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THERMAL RUNAWAY DETECTION AND/OR PREVENTION

(57)

The present disclosure relates to a battery, comprising: at least one battery cell; a sensor associated with the at least one battery cell; and a safety system associated with the sensor and the battery, wherein the safety system is configured to generate a warning and/or shut down signal based on a signal from the sensor. Further, the sensor is a deformation sensor.

The deformation sensor may comprise at least one sensor from a group, comprising:

pressure sensors, flexible force sensors, stress sensors, strain sensors, deformation sensors, bending sensors, piezo-electric elements, volume change sensors, capacitive sensors, position measurement sensors, shape sensors or any similar elements or components capable of generating a detection signal indicative of a change in the form or shape of the battery cell.

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THERMAL RUNAWAY DETECTION AND/OR PREVENTION

The present disclosure relates to batteries, comprising: at least one battery cell; a sensor associated with the at least one battery cell; and a safety system associated with the sensor and the battery, wherein the safety system is configured to generate a warning and/or shut down signal based on a signal from the sensor.

If a battery cell, in particular a Lithium-Ion battery, is overheated, overcharged, exhibits a production flaw or fault, is punctured or otherwise damaged, a fire hazard, such as a thermal runaway, can occur. When this happens, the cell heats up very quickly because the reaction generates more heat, which in turn will increase the reaction speed, which will generate even more heat and so on. The product of this reaction and the heat is a large amount of flammable gas that will be vented from the cell. This gas could potentially cause a fire or explosion.

Such batteries have measures in place to prevent this, such as a battery management system that continuously or at least regularly monitors at least one of voltage with a voltage sensor, current with a current sensor and temperature with a temperature sensor, so that excessive temperature, overcharging and overvoltage are prevented. However, problems may still occur when such a conventional system fails entirely or fails to identify problems even when functioning to specification. This can occur for example, when a cell develops a small leak, through which flammable electrolyte gasses are vented. Such a problem will not be detected by measuring current, voltage and/or temperature. Further, performance of known system leaves to be desired in terms of time available after detection of events potentially leading up to a the thermal runaway, in that warnings are generated – even with such known systems functioning to specification – only very shortly before thermal runaway actually occurs. Some embodiments of temperature sensors are relatively complex and costly to be sufficiently reliable and accurate, and in a battery comprising a plurality of cells, temperature sensors would need to be linked with all cells, raising costs and complexity to practically and commercially unacceptable levels, or the battery would have to include a concession in terms of combining a number of cells to be monitored by any single temperature sensor, but then each temperature sensor is very likely to be remote from a cell where thermal runaway is impending, and/or could the cut-off threshold temperature would have to be lowered to a level where normal operation could also be interpreted as an indication of impending thermal runaway. Cheaper and less accurate temperature sensors are available, but would prove even less effective in as far as an advance warning about an impending thermal runaway is concerned. As a known safety measure when using a temperature sensor, a threshold temperature as an indicator for a thermal runaway is set relatively low, to ensure with more certainty that

thermal runaway is detected with some time to try to prevent it from actually occurring. However, on the downside, batteries are then often switched off unnecessarily under circumstances which would not lead unchecked to a thermal runaway. Furthermore, the phenomenon of thermal runaway is often triggered already at even lower temperatures than such a threshold temperature, so that the lower threshold buys more time at the cost of potentially switching off during normal operation, and without any certainty of being able to prevent a thermal runaway from actually occurring.

As an alternative or additional measure, it has been proposed to include a gas sensor, but when gas is detected, explosion or fire could instantaneously thereafter occur. Gas detection is by definition too late.

A thermal runaway is undesirable under any circumstance. However, in particular also in Marine environment on vessels or ships, electric propulsion is lately being applied, wherein at least one electric motor is powered using batteries. As is well known to the skilled person in the field of Marine applications, a fire and in particular an electric fire, which is even more difficult to fight than a conventional fuel fire, on a ship or vessel is extremely dangerous and must be avoided practically at all costs. Unnecessary switch off of batteries may be considered – in a marine environment – to be less undesirable than an electric fire, but leaves a ship or vessel potentially unpowered and without propulsion, resulting an extremely situation nonetheless.

The reason for an electric fire to be more difficult to fight than a conventional fire, is as follows. Figure 14 exhibits a schematic representation of a battery cell, comprising a carbon anode where heating starts at 1, when a battery heads to a thermal runaway state, causing protective layer breakdown at 2, breakdown of electrolyte (lithium salt in organic solvent in case of a Li-Ion battery cell) into flammable gasses at 3, and melting of separator, possibly causing a short circuit, at 4. Such phenomena are also encountered in other types of battery cells for example with Li-Tatanate or other anode materials. Also, in the exemplary case of Li-Ion battery cells, the Lithium metal oxide cathode breaks down, freeing oxygen, and forming with the freed flammable gasses from the electrolyte a combustible or even explosive combination. The reason for such electric fires to be so hard to fight, is that electric fires fuel themselves with flammable gasses from the electrolyte and oxygen from the cathode, so that cutting off oxygen supply to an electric fire will not suffice to smother the fire and when a fire starts, it develops out of control.

Figure 15 shows how thermal runaway in one cell of one battery – potentially in a series of batteries – may inflame adjoining or neighbouring cells and even batteries. For the result in the

graph of Figure 15, a temperature based safety system was disabled and thermal runaway caused by intentional overcharging or any other cause. The graph shows the thermal runaway effect occurring within second, and that temperature is an inherently unsuitable parameter for thermal runaway detection and/or prediction, because thermal runaway is already triggered at approximately 25°C, far below any threshold that can be set for detection and/or prediction, which would preclude normal operation as well.

Batteries of the present disclosure have been developed with the objective of providing improved batteries that are less susceptible to thermal runaway, or at least allow earlier, more reliable and generally improved detection and/or prevention of impending thermal runaway, and to this end, batteries according to the present disclosure exhibit all features of the appended independent battery claim.

Through the implementation of a deformation sensor, earlier warning can be generated of an impending thermal runaway in a much more accurate and reliable manner, being much more reliably indicative of a situation that could result in thermal runaway, such as overcharging, overheating, production faults, punctures and/or other damage.

Novel detection of deformation of battery cells has unexpectedly and inventively yielded very useful effects and insights about impending thermal runaway, as well as the means to timely generate a detection of prediction signal, based on which the safety system may adapt control of the battery and/or the individual battery cell or even force a shut down thereof. More in detail, the first tell tale signs of impending thermal runaway based on deformation measurements using a flexible force sensor were detected – during confidential testing – 15 to 25 minutes before actual thermal runaway occurred, and a pressure sensor in or on the battery cell yielded reliable detection signals of impending thermal runaway more than two minutes prior to actual thermal runaway from occurring. Thus it is clear, also from the temperature based graphic of figure 15, that detection through deformation of a battery cell by far in time precedes a detectable upswing of the temperature, which could be caused also within normal operational parameters and would enable unjustified shut down.

Many additional and/or alternative sensors indicative of deformation of a battery cell may be employed, such as pressure sensors, flexible force sensors, stress sensors, strain sensors, deformation sensors, bending sensors, piezo-electric elements, volume change sensors, capacitive sensors, position measurement sensors, or any similar element or component capable of generating a detection signal indicative of a change in the form or shape of the battery cell.

Sensors may monitor size and/or shape of any battery cell in isolation, but also in relation to an environment thereof, such as neighbouring battery cells or a battery housing, for example by measuring an instantaneous distance of the battery cell to a neighbouring battery cell or an inner wall of the battery housing. Such sensors may be as simple as an electrically conductive wire around a battery cell in at least one orientation, through which a low current may be passed. If the cell deforms, and in particular: swells, the wire breaks or is stretched, with an associated increase or decrease of the resistance of the wire indicating the swelling of the battery cell and allowing a detection result that the cell is about to enter into a state of thermal runaway, well in time to adjust battery cell control and/or effect shut down. Conversely, the deformation sensor may be configured to detect a reduction in size, associated with venting. Thus deformation sensors are able to detect swelling associated with overheating, overcharging and the like, while a subsequent reduction in size is indicative of venting, together enhancing the conclusion that the cell is in thermal runaway. A simple implementation of such deformation sensor is a conducting pad with high impedance that changes with stretch and/or compression. This pad will have a flexible PCB attached that enables the measurement of the impedance of the pad. In may, if not most, if not all embodiments, deformation sensors can be realised cost effectively and can be easily integrated in batteries and safety systems thereof.

An alternative embodiment of a deformation sensor has the form of a pressure sensor. The benefits of the pressure sensor are that an early warning signal of internal cell failures is generated. Confidential tests have shown more than 15 minutes of warning time during an overcharge test. Many mechanisms are detectable, such as detection of many failure mechanisms in the cell, amongst which overcharge, leakage, internal shorts. Moreover, such pressure sensors exhibit marked advantages, such as low cost implementation, low energy consumption, small build volume, and reference is made here to for example US4503705A, while more and other examples of commercially available pressure sensors are shown in figures 16 - 18.

In a similar manner, using for example a pressure sensor, also bending can be measured. If the sensor is bent, the cell is swollen as a precursor of thermal runaway. A piezo-element can detect pressure and can be used in a similar way. A sensor can be used that detects a change in volume, e.g. a flow of gas/liquid, to detect swelling of the battery cell. A capacitive sensor may be used to detect a change in the cell. A position measurement sensor may be used to detect displacement of (a) part(s) of the cell

The present invention is further elucidated in the following description with reference to the accompanying schematic figures, in which:

Figure 1 shows a battery according to the invention in perspective view;

Figure 2 shows the battery of figure 1 in perspective view with parts taken away in order to show the battery cell stack inside the battery;

Figure 3 shows the battery cell stack of figure 2 in perspective view;

Figure 4 shows the battery cell stack of figure 2 in exploded view;

Figures 5 to 13 show steps of an embodiment of the method for assembling the battery cell stack of figure 2;

Figure 14 exhibits a schematic representation of a battery cell to clarify the mechanism of a thermal runaway, discussed above;

Figure 15 shows the manner in which thermal runaway in one cell of a battery inflames neighbouring cells and even batteries, as discussed above; and

Figures 16 – 18 show typical embodiments of commercially available pressure sensors.

Figures 1 and 2 show a battery 1. The battery 1 has a container 3 having a bottom wall 5 and four side walls 7 extending from the bottom wall 5. The edges of the side walls 7 opposite to the bottom wall 5 together form the circumferential edge 9 of an opening 11 of the container 3. The container 3 thus has a closed bottom 3a and an open top 3b. The open top 3b is closed by a lid 13. The lid 13 has a circumferential flange 15 that is arranged on a circumferential flange 17 of the circumferential edge 9 of the opening 11. The lid 13 and the container 3 are coupled by means of fasteners 19 that fasten the flange 17 of the container 3 to the flange 15 of the lid 13. A seal 19 is arranged between flange 15 and flange 17.

In the container 3 is arranged a battery cell stack 21. In the container 3 is also arranged a circuit board assembly 23 that is part of a battery management system for the battery cell stack 21.

Arranged on the lid 13 are two main connectors, a positive main connector 25 and a negative main connector 27. The positive main connector 25 is electrically connected inside the container 3 to a positive terminal 29 of the battery cell stack 21 via a positive lead (not shown). The negative main connector 27 is electrically connected inside the container 3 to a negative terminal 31 of the battery cell stack 21 via a negative lead (not shown). The positive main connector 25 and a negative main connector 27 are configured for electrically connecting the battery cell stack 21 to electrical components of an electrical system. Arranged on the lid 13 are two battery management connectors 33, 35 that are electrically connected inside the container 3 to the circuit board assembly 23. The battery management connectors 33, 35 are configured for

electrically connecting the battery cell stack 21 to components of a battery management subsystem of the electrical system to which the battery cell stack 21 is connected via the main connectors 25, 27.

