Luvata hollow conductors – enabling more efficient electric vehicles with direct stator cooling

I. Summary

In order to meet the growing need to decarbonize transportation, the use of electric vehicles (EVs) will need to increase. Direct-cooled motors with hollow conductor stators offer several advantages over the indirect-cooled motors currently used in EVs. More effective cooling of the motor windings enables a higher power output, increased efficiency – especially at partial loads, and the use of lower temperature grade permanent magnets, meaning smaller, more efficient motors can be built using cost-effective off-the-shelf materials.

II. Market background

According to the European Environment Agency, in 2019 transport accounted for nearly 30% of the EU's total CO_2 emissions, with road traffic making up 72% of that total.

Rising concerns about climate change, and the desire to reduce the CO_2 and other emissions that are causing it, has led the EU to introduce stricter emission targets for new cars and vans and approve a proposal to cut CO_2 emissions from new trucks by 30% by 2030 compared to 2019 levels. This means the need to switch to electric vehicles has taken on growing urgency.

When considering the cradle-to-grave lifecycle of a vehicle (including production and end-of-life disposal), EVs are already often cleaner than those powered by fossil-based fuels – and the balance will be tipped even further in their favor as the availability of clean, renewable electricity continues to increase.

For now, squeezing maximum efficiency from EVs, and avoiding the use of expensive specialized materials to build the motors that power them, is a key enabler for the switch to large-scale adoption.

III. Direct versus indirect cooling

In electric motors, the current flows in the windings, which are made of copper because of its low resistance. Electrical losses are an unavoidable obstacle and increase with the amount of current; for example, doubling the current quadruples the losses, which increases heat in the motor. In addition, magnetic losses heat both the stator and the rotor, further increasing the heat load. This heat can be extracted by direct or indirect cooling.

Figure 1

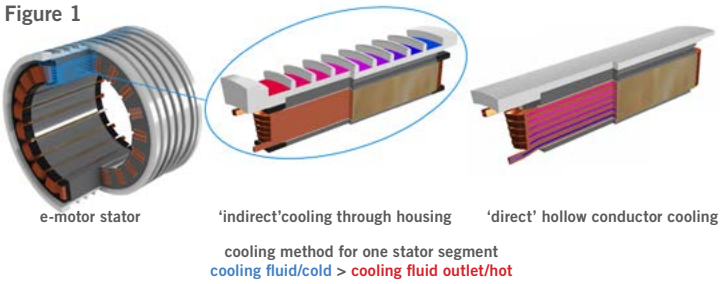


Figure 1. Exemplary stator segment to visualize the general concept of state-of-art indirect cooling and the innovation of direct cooling through hollow conductors. Source: hyperdrives GmbH.

Most smaller electric motors today use indirect cooling, as they have for more than a century. A cooling fluid, water glycol, in the motor housing transports heat to a heat exchanger where it is re-cooled by air before being returned to the housing. The drawback of this method is its limited heat flow, especially for the wire enamel and slot liner, which have low thermal conductivity. This can be seen in Figure 1, taken from a thermal simulation of conventional indirect liquid cooling.

Figure 2

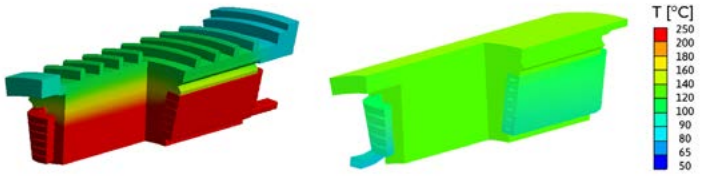


Figure 2. Thermal simulation image showing the efficient cooling enabled by hollow conductors in an exemplary stator segment. Source: hyperdrives GmbH

As can be seen in Figure 2, taken from a thermal simulation of direct liquid cooling, direct stator cooling does not suffer from this problem. Using hollow conductors enables more efficient cooling as a cooling fluid or gas can be circulated in direct contact with the inside of the conductor. This allows for significantly higher stator currents and therefore smaller, more compact motors.

