LAMBORGHINI AVENTADOR — 7-SPEED AMT WITH FASTEST GEAR SHIFT

With the new flagship model, the Aventador, Lamborghini ran counter to the industry trend of fitting Dual Clutch Transmissions. Oerlikon Graziano instead developed a tightly packaged customised Automated Manual Transmission which handles 750 Nm of torque and provides shift speeds of just 50 ms.

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REASONS FOR THE AUTOMATED MANUAL TRANSMISSION

There is a renewed interest in Automated Manual Transmissions (AMT) from sectors of the automotive industry such as supercar and hybrid vehicle manufacturers. The combination of compact packaging, high efficiency, and new evolutions in control strategy means that for some of these applications an AMT is more suitable than a Dual Clutch Transmission (DCT) or conventional manual transmission.

The new 515 kW (700 bhp) Aventador uses a seven-speed AMT with the fastest gear-shift of any synchromesh road vehicle transmission. Designed and manufactured by Oerlikon Graziano, the gearbox weighs just 79 kg and is therefore 20 % lighter than its predecessor applied with the Lamborghini Murcielago. It also uses a novel shift system to achieve the rapid shift time of just 50 ms, ❶.

The customer brief for the transmission included very tight packaging requirements, a high level of emotional involvement for the driver and very high input torque and speed. All this was to be delivered without compromising durability and within a demanding project timescale. To achieve these goals, the supplier's engineers worked as a single team with Lamborghini in deep cooperation from day one.

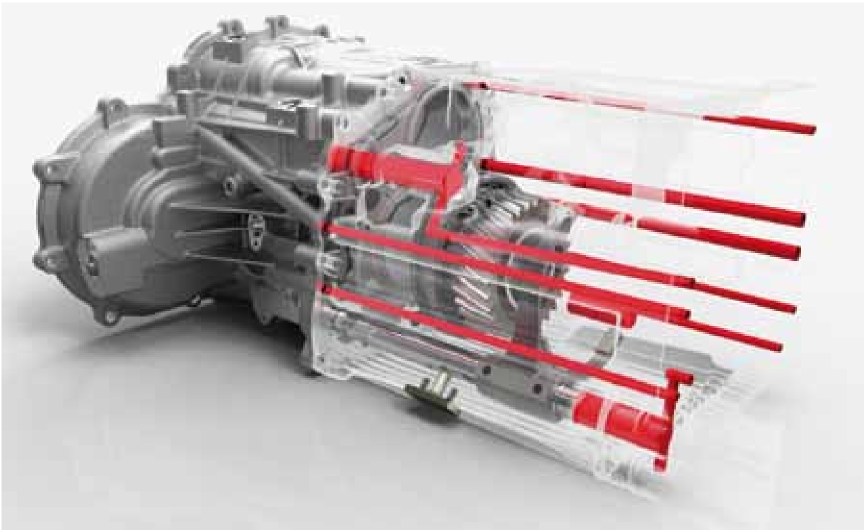
To maximise occupant space, the Aventador features a slim transmission tunnel within its carbon fibre monocoque. The package limitations ruled out the use of a DCT because insufficient space was available for the large dual clutch packs required to handle the input torque of 750 Nm and input speeds up to 9000 rpm. The AMT previously used in the Lamborghini Murcielago would not package within the new car as well.

The compact transmission design was made possible by extensive use of advanced analytical techniques, allowing substantially reduced centre distances between the shafts and reduced clearances between the transmission and the vehicle body.

Further savings in package size were achieved by integrating the hydraulic system into a compact self-contained unit without any external pipe runs, all connections being internal through the transmission casings, ❷.

The engineering team was tasked with providing a strong emotional link between the driver and the car. This is reflected in the engineering targets which included unprecedented shift times. The crucial element in faster shifting is the ability to move into the next gear while the system is disengaging the previous one. The transmission applies this principle, well understood from experiences with DCTs, but with the light weight and compact package that is possible with an AMT when no manual option is required.

