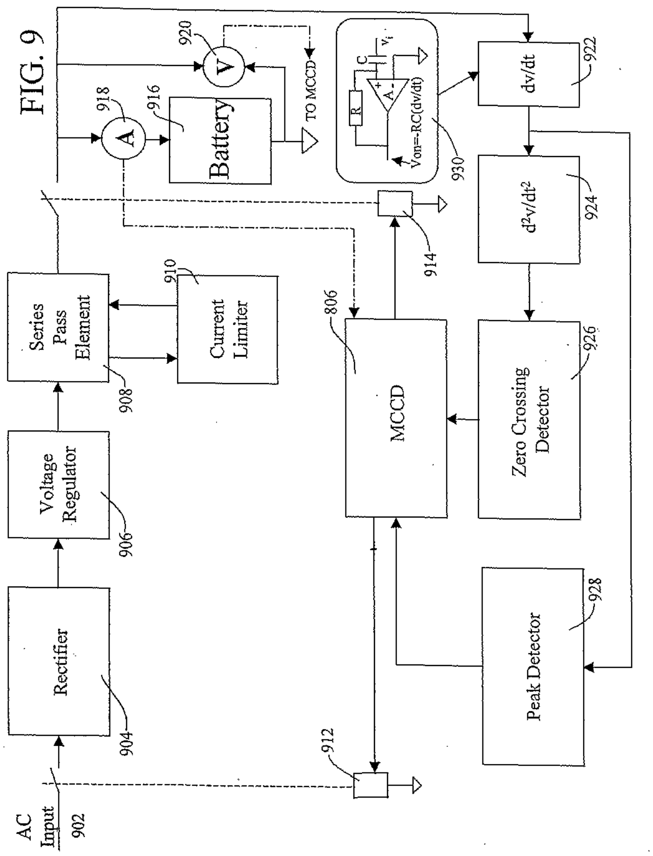

Battery
810
804
808
802
AC
Input
Rectifier
Charge Process
Control Device IC
806
MCCD

FIG. 9


AC
Input
902
Rectifier
904
Voltage
Regulator
906
Series
Pass
Element
908
Current
Limiter
910
912
914
A
918
Battery
916
V
920
TO MCCD
R
C
A
V_{on}=-RC(dv/dt)
930
dv/dt
922
d^2v/dt^2
924
MCCD
806
Zero Crossing
Detector
926
Peak Detector
928

【国際調査報告】

INTERNATIONAL SEARCH REPORT

International application No. PCT/US01/31141

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H02J 7/00
US CL : 320/119
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 320/119, 116, 125, 128, 138

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,629,601 (Feldstein) 13 May 1997 (13.5.1997), see entire document	1-8, 12, 13
A	US 5,900,718 (Tseter) 04 May 1999 (04.05.1999)	1-15
A	US 5,701,068 (Baer et al.) 23 December 1997 (23.12.1997)	4,5,6,7,8

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 December 2001 (06.12.2001)	28 DEC 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-7723	Authorized officer Lawrence Luk Telephone No. (703)305-0617

Form PCT/ISA/210 (second sheet) (July 1998)

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アメリカ合衆国，カリフォルニア　９０７４０，シール　ビーチ，シックスス　ストリート　２４２

Ｆターム(参考) 5G003 AA01 BA01 CA01 CA17 GC05
5H030 AA03 AA06 AS08 BB03 FF42 FF43 FF44 FF52