NCAP STATOR COOLING

NCAP stator cooling is an enhanced method of stator winding encapsulation that is low cost, simple, and highly effective at removing heat designed for hairpin style or wire-wound motors.

CONVENTIONAL ENCAPSULATION OF ELECTRIC MOTOR STATOR WINDINGS

Encapsulation of stator windings is most often applied to wire wound motors and involves the use of a thermoset resin such as epoxy that is caused to fill the spaces between the windings and the stator lamination steel in both the stator slot regions and the end-windings. Many different methods are used to achieve this with one of them being full encapsulation or potting in which both the slots and end-windings are fully encapsulated by filling a mould that surrounds the windings.

In most cases the thermal conductivity of the resin is enhanced by filling it with a powdered material that has high thermal conductivity. This filling can improve the thermal conductivity of the resin but increases its viscosity. Process difficulties increase with increasing viscosity and this limits the maximum thermal conductivity to under 4W/(mK). It is however much more conductive than the air it replaces which has a thermal conductivity of 0.025W/(mK).

The filled slots allow heat to be conducted more efficiently into the stator steel than can be achieved by an unfilled motor. Once the heat reaches the stator steel it can readily move in a radial direction to the motor casing where it is removed with a cooling jacket or air. The encapsulated end-windings can be sprayed with oil to assist with heat removal in these regions. Alternatively, the space between the encapsulated end windings and the inside of the motor casing can be filled with the filled epoxy so that heat is conducted through the resin, radially across to the inside surface of the case.

The manufacturing process typically involves the stator being mounted in a vertical position and placed in a chamber that can be evacuated. Moulds coated with a suitable release agent are placed over the end-windings top and bottom and clamped onto the ends of the stator. A tube, of similar diameter to the rotor, is also coated with a release agent and inserted into the stator and expanded onto the stator slots and the internal surface of the moulds. The expansion can be accomplished using air pressure or by another mechanical means such as wedging or axial compression.

A vacuum is created in the chamber and epoxy is poured into the upper mould and allowed to flow through the slots into the lower mould. Typically the stator is preheated so as to reduce the viscosity and to begin the curing process immediately the system is filled. The vacuum is released as soon as the gravity filling is completed and any small voids that remain are collapsed to a small fraction of their size dependent on the level of vacuum used in the chamber. To assist the impregnation of more viscous materials the vacuum and release process can be repeated a few times. The stators are then removed from the vacuum chamber and most often cured for some hours at a high temperature. Once cured the inner tubes and moulds are removed, cleaned, recoated with release agent and returned to the beginning of the production line.

A number of different companies offer this encapsulation method and or the resins systems to support it. Details of these methods can be found in these videos

https://www.youtube.com/watch?v=gQFneH3YiMc&t=38s DEMAK https://www.youtube.com/watch?v=rejK4UQt164&t=1314s HUNTSMAN

https://www.youtube.com/watch?v=17oTVQtxUpo&t=29s HUBERS

https://www.youtube.com/watch?v=-7ggUBiZQvs DAHENG https://www.gluepotting.com/

TYPICAL ENCAPSULATED STATOR WINDINGS

Ultimate Transmissions NCAP description Jan 2022

NCAP SYSTEM

The NCAP system simply replaces the upper and lower moulds of conventional encapsulation with permanent moulds made of a solid material such as aluminium with thermal conductivity as much as 100 times that of conventional encapsulation resins.