In figure 3 the battery cell stack 21 is shown, with the lid 17, the container 3 and the circuit board assembly 23 removed. In figure 3 is shown that the battery cell stack 21 is at its upper end 21a provided with a frame 37 that has two flanged frame elements 39, 41. In figure 2 is shown that the flanged frame elements 39, 41 are supported by the side walls 7 of the container and are more in particular arranged on the flange 17 of the circumferential edge 9 of the container 3. The lower end 21b of the battery cell stack is arranged in the container 3 and is located near the bottom wall 5 of the container 3. As shown in figure 2, the battery cell stack 21 is coupled to the container 3 near the bottom wall 5 thereof via a layer 43 of cured resin in which the lower end 21b of the battery cell stack 21 is submerged.

In figure 3 is shown that when the circuit board assembly 23 of the battery management system is removed, battery management terminals 45 are revealed that electrically connect the battery cells of the battery cell stack 21 to the circuit board assembly 23 of the battery management system, as will be explained in more detail herein below under reference to figures 5 to 13.

In figure 4 an exploded view is shown of the battery cell stack 21 that is shown in figure 3. In figures 3 and 4 the battery cell stack 21 is shown having fourteen battery cells 47. The battery cells 47 are flat and have a substantially rectangular front face 47a and rear face 47b. Each battery cell 47 has a positive tab 49 and the negative tab 51 that are arranged along one edge of the front and rear face. The battery cells 47 are stacked such that of each pair of neighbouring battery cells 47 the front face or rear face of one of the pair of battery cells 47 faces the front face or rear face of the other one of the pair of neighbouring battery cells 47. Each battery cell 47 is arranged between two separation sheets 53.

The battery cells 47 are oriented in the stack of battery cells 47 such that for each pair of neighbouring battery cells 47, the positive tab 49 of one of the pair of battery cells 47 neighbours the negative tab 51 of the other one of the pair of battery cells 47. As shown in figure 4, as a result, there are two rows 55, 57 of tabs 47, which rows 55, 57 extend parallel to each other in the stacking direction A, wherein each row 55, 57 has alternately positive tabs 49 and negative tabs 51.

Arranged adjacent the stack 59 of battery cells 47, there are two stacks 61, 63 of clamp bars 65. Of each two neighbouring battery cells 47 of the stack 59 of battery cells 47, one of the

tabs 49, 51 of one of the two battery cells 47 and one of the tabs 49, 51 of the other one of the two battery cell 47 are clamped against each other between a pair of neighbouring clamp bars 65 of the first stack 61 of clamp bars or between a pair of neighbouring clamp bars 65 of the second stack 63 of clamp bars. The first stack 61 of clamp bars 65 is associated with the first row 55 of tabs 49, 51. Each pair of neighbouring clamp bars 65 of the first stack 61 of clamp bars 65 has clamped there between a positive tab 49 and a neighbouring negative tab 51 of the first row 55 of tabs 49, 51. The second stack 63 of clamp bars 65 is associated with the second row 57 of tabs 49, 51. Each pair of neighbouring clamp bars 65 of the second stack 63 of clamp bars has clamped there between a positive tab 49 and a neighbouring negative tab 51 of the second row 55 of tabs 49, 51.

Thus, the battery cells 47 of the stack 59 of battery cells 47 are electrically connected in series.

The positive tab 49 of the final battery cell 47 at the first end 59a of the stack 59 of battery cells 47 is clamped between the final clamp bar 65a of the first stack 61 of clamp bars 65 at the first end 61a of the first stack 61 of clamp bars and a first end bar 67. The final clamp bar 65a of the first stack 61 of clamp bars has a recess 69 wherein a part of the positive terminal 29 is arranged, such that the positive tab 49 of the final battery cell 47 at the first end 59a of the stack 59 of battery cells 47 is clamped against the part of the positive terminal 29 that is arranged in the recess 69. The positive tab 49 of the final battery cell 47 at the first end 59a of the stack 59 of battery cells 47 is thus electrically connected to the positive terminal 29.

The negative tab 51 of the final battery cell 47 at the second end 59b of the stack 59 of battery cells 47 is clamped between the final clamp bar 65b of the first stack 61 of clamp bars 65 at the second end 59b of the first stack 59 of clamp bars and a neighbouring previous clamp bar 65 of the first stack of clamp bars. The final clamp bar 65b of the first stack 61 of clamp bars 65 has a recess (not shown) wherein a part of the negative terminal 31 is arranged, such that the negative tab 51 of the final battery cell 47 at the second end 59b of the stack 59 of battery cells 47 is clamped against the part of the negative terminal 31 that is arranged in the recess. The negative tab 51 of the final battery cell 47 at the second end 59b of the stack 59 of battery cells 47 is thus electrically connected to the negative terminal 31.

As shown in figure 4, each clamp bar 65 and the first end bar 67 has a clamping face 73 that is provided with a conductive element 75, such that one of the opposing clamping faces of neighbouring clamp bars 65 between which the positive tab 49 and negative tab 51 of neighbouring battery cells 47 are clamped is provided with the conductive element 75. The conductive element 75 is at one end thereof in conductive contact with one of the positive tab 49 and negative tab 51

that are clamped between the neighbouring clamp bars 65, while the other end of the conductive element 75 embodies one of the battery management terminals 45 and is configured as an electrical connector.

Together with a first leaf spring element 79 and a second leaf spring element 81, the clamp bars 65, the first end bar 67 and a second end bar 71 are arranged on the frame 37. The frame 37 comprises the flanged frame elements 39, 41 that extend parallel to the clamp bars 65 and to the end bars 67, 71. The frame 37 further comprises two frame elements 83, 85 that extend perpendicular to the flanged frame elements 39, 41 and along opposite sides of the combined stacks 61, 63 of clamp bars 65. The frame elements 83, 85 have on their sides facing the ends of the clamp bars 65 a C-shaped cross section. The ends of the clamp bars 65 are received between the legs of the C-shaped cross section.

The first leaf spring element 79 is arranged between the first flanged frame element 39 and the first end bar 67. The second leaf spring element 81 is arranged between the second flanged frame element 41 and the second end bar 71 that is arranged on the final clamp bars of the first stack 61 and second stack 63 of clamp bars. The first leaf spring element 79 and the second leaf spring element 81 are oriented such that the spring elements can be compressed in the stacking direction of the first and second stack 61, 63 of clamp bars 65. Both leaf springs 79, 81 have two spring parts, a first spring part located between the rods 87 and 89, and a second spring part located between the rods 89 and 91.

The clamp bars 65, the first end bar 67, the second end bar 71, and the flanged frame elements 39, 41 have holes 77 arranged therein through which holes 77 rods 87, 89, and 91 extend. The rods 87, 89, 91 are coupled at the ends thereof to the flanged frame elements 39, 41, by means of a pull arrangement that allows to pull the flanged frame elements 39, 41 toward each other, wherein the rods 87, 89, 91 serve as tie-rods. Here the pull arrangement is embodied by bolts 93 that engage a threaded axial hole in the rods 87, 89, 91. The bolts 93 extend through holes 77 in an end plate 95. The heads of the bolts 93 contact the end plate 95. By screwing the bolts 93 into the threaded holes in the rods 87, 89, 91, the end plates 95 are pushed against the flanged frame elements 39, 41, such that the flanged frame element 39 is pulled towards the flanged frame element 41. By pulling the flanged frame element 39 towards the flanged frame element 41, the first leaf spring element 79 and the second leaf spring element 81 are compressed. The clamp bars 65 arranged between the first leaf spring element 79 and the second leaf spring element 81 are clamped against each other by means of the compression force that results from compressing the first leaf spring element 79 and the second leaf spring element 81. Each pair of positive tab 49 and

negative tab 51 that is arranged between two neighbouring clamp bars 65 is thus clamped against each other the influence of the compression force that results from compressing the first leaf spring element 79 and the second leaf spring element 81.

5 The rods 87, 89, 91 do not only serve as tie-rods. By extending through the holes 77 of the clamp bars 65, the rods 87, 89, 91 couple neighbouring clamp bars 65 in each stack 61, 63 of clamp bars, such that relative movement between neighbouring clamp bars 65 in each stack 61, 63 of clamp bars in a direction perpendicular to the direction of stacking is prevented.

10 As shown in figure 4, each battery cell 47 is arranged between two separation sheets 53. The separation sheets 53 are at the end 53a thereof that is near the positive tab 49 and negative tab 51 of the battery cell 47 coupled to the frame 37 on which the clamp bars 65 are arranged. In particular the separation sheets 53 that are arranged between two battery cells 47 are provided with tabs 97. Each tab 97 is provided with a hole 77 and extends in a slot 99 provided in a respective
15 clamp bar 65 or in a slot 101 provided in the clamping face of a respective clamp bar 65, such that the hole 77 of the tab 97 aligns with the hole 77 in the clamp bar 65. One of the rods 87, 91 extends through the hole 77 of the tabs 97, such that the separation sheets 53 provided with the tabs 97 are coupled to the clamp bars 65 and to the frame 37 via the rods 87, 91. Each pair of separation sheets 53 on opposite sides of a battery cell 47 are coupled to each other at the end 53b opposite to the
20 clamp bars 65 and are spaced apart by means of at least one spacer element 103 arranged between the separation sheets 53. The spacer element is arranged such that it supports the battery cell 47 along the edge 47c thereof opposite the positive tab 49 and negative tab 51. In the embodiment shown in figure 4 all separation sheets 53 and spacer elements 103 have holes 105 arranged therein through which threaded rods 107, 109, and 111 extend. The threaded rods 107, 109, 111 couple the
25 separation sheets 53 and the spacer elements 103. Nuts 113 are arranged on the ends of the threaded rods 107, 109, 111. As shown in figure 4, there are also spacer elements 115 arranged between the separation sheets 53 at the end 53a of the separation sheets 53. Threaded rods 117, 119 are arranged through holes 121 in the separation sheets 53 and the spacer elements 115 for coupling the separation sheets 53 and the spacer elements 115. Nuts 125 are arranged on the ends
30 of the threaded rods 117, 119.

In figures 5 to 13, steps of an embodiment of the method for assembling the battery cell stack 21 are shown.

35 In figure 5 the first flanged frame element 39 is shown having mounted thereon the three rods 87, 89, and 91, that extend perpendicular to the first flanged frame element 39 and parallel to

each other. As shown after mounting the three rods 87, 89, and 91, the first leaf spring element 79 is slid over three rods 87, 89, and 91.

In figure 6 is shown that subsequently the first end bar 67 is slid over three rods 87, 89, and 91. As shown the first end bar 67 has a recess in its clamping face 73 in which recess one end 75a of the conductive element 75 is arranged.

In figure 7 is shown that the first separation sheet 53 is arranged adjacent the first end bar 67.

In figure 8 is shown that the first battery cell 47 is arranged on the first separation sheet 53 with its front face (not shown) contacting the separation sheet 53 and its rear face 47b facing away from the separation sheet 53. The positive tab 49 and negative tab 51 of the first battery cell 47 are arranged on the first end bar 67, such that the contact faces of the tabs 49, 51 are contact with the clamping face 73 of the end bar 67. The contact face of the positive tab 49 is thus in contact with the conductive element 75. The first end bar 67 is made of an electrically insulating material such that arranging the positive tab 49 and negative tab 51 of the first battery cell 47 on the first end bar 67 does not result in short circuiting the first battery cell 47.

In figure 9 is shown that subsequently, a second separation sheet 153 is arranged on the rear face 47a of the first battery cell 47, wherein the tabs 197 of the separation sheet 153 are slid over the rods 87 and 91. Furthermore, spacer elements 103, 115 are arranged between the separation sheets 53, 153.

