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TECNOMOBELET – ADAPTION OF VAN FOR ELECTRIC PROPULSION AND DESIGN OF STEERING, COOLING AND BRAKING ASSISTANCE SUBSYSTEMS

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Abstract. *The current need of reducing toxic emissions gases in the transport sector leads to the necessary electrification of transport and development of technology for electric mobility. This motivated a multidisciplinary group, from the Faculty of Engineering of the University of Brasilia Gama Campus, to start a project to convert a Peugeot Boxer Van with a 2.8L diesel motor to electric propulsion.. The diesel engine was replaced by a water-cooled three-phase 60kW induction motor from WEG, with its necessary control driver. The original brake subsystem was replaced by an electrical driven vacuum pump servo system, connected to the original hydraulic brake. The hydraulic steering subsystem driven by a hydraulic pump was replaced by an electrically-assisted steering system. The electric motor cooling subsystem was designed using the original radiator with an appropriate flow driven by an electric water pump for circulation. The design of these subsystems for the mechanical transformation were finalized and the next phase will be to test the Van on a (roller) chassis dynamometer, before the dynamic road test.*

Keywords: *automotive electric motor, manufacturing process, conversion of low-cost combustion engine to electric, steering subsystem, brake subsystem.*

1. INTRODUCTION

The current need to reduce toxic gas emissions associated with the transportation sector leads to the necessity of electrification in transportation and the development of technology for electric mobility. This has motivated a multidisciplinary group, from the Engineering Faculty at the University of Brasilia Gama Campus, to undertake a project to convert a 2008 Peugeot Boxer Van HDI model equipped with a 2.8L diesel engine to electric propulsion. The activity is part of the research project "Tecnomobelet" that aims to design a methodology for converting internal combustion vehicles into electric vehicles and develop technology to electrify utility vehicles (ELS, 2018).

A group of students and lecturers started to study the necessary modifications to install the electric motor and other necessary items for its functioning.

The challenge of the project is the design of the necessary couplings and supports to install the electric motor as well as the design of a new brake assistance subsystem, a new steering assistance subsystem and a new cooling subsystem for the water-cooled electric motor and driver because all the original subsystems were driven by the mechanical power of the diesel motor.

2. METODOLOGY

One of the first methodologies to convert conventional internal combustion engine cars to electric was presented by Costa, Washington da.. (2009) for a van type VW Kombi. Costa, M (2014) presents a platform for electric vehicles traction conversion using a roller dynamometer. This platform was used by Viera (2015) and Freitas et. al. (2017) to assess the conversion of a mini car, while Nascimento (2017) used the platform to assess the regenerative braking capacity of an electric vehicle.

2.1 ADAPTING THE VAN

The project started with the survey of all the parts that could be removed and adapted from the vehicle, in order to install the electric motor and its control system in the original engine compartment. Figure 1(a) shows a picture of the Van and figure 1(b) shows the vehicle without the internal combustion engine (diesel motor) and accessories.

Figure 1. (a) Peugeot Boxer 2.8, model HDI, year 2008 (b) Van without diesel motor

Table 1 lists the removed or adapted vehicle parts.

Table 1. Parts and components removed or adapted.

Components	Procedure
Internal combustion engine;	Removed
Air filter and air lines;	Removed
Expansion reservoir;	Reutilized
Exhaust system, mufflers and pipings;	Removed
Gas tank and hoses;	Removed
Clutch	Removed
Water pump	Replaced
Hydraulic power steering	Removed
Vacuum pump	Replaced
Air conditioning	Removed
Radiator	Reused
ECU	Removed
Steering column	Adapted

2.2 Replacement of diesel engine

The diesel engine was replaced by a water-cooled three-phase 60kW induction engine and electronic controller driver from a Brazilian Manufacturer WEG. The power trains was dimensioned in order to meet the urban driving needs of the New European Driving Cycle NEDEC (Lopes L.L L.2021). To join the motor to the gearbox, an intermediate plate was developed, fixing the gearbox housing to the electric motor housing. The gearbox was fixed to the diesel engine by very robust screws, but the electric motor is fixed by 4 M8 screws close to the axle, in addition to having two areas for fixing the side screws. Figure 2 shows the electric motor coupled to the gearbox.

