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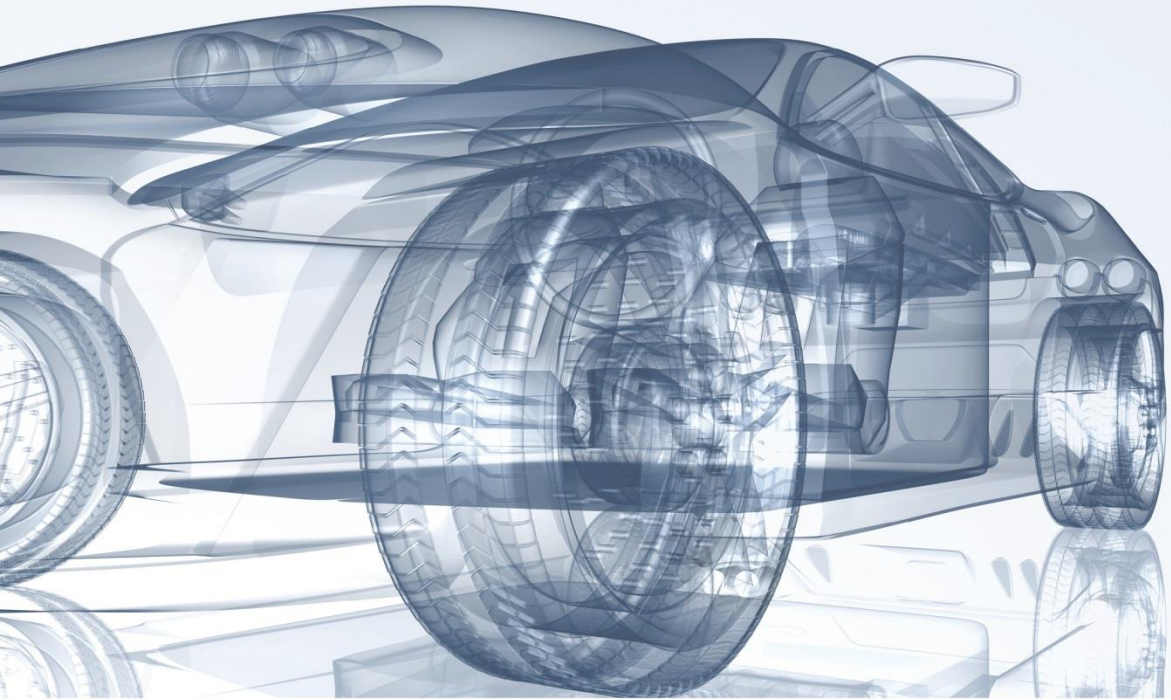

The 30th International
Electric Vehicle
Symposium & Exhibition

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Messe Stuttgart, Germany

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EV Transmission: Lessons Learnt

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Agenda: Main Lessons

- Why a transmission?
- How many speeds / ratios?
- Shift method for multi-speed
- Efficiency & durability
- Low noise optimisation
- Mounting strategy

Why do EVs need transmissions?

Performance

- Map vehicle level torque-speed operating point into e-drive capability envelope
  - E-drives *size, cost & mass* are mainly driven by *torque*
  - Faster motors are generally smaller for the same power