In figure 10 is shown that subsequently the first clamp bar 65 of the first stack 61 of clamp bars, is slid over the rods 87 and 89. The first clamp bar 65 has arranged thereon the positive terminal 29. The part 29a of the positive terminal 29 arranged in the recess of the first clamp bar 65 is faced toward the contact face of the positive tab 49, such that the positive terminal 29 is brought in electrical contact with the positive tab 49. As shown both ends of the first clamp bar 65 have a rebated edge part. The rebated edge parts have arranged therein the holes 77, such that the rods 87, 89 extend through the rebated edge parts. The rebated edge part 125 through which the rod 87 extends embodies the slot 101 for a tab 97 of the next separation sheet 53. The rebated edge part 127 through which the rod 89 extends is complementary to a rebated edge part of the first clamp bar 65 of the second stack 63 of clamp bars 65, as will be explained under reference to figure 13.

In figure 11 is shown that a strain sensor 129 is arranged on the rear face 47b of the first battery cell 47 that is accessible through an opening 131 in the separation sheet 53. The

deformation sensor 129 can be embodied as a pressure sensor, a flexible force sensor like one known from US-4503705, a stress sensor, a deformation sensor, a bending sensor, a piezo-electric element, a volume change sensor, a capacitive sensor, a position measurement sensor, or any similar element or component in as far as it is capable of generating a detection signal indicative of a change in the form or shape of the battery cell 47.

The deformation sensor 129 may be connected to a dedicated or an integrated safety module of a safety system on or of the circuit board assembly 23, to enable the safety module to generate a warning in case of a detected change in the form or shape of the battery cell 47, or even a shut off command to automatically avoid the battery cell from reaching thermal runaway and potentially even fire.

Additionally, the battery may comprise a temperature sensor (not shown), a gas detection sensor (not shown) or the like, which may be provided at or on the battery cell 47. Such additional sensors may be connected to their own safety modules or a common safety module on or of the circuit board assembly 23. Thereby back-up detection of tell tale signs of an impending thermal runaway is provided, in case the strain, stress or other sensor fails.

In figure 12 is shown that a second battery cell 147 is arranged on the second separation sheet 153 with its rear face (not shown) contacting the second separation sheet 153 and the deformation or pressure sensor 129, and with its front face 147a facing away from the separation sheet 153. The negative tab 151 of the second battery cell 147 is arranged on the first clamp bar 65, such that the contact face of the negative tab 151 is in contact with the clamping face 173 of the first clamp bar 65. The positive tab 149 of the second battery cell 147 is arranged above the negative tab 51 of the first battery cell 47, such that the contact faces of the negative tab 51 and positive tab 149 are facing each other. The second battery cell 147 (or any other cell or selection of the total eventual number of cells, for that matter) may also carry a deformation sensor 129, the same as the deformation sensor 129 on the first battery cell 47. Additionally, the battery may comprise a temperature sensor (not shown), a gas detection sensor (not shown) or the like, which may be provided at or on the second battery cell 147.

Examples of pressure sensors as embodiments of deformation sensors 129 are known from US 4503705 and shown in figures 16 – 18.

In figure 13 is shown that subsequently, the tabs 197 of a third separation sheet 253, and the first clamp bar 165 of the second stack 63 of clamp bars are slid over the rods 87, 89 and 91. Before sliding the third separation sheet 253 and the first clamp bar 165 of the second stack 63 of

clamp bars over the rods 87, 89 and 91, one tab 197 of the third separation sheet 253 is arranged in the slot 99 in the clamp bar 165, such that the hole in the tab 197 aligns with the hole 77 in the clamp bar 165. The third separation sheet 253 is arranged on the front face 47a of the first battery cell 47. Furthermore, spacer elements 103, 115 are arranged between the separation sheets 53, 153.

5 The first clamp bar 165 of the second stack 63 of clamp bars has arranged in a recess of its clamping face that faces the positive tab 49 of the second battery cell 47, one end of the conductive element 175. As shown in the detail of figure 13, after sliding the first clamp bar 165 of the second stack 63 of clamp bars over the rods 89 and 91, the contact faces of the negative tab 51 of the first battery cell 47 and of the positive tab 49 of the second battery cell 147 are brought in direct
10 contact, thereby providing an electrical connection between the first battery cell 47 and the second battery cell 147. As shown in figure 13, the first clamp bar 165 of the second stack 63 of clamp bars is provided with four rebated edge parts, two at each end thereof. The first rebated edge part 135 through which the rod 89 extends is complementary to and in contact with the rebated edge part 127 of the first clamp bar 65 of the first stack 61 of clamp bars. The clamp bars 65, 165 are
15 made of an electrically insulating material such that allowing the first clamp bar 65 of the first stack 61 of clamp bars and the first clamp bar 165 of the second stack 63 of clamp bars does not result in short circuiting the second battery cell 147. The second rebated edge part 137 through which the rod 89 extends is complementary to a rebated edge part of the second clamp bar of the first stack 61 of clamp bars that is slit over the rods 87 and 89 in a later step during assembly of the
20 battery cell stack 21. The third rebated edge part 139 through which the rod 91 extends embodies a slot 101 in which the tab 97 of the second separation sheet 53 extends. The fourth rebated edge part 141 through which the rod 91 extends embodies a slot 101 in which the tab of a fourth separation sheet will extend in a later step during assembly of the battery cell stack 21.

25 As shown in figure 13, the clamp bar 65 of the first stack 61 of clamp bars and the clamp bar 165 of the second stack 63 of clamp bars are offset in the stacking direction, in particular offset by half the height of one clamp bar 165 measured in the stacking direction.

For further assembling the battery cell stack 21 the steps as explained under reference to
30 figures 8 to 13 are repeated for each two subsequent battery cells, wherein in the steps as explained under reference to figures 9 and 10 in stead of a clamp bar having arranged thereon a positive terminal, a clamp bar is slid over rods 87 and 89 that is a mirror image of clamp bar 165 that is shown in figure 13. When the last battery cell of the stack 59 of battery cells is arranged on the stack, the positive tab of the last battery cell is brought into contact with the negative tab of the one
35 but last battery cell by sliding a last clamp bar of the second stack 63 of clamp bars that corresponds to clamp bar 165 of figure 13 over the rods 89 and 91. Subsequently, the last clamp

bar of the first stack 61 of clamp bars is slid over the rods 87 and 89. The last clamp bar of the first stack 61 of clamp bars has arranged in a recess thereof the negative terminal 31, such that the part of the negative terminal 31 arranged in the recess is brought into contact with the contact face of the negative tab of the last battery cell 47. Subsequently, the second end bar 71 and the second leaf spring element 81 are slid over the rods 87, 89, and 91, after which the second flanged frame element 41 is coupled to the ends of the rods 87, 89, and 91, by means of bolts that are screwed in threaded axial holes 143 of the rods 87, 89, 91. Subsequently, the bolts are tightened thereby pulling the flanged frame elements 39, 41 towards each other and compressing the leaf spring elements 79, 81, such that the positive tabs and negative tabs of the battery cells that are arranged in contact with each other between two clamp bars of either the first stack 61 of clamp bars and the second stack 63 of clamp bars are clamped against each other under influence of the compression force that results from compressing the leaf spring elements 79 and 81.

The first end bar 67, the second end bar 71, and the clamp bars 65 are all made of an electrically insulating material.

In stead of two stacks of clamp bars wherein the clamp bars of the first stack and the clamp bars of the second stack are arranged end-to-end, a single stack of clamp bars may be used wherein the clamp bars of the first stack and the clamp bars of the second stack are replaced with clamp bars that extends along the whole upper edge of the battery cells 47 on which the tabs are arranged.

Although the principles of the invention have been set forth above with reference to specific embodiments, it must be understood that this description is given solely by way of example and not as limitation to the scope of protection, which is defined by the appended claims.

CONCLUSIES

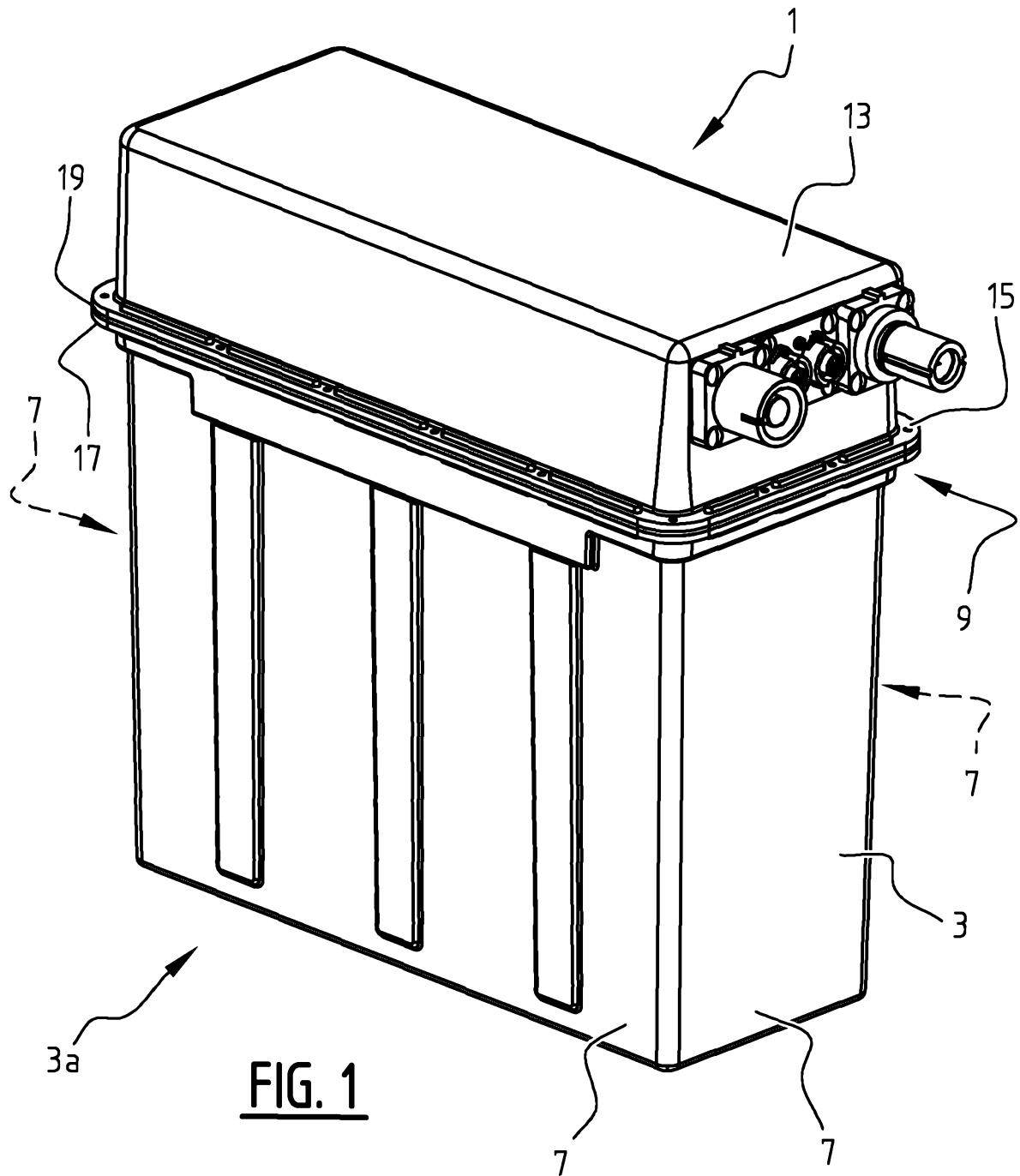
1. Batterij, omvattende:

