David Ezequiel León Fierro

Method for Trend Analysis on Durability Tests for Electric Drivetrains

BACHELOR'S THESIS GRADE

Supervisor at URV:
Àngel Cid Pastor

Supervisor at Applus+ IDIADA:
José Ramón Castro Albarrán

Degree in Industrial Electronics and Automation Engineering

UNIVERSITAT ROVIRA I VIRGILI

Tarragona

2021

Abstract

On this project we will see the development of a tool created during the internship in Applus+ IDADA to solve an issue on the realization of the trend analysis on the durability test for electric drivetrains.

We will explain what types of tests are performed in the laboratory and evaluate the equipment available for testing. Then we will study the method used to carry out this task and we will evaluate different options to solve the issue considering the customer's requirements and keeping in mind the idea of making a functional tool adaptable to other teams in the laboratory.

After deciding which solution is better for the fulfillment of the objective, we will explain its development and the results we obtain with it. Then we will make a brief analysis of a test by studying the parameters of interest and taking conclusions about the durability test.

Last, we will discuss the conclusions of the project as well as future improvements that can be applied to the tool to increase its functionalities.

Resumen

En este proyecto veremos el desarrollo de una herramienta creada durante la estancia de prácticas en la empresa Applus+ IDIADA para resolver un problema con la realización de un análisis de tendencias en los ensayos de durabilidad para los motores eléctricos.

Explicaremos qué tipo de ensayos se realizan en el laboratorio, así como el material del cual disponemos para llevarlos a cabo. Evaluaremos el método empleado para efectuar esta tarea y estudiaremos diferentes opciones para solventar el problema, considerando las necesidades del cliente además de pensar en desarrollar una herramienta funcional y adaptable a otros equipos del laboratorio.

Una vez escogida la mejor opción para el cumplimiento del objetivo, explicaremos su desarrollo y los resultados que obtenemos mediante ella. Después haremos un breve análisis de un ensayo estudiando los parámetros de interés y extraeremos conclusiones sobre el ensayo de durabilidad.

Finalmente, expondremos las conclusiones del proyecto, así como futuras mejoras que pueden aplicarse a la herramienta para incrementar sus funcionalidades.

Resum

En aquest projecte veurem el desenvolupament d'una eina creada durant l'estància de pràctiques a l'empresa Applus+ IDIADA per resoldre un problema amb la realització d'un anàlisi de tendències als assajos de durabilitat pels motors elèctrics.

Explicarem quin tipus d'assajos es realitzen al laboratori, així com el material del que disposem per a dur-los a terme. Avaluarem el mètode emprat per efectuar aquesta tasca i estudiarem diferents opcions per resoldre el problema, tenint en compte les necessitats del client a més de pensar en desenvolupar una eina funcional i adaptable a altres equips del laboratori.

Un cop escollida la millor opció per a l'acompliment de l'objectiu, explicarem el desenvolupament i els resultats que obtenim mitjançant aquesta. Després farem un breu anàlisi d'un assaig estudiant els paràmetres d'interès i extraurem conclusions sobre l'assaig de durabilitat.

Finalment, exposarem les conclusions del projecte, així com futures millores que poden aplicar-se a l'eina per incrementar les seves funcionalitats.

Table of Contents

Abstract iii

Resumen iv

Resum v

Table of Contents vi

List of Figures viii

Glossary and abbreviations x

I. Introduction 1

1.1. The Company 1

1.2. Objective 2

II. Theoretical Background 3

2.1. Synchronous motors 3

2.2. Induction motors 7

2.3. Brushless DC motors 12

2.4 Permanent Magnet Synchronous Motor (PMSM) 12

III. E-Motor Lab 13

3.1. Test bench equipment 13

3.2. Types of tests 18

IV. Trend Analysis 21

4.1. Data Acquisition 21

4.2. Data processing 22

4.3. Data Reporting 22

4.4. Initial Trend Analysis Tool 23

4.5. Solutions 28

V. Trend analysis tool description 33

5.1. Excel file 33

5.2. Analysis Code Explanation 36

5.3. Plotting Code Explanation 41

VI. Report Analysis 43

6.1. Uncommon behavior during the test 43

6.2. Analysis of the Results 44

VII. Conclusions and Future Improvements 46

7.1. Conclusions 46

7.2. Future Improvements 47

VIII. References 48

List of Figures

Image 1: Applus+ IDIADA around the world..1

Image 2: Starting of a synchronous motor 4

Image 3: Induced torque at starting 5

Image 4: Starting of an induction motor..8

Image 5: Phase equivalent circuit of an induction motor 9

Image 6: Power-flow diagram 10

Image 7: HTOE test example. 19

Image 8: PTCE test example. 19

Image 9: Example of operating points in a PTCE test. 20

Image 10: Page example of the report 23

Image 11: Task flow diagram..24

Image 12: Excel file to import and treat the data 25

Image 13: Example of the torque data...25

Image 14: Example of the torque's deviations from one cycle 25

Image 15: Mean value of the torque's deviations for the selected cycle at the OPs 25

Image 16: Internal temperature signal, DUT1, OP2...43

Image 17: Efficiency, DUT1, OP2 44

Image 18: Internal temperature signal, DUT2, OP3...44

Image 19: E-Motor speed , DUT2, OP3...44

Image 20: Efficiency, DUT2, OP3 44

Image 21: DUT1 Total torque deviation 45

List of Tables

Table 1: Gearbox details 14

Table 2: Measurement elements 17

Table 3: PATools File extensions 21

Table 4: Parameters of the test on a report page 23

Table 5: Information for the number of graphs 26

Table 6: Approximate time of the analysis tasks 27

Table 7: Comparison of the methods 31

Table 8: Operating points configuration 34

Table 9: Setpoint voltage configuration 34

Table 10: Signals and variables' name 34

Table 11: Result configuration table 34

Table 12: Test information - 1 35

Table 13: Test information - 2 35

Table 14: Channel Groups classification example 37

Table 15: Results array example 39

Table 16: Example of arrDataCh operation 40

Table 17: Example of a channel group for the reporting task 41

Glossary and abbreviations

PCU: Real-time computer

UPC: Control computer

DCU: Direct control unit

VES: Vehicle energy system

DUT: Device under test

I. Introduction

1.1. The Company

IDIADA Automotive Technology SA is a global company dedicated to the automotive industry that offers design, engineering, testing, and homologation services to its clients around the world.

Its headquarters is in Santa Oliva (Tarragona), but it has international presence in 25 countries. Counts on world-class testing facilities and constant innovation of services and technologies.

Image 1: Applus+ IDIADA around the world

1.2. Objective

The goal of this project is to develop a tool that will be used for the analysis of parameters on drivetrains for the electrical vehicle. First, we will study what electrical motors are more common for their use on electrical vehicles. After this, we explain the laboratory equipment we used to realize the two types of tests we can develop and explain what they consist of.

Then we will explain the test we have decided to study on this project, the precedents, and the development of the tool we have created to analyze the obtained results from the test.

Last, we will see the conclusions from the realization of this project and the use the laboratory could give to the tool and some possible improvements to widen its functionalities.

II. Theoretical Background

Nowadays, the automotive industry has had many improvements in terms of technology and the electric vehicle it's not an exception. With the last advances, different types of electric motor have been studied to obtain many possibilities depending on the purposes to focus on.

On the following section, we will see different types of electric motors used on vehicles, a brief explanation and the advantages and disadvantages.

2.1. Synchronous motors

One of the main characteristics of these machines, either motors or generators, is that the rotational speed n (in rpm) is highly linked with the network frequency of the AC:

$$n_{sync} = \frac{60f}{p} \quad (1)$$

Being 'p' the number of the machine pair of poles.

These types of machines are submitted to the electromagnetic reciprocity principle, this means that they can work as a generator as well as a motor offering great results. Other main property of the synchronous motor is its high torque, this can be up to three times the nominal torque and keep constant speed in front of load variations. Consequently, these types of machines are mainly used on the industry, but the good results implied the consideration on using them on electric vehicles.

2.1.1 . Starting on Synchronous Motors

One of the more important problems that these types of machines must face is that they have a difficult starting.

The stator is excited by a three-phase current supply, and this will produce a uniform rotating magnetic field (RMF) called $\mathbf{B_S}$. The rotor is excited by a DC power supply, so it acts as a permanent magnet which we call its magnetic field $\mathbf{B_R}$. The rotor's field tends to get aligned with the stator field, just as two magnets will try to align if they were facing each other. Due to the stator's RMF, the rotor along its magnetic field will also rotate trying to align the poles. The bigger the angle between the two fields is, the greater the torque will be, until reaching its maximum.