Efficiency

- Select & manipulate e-drive operating points to *minimise system losses*

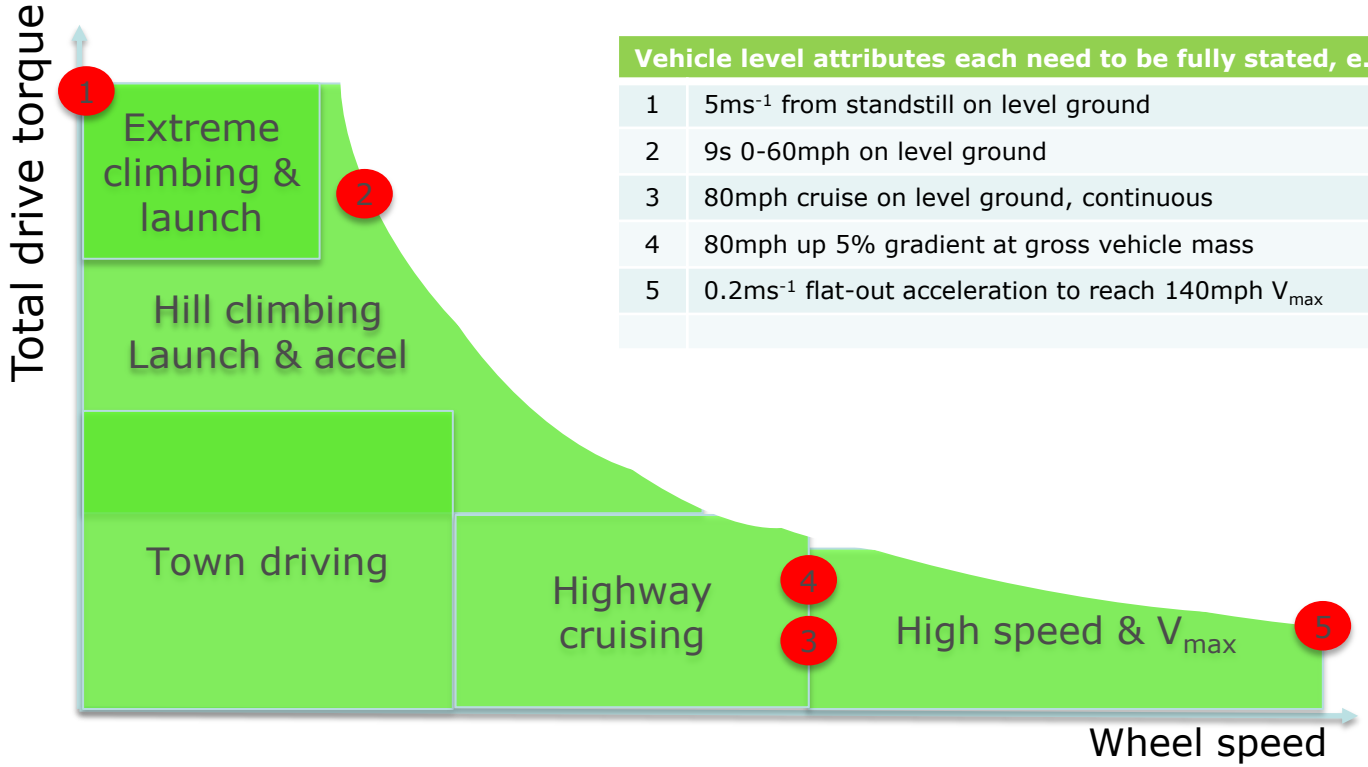
Transmit power

- *Offset axis* of e-drive from driveline axis
  - Non-concentric
  - Non-parallel
- (Mechanical) torque vectoring

System attribute optimisation

- Smaller machine + transmission
  - = *Smaller* system
  - = *Cheaper* system
  - = *More capable* system

Vehicle level performance requirements

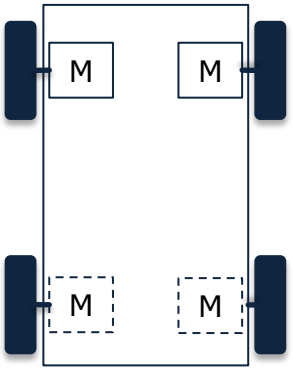


Vehicle level attributes each need to be fully stated, e.g.	
1	5ms^{-1} from standstill on level ground
2	9s 0-60mph on level ground
3	80mph cruise on level ground, continuous
4	80mph up 5% gradient at gross vehicle mass
5	0.2ms^{-1} flat-out acceleration to reach 140mph V_{max}

No transmission – wheel motors

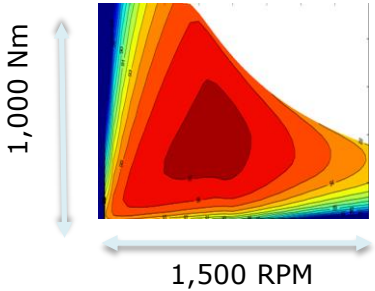
Configuration

- ✓ Simple development programme = one motor and motor control system
- Multiple machines needed
- At least 2 motors needed
- ✓ Control system not complex
- Option of torque vectoring
- ✓ Torque vectoring as standard



