(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 August 2017 (24.08.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/140354 A1

(51) International Patent Classification:
H02J 7/00 (2006.01) *H02J 7/14* (2006.01)
B60L 11/18 (2006.01)

(21) International Application Number:
PCT/EP2016/053330

(22) International Filing Date:
17 February 2016 (17.02.2016)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant: TOYOTA MOTOR EUROPE [BE/BE]; Avenue du Bourget 60, 1140 Brussels (BE).

(72) Inventors: KOMIYAMA, Keita; Rue de Geneve 13, 1140 Evere (BE). KATOH, Yuki; Rue Henrotte 46, 1150 Brussels (BE).

(74) Agents: INTÈS, Didier et al.; Cabinet Beau de Loménie, 158 Rue de l'Université, 75340 Paris Cedex 07 (FR).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: SYSTEMS AND METHODS FOR BATTERY CHARGE CONTROL

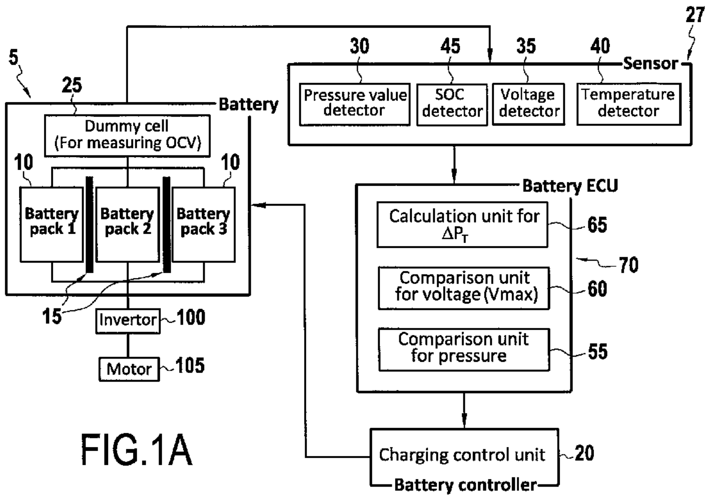

FIG.1A

(57) Abstract: A charging control system for a battery (5) is provided. The system comprises temperature sensing means (40) configured to provide a temperature value associated with the battery, voltage sensing means (35) configured to provide a voltage value associated with the battery, pressure sensing means (30) configured to provide a pressure value associated with an internal portion of the battery, and a controller (20). The controller is configured to determine, before a charging process is started, a threshold pressure change associated with a full charge of the battery based on map data selected from a predetermined data map associated with the battery monitor, during the charging process, a present voltage value obtained by the voltage sensing means and a total pressure change based on a present pressure value obtained by the pressure sensing means, continue the charging process when the present voltage value exceeds an upper limit voltage value, and the total pressure change is less than the threshold pressure change and terminate the charging process when the present voltage value exceeds the upper limit voltage value, and the total pressure change is greater than or equal to the threshold pressure change.

WO 2017/140354 A1

SYSTEMS AND METHODS FOR BATTERY CHARGE CONTROL

Field of the Disclosure

[001] The present disclosure is related to systems and methods for controlling charging of a battery. More particularly, the present disclosure is related to managing a charge state based on an internal pressure measure within the battery.

Background of the Disclosure

[002] During charging of a battery, e.g., a lithium ion battery, total voltage at the battery pack may increase sharply due to increasing overvoltage at certain laminating parts at which degradation has occurred. Thereby, total voltage reaches an upper bound voltage, which is set in order to prevent overcharging, and the charging system stops charging considering that the battery pack is fully charged.

[003] However, as degradation of the battery progresses the battery pack is typically not yet fully charged (i.e., state of charge (SOC) < 100%) when charging is stopped as a result of reaching the upper bound voltage. Therefore, available amount of energy from the battery decreases due to the degradation dispersion.

[004] US 2004/0096749 is directed to preventing overcharging a all laminating parts of a battery using a characteristic charging capacity rate, which remains substantially unchanged until SOC approaches 100%. However, US 2004/0096749 does not take into consideration the influence of overvoltage when the battery has degraded due to use. In addition, the techniques disclosed therein require the implementation of special materials.

SUMMARY OF THE INVENTION

[005] The inventors of the present invention desire to enable increasing energy stored in a battery at full charge while limiting the possibility for overcharging of and damage to the battery.

[006] Therefore, according to embodiments of the present disclosure, a charging control system for a battery is provided. The charging control system may include temperature sensing means configured to provide a temperature value associated with the battery, voltage sensing means configured to provide a voltage value associated with the battery, pressure sensing means

configured to provide a pressure value associated with an internal portion of the battery, and a controller. The controller may be configured to determine, before a charging process is started, a threshold pressure change associated with a full charge of the battery based on map data selected from a predetermined data map associated with the battery, monitor, during the charging process, a present voltage value obtained by the voltage sensing means and a total pressure change based on a present pressure value obtained by the pressure sensing means, continue the charging process when the present voltage value exceeds an upper limit voltage value, and the total pressure change is less than the threshold pressure change, and terminate the charging process when the present voltage value exceeds the upper limit voltage value, and the total pressure change is greater than or equal to the threshold pressure change.

[007] By providing such a system it may be possible to discount an allowable voltage range to more completely charge a battery that has undergone degradation. This in turn enables greater energy availability with reduced risk of damage to the battery.

[008] The selection of the map data may be based on a pre-charging temperature value obtained from the temperature sensing means, a pre-charging voltage value obtained from the voltage sensing means, and a pre-charging pressure value obtained from the pressure sensing means.

[009] The controller may be configured to increase the upper limit voltage value when the present voltage value exceeds the upper limit voltage value, and the total pressure change is less than the threshold pressure change.

[010] The controller may be configured to compensate for creep in one or more portions of the battery by modifying the selected map data based on an initial internal pressure measurement, the pre-charging process pressure value, and the pre-charging temperature value.

[011] The controller may be configured to compare the initial internal pressure measurement and the pre-charging pressure value, and when the initial internal pressure measurement is greater than the pre-charging process pressure value, select new map data associated with the pre-charging pressure value.

[012] The data map may include a collection of experimentally measured internal pressures, open circuit voltages, and temperatures of a representative battery under representative conditions of use of the battery.

[013] The pressure sensing means may include at least one tactile sensor embedded in the battery.

[014] The at least one tactile sensor may be positioned parallel to a laminated direction of a battery cell of the battery.

[015] A state of charge sensor configured to determine a state of charge of the battery may be provided.

[016] The voltage sensing means may include a dummy cell connected to one or more battery packs associated with the battery.

