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Development of a Thermoelectric Test for Electrical Contactors

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Abstract

In the economic model in which we develop, there is a dependence on the means of transport that every day is increasing and due to the importance of electrification in the issue of efficient and clean transportation, has caused the need for companies supplying components for automotive manufacturers to evolve and develop new technologies to stay ahead of the needs of their customers being in full evolution towards electrified transport. This evolution extends not only to manufacturing but to the test methods that currently exist, since automotive standards require suppliers to test in laboratory, the components they sell to their customers to ensure their correct operation.

Keywords: Electrical Contactors, Powered Thermal Cycle Endurance, Busbars, Electrification Industry

1. Introduction

The automotive industry can be separated into two main sectors. The OEM (original equipment manufacturer) or the automotive manufacturer and the suppliers that provide the components to the OEMs. This model requires the suppliers to acquire technical knowledge such as prototyping, validation, testing, etc. To ensure the proper operation of the components that will be assembled in the vehicles. Some components are considered safety such as brake sensors, brake pads or in the electrification industry, the relays, and other electrical components [1].

One of these components is the electrical contractors. Electrical contactors are devices used to control the flow of current in an electrical system by passing current through a coil which, in turn, generates a magnetic field sufficient to move a movable contact, allowing a circuit to be closed (Figure 1). Vehicles and other electrical systems typically use it to control the flow of current from the charger to the vehicle's batteries or from the batteries to the motor. They are very important devices because it is not only an element that gives way to the current through the charging system, but it is also used as a safety element, giving the possibility of cutting the current when the situation requires it.

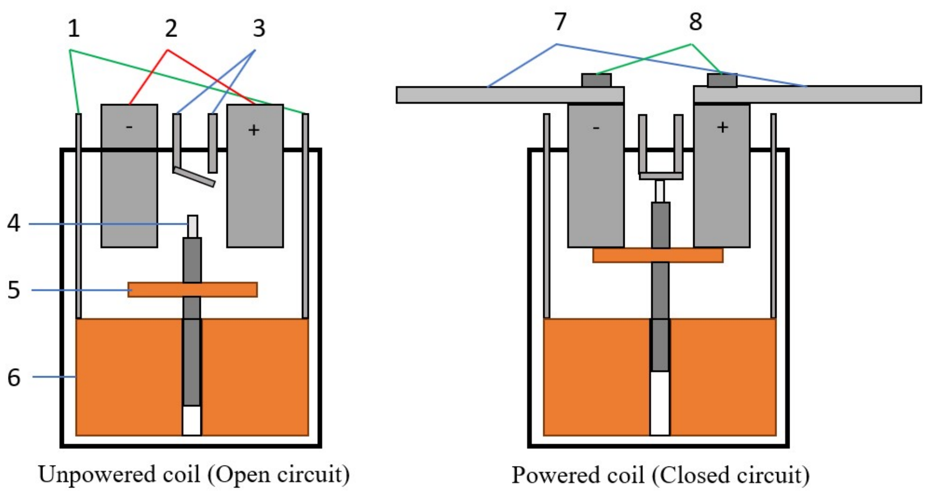

Figure 1: Electrical contactor basic diagram

Table 1: Basic elements of an electrical contactor

Element	Description
1	Low voltage coil terminals
2	Stationary or high-voltage terminals
3	Auxiliary terminals
4	Auxiliary plunger
5	Moveable contact
6	Coil
7	Busbar
8	Fastening bolts

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The architecture associated with the use of a contactor in an electrical vehicle typically requires two contactors in parallel, one for the negative pole and another one for the positive pole, in the positive pole, a fuse is inserted in the system as a redundant safety component in case the contactor failed to open the circuit (Figure 2) [2].