Following the induced torque formula, we can see that at the time $t = 0\,s$ the induced torque is null.

$$\tau_{ind} = k \cdot B_R \times B_S \tag{2}$$

As the rotor has no initial rotation, the north pole of the permanent magnet field is attracted by the south pole of the RMF. It will start to move in the same direction (at t = 1/240 s, $\tau_{ind} \neq 0$, counterclockwise) but this initial speed is very low. The south pole of the RMF will be replaced by the north pole and it will give repulsive force ($\tau_{ind} \neq 0$, clockwise), as a manner of fact the rotor won't be able to start. We can see this clearer on the following images :

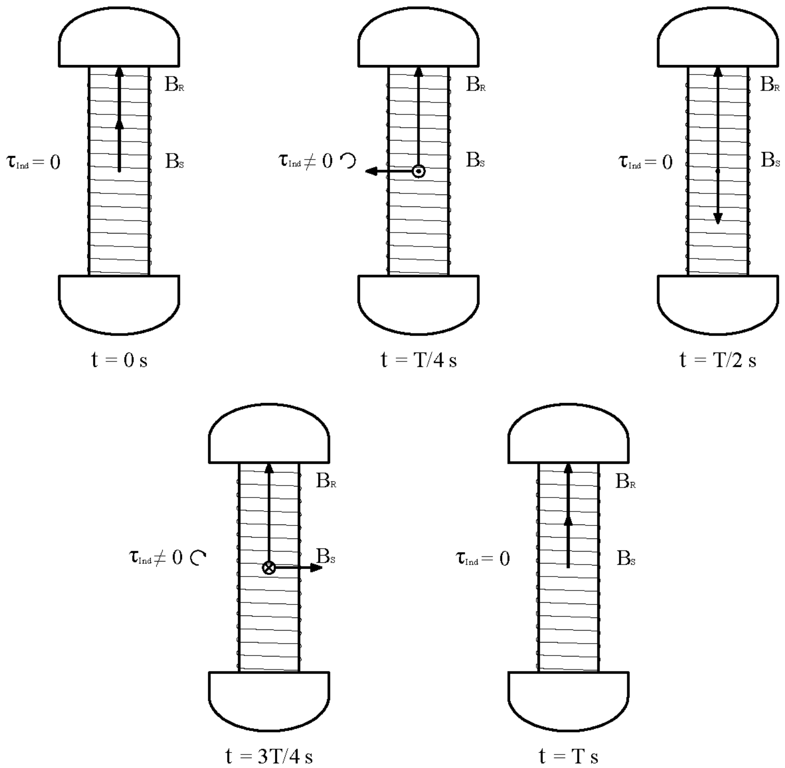

Image 2: Starting of a synchronous motor

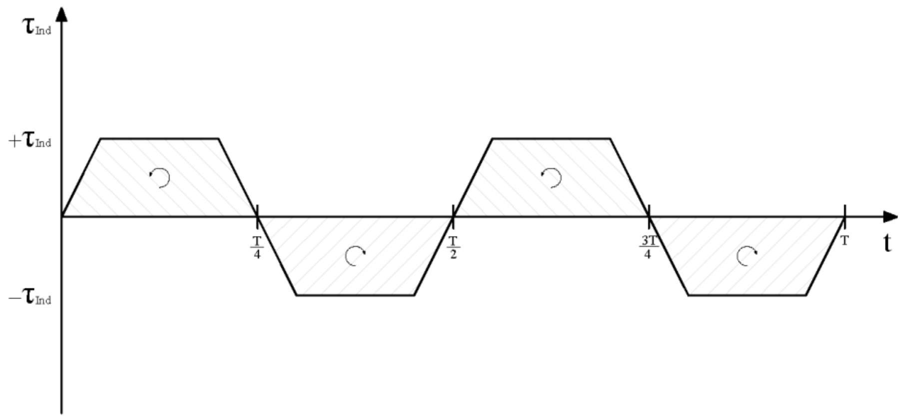

Image 3: Induced torque at starting

To solve this problem, there exists some solutions:

1- Reduce the magnetic field speed of the stator to increase the time the north pole from the RMF is engaged with the south pole from the static magnetic field.
   - As we can see in the formula (1) the frequency is directly related to the speed, this means that the frequency is going to increase slowly until the synchronous speed is reached to avoid mechanical vibrations. The disadvantage of using this method is that an external system is needed to make this possible.

2- Using an external primary motor to accelerate the synchronous machine. As the machine is acting as a generator at this time, loads cannot be connected to it. By the time the machine reaches its synchronous speed, the primary motor is disconnected, then the machine will be acting as a motor.

3- Using damper windings, is the most popular technique used to start the synchronous machines. It consists in special bars attached to the rotor and short-circuited with a big ring around the rotor.
   - First, it’s needed to disconnect the winding from its DC source so as not to create a static magnetic field (B_R) and short-circuit them using the damper windings.
   - The RMF will induce voltage and current through the bars, and these will produce a magnetic field on the winding (B_w). Following the

formula (2) we'll see an induced torque on the bars and consequently, on the rotor.

$$\tau_{ind} = k \cdot B_W \times B_S \quad (3)$$

As B_S rotates, B_w will change its orientation and, as a result from this, the induced torque will rotate in the same direction making the rotor move when the magnetic field are not in the same direction. Even if the rotor has acceleration, its speed won't reach the synchronous speed, as previously said, the induced torque will only appear when the magnetic field are not in the same direction. Once the speed is near n_{sync}, the DC circuit can be connected to its source to completely reach the synchronous speed and to be able to add loads to the machine.

2.1.2. Power losses on AC machines

The AC generators consume mechanical power to produce electrical energy, while AC motors consume electrical energy to produce mechanical power. In both cases we know all the supplied power won't be the same as the output, there always exists losses during the process.

The AC machine efficiency is defined by:

$$\eta = \frac{P_{OUT}}{P_{IN}} \text{ x } 100\ \% \quad (4)$$

$$\eta = \frac{P_{IN} - P_{Loss}}{P_{IN}} \text{ x } 100\ \% \quad (5)$$

The copper losses are produced by the resistive warming that the stator and the rotor machine present. The stator copper loss (P_{SCu}) on a three-phase machine is given by:

$$P_{SCu} = 3 I_A^2 R_A \quad (6)$$

Where I_A stands for the induced phase current and R_A stands for each phase resistance from the armature.

The rotor copper loss (P_{RCu}) on a synchronous machine is given by:

$$P_{RCu} = 3I_F^2R_F \tag{7}$$

Where 'I_F' is the current flowing on the rotor winding and 'R_F' the winding resistance.

The iron losses are the eddy current and hysteresis losses presented in the magnetic material of the machine.

The mechanical losses are caused by mechanical friction on the machine bearings and the air friction caused by the moving parts and the air inside the motor cage.

2.1.3. Disadvantages

The main disadvantage of using this type of machines is the fact that they count on pieces as brushes or commutators which tend to wear out relatively quickly requiring replacements and a high level of maintenance.

2.2. Induction motors

As in the synchronous motors, the stator is excited by a three-phase current supply and a rotating magnetic field $\mathbf{B_S}$ is generated, which speed is n_{sync}. Due to the relative movement of the rotor from the stator's magnetic field, voltage, and current are induced on the rotor bars. This indicates that current flow will appear on them. On the top bars the current flow will go to the outside of the page and on the bottom bars it will go towards the page. This will generate a static magnetic field $\mathbf{B_R}$, and the combination of the two magnetic fields will produce an induced torque.

$$\tau_{ind} = k \cdot B_R \times B_S \tag{2}$$

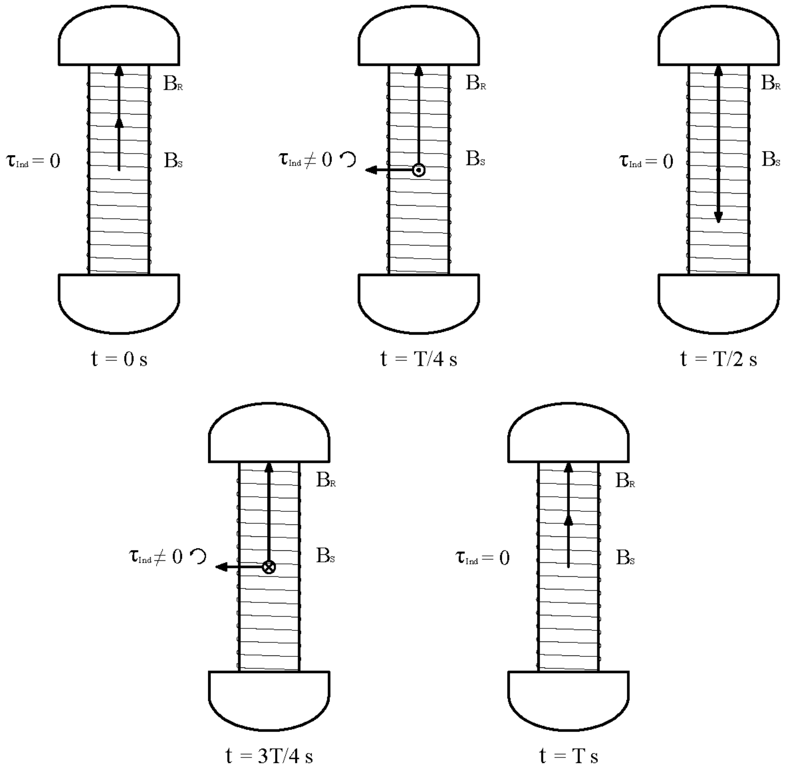

Image 4: Starting of an induction motor

One important fact is that the rotation speed from the rotor has a limit: it can’t be the same rotation speed as the synchronous speed. If this happened, it wouldn't exist relative movement and no voltage would be induced, so it wouldn't exist current. Therefore, no magnetic field would be generated, and the motor would end up stopping.

