Electrical Boost for Hesitant Vehicles

Cummins Generator Technologies' engineers have been looking at ways to improve the performance of automotive diesel engines using high-speed electrical machines.

Most drivers have experienced a phenomenon known as 'Turbo Lag'. This is the time delay between the driver pressing the accelerator pedal and the engine accelerating to the required speed. A possible solution to reducing turbo lag is to assist the turbo charger electrically.

Electrically Assisted Turbocharging (EAT) consists of integrating a high-speed electrical machine to help overcome the turbo lag on a diesel engine, especially at low engine revs, by incorporating an electrical assist motor between the turbine and compressor wheel. This reduction in turbo lag not only improves the driver experience, the fuel is burnt more cleanly and more energy is extracted from the fuel, which reduces emissions and fuel consumption.

In particular, the system is well-suited to turbocharged diesel engines fitted with an exhaust wastegate (used to avoid 'over-boosting') where the by-pass gases would drive the electrical machine, which would then feed power back to the vehicle's electrical system, further improving its efficiency and reducing the impact of the generator which drains power from the engine in normal operation.

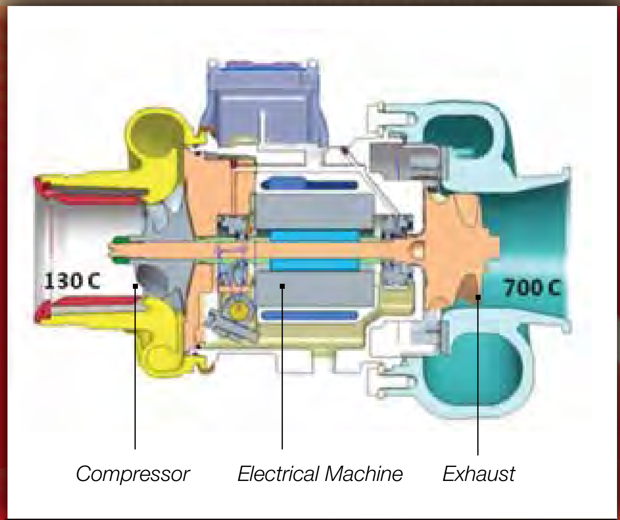

Figure 1

Fitting a high speed machine to a turbocharged diesel engine presents some real engineering challenges. Not only are its components operating close to their mechanical limits, but as the machine is likely to sit in-between the turbocharger's turbine and compressor wheels, as shown in Figure 1, it also has to operate in a very thermally-aggressive environment with exhaust temperature as high as 800°C. Tackling those thermal and mechanical challenges has been a key aspect of Cummins Generator Technologies' work on the type of high speed machine that would be suitable for use with a turbocharged engine.

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Three different electrical machine designs shown in Figure 2 were examined by Cummins Generator Technologies' engineers, including the Induction Machine (IM), selected for its robustness and two different Permanent Magnet Synchronous Machines (PMSM) options. These were the distributed wound inset PMSM and a concentrated wound surface mount PMSM.

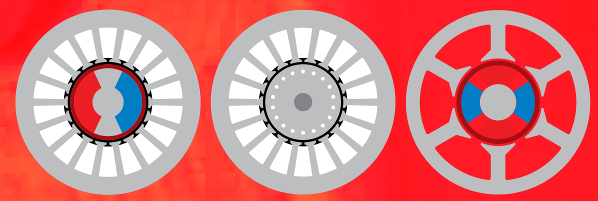

Figure 2
Compared electrical machines topologies:
a) Induction Machine, b) Distributive-wound Inset PMSM
c) Concentrated-wound Surface PMSM

All three options were subjected to intense scrutiny by Cummins Generator Technologies' researchers, in order to determine the best high speed machine configuration. In particular the group focused on the heat-resisting performance of different solid and laminated metallic components used in the rotor and stator of the Induction Machine. Likewise, the distributed wound PMSM option was also considered in detail, utilising 2-D computer modelling and 3-D finite-element analysis (FEA), not least to estimate complex rotor losses. Similar in-depth analysis was also applied to the concentrated wound PMSM design, particularly concerning the abilities of the design to withstand and operate effectively within the high-temperature environment.

By comparing not only the electromagnetic, but also the thermal and mechanical issues within those three possible designs, Cummins Generator Technologies' researchers were able to apply a truly 'multi-domain' approach to the design of future high speed electrical machines, taking into full account their very challenging operating environment. The group ultimately concluded that the distributed wound inset PMSM cannot achieve the required performance without significant Power Electronic converter over-sizing, while the concentrated wound six-slot, four-pole PMSM has excessive rotor losses at the frequencies considered, resulting in elevated rotor temperatures which are well above the magnet's capability to withstand them.

Although the Induction Machine rotor losses are relatively high, by suitable choice of rotor materials, multi-domain optimization and the invention of a new rotor design by Cummins Generator Technologies' engineers, high power-densities can be achieved (20MW/m³ compared 1MW/m³ for a conventional synchronous machine). Based on the aforesaid considerations the induction machine is chosen for electrically-assisted turbocharging. Figure 3 shows a cross section of the rotor and figure 4 the machine on test.

Figure 3
10kW, 80000rpm, 20MW/m³ Induction Machine Rotor

Figure 4
Induction Machine on test bed