[017] The voltage value may be an open circuit voltage of the battery.

[018] The battery may a lithium-ion, solid-state battery.

[019] According to further embodiments, a vehicle comprising the charging control system discussed above may be provided.

[020] According to still further embodiments, a method for charging a battery is provided. The method includes determining a temperature value associated with the battery, determining a voltage value associated with the battery, determining a pressure value associated with an internal portion of the battery, determining, before a charging of the battery is started, a threshold pressure change associated with a full charge of the battery based on map data selected from a predetermined data map associated with the battery, charging the battery, monitoring, during the charging, a present voltage value obtained by the voltage sensing means and a total pressure change based on a present pressure value obtained by the pressure sensing means, continuing the charging when the present voltage value exceeds an upper limit voltage value, and the total pressure change is less than the threshold pressure change, and terminating the charging when the present voltage value exceeds the upper limit voltage value, and the total pressure change is greater than or equal to the threshold pressure change.

[021] By providing such a method it may be possible to discount an allowable voltage range to more completely charge a battery that has undergone degradation. This in turn enables greater energy availability with reduced risk of damage to the battery.

[022] The selection of the map data may be based on a pre-charging temperature value obtained from the temperature sensing means, a pre-charging voltage value obtained from the voltage sensing means, and a pre-charging pressure value obtained from the pressure sensing means.

[023] The method may include increasing the upper limit voltage value when the present voltage value exceeds the upper limit voltage value, and the total pressure change is less than the threshold pressure change.

[024] The method may include compensating for creep in one or more portions of the battery by modifying the selected map data based on an initial internal pressure measurement, the pre-charging process pressure value, and the pre-charging temperature value.

[025] The method may include comparing the initial internal pressure measurement and the pre-charging pressure value, and when the initial internal pressure measurement is greater than the pre-charging process pressure value, selecting new map data associated with the pre-charging pressure value.

[026] The predetermined map may include a collection of experimentally measured internal pressures, open circuit voltages, and temperatures of a representative battery under representative conditions of use of the battery.

[027] The method may include determining a state of charge of the battery and modifying the threshold pressure change based on the state of charge of the battery before the charging is started.

[028] Additional objects and advantages of the invention will be set forth in part in the description which follows, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

[029] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

[030] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[031] Fig. 1A is a schematic diagram of a charging system for a battery according to embodiments of the present disclosure;

[032] Fig. 1B is a schematic diagram of an exemplary open circuit voltage measuring configuration;

[033] Fig. 2 shows an exemplary representation of an internal portion of a battery including pressure sensors;

[034] Fig. 3 is a flowchart showing one exemplary method for charge control according to embodiments of the present disclosure;

[035] Fig. 4 is a flowchart showing one exemplary method for creep compensation;

[036] Figs. 5A and 5B are representations of an exemplary data maps according to embodiments of the disclosure; and

[037] Fig. 6 is an exemplary graph showing a relationship between pressure, voltage, and available energy during a charging process.

DESCRIPTION OF THE EMBODIMENTS

[038] Reference will now be made in detail to the present exemplary embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[039] Fig. 1A is a schematic diagram of a charging system for a battery according to embodiments of the present disclosure. The system may include a battery 5, one or more sensors 27, battery control unit 70, and a charging control unit 20. Battery 5 may include one or more battery packs 10, one or more pressure sensing membranes 15, and a dummy cell 25, among others. Battery 5 may be any suitable type of battery, for example, a lithium ion battery, a NiMH battery, lead acid battery, etc.

[040] Battery 5 may be connected to an inverter 100 which may in turn be connected to one or more motors 105, to permit energy stored in battery 5 during a charging process to be stepped up by inverter 100 and fed to motor 105 during a discharging process, thereby resulting in movement of the vehicle.

[041] Battery packs 10 may be installed within a housing associated with battery 5. For example, battery 5 may include a housing 11 comprising any

suitable material for housing battery packs 10, e.g., of metal, plastic, composite, etc. Such a housing 11 may be configured to have one or more battery packs 10 placed and connected therein, and subsequently the housing 11 may be closed, e.g., by fastening (e.g., bolting) a cover onto an open portion of the housing 11.

[042] According to some embodiments, one or more bolts (not shown) may extend over a length or width of the housing and following placement of a cap (not shown) over the open portion of housing 11, a nut may be affixed to the one or more bolts and tightened, resulting in closure of the housing 11. One of ordinary skill in the art will understand that bolted configurations of this type may undergo a creep phenomenon in which changing stresses applied to the bolts over time result in permanent deformation of the bolts used for the fastening, and an expansion/enlarging of space within the internal cavity of battery 5 housing the battery packs 10. Therefore, pressure within the internal cavity of battery 5 changes based on expansion of the battery packs 10 and as a function of creep. Embodiments of the present disclosure take such creep and expansion into account as described below.

[043] Each battery pack 10 present in battery 5 may be connected in series or in parallel to other battery packs 10 present in battery 5. One of skill in the art will recognize that various criteria such as a desired voltage, a desired maximum current, etc. may be considered when designing a battery and connections as described herein.

[044] One or more pressure sensors 15 may be provided within battery 5. For example a pressure sensor 15 may be placed in between each battery pack 10 within battery 5, such that pressure arising due to expansion of each battery pack 10 may exert a force on the one or more pressure sensors 15 based on the amount of expansion. In addition, pressure sensors 15 may further be provided between an end of the housing 11 of battery 5 and the terminal battery pack 10 within battery 5.

[045] According to some embodiments, pressure sensors 15 may be positioned parallel to a laminated direction of the battery packs 10 within battery 5 (see Fig. 2).

[046] The number of pressure sensors included within battery 5 may be determined based on the number of battery packs 10, and/or any other criteria one of skill in the art may determine suitable. For example, where to battery

packs 10 are present within battery 5, one pressure sensor 15 may be placed between these two battery packs 10. Similarly where three battery packs are present within battery 5, two pressure sensors 15 may be placed within battery 5, a first pressure sensor 15 in between the first battery pack any secondary pack, and a second pressure sensor 15 placed in between the second battery pack and the third battery pack.

[047] Pressure sensor 15 may comprise any suitable pressure sensing device, and may be, for example, a tactile sensor having a thickness suitable for measuring expansion and contraction of battery packs 10. According to some embodiments a thickness of pressure sensor 15 may range between for example, 0.01mm to 1mm, and according to some embodiments, 0.1mm.