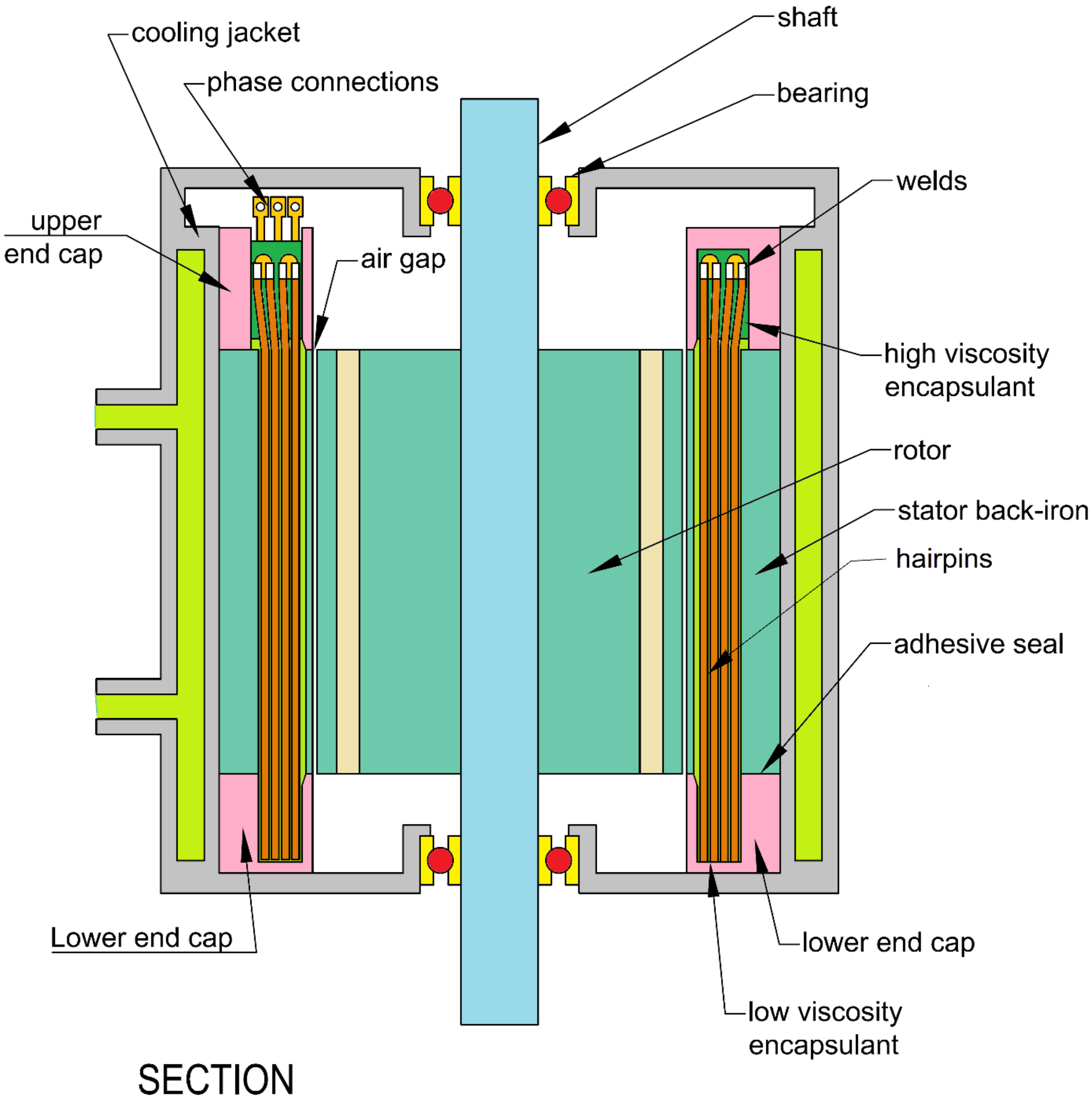


Fig. 2 Diagrammatic representation of the NCAP system

As shown in Fig. 2, the annular U shaped “end-caps” are designed to allow the end-windings to fit tightly into them and are attached to the end of the stator with a sealant adhesive. The expandable inner tube is inserted in the usual way and expanded against the inner surface of the stator and the endcaps so as to fully seal from leakage. The encapsulant is poured from the top (the weld end of the motor) in the conventional manner but only up to the top of the slots using a material with high viscosity and modest thermal conductivity. The upper end winding section where the spacing between the conductors is relatively large may be filled with a less viscous material with higher thermal conductivity. The filling is carried out using a vacuum chamber if required although the lower viscosity may make this unnecessary.

The phase windings pass through the endcaps in positions that suit the detailed design.

The thermal conductivity of aluminium is 240W/(mK) almost 60 times the thermal conductivity of the best filled epoxy. Because the aluminium wraps around the windings it can remove heat very efficiently on three sides and conduct it directly to the inside surface of the motor casing . In the lower part the hairpins can be compressed together so that the insulation material, through which the heat must pass is reduced to an absolute minimum. The insulation on the hairpins is of a thickness that will guarantee the insulation is maintained without the need for a slot liner.

The OD of the end caps and the OD of the stator material can match very closely and the fitting of the fully assembled stator can be achieved using thermal expansion to ensure a tight fit. This assembly process could be done either before or after encapsulation.

