Tesla electric vehicles batteries

for students

Funded by the Erasmus+ Programme of the European Union

STEP AHEAD II

The support of Professional development of VET teachers and trainers in following of New trends in Automotive Industry
Automotive Innovation & Teacher training Academy
2018-1-SK01-KA202-046334

Tesla electric vehicles batteries

The aim of the lesson:
To gain knowledge about the constitution and function of electric vehicles batteries cells.

APPENDIX 3

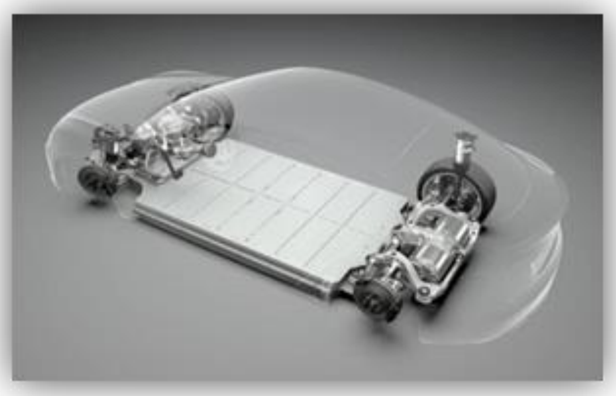
Tesla Electric Vehicles Batteries

This image is available under the licence Creative Commons Atribución-CompartirIgual 4.0 Internacional
(Source 2019-11-15 https://es.m.wikipedia.org/wiki/Archivo:Tesla_Model_S_(Facelift_ab_04-2016)_trimmed.jpg)

Authors:
Juan Francisco Susarte Zamora
Álvaro Doural
Juanjo Martínez

Tesla Electric Vehicles Batteries

Packs



Paquete de baterías Model 3.

Distinct from the cell and the module, the battery pack is an intelligent device which can be controlled by the Battery Management System (BMS) to maximize the performance, to guarantee a safe functioning and to adapt the output to avoid excessive degradation of its performance capacity in the long run.

Cells became modules by adding mechanical frames, Bus Bars, the cooling interface and a sensor harness. Each of these elements has an additional support to transform modules into intelligent and safe battery packs.

Modules mechanical frames are interconnected with the mechanical structure of the battery. This structure must hold a battery pack of more of 600 kg. This provides enough rigidity and resistance for the rest of the car, improving the driving dynamics and its safety in case of a car crash.

Modules are electrically connected by high voltage Bus Bars, in addition to a thermal connection by means of the cooling system with the combination of rigid and flexible pipes.

The sensors harness is in charge of powering BMS, which works as a controller for the battery system to maximise its performance and safety.

Moreover, the battery includes fuses to avoid an excessive power surge, a contact to turn on and off the battery from the rest of the vehicle, and an input-Output I/O connector to connect electrically and thermally the battery to the car.

Model S and X 100kwh battery pack has an absolute energy capacity of 102,4kWh. Its type 18 650 8.256 cells are arranged in a 96s 86P configuration with a nominal voltage of approximately 400V.

The weight of the battery is 641kg, which offers a gravimetric energy density of 182,5W*kg. This means 63% of the battery is the mass corresponding to the cells.

Energy capacity is calculated by multiplying the cell capacity by the pack nominal voltage and the number of cells connected in parallel.

$$E = Capacidad\ de\ la\ celda\ \times Vnominal\ paquete\ \times Celdas\ en\ Paralelo$$
$$E = 3{,}4Ah \times 400V \times 86P = 116.9kWh$$

The gravimetric energy density of the battery is calculated by dividing the energy capacity by the battery mass.

$$DEG = \frac{E}{masa\ de\ la\ batería} = \frac{116.9kWh}{641kg} =$$ 182,5W*kg

As we know the definite mass for each cell, we can also conclude that the battery has an approximate weight of 404 kg, therefore, 237 kg of the battery are components which are not cells

$$Masa\ total\ de\ las\ celdas = (96s * 86P) * 49g = 404{,}5kg$$

$$\frac{404{,}5kg}{641kg} = 0{,}63 = 63\%$$

The maximum power Tesla can get from its battery is 567kwh. The power output of our battery is affected by our voltage, which is defined by the voltage in a cell by the number of these cells connected in series, the maximum electric current of the cell and by the battery resistance.

The alfa power (Pα) is simply the battery voltage multiplied by the intensity of its electric current

Pα = V * I

The voltage of the battery (V) when it is producing energy will be lower than when the circuit is open (Vca). That difference is also known as delta voltage (Vδ).

V = Vca – Vδ

Vδ is calculated by multiplying the maximum intensity of the combined cells by the resistance of the battery.