Figure 2. Electric motor coupled to gearbox

The original engine and gearbox are supported by three attachments: two upper pads, one attached to the engine and the other to the gearbox, and, to prevent rotation of the assembly, a third lower pad attached to the gearbox. As the exchange will be maintained, its upper and lower cushions have been used and kept unchanged.

To support the engine exchange assembly on the side of the electric motor, a support was developed that attaches to the upper and eyebolts of its frame and rests directly on the attachment of the upper cushion in the engine compartment, discharging the bending efforts generated by the oscillation of the vehicle due to floor undulations. The motor support is made of 2 mm thick flat sheet. The original rubber pad can be suppressed due to the low vibration of the electric motor.

Figure 3. a) Electric motor support b) coupling plate electric motor/gearbox

A coupling for the electric motor and gearbox housing was developed. It consists of a fixing plate that uses the gearbox housing fixing screws to the original motor and allows the electric motor to be fixed by its 4 screws close to the shaft.

The gear shift differential is placed far to the left of the body, causing a difference in length between the two axles that connect to the wheels. The left axle has a tulip-type articulation next to the differential and the axle that will make the connection of power to the wheel by means of a homokinetic articulation.

The right axis, on the other hand, has an extension to the tulip-type joint, which is in the same mirrored position as the one on the left side. From them, the semi-shafts that connect to the wheels by means of homokinetic joints are originated.

As the right axle shaft is long, at the same distance from the gearbox to the center of the vehicle there is a flanged sleeve, previously fixed directly to the diesel engine block in the upper position of the axle shaft, which keeps it aligned transversely.

A bracket, fixed to the front suspension unit, was developed to secure the flanged sleeve. In order not to interfere with the electric motor, the position inferior to the semi-shaft was adopted.

The vehicle's original transmission system was used without the clutch assembly, where the first and fifth and reverse gears were removed along with their respective drive and synchronized forks, in order to reduce the weight and inertia of the assembly. Reverse gear will be activated via inversion of the electric motor. Figure 5 shows the modification of the transmission.

Figure 5. Preventive Maintenance and Transmission Modification

In order to dimension the mechanical resistance of the coupling, fixing and attachment elements, a simulation was performed with Ansys program and as a result, a flange to fix the electric motor to the transmission, a sleeve of rigid coupling to connect the motor to the transmission, and a support for fixing the motor were designed.

2.3 **Numerical simulation of the coupling**

The mechanical simulations performed are intended to certify that the designed coupling is capable of withstanding the mechanical loads to which it will be subjected. The assembly diagram of the coupling is shown in Figure 3b, while Figure (6-a) shows the flange and shaft coupling together

The 3D model was imported from CATIA V5R20 software into ANSYS 2018 and its mesh was created. The configuration was performed with respect to the keyed part as well as the fit of the flange to the coupling Figure (6-b). It should be noted that for the mesh to be acceptable, the Element Quality should be as close to 1 as possible, 0.05 being the limit for an acceptable mesh. In addition to this factor, the Skewness was used, the closer to 0 the better, being distortions greater than 0.95 unacceptable (LEE, 2020).

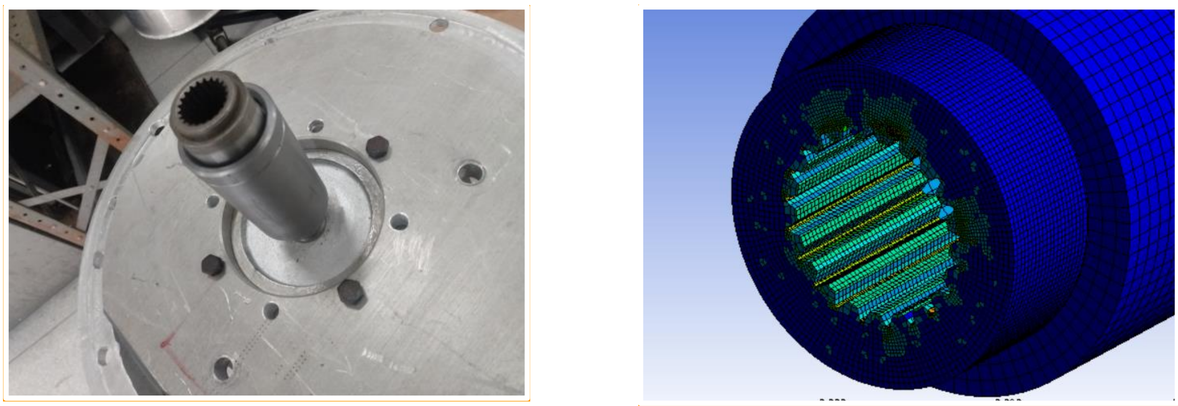

Figure 6. (a) Motor support flange and the shaft coupling. (b) Mesh element quality of the coupling meeting Element Quality and Skewness criteria.

