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SUSTAINABLE MOBILITY:

The engineering challenges of EVs

MITSUBISHI HEAVY INDUSTRIES

EXECUTIVE SUMMARY

Within the next 10 years the bulk of the automotive sector's production and sales will swing from petrol and diesel vehicles to a majority of battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs).

Managing this momentous shift will require the industry to overcome some substantial challenges.

Most significantly, the current price is the biggest barrier to greater consumer demand for EVs. High costs also mean that very few EVs are currently profitable for manufacturers.

Another big challenge is improving range. This will require better battery technology, better designs and the embracing of various kinds of innovations to help the vehicles drive further for longer on a single charge.

There will also be some very specific issues to look at around the driving experience, such as Noise, Vibration and Harshness (NVH).

Addressing these substantial engineering and manufacturing challenges will require the industry to collaborate more than it has done previously.

It will require car makers to invest heavily in EV-specific manufacturing lines to get the most out of the machines.

And it will mean companies and individuals throughout the supply chain being obsessive about detail, right down to the smallest of components.

SECTION 2 – INTRODUCTION

Electric vehicles are at a tipping point. This phrase, popularized by Malcolm Gladwell's bestselling book of the same name[1] , describes the moment cultural phenomena move from the preserve of a few innovators and early adopters into the mainstream.

In many developed economies, electric vehicles (EVs) are now approaching this moment: according to the International Energy Agency (IEA)[2] , the number of EVs on the roads (including plug-in hybrid electric vehicles [PHEVs]) is due to rise from 5.1 million globally in 2018 to more than 250 million in 2030, with China, Europe and the US leading the way. That's a jump from 0.5% to over a quarter of passenger vehicles in just over a decade.

Car makers and their suppliers, meanwhile, are working to even more optimistic projections for EVs' market share. At a European conference on the future of drivetrains[3] , Volkswagen/Audi revealed it was working to an assumption that by 2030 one third of its vehicles would be BEVs and the remainder either HEVs or internal combustion engines (ICEs). Similarly, engine and transmission supplier Schaeffler is expecting that 30% of the drivetrains it works on will be for BEVs, 40% for HEVs and 30% ICEs.

That is potentially 70% of all cars being manufactured in Europe having some sort of electric drivetrain, be it hybrid or fully electric.

This rapid switch to electrification of vehicles means automotive original equipment manufacturers (OEMs) and their suppliers are rethinking the way they design and build components. And they are doing so under the pressures of heightened consumer expectations and increasingly strict legislation relating to vehicles' CO_2 emissions. In some countries this has even resulted in a hard deadline for all new vehicles to run on electric drivetrains.

In the pages that follow, we outline the challenges facing OEMs and their suppliers as they switch to EV-dominant production, and some of the engineering innovations taking place to help the industry rise to these challenges.

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[1] The Tipping Point: How Little Things Can Make a Big Difference, Malcolm Gladwell, 2000
[2] Global EV Outlook 2019, IEA, May 2019
[3] DRITEV 2019

SECTION 2 – CHALLENGES

Car makers face the prospect of major changes to their manufacturing processes over the next decade as they seek to improve both the economics and performance of EVs.

The challenge is stark: according to McKinsey[4] , most OEMs today do not make a profit on selling EVs, with mid-market EVs on average $12,000 more expensive to produce than their ICE counterparts.

While OEMs take the hit on much of this price difference, impacting their profits, cost is also the biggest barrier to greater uptake from consumers: in a survey of road users in the UK, 41% said cost was the biggest barrier to them purchasing an EV.

OEMs not only need to find ways of producing EVs for less. They also need to improve the vehicles' performance: the same survey of UK road users also found that 28% are put off by what they perceive as the low range of EVs; and 16% were put off by the relatively small number of models available when compared to diesel and petrol vehicles.

Overcoming these hurdles requires automotive manufacturers and their suppliers to produce more efficient EVs capable of driving further for longer, across a wide variety of models and at a lower cost.