The big benefit of this method is that it treats the heat where it is generated, in the winding itself instead of in the housing. Effective cooling of the stator also ensures a lower rotor temperature, enabling the use of less expensive lower temperature graded permanent magnets.

Hollow conductors in electric motors are not a fundamentally new invention; they have been used for decades in large electric motors and generators, where the distance between the heat-generating winding and the coolant in the housing is too long for indirect cooling to be effective. However, with smaller motors the challenge up to now has been the dimensions of the conductor, as little as 1 mm, which increases manufacturing complexity and negatively affects coolant circulation causing high pressure demand on the pump side. Solving this challenge has paved the way for the use of hollow conductors in smaller direct-cooled motors.

The challenges of direct cooling

Direct cooling is not without its challenges, however. These include the high pressure drop in the hydraulic cooling system, the need to seal the connection joints and to use a cooling fluid with sufficient insulation properties, and more complex manufacturing processes. With hollow conductors there is also a limit to how small the motor can be made. Frequency is also limited as increased frequency would require even finer conductors. However, direct-cooled motors typically allow for frequencies of up to 1 kHz, which is suitable for consumer EVs and commercial vehicles.

IV. The benefits of direct-cooled electrical motors

Direct cooling offers the highest power density for an electric motor – especially continuous power output – alongside excellent efficiency over a broad range. Partial load is the most realistic use case for an electric motor, and tests conducted in an evaluation prototype created by German company hyperdrives GmbH have shown that a direct-cooled motor offers approximately twice the power output at peak load and three times the power output at continuous steady-state operation compared to a standard, indirect-cooled motor.

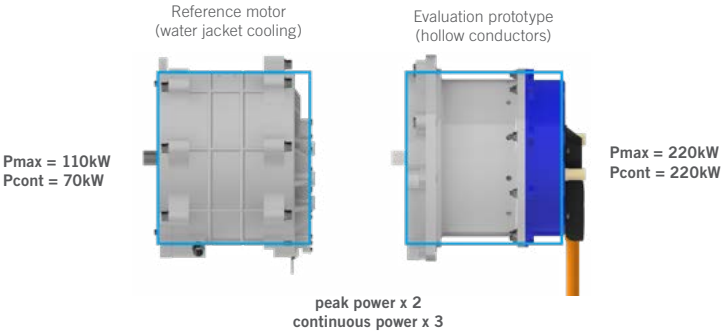


Figure 3. Comparison of peak and continuous power between an indirect and a direct-cooled electric motor. Source: hyperdrives GmbH

The higher efficiency of direct-cooled motors means that smaller power units can be used in EVs, saving both weight and costs. It also enables the use of electric powertrains in larger vehicles such as trucks. Direct-cooled motors can use standard, cost-effective materials, including magnets, providing higher performance at a lower cost – a key enabler for the wider adoption of EVs.

The benefits of direct-cooled motors in various applications (100 kW–2 MW)

Automotive

- Excellent efficiency at partial loads
- Outstanding performance with standard materials
- Competitive performance-to-cost ratio

Commercial vehicles

- Excellent robustness and durability due to reduced stator temperature level, especially for the winding insulation
- High efficiency across the full operation range and high constant power density
- Machine size optimized for minimal total cost of ownership

Aviation

- Unparalleled overload capability optimized for constant flight operation and maximum system efficiency
- Low noise and vibration

Industrial applications

- High torque and power density and excellent efficiency across the full operation range
- Tight control of motor temperature
- Low torque ripple, noise, and vibration

V. Luvata and hollow conductors

Luvata has been manufacturing hollow copper conductors for demanding applications for nearly 60 years and provides automotive-grade material for high-performance products. Luvata can manufacture hollow conductors of various sizes, with short lead times. Sizes start from 3 x 2 mm (< 0.07 kg/m) and continue up to above 100 mm in width (> 30 kg/m). Luvata also supplies conductors in small quantities for testing and prototyping.