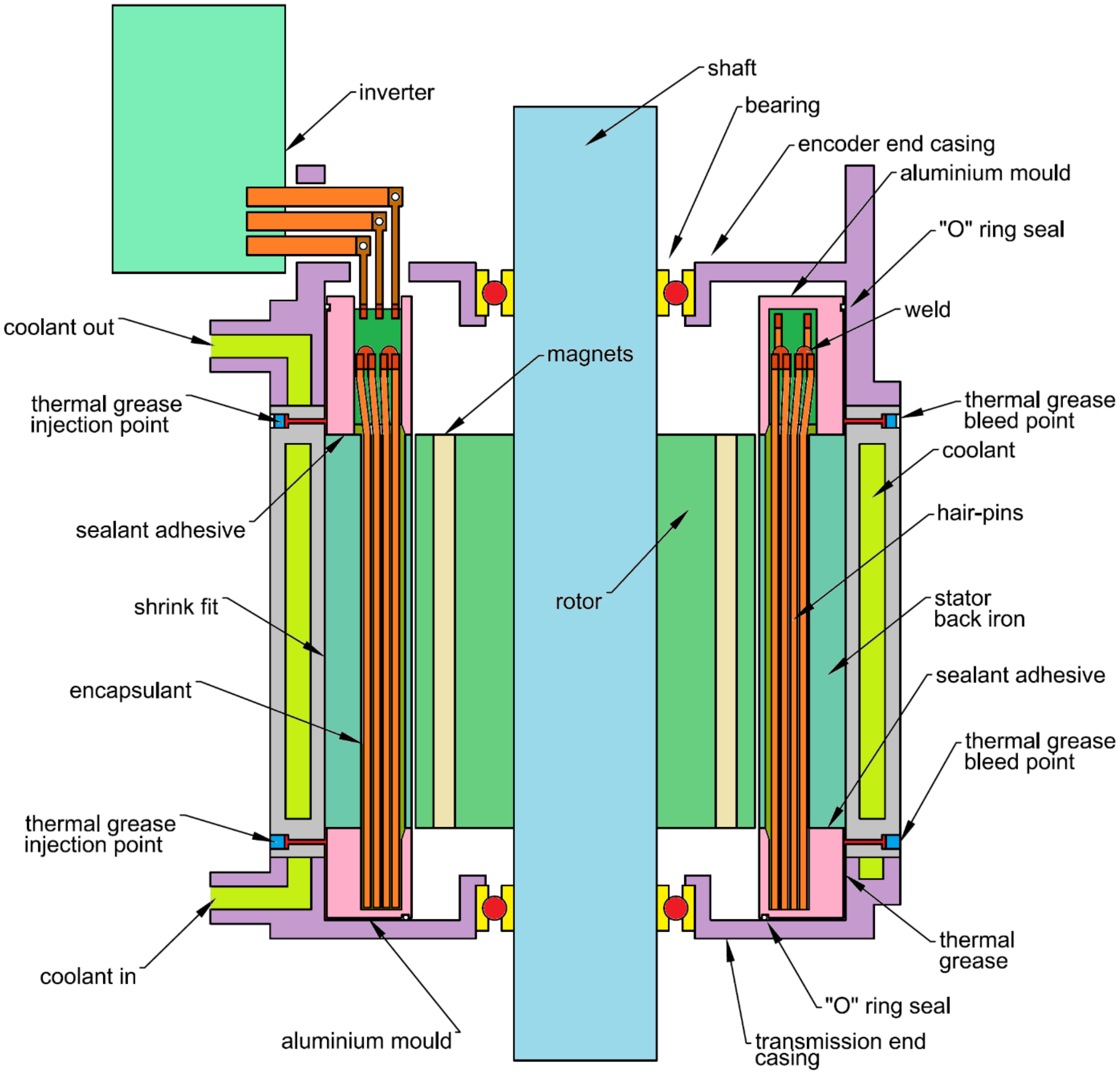
NCAP APPLIED TO AN APP 310 MOTOR

The APP 310 motor uses a stator that is fitted tightly into a cooling jacket designed to carry liquid through it removing heat directly from the stator steel. Almost all of the heat is removed via this route. The hairpins are not encapsulated, and end-spray is not used to cool them. This simplifies the motor but reduces its power density significantly.

The cooling jacket contains galleries that move the liquid circumferentially into galleries located in the end casing components that then pass through the cooling jacket. Two casings one on the transmission side and one on the encoder side are bolted over the ends of the cooling jacket. One is fed with coolant, and one discharges it.

These casings pass loosely over the end-windings without any interference resulting a very simple assembly process. The three phase connections pass through the encoder end casing and are later bolted to busbars that are brought in from the side along with the invertor.

