SUPERCOOL

Enhanced peak performance through innovative cooling.

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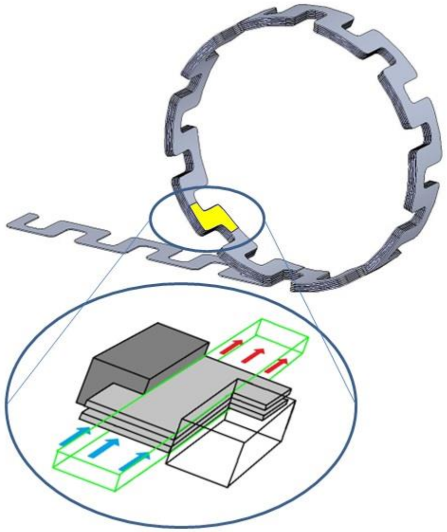
A NEW INNOVATIVE COOLING TECHNIQUE building on the use of a laminated winding organized in layers are currently developed at the division of Industrial Electrical Engineering and Automation (IEA) located at Lunds Tekniska Högskola (LTH). The laminated design introduces a small space between each layer enabling a coolant to pass through the winding turns cooling directly at the conductor, where most of the heat losses are generated. Traditional cooling techniques of an electrical machine includes air cooling of the casing, spraying oil at the end turns, water or oil cooled jackets etc. By increasing the effectiveness of the cooling system one can let higher currents through the machine increasing its power output. This enables the use of smaller machines with peak efficiency nearer the nominal operating point but keeping the ability to deliver high power output if necessary. The ability to both have high efficiency and great power on demand is greatly attractive for the automotive industry where electrical machines are appearing more and more frequently through increasing demand of hybrid and all electric vehicles.



Prototype	M1	M2	M3
Inner radius [mm]	58	66	63
Outer radius [mm]	69	79	76
Length [mm]	25	28	100
Number of teeth	20	22	6
Winding turns	12	17	12
Phases	1	2	3
Nominal power [kW]	1	1	80

Figure 1 Illustration of the laminated winding design. A coolant is able to flow through the winding laminates, table 1 show winding parameters of the three winding prototypes.

The choice of coolant which are to be used in the laminated design fell on air based on its availability due to the fact that many modern busses and long haul trucks use pressurized air for example in their brakes and shock absorbers. Since a pressurized air system already exists in these types of vehicles the integration of an air cooled machine will be easier.

Kjellstrand R., Akujärvi V. (2013), *Modeling and evaluation of laminated windings,* TEIE-5311, IEA.
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THE THERMAL CAPABILITIES of the laminated design are investigated by measurements and simulations. There are three machine prototypes of interest; M1 and M2 are both measured and modeled while M3 are only modeled for. Measurements are done by leading current through the winding and at the same time cool it with air. The winding and air temperature, heat losses, air flow and pressure drop are measured during the heating and cooling process. From these measurements one can determine the ideal pump power needed from an air cooling system to hold a certain winding temperature at a given amount of current density in the winding conductor.

The prototype winding M1 is designed to deliver a power of 1 kW which is too small to use in a bus or long haul truck. The results from measurements on M1 are used to verify the validity of an analytical model. The model is later used to simulate the performance of prototype M3 which holds four times the axial length of M1. This prototype will have a nominal tractive power of 80kW at a current density of 10 A/mm^2; the ability to overpower this machine with help of air cooling is examined.

RESULTS from simulations and measurements indicate an increased ability to withstand high current densities with help of the laminated design. Simulation results from the large machine (figure 2) show an ability to use excessive amounts of current while keeping the pump power within reasonable ranges as the common size of pressurized air compressors is 4 kW. The large machine is capable of handling current densities as high as 25 A/mm^2 holding a winding temperature of 140˚C. This amount of current is twice the peak capability of a conventional electrical machine of the same size. The geometry of the winding influences the cooling performance and the design in its current state is sensitive to error margins in the building process.

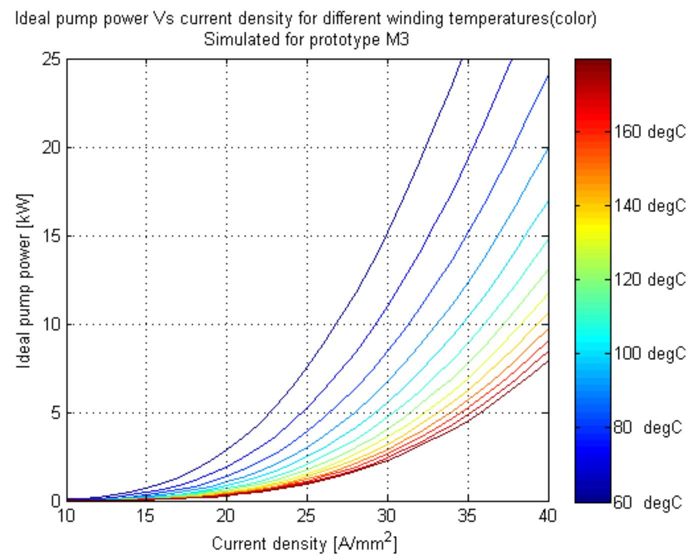

Figure 2 Simulated results from prototype machine M3.

Traction power [kW]*	80	105	130	155	165	?	?
Current density [A/mm²]	10	13	16	19	21	25	30
Heat loss [kW]	2.8	4.7	7.1	10.1	12.3	17.5	25.2
Ideal pump power [kW]	0.06	0.19	0.45	1.2	1.9	4.4	10.1
Efficiency [%]	96.6	95.6	94.5	93.2	92.1	?	?

*Table 2 Cooling efficiency parameters from prototype M3. *Estimated*

CONCLUSIONS from measurements and simulations show increased cooling efficient and thereby higher current capabilities. Axially shorter machines give better cooling performance since they induce a smaller pressure drop enabling the use of more effective fan or pump cooling system instead of a compressor. The spacing between winding turns is sensitive to error margins and need to be held as even as possible.

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