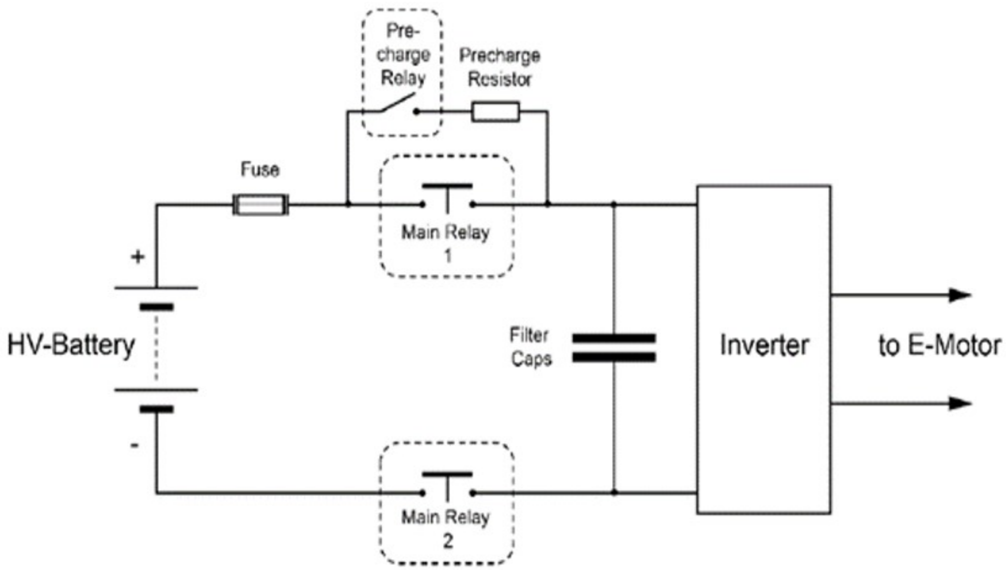

Figure 2: Electrical contactor system diagram [2]

The manufacturers of electrical contractors have the responsibility of carrying out tests that are representative of the application in which the device will be used to guarantee the correct functionality and safety of the device. The tests performed by the suppliers are made at component level, meanwhile the OEM perform tests at vehicle level. Its important to mention this since the tests that are performed at component level had different requirements since the tests generally does not consider a complete system but only just the component to validate or in some cases, some components that are part of the surroundings in the system, but the parameters and requirements are different from vehicle or system level compared to component level validations. [3] The OEM or customers provide technical specifications that expose tests and parameters to which the contactor will be exposed during its useful life. One of these tests is the thermoelectric test that is exposed in this article.

This test aims to validate the component's ability to operate within its functional specification limits when subjected to power and temperature cycles that cause fatigue-related failures. The test must run inside a thermal chamber that allows to program thermal cycles while activating 24 dual contactors (48 individual contactors) simultaneously, that is, closing the circuit of the 24 dual contactors to flow a current profile that varies over time, being connected the contactor or unit number 1 to the positive of the power supply and the unit number 24 to the negative in order to make it flow the current profile through the 24 dual contactors at the same time. The CR (Contact Resistance) that each contactor has at all times should be monitored and the temperature delta between the hottest and coldest unit should not exceed 25°C, in order to maintain the temperature homogeneously between all units at the same time.

2. State of art

In contactors and relays related literature it is stated that the electrical contact joints and electromechanical components such as the coil, spring, and the actuator, are crucial to the electrical and thermal efficiency of the device [4]. The combination of those components and parameters converges in one value that help to determine the efficiency of the power transfer though an electromechanical joint is optimized. This value is called contact resistance. The contact resistance is the resistance to the current flow due to the contact surface conditions and pressure between the two parts meaning that if the contact resistance is low (zero resistance would be a hypothetical ideal value), the electrical contact is optimized and if the resistances is higher, there are several factors that can be improved to reduce the contact resistance. Surface roughness is one of the parameters that might affect the contact resistance. All surfaces have a level of roughness having peaks and valleys at a micro scale level which affect the electrical power transfer since the power transfer cannot be effective though all the surface due to those peaks and valleys [5]. The pressure of the movable contact with the stationary terminals is one other factor that is important at the time of improving the electrical and thermal efficiency. The design of the coil and the spring which push the movable contact against the stationary terminals if very important because if the pressure is not optimal, the amount of electrical transfer spots (a spots) can be affected so if the pressure is optimal and in combination with a well-studied surface roughness, the contact resistance will be lower [6]. The impurities of the material is an important factor at the time of determining the material of the conductor. The impurities of the material can significantly increase the resistivity of the material, affecting the electrical and thermal efficiency [7].