Vδ = I * R

Therefore, to calculate the maximum power of a battery first we have to know its resistance.

Cells resistance is very much affected by factors such a change in its state, the temperature of the discharging speed. To simplify it we will use a number for a discharge of 10 seconds of 1 C to 25ºC. The resistance of an individual cell would be approximately 30mΩ.

The resistance of the wire link (Rec) which connects cells with Bus Bar is approximately 1mΩ per union. Each Bus Bar has an approximate resistance of 0,1mΩ to room temperature.

The resistance of a series (R-series) is, therefore, the cell resistance (R-cell) plus the double of the wire link resistance, since there would be a union in the positive terminal as well as in the negative terminal. All this has to be divided by the number of cells connected in parallel.

R-series = R-cell+ (2*Rec) / number of cells in parallel
R-series = 30mΩ + (2*1mΩ) / 86 = 0,372mΩ

The resistance of the module (R-module) is the resistance of the series plus half resistance of the Bus Bar, all of it multiplied by the number of cells in series within the module, we previously mentioned modules were 6.

R-module = (R-serie + (R del Bus bar/2)) * number of cells in series
R-module = (0,372mΩ + (0,1mΩ / 2)) * 6 = 2,53mΩ

in addition to the resistance of the module, we can also observe the resistance of the high voltage Bus Bar which is connecting modules.

It would be approximately 0,02mΩ.
The resistance of the high voltage connection is 0,20mΩ.
The fuse resistance is 0,23mΩ.
The shunt resistance allows BMS to measure the pack current intensity which is 0,05mΩ and the high voltage connector resistance which is 0,2mΩ.

Therefore, the total resistance of the pack is calculated as the module resistance (R-module) multiplied by the number of modules in series (Ms), plus the resistance of the high voltage Bus Bar by the number of modules in series minus the intensity of these, plus the resistance of the connector (R-ct), plus the fuse resistance (R-fus), plus the shunt resistance (R-sh) and plus the HV connector resistance (RCHV)

RT = (R-module * Ms) + (R de HV Bus Bar *(Ms - I)) + Rct + Rfus + Rsh + RCHV

This gives us as a result the resistance of the pack, 41,8mΩ.

The cells resistance represents approximately 80% of the total resistance of the battery.

With this information we can deduce that with a maximum output power of 567kW, the intensity of our battery pack will be from 1.800A to 2.000A depending on the charging state and the cell temperature.

The result of this is a cell current intensity of about 21A to 23A, which is equivalent to 6,2C to 6,7C per cell like a short - term power peak

Hereafter we will have a look at the structure of a battery pack:

Mechanical structure of a battery pack

The mechanical structure of a pack holds more than 600 kg of the battery plus the fact of being the base to support the rest of the vehicle structure. It has been designed to provide enough rigidity, to allow the car to have a nice, driving dynamics and to pass the Crash Tests.

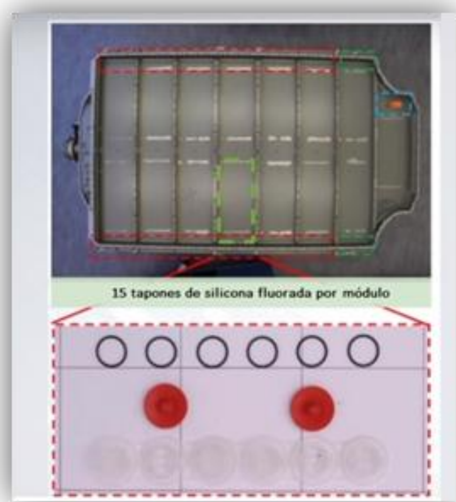
Thicker longitudinal crossbars increase resistance to lateral impacts and the longitudinal bending. Meanwhile the other crossbars provide additional torsion rigidity and also resistance of lateral impact. Tesla also used internal sections to physically separate each module, which is useful to prevent the spread of fire in case of fault.

The results in a test done in 2015 showed what happens to a cell when it is pierced by nails and when it is kept at high temperatures for long periods of time. Considering US requirements, the results shown that fire is possible, so it is important to design a strategy to extinguish battery fires.

Celda perforada

Celda sometida a alta temperatura

Let’s see how this strategy goes:



Physical separation between modules (upper part) and the fluoridated silicon plugs (lower part).

Starting with the modules, they are separated by mica layers which are placed around the module to provide electric insulation among these. These sheets are also very stable till they reach temperatures of about 900ºC, therefore, in case of an error within a cell it won’t immediately decomposed and it will keep an ideal electric insulation from module to module.