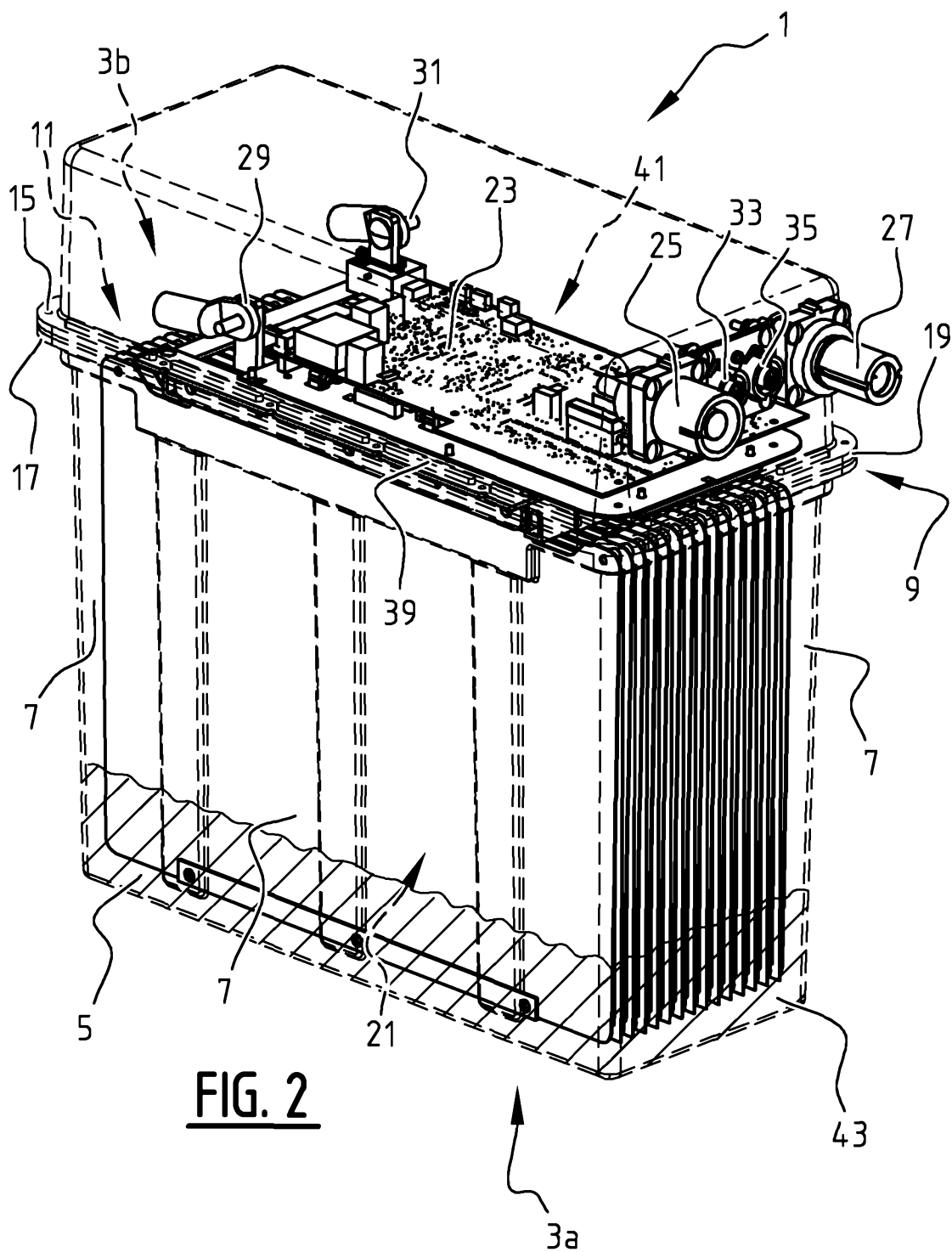
- ten minste één batterijcel;
- 5 - een sensor, in samenhang met de ten minste éne batterijcel; en
- een veiligheidssysteem, in samenhang met de sensor en de batterij, waarbij het veiligheidssysteem is geconfigureerd voor het genereren van een waarschuwings- en/of uitschakelsignaal, op basis van een signaal van de sensor,
- MET HET KENMERK DAT
- 10 - de sensor een deformatiesensor is.

2. Batterij volgens conclusie 1, waarbij de deformatiesensor ten minste één sensor omvat, uit een groep van sensoren, omvattende:

- druksensoren, flexibele krachtsensoren, mechanische-spanningssensoren, deformatiesensoren,
- 15 vervormingssensoren, buigsensoren, piëzo-elektrische elementen, volumeveranderingssensoren, capacitieve sensoren, positiemetingssensoren, vormsensoren of enige vergelijkbare elementen of componenten, die in staat zijn tot het genereren van een detectiesignaal, dat indicatief is voor een verandering in de vorm of vormgeving van de batterijcel.

- 20 3. batterij volgens conclusie 1 of 2, waarbij de deformatiesensor een geleidende laag met hoge impedantie is, die verandert bij rek en/of compressie, en waaraan een flexibele PCB is aangebracht, die het mogelijk maakt om de impedantie van de laag te meten.