Performance

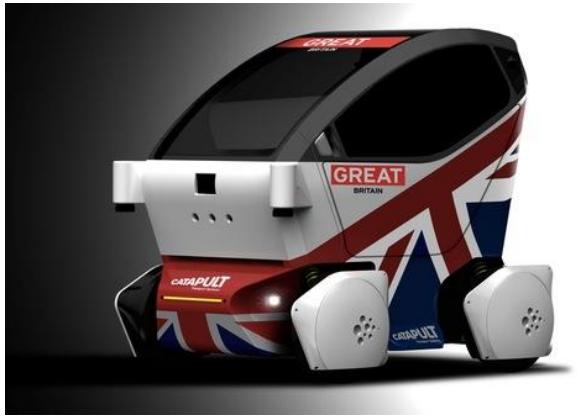
- Very high torque / limited by package
- × Multiple large diameter motors with high copper content
- Low speed = inefficient for current motor technology
- × Challenging motor design
- Range limited by efficiency
- × Limited performance and potential durability
- Durability risk from high losses
- Gradeability and launch requirements very challenging
- × Multiple motors require higher level safety cases

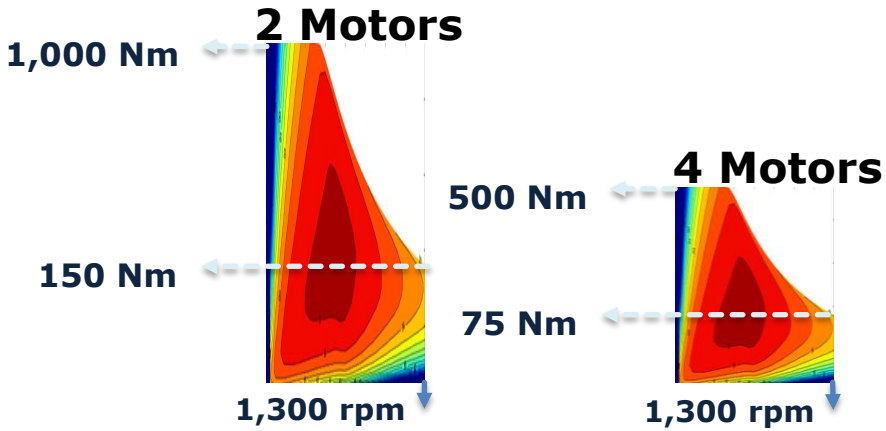


No transmission – wheel motors

- Best suited to low-performance applications where interior space is key,
- e.g. autonomous 'pods':

Vehicle	
Max torque	**2,000 Nm**
Max speed	**160 kph**
Torque at Max speed	**300 Nm**



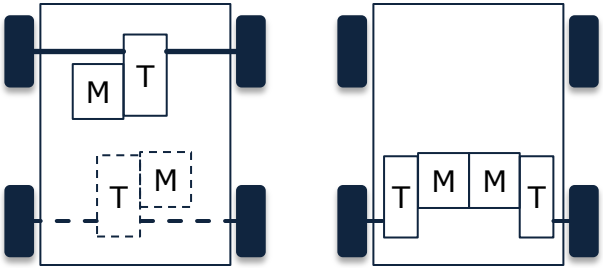


Single speed transmission

Configuration

- ✓ Single motor options
- ✓ Smaller, lighter and lower cost motor for same power
- ✓ Control system development not affected
- • Multiple motor options available for increased performance

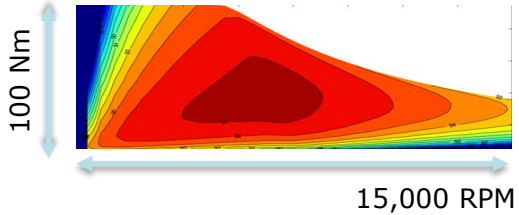
- Different OEMs offers the option of single machine per axle
- Ratio of up to 15:1 typically with 2 stages by addition of transmission

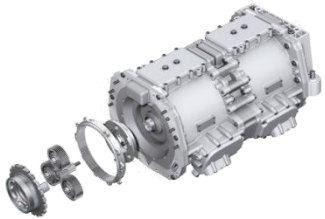


Performance

- ✗ Additional BoM cost of transmission
- ✗ Additional development programme for transmission
- ✗ Performance only optimised in limited range of operating conditions

- Wheel torque manipulated by ratio – enables smaller motor for same power
- Ratio enables motor to operate at speeds and torques where efficiency is optimised