To incorporate NCAP cooling the moulds that receive the encapsulant are made slightly smaller in diameter (200 – 400 microns) than the inside diameter of the cooling jacket and end casings. This allows the same assembly method to be used as in the current design. The gap between the moulds and the casing is filled with a thermally conductive grease or paste so that large quantities of heat can pass into the casings under a very small temperature differential. In order for the space to be effectively filled with grease the aluminium moulds are designed to include “O” rings that seal it off from the casing. Injection points and bleed points are drilled into the casing to facilitate filling and plugging ensuring a 100% fill of the material. No modification of the cooling jacket, and end casings is required. The encapsulation can be carried out before or after the shrink fitting of the stator. The hairpin end-windings will require some minor changes to ensure that they become as close as possible to each other and so as to insulate the welded sections which do not need to be coated as they will be fully encapsulated.



SCHEMATIC APP 310
without modification to end casings

THERMAL BEHAVIOR

Simulations of the thermal capabilities of the NCAP system without any modifications to casing can be carried out using only conduction characteristics of the materials and accurate 3D modelling of the geometry. In the form described here the system does not rely on any convection characteristic ensuring that relatively accurate predictions of temperature can be made without the need for physical testing. This is very different to the difficult to predict and inherently stochastic nature of all forms of end spray cooling. Like any cooling system NCAP will result in hotter and cooler zones but these will be precisely determinable. NCAP is not be subject to the random hotspots that result from the relatively uncontrolled flow of coolant over the conductors as occurs with dribble or spray cooling.

Using the VW APP 310 motor as a bench mark and without any modifications to the casing parts comparative simulations have been carried out. At this stage we have undertaken preliminary thermal simulation only for the "knee" point on the Peak Performance curve taking this point as being 400 Nm and 4025 rpm. The increase from 310 Nm to 400 Nm at this point requires an increase in current of 40% and almost a doubling of the ohmic conductor heating from 3700 W to 6800 W with further increases in the iron and magnets.

Our simulation of this motor gives the maximum temperature after 60 seconds for 310 Nm and 4025 rpm as being 153°C. We assume that all components of the motor are at 80°C at time zero and that the coolant is held constant at 80°C.

For the APP310 at 400 Nm and 4025 rpm in its current form this temperature increases to 214°C.

For the APP310 incorporating ENCAP as shown in Fig. 2 our simulation predicts a maximum temperature at 400 Nm and 4025 rpm as being 151°C.

The effect of ENCAP on Continuous Performance will be considerably more beneficial than for Peak Performance because Continuous Performance is not affected by thermal inertia and is only dependent on equilibrium heat transport.

Our simulation gives the 0-100 kph acceleration time of an ID3 vehicle with Peak Torque of 400 Nm and Peak Power of 170 kW of 5.3 seconds. This compares to 7.2 seconds using 310 Nm and 130 kW.

COST AND WEIGHT

The manufacturing cost is estimated at less than $30.00. Including the amortization of machinery. A complete production line for 20 motors per hour estimated as 1.5 million Euros. The weight will increase by around 2kgs.

The endcaps weigh around 2kg and can be manufactured using diecasting with a machining only of the outer face. The quantity of encapsulant is less than 200 cc. The manufacturing process involves the following steps after stator and hairpin manufacturing insertion and welding which remain fundamentally unchanged.