To describe this relative movement or relative speed it is used the term slip s, which indicates the relative speed as a percentage of the synchronous speed.

$$s = \frac{n_{Sync} - n_m}{n_{Sync}} \cdot 100\% \tag{8}$$

From this equation, we can extract the following:

$$n_m = (1 - s) \cdot n_{Sync} \tag{9}$$

Both equations can be used with angular speed:

$$s = \frac{\omega_{Sync} - \omega_m}{\omega_{Sync}} \cdot 100\% \tag{10}$$

$$\omega_m = (1 - s) \cdot \omega_{Sync} \tag{11}$$

2.2.1. Starting on induction motors

On induction motors, there's no problem with starting. They can start without help but, in some cases, this is not useful because the starting current is quite high and could be dangerous for other systems or even affect to the efficiency by decreasing it.

Winding motors can be started with low current using an extra resistor on the rotor circuit at the starting moment. This resistor allows incrementing the starting torque and decreasing its current at this time.

Moreover, if reducing the starting current is desired, it could be done by changing from a delta connection, which has elevated current, to a star connection during the starting process.

2.2.2. Power loss on induction machines

To talk about the power losses, we are going to use the following diagram and the equivalent circuit.

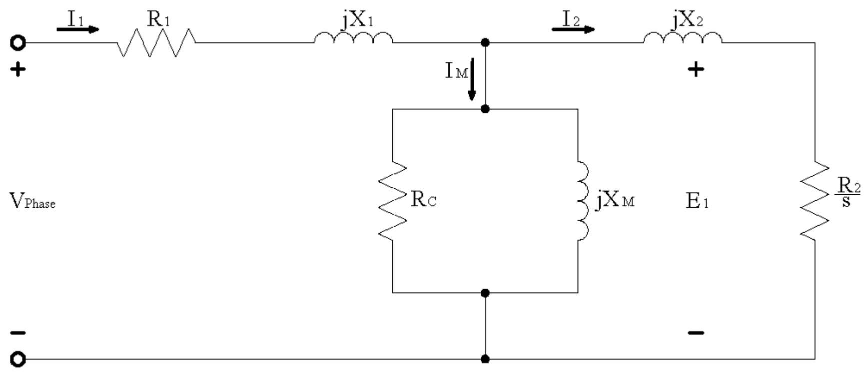

Image 5: Phase equivalent circuit of an induction motor

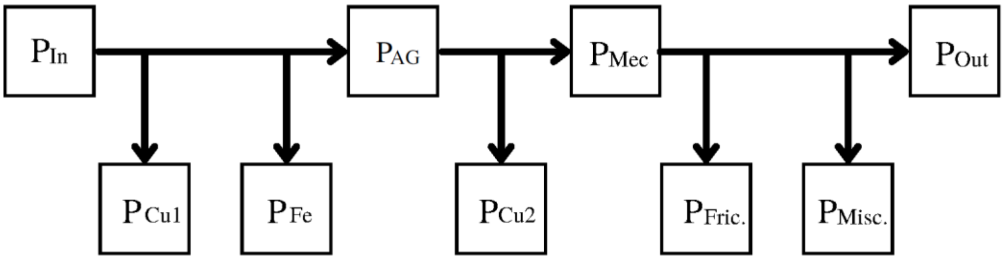

Image 6: Power-flow diagram

As we can see, the power supplied P_{In} is not the same as the output. On the stator we can find the losses produced on the winding, P_{Cu1}:

$$P_{IN} = 3 \cdot V_1 \cdot I_1 \cdot cos\varphi_1 \tag{12}$$

$$P_{Cu1} = 3 \cdot I_1^2 \cdot R_1 \tag{13}$$

Also, there always exists nucleus losses, P_{Fe}, caused by hysteresis and Foucault's current. At this point we can get the power at the air gap, P_{AG}, by subtracting the losses from the input power.

$$P_{AG} = P_{IN} - P_{Cu1} - P_{Fe} \tag{14}$$

Also, we can get this result from the equivalent circuit:

$$P_{AG} = 3 \cdot I_2^2 \cdot \frac{R_2}{s} \tag{15}$$

With these terms and the power losses on the rotor, P_{Cu2}, we can obtain the mechanical power P_{Mec}.

$$P_{Cu2} = 3 \cdot I_2^2 \cdot R_2 \tag{16}$$

$$P_{Mec} = P_{AG} - P_{Cu2} \tag{17}$$

Notice that if we compare (15) and (16) we get a directly proportional relation between these powers, as more slip, more rotor losses.

$$P_{Cu2} = s \cdot P_{AG} \tag{18}$$

Also, this allows us to calculate the mechanical power by only knowing the air gap power:

$$P_{Mec} = (1 - s) \cdot P_{AG} \tag{19}$$

If the rotor is at rest, $s = 1$, all the power goes to the rotor because at this point the mechanical power must be zero.

Last, if we know the mechanical and air friction losses and the miscellaneous losses, we can find the output power P_{Out}:

$$P_{Out} = P_{Mec} - P_{Friction} - P_{Misc} \tag{20}$$

The induced torque it’s defined as the generated torque on the conversion from electrical to mechanical power.

$$\tau_{ind} = \frac{P_{Mec}}{\omega_m} = \frac{(1 - s)P_{AG}}{(1 - s)\omega_{sync}} \tag{21}$$

$$\tau_{ind} = \frac{P_{AG}}{\omega_{sync}} \tag{22}$$

The fact that the induced torque can be obtained by knowing the electromagnetic power and the synchronous speed is the reason why calculating P_{AG} is considered useful.

2.2.3. Disadvantages

One of the main disadvantages of these machines is that they cannot be used as generator because of their characteristics.

2.3. Brushless DC motors

As their name implies, brushless DC motors do not adopt the brushes for commutation. They have been the more commonly used motor for EV's. On this type of motors, contrary to the brushed DC, the armature is stationary, and the permanent magnet serves as the rotor. Due to the lack of brushes, the commutation becomes more complex, and an electronic control is needed.

From these motors, we can find two types, BLDC Hub and BLDC in-runner motor. On the BLDC Hub type motor, the rotor of the magnet acts as the wheel of the vehicle. These motors have an advantage over the BLDC in-runner motors which is that there are fewer mechanical losses because they don't need a transmission unit. On the other side, we cannot have gear ratio of high-power motors due to the size limitation. They are commonly used on cycles and motorbikes.

On the BLDC in-runner motors, the rotor is located inside, consequently they are used in applications where a transmission unit is required which usually are 3-wheeled or 4-wheeled electric vehicles.

The main advantages of BLDC motors are that they need less maintenance because the absence of brushes. Consequently, this will improve their efficiency and also their will last longer than brushed motors.

On the other hand, these motors will be more expensive due to the complex design, the extra electronical components, and the complex control it requires.

2.4 Permanent Magnet Synchronous Motor (PMSM)

The main characteristic of these type of motor is that the inductor consists of permanent magnets. These motors are a great option to be applied in traction application as electric vehicles instead of using induction motors. They present higher power density and up to a 2% higher efficiency than induction machines.

One drawback of the PMS motors is that the magnets can be demagnetized due to the heat or other circumstances during its service life.

III. E-Motor Lab

The Electric motor laboratory (E-Motor Lab) is a two-year-old laboratory which main function is to evaluate the endurance of the electric motor or traction units through durability cycles with client-customized profiles.

For these endurance tests, the laboratory counts on with test benches and the configuration that we use is back-to-back, which allows us to test the machines acting as motor or as generator thanks to the electric motor characteristics.

3.1. Test bench equipment

The E-Motor Lab offers first-class facilities for the testing and development of electric motors and traction units. In this section, we will explain some equipment needed for the tests.

The E-Motor-Lab has 15 test benches that are designed for endurance test of electrical motors. Each test bench can be used with two E-motors using the two gearboxes mounted on the test bench: one will follow a torque profile, acting as motor and, the other will follow a speed profile, acting as mechanical load. This is also called back-to-back configuration.

3.1.1. Baseplate

The function of the baseplate is to maintain and ensure the horizontality of the motors and the climatic chamber during the test. It also reduces the heat exchange surface and withstand the vibration generated during the test by mean of a pneumatic leveling system.

3.1.2. Transmissions

Every test bench counts on two high quality gearboxes that allow us to mechanically connect both DUTs and configure them to follow a torque or speed profile, this means that it allows the devices to act as motor or as generator.