The present work is not taking into consideration the contact resistance as a key factor for the design of the equipment. This work is focused on the integration of the equipment and not the optimization of the contactor itself.

3. Objetive

The objective of the project is to develop a test that allows to validate the electrical contactors according to the customer specifications, creating an environment that represents in the closest way to the application in the field, the conditions to which the contactor will be exposed throughout its useful life, considering the following points:

- Understand how a load profile provided by the customer can be simplified without moving the test away from the application conditions.
- Develop a method to analyze the thermal behavior of electrical contactors when tested simultaneously on the equipment.
- Determine if there is any alternative material to copper to be used as an electrical connector (busbar), having a similar thermal and electrical behavior.
- Compare the thermo-electric behavior of the alternative material with that of copper through a simulation.
- Fabricate a functional station in which the test can be run to perform product and process validations.

4. PTCE (Power Thermal Cycle Endurance) Station

Thermal fatigue tests have the purpose of stressing the material of interest or the interactions between components in a device. This thermal fatigue testing is based on an effective test method called accelerated life test (ALT) which have the purpose of evaluate reliability by applying a stronger stress than its normal operation condition to evaluate the failure rate within a short period of time [8]. An example of the application of an ALT thermal fatigue test is the electronic devices in which the solder joints need to be tested under thermal and electrical circumstances to determine its operational limits [9]. In the case of the electrical contactors, it is important to evaluate the interactions between the components when subjected to electrical and thermal stress.

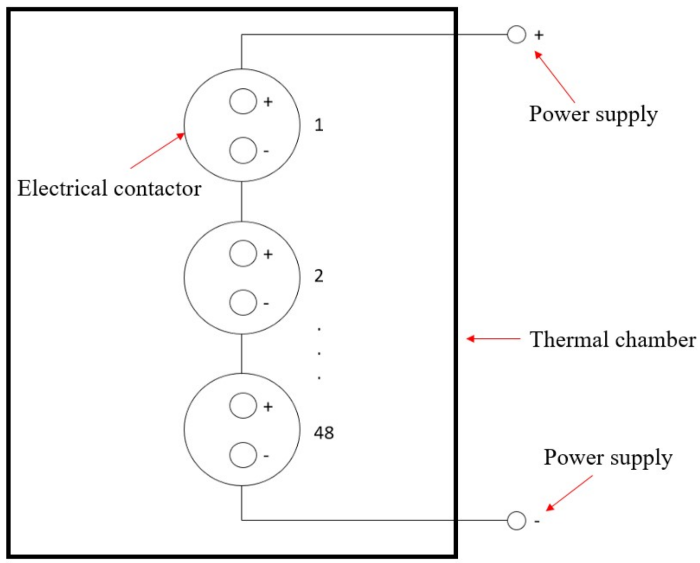

Figure 3: PTCE basic diagram

The prototype station of PTCE (Powered Thermal Cycle Endurance, Figure 3) is called Marlin. The station is composed of the following elements (refer to Figures 4 and 5):

- Thermal chamber (green): This chamber will be used to change and control the operating temperature of the contactors.
- Data recorder or DAQ (data acquisition) (yellow). With this element, the data of the thermocouples to measure the temperature and the tools that measure the resistance (CR) will be collected.
- Low power supply (blue): It will be used to energize the coils and activate the electric contactors.

- High power supply (red). This will be used to pass the customer current profile through the contactors.
- Computer (orange): It is the central element of the system since through a program specially made for this station, all the aforementioned elements are controlled.

Figure 4: PTCE Marlin prototype station

In order to connect the dual contactors inside the thermal chamber to the high-power supply, metal conductors called busbars are used. In Figure 6 we can see the top view of the chamber with the 24 dual contactors and the busbars, and the scheme of the high-power source connected to the system.