❶ Seven-speed AMT with the fastest gear-shift of any synchromesh road vehicle transmission



2 Savings in package size were achieved by integrating the hydraulic system into a compact self-contained unit within the transmission case

INDEPENDENT SHIFT RAIL TECHNOLOGY

A conventional AMT uses the established H-pattern gearshift of a manual gearbox, in which the various gears are selected by sliding selector rails that lie parallel to each other. The jump from one rail to another corresponds to the dogleg in the middle of the H, called cross-gate movement. Two actuators power the automatic shift; the actuator engaging the desired gear has to wait until the cross-gate actuator has selected the correct rail. Oerlikon Graziano together with Vocis Driveline Controls devised a strategy called Independent Shift Rail (ISR) for the transmission that eliminates this constraint.

In the ISR transmission, there is no cross-gate motion and consequently no cross-gate actuator. Instead, each rail is operated directly by its own actuator, 3. One rail selects either 1st or reverse, one 2nd or 4th, one 3rd or 5th and one 6th or 7th. This means that no two sequential gears are on the same shift rail until the last change into the 7th, the top gear. As a result, the system can begin to move the rail for the next gear while still withdrawing the previous one, allowing the shift to be accomplished faster.

Even with the ISR architecture, ultra-fast shift speeds would not be possible without careful optimisation of the entire system. For example the gear change paddles are hard-wired into the Transmission Control Unit (TCU), eliminating the time required for the Controller Area Network (CAN) bus to poll the system. Furthermore, very accurate measurement and control of the actuation current ensures precise and progressive control of the high-precision hydraulic valves. The valves, specified by Vocis and designed
for this application, are critical not just to a fast change but also to shift quality.

To further increase the speed of the shift, the software has to be optimised. Control systems are often designed after the gearbox hardware is frozen and must operate within the constraints of the existing mechanical layout. Simultaneous engineering of the mechanical architecture and the software allowed taking best advantage of the inherent dynamic behaviour of the system. After modelling component elasticities and inertias, the system responses were simulated and optimum strategies for shift execution identified, eliminating much of the compromise inherent in this area.

The algorithms critical for effective high-speed shift control, are based on a core Vocis software platform, tailored for the specific application. The software was developed using software-in-the-loop methods within the model-based development environment Ascet by Etas, followed by hardware-in-the-loop testing in the Etas Labcar environment for execution and automation of control unit tests. Software change management was controlled using a database to give reliable, secure access to up-to-date revisions during periods of rapid development.

The first ten transmissions used a Vocis TMS20 rapid prototyping controller running Matlab/Simulink executable files. The production TCUs are based on an MPC5567 processor and manufactured to a Vocis specification based on the output of hazard analysis.

ANATOMY OF A SHIFT

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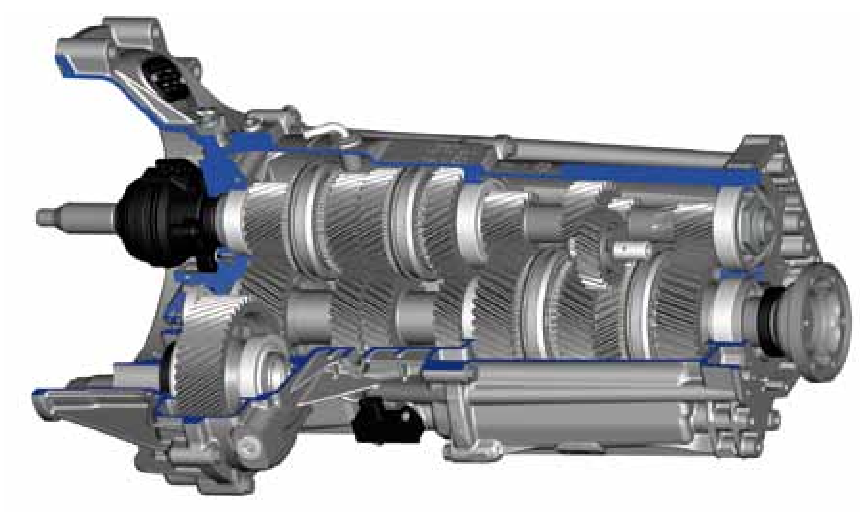
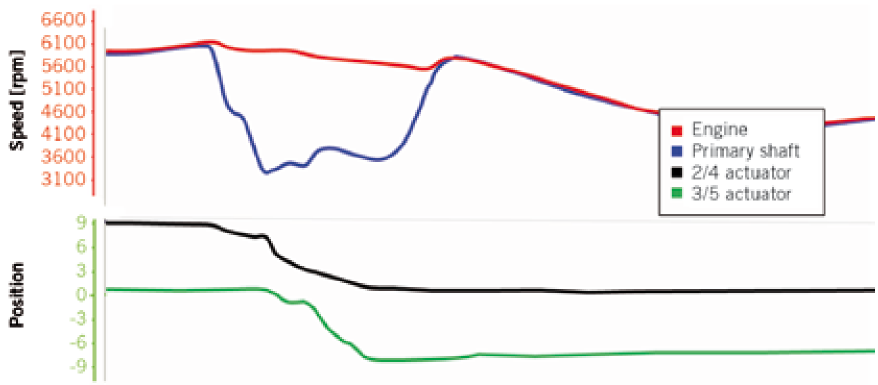