And they will have to do so against the backdrop of ever-stricter limits on the levels of CO_2 that new – and in some cities, existing – vehicles are allowed to emit. In some countries these limits are being taken down to zero emissions, setting a hard deadline for EV-only production in many key markets: in 2030 India, Israel and multiple European nations including Ireland and Sweden will introduce a ban on the sale of new petrol and diesel vehicles. The major economies of the UK and France will follow in 2040.

[4] Making electric vehicles profitable, McKinsey, March 2019

SECTION 3 – VEHICLE SOLUTIONS

Success in shifting to predominately EV production will require OEMs and their suppliers to work on everything from complete redesigns of EV transmissions to improvements in the production of the smallest of components.

Collaborative working across the supply chain and with those outside the automotive industry, such as academics and complementary business sectors like electronics, will be needed.

And electric drivetrains prevent specific engineering difficulties that will need to be tackled, distinct from those associated with ICEs.

The rest of this section will focus on three areas of engineering challenges, and some of the solutions currently being developed. The three areas are the two broad categories of cost and range, followed by the specific Noise, Vibration and Harshness (NVH) challenges presented by EVs.

SECTION 3.1 - COST SOLUTIONS

The higher cost of EVs versus ICE vehicles is dependent on a range of factors, including economies of scale and inefficient production methods.

But by far the biggest influence is the cost of the battery.

However, batteries' cost impact is falling. According to analysis by Bloomberg[5] , in 2015 the battery made up more than 57% of the total cost of a midsize US car. This has shrunk to 33% in 2019, and by 2025 the battery will be just 20% of total vehicle cost.

Rapid progress has been made thanks to collaboration between automotive OEMs and electronics manufacturers. For example, Tesla and Toyota both partner with Panasonic on the development of battery technology, while Volkswagen is collaborating with Samsung SDI, the battery manufacturing business of the Korean electronics giant[6].

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[5] Electric Car Price Tag Shrinks Along With Battery Cost, Bloomberg, April 2019
[6] Car Manufacturer & Battery Manufacturer partnerships emerge in the fight for supply, EV Trader, March 2019

EMBRACING CHOWA

Close working and partnership are occurring in almost every manufacturing sector today as businesses seek to make the most of emerging technologies and succeed in competitive global markets. The Japanese have a term for this kind of close working: "chowa". Roughly translated, it means "a spirit of harmonious partnership".

The automotive sector should learn the lesson from the gains it has made through partnerships on battery technologies and embrace chowa, collaborating on every aspect of EV design and build that can help bring down costs and improve performance.

Partnering during the next decade of transition from ICEs to electric drivetrains would be particularly beneficial in helping manufacturers reduce their overheads, according to McKinsey: "At a time when OEMs face the possibility of retooling numerous models and platforms for electrification, collaborating with other OEMs can reduce the fixed-cost burden of R&D, tooling, and plants[7]."

Such collaborations are already taking place: in 2019 Jaguar Land Rover and BMW announced a partnership on electric drive units with the aim of achieving "efficiencies arising from shared research and development and production planning as well as economies of scale from joint procurement across the supply chain[8]".

[7] Making electric vehicles profitable, McKinsey, March 2019
[8] Jaguar Land Rover & BMW Group Announce Collaboration For Next Generation Electrification Technology, Jaguar Land Rover, June 2019

ELECTRIC FOCUS

Collaborations such as Jaguar Land Rover and BMW's do not only make sense in terms of reducing overheads and improving economies of scale.

They also force the creation of EV-dedicated manufacturing lines and models. Having a manufacturing line entirely focused on EVs can drive efficiency and cut costs: analysis[9] of two OEMs codeveloping a dedicated EV platform reveals they could cut costs by $1,500 to $2,000 per vehicle.

Focusing purely on EVs can free up everyone from designers to heads of production to reimagine everything from vehicle layouts to manufacturing processes. As the next section will show, EVs with greater range invariably are EV-only models with dedicated manufacturing lines.

One example of EV-focused innovation that will potentially both improve performance and cut costs comes from a partnership between global driveline technology leader GKN Automotive and the University of Nottingham in the UK[10] . They are developing an EV powertrain that could be up to 25% smaller than current systems, 25% cheaper, 20% lighter and 10% more efficient.