Table 1: Gearbox details

Operating Point	Speed (rpm)	Torque (Nm)	Power (kW)	Gear Ratio
Maximum rated	3000	3000	160	1:-1

3.1.3.Climatic Chamber

Every test bench has a climatic chamber. These climatic chambers work with different ambient temperatures, from -40ºC to + 120ºC. Furthermore, they count on an integrated coolant conditioning unit. Together, they are used to control the temperature of the traction units and submit them to the temperature profiles proposed by the client.

3.1.4. Battery simulator (VES)

The battery simulator, also called Vehicle Energy System, is the interface between the AC power supply net and the DC power supply system. Due to the configuration used for these motors, the back-to-back configuration, we need one VES per test bench. They are designed to provide up to 1000 V, 1000 A, and 250 kW. It's a subsystem which control is integrated with the test bench. This will allow us to activate it manually or automatically through its automation system interface which will be explained on the following sections.

As HMI (human machine interface), it has an embedded touch panel to inform the operator about the status of the battery simulator and to navigate through the error messages. It also has an insulation meter for monitoring the insulation condition on the DC side.

3.1.5. Power box

The power box is the link between the DUTs and the power supply coming from the vehicle energy system, in this case, the battery simulator.

As for the protection of the machines and the laboratory staff, it has integrated safety systems that lock the power box door in case there is voltage on the copper bars and stop the test bench in case the door opens.

3.1.6. Automation system's software

The test benches work based on the software ecosystem that the customer has created: PATools TX.

PATools TX, from Kratzer Automation, is an automation system's software used to perform the test bench tasks efficiently and reliably.

In this case, a PATools system is distributed over two PCs: a control PC (UPC), and a real-time PC (PCU). These will be explained next.

3.1.7. Control PC (UPC)

This computer is used as a programming and controlling interface of the real-time PC (PCU). To carry out these tasks, it counts on a Windows OS and a PATools software ecosystem and both computers are connected via local computer network. The most used applications are the following:

- PA Controller: allows us to display features of the running machine obtained by the real-time PCs (testing time, error occurred, temperatures, …)
- PA Configurator: allows us to develop and configure test applications, also allows us modifying the source code of the bench.

3.1.8. Real-time PC (PCU)

The real-time PC, located in the control and measurement cabinet, it's considered the brain of the test bench. This is because it executes the programmed tests and the real-time operations needed for the data acquisition of the sensors and actuators of the system.

3.1.9. Control and Measurement Cabinet

These control cabinets, along with the real-time PC, are responsible for the measurement and control of the different devices composing the test bench. To be able to monitor these tools, these cabinets are linked with the test benches and all together with the control PCs via the EtherCAT protocol.

These are some of the control elements:

- Light indicators: on the top of the cabinet, indicate the status of the test bench according to a color code.
- Key switch for discharge selection: Enables the DUT discharge on the discharge resistor.
- Mode selector: it is a three-position selector to choose the mode of the test bench.
    - Setup: no DC power is allowed on the Power box.
    - Monitored: the test bench can be run in manual mode at low speed, low torque. The climatic chamber can be opened with the handset and the power box will be closed and locked.
    - In operation: the test bench can be run in manual or automatic mode, up to the maximum values of speed and torque. The climatic chamber will be automatically closed.
- Mode validation button: It allows the user to switch the previous mode selected with the mode selector. If the operator selects a mode without validating it, no changes will be made on the system. Furthermore, in case all the safety-related conditions are not met when selecting a new mode, it won't be possible to validate the change.

- Door opening request button: it allows the operator to request the opening of the climatic chamber. If the action is allowed, the button light will flash.
- Emergency stop button: it triggers an emergency stop of the bench, activating the light indicator, and notifying to PATools the status which immediately stops the test.
- Quit button: when an error trigger a fast stop, after the operator removes the error caused, this button must be pressed to let the bench exit from the error state.

3.2.10. Measurement Equipment

Every test bench counts on measurement equipment to monitor the devices or bench parameters. For example, the measurement of the cabinet or DUTs' temperature, the speed, or the torque of the machines, etc.

As for the speed and torque measurements every test bench has four torque transducers with an integrated speed measurement system. Some advantages of using this configuration are the elevated accuracy and the space optimization because they are coupled with the gearboxes.

The next table shows the elements used for the acquisition of this data.

Table 2: Measurement elements

In addition to this equipment on the test bench, we must use the sensors of each engine. As the machines are already validated by the client, we can trust these sensors not to get wrong data from them.

The real-time computer (PCU) is responsible for receiving all the data which will be used to make the necessary regulation loops.

3.2. Types of tests

Durability tests are used to emulate a service life of the motor in a short period of time. The profiles have been calculated to emulate several years and kilometers of performance in a test that usually lasts for three to six months. Despite test profiles are normalized in the industry, every manufacturer adapts it to their requirements.

Two of the most used tests are:

- HTOE (High Temperature Operating Endurance). Durability tests at high constant ambient and cooling temperatures.
- PTCE (Powered Thermal Cycle Endurance). Durability test with a wide range of ambient and cooling temperature.

On one hand, we have the HTOE test that simulates, in a compact format, the thermal load on a component during the vehicle service life. It consists of raising the ambient and cooling temperature from room temperature to the required by the client. Depending on their necessities, the temperature may change along the entire test, but the machines will be stopped during this variation. As already said, the test will only run at constant ambient and coolant temperatures.

This test serves to verify the quality and reliability of a component as a result of faults that occur due to thermal loads. Examples of this could be the appearance of oxidation or grease migration.

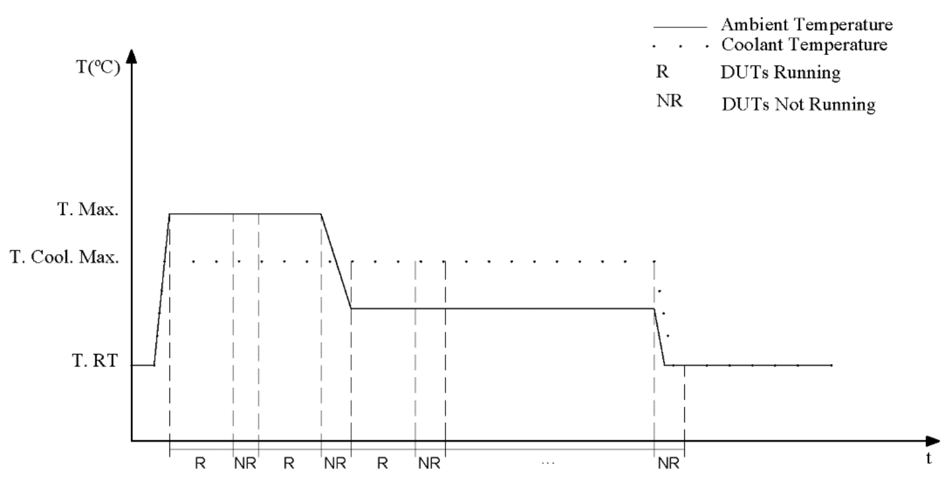

Image 7: HTOE test example.

On the other hand, we have the PTCE test that simulates, in a compact format, the thermal load on a component during temperature changes that occur over the vehicle service life. Its temperature profile consists of changing along the test, for example, from room temperature to a minimum temperature, and after a period of time, change to the maximum temperature.

Different from HTOE tests, the motors are thought to undergo through these variations to study the quality and reliability of the components as a result of faults occurred due to thermomechanical loads. The results could be the aging, cracking on welded or adhesive joints, and poor seals or housing connections.

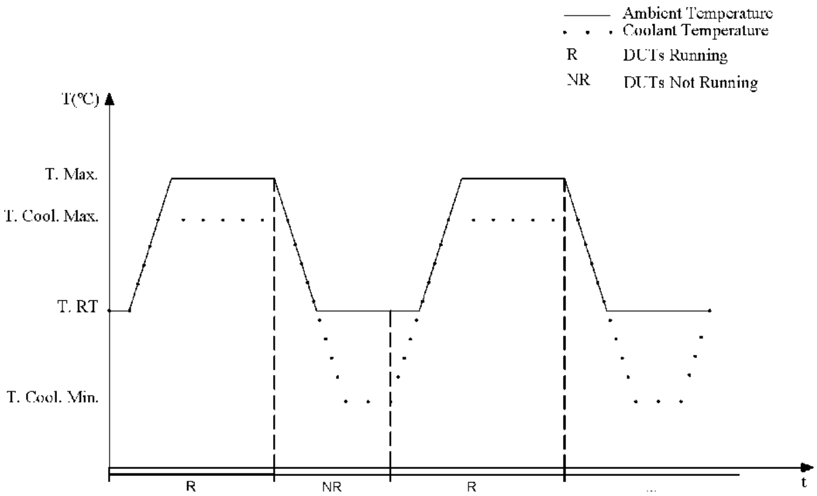

Image 8: PTCE test example.

An important fact for both types of tests is the use of operating points. These are defined by the client and are usually set when there exists a stressful situation for the prototypes. These critical points are important because we use them to analyze the behavior of the machines, take results about correcting some features of the devices and also, confirm us their expected life cycles.

