PROTEAN

Magnetics Poles Apart

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Views from our CTO

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EV motor and inverter designs have converged into highly integrated systems with more torque and power. But magnet or magnet-free motors is still a key industry question.

Introduction

There is some convergence in electric powertrains appearing on the market and in development but, more interestingly, I also see divergence.

With the increase in uptake of electric vehicles we're seeing both updated versions of well-established models and the emergence of new models from both the usual OEM's and new players.

The electric powertrains, i.e. motors, associated electronics and transmission under the hoods of these vehicles, indicate some interesting directions in technology development.

I believe we are observing the first results of serious resources going into the engineering of electric motors and inverters motivated by an electric vehicle market that has, at last, taken off. It's not that previous versions weren't good products, but now there is money to be made by small improvements in efficiency, torque and power output, noise and vibration, performance and cost.

As vehicles evolve from being essentially electric versions of platforms designed for internal combustion engines through to native electric vehicles, it's reasonable to expect the powertrains to become optimised to the task in hand.

For similar applications presumably we'll converge on rather similar solutions. There are some well thought-out roadmap reports available that attempt to pin-point what those optimised solutions will look like and where the big technical challenges are that need to be overcome to get there.

If the answers were clear, everyone involved in EV development would be heading in the same direction. The latest generation of vehicles tells us otherwise.

Before focusing on the divergence, it's worth noting that there are some marked convergence trends.

Convergence

Most outwardly obviously, there is the move to much more highly integrated systems. The latest systems typically accommodate the electric motor, its electronics, the reduction gear and the differential in a single housing. This is considerably more compact, saves mass and cost and has some electrical advantages too.

Torque and power output has increased so that the vehicle has better acceleration performance. There's a trade-off here with cost and size, so the choice to improve performance is not a straight-forward one. I can think of three reasons why, for instance, Nissan, BMW and Renault might have done this in their recently released upgrades to their Leaf, i3 and Zoe models respectively:

1. Because they can. Design improvements in the motor and inverter and the experience gained from the earlier versions mean they can get more out their system without changing the overall package externally. That's important because there's no re-design of other components needed to support the higher performance.

2. Because compared to internal combustion engines, getting more out of an electric drive system incurs less added cost.

3. The Tesla effect. The ludicrous performance of the Tesla Model S has left owners wondering how they ever had any free time back in the days when it took more than three seconds to reach 100 km/hr, and has set an expectation of electric vehicle performance. This may well turn out to be an early adopter effect, and looking to the future of autonomous vehicles high acceleration will only result in spilled coffee.

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Divergence

Now to divergence. A couple of years ago, anything other than a permanent magnet synchronous motor was pretty eccentric in an electric vehicle. Tesla was a notable exception with all of their models using asynchronous induction motors, as was Renault which adopted a synchronous rotor-wound motor for the Zoe. The latter is conceptually similar to the permanent magnet motor, except that the magnet blocks are replaced by electro-magnets.

There are pros and cons to each of these motor types on which I don't really want to elaborate here as they are widely discussed, but they're all perfectly serviceable solutions. Nevertheless, permanent magnet motors start off with the underlying advantage that they're providing magnetic field for free.

That's not to say that easy statements about better efficiency or more torque are always valid as there are many aspects to designing an electric motor of any variety, and trade-offs against size and cost. However, when designing a motor with a particular performance for an electric vehicle a permanent magnet motor will generally turn out smaller and lighter.

On the whole, I'd expect that, in most applications, permanent magnet motors would become the favoured option. Sure enough, Tesla have adopted a permanent magnet motor in the Model 3 in a departure from previous design decisions, and the Jaguar I-Pace comes to the market with two permanent magnet motors, by way of example.

But at the same time others, for example BMW with their "Gen 5" electric powertrains and Audi, are showing electric platforms based on asynchronous magnet-free motors. This is not an accident or oversight but a well-considered decision based on concerns about the price and supply of rare earth magnets.

Rare earth magnets are an expensive component of a permanent magnet motor. At today's prices the cost of the magnets may be offset by the ability to reduce the cost of other components that using rare earth magnets enables. However, that might change. At the beginning of the decade prices were several times higher and they may rise again, plus the cost of the remainder of the electric drive system is falling so the magnet cost could become a higher fraction of the total.

These magnet-free systems remove the uncertainties of price fluctuations and supply.

Meanwhile, engineers that have opted for permanent magnet solutions are designing motors that reduce the volume of magnets by careful design of the magnetic circuit, in particular making maximum use of reluctance torque in combination with the permanent magnet induced torque.

At the same time magnets that reduce or eliminate the most expensive elements such as dysprosium and terbium are being developed, rare earth magnet recycling processes exist at an experimental level, and there's research into better methods for extracting the not-particularly-rare, rare earth elements.

With increasing demand there is high motivation for improving the supply and that will undoubtedly lead to technological break-throughs that may remove the worries associated with using magnets.

The time span between an engineering team making the decision on the type of motor to be used and that motor appearing in a production vehicle is several years. That motor will remain in production for a few years more and in use for even longer. So the crucial decision of magnets or not is made with a good deal of effort at trying to predict the future.

Clearly there was no consensus across the industry a few years ago when this latest generation of motors were designed, and that's a reflection of different sensibilities as much as of different predictions of the future and different design goals.

For today's electric vehicle drivers the impact is minimal. The price and shape of the vehicle may be marginally affected but you'd be hard pressed to notice whether your electric motor contains magnets or not from your vehicle's driving characteristics.

However, OEM's are ruthless when it comes to costs so these basic architectural decisions relating to the powertrain are crucial for engineers.

The magnet vs. no-magnet debate will continue with technology improvements in both directions, but it is not the only area of divergence or experimentation.

A new breed of power transistors based on wide band-gap semi-conductors is now relatively mature and offers greatly improved performance for a rapidly decreasing cost premium. When and in which applications to adopt this technology are further decisions requiring prediction of the future. And, while most production electric vehicles opt for a single fixed-gear ratio there are both direct-drive, i.e. no gears, and two-speed systems available, each with its own merits.

Whether this is a relatively short-lived variety eventually converging to optimal solutions for each vehicle type, or whether no single powertrain architecture will ever dominate, remains to be seen.

Whatever happens, scientists and engineers will enjoy the challenges of improving on today's technologies and vehicle owners, drivers and passengers will enjoy the benefits.

About the author

Dr. Chris Hilton has been Chief Technology Officer at Protean Electric for over a decade.

These "Views from our CTO" provide an insight into the themes, thoughts and industry observations from an automotive technology CTO.