However, this is an R&D project in its early stages and it will be two years before a prototype is revealed. In general, the cost benefits from EV-dedicated manufacturing lines and vehicles only tend to occur in the medium to long-term: while the cost of materials used in EVs on dedicated platforms may come down, the additional cost of setting up these separate product lines is substantial.

McKinsey estimates[11] these additional costs could total $1 billion, requiring a manufacturer to find $4,000 of savings on each vehicle and to sell 50,000 EVs per year to recoup the outlay over a five-year period. That is a big bet: the world's top-selling mass market EV is the Nissan Leaf, 87,000[12] of which were sold in 2018.

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[9] Making electric vehicles profitable, McKinsey, March 2019
[10] UK Consortium in £8M project to design EV powertrain for global market, Green Car Congress, June 2019
[11] Making electric vehicles profitable, McKinsey, March 2019
[12] Nissan Leaf EV First to Pass 400,000 Sales, but Tesla Model 3 Topped 2018, Extreme Tech, March 2019

SECTION 3.2 - RANGE SOLUTIONS

After cost, driving range remains the biggest barrier to the mass adoption of EVs.

Range anxiety – the fear of being stranded in an EV with an empty battery – is a phenomenon that will only be overcome through a combination of extensive fast-charging infrastructure that matches the ease and speed of refuelling petrol and diesel vehicles, and improved vehicle range from a single charge.

OEMs are focused on the latter part of this equation and, as mentioned in the previous section, collaborations between OEMs and electronics manufacturers are helping to rapidly improve the cost and performance of the lithium-ion battery technology used in EVs.

Similarly, just as there are cost benefits to OEMs having dedicated EV manufacturing lines and different models from their ICE vehicles, range can also be substantially improved.

One study[13] found that OEMs with dedicated EV manufacturing lines and vehicle models are consistently outperforming those that are simply trying to insert an electric drivetrain into an ICE chassis. For example, instead of trying to squeeze the battery pack into the space occupied by the fuel tank in an ICE model, dedicated EV models can install the battery pack in its optimal rectangular shape in the center of the vehicle. This difference in design, the study found, can deliver up to twice the driving range.

[13] Trends in electric vehicle design, McKinsey, October 2017

TURBOCHARGING RANGE

While setting up separate manufacturing lines for dedicated EV models delivers clear range benefits, this doesn't mean there aren't lessons that can be taken from traditional ICE manufacturing.

After all, for more than a decade OEMs have been focused on improving the efficiency and sustainability of fossil fuel vehicles, making cars drive further for longer on less fuel and emitting less CO_2.

Turbochargers have been a key component in this trend. Fitting a turbocharger adds to an engine's efficiency by reusing the energy within exhaust gases to deliver additional drive from the same amount of fuel.

That increased efficiency means less carbon dioxide is produced overall, making cars greener.

Manufacturers of turbocharger technology are now exploring ways of extending the range of EVs. For example, Mitsubishi Turbocharger and Engine Europe (MTEE) has investigated the possibility of a range extender for EVs that could help charge the battery while driving[14].

[14] How To Cure The Range Anxiety Of Electric Cars, Forbes, May 2018

SHIFTING GEAR

Another feature of ICE vehicles that could help automotive manufacturers in their bid to boost EV range might be gears.

Full EVs currently tend to have single-speed gearboxes, as the transmission in an electric drivetrain is far more efficient than that found in a petrol or diesel vehicle. ICEs have a very narrow range of engine speed, or revs, where they produce usable torque and power. Complex gear ratios are required to keep the engine within this narrow rev range as the speed of the vehicle changes.

Electric motors do not have the same problem: they are high revving and remain efficient across a broad rev range. They also produce good torque at a low rev range, and can therefore operate with a one-speed gearbox.

However, OEMs and drivetrain suppliers are now proposing that gears could play a role in improving the range of EVs, and moving towards two-shift transmission systems.