The shaft coupling material is SAE 1045 steel. The simulation result for the von-Mises stress has a maximum of 22.503 MPa. Thus, it is possible to see that the yield stress of SAE 1045 steel is 310 MPa and analyzing the maximum found in the simulation, there is a margin of 287.5 MPa for the material to deform plastically, i.e., permanently. Knowing also that the stress for rupture of the material is 565 MPa, it is safe to say that the torque exerted will not cause rupture of the material.

The equivalent stress result for the von-Mises criterion was obtained and with the yield stress value of the material, the safety factor (SS) can be calculated for the simulated part, equation (1)

$$FS = \frac{\sigma_{limite}}{\sigma_{vonMises}} = \frac{310\ MPa}{22{,}5\ MPa} = 13{,}77 \qquad (1)$$

Another analysis for the project is to determine how much this part would deform if it were subjected to the situation when it has the peak torque of the motor. Thus, the directional deformation of the part was simulated, focusing on the same axis to which the torque was applied. The maximum deformation occurs in the keyed region and has a dimension of (6.1×10-8) meters, a very low deformation.

2.4 New brake assistance subsystem

Diesel vehicles, with few exceptions, do not have air flow control butterfly, being equipped with mechanical vacuum pumps to activate the brake servo. This mechanical vacuum pump is driven by the internal combustion engine. With the installation of the electric motor, the mechanical driven vacuum pump must be replaced by an automotive electric vacuum pump, present in some models of internal combustion engine vehicles. The original hydro-vacuum brake servo system was replaced by an electric-hydro-vacuum brake servo system connected to the original hydraulic brake.

The electric vacuum pump will be responsible for generating the vacuum pressure present in the brake booster compartment, and this must be sufficient to ensure that the pedal actuating force multiplication required to safely brake the vehicle is achieved. A control system will be implemented in order to ensure that the vacuum present in the brake booster compartment is always within the optimum operating values.

An optimal value will be defined for the vacuum pressure in the brake booster compartment. A sensor will monitor the actual vacuum pressure in the compartment and send a signal to the controller. The actual value obtained from the sensor and the predefined optimum value will be compared in order to check if the system is operating as desired. The controller, through this comparison, sends a command to increase or decrease the power supply to the electric vacuum pump in order to ensure that the pressure present in the brake booster compartment approaches the ideal value. A closed loop control system with feedback will then be implemented. Also in the project to implement the control system, techniques will be implemented to ensure the stability of the system. A schematic of the test bench for the new brake servo system to be implemented in the vehicle can be observed in Fig. 7.