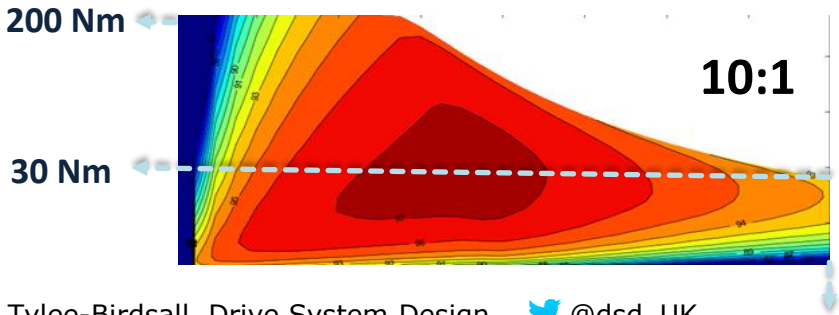


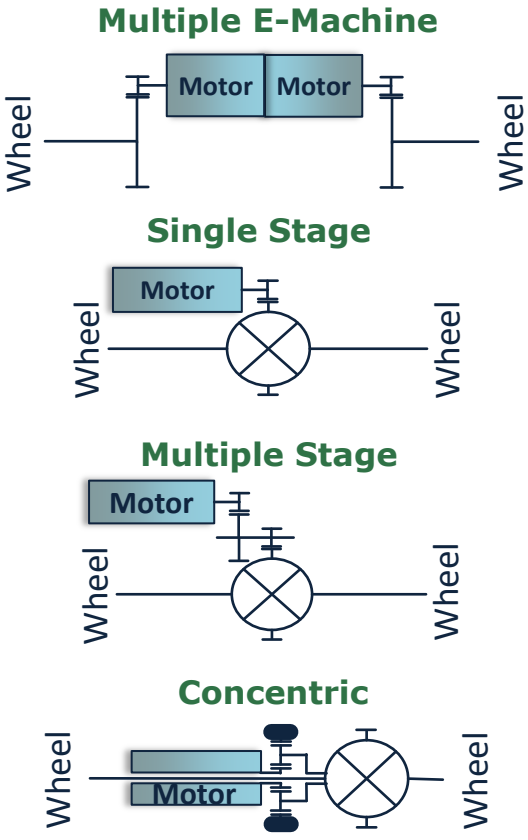


Single speed transmission

- Still aimed at small to medium vehicles assumed 2WD
- Single e-machine will deliver power to axle
- Package is made versatile by transmission
- Various potential locations on vehicle

Vehicle	
Max torque	**2000 Nm**
Max speed	**160 kph**
Torque at Max speed	**300 Nm**





Multi-speed transmission

Configuration

- ✓ Single motor configuration covers a wide range of performance requirements
- ✓ Vehicle performance and efficiency optimised
- • Multiple motor options available for increased performance

Performance

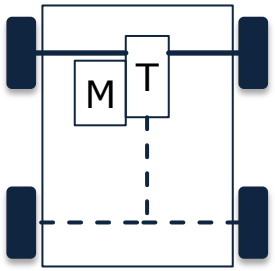
- • Multiple ratios enable vehicle performance to be optimised for low end torque, top speed and operating conditions
- • Cost of additional ratios (>2) is relatively low when compared to actuation and control system

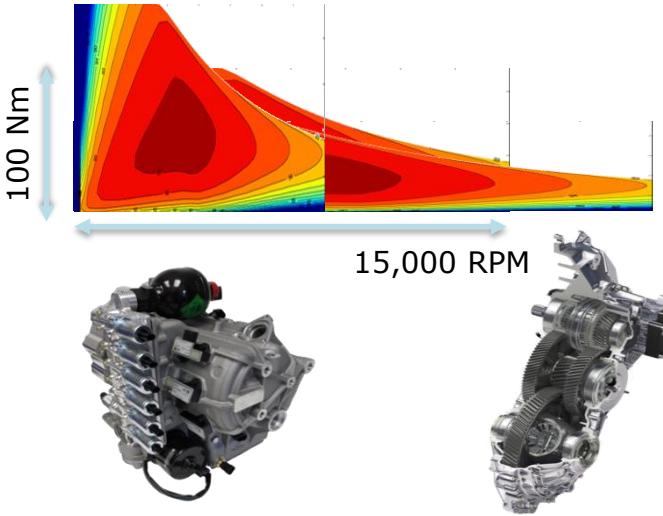
Configuration

- ✓ Single motor configuration
- ✓ Vehicle performance and efficiency optimised
- • Multiple motor options available for increased performance

Performance

- × Additional BoM cost of transmission and actuation
- × Additional development programme for transmission, actuation and control
- × Motor control for shift synchronisation





Multi-speed transmission

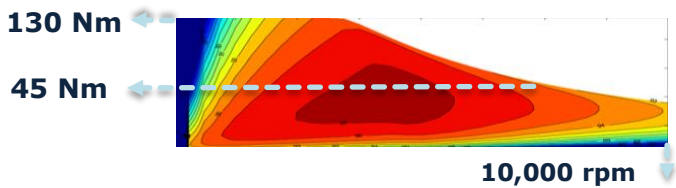
Existing Vehicle → **Ratios** = **Smaller E-Machine**