At a European conference on the future of drivetrains[15] , Schaeffler, Volvo, Mahle, ZF, GKN and Volkswagen all presented two-speed transmission concepts. It was claimed that adding a second gear ratio could help boost the range of vehicles for out-of-town and highway driving, as well as improving acceleration and top speeds.

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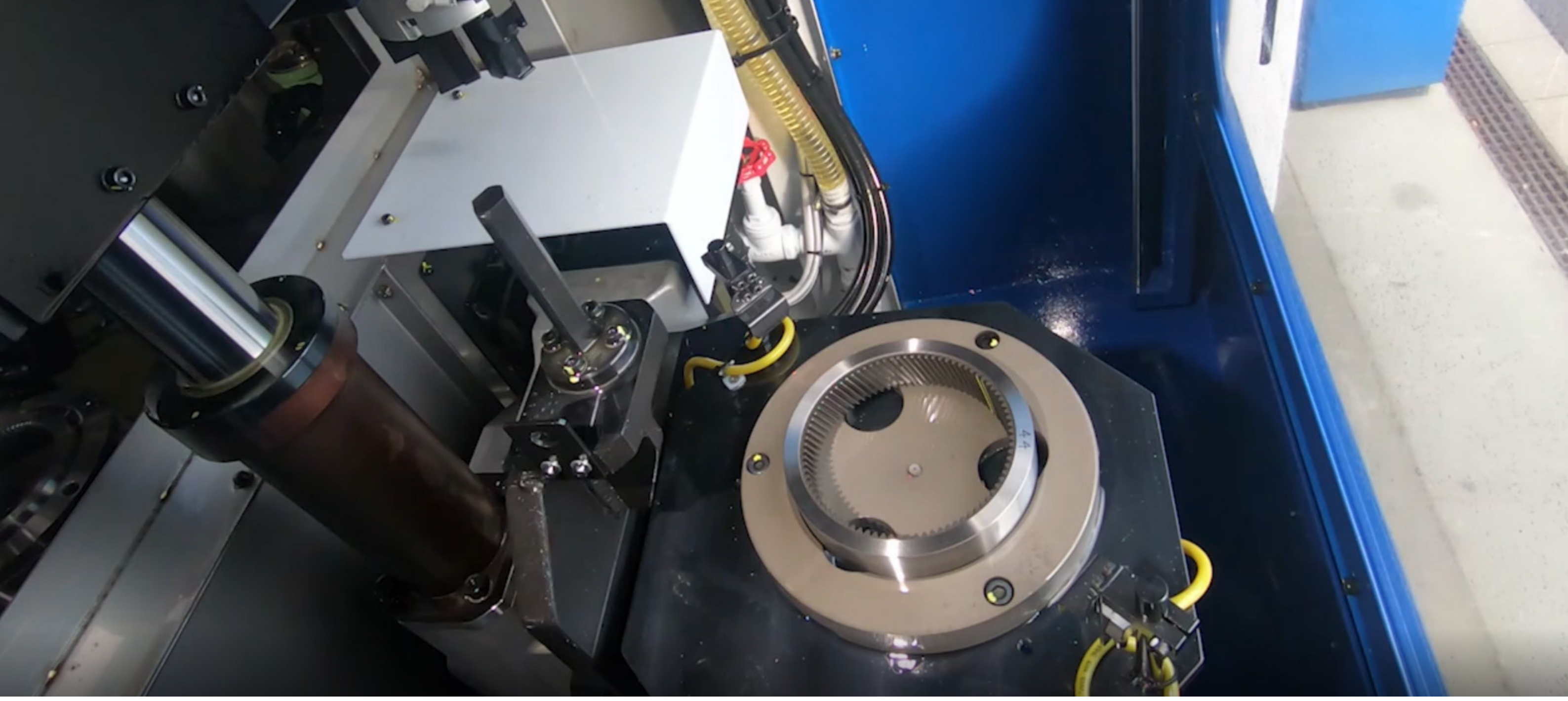
[15] DRITEV 2019



SECTION 3.2 -
NOISE VIBRATION AND HARSHNESS (NVH) SOLUTIONS

While cost and range may be the big barriers to people buying EVs, automotive OEMs also have to be alert to the less obvious engineering challenges of EVs.