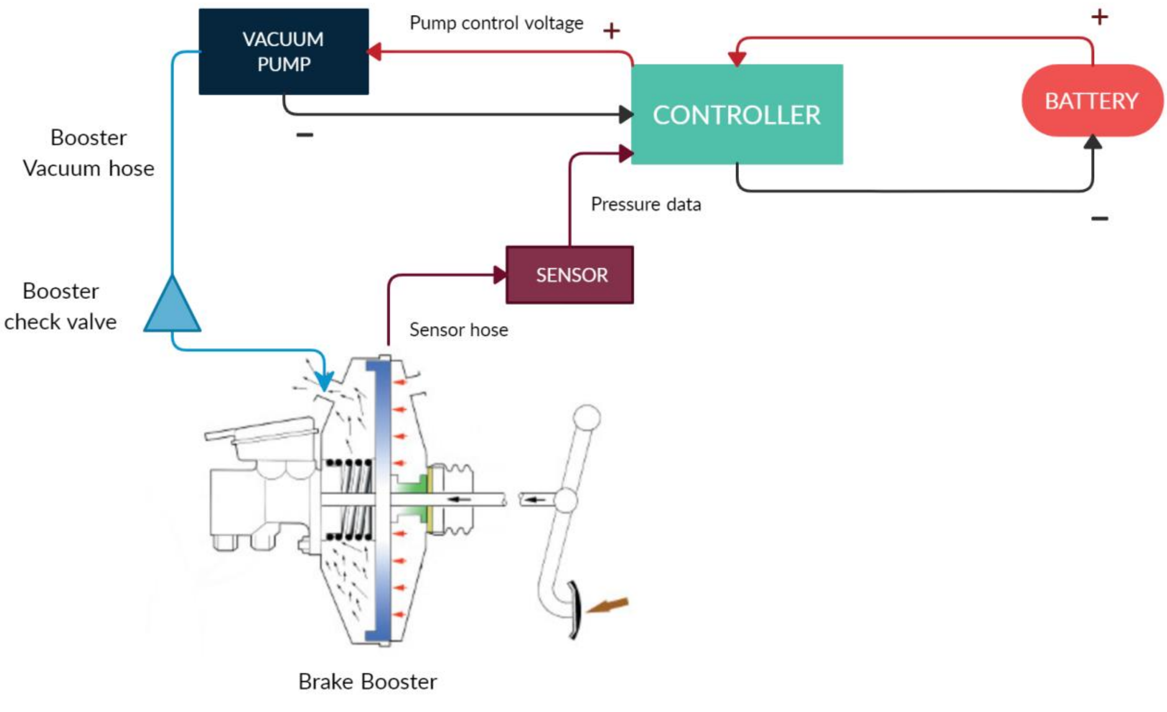

Figure 7 Bench test setup diagram

2.5 New steering assistance subsystem

This vehicle originally had a hydraulic power steering system, which uses a pump to pressurize the hydraulic oil, and assist the drivers to steer the vehicle, reducing the needed effort. The pump was driven by the internal combustion engine. To keep a power steering assistant, there were two alternatives: (i) an electro-hydraulic system or (ii) an electric system. For the first option it would be necessary to manufacture the supports to uphold the system and add an electric motor to pressurize the pump. For the second alternative it would be only necessary to adapt the electric system to the steering system.

The electric system is small and easy to install. It uses an electric motor and all the components are grouped together. The ZF TRW manufacturer affirms the electro hydraulic system is more efficient than the hydraulic one. The electro hydraulic system, in comparison with the conventional hydraulic system, uses only 25% of the energy to operate and it generates a fuel economy up to 0.3l/100km and it reduces the carbon dioxide's emission up to 7g/km. The better performances are explained because the hydraulic system is always connected to the engine, it consumes energy from the engine all the time, while the electro-hydraulic system and the electric system just use energy on demand. (TRW, 2020)

The power steering pump, the oil tank and the hoses were removed. An electric steering system originally from a Volkswagen Up was adapted and installed. The original rack and pinion steering system were maintained. The oil outlets/inlets of the valve and the hydraulic cylinder were isolated. The choice of the electric column was made from the models available at the university when the conversion was made.

2.6 New cooling subsystem

Design of a new water cooling subsystem for the electric motor. The cooling subsystem with the replacement of the original pump by an electric pump was preceded by the thermodynamic calculation of the performance of the coolant flow. The electric motor cooling subsystem was designed using the original radiator with an appropriate flow driven by an electric water pump for circulation.

For cost reduction, the original radiator already present in the vehicle was used, as it was in good condition and maintains the vehicle's original fixings, despite being oversized for the new engine. Table 2 shows an estimate of the amounts of heat that should be removed from the engine and electronics controller by the cooling system.

Table 2. Thermic efficiency

Engine	Power	Efficiency	Heat loss
Diesel Peugeot	93.4 kW	30%	65.4 kW/h
Elétrico WEG VE-M01	60 kW	95%	3.0 kW/h

The original cooling system was designed to attend a heat loss of 65 kW/h while the new system barely needs to lose 3kW/h. So the new cooling system will use less than 5% of the capacity of the original cooling structure.

