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Mechatronics drives safety, convenience and efficiency

Electronic control of mechanical automotive applications presents highly demanding design challenges requiring experience in conventional PCB and specialised high temperature thick film substrate technology to create reliable mechatronic system solutions.

The use of mechatronics in automotive applications is increasing rapidly and this trend can be seen in advanced safety solutions such as Electronic Stability Control (ESC), Collision Mitigation Braking (CMB) and Lane Keep Assist (LKA), as well as convenience solutions that include Active Cruise Control (ACC), Traffic Jam Assist (TJA) and Park Assist (PA). These mechatronic safety and convenience solutions are commonly described as Advanced Driver Assistance Systems (ADAS).

Improving the efficiency of internal combustion engine vehicles also remains a priority for manufacturers serving markets with fuel-efficiency regulation. Mechatronic efficiency solutions include Intelligent Heat Management (IHM), Electric Power Steering (EPS), Electrically Assisted Turbocharger (EAT), Dual Clutch Transmission (DCT), Variable Valve Timing/Lift (VVT/VVL) and Petrol/Diesel Direct Injection (GDI/DDI). While full hybrids remain a niche technology, due to their unfavourable cost-benefit ratio, micro-hybrids and mild hybrids are leading the hybrid powertrain revolution via much lower component costs with significant potential to boost efficiency.

Improving efficiency

Thermodynamic optimisation is one of the most cost-effective opportunities to advance the efficiency of internal combustion engines. Intelligent Heat Management (IHM) improves fuel efficiency by regulating engine cylinder temperature. A cold engine is much less efficient than a hot engine at converting heat from burning fuel into mechanical energy. Moreover, a cold diesel engine can suffer premature wear due to engine knock. Conversely, overheating must be prevented to extend engine longevity. Through precise temperature control, Intelligent Heat Management (IHM) is able to improve engine efficiency whilst ensuring longevity.

Traditionally, engines have been cooled by circulation of water via an inefficient mechanical pump directly connected to the crankshaft. Heat is carried away from the engine by water to a fan-cooled radiator located near the perimeter of the engine bay. While old vehicles used an inefficient mechanical fan to cool the radiator, most modern vehicles use an intelligent electrically-driven fan that can be shut off when it is not needed, thereby saving energy. The success of Intelligent Heat Management (IHM) fans has inspired a number of leading manufacturers to abandon inefficient mechanical water pumps for intelligent electrically-driven water pumps in their latest vehicles.

Intelligent Heat Management (IHM) solutions such as electric water pumps help manufacturers meet fuel-efficiency performance targets by allowing accelerated attainment of
optimal engine temperature from a cold start. Electric water pumps offer gains in fuel-efficiency performance in two fundamental ways. First via superior engine temperature control achieving more efficient engine combustion and secondly by intelligently controlling the water pump to reduce electrical energy consumption by 70 to 85 percent during a wide range of city and highway driving conditions. The improved performance of engines utilising electric water pumps are validated via fuel-efficiency test procedures such as US EPA Federal Test Procedure (FTP75/US06), New European Driving Cycle (NEDC), Japan JC08 and/or Worldwide Harmonised Light Vehicle Test Procedure (WLTP).

**Demanding application**
Managing the power requirements for an intelligent electrically-driven water pump brings its own challenges when developing the control electronics, not least of which is its location. The engine bay is a harsh environment subject to extremes in temperature and vibration offering less space with every new generation of automobile and as a result it is becoming necessary to increase the integration of control electronics and mechanical elements, hence the rise in mechatronics.

This was the challenge presented to TT Electronics’ Sensing and Control design team when asked to develop an intelligent power module (IPM) that could be integrated within the housing of a brushless DC (BLDC) motor intended to replace a mechanical pump in an engine cooling system. The specification called for an IPM with a 400W motor using sensor-less feedback to be housed in a single unit mounted directly on the engine. The company has experience in this field, having developed a 200W IPM and electronic modules for manufacturers serving the automotive sector.

In this case the requirements were further constrained by the need to integrate the module into a space measuring just 50 x 50mm, while being able to deliver up to 70A per phase. The module also had to provide communications in the form of PWM and LIN interfaces which would naturally be susceptible to - and need to be protected from - the EMC present in an automotive application. The physical requirements of the power component alone dictated a bespoke and carefully designed solution, comprising the electronics and associated heat sink, along with the connection to the motor itself.

The fundamental challenge in this application was the operating temperature and,
from the experience gained in this field, the design of circuit boards which are particularly well suited to automotive applications where power density must be delivered under extreme conditions in terms of temperature and vibration (see Ceramic vs Epoxy PCBs). In this application, the specification was a thick-film ceramic substrate - an approach that had been attempted but proved too difficult for the client’s design team. Fortunately, TT Electronics has been producing this kind of mechatronic solution in high volume for leading manufacturers in the automotive industry since 1998, and has accrued extensive experience and data which meant it was able to develop an IPM capable of meeting this additional and extremely challenging requirement.

While the space restrictions and power density would be demanding for any developer, the real challenge came from the operating temperature as the IPM was required to function at an operating temperature of 150°C, with a water temperature of 128°C. Standard automotive components are only qualified to operate at up to 125°C, so immediately the solution needed to exceed convention. In addition, the lifetime for the IPM had to be in excess of 7,000 hours, under normal conditions, exceeding the operating temperature of any component will significantly reduce its working life. Meeting these requirements using a thick film, high temperature substrate and bare-die components was the prescribed solution for this application. Due to understanding the expansion coefficients of all materials, with particular focus on thermal management, the design team achieved the project’s goals that would not have been possible using conventional PCB substrates and components.

**Ceramic vs Epoxy PCBs**

The advantages of using a thick-film technology or ceramic substrate are numerous meaning that although they are currently slightly more expensive than epoxy (FR-4) substrates, their use is increasing. Ceramic substrates can operate in temperatures above 200°C (compared to just 130°C for epoxy/FR-4), with much better thermal conductivity than FR-4 and less mechanical stress (leading to a shorter working life). This also leads to better thermal stability, making it much less likely to suffer under thermal stress than FR-4; this presented particular challenges when designing the integrated water pump. The coefficient of thermal expansion of ceramic is also much closer to that of semiconductor components than FR-4 which contributes to its greater reliability in thermally challenging applications. These considerations mean that the system cost of an FR-4 based solution in applications where thermal stability is imperative can actually be higher than the system cost of using a ceramic PCB, due to the need for additional and often complex cooling solutions.

**Conclusion**

The integration of electronic control in automotive applications is increasing rapidly, creating design challenges for automotive OEMs and their suppliers. With extensive experience in this field, the company is able to provide the design expertise and technologies needed by more manufacturers ensuring the automotive supply chain is able to continue to meet such challenges.