Vehicle	
Max torque	2,000 Nm
Max speed	160 kph
Torque at Max speed	300 Nm

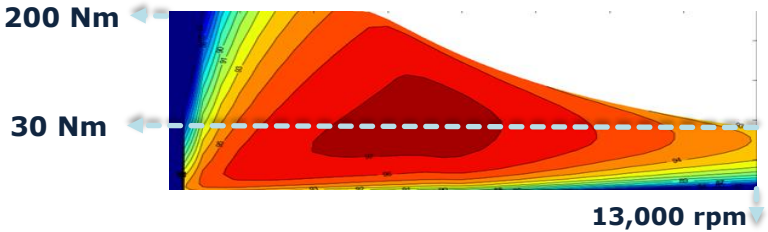
15:1

10:1

7:1



Existing E-Machine → **Ratios** = **Improve Vehicle Attributes**



15:1

10:1

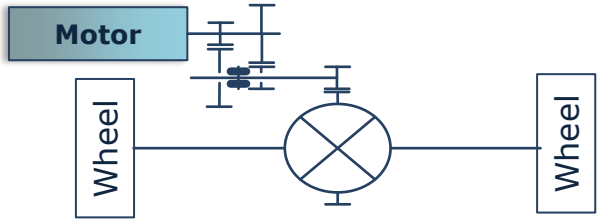
7:1

Vehicle	
Max torque	3,000 Nm
Max speed	190 kph
Torque at Max speed	430 Nm

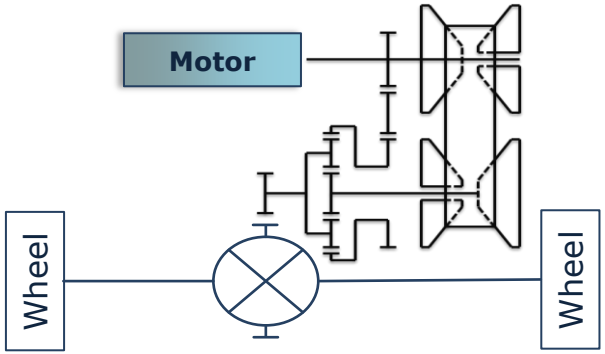
Multi-speed transmission

- Increased *performance* attribute requirement
  - Launch headline figures
  - Top speed headline figures
  - Off road capability
  - Vehicle modes
- Increased *efficiency* attribute requirement
  - Increased Range
- Package is versatile as with single speed transmission
- AMT, DCT, Automatic, Mechanical CVT, Electric IVT?

Stepped Ratio



Variable Ratio



Gearshift Method / Ratios

Number of ratios?

Shift time vs Shift step

- Gearshift needs to be smooth but torque demand satisfied quickly (<250ms)
- 2 speed transmission can typically require shift steps of up to 2.5:1
- Ratio steps of~**1.4:1** give response and refinement

Level of performance optimisation

- 2 ratios optimise for launch and high speed
- 3 ratios also optimise for motorway cruise
- More ratios = more time at max efficiency
- Additional ratios have little impact on cost, efficiency or development

Shift Type?