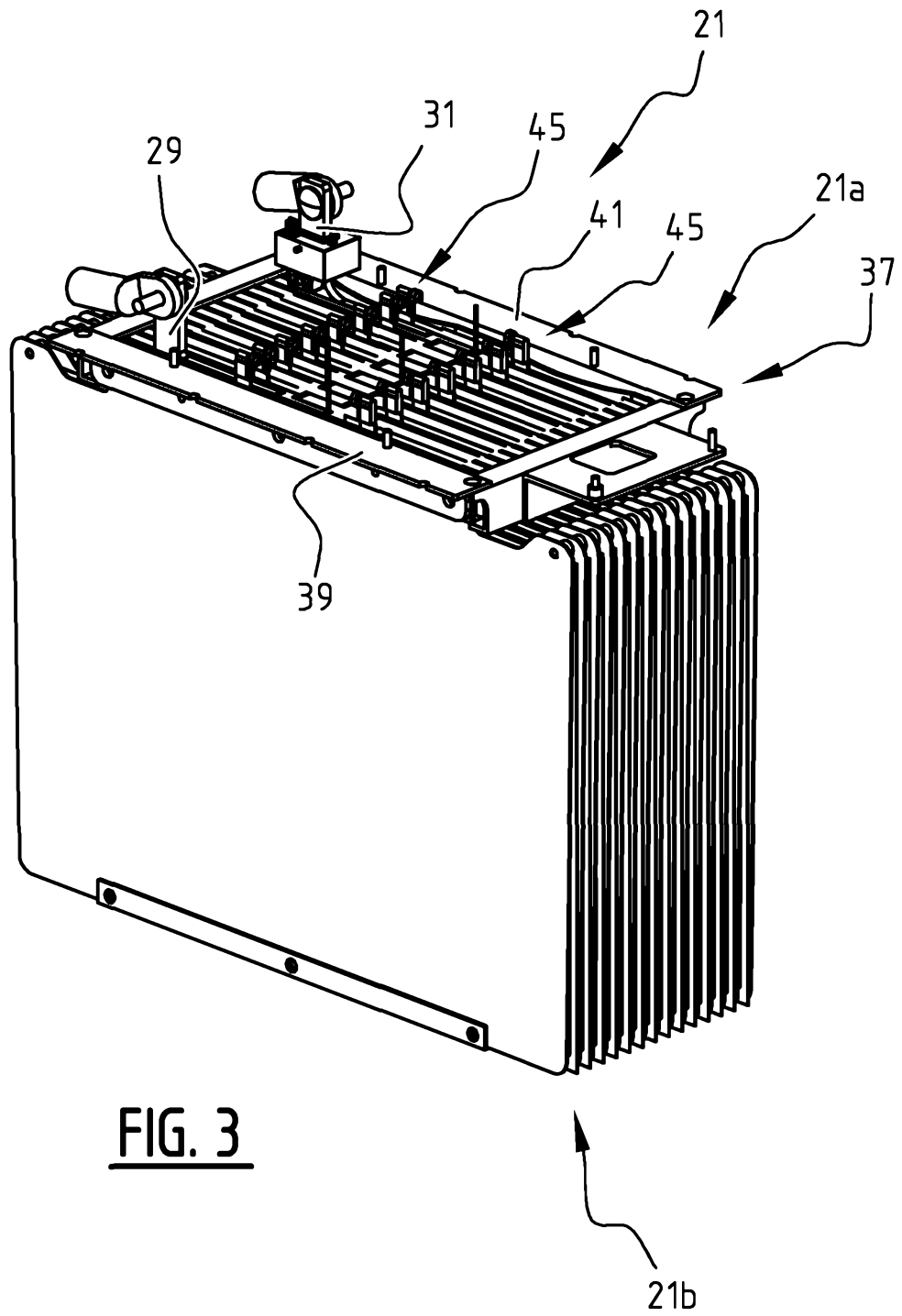


FIG. 3

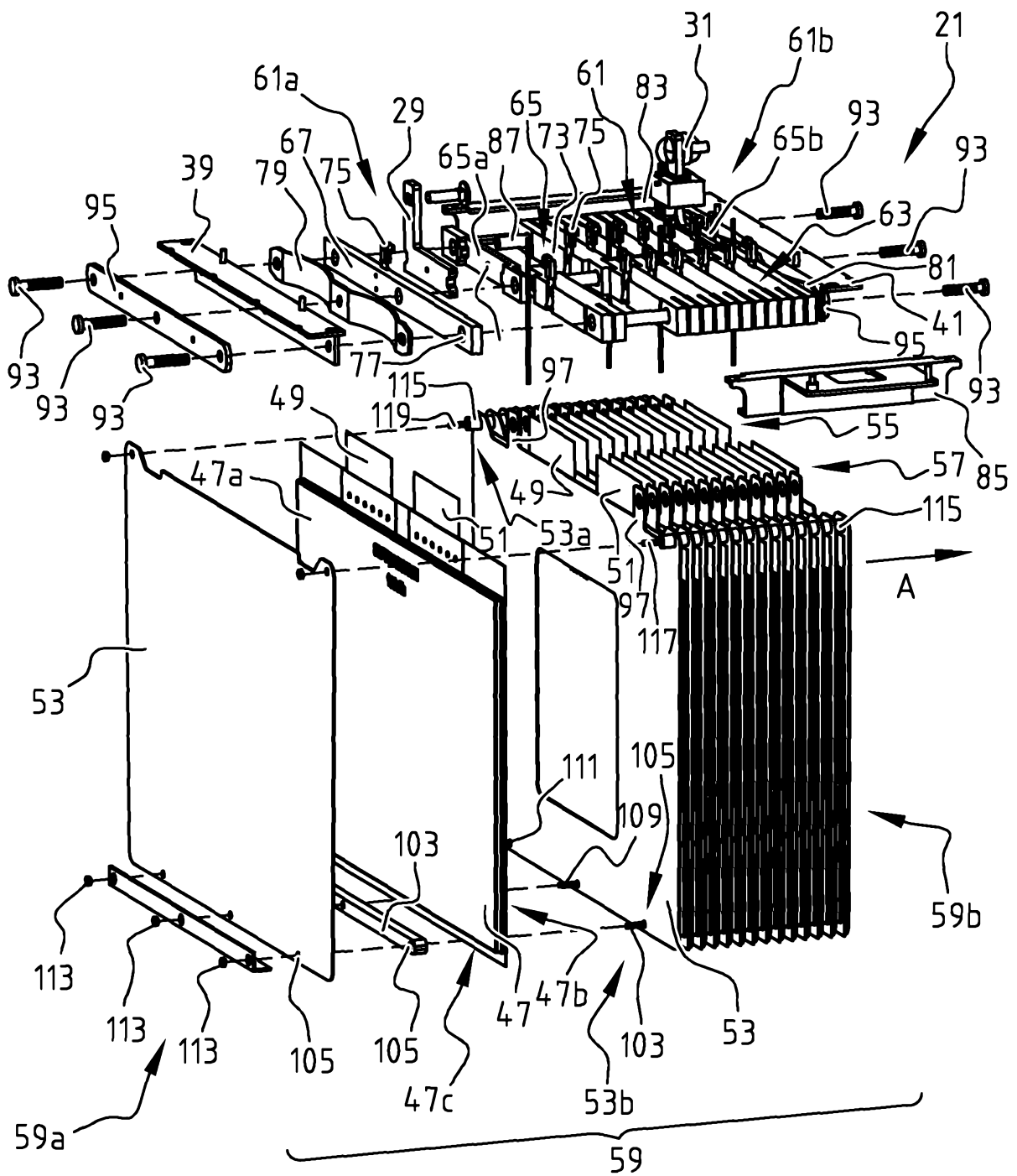
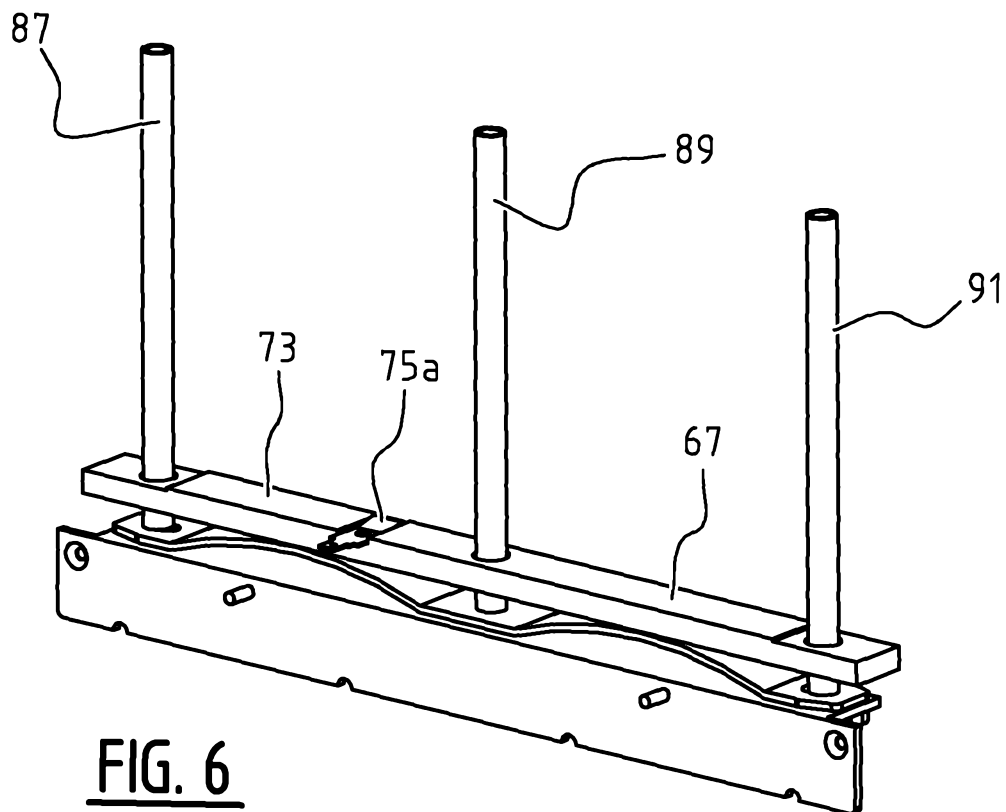
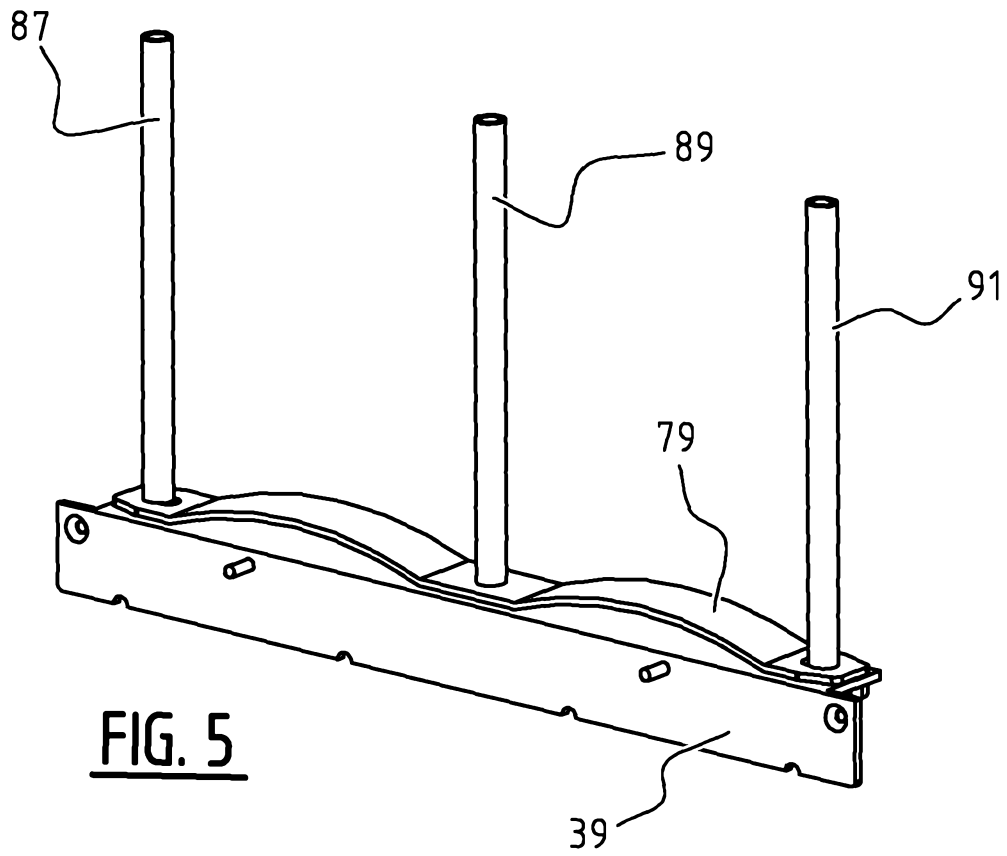


FIG. 4



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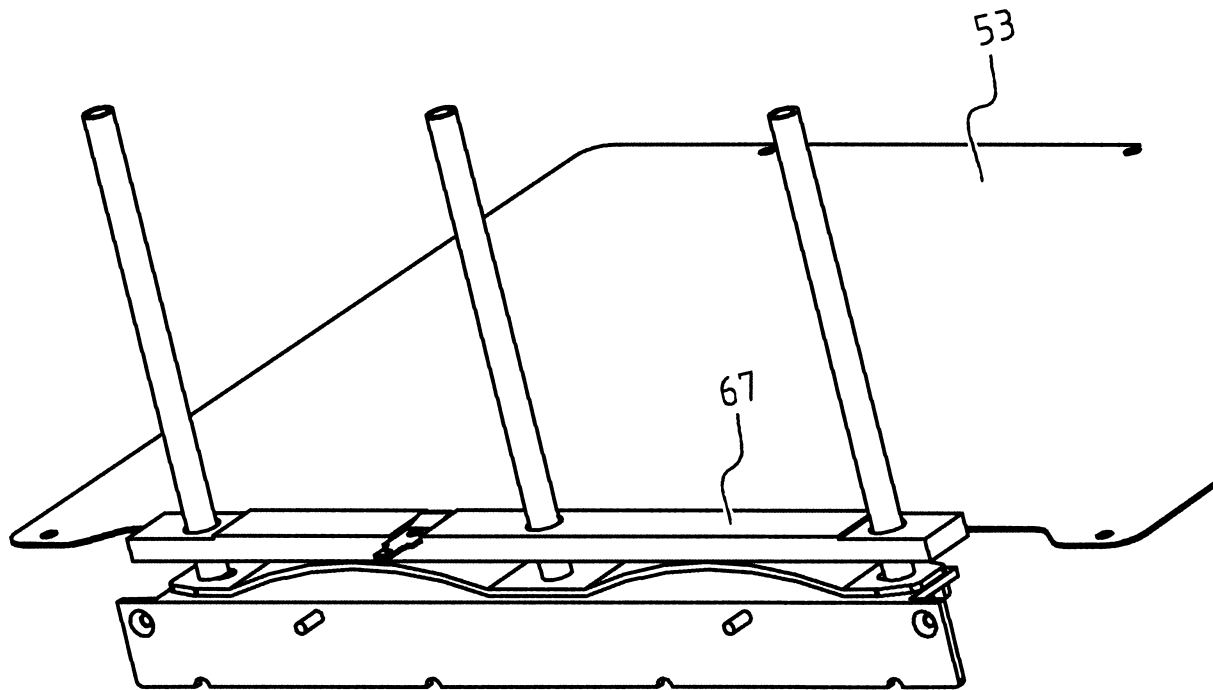