Table 3. Heat generation

Equipment	Characteristics
Motor VE-M01	60 kW
Maximum flow	18 L/min
Minimum flow	2.0 bar
Inverter CVW 500	1.75 - 3.6 kW
Minimum flow	8 L/min
Maximum flow	20 L/min
Working pressure	0.5 - 2.0 bar
Maximum pressure	2.5 bar

The proposed cooling system is composed of an expansion reservoir where the coolant is stored, an electric pump for liquid circulation, a radiator to perform the heat exchange, and a set of hoses and connections responsible for interconnecting this system. The idea behind this assembly is to keep it as close as possible to the original ICE cooling system. The only main difference is the amount of heat produced by the electric powertrain and the liquid circulation pump.

The liquid in the reservoir is pumped through a single outlet of the pump and routed separately, via a line splitter, to the electric motor and to the inverter motor drive where it removes heat from the components. Then the cooling lines meet again and proceed through a single line to the radiator, where the liquid loses, through conduction, the heat previously acquired. The schematic in Fig 7 shows the coolant flow within the system as well as the heat behavior in this application (Çengel, 2012).

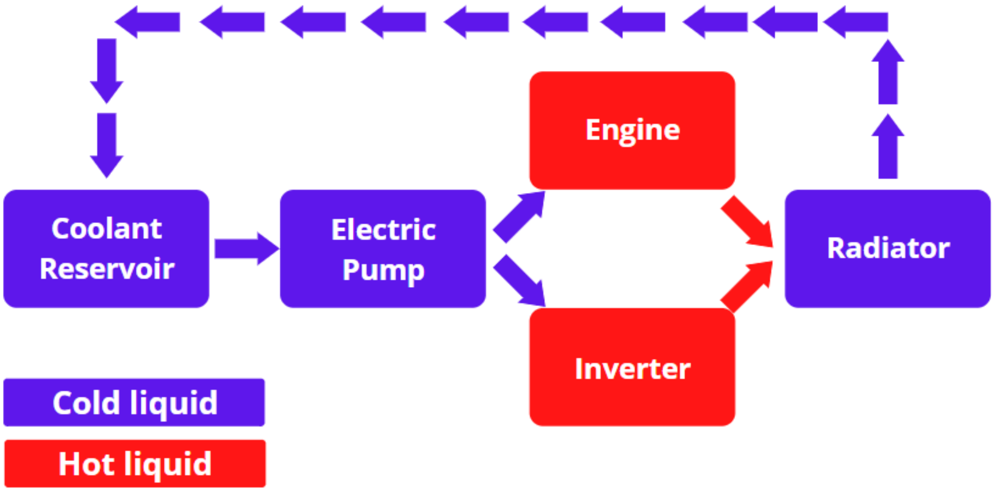

Figure 8: Cooling system heat schematic

3. RESULTS AND CONCLUSION

The adaption of the Van replacing the internal combustion motor with an electric motor and the design of several subsystems is part of a research project to gain knowledge on the conversion of vehicles and to analyse its technical and economic feasibility. Besides this, this project has also provided the students from various engineering courses at the Engineering Faculty of the campus Gama of the University of Brasilia the possibility to experience and verify the difficulties allowing the practical learning in this type of adaptation.

The diesel motor was replaced with an electric motor, with the necessary adaptations to support the new motor and its coupling to the gearbox. The vehicle's original transmission system was used without the clutch assembly, where the first and fifth and reverse gears were removed along with their respective drive and synchronized forks, in order to reduce the weight and inertia of the assembly. The mechanical coupling was assessed through numerical analyses in order to calculate stress and deformation.

The brake and steering assistance subsystems had to be modified as they were originally mechanically driven by the internal combustion engine. The new braking system was modified from a hydro-vacuum system to an electric-hydro-vacuum system, with the installation of an electric driven vacuum pump. The original steering assistance subsystem was replaced by a fully electric steering system, significantly reducing the energy consumption of this subsystem.

The cooling subsystem was adapted keeping as close as possible to the original configuration to attend to the cooling needs of the electric motor and its electronic driver, which are far below the demands of the internal combustion engine.

The design of these subsystems for the mechanical transformation were finalized and after assembling all the new subsystems into the vehicle, the Van will be tested on a (roller) chassis dynamometer to assess the functioning of all the new designed subsystems.

4. ACKNOWLEDGEMENTS

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