Torque interrupt

- Manual
- AMT

Powershift

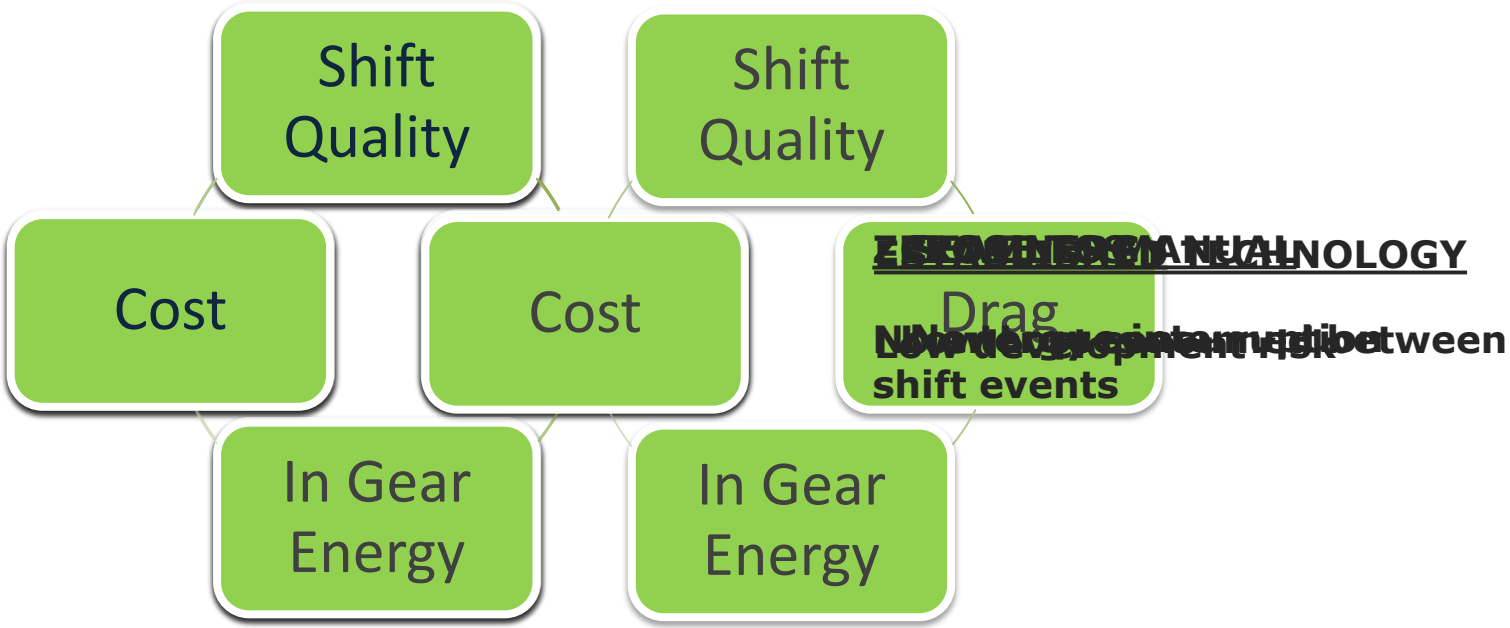
- Automatic
- DCT
- Other?

Customer expectation is based on cost, perceived refinement and popularity of single speed

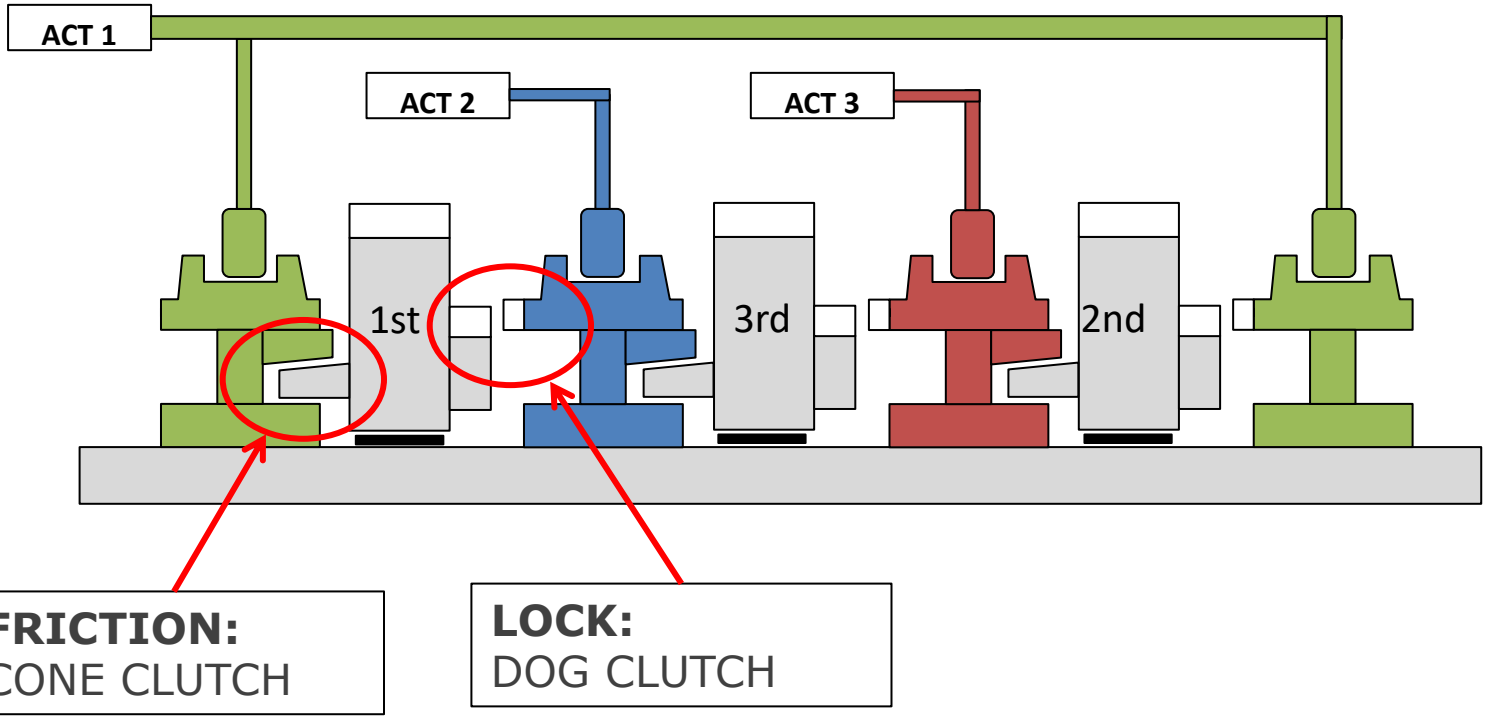
Multispeed EV powertrains generally require powershift for passenger car applications