FIG. 7

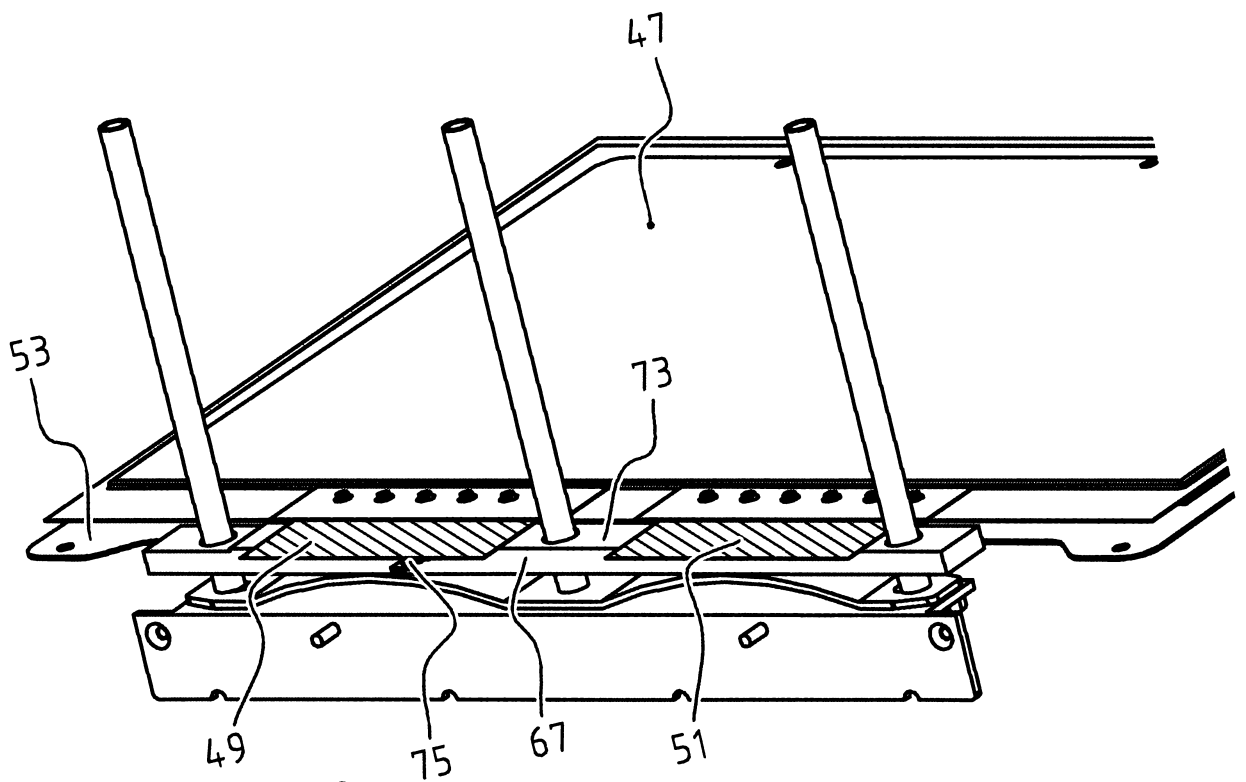
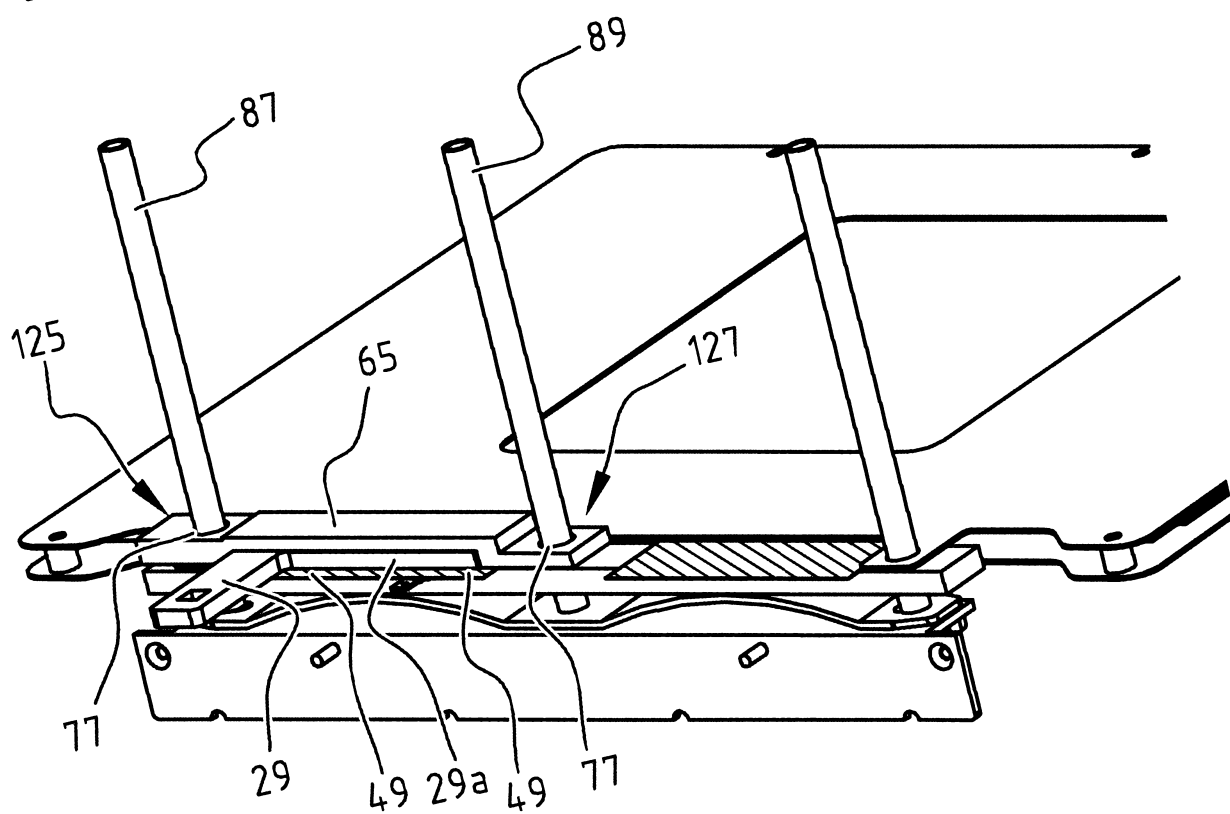
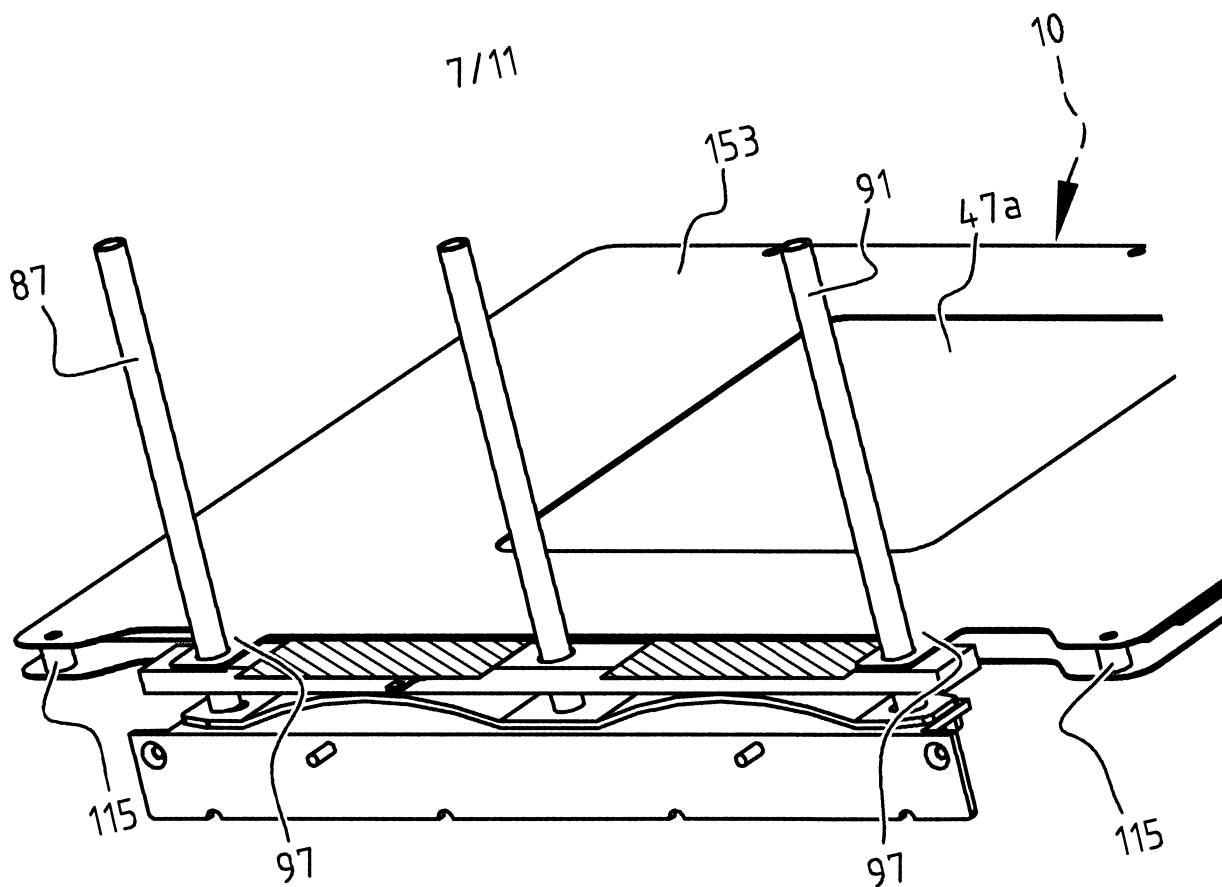


FIG. 8



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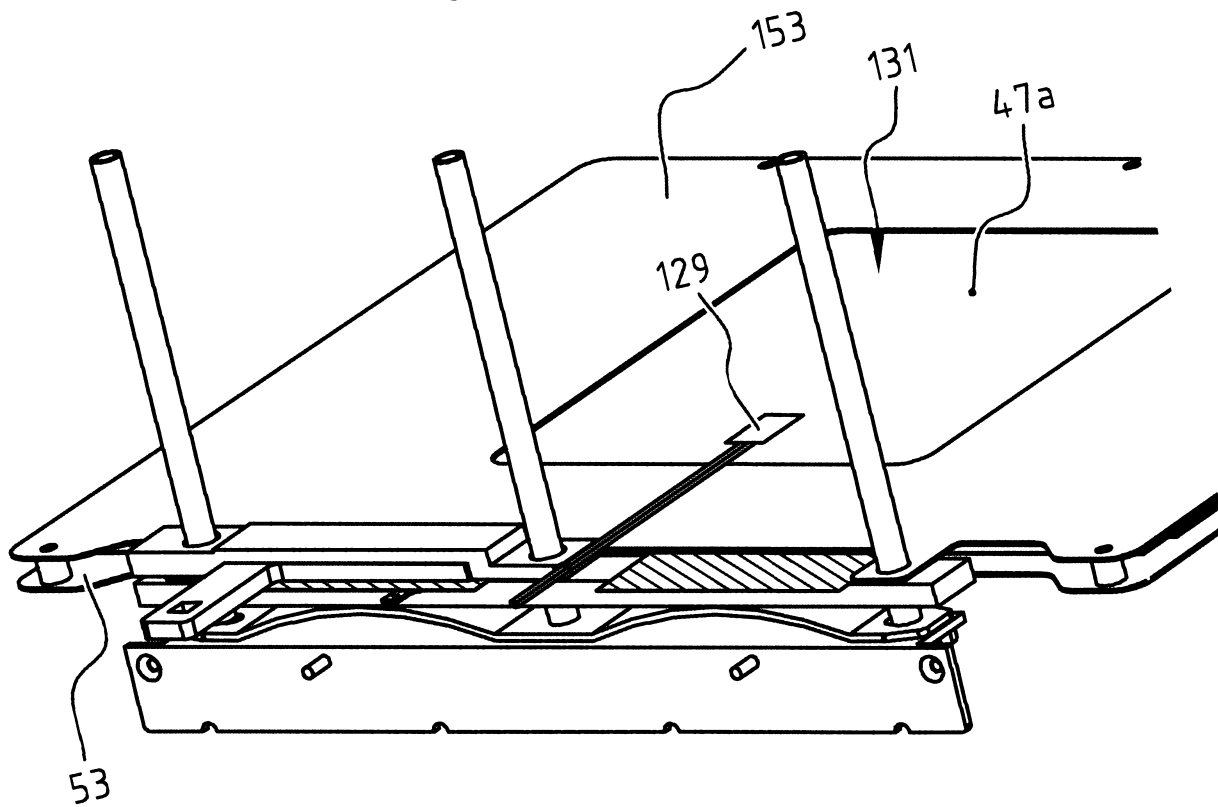