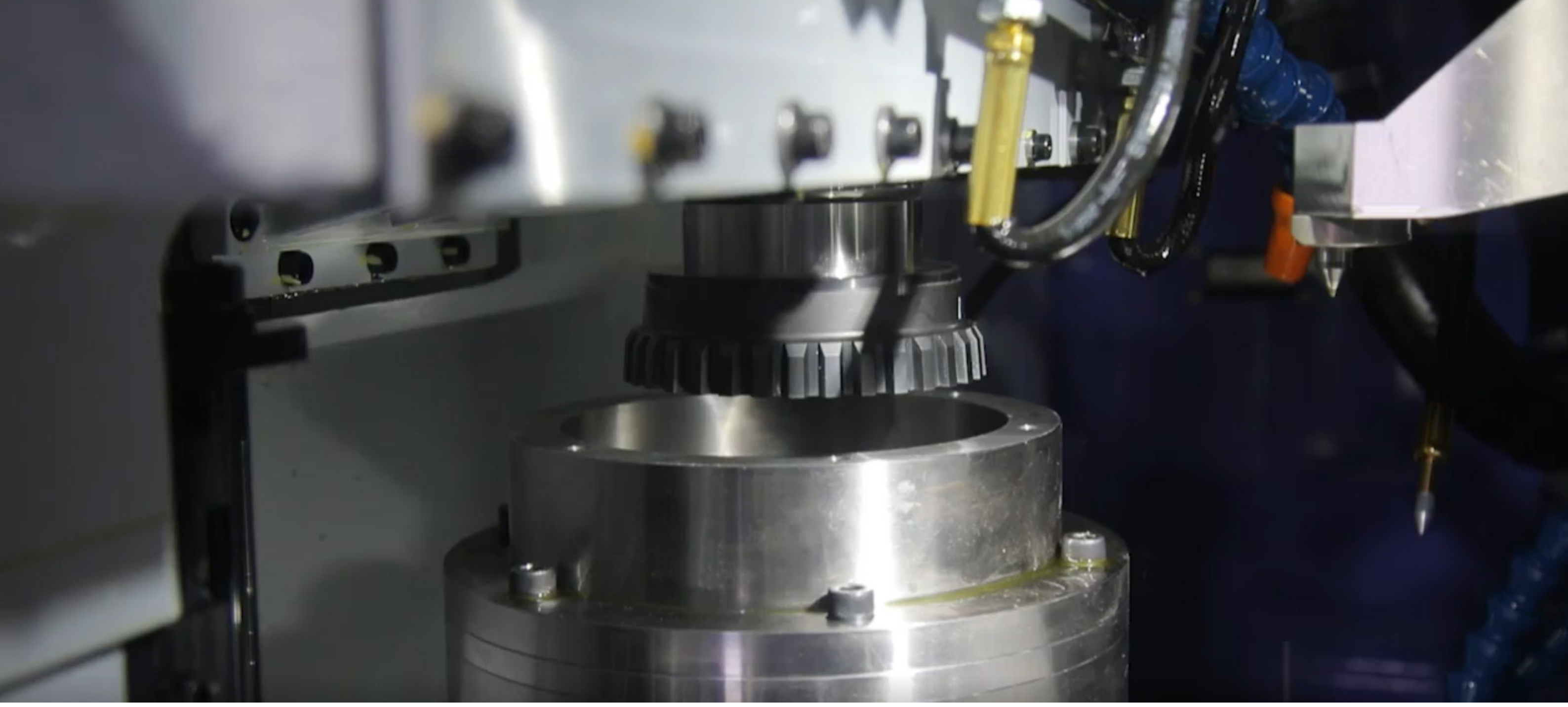
Sitting firmly in this category is the issue of Noise, Vibration and Harshness (NVH). Now NVH is nothing new to car makers, and acoustic engineers have long been employed to ensure a car sounds right and is a “smooth” ride.

However, contrary to popular opinion, EVs are not silent. Removing an ICE and replacing it with an electric drivetrain does not eliminate NVH issues. It merely reveals new challenges.