Reduction of losses requires innovative solutions

Considerations for EV shift system



MSYS Powershift System



Efficiency & Durability

Efficiency

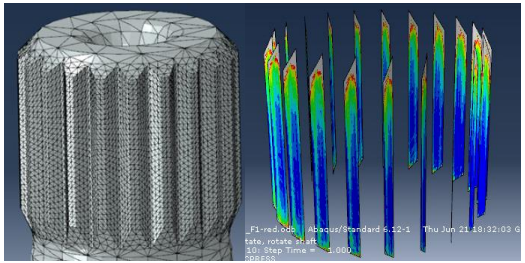
- Minimise bearing loads allows high efficiency bearings
- Mesh design for high efficiency – maintain low noise
- Active & passive lubrication systems minimise losses to fluid
- Actuation system losses to be minimised (**MSYS**)

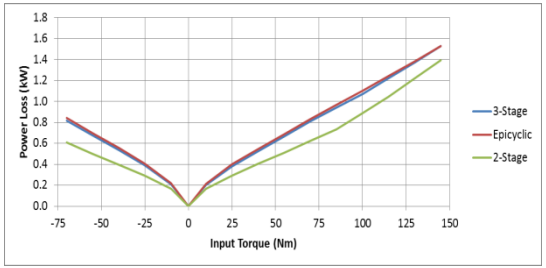
Spline fretting and bearing damage

- Consideration of interfaces and tolerance stacks
- Dry areas of transmission
- Integrating of motor into the transmission structure

High e-machine speeds

- Lubrication issues
- High sliding speed at the mesh





NVH Optimisation

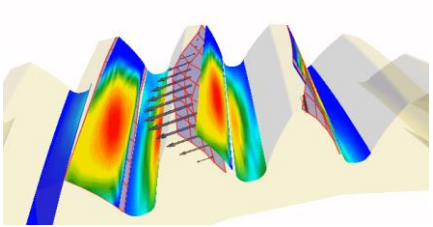
- No ICE has reduced the allowable noise emitted from transmissions
- What is important?

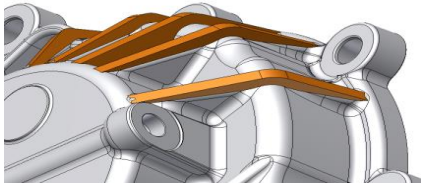
Gear mesh design
  - Very low transmission error
  - Optimisation of TE with contact stress and efficiency

Casing design
  - Reducing modal response to excitation
  - Modifying stiffness to move modes away from operating frequencies

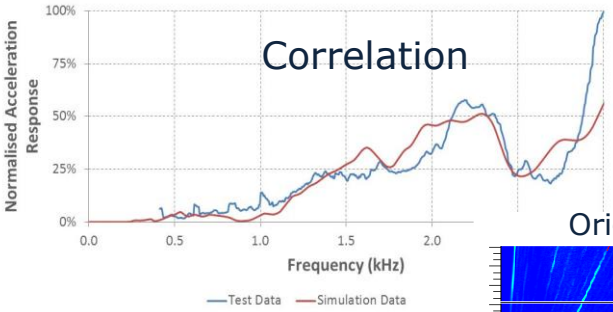
E-machine
  - Additional source of excitation: torque ripple & radial vibration