FIG. 11

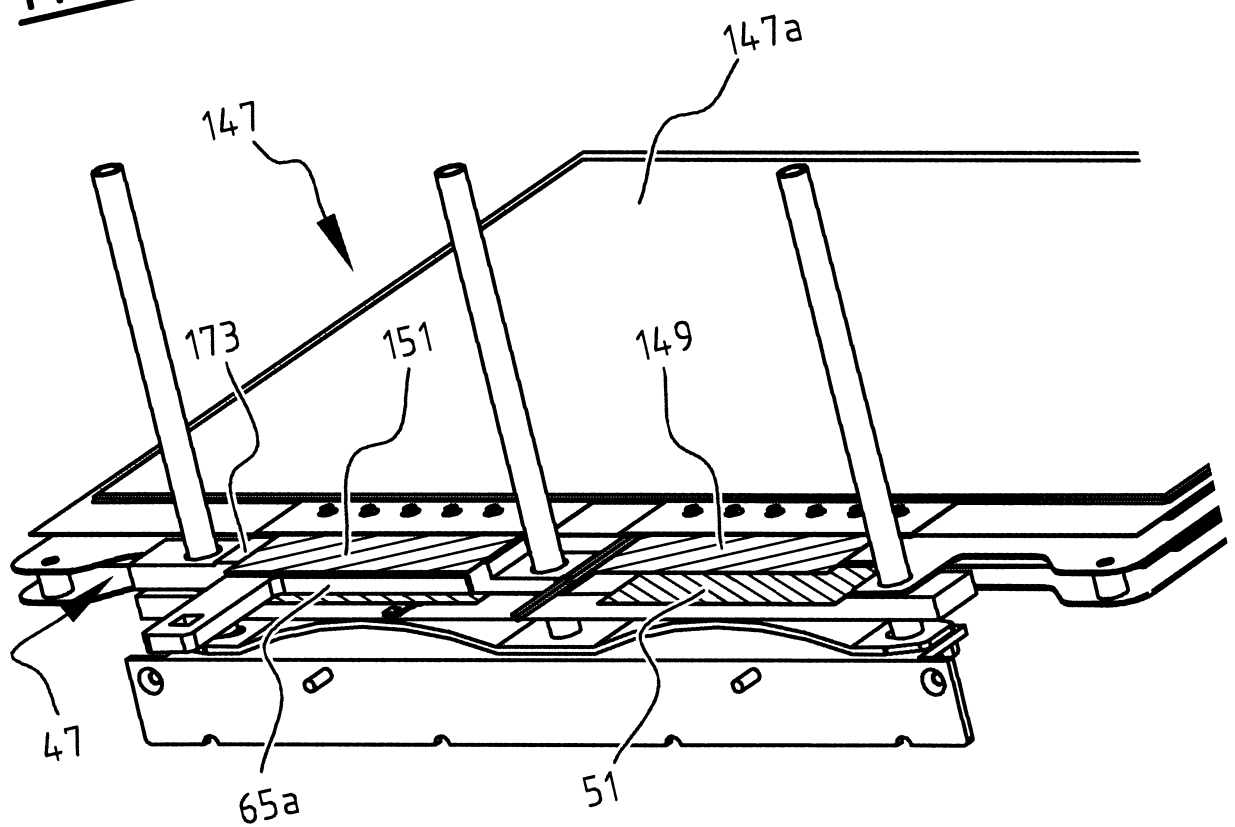


FIG. 12

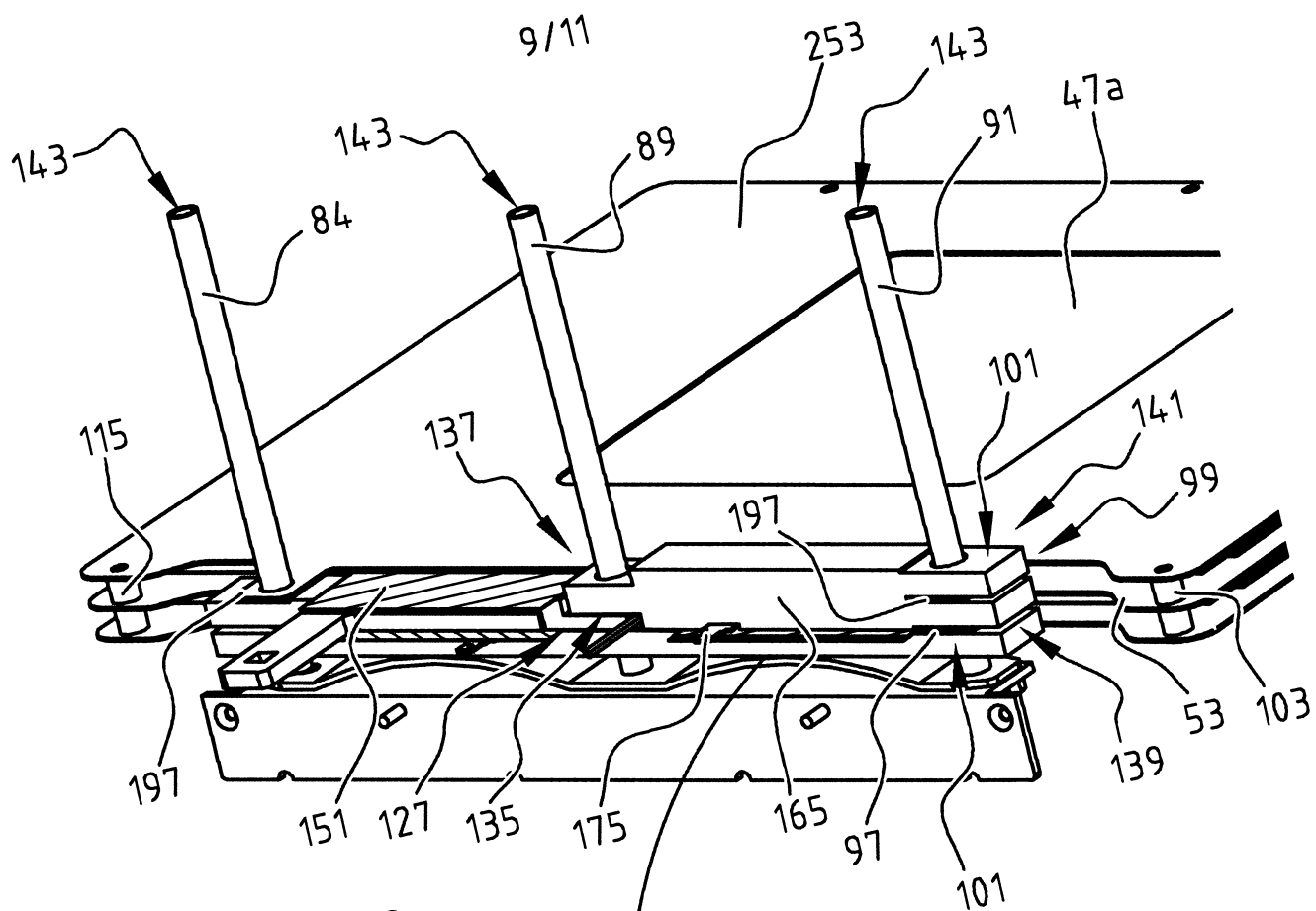
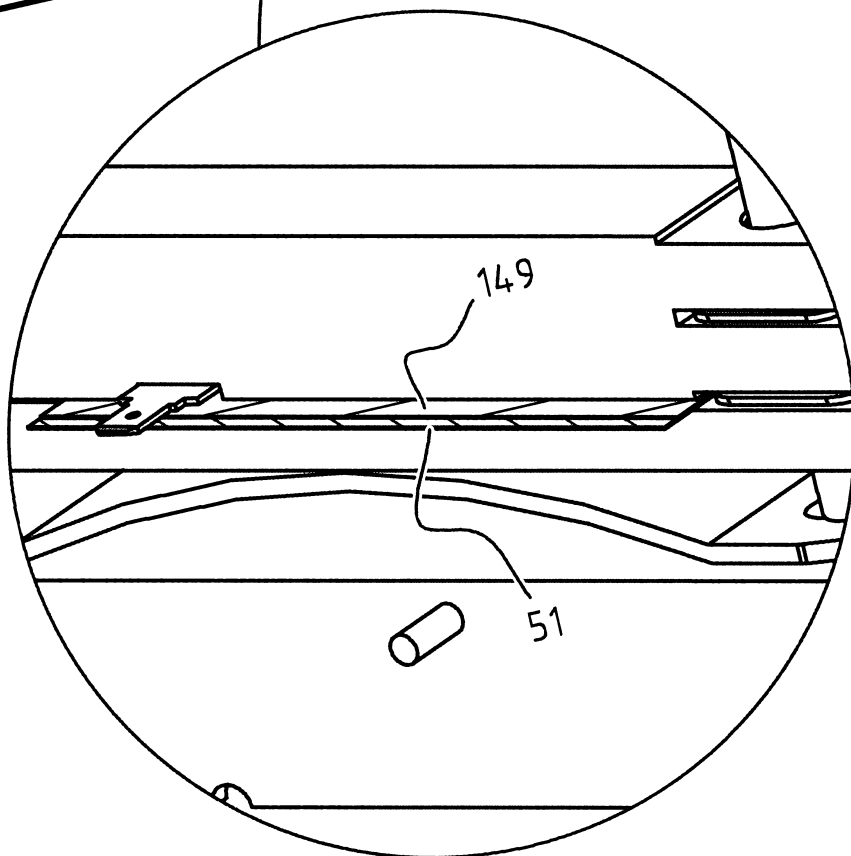