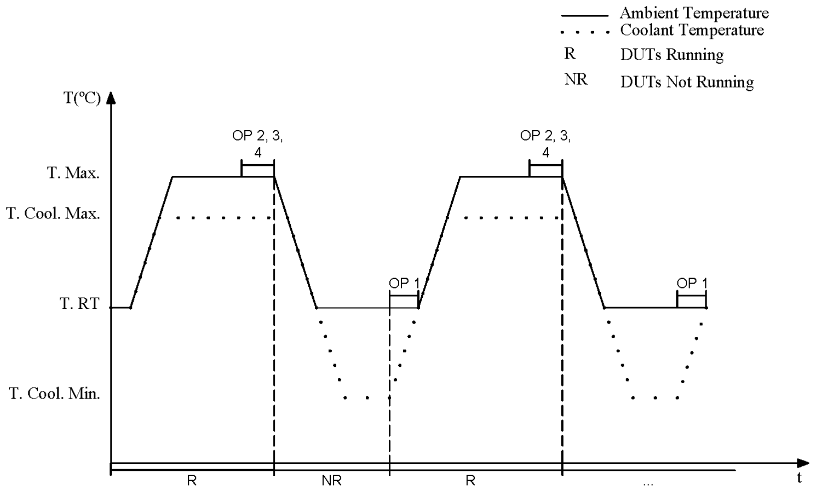

Image 9: Example of operating points in a PTCE test.

Due to the extreme conditions during all the test, it is convenient to program some stops to make revisions of the test benches and the machines. For example, visual inspection looking for leakages or corrosion signs, status of the cooling systems, status of the climatic chamber, etc. The client can set some stops to check features that are under their interest, but the laboratory team can suggest more periods for the inspections of the equipment.

IV. Trend Analysis

In the laboratory, we generate trend analysis to investigate the obtained data from the endurance tests. The aim of these tests is to verify the quality and reliability of components after being exposed to thermomechanical loads. Furthermore, they help us to identify problems on the drivetrains, and see the behavior of some important parameters over the entire life cycle of an electric motor.

In this section, we are going to explain how the trend analysis was made, from the data acquisition to the report and the disadvantages that this carried out. After this, we're going to explain the alternative solutions we thought to solve the problems and justify the selection of the method we have implemented. Finally, we are going to describe the tool we have created.

4.1. Data Acquisition

In the chapter 3.1.8. Real-time PC (PCU), we have explained that these computers are used to record and save the data of the sensors and actuators from the test bench. Despite this, we must use the control PCs (UPC) to create and configure the test applications. Don't forget that these applications must follow the client's conditions and requirements as the recording periods, the sensors' signal, or the sampling frequency, between others.

Despite the customer requirements, we can decide the extension of the file where we will have the recorded data. Due to the laboratory advice, we decided to just consider the file extensions shown on the next table.

Table 3: PATools File extensions

PA Tools File Extensions
.CSV
.MF4
.MDF

4.2. Data processing

This point first refers to the processing of the files that the real-time PC has created and the following treatment of the recorded signals, this is also called the post-processing task.

In our case, we don't need every signal that is on the files and is the programmer's duty to find the best way to select the information that can be useful for the trend analysis.

A common tool used on the laboratory for these types of analysis and signals processing is National Instruments DIAdem (from now on, DIAdem). This is a data management software for aggregation of measurement data, inspection, analysis, and reporting.

DIAdem has been created for the post-processing of measurement data. It includes tools for the specific analysis functions and an interface that helps to view and investigate the data. This software can be used with many data file formats by using DataPlugins. Furthermore, this software allows to develop scripts to automatize repetitive post-processing tasks and getting a complete, accurate, and actionable information result.

4.3. Data Reporting

Once all the data is processed and analyzed, we must represent the results on a document that will be presented to the client. The goal of this document is to emphasize the analysis and the results, making them clear and well understood. On this document the client must detect the configuration and under what conditions has been tested the parameters they are visualizing at every moment. For example, for the analysis of the current of the DUTs at some operating point, we should show the following:

Table 4: Parameters of the test on a report page

Operating point number	Date of testing
Name of the DUT	Conditions required by the client
DUT role	Type of test
Name of the signals	Other

Image 10: Page example of the report

With all these and other features we may consider important to the analysis, we will get a clear and understandable document on which the client can get its own conclusions apart from those we already offer.

4.4. Initial Trend Analysis Tool

The first method to obtain the trend analysis was poorly automated and optimized, thus it required many steps and the use of different tools to reach the final report. The main disadvantage was the very long and repetitive process, which had a great potential to be improved.

The next diagram shows the tasks we had to perform to carry out the analysis of the data until get the final report. These tasks will be explained on the following sections.

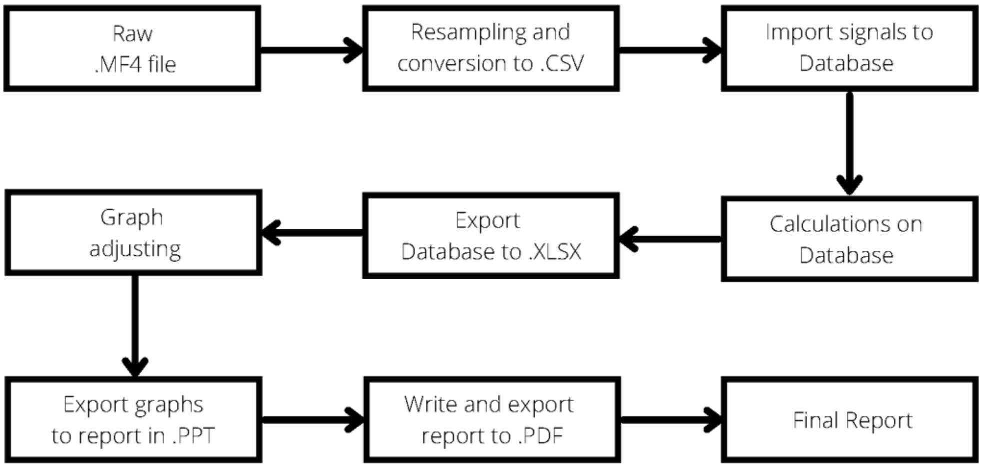

Image 11: Task flow diagram

4.4.1. Data Acquisition

As explained previously, the PCU (real-time PC) provide us with the recorded data files. These files contain many channels because it records the sensor data from the test bench as well as the ones from the two motors. The number of signals easily goes above two hundred. Also, according to the requirements of the client, all these channels are recorded in different frequencies.

Since the colleagues are used to record the files in .MF4 and visualize the data with DIAdem, it was decided to avoid deviation from this work methodology as much as possible. Using a simple script of DIAdem, we convert the file to a .CSV format to work with data tables in Excel. A consequence of using this program is that all the channels need to be recorded at the same frequency, if not, we would have to treat them individually and the data processing time would be unnecessarily high. For this reason, the script also resamples the data to a 10 Hz frequency.

The fact of using this tool, is that it converts the file without treating any data, this means that the Excel file will contain all the signals that are not useful for this analysis and the conversion time will be extremely high.

4.4.2. Data Processing

As for the data processing task, the team created a tool to import the information of the operating points from the selected channels. To do this, an Excel file was prepared to store the data. This file contained a configuration sheet where the operating points time would be indicated, also it contained a sheet per operating point with the names of the channels we wanted to import and for last, a sheet to save the treated data of all the operating points.

Image 12: Excel file to import and treat the data

The following image shows the data of the torque from a randomly selected cycle after importing the resampled files.

Image 13: Example of the torque data

Once we had this information, we used the Excel functions to operate with the channels. Continuing with the previous example, the following image shows the deviation of the torque values at the defined time.

Image 14: Example of the torque's deviations from one cycle

After treating all data from the files, we can take the calculated information to the "DATA" sheet. Here there will be the mean of one-second-long signals from each cycle.

Motor Role	Supp. Voltage	Cycle	Time_test	Total_Torque EM1_dev	TorqueEM1 _Right _Axis_dev	TorqueEM1 _Left _Axis_dev	Total_Torque EM1_dev	TorqueEM1 _Right _Axis_dev	TorqueEM1 _Left _Axis_dev	Total_Torque EM1_dev	TorqueEM1 _Right _Axis_dev	TorqueEM1 _Left _Axis_dev
2	350	820	950,00	8,02%	8,48%	7,57%	6,82%	6,98%	6,66%	10,25%	9,49%	11,02%

Image 15: Mean value of the torque's deviations for the selected cycle at the OPs

At this point, we found that the size of the file was big enough not to allow us to develop the reporting task in the same document. Consequently, we had to export the operating points data to other Excel file to continue with the elaboration of the analysis.