[048] Once the battery 5 has been assembled and closed, for example with a cover bolted to battery housing 11 as described above, an initial pressure $P_{initial}$ inside battery 5 may be measured at a plurality of open circuit voltages (e.g., OCVs corresponding to SOCs of between 10 and 100 percent at increments every 5 percent), and these values stored in memory of battery ECU 70. This value may be used throughout the life of battery 5 as a comparison to a current pressure P within battery 5, as measured by pressure sensors 15 and pressure detector 30.

[049] Fig. 2 shows an exemplary representation of an internal portion of a battery including pressure sensors. Arrows shown at figure 2 represent application of pressure forces on pressure sensors 15 as well as, at the external portion of the left and right battery packs 10, forces exerted on the walls of housing 11 battery 5 based on expansion of battery packs 10. One of skill in the art will understand that while battery packs 10 may also exert forces in the Y direction, for purposes of the present disclosure forces exerted in the X direction will be considered for determination of pressure within battery 5.

[050] Battery 5 may also include one or more dummy cells 25 conductively linked to battery packs 10 to permit measurement of an open circuit voltage V_{ocv} across the totality of battery packs 10 present within battery 5. For example, a dummy cell 25 configured to provide a dummy load may be connected in parallel with each of battery packs 10 present within battery 5, and the output (i.e., open circuit voltage) may be provided to sensor bank 27, and more particularly voltage detector 35. One of skill in the art will recognize that more than one dummy cell 25 may be provided, for example one dummy

cell for each battery pack 10 present in battery 5, and such a configuration may aid in determination of a faulty or failing battery pack 10.

[051] Figure 1B shows an exemplary schematic including dummy cell 25 connected with battery 5 and a switch 6 configured to close a connection of dummy cell 25 thereby engaging circuit 2. Closing of switch 6 thereby enables measuring an open circuit voltage V_{ocv} across circuit 2 shown in figure 1B, while normal operation of battery 5 (i.e. while not measuring an open circuit voltage V_{ocv} of battery 5) utilizes circuit 1.

[052] In addition to pressure sensors 15 and dummy cell 25, battery 5 may include additional sensors, for example one or more temperature sensors, current sensors, etc. Sensors present in battery 5 may be configured to provide signals to sensor bank 27, thereby enabling sensor bank 27 to monitor information associated with battery 5 during a charging and/or discharging process (e.g. open circuit voltage V_{ocv}, pressure, temperature, etc.) and to provide the information to battery ECU 70, among others.

[053] Sensor bank 27 may include a pressure value detector 30, a state of charge detector 45, a voltage detector 35, a temperature detector 40, among others. For example pressure sensors 15 may be configured to provide information to pressure value detector 30, in order to enable pressure value detector 30 to determine a pressure force being exerted on pressure sensor 15.

[054] Similarly voltage detector 35 may receive input from dummy cell 25 in order to determine an open circuit voltage V_{ocv} of battery 5, and/or of each individual battery pack 10 within battery 5.

[055] State of charge detector 45 may be configured to receive current information from a current sensor as well as voltage information from dummy cell 25 in order to determine a state of charge (SOC) of battery 5.

[056] Temperature detector 40 may be configured to receive information from a temperature sensor within battery 5 in order to determine the temperature of battery 5.

[057] Values from sensor bank 27 may be provided to battery ECU 70, with battery ECU 70 providing command signals battery controller 20 (e.g. charging control commands). For example battery ECU 70 may include a calculation unit 65 for determining a threshold pressure differential ΔP_T which may be calculated based on an open circuit voltage V_{ocv} of battery 5 as

measured by voltage detector 35 and a current pressure P within battery 5 as measured by pressure value detector 30 during a pre-charging process (i.e., before battery 5 begins charging). This will be described in greater detail below with reference to figures 4, 5A and 5B.

[058] Battery ECU 70 may further include a voltage comparison unit 60 configured for comparing a current voltage V as measured by voltage detector 35 (i.e., the open circuit voltage V_{ocv} of battery 5) with a predetermined initial maximum voltage V_{max} of battery 5. One of skill in the art understands that an intial maximum voltage V_{max} of battery 5 may be determined in advance based on a design of the battery, and stored in, for example, a read-only memory (ROM) associated with battery ECU 70, or another computer present on the vehicle. Further, for purposes of the present disclosure, it will be assumed that the current voltage V and open circuit voltage V_{ocv} of battery 5 at any particular point in time are equal.

[059] Pressure comparison unit 55 may also be provided in ECU 70 for comparing a pressure differential ΔP measured during the charging process by pressure value detector 30 (e.g. via repeated sampling by pressure value detector 30 of pressure sensors 15), with threshold pressure differential ΔP_T.

[060] Battery ECU 70 may include memory configured to store values obtained from sensor bank 27, among others. For example, battery ECU 70 may store pressure values obtained from pressure value detector 30, voltage values obtained from voltage detector 35, temperature values obtained from temperature detector 40, etc. as well as map values associated with data experimentally obtained from an exemplary battery design corresponding to the battery 5 installed in the vehicle.

[061] A history of values may be compiled and stored over the life of the battery 5 during use of the vehicle, and according some embodiments when the vehicle is stored (i.e., not being driven). By compiling such data it may be possible to determine the history of temperatures, voltages, pressures, etc. to which battery 5 has been subjected. Such a history may be used to augment processes described below for determining values to be used when compensating for creep.

[062] One of skill in the art will understand that the memory associated with battery ECU 70 may be comprised within battery ECU 70, or may be present

on and or in other systems of the vehicle providing communication access to battery ECU 70.

[063] Battery controller 20 may comprise any suitable battery controller configured to control a charging process resulting in the recharging the battery packs 10 associated with battery 5. As one of skill in the art understands, lithium ion batteries in particular require relatively strict charging circumstances to be maintained during a battery charging process in order to avoid dangerous conditions such as overheating and overcharging. Therefore, battery controller 20 may be configured to control current and voltage provided to battery 5 during the charging process, among others. For example, when it is determined that a battery is not fully charged battery controller 20 may provide a predetermined current I at a predetermined voltage suitable for charging battery 5.

[064] Fig. 3 is a flowchart showing one exemplary method for charge control according to embodiments of the present disclosure. In a pre-charging process (i.e. before charging a battery 5 begins) battery ECU may initially obtain a temperature of battery 5 as determined by temperature detector 40 based on information provided by a temperature sensor present in battery 5 (step 305).

[065] A current pressure P within battery 5 is then obtained from pressure value detector 30 based on information provided by pressure sensors 15 within battery 5 and an open circuit voltage V_{ocv} obtained by placing switch 6 in a position such that circuit 2 is engaged thereby permitting measurement of open circuit voltage V_{ocv} by voltage detector 35 (step 310).