FIG. 13



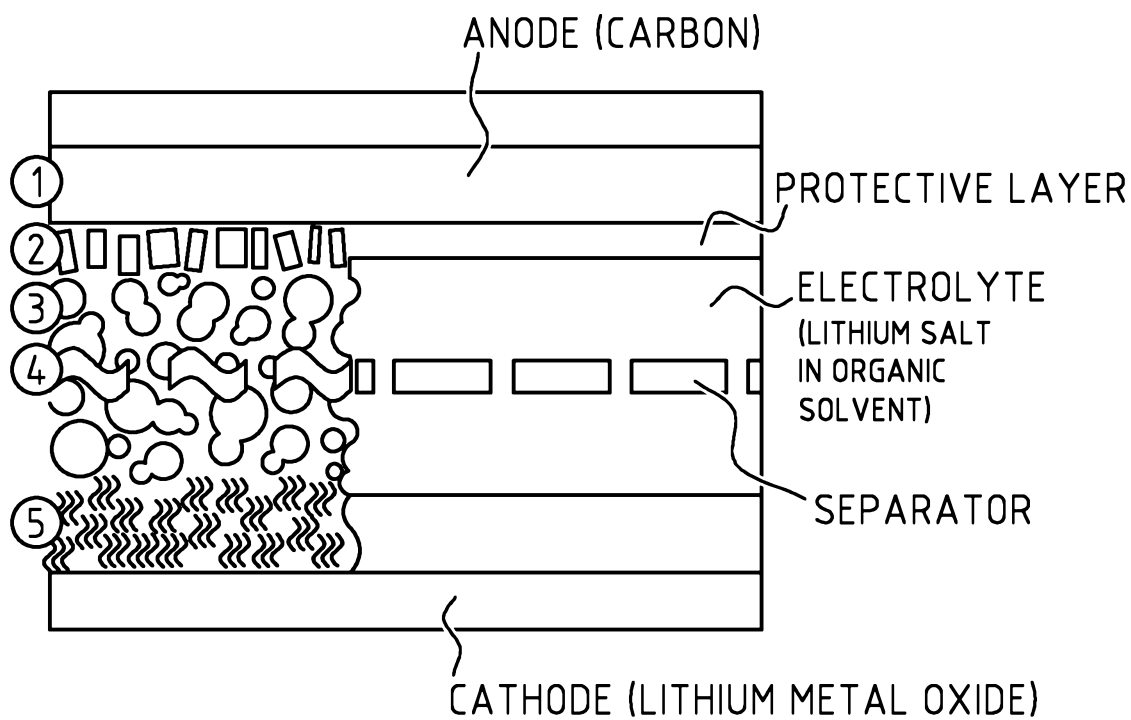


FIG. 14

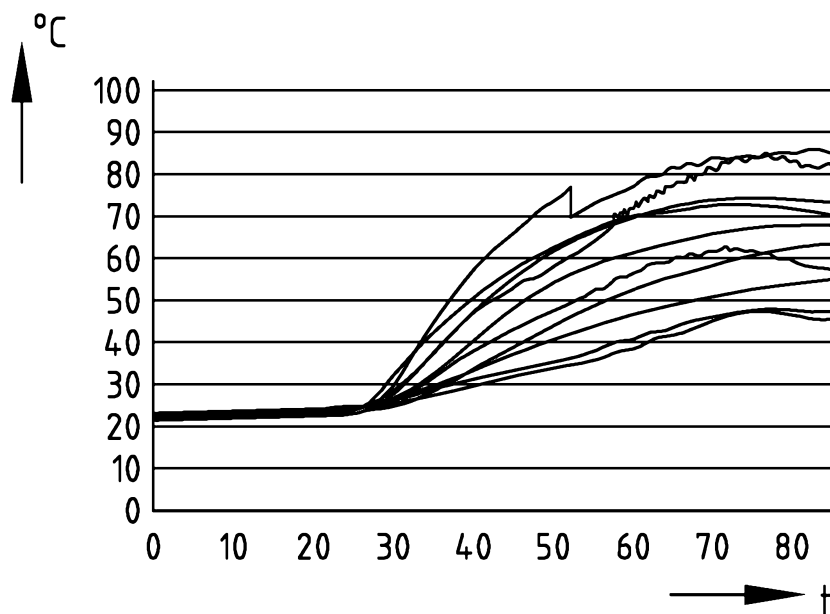


FIG. 15

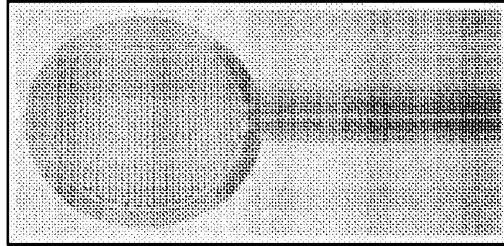


FIG. 16

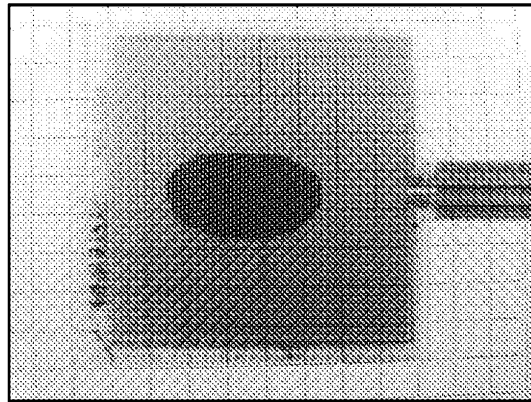


FIG. 17

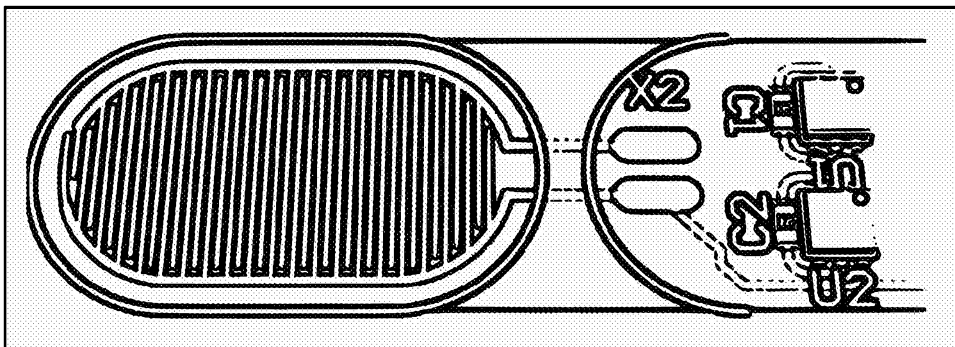


FIG. 18

ABSTRACT

The present disclosure relates to a battery, comprising: at least one battery cell; a sensor associated with the at least one battery cell; and a safety system associated with the sensor and the battery, wherein the safety system is configured to generate a warning and/or shut down signal based on a signal from the sensor. Further, the sensor is a deformation sensor.

The deformation sensor may comprise at least one sensor from a group, comprising: pressure sensors, flexible force sensors, stress sensors, strain sensors, deformation sensors, bending sensors, piezo-electric elements, volume change sensors, capacitive sensors, position measurement sensors, shape sensors or any similar elements or components capable of generating a detection signal indicative of a change in the form or shape of the battery cell.

Representative Drawing for Publication Purposes:

Figure 11

SAMENWERKINGSVERDRAG (PCT)

RAPPORT BETREFFENDE NIEUWHEIDSONDERZOEK VAN INTERNATIONAAL TYPE

IDENTIFICATIE VAN DE NATIONALE AANVRAGE	KENMERK VAN DE AANVRAGER OF VAN DE GEMACHTIGDE
	W/2VX60/MLa/5
Nederlands aanvraag nr.	Indieningsdatum
2019810	26-10-2017
	Ingeroepen voorrangsdatum
Aanvrager (Naam)	
EST-Floattech B.V.	
Datum van het verzoek voor een onderzoek van internationaal type	Door de Instantie voor Internationaal Onderzoek aan het verzoek voor een onderzoek van internationaal type toegekend nr.
24-02-2018	SN70732
I. CLASSIFICATIE VAN HET ONDERWERP (bij toepassing van verschillende classificaties, alle classificatiesymbolen opgeven)	
Volgens de internationale classificatie (IPC)	
H02J7/00;H01M10/48	
II. ONDERZOCHE GEBIEDEN VAN DE TECHNIEK	
Onderzochte minimumdocumentatie	
Classificatiesysteem	Classificatiesymbolen
IPC	H02J;H01M
Onderzochte andere documentatie dan de minimum documentatie, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen	
III. ☐	GEEN ONDERZOEK MOGELIJK VOOR BEPAALDE CONCLUSIES (opmerkingen op aanvullingsblad)
IV. ☐	GEBREK AAN EENHEID VAN UITVINDING (opmerkingen op aanvullingsblad)

**ONDERZOEKSRAPPORT BETREFFENDE HET
RESULTAAT VAN HET ONDERZOEK NAAR DE STAND
VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE**

Nummer van het verzoek om een onderzoek naar
de stand van de techniek

NL 2019810

A. CLASSIFICATIE VAN HET ONDERWERP

INV. H02J7/00 H01M10/48
ADD.

Volgens de Internationale Classificatie van octrooien (IPC) of zowel volgens de nationale classificatie als volgens de IPC

B. ONDERZOCHETE GEBIEDEN VAN DE TECHNIEK

Onderzochte minimum documentatie (classificatie gevolgd door classificatiesymbolen)

H02J H01M

Onderzochte andere documentatie dan de minimum documentatie, voor dergelijke documenten, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

Tijdens het onderzoek geraadpleegde elektronische gegevensbestanden (naam van de gegevensbestanden en, waar uitvoerbaar, gebruikte trefwoorden)

EPO-Internal, WPI Data

C. VAN BELANG GEACHTE DOCUMENTEN

Categorie *	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
X	WO 2015/151331 A1 (TOYO TIRE & RUBBER CO [JP]) 8 oktober 2015 (2015-10-08) * alinea [0002] - alinea [0045]; figuren 1a, 1b *	1-3
X	EP 3 128 573 A1 (TOYO TIRE & RUBBER CO [JP]) 8 februari 2017 (2017-02-08) * alinea [0001]; figuren 1-3 * * alinea [0007] - alinea [0017] * * alinea [0020] - alinea [0066] *	1-3
X	WO 2012/073770 A1 (TOKAI RUBBER IND LTD [JP]; MURAYAMA MASARU [JP]; MURAMATSU ATSUSHI [JP]) 7 juni 2012 (2012-06-07) * alinea [0036] - alinea [0105]; figuur 1 * ----- -/-	1-3



Verdere documenten worden vermeld in het vervolg van vak C.



Leden van dezelfde octrooifamilie zijn vermeld in een bijlage

* Speciale categorieën van aangehaalde documenten

"A" niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft

"D" in de octrooiaanvraag vermeld

"E" eerdere octrooiaanvraag, gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven

"L" om andere redenen vermelde literatuur

"O" niet-schriftelijke stand van de techniek

"P" tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur

"T" na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwerend is voor de octrooiaanvraag, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding

"X" de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur

"Y" de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht

"&" lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

Datum waarop het onderzoek naar de stand van de techniek van internationaal type werd voltooid

16 maart 2018

Verzenddatum van het rapport van het onderzoek naar de stand van de techniek van internationaal type

Naam en adres van de instantie

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040
Fax: (+31-70) 340-3016

De bevoegde ambtenaar

Kreutz, Joseph

**ONDERZOEKSRAPPORT BETREFFENDE HET
RESULTAAT VAN HET ONDERZOEK NAAR DE STAND
VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE**

Nummer van het verzoek om een onderzoek naar
de stand van de techniek

NL 2019810

C.(Vervolg) VAN BELANG GEACHTTE DOCUMENTEN

Categorie *	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
A	WO 2015/039889 A1 (BOSCH GMBH ROBERT [DE]) 26 maart 2015 (2015-03-26) * samenvatting; figuur 1 * -----	1-3

**ONDERZOEKSRAPPORT BETREFFENDE HET
RESULTAAT VAN HET ONDERZOEK NAAR DE STAND
VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE**

Informatie over leden van dezelfde octrooifamilie

Nummer van het verzoek om een onderzoek naar
de stand van de techniek

NL 2019810

In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
WO 2015151331	A1	08-10-2015	CN 106165187 A 23-11-2016
			EP 3128600 A1 08-02-2017
			JP WO2015151331 A1 13-04-2017
			KR 20160127103 A 02-11-2016
			TW 201537807 A 01-10-2015
			US 2017018820 A1 19-01-2017
			WO 2015151331 A1 08-10-2015

EP 3128573	A1	08-02-2017	CN 106165145 A 23-11-2016
			EP 3128573 A1 08-02-2017
			JP WO2015151332 A1 13-04-2017
			KR 20160128363 A 07-11-2016
			TW 201537806 A 01-10-2015
			US 2017092997 A1 30-03-2017
			WO 2015151332 A1 08-10-2015

WO 2012073770	A1	07-06-2012	CN 103229347 A 31-07-2013
			CN 105244556 A 13-01-2016
			CN 105244557 A 13-01-2016
			DE 112011101585 T5 16-05-2013
			JP 5916623 B2 11-05-2016
			JP WO2012073770 A1 19-05-2014
			US 2013089765 A1 11-04-2013
			WO 2012073770 A1 07-06-2012

WO 2015039889	A1	26-03-2015	DE 102013218681 A1 19-03-2015
			US 2016226109 A1 04-08-2016
			WO 2015039889 A1 26-03-2015

WRITTEN OPINION

File No. SN70732	Filing date (day/month/year) 26.10.2017	Priority date (day/month/year)	Application No. NL2019810
International Patent Classification (IPC) INV. H02J7/00 H01M10/48			
Applicant EST-Floattech B.V.			

This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the application
- ☐ Box No. VIII Certain observations on the application

	Examiner Kreutz, Joseph
--	----------------------------

WRITTEN OPINION**Box No. I Basis of this opinion**

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.
2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:
 - a. type of material:
 - ☐ a sequence listing
 - ☐ table(s) related to the sequence listing
 - b. format of material:
 - ☐ on paper
 - ☐ in electronic form
 - c. time of filing/furnishing:
 - ☐ contained in the application as filed.
 - ☐ filed together with the application in electronic form.
 - ☐ furnished subsequently for the purposes of search.
3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.
4. Additional comments:

Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Yes: Claims	2, 3
	No: Claims	1
Inventive step	Yes: Claims	
	No: Claims	1-3
Industrial applicability	Yes: Claims	1-3
	No: Claims	

2. Citations and explanations

see separate sheet

ITEM V

1. Cited documents.

Reference is made to the following documents:

- D1 WO 2015/151331 A1 (TOYO TIRE & RUBBER CO [JP]) 8 oktober 2015 (2015-10-08)
- D2 EP 3 128 573 A1 (TOYO TIRE & RUBBER CO [JP]) 8 februari 2017 (2017-02-08)
- D3 WO 2012/073770 A1 (TOKAI RUBBER IND LTD [JP]; MURAYAMA MASARU [JP]; MURAMATSU ATSUSHI [JP]) 7 juni 2012 (2012-06-07)

2. Independent claim 1.

D1 discloses a

batterij, omvattende:

- ten minste één batterij cel (1);

*- een sensor (5), in samenhang met de ten minste éne batterijcel;
en*

- een veiligheidssysteem (descr. paragraph [0002]), in samenhang met de sensor en de batterij, waarbij het veiligheidssysteem is geconfigureerd voor het genereren van een waarschuwings- en/of uitschakelsignaal, op basis van een signaal van de sensor,

waarbij

- de sensor een deformatiesensor is.

The subject matter of claim 1 is therefore not novel.

Documents D2 (fig. 1-3 and corresponding description) and D3 (fig. 1 and descr. paragraphs [0036] - [0105]) are equally significant to the novelty of the subject matter of claim 1.

3. Claim 2 and 3.

Claim 2 is unclear in that it refers o multiple possibilities to realize a battery as defined in claim 1 of the application. Furthermore, such deformation sensors are known to the skilled man (see some examples disclosed in D1 paragraph [0036]). Features defined in claim 2 are therefore usual in this technical field and using them in a battery as the one defined in claim 1 does not involve an inventive step.

Claim 3 merely refers to a way to realize the deformation sensor defined above which appears obvious to the skilled man and does not involve any inventive step.