4.4.3. Reporting Task

To make the analysis of the data easier, we decided to visualize the data of the tables on graphs to see the trend of the parameters over the testing time. This involves creating a large number of figures due to the parameters of each motor. We can see an approximation on the following example.

$$Number\ of\ graphs = Parameters \cdot DUTnumber \cdot OP \cdot DUTRoles \quad (23)$$

Table 5: Information for the number of graphs

Number of parameters	DUTnumber	Operating Points	DUT Roles
10	2	4	2

$$Number\ of\ graphs = 10 \cdot 2 \cdot 4 \cdot 2 = 160\ graphs \quad (24)$$

As you can see, we had to plot a big number of graphs. To avoid creating as many as we have calculated, we decided to leave the data in function of the machines' role which could be easily done thanks to the Excel features. Consequently, the configuration of some graphs had to be changed when the role switched. Recall that this task had a low level of automation and had to be done manually.

After this process, to represent these data on a document, we decided to create a PowerPoint presentation to show every parameter's curve at each operating point with both machines' role and the features commented on 4.3. Data Reporting.

Due to the poor automation, the creation of the report supposed one of the most tedious tasks. Each of the graphs had to be exported from the Excel to the presentation and had to be placed on the correct location. Notice that the large number of figures meant an increased chance of committing errors.

Once these processes were done, we proceeded to analyze the results to take conclusions and study the behavior of the components and the machines over the duration of the test.

4.4.4. Time Consumption

The creation of every report supposed a process that consumed a lot of time. The following table shows an approximation of the time we spent on the development of this analysis with the information shown on *Table 7: Information for the number of graphs*.

Table 6: Approximate time of the analysis tasks

Task	Approximate task consumption for 500 files
Resampling and conversion to .CSV	$\frac{1\ min}{file} \cdot \frac{1\ h}{60\ min} \cdot 500\ files = \ 8{,}34\ h$
Import signals to database	$\frac{1{,}5\ min}{file} \cdot \frac{1\ h}{60\ min} \cdot 500\ files = \ 12{,}5\ h$
Calculations on database	$2\ h$
Graph adjusting	$4\ h$
Export graphs to report in .PPT	$6\ h$
Write and export report to .PDF	$8h$
Total	$\approx \mathbf{40}\ \boldsymbol{h}$

As you can see, the complete realization of this analysis could take a long time. In addition to this, the total time is directly affected by increasing the number of operating points provided by the client because it increases the graph adjusting and the exporting graphs time.

4.4.5. Disadvantages

There are some disadvantages of using this method to get a final report. The first disadvantage we could find is the fact that there exist many files and programs to use until getting the final document. This could be confusing for a new teammate and make the tool not portable because of the size of the different tools (DIAdem files, Excel templates, PowerPoint Templates).

Next, emphasize the fact of the many repetitive and monotone tasks there exist on the process that could imply an increase in the probability of making mistakes. In addition to this, as making the report could last many days using this method, it could have implications on the developer causing fatigue and even job dissatisfaction.

All these disadvantages caused excessive time consumption, and this also may be reflected as a waste of money. For these reasons, the team decided to invest on solving all these issues, creating a single tool to unify all the process, reduce the failure probability and increase the report reliability.

4.5. Solutions

To achieve the desired result, we could proceed by different ways. To determine which is considered the best method to carry out this tool, we decided to compare different solutions with their respective advantages and disadvantages.

4.5.1. Control PC programming

As first option, we could use the control PC (UPC) and create a program that would take the data from the PCU when the motors are running, this means working at real time. The required configuration (on the UPC) would have specific starting and stopping times for every operating point because those would be the intervals that are useful for the process.

One of the main issues we could think on by using this method is that we lose the reference of the signal. We cannot see the evolution of the signal before nor after of the critical point. To solve this, we thought on running a setting up cycle to configure and synchronize the real time of the point we are interested in.

To visualize the data, the created file could be exported to an Excel. After this, we would have a table with all the operating points results, and we could use a part of the old method to complete the analysis and make the reporting task.

The advantages of using this method are that the signal processing would be done before testing. The other great advantage is that no resampling would be needed, and both implies saving time and memory usage.

On the other hand, the disadvantages of using this method are that, although proposing the solution of the setting up cycle, it's very difficult to operate only at the specified time due small variations on the system. Furthermore, it's difficult for the theoretical time to coincide with the real time and this bring us a high probability of losing data. These errors would be directly reflected in the analysis of the data.

As there are many types of tests, the starting, and ending parameters are different, so there would be many configurations which increase the possibilities of making mistakes when starting the tests.

Other disadvantage of modifying or creating a tool on the Control PC is that it increases the failure probability of the test, on other words, not meeting the customer's specifications. We should avoid making modification on the client testing configuration.

As for the report, to avoid copying the graphs one by one, an Excel macro could be done to send all the graphs to the report automatically.

This solution maintains the disadvantage of having multiple programs to use for making the analysis, which make the tool not portable, heavy in terms of memory, and confusing if the team wants to make improvements.

4.5.2. NI DIAdem:

In this method, we would use the software DIAdem. As we have explained in 4.4.1. Data Acquisition this software is focused on the data inspection, analysis, and reporting.

Using this software, we wouldn’t need to make any modifications on the Control PCs tool because DIAdem doesn’t have relation with the test running. This will avoid testing failures caused by the programming. Furthermore, the files we would obtain from the PCUs (real-time PCs) would be the same extension as the ones used for other purposes on the laboratory (.MF4).

The development of the tool wouldn’t be complicated since DIAdem has many features, this allows us to work easily with the signals and analyzing the testing data at any time to report the prototypes’ status daily. It has a good visualization of errors that can help to the evolution of the tests.

For the reporting task, as DIAdem counts on tools for this process, it could be done using the same software, solving the disadvantage of having many files of the tool. Moreover, making changes of the graphs wouldn’t be a problem because it would be automized according to some developing parameters. This implies automating the generation of the report, which will save a lot of time.

The disadvantages of using this method are that an advanced license would be needed to create the scripts and to be able to use more tools than basic users. This also means that not everyone is allowed to modify the code to make improvements. Another disadvantage is that, depending on the data files size, the program could be slower than other methods.

4.5.3. Python

In this option, we considered creating the tool using Python 3. Nowadays, Python 3 is one of the most used languages and still raising. It is a multiplatform and open-source language that is globally used, and it's considered the only alternative which is free and powerful as for scientific calculations.

Learning the language wouldn't be a problem due to the large number of documentations provided by its global community. Furthermore, there exists many libraries that we could use to make the tool's development clear and easier.

Despite these advantages, using this method would imply the creation of functions for the evaluation of the tests and the development of an interface for the error detections. Consequently, this would increase the tool creation time of the and we would miss the functions DIAdem offers with the previous method. Recall that this is a software widely used in the laboratory.

As for the report, the only disadvantage is that it would have to be done on another program. This would increase the number of programs we would have to execute for the complete trend analysis, and this was an issue we wanted to solve.

4.5.4. Selected Method

To compare all the advantages and disadvantages of the solutions a table has been created to decide which method is better for the development of the tool.

Table 7: Comparison of the methods

Solution	**Usage**	**Integrity**	**Reporting**	**Future Improvements**	**Total**
UPC	3	3	2	2	**10**
Python	3	3	2	4	**12**
DIAdem	5	4	5	4	**18**

As we can see on the table, the best solution we have found is to develop the tool using DIAdem because, as for our understanding, it will be faster and easier to use for everyone in the laboratory. Also, as we have explained before, this tool has many features for the signal analysis, which will be a great advantage for the goal of the tool and future improvements.

V. Trend analysis tool description

5.1. Excel file

One of the aims of developing this tool, was to eliminate as many different programs as possible. Despite this, we considered that keeping a file on Excel would provide us some advantages rather than developing the entire tool on DIAdem.

This document has been thought to be the configuration interface between the user and the program. This would provide the tool with the fact of being portable, this means that the same tool could be used for different laboratory teams.

On this file we will have the configuration of the operating points and channels, the conditions to analyze the signals and how the results are going to be represented on the tables. All these features will be following explained.

5.1.1. Operating Points Configuration

In the section 3.2. Types of tests, we explained the importance of the operating points. In the next table we can see some of the configuration parameters for each point.

In order to allow to all the teams in the laboratory use this tool on different projects, we decided to create a dynamic table that allow setting up as many operating points as the user desires. As we will see on following sections, this feature has been developed on the scripts (Code 7).

Table 8: Operating points configuration

Furthermore, we also created a table for the voltage values and their accepted tolerance. This will be used to get the right result of the test according to the theoretical value of the voltage.

Table 9: Setpoint voltage configuration

5.1.2. Signals and Variables' Configuration.

As one of this tool goals is to be useful for other teams, we must take in consideration the fact that not every team works with the same client. This means that the UPC (Control PC) will have another configuration and, consequently, other signal names.

To adapt the Excel file to this fact, we decided to create a table where there will be the variable names used in the code of the tool and the user would only have to write the signal name.

Table 10: Signals and variables' name

5.1.3. Results Configuration

To get a result easy to understand, we decided to allow the user to select the information they want to be shown on the tables. They will have a table to introduce features as the signals' name, the channels they want to analyze, and the operation they want to apply. Furthermore, the user will have the possibility to select the channel without having to delete any rows of the configuration by using a selecting column.