Modules are also separated on its upper side and lower side by metal sheets which keep the battery assembled. Moreover, it has an insulation layer 9,3mm thick which avoids the heat getting into the compartment.

If there is any error in a cell gas pressure will be generated, that is why it is important to have good ventilation within the pack. Since each module is physically separated, each of them should have their own ventilation openings. Except those two modules on the front part which are stacked one over another and share their ventilation ports.

For these openings, fluorated silicon plugs are used, because they allow a good sealing of the battery as they do not degrade as they get older. When there is a presence of hot gases, these decomposed easily allowing the flow through the openings.

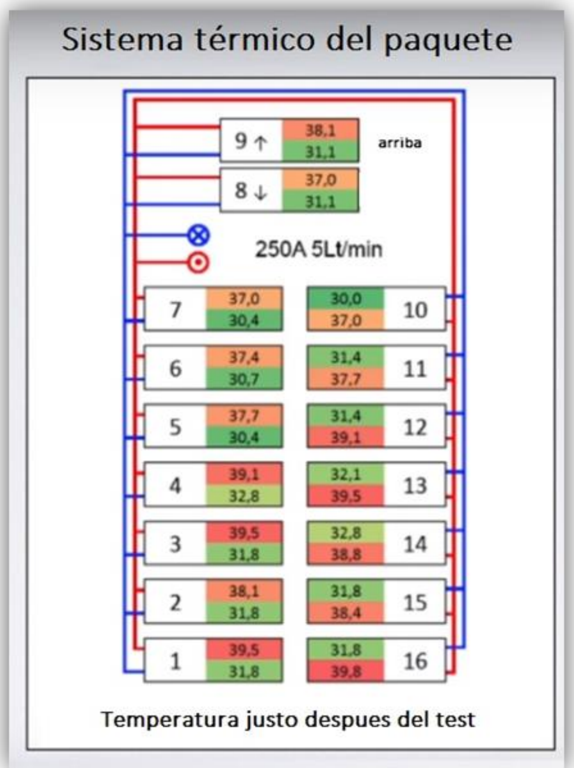
High Voltage Bus Bars connect 16 modules in series as we can observe in the image, the red part is the positive terminal and the black one the negative.

These Bus Bars are made of tin, they have a transversal section of 75mm2, longer than the ones used to match together the stacked front modules, which are connected through the main fuse. To finish with the packs, we will deal with its cooling system.

Results of different tests made by AVL show that the 100kwh battery pack provides good information about the cooling system.

The test consisted of repeated cycles of charging and discharging of 250A till the moment a stable temperature was reached. The test started at 20ºC with a coolant flow of 5L/m.

In the following diagram the cold side of the coolant flow is shown in blue and the hot one in red.



The coolant is divided from the very beginning to provide service to the 16 modules in parallel. The hot side in each module is connected in parallel to the hot output of the battery. Each module has two NTC sensors, which allow to measure the temperature of the coolant when going into the circuit and when getting out of it.

It is important to minimize the temperature changes in each cell, as the hotter they get, the sooner they degrade.

We can see in the image that under the conditions previously mentioned there are important temperature differences, reaching 8 degrees of difference between the entry and exit points as we can see in module 16. Moreover, there are almost 10 degrees temperature difference on the whole pack.

This temperature difference in modules arises because of the way in which the coolant circulates between cells. As it is an "s" shape movement it gets hotter and hotter till it goes out. As we have previously seen the cooling process in modules, Tesla has already started to replace this cooling system used in Model S and X, with a new one they are using in Model 3.

Conclusion

21 700 cells are the future in the short run for Tesla cells. The company will stop manufacturing 18 650 cells. They are already working on it for next Model 3 and Power Wall. According to Elon Musk, from Tesla, they will be cheaper and with a greater energy density, the greatest all over the world.

Tesla has relied on these battery formats, just the contrary as other traditional manufacturers have done. The intention of the Californian brand is to reduce costs with this type of cell. No doubt, they have already got the honour to be leading the sector of 100% electric vehicles.

The technology of Tesla batteries will be remembered as a key technological development in history, completely transforming automotive industry and that in just 5 years since it was released with the initial researches of Model S has proved that the lifespan and performance of the battery in real world is very efficient. And for sure, they will continue overcoming expectations.

The prospective for this technology is based in getting a battery ready to store a huge quantity of energy in a smaller space. The aim is to solve the main inconvenience of electric vehicles according to customers, that is, the autonomy and the charging time of these vehicles.

With current progresses in cells research, which show they are able to store more energy for longer periods of time, and with the possibilities opened by capacitors, it won’t be long the moment in which we could see cars with an equal or superior autonomy to that of a combustion engine vehicles, and with faster charging times.

NOTES: