E-motor liquid management module optimized for thermal and flow performance

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ABSTRACT

Today, the electric motors used in vehicles are demanding new optimization in assembly and in cost reduction to minimize the size and maximize the efficiency of the electrical machines. The last is related to the lubrication and thermal management of the system, so, the more efficient the cooling and the lubrication are, the more efficient an electric motor can become. This gives the possibility of reducing the size and costs of the electric motor. Considering this, by having the filtration and cooling components in a single module, it is possible to have greater thermal exchange efficiency, less pressure loss and reduce pump power, which leads to smaller components and a more optimized system overall for mounting on the electric motor. Thus, by comparing the performance of separated components (filter, pump, oil pan and pipe system) versus an integrated module, this work aims to verify if the advantages expected by using an optimized module are confirmed. The evaluations are based on literature review and 3D numerical simulations.

INTRODUCTION

According to the Paris Agreement, the average global temperature must not increase more than 1.5°C. This is established as a goal for all businesses and strongly motivates the efforts to reduce the Green House Gas emissions. One of the industries that is in high dedication is the automotive business, with proposals to reduce vehicle emissions. Among other options, one can find the use of biofuel, hydrogen and electrification. Each of one of the technology developers is seeking the most advantageous energy source that each country can use in its strategy. It is inevitable that the electrification of vehicles becomes a global objective and a promising technology, once all countries have the possibility to use an already established source of electrical energy.

The electrification of vehicles is already a reality and is experiencing an increasing demand in the market. The available technologies are robust and well-known, with high torque, acceleration and speeds. However, they are facing some barriers like poor infrastructure to load batteries, low range vehicles and difficulties related to the long-term reliability to keep same voltage and power. These difficult the adoption of the solution by the final customer. All those barriers can have a lower impact if the electrical motor can be as efficient as possible, which yields to a search for more efficiency and higher performance electrical motors.

The performance of electrical motor is given by Performance motor less the losses. Those losses can be split into mechanical, electric and magnetic losses. The last 2 have a big influence on the final performance and on the heat generation.

In electrical motor technology, there exists the correlation of a magnetic field generated, and an amplification done by metal interfaces forming the magnetic circuit. The heat formed by electric and magnetic energy being converted into other energies are the losses which bring high amount of performance losses. These are simulated and explained by Lenz, Joule and Foucault's law. The first law is the basic to understand the source of current in metals. When a magnetic flux is applied in a coil or near a metal, it generates a current in opposite vector direction sum with the parasite current from Foucault’s law. This electric current, when facing the resistance of parts, creates heat by Joule’s law**.** This heat increases the temperature and accumulates in the part. An increase of temperature increases the chemical dynamics of the part, which yields to an increase of defects and higher atomic energy, bringing an increase of electrical resistance of metals. This brings a higher loss to the performance. So, if the temperature of electrical machines is not considered in the project and design, the performance loss of the electrical motor will bring a big impact on the motor efficiency, making it more expensive and with no good range. This impact is from metal electrical resistance increase (giving more heat and more loss) to degradation or burning of polymeric insulators of parts or resin bringing short circuit or risks of thermal collapse events.

Thinking about this, MAHLE is investing always to bring the best solution possible in cooling systems. For electrical vehicles, there is an oil management module, internally named Oil Gear Application (OGA). It is an all-in-one solution, ready to install motor and manage all cooling systems of electrical machina, inverter and transmission. This solution brings the complete system with oil pan, oil cooler, pump and oil filter, all integrated in one product (see Figure 1).

Heat of engine can be removed by water jacket or oil passing internally the components of electrical machines and finally transferred to a cooler in external component.

The objective of this work is to compare the advantages and the performance from separated components in an application (non-module) and the all-in-one MAHLE OGA.

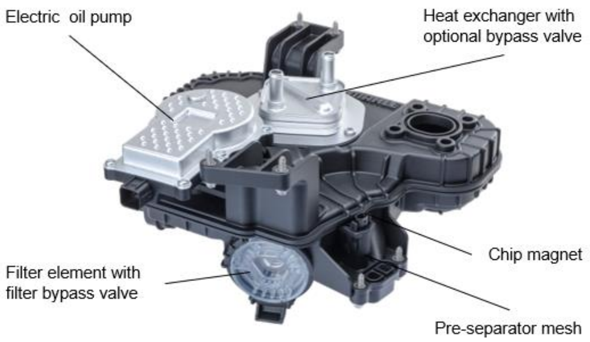


Figure 1. Oil Gear Application – OGA.

DISCUSSION – BIBLIOGRAPHY

The electric motor cooling system is also being used to cool and lubricate the gears of the transmission, which yields to a double function of the system. In Figures 2 and 3, it is possible to see an example that, combined with the motor, there is an integration of the transmission and the liquid management module (OGA) and how a cooling system and pipes can be distributed inside the electrical machine.