Table 11: Result configuration table

5.1.4. Test Information

On other sheet, we created a table where the user could write information about the testing as the type of test, name of the DUTs, initial and final date, between others. This will be used for the generation of the reporting, making the task as more automated as possible.

Table 12: Test information - 1

InitialDate	EndDate	TestBench	Motor Model	Test Type
07/01/21	13/02/21	12	MOD1	PTCE

Table 13: Test information - 2

DUT1 Name	DUT2 Name	Test Case	Load Profile
DUT1	DUT2	PTCE_Example	LP_example

5.1.5. Operating Point Results

As for the results, there will be as many sheets as operating points. Each of the sheets will contain the results of the analysis that has been done according to the configuration set by the users at the configuration tables previously explained.

On the following table we can see the result of ten cycles obtained after the analysis following the configuration on the Table 13: Result configuration table.

5.2. Analysis Code Explanation

5.2.1. Main Script

The main code (Code 1), will carry out the necessary functions to realize the analysis of the tests according to the configuration set on the Excel file.

When executing the program, it will delete any information left on DIAdem to avoid getting wrong information as previous channels or previous global variables data. After this, it will call two functions:

The first function (Code 2) contains some functions to make the program easier to develop, for example to calculate the mean value of an interval of a channel, we could proceed executing the function DIAdem already has, which is:

```
Set ChnResult = ChnStatisticsChannelCalc ( Channel, eStatsArithmeticMean, Start_ind, End_ind, False, False, True, "NameName")
```

The words in cursive are the variables that we should change every time we wanted to use the function. Writing this can be a waste of time because it is difficult to remember, and we would have to look for the function's parameters many times. For this reason, we created a function called *MeanValue (Channel, Start_ind, End_ind)* which will be easier to use because only needs the name of the channel, and the starting and ending indexes to get the result of the operation. Also, it is easier for other people to read the code and make it well understanding.

The second function (Code 3) includes all the specifics scripts for the analysis tool, the declaration (and initialization if needed) of the global variables of the program. Also contains the definition of two new classes:

- OPvar: contains the value of the operating points' parameters: voltage, speed, power, and operating point number.
- OPResuls: contains a dynamic array which size depends on the number of configured operating points.

After these functions, the program asks the user to select the configuration file and the data to analyze. Then it will make sure there are no problem with the selected documents, and it will reorder them by their name to dispose the results from the minor cycle to the last. At this point of the code, the post-processing of the test will begin.

5.2.2. Get_Channels Script:

This function's goal (*Code 4*) is to get the necessary channels for the program and discard the ones that won't be useful.

The code will read the information from the *Table 12: Signals and variables' name*. First reads the entire column, saving its coordinates, to get the number of channels which coincides with the repetitions of the following loop.

In the loop, the program will read the signals' name, and it will search it on the file that's being analyzed. Then, it will change it with the one indicated on the *Script Name* column and calculate the channels' frequency to classify them according to the result.

Table 14: Channel Groups classification example

After sorting the necessary channels, it will delete the signals that we won't use for this tool. Furthermore, it will create an extra group to add information about the test as the motor's role or the cycle number.

5.2.3. Get_OP_Data Script:

This function (*Code 7*) consist of getting the information about the operating points from the *Table 10: Operating points configuration*.

First, it gets the mean value of the voltage from the test. After this, we compare the obtained value with the *Table 11: Setpoint voltage configuration* and it keeps the theoretical value that matches with the result. This data will be used to get the right information from the operating points' table.

The data obtained from the table will be saved in an instanced variable from the class Opvar. This means that each operating point variable will contain the information of the operating point's time, torque, speed, power, and name.

The last part of this script consists of reading the Excel sheets' name to compare them with the names of the operating points. If there are names that doesn't match with the sheets already created, the program will add as many sheets as new operating points.

This function will return an array that contains the new operating points.

5.2.4. ReadOperations Script

This function (*Code 10*) reads the *Table 13: Result configuration table* and it actuates according to the conditions written on it. It will read the first column which indicates what channels the user wants to show, and it will save the information in an array.

After this, the code will read the operation and the first channel considering the previous array. If the operation needs a second channel, this will be read too.

Next, it will call the function CalculateOperation to get the analyzed data of the operating points. We will explain this function later.

For last, if there have been new operating points, the program will read the *Data name* column and it will write the information on the corresponding sheets.

5.2.5. CalculateOperation script:

This function (*Code 11*) receives as parameters the operation read, the channel name, the second channel name, which can be empty, and an array to save the data.

First, it will identify the first channel and determine if it must be treated on a special way (*Code 13*). The only special channels will be those whose torque is not the total torque but the torque of one of the motor axles.

After this, it will check the operation the user wants to realize. For this project, we have only implemented four operations: the average, the standard deviation, the difference of an interval, and if it's an information channel, the operation will be *no* *operation*, which means a special treatment. Despite this, the function is thought to be easily improved if more operations are needed.

Each operation function returns a value that will be saved in the corresponding operating point position from the results array.

To explain this, we will say the name of the array is ResultArray.

ResultArray is an object array instanced from the class CResults. This class contains a dynamic array which length depends on the number of operating points; this means that each item of the ResultArray will contain as many positions as operating points exist. For lasts, the size of the array will be equal to the number of channels the user wants to analyze. Check the next example.

Suppose we have 2 channels, 4 operating points, and the operation we want is the mean value:

Table 15: Results array example

ResultArray(0).Opn(0)	Channel 1 mean value at OP1
ResultArray(0).Opn(1)	Channel 1 mean value at OP2
ResultArray(0).Opn(2)	Channel 1 mean value at OP3
ResultArray(0).Opn(3)	Channel 1 mean value at OP4
ResultArray(1).Opn(0)	Channel 2 mean value at OP1
ResultArray(1).Opn(1)	Channel 2 mean value at OP2
ResultArray(1).Opn(2)	Channel 2 mean value at OP3
ResultArray(1).Opn(3)	Channel 2 mean value at OP4

To sum up, this function calculates each value of the operation for every operating point for one position (channel) of the ResultArray.

5.2.6. WriteOPData Script:

The aim of this script function (*Code 17*) is to write the analyzed channel data on the Excel table according to the operating points. To achieve this, it will use the array explained on the previous section: ResultArrray (in this code the name is DataTrend).

There's a loop that will run over the DataTrend, saving the data of each operating point in another array (arrDataCh) to make the reading clearer. In each loop it will write the information from all the channels in the sheet of the corresponding operating point. Furthermore, this information will be written after the last written cell to keep an order.

The following table shows an example with 4 channels, at least 1 operating point and the mean value operation.

Table 16: Example of arrDataCh operation

arrDataCh(0)	DataTrend(0).Opn(0)	Channel 1 mean value at OP1
arrDataCh(1)	DataTrend(1).Opn(0)	Channel 2 mean value at OP1
arrDataCh(2)	DataTrend(2).Opn(0)	Channel 3 mean value at OP1
arrDataCh(3)	DataTrend(3).Opn(0)	Channel 4 mean value at OP1

After executing this function, we will have one more row on the data table of the test for each operating point, and it will be repeated with all the selected testing files.

5.3. Plotting Code Explanation

5.3.1. Main_Plotting Script

For the reporting task, the team decided to separate it from the analysis part due to the possibility of wanting the analysis but not the reporting to check the results and if all the parameters of the test are going well. For this reason, we created a separate program but with the same software, DIAdem.

In the main code (*Code 18*) we let the user select the file where the data is saves and then we declare and initialize all the global variables that will be used. The program will read the sheets and automatically will separate them in groups, a channel group per sheet. Despite this classification, we also separate the channels according to the DUT role.

Table 17: Example of a channel group for the reporting task

OP2	
Role1	**Role2**
TotalTorqueEM1_R1	TotalTorqueEM1_R2
TorqueEM1_Right_R1	TorqueEM1_Right_R2
TorqueEM1_Left_R1	TorqueEM1_Left_R2
TotalTorqueEM2_R1	TotalTorqueEM2_R2
TorqueEM2_Right_R1	TorqueEM2_Right_R2
TorqueEM2_Left_R1	TorqueEM2_Left_R2
SpeedEM1_R1	SpeedEM1_R2
SpeedEM2_R1	SpeedEM2_R2

Last, it will call the different scripts to execute the plotting of the signals.

5.3.2. Graphs Plotting

For the plotting task, we have created some functions that make the task easy. We have worked the same way as we did with the analysis task.

We decided to divide the task in different scripts due to there are some parameters that need a special treatment, for example the torque needs more graphs, and the temperatures needs more signals. Despite this, the scripts follow the same idea. First, it selects the channels we are going to work with and set the configuration for the graphs which could be the color or the type of lines.

Later, it will plot every channel in the corresponding graph and, when this is done, it will adjust the graph axes according to the signal limits. This will be done for every graph on the sheets of report.

As explained before, this is the pattern the plotting codes will follow. The changes are only for specifics features.