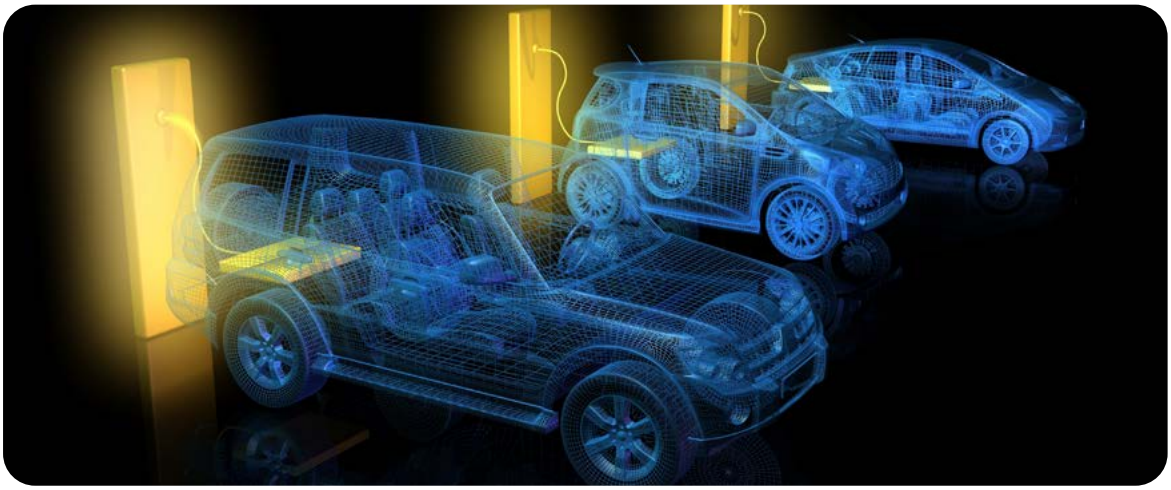
Luvata conductors are made of high purity oxygen-free copper and are ideal in applications where high electrical and thermal conductivity are essential requirements. Oxygen-free copper can be joined with all welding and brazing methods and is suitable for manufacturing processes requiring extreme deformability. Oxygen-free copper also has better bending properties compared to the standard ETP grade often used in stator windings.

Hollow conductors have many applications, including:

- Electric vehicles (EVs) / stator direct cooling
- MRI devices / gradient coils
- Cancer treatment: proton therapy and boron neutron capture therapy
- Electric magnets for high-energy physics applications
- Particle accelerators
- Generators
- Induction furnaces / induction heating and melting
- Plasma research devices
- Electrodynamic vibration test systems
- Ion implantation units for the microcircuit industry
- High-gradient separators
- Waveguides
- Liquid-cooled transformers

VI. Conclusion

Direct-cooled electric motors using hollow conductors offer many advantages over standard electric motor designs. A direct-cooled electric motor enables higher power density and can be constructed from standard materials in smaller sizes. All this will be needed to scale-up the use of EVs and make them as affordable, efficient, and sustainable as possible –
and Luvata has the experience, expertise, and solutions to help make it happen.



About Luvata

Luvata is a world leader in metal solutions manufacturing and related engineering services, serving industries such as renewable energy, automotive, healthcare, and power generation and distribution. The company's continued success is attributed to its longevity, technological excellence, and strategy of building partnerships beyond metals. Luvata employs approximately 1,400 staff in six countries, and its partners include ABB, CERN, Siemens, and Toyota. Luvata is a group company of Mitsubishi Materials Corporation.

About hyperdrives

hyperdrives is a Munich-based start-up that designs and tests electric drivetrains using oxygen-free copper hollow conductors from Luvata.

Get in contact with the hyperdrives team through **info@hyperdrives.de** or visit **www.hyperdrives.de** to find out more.

Find out more at **luvata.com/products/hollow-conductors**

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(1) A. Reinap, M. Gabassi, M. Alaküla, M. Andersson, "Assessment of cooling integration with direct cooled windings", IEEE International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference, 2018