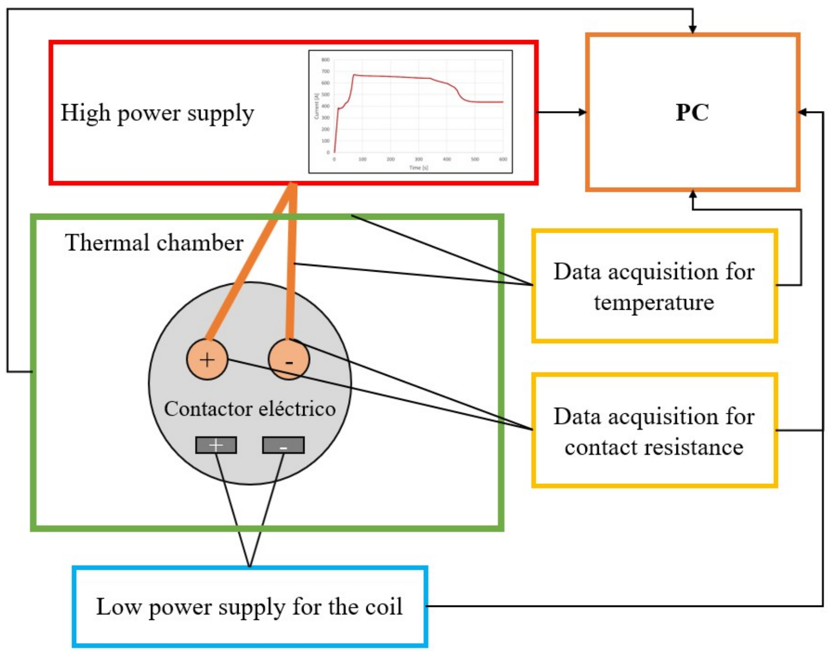

Figure 5: Communication between PTCE elements

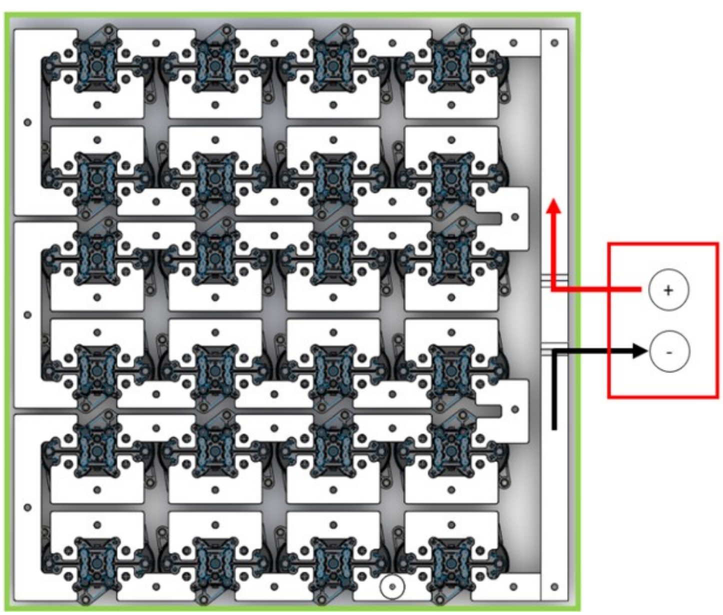

Figure 6: Top view of the chamber with the dual contactors and the busbars

5. Busbars

Two materials were evaluated for the busbars: Aluminum 6101 (Al) for its low cost and Copper C11000 (Cu) for its good electrical conductivity. To determine which is the most suitable material, the electrical conductivity and thermal conductivity were considered (Table 2). These properties are inherent in each material.

Table 2: Electrical and thermal properties of the aluminium and copper

Property	**Aluminum**	**Copper**
Electrical Conductivity	56% IACS @68°F	101% IACS @68°F
Thermal Conductivity	136 [BTU/(hr·ft·°F)]	231 [BTU/(hr·ft·°F)]
Electrical Resistivity	$3.21 \times 10^{-8} \Omega m$	$1.72 \times 10^{-8} \Omega m$

The values show a difference in electrical conductivity of just over 50% for copper with respect to aluminum and approximately 60% in the thermal conductivity of copper over aluminum, meaning that copper has better electrical and thermal conductivity so that to have the same performance, it will be necessary to increase the cross section of aluminum to counteract the differences in its properties.