[066] A threshold pressure differential ΔP_T may then be determined based on at least one of a temperature, open circuit voltage V_{ocv}, and the present pressure P of battery 5 (step 315). The process for determining the threshold pressure differential ΔP_T and compensating for creep will be discussed with reference to figures 4, 5A, and 5B.

[067] Fig. 4 is a flowchart showing one exemplary method for creep compensation using a current temperature T of battery 5, while Figs. 5A and 5B are representations of an exemplary experimentally determined data map relating temperature, pressure, and open circuit voltage V_{ocv} of an exemplary battery. As will be discussed, such maps may be used for determining a threshold pressure differential ΔP_T.

[068] The data map of figures 5A and 5B may be created in advance based on experimental data obtained on an exemplary battery 5 in an assembled condition and stored in memory of ECU 70. For example an assembled battery 5 may be subjected to various temperatures T (e.g. at increments of 10 degree C, between -40 degrees C and 60 degrees C) at predetermined intervals of open circuit voltages (e.g., an interval of 0.01 V).

[069] An internal pressure P of battery 5 may then be measured at each of these temperatures T and open circuit voltages. For each 10 degree C increment, a collection of map points demonstrating a relationship between open circuit voltage V_{ocv} and internal pressure of battery 5 at the particular temperature may be created and stored based on the measured pressure P at the open circuit voltage V_{ocv} increment. Such a collection of map points corresponds, to each of lines T1-Tx shown in Fig. 5A. Notably, temperatures falling between lines of the 10 degrees C lines (or any other selected interval) may then be interpolated by, for example, linear interpolation.

[070] In order to determine a threshold pressure differential ΔP_T, ECU 70 may obtain a current temperature T of battery 5 from temperature detector 40 (step 405). Based on the determined current temperature T of battery 5, ECU 70 may refer to the data map as generated above, see figure 5A, to select map data (i.e., an initial temperature line) for example, T1.

[071] Voltage comparison unit 60 may then obtain the current open circuit voltage V_{ocv} of battery 5, thereby enabling identification of a point along the selected map data (e.g., temperature line T1) shown at 5A.

[072] Pressure comparison unit 55 may then obtain a current pressure P within battery 5 from pressure value detector 30 and compare the current pressure P to determine whether it is less than the initial pressure $P_{initial}$ as measured at the same temperature following completion of battery assembly (step 410). If the current pressure P is equal to or within a reasonable tolerance (e.g., ± 5 bar, ± 10 bar, etc.) of the initial pressure $P_{initial}$, then the initially selected map data (e.g., temperature line T1) is used for determination of the applicable threshold pressure differential ΔP_T (step 420).

[073] Where the current pressure P is determined to be less than the initial pressure $P_{initial}$ for the current temperature and open circuit voltage V_{ocv}, creep has likely occurred and therefore new map data should be selected from the data map to compensate for creep (step 415).

[074] This compensation for creep may be performed, according to some embodiments, by traversing the y-axis directly from the initial pressure $P_{initial}$ to the point at the current pressure P and current open circuit voltage V_{ocv}. The intersection of this point on a collection of map data (e.g., temperature line Tx) may then be selected as the new map data. An exemplary representation of this determination can be seen at figure 5B. If the point P does not fall directly on a predetermined collection of mapped data, a temperature line Tx falling outside of a 10 degree C increment may be interpolated by, for example, linear interpolation at the current pressure P and the current open circuit voltage V_{ocv}.

[075] To determine the threshold pressure differential ΔP_T, a pressure change from the current pressure on the selected temperature line to a maximum pressure P_{max} on the same temperature line is calculated based on equation 1.

$$\Delta P_T = P_{max} - P \qquad \ldots(1)$$

[076] Where maximum pressure P_{max} is determined experimentally at a range of temperatures for an exemplary new battery 5 having 100 percent state of charge (i.e. an open circuit voltage V_{ocv} equivalent to the battery's full charge open circuit voltage V_{ocv}). Based on this, one of skill will recognize that P_{max} will be changed in accordance with which SOC is to be associated as V_{max}.

[077] Once the threshold pressure differential ΔP_T has been calculated by calculation unit 65, a charging process may begin, and battery controller 20 may allow current to begin flowing to battery 5 (step 320).

[078] During the charging process battery 5 may be continuously monitored (e.g., at a predetermined sampling rate) and voltage comparison unit 60 may receive information from voltage detector 35 indicating a current open circuit voltage V_{ocv} of battery 5. Voltage comparison unit 55 may compare the voltage V with an initial maximum voltage V_{max} determined based on the design characteristics of battery 5 and its intended 100 percent charged maximum voltage (step 325). This initial maximum voltage V_{max} may be stored in memory associated with battery ECU 70 for access by voltage comparison unit 60. Where the current voltage V is not greater than the initial maximum voltage V_{max} (step 325: no), battery controller 20 causes the charging process to continue uninterrupted for the present sample.

[079] When it is determined that the current voltage V is greater than or equal to the initial maximum voltage V_{max} (step 325: yes) a current pressure differential ΔP is determined based on equation 2.

$$\Delta P = P_x - P \quad \ldots(2)$$

[080] P_x being a current internal pressure of the battery 5 at a time t where the current voltage V has exceeded the initial maximum voltage V_{max}, and P being the pressure determined during the pre-charging process at step 315.

[081] Pressure comparison unit 55 may then compare the current pressure differential ΔP to the threshold pressure differential ΔP_T to determine whether the current pressure differential ΔP is greater than the determined threshold pressure differential ΔP_T (step 330). Where the current pressure differential ΔP is determined to be greater than or equal to the threshold pressure differential ΔP_T (step 330: yes), battery controller 20 may stop the charging process (i.e. stop flow of current to the battery 5).

[082] If it is determined that the current pressure differential ΔP is less than the threshold pressure differential ΔP_T (step 330: no) the initial maximum voltage V_{max} may be increased for the present charging cycle to V_{max}'. In other words based on the fact that the threshold pressure differential ΔP_T has not been exceeded, it can be reasonably assumed that the battery 5 has not reached a 100 percent state of charge, and therefore the maximum voltage V_{max} is currently too low to reflect 100% SOC with a present condition of battery 5. By basing the charge cycle on both V_{max} and ΔP_T, it becomes possible to better enable the battery to reach a 100% state of charge 100 and avoids loss of energy storage.

[083] Figure 6 shows exemplary graphs indicating a relationship between pressure, voltage, and available energy during a charging process, as described above.

[084] As shown in the lower graph figure 6 although the maximum voltage V_{max} may be reached, the current pressure differential ΔP has not exceeded the threshold pressure differential ΔP_T as determined at step 315. Therefore the maximum voltage V_{max} is increased (see 3 in the bottom graph of figure 6), and the battery 5 permitted to charge for an additional period of time, this additional charging corresponding to an otherwise lost amount of energy stored in battery 5.