Without the sound of an ICE, the driver becomes aware of other noises, such as high frequency electric motor generator noise, power control unit high frequency switching noise, power-split system gear whine, the engine start/stop noise and vibration.

Addressing these new NVH issues requires an attention to detail that goes all the way down to assessing how individual components are made.

This is especially true when considering the transmission systems OEMs install into EVs and HEVs.



PLANETARY SOUNDS

Whether they are multi-speed HEVs, one-speed EVs or those with the proposed new two-speed transmissions, it is highly likely their powertrains will rely on planetary gear systems as their key speed to torque conversion component.

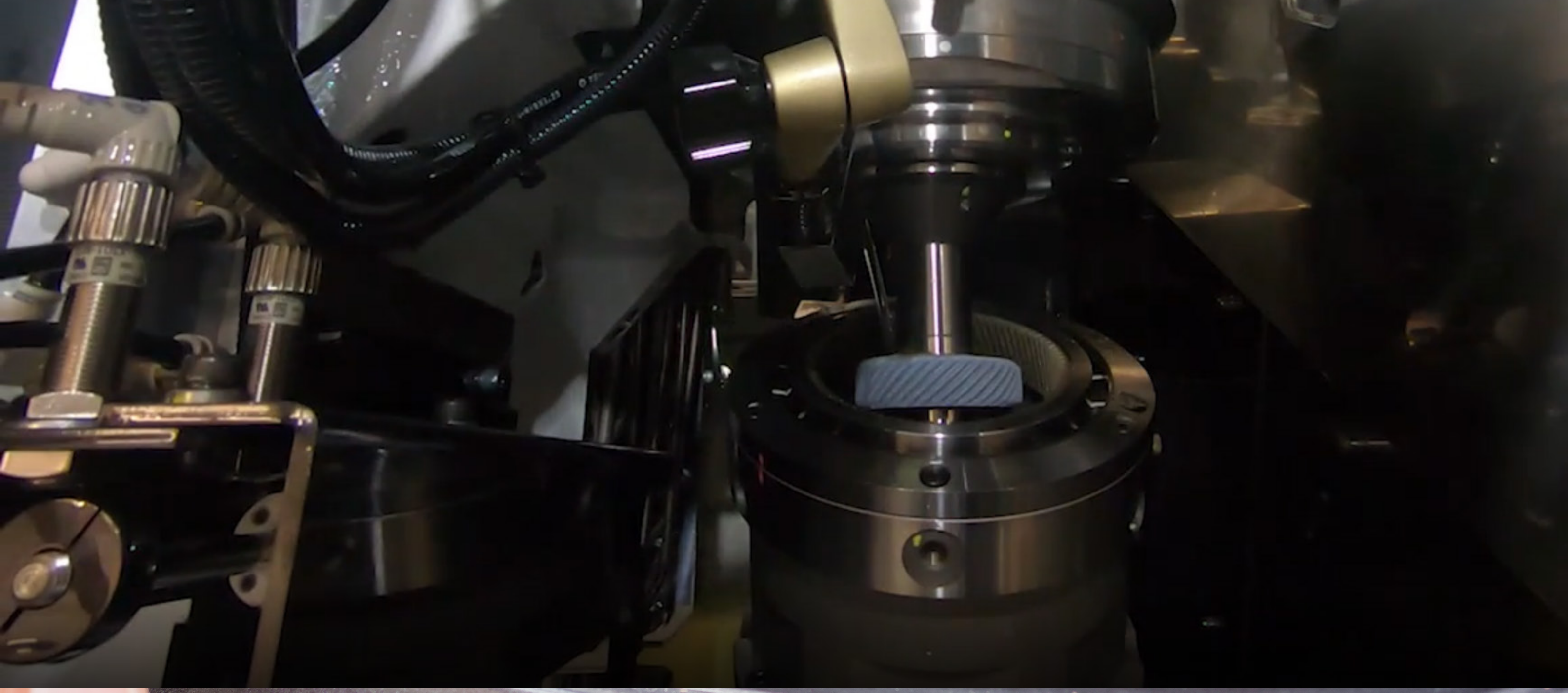
These systems are also used in automatic ICEs, but the absence of engine noise in an EV means the planetary gearing's inner workings can become a cause of NVH issues without due care and attention to the gearing components inside.