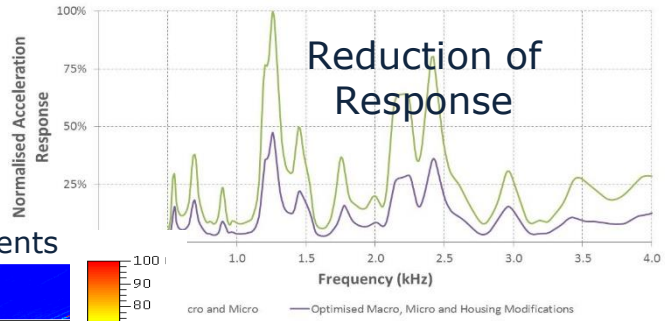
Mounts and additional structure



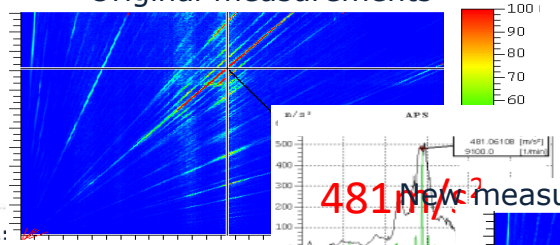


NVH Optimisation Method

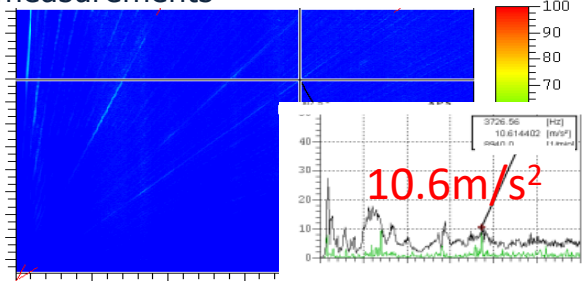


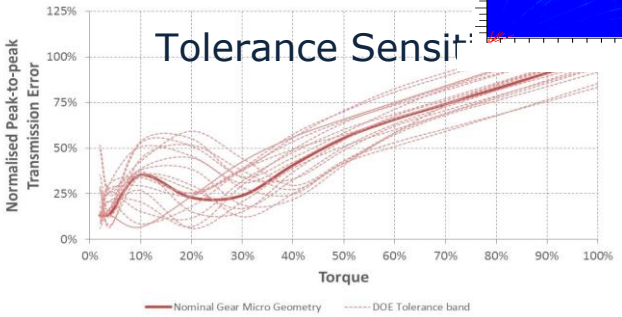


Original measurements



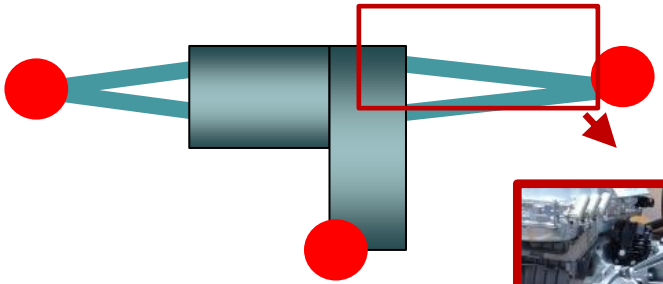
New measurements





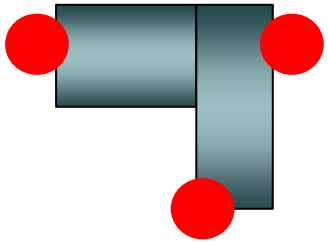
Mounting Strategy

Wide Mounts



- ✓ Good for transients / load reversals
- ✓ Meets existing mount positions
- × Large very stiff structure needed
- × Risk of vibration response in critical 1-3kHz region
- × Airborne noise risk

Narrow Mounts



- ✓ No large structure to excite
- × Difficult to meet transients/ load reversals
- × Structure borne noise risk

PACKAGE RULES!!

Lessons Learnt

1. **Number of speeds**
   - No transmission – Small pod type vehicles
   - Single speed transmission – Modest applications
   - Multi-speed transmission – Improved requirements
2. **Shift system must powershift and have low losses**
3. **Maximising efficiency is part of design process**
4. **Integration of motor and transmission is best to avoid interface durability issue**
5. **NVH is critical consideration – no excuses for noisy transmissions**
6. **Mounting strategy is very important for NVH**

EV Transmission: Lessons Learnt

Any Questions?

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