[085] Throughout the description, including the claims, the term "comprising a" should be understood as being synonymous with "comprising at least one" unless otherwise stated. In addition, any range set forth in the description, including the claims should be understood as including its end value(s) unless otherwise stated. Specific values for described elements should be understood to be within accepted manufacturing or industry tolerances known to one of skill in the art, and any use of the terms "substantially" and/or "approximately" and/or “generally” should be understood to mean falling within such accepted tolerances.

[086] Where any standards of national, international, or other standards body are referenced (e.g., ISO, etc.), such references are intended to refer to the standard as defined by the national or international standards body as of the priority date of the present specification. Any subsequent substantive changes to such standards are not intended to modify the scope and/or definitions of the present disclosure and/or claims.

[087] It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims.

CLAIMS

1. A charging control system for a battery, comprising:
temperature sensing means configured to provide a temperature value associated with the battery;
voltage sensing means configured to provide a voltage value associated with the battery;
pressure sensing means configured to provide a pressure value associated with an internal portion of the battery; and
a controller configured to:
determine, before a charging process is started, a threshold pressure change associated with a full charge of the battery based on map data selected from a predetermined data map associated with the battery;
monitor, during the charging process, a present voltage value obtained by the voltage sensing means and a total pressure change based on a present pressure value obtained by the pressure sensing means;
continue the charging process when the present voltage value exceeds an upper limit voltage value, and the total pressure change is less than the threshold pressure change; and
terminate the charging process when the present voltage value exceeds the upper limit voltage value, and the total pressure change is greater than or equal to the threshold pressure change.

2. The method according to claim 1, wherein the selection of the map data is based on a pre-charging temperature value obtained from the temperature sensing means, a pre-charging voltage value obtained from the voltage sensing means, and a pre-charging pressure value obtained from the pressure sensing means.

3. The charging control system according to any of claims 1 and 2, wherein the controller is configured to increase the upper limit voltage value when the present voltage value exceeds the upper limit voltage value, and the total pressure change is less than the threshold pressure change.

4. The charging control system according to any of claims 1 to 3, wherein the controller is further configured to compensate for creep in one or more portions of the battery by modifying the selected map data based on an initial internal pressure measurement, the pre-charging process pressure value, and the pre-charging temperature value.

5. The charging control system according to claim 4, wherein the controller is configured to compare the initial internal pressure measurement and the pre-charging pressure value, and when the initial internal pressure measurement is greater than the pre-charging process pressure value, select new map data associated with the pre-charging pressure value.

6. The charging control system according to claim 5, wherein the predetermined map comprises a collection of experimentally measured internal pressures, open circuit voltages, and temperatures of a representative battery under representative conditions of use of the battery.

7. The charging control system according to any of claims 1 to 6, wherein the pressure sensing means comprises at least one tactile sensor embedded in the battery.

8. The charging control system according to claim 7, wherein the at least one tactile sensor is positioned parallel to a laminated direction of a battery cell of the battery.

9. The charging control system according to any of claims 1 to 8, further comprising a state of charge sensor configured to determine a state of charge of the battery.

10. The charging control system according to any of claims 1 to 9, wherein the voltage sensing means comprises a dummy cell connected to one or more battery packs associated with the battery.

11. The charging control system according to any of claims 1 to 10, wherein the voltage value is an open circuit voltage of the battery.

12. The charging control system according to any of claims 1 to 11, wherein the battery comprises at least one of a lithium-ion solid-state battery and a lithium-ion liquid electrolyte battery.

13. A vehicle comprising the charging control system according to any of claims 1 to 12.

14. A method for charging a battery, comprising:
determining a temperature value associated with the battery;
determining a voltage value associated with the battery;
determining a pressure value associated with an internal portion of the battery;
determining, before a charging of the battery is started, a threshold pressure change associated with a full charge of the battery based on map data selected from a predetermined data map associated with the battery;
charging the battery;
monitoring, during the charging, a present voltage value obtained by the voltage sensing means and a total pressure change based on a present pressure value obtained by the pressure sensing means;
continuing the charging when the present voltage value exceeds an upper limit voltage value, and the total pressure change is less than the threshold pressure change; and
terminating the charging when the present voltage value exceeds the upper limit voltage value, and the total pressure change is greater than or equal to the threshold pressure change.

15. The method according to claim 14, wherein the selection of the map data is based on a pre-charging temperature value obtained from the temperature sensing means, a pre-charging voltage value obtained from the voltage sensing means, and a pre-charging pressure value obtained from the pressure sensing means.

16. The method according to any of claims 13 to 14, comprising increasing the upper limit voltage value when the present voltage value

exceeds the upper limit voltage value, and the total pressure change is less than the threshold pressure change.

17. The method according to any of claims 14 to 16, comprising compensating for creep in one or more portions of the battery by modifying the selected map data based on an initial internal pressure measurement, the pre-charging process pressure value, and the pre-charging temperature value.

18. The method according to claim 17, comprising comparing the initial internal pressure measurement and the pre-charging pressure value; and when the initial internal pressure measurement is greater than the pre-charging process pressure value, selecting new map data associated with the pre-charging pressure value.

19. The method according to claim 18, wherein the predetermined map comprises a collection of experimentally measured internal pressures, open circuit voltages, and temperatures of a representative battery under representative conditions of use of the battery.

20. The method according to any of claims 14 to 19, comprising determining a state of charge of the battery and modifying the threshold pressure change based on the state of charge of the battery before the charging is started.

21. The method according any of claims 14 to 20, wherein the battery comprises at least one of a lithium-ion solid-state battery and a lithium-ion liquid electrolyte battery.