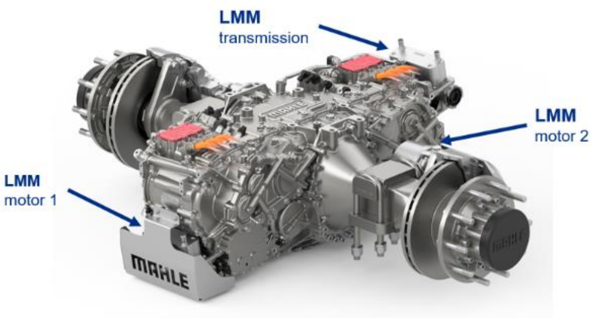


Figure 2. Example of integration of OGA module and transmission.

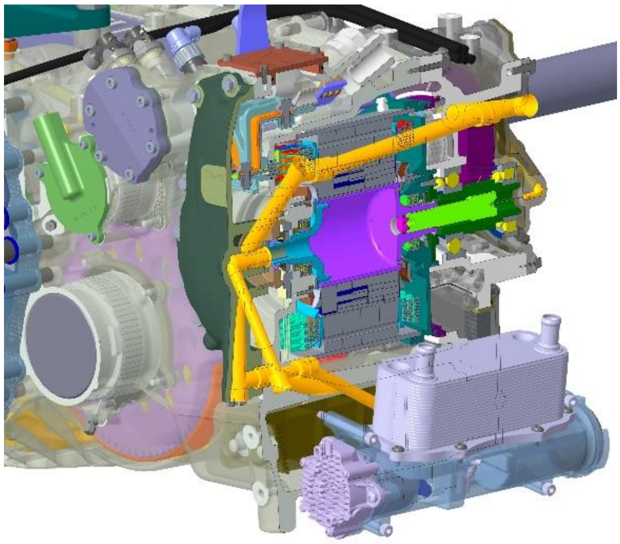
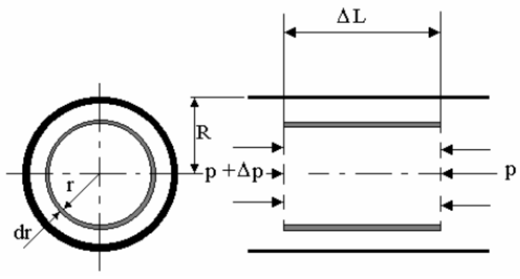


Figure 3. Example of cooling system in electrical motor.

The module efficiency is highly related to the design of an optimized cooling circuit (low pressure drop, high filtration and properly designed oil cooler). In that way, the OGA option can bring an advantage when compared to a construction build with connecting ducts. A construction with connected ducts may have a long path for the flow to go through. Remembering that the pressure drop increases with the duct length and with the decreasing of the duct diameter (see equations in Figure 4), it is advantageous to have a unified module, where the flow can go through all the necessary components in a compact geometry and avoid a long length circuit duct. Since the flow shear rate and pressure drop have a direct relation with length of pipe and the square of the pipe diameter, having a tailor-made plastic part allows the definition of an optimized design, reducing the number of curves and performing a design that is dedicated to better flow behavior.



$$\Delta p = \frac{32\mu \Delta L u_m}{D^2} \qquad \tau = \mu \frac{du}{dy}$$

Figure 4. Tutorial fluid flow theory D.J.DUNN.

REVISION - OGA

The OGA (figure 1 and figure 9) itself is formed by filter, a pump, an oil cooler, thermostat valve, thermal couple, and the housing that also have the function of ducts and pan, all integrated in one component. Once is a very compact component enable that electrical motor does be compact with continuous performance peak > 70% (when water jacket).

The filter (figure 5) is oriented to BEV and HEV liquids and efficiency with a multitude of media formed with multilayer of cellulose, synthetical and glass. The technology of filter medias is developed to have a range of particle size and efficiency from 8µm/99,5% to 150 µm/100% and low pressure loss. The media is reinforced with a support grid and endcap, guided by the cover.

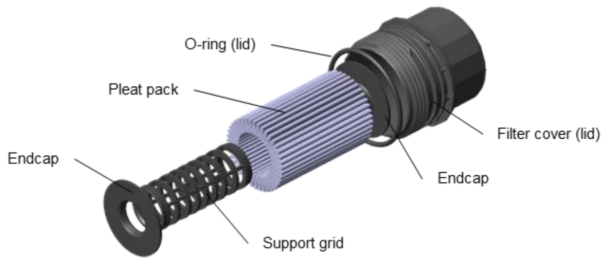


Figure 5: filter elements in liquid filtration example

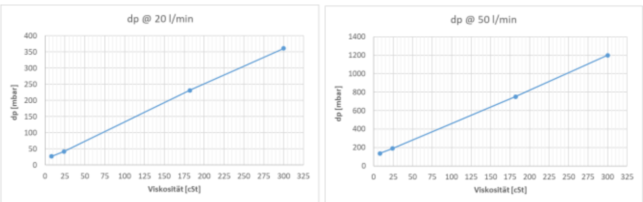


Figure 6: Example of pressure loss in a with 20 L/min and 50 l/min.

The pump (figure 7) is tailor made for application for traction the motor cooling and lubrication. It has a very variable compact design with integrated multiple hydraulic stages going from 50W to 250W and 12V to 24V controlled by LIN or CAN signal.

The Oil cooler (figure 8) is a stack plates with turbulator with new design to specific E-drive application and requirements, bringing low pressure loss, high performance size and low weight. The power of performance requirements is from 8kW to 12kW.

Figure 7: Example of liquid module pump

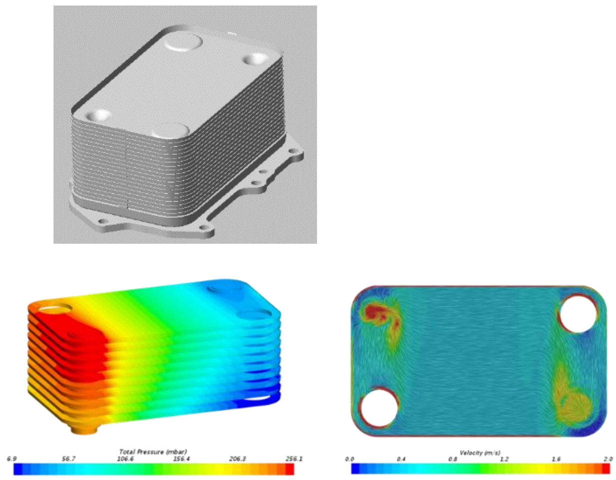


Figure 8: Example of liquid module oil cooler

The housing is the main part of the OGA, is the part where all components are fixed, and free design is done to accommodate the best duct design as possible. The housing is a joining of 2 parts welded, which is possible to have a complex design, improving flow rate, reducing the foaming and cavitation and bringing a very clean part. All components integration improves the NVH when compared with aluminum housing, once polymers have the characteristic of damp vibrations. Also, when comparing the aluminum housing with plastic module, is expected a mass reduction up to 18% when removing the pipes and components from e-motor. Also improve package requirements and interfaces.

All components can be seen in Figure 1 and with liquid illustration in figure 9.

Figure 9: Example of liquid module

REVISION – SEPARATE COMPONENTS

Standalone components are all the parts commented in the oil module management but assembled separated in the e-motor like in the image 10 below.

To the final product be performing with separate components, it is necessary to develop and adjust individually each to fit in the final customer interface and system, which can bring a wide range of variation and imply in higher variant of possible risks. Which also would demand a more complex usage of resources and expert teams to develop the cooling system, validate the components and possibility of impact in quality in field. Also, normally they are integrated in the housing of the motor which will bring a machining and mass yields to expected cost increase when compared with polymeric part.

Standalone components are very used in electric motor assembled in the USA market.

Figure 10: example of separate components assembled in e-motor housing [3]

REVISION – COMPARISON OF SEPARATE COMPONENTS VS MODULE

A comparison between the OGA module and the set of separated components in terms of pressure drop is performed using CFD analysis. The properties and mass flow values are based on real conditions and can be seen in Table 1.

Table 1. Fluid properties for the flow simulation.

Temperature [ºC]	110
Density [kg/m³]	770
Viscosity [Pa.s]	0.004
Volume flow [L/min]	12.5

For each case the following parts are considered in simulation (Table 2):

Table 2. Parts for the module and separated components used in the simulation.

	Separated components	OGA
Length of pipe	500mm	500mm
90° Curves	5	3
Filter	Oil Eletric vehicle Standard OX 1121	Oil Eletric vehicle Standard OX 1121
Pump	Standard	Standard
Pipe Diameter	10mm	Variable geometry

OGA cooling liquid flow path considered in simulation

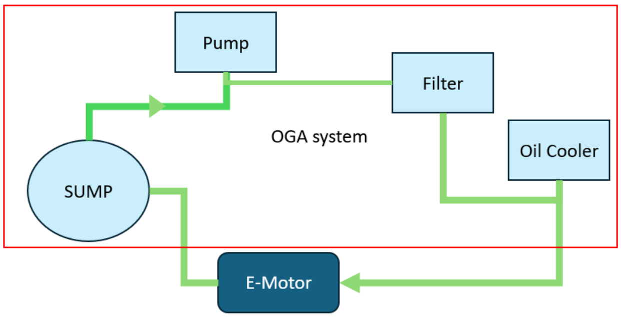


Figure 11: MAHLE liquid management module circuit illustration

Results:

For the OGA module, the total pressure drop calculated is approximately 38.5 kPa, whereas for the construction using pipes, this value is 45.6 kPa. This represents a difference of about 15.5%. In Figures 12 and 13, it is possible to see the total pressure contour and streamlines with velocity contours for the OGA module.