The following cross-sections were proposed for copper and aluminum respectively:

Table 3: Aluminium and copper busbar cross section dimensions

Material	**Length** $[mm]$	**Width** $[mm]$	**Area** $[mm^2]$
Aluminum	28.7	9.525	273.36
Copper	28.7	6.35	182.25

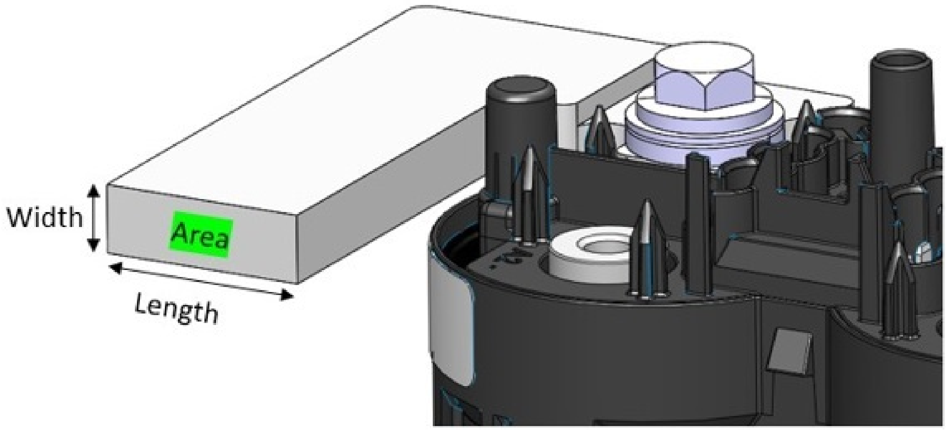

Figure 7: Busbar cross section

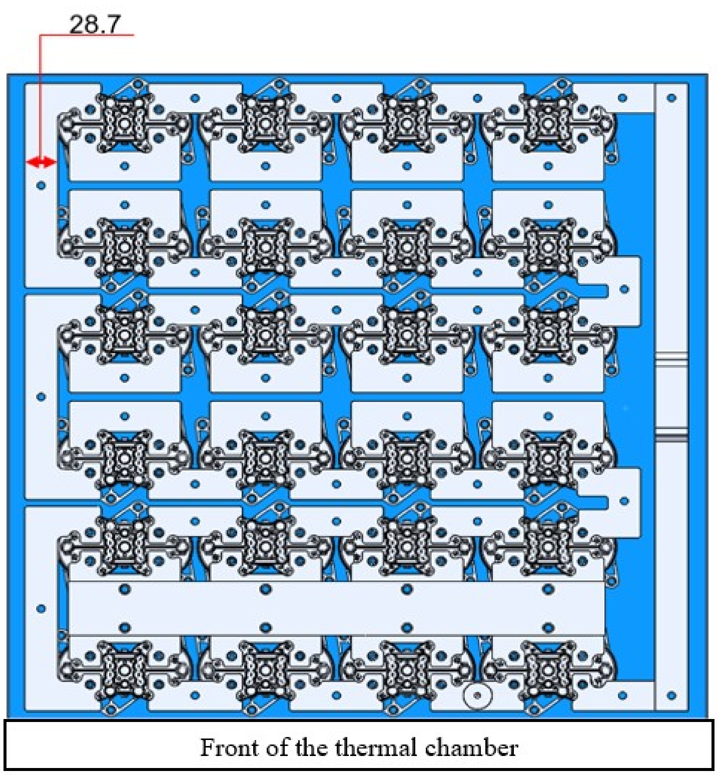

Figure 8: Top view of the thermal chamber with the busbar width

The width between copper and aluminum busbars remained constant due to the limited space in the thermal chamber. Once the busbars were designed to fit in the chamber, it was found that only the material thickness could be modified. Since the cross sections and geometries of the busbars were selected, simulations were performed in ANSYS to determine how much the busbars are heated, considering the section area, constant current of 800A, ambient temperature of 23°C for 30 minutes (Figures 9, 10, 11 and 12).