VI. Report Analysis

After generating the report according to the configuration set by the user, we must analyze it and add some comments about the incidents that occurred while running the test. Furthermore, we must take some conclusions about the behavior of the machines and everything we consider important for the client. This report will be presented to them in order to simplify the results.

6.1. Uncommon behavior during the test

The first incident we must explain is the gap that exists between the hours 2380 h and 2480 h. This was caused by an error with the behavior of one of the DUTs that affected to more than 30 cycle tests. Consequently, the data of these cycles is not valid. To solve this problem and prevent it from repetition, the team flashed both machines.

The next event we can stand out is the gap due to an error from 2510 h to 2630 h. We can observe this clearly on the coolant temperature at the operating point four. Despite we observe that the delta value increased, these cycles were still valid because of the tolerance the client defined for this parameter. At 2630 h, the performance of the coolant temperature was improved significantly, and the value remained practically constant until the end of the test.

Last, we must comment that it existed a failure on one of the internal temperature sensors. Consequently, it's value remains constant during the entire test.

Image 16: Internal temperature signal, DUT1, OP2

6.2. Analysis of the Results

At this point of the process, it's the team work to study the results and extract conclusions of the test to present them on the report that will be delivered to the client.

As we know, the temperature is directly related with the copper and mechanical loses and this will affect the machines' efficiency. We can see this on the *Image 20* and *Image 21*.

Image 17: Efficiency, DUT1, OP2

When the temperature increases, the efficiency decreases and vice versa. This is due to the fact that some components, for example the bearings, suffer an expansion. Consequently, there will be more friction (mechanical loses) and the efficiency will decrease.

Continuing with this example, other parameters we can observe are the motor speed, which is related with the core losses, the temperature, and the efficiency. On the following images, we can see how at 2700 h a decrease on the temperature and the motor speed implies a raise on the efficiency.

We can also see that this makes sense thanks to the equation of the efficiency of the motor:

$$\eta = \frac{\tau_{ind} \cdot \omega_m - (P_{Core} + P_{Mec})}{P_{IN}} \tag{25}$$

$$v \downarrow, T \downarrow \therefore P_{Core}, \downarrow P_{Mec} \downarrow \therefore \ \eta \uparrow$$

Image 18: Internal temperature signal, DUT2, OP3

Image 19: E-Motor speed , DUT2, OP3

Image 20: Efficiency, DUT2, OP3

Another event we can notice on the parameters is the relation between the efficiency and the deviation of the torque. When the deviation increases so does the efficiency. The reason of this, can be that when the torque is farther from the target point, the condition of the machines is not extreme as desired, consequently the efficiency is better.

Image 21: DUT1 Total torque deviation

VII. Conclusions and Future Improvements

7.1. Conclusions

On this project, we addressed the problem of the study of the parameters' trend from an endurance test. One of the achieved goals we can stand out from this work is to decrease the possibilities of human mistakes by automating all the processes, from the acquisition of the data until the creation of the report. To carry this out, we decided to develop the tool using the NI Diadem software due to it provides us more advantages than other studied methods.

Another problem we solved in this project has been the fact of using different programs to get to the final report. Now we only use an Excel file configuration and one of the DIAdem's scripts depending on whether the user wants to get the analysis or the report. This also has been performed with the idea of allowing other laboratory teams to use the tool which makes the tool have a level of portability.

With all these features, we have achieved a tool which obtained results are in accordance with the initial expectations, this means that we can use this process to get a report that can be presented to the client saving a lot of time in comparison with the previous method, consequently the department will have better earnings. Furthermore, due to the documentation of the code, future teammates will be able to improve the tool without complications.

From an academic point of view, this project helped me to reinforce and increase the knowledges about programming and electric motors. In addition, I have had the possibility of learning how a real industry department works thanks to I have been taking on more responsibilities over the weeks and this can be of great interesting for my future work life.

7.2. Future Improvements

Despite we have a tool that accomplish with the initial requirements, there are many possibilities of improving it. Next, we will comment some of them.

In order to simplify the usage of the tool, we could create an interface on DIAdem that would allow to configure the testing data without opening the Excel file. Another feature we could apply to this interface is that the user would be able to select whether the analysis of the tests or to create the report with the selected Excel document. This way the user would have to work only with one file, which would be a great advantage.

As for the testing, we could add some functions to detect when the testing is not going as expected. This would inform the user the specific information when the error occurred, for example if it exists a problem with one of the temperatures at some point, it will communicate the time the deviation occurs and the theoretical and real value of the parameter. This will avoid testing the machines when the conditions aren't optimal, consequently we will save time and we will have better results.

With these modifications and some others that will appear when the needs of the teams require, it can become a multipurpose tool that will help the development of the testing and the reporting tasks.

VIII. References

4.2 Arranque del Motor Sincrónico. (2020, April 16). [Video]. YouTube. https://www.youtube.com/watch?v=TsiB9jpwU_c&ab_channel=Dr.Jos%C3%A9LuisDur%C3%A1n-G%C3%B3mez

Applus+ IDIADA. (2020). *E-motor test bench phase 2* (No. 41102–01).

Applus+ IDIADA in brief. (n.d.). Applus+ IDIADA. Retrieved April 2021, from https://www.applusidiada.com/global/en/about-us/inbrief

Chapman, S. J. (2012). *Electric Machinery Fundamentals 5th edition* (5th ed.). McGraw-Hill Education.

DIAdem 2018 Help. (n.d.). NI Diadem. Retrieved March 2021, from https://zone.ni.com/reference/en-XX/help/370858P-01/

E09.- Máquinas rotativas de corriente alterna. (n.d.). BIRT LH. Retrieved July 2021, from https://ikastaroak.birt.eus/edu/argitalpen/backupa/20200331/1920k/es/IEA/E/E09/es_IEA_E09_Contenidos/website_index.html

Efficiency and Loss Mapping of AC Motors. (n.d.). HBM. Retrieved July 2021, from https://www.hbm.com/en/6207/white-paper-efficiency-and-loss-mapping-of-ac-motors/

Excel specifications and limits. (n.d.). Microsoft. Retrieved April 2021, from https://support.microsoft.com/en-us/office/excel-specifications-and-limits-1672b34d-7043-467e-8e27-269d656771c3

Gopel electronic. (n.d.). *Endurance Test Bench for DC Motors under Development*. Retrieved June 2021, from https://www.goepel.com/en/automotive-test-solutions/test-systems/electric-motor-test-bench/endurance-test-bench.html

Hashemnia, N., & Asaei, B. (2008, September). *Comparative study of using different electric motors in the electric vehicles*. Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/ICELMACH.2008.4800157

Introduction to lv 124 Compliant Products & Services. (2017). *Espec*. Published. https://www.espec.co.jp/english/inquiry/catalog/lv124.pdf

Karthik, S. H. (2019, May 3). *Types of Motors used in Electric Vehicles*. Circuit Digest. Retrieved September 2021, from https://circuitdigest.com/article/different-types-of-motors-used-in-electric-vehicles-ev

Mora, J. F. (2008). *MAQUINAS ELECTRICAS* (6th ed.). McGraw-Hill Education.

Motores Síncronos. (2014). *ACTA*. Published. https://www.acta.es/medios/articulos/ciencias_y_tecnologia/029001.pdf

Patil, M. S., & Dhamal, S. S. (2019, December). *A Detailed Motor Selection for Electric Vehicle Traction System*. Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/I-SMAC47947.2019.9032616

Permanent magnet synchronous motor. (2021). Engineering Solutions. Retrieved October 10, 2021, from https://en.engineering-solutions.ru/motorcontrol/pmsm/

Radicon. (n.d.). *Series H - Inline Industrial Gearboxes*. Retrieved July 2021, from https://radicon.com/single_product/series-h-inline-industrial-gearboxes

Rodríguez, C. (2020). *Programación Python* (2020th ed.). Tokio New Technology School.

Sharifan, S., Ebrahimi, S., Oraee, A., & Oraee, H. (2015, September). *Performance comparison between brushless PM and induction motors for hybrid electric vehicle applications*. Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/OPTIM.2015.7492473

SynRM | Un nuevo gigante en el mundo eléctrico. (2021, January 15). [Video]. YouTube. https://www.youtube.com/watch?v=lpKbCs8uwDo&ab_channel=LesicsEspa%C3%B1ola

Test systems Battery Simulation. (n.d.). Kratzer Automation. Retrieved August 2021, from https://www.kratzer-automation.com/testsystems/en/test-bench-solutions/battery-simulation/

Tools for Test Stand Automation. (n.d.). Kratzer Automation. Retrieved July 2021, from https://www.kratzer-automation.com/testsystems/en/software-solutions/test-stand-automation-with-patools/

Xue, X. D., Cheng, K. W. E., & Cheung, N. C. (2008, December). *Selection of Electric Motor Drives for Electric Vehicles*. Institute of Electrical and Electronics Engineers. https://ieeexplore-ieee-org.sabidi.urv.cat/document/4813059