3 The compact design was made possible by extensive use of advanced analytical techniques, allowing substantially reduced centre distances between the shafts



4 Although gear shifting takes place in milliseconds, there is a defined sequence of individual operations

individual operations, each one scheduled and controlled by the Vocis software. 4 shows the full sequence for a shift from 4th to 5th gear.

Initially, the engine speed (red line) matches the primary gearbox shaft speed (blue line). The first milestone occurs when the driver requests a shift. Elasticity in the driveline causes the input shaft to break away and slow relative to engine speed (second milestone). At this point, the 2/4 gear selector rail begins move towards disengaging 4th gear. At the third milestone, the actuation system for 5th gear is preloaded. At the fourth milestone, to coincide with torque reversal in the driveline, the 2/4 selector rail disengages 4th gear at the point of lowest mesh load. The primary shaft speed is at its lowest. At the fifth milestone, while 4th gear is still disengaging, the 3/5 selector rail begins synchronisation of 5th gear. At the sixth milestone, 5th gear is fully engaged.

From this point, the primary shaft speed builds up quickly to match engine speed and the 2/4 selector rail continues its travel to take 4th gear into a clearance (neutral) position.

RESULTS

The first prototype transmissions were delivered within 13 weeks of the project start, with the first implementation in a running vehicle just three weeks later. This was partly due to an extensive programme of in-house rig development which included component fatigue testing on dedicated rigs for the gears and synchronisers, hydraulic system fatigue testing in a climatic chamber, and lubrication verification at all attitudes with a rock-and-roll rig, 5.

Unlike many early prototypes that serve only as proof of concept, the transmissions were fully functioning and sufficiently representative to allow early engineering vehicles to be used for demanding board-level evaluation. The result of this combination of design techniques and operating strategies is a minimum shift time achieved of just 50 ms, making this the world's fastest-shifting transmission with synchronisers. The software is configured to provide three shift modes: Strada, Sport and Corsa. The most refined of these is Strada which provides the smoothest gearshift with minimal engine braking to suit a relaxed driving style. The Sport mode introduces an aggressive throttle blip during downshifts, briefly exceeding the target engine speed to ease the blend into the new ratio and provide a more emotive driving experience. Corsa mode is intended for race track driving. It provides aggressively fast shifts but also keeps the car feeling neutral and stable by providing controlled engine braking.

5 Lubrication verification at all attitudes with a rock-and-roll rig

CONCLUSION

A close working relationship between the development partners ensured that the transmission enjoyed a swift design phase and was able to take advantage of solutions that would not be available within the confines of existing architecture. The AMT is optimised in shift time, feel, packaging and weight. As it was designed specifically for the Aventador application it is not affected by the compromises dictated by an off-the-shelf unit.

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