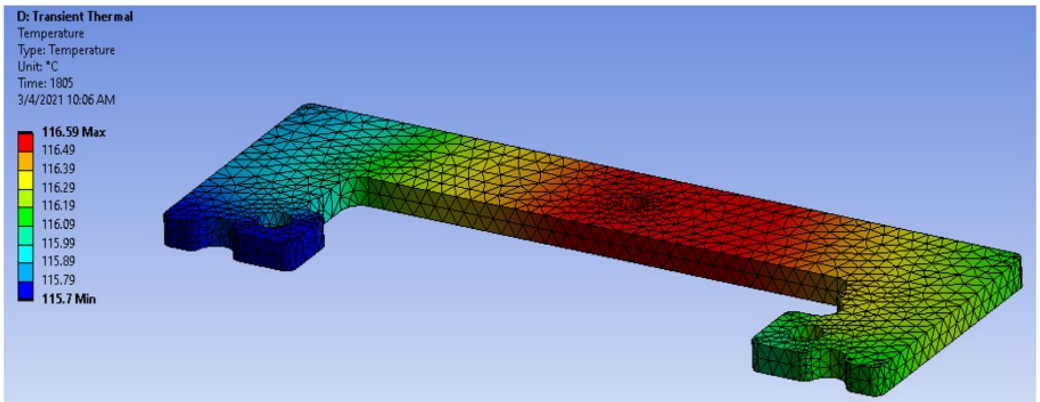

Figure 9: Copper busbar thermal simulation

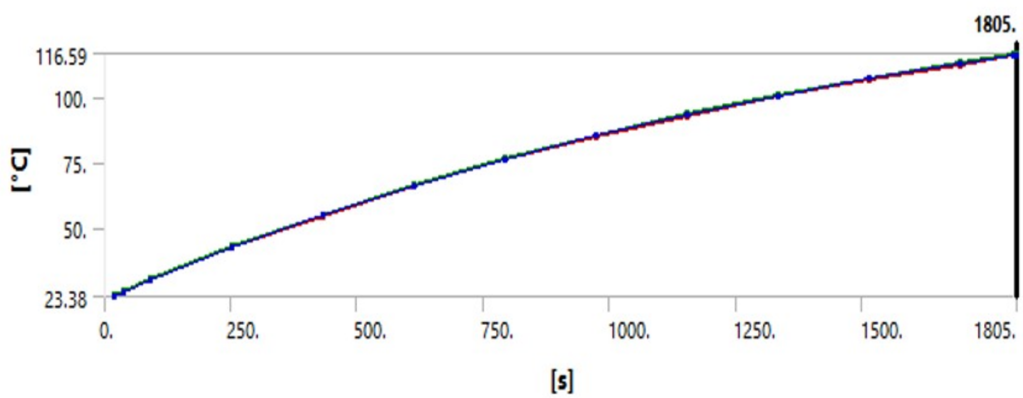

Figure 10: Copper busbar thermal simulation result

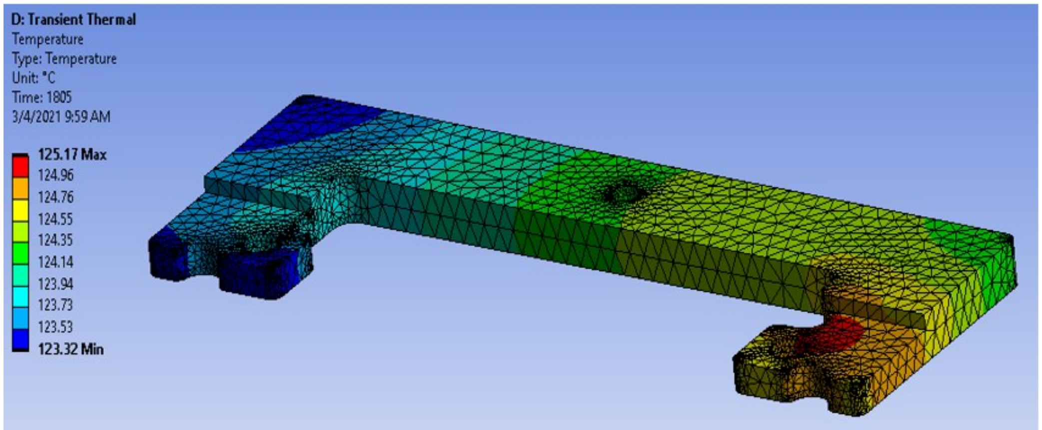

Figure 11: Aluminium busbar thermal simulation

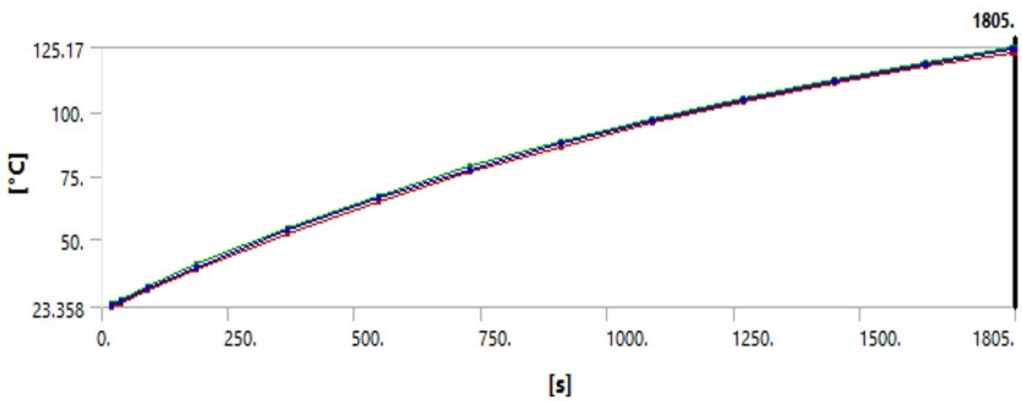

Figure 12: Aluminium busbar thermal simulation result

The resistance of the busbars was calculated with the following formula:

$$R = \rho \cdot \frac{L}{A} \quad (1)$$

Where:

ρ = Electrical Resistivity
L = Busbar Length
A = Cross Section Area

Solving the equation for aluminum at room temperature (20°C):

$$R_{Al} = \left(3.21 \times 10^{-8} \Omega m\right) \cdot \left(\frac{193 \times 10^{-3} m}{273.36 \times 10^{-6} m^2}\right)$$

$$R_{Al} = 0.02266 \times 10^{-3} \Omega$$

Solving the equation for copper at room temperature (20°C):

$$R_{Cu} = \left(1.72 \times 10^{-8} \Omega m\right) \cdot \left(\frac{193 \times 10^{-3} m}{182.25 \times 10^{-6} m^2}\right)$$

$$R_{Cu} = 0.01821 \times 10^{-3} \Omega$$

Because copper has lower electrical resistance, it was selected as the material to fabricate the busbars. In order to verify and check the equations, a resistance measurement was made in a busbar with the same geometry as the one considered in the equations, obtaining the same result (Figures 13 and 14).

Figure 13: Milometer showing the measurement on a copper busbar

Figure 14: Milometer connected to a copper busbar

The prototype PTCE station is shown below:

Figure 15: Inside of the Marlin PTCE prototype station

6. Results and Conclusions

Once the PTCE station was built (Figure 15), the current profile provided by the customer was run 20 times in each of its temperatures and the following results were obtained:

Table 4: Test results after the first 20 cycles.

		Temperature [°C]			
No.	**Description**	**-40**	**-20**	**0**	**40**
1	Temperature delta	20.8	22.3	24.3	21
2	Hottest part	88.5	115.8	140.4	179.7
3	Coldest part (relative to the hottest part)	67.7	93.5	116.1	158.7
4	Temperature rise	128.5	135.8	140.4	139.7

The customer was interested in maintaining a maximum temperature delta of 25°C, meaning that the parts have a relative homogeneous temperature between them within the temperature chamber. And having a temperature rise of between 130°C and 140°C, meaning that the parts must heat up at least 130°C to ensure that the parts are getting stressed enough for the test, so accepting an error of ±5, the results are accepted.

This PTCE station for electrical contactors will increase the testing capabilities, increasing the opportunities against new customers or new businesses.

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