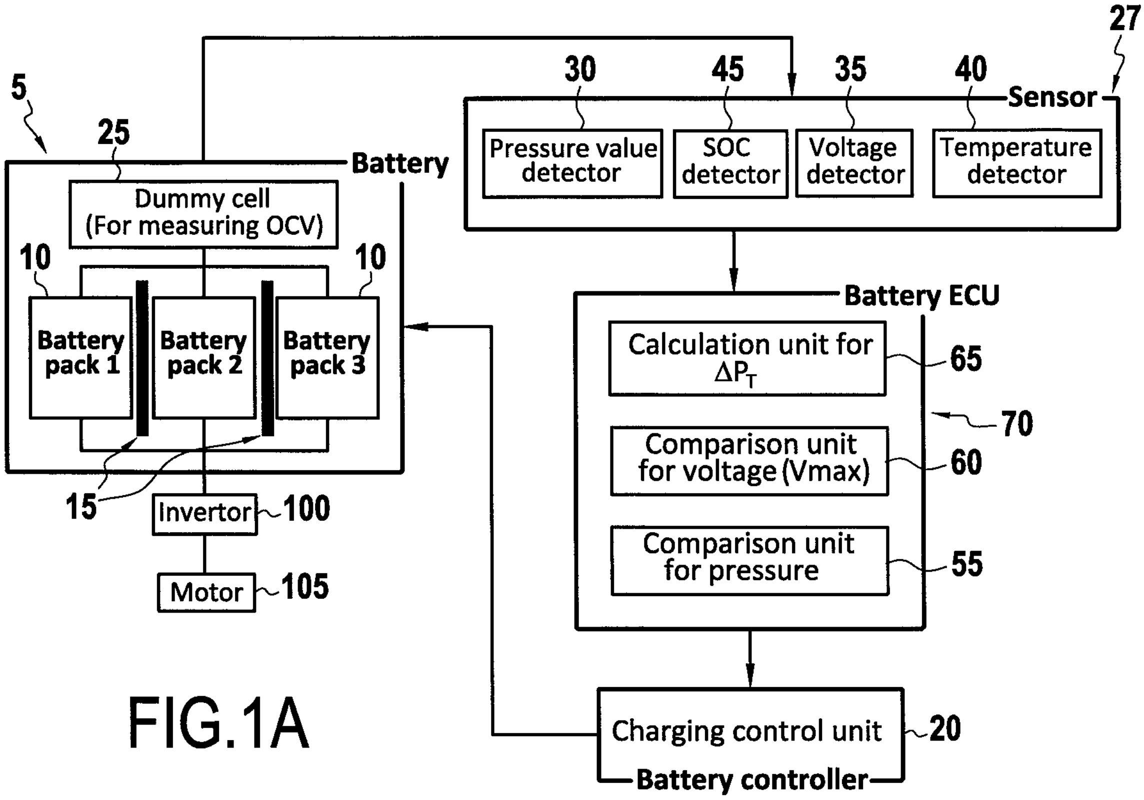

FIG.1A

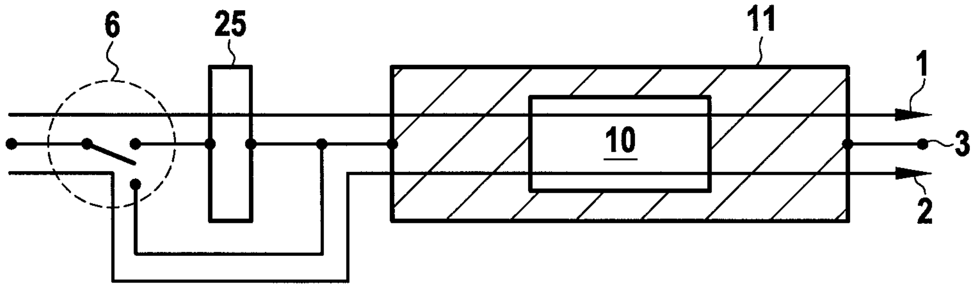

FIG.1B

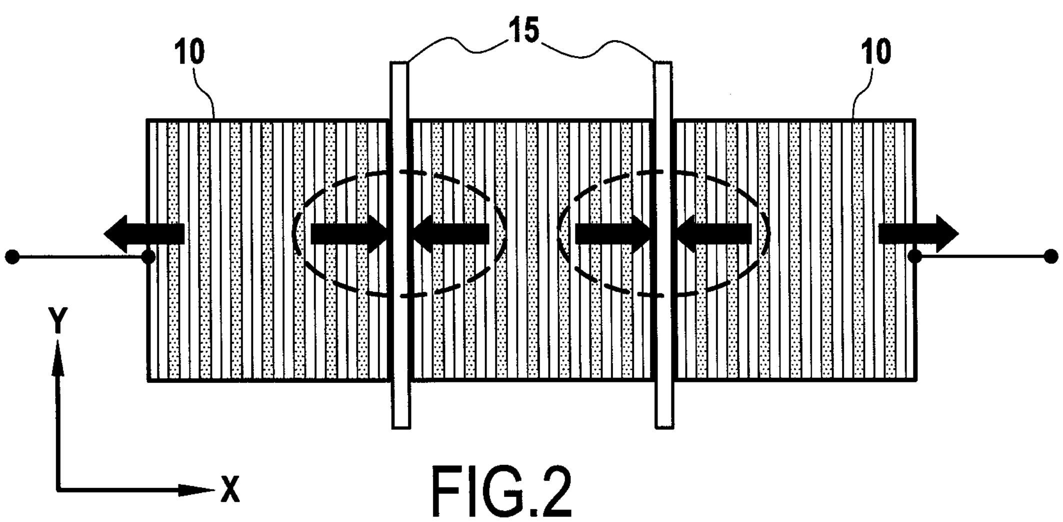

FIG.2

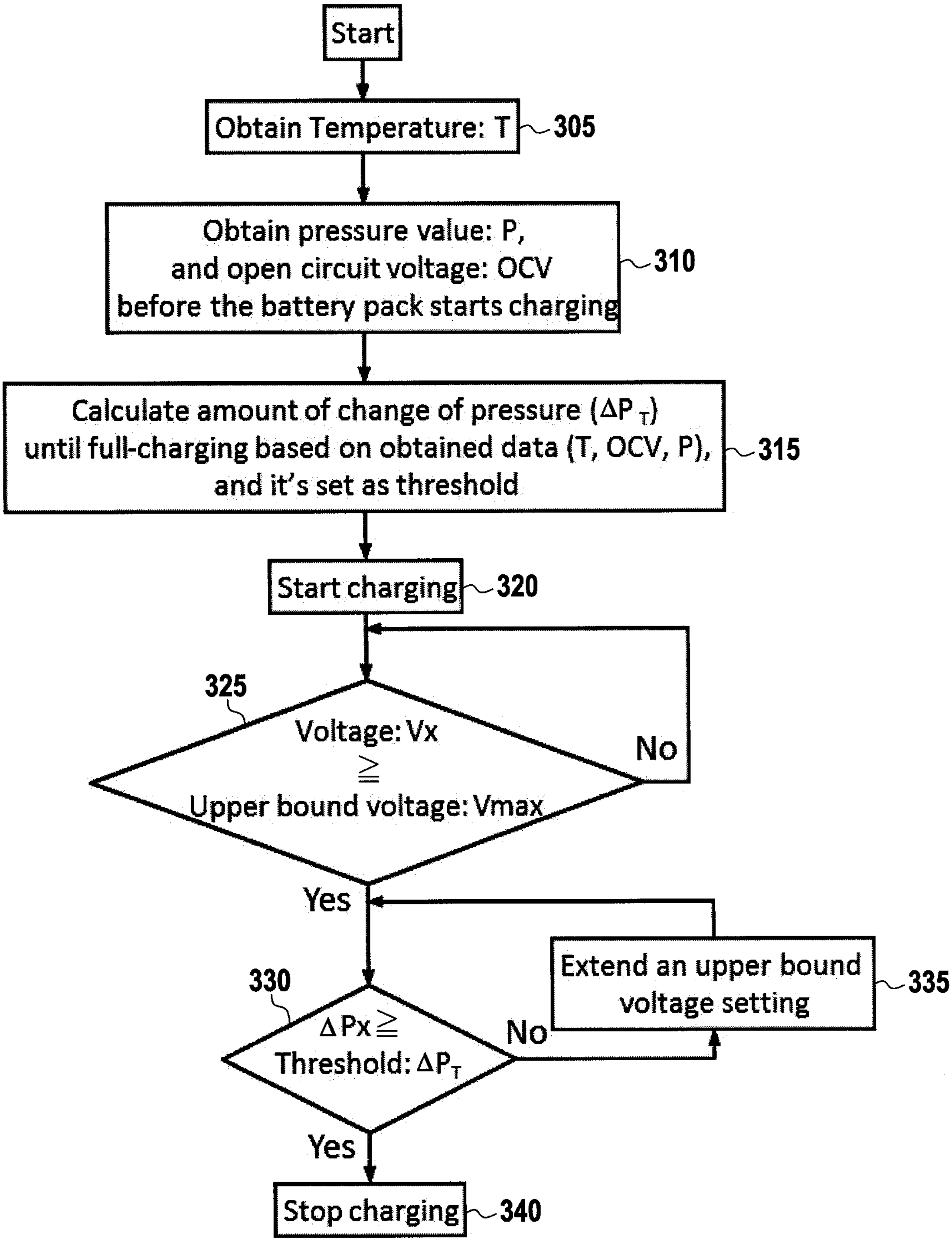
Start
Obtain Temperature: T
305
Obtain pressure value: P, and open circuit voltage: OCV before the battery pack starts charging
310
Calculate amount of change of pressure (ΔP T) until full-charging based on obtained data (T, OCV, P), and it's set as threshold
315
Start charging
320
325
Voltage: Vx ≧ Upper bound voltage: Vmax
No
Yes
330
ΔPx ≧ Threshold: ΔPT
No
Extend an upper bound voltage setting
335
Yes
Stop charging
340