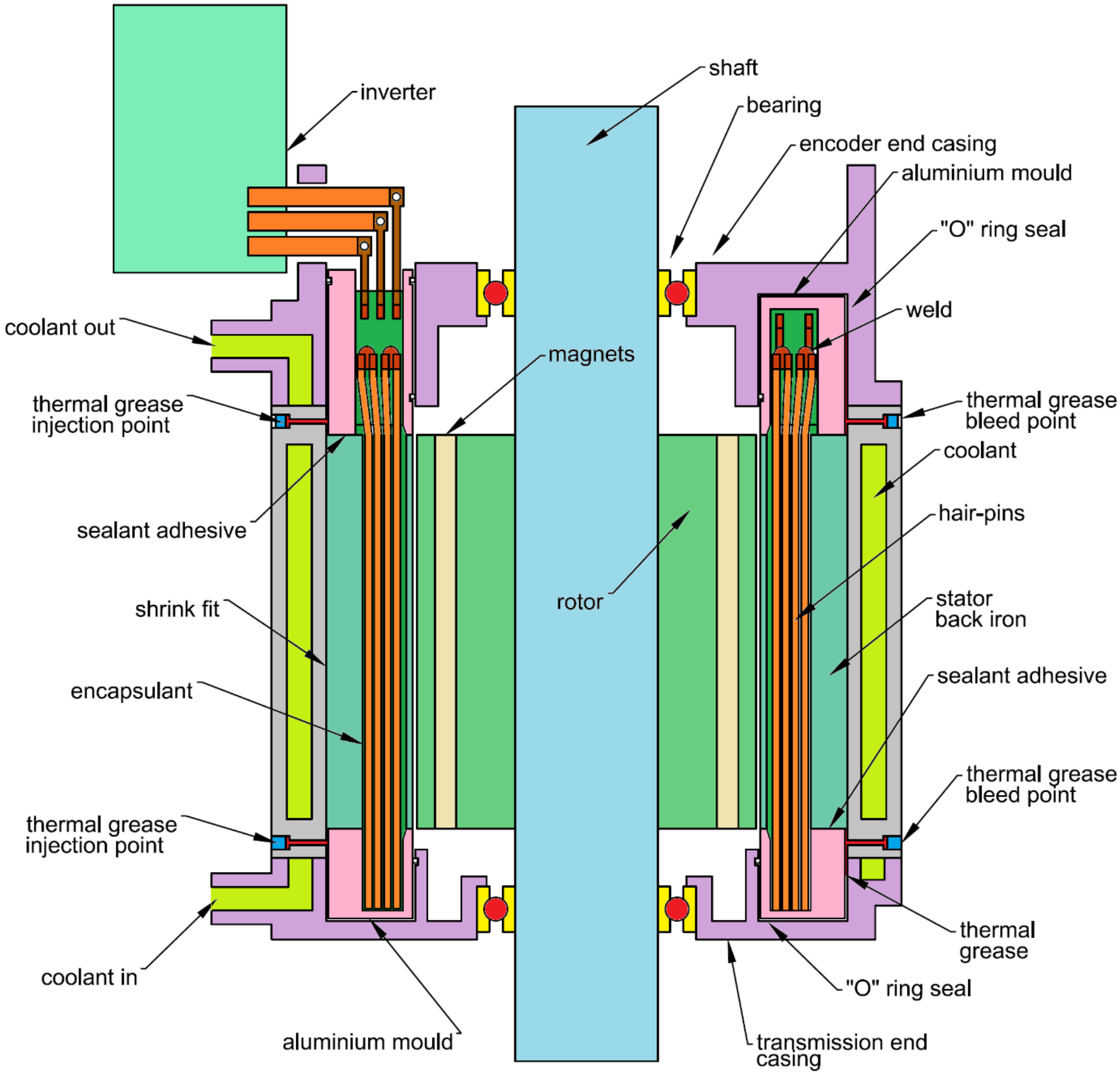
1. Manufacture of endcaps
2. Insertion of endcaps including gluing or friction fit onto end of stator over end-windings.
3. Insertion and expansion of expandable core
4. Preheating of stator endcaps and core
5. Vacuum and filling
6. Removal and curing of encapsulated stator
7. Cooling, core collapse and removal of core.
8. Cleaning and coating of expandable core.
9. Thermal shrink fit of stator inside motor case.

EDDY CURRENTS

Some eddy currents already exist in the end windings, and these are considered to be so small that they are most often ignored in efficiency simulations. It is considered that similar eddy currents will be set up in the endcaps if aluminium is used as the material but again they will have an almost negligible effect on the motor efficiency. Commercially available ceramic materials such as Aluminium Nitride can deliver thermal conductivities of 170W/(mK) if it is necessary to eliminate these small losses.

OPTIMIZATION

The ENCAP cooling system applied to the APP 310 motor can be further optimized by modifying the end casings so as to more fully wrap around the aluminium moulds complete with the thermally conductive grease or paste.



SCHEMATIC APP 310
with modification to end casings

In this way significantly more heat can flow into the casing out of the end-windings both during short applications of peak power and when operating continuously. The modifications do not fundamentally change the design and are likely to significantly increase power density or lower peak temperatures.

TRICKLE IMPREGNATION

Trickle impregnation can be used as an alternative to potting with the aluminium endplates modified to receive the epoxy via openings in the inside surface. We do not have this process fully developed and recognise that the thermal conductivities of the trickle epoxies can not be as high as the potting materials because they rely on capillary action demanding lower viscosities.