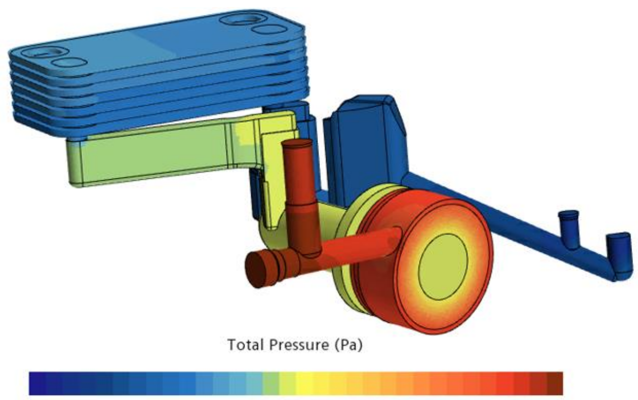


Figure 12. Total pressure in OGA module.

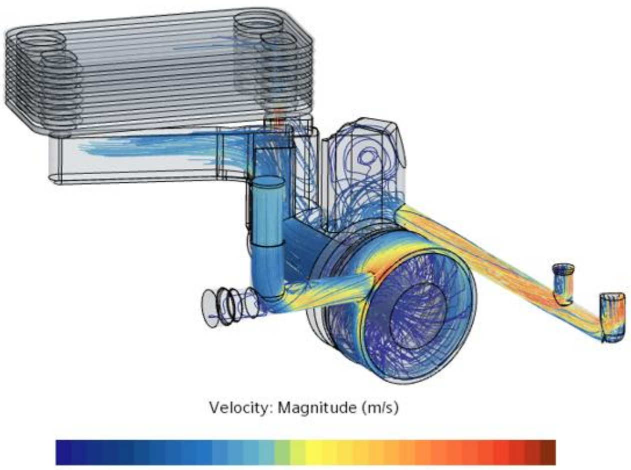


Figure 13. Streamlines with velocity contours in OGA module.

Discussion

The better performance of MAHLE liquid management module in pressure drop is related to tailor made design with improvement of ducts, with a shorter vary length and variable sections of ducts. This is reinforced even with a higher number of curves in OGA, the pressure drop is lower than 10mm continuous pipe. Reducing yet the interfaces, pressure side filtration, reduction of cavitation and foaming.

As cited, the OGA is an all-in-one module, in this case, MAHLE does all the start of art design of plastic parts, Oil cooler, filter and specify all to have the best technical solution as possible. In this case, it is a tailor-made solution for electrical vehicles. Which implies having all engineering, components and product validation, logistics and production provided in best quality from MAHLE side, giving a just assembly oil management system. In this case, the separated components imply in customer to buy and develop components one by one, which brings more resources demand and multiple validation, higher interface risks and more variants in system. Making the development of product more complex than in all solution.

CONCLUSION

MAHLE liquid management system represents a better pressure drop results than a separate components with more curves and interactions, meaning that is possible to improve the design or e-motor of vehicle in following ways:

- Keep the same motor and increase performance/power by increasing flow and improving cooling.
- Decrease size of e-motor and reduce costs by reaching better power/performance by increase cooling
- Reduce the pump force in OGA and reduce the formation of foaming and cavitation.

Even so, the if OGA can have equivalent flow performance as separate components, can bring other advantages as mass reduction, lower storage and logistics costs once is only 1 supplier for all components, reduce interfaces, machining and sealing surfaces, connectors, pipes and screw reduction, and other components integration reduction. Reduction of production of vehicle, testing team specialization and quantity of people.

Also, for business strategy, it is also possible to not have an expert team in fluid flow this known-how can be from MAHLE expertise.

So, MAHLE liquid management module is beneficial to have a very compact system, in tailor made design, attending very good pressure drop. Which can improve the electrical motor performance and power.

REFERENCES

[1] Fluid flow theory; D.J.DUNN

[2] The Paris Agreement | UNFCCC; < https://unfccc.int/process-and-meetings/the-paris-agreement >

[3] Picture from CDN Motor image - did-you-know-ev-motors-had-oil-filters-check-them-on-the-model-y.jpg (1920×1080)