FIG.3

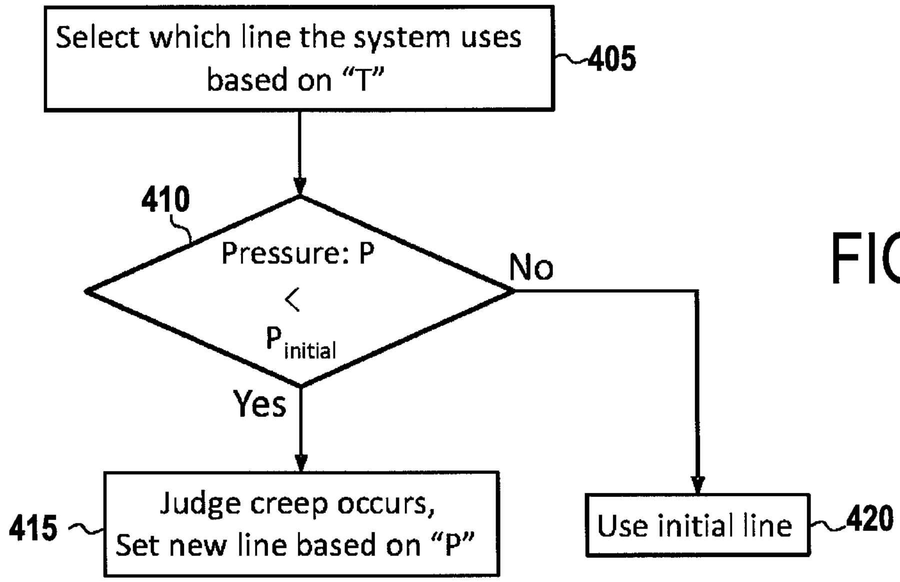

FIG.4

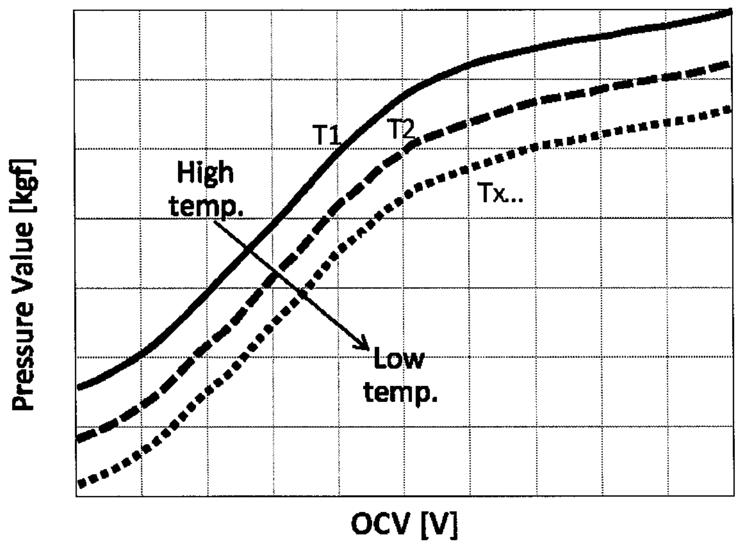

FIG.5A

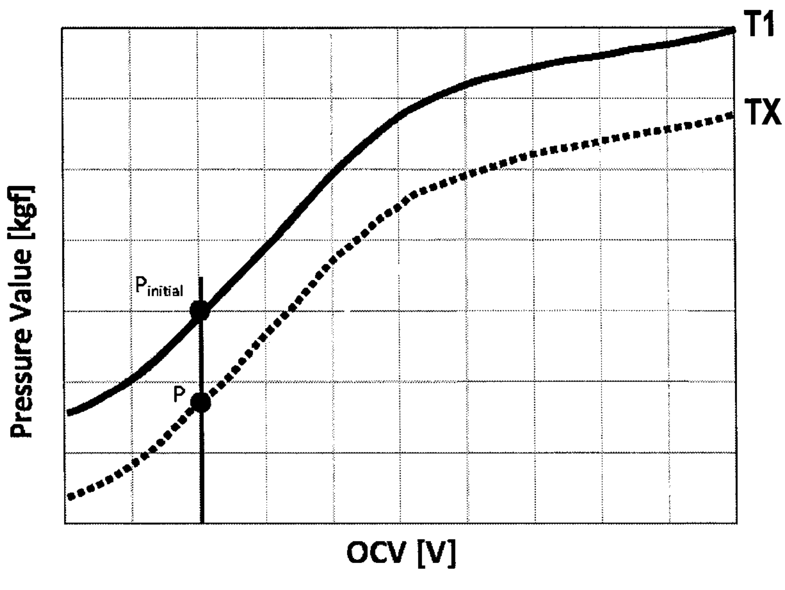

FIG.5B

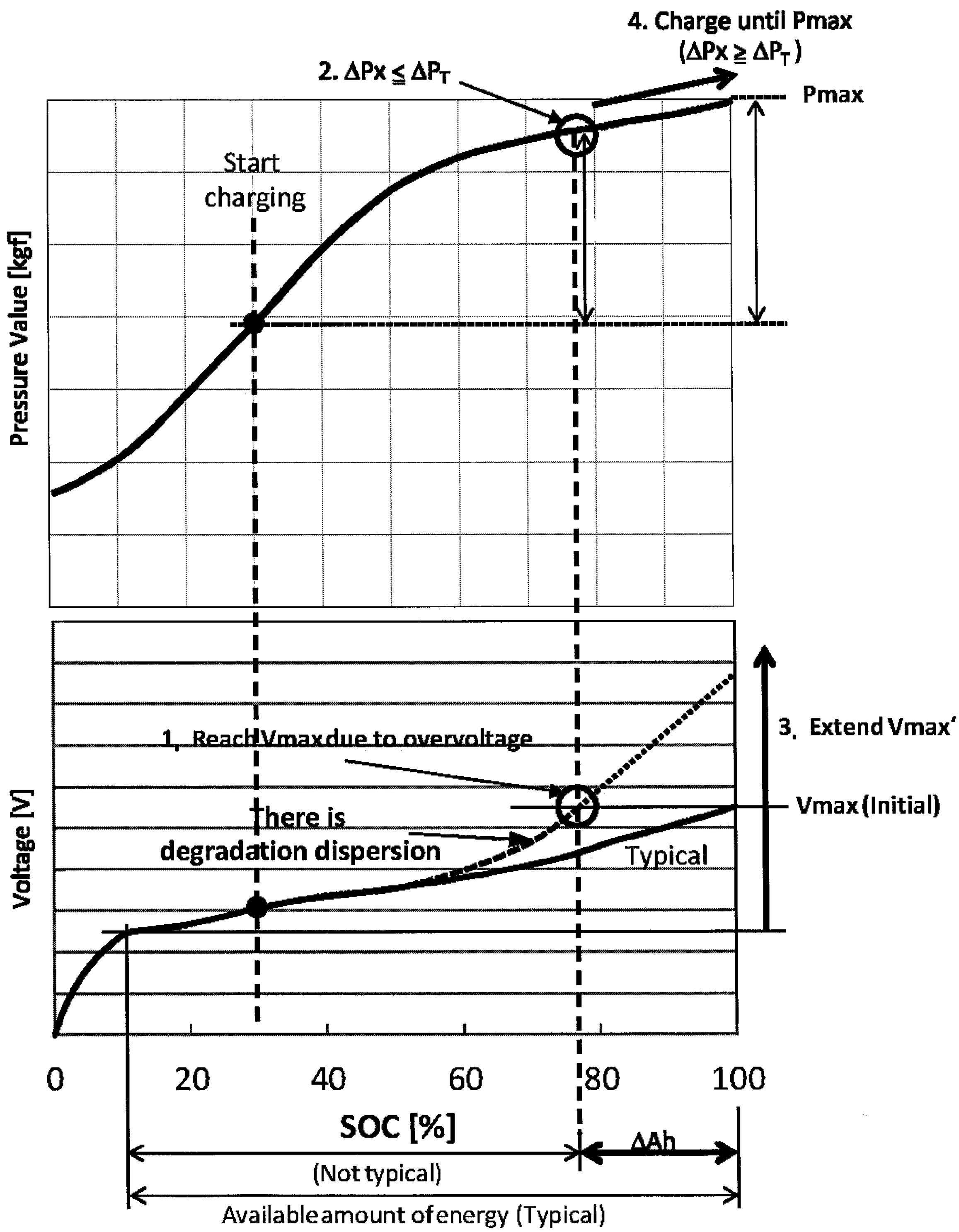
4. Charge until Pmax
(ΔPx ≥ ΔPT)
2. ΔPx ≤ ΔPT
Pmax
Start
charging
Pressure Value [kgf]
3. Extend Vmax'
1. Reach Vmax due to overvoltage
Vmax (Initial)
There is
degradation dispersion
Typical
Voltage [V]
0
20
40
60
80
100
SOC [%]
ΔAh
(Not typical)
Available amount of energy (Typical)

FIG.6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/053330

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02J7/00 B60L11/18 H02J7/14
ADD.

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)
H02J B60L H01M

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)

EPO-Internal, WPI Data, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 094 033 A (DING YI [US] ET AL) 25 July 2000 (2000-07-25) abstract column 6, line 23 - line 38; figure 10 column 7, line 63 - column 8, line 15 -----	1-21
A	EP 1 246 336 A2 (JAPAN STORAGE BATTERY CO LTD [JP]) 2 October 2002 (2002-10-02) paragraph [0014] - paragraph [0015]; figures 9-11 -----	1-21
A	KR 2016 0006443 A (HYUNDAI MOBIS CO LTD) 19 January 2016 (2016-01-19) abstract -----	1-21
A	US 2014/199569 A1 (SISK BRIAN C [US]) 17 July 2014 (2014-07-17) paragraph [0066] - paragraph [0068]; figures 2-4 -----	13

☐ 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 but 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
4 October 2016	12/10/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Braccini, Roberto

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/053330

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 6094033	A	25-07-2000	NONE			
EP 1246336	A2	02-10-2002	EP	1246336	A2	02-10-2002
			EP	1667308	A2	07-06-2006
			EP	2278682	A1	26-01-2011
			JP	4019734	B2	12-12-2007
			JP	2002359008	A	13-12-2002
			US	2003052647	A1	20-03-2003
KR 20160006443	A	19-01-2016	NONE			
US 2014199569	A1	17-07-2014	US	2014199569	A1	17-07-2014
			WO	2014109893	A1	17-07-2014