This is especially true of internal ring gears. While external gears have been optimized in production in their conventional set-up for many years, internal ring gears have been made using relatively low-cost techniques that do not include finishing processes like gear grinding, leading to a rough finish. In ICEs the NVH issues caused by the rough finish were minimal, as they were masked by the sound of the engine.

But the ascent of planetary gearing systems in EV powertrains means it is now necessary to ensure internal ring gears are of a similarly high quality as their external-gear counterparts.

Achieving this means replacing the conventional ring-gear production techniques of shaping and broaching with the alternative process of skiving.

This process, which involves the continual cutting away at the gear to create its teeth, allows for better productivity and higher flexibility. However, its industrialization on a large scale is being inhibited by a shortened tool life, due to the intensity of the process.



SUPER SKIVING AND INTERNAL GENERATING GEAR GRINDING

In response, Mitsubishi Heavy Industries Machine Tool (MAT) has developed a proprietary Super Skiving Cutting (SSC) tool with the objective of improving the cutting conditions and increasing the tool life.

The SSC is a skiving tool consisting of multiple blades. Each blade represents a pinion skiving tool with a specific amount of cutting teeth. The cutting volume can therefore be more widely distributed and the cutting load per tooth can be reduced.

Testing by the Machine Tool Laboratory at Germany's Aachen University[16] found that the SSC technique could improve the cutting of hard metals necessary for ring gears.

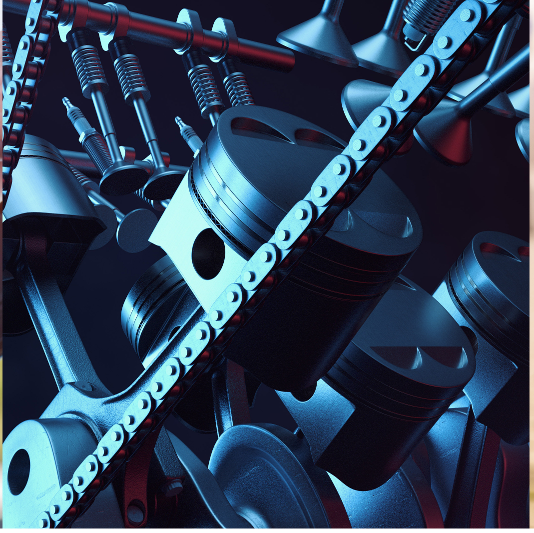
It could deliver a longer life for the cutting tool itself, making the skiving process more cost-effective. The process also reduces distortion in the final heat treatment that ring gears receive to give them the necessary hardness to cope with the loads in the vehicle's gearing system.

After this heat treatment gears are finished through a grinding process that, like skiving, has until recently been difficult to scale for mass production.

The grinding of the gears refines them and eliminates any distortion that occurs in heat treatment.

To make the grinding process more efficient and better suited to mass production, MAT has developed an internal generating gear grinding machine that has the world's first continuous internal grinding process.

[16] Monden, T; et.al.: Super Skiving Cutter - An Innovative Process Modification for Gear Skiving, Mitsubishi Heavy Industries Technical Review Vol. 56 No. 1, 2019


CONCLUSION

Automotive manufacturers and their supply chains are going through a period of unprecedented change.

While the challenge of the past 10 years has been to make vehicles more efficient, for the next decade it will be to electrify as rapidly as possible – both to meet consumer demand and to be able to withstand the banning of new petrol and diesel vehicle sales set to come into force in multiple economies from 2030.

Doing so will require car makers and their supply chains to be innovative in how they design and manufacture every single component of EVs.

It will require new levels of collaboration and a willingness to dedicate production lines to EV-specific models. Current thinking on how EV transmissions should operate will need to be challenged.

And investment in equipment that can deliver the quality and efficiencies required to take EVs mainstream will be essential.