The drive for durability

David Cooper examines the technologies behind some of the key transmission components – their materials, manufacture and the design issues involved

Within a racecar, the business of the transmission subsystem is the controlled application to the racetrack of the power and torque delivered by the engine. While most of the fundamental principles of racecar transmissions have remained unchanged for decades, it is in the subtle refinements of power transmission systems and their integration where transmission engineers are making a difference.

The requirement for a transmission system is fundamentally linked to the nature of the internal combustion engine, which exhibits its maximum torque and power within what is realistically only a narrow band of engine speeds. The need therefore for a transmission system capable of keeping the engine within a relatively optimum operating window while wheel speeds vary significantly is essential.

While systems such as continuously variable transmissions (CVTs) provide a solution which is at least conceptually more efficient in terms of keeping the engine at its optimum speed, a series of discrete ratios provided by a geared system has become the solution for virtually all race series. Possibly the reason for the relative obscurity of CVTs lies with the rule makers, who banned them in Formula One before they could be raced during the mid-1990s, out of fears that better-funded teams could optimise the systems and dominate.

The first requirement though is for a means to de-couple the engine from the geared drivetrain, to enable standing starts and usually for gear changes as well. This may be achieved through the use of a friction clutch or fluid coupling – a natural starting point for a tour through a transmission system.

Clutches

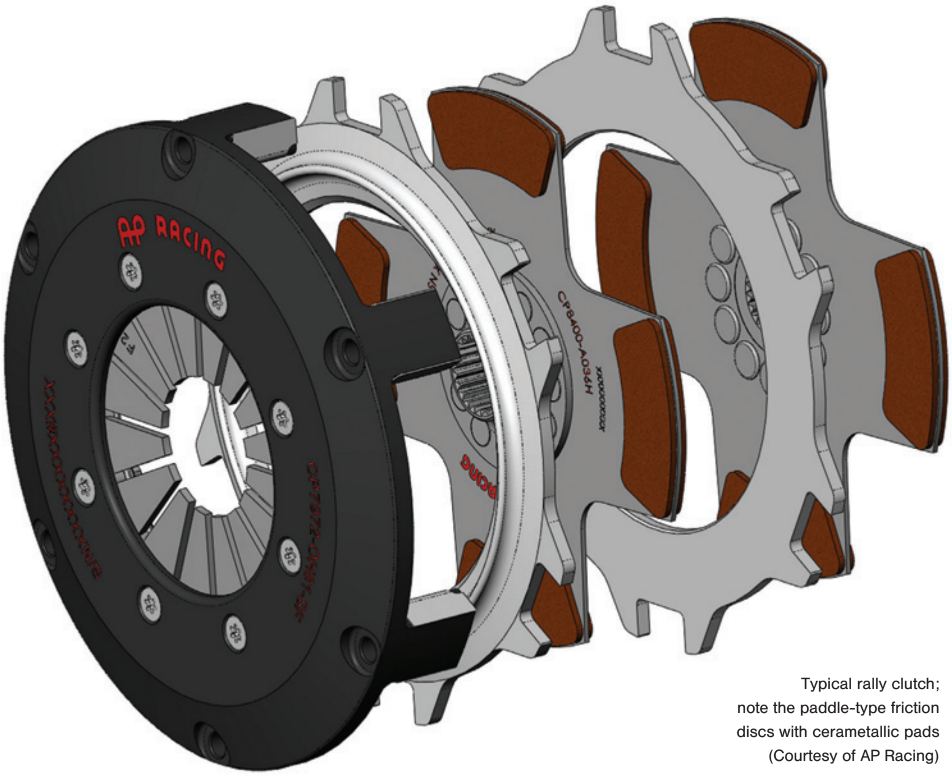
Once the power leaves the engine's crank or flywheel (if present), the first component in the system is typically the clutch. Clutch design is a complex area, but the principles remain largely the same throughout motorsport. Nearly all motorsport clutches are of the friction type, consisting of (usually) between one and four friction plates, a pressure plate and some form of spring to provide an axial force that presses the plates together in order to transmit engine torque.

The performance of a clutch is usually defined as its torque capacity, which is the level of torque it can transmit before slipping occurs. This is a function of the friction material used (specifically its coefficient of friction), the contact area available and the axial force available to keep the plates in contact. The friction available is a function of the materials' coefficient of friction multiplied by the spring force, derived via an integral for the area of an annular ring. The equation below provides the torque capacity of a singular disc surface (one side), which can then simply be multiplied by the number of friction surfaces involved to determine the total torque capacity for a clutch design.

$$T = \frac{F\mu}{3}\,\frac{D^3 - d^3}{D^2 - d^2}\,N$$

Torque capacity (T), is a function of spring force (F), coefficient of friction (μ), disc outer diameter (D) and inner diameter (d), and the number of friction surfaces (N)

From this brief analysis of the mathematics behind a clutch's torque capacity it can be seen that the coefficient of friction available, the spring force used, the size of the friction discs and the number of friction discs are the design factors that influence the clutch's ultimate torque capacity. While undoubtedly important, this is not always the most important design factor. Reducing diameter results in a reduction in rotational inertia, which is always valuable for drivetrain response; a balance must be struck, however, as too small a diameter



Typical rally clutch; note the paddle-type friction discs with cerametallic pads (Courtesy of AP Racing)

clutch becomes impossible for the driver to control without complex electronic systems.

Selection of torque capacity is also important, with one manufacturer suggesting it should be about 1.25-1.5 times the engine's maximum torque, to ensure no slip, but also less than twice the torque to ensure that the clutch can slip if an excessive torque spike is transmitted back up the driveline from the wheels, so saving the engine.

Provision of the axial clamping force that engages and disengages the clutch typically comes from either one (or several in the case of more complex Formula One-style clutches) diaphragm springs, which may either be pushed towards the clutch stack or pulled away from it to disengage the force and allow the plates to de-couple the drive. While diaphragm springs are the mainstay for cars, motorcycle clutches typically use a series of coil springs.

Motorcycle clutches also differ from their automobile counterparts in that they are of the 'wet' type, running (somewhat counter-intuitively) bathed in engine oil, providing a good measure of liquid cooling. This does prohibit the use of certain engine oils containing friction-reducing additives though, which cause the clutch to slip and contaminate the friction material – as any motorcyclist who has unwittingly used standard car engine oil can attest!

For the most part, however, motorsport clutches (and now some high-performance motorcycle clutches) are completely dry and exterior to the engine. There are three types of friction material – organic, sintered metallic or cerametallic materials and carbon-carbon type materials. The greatest factor in material selection is the expected operating temperature: while all three types will probably get a car off the line, as they heat up the coefficient of friction can change significantly, resulting in slip, particularly with the organic materials, which leads to a degrading spiral of increased heat and slip, so organic friction materials are rarely seen in performance racing clutches.

More typically a sintered metallic type is used, based on either bronze or iron. Sintered bronze materials tend to have a lower coefficient of friction than organic materials, but greater thermal stability. Sintered iron materials show a significant increase in friction, with only a moderate decrease at high temperatures, but having higher friction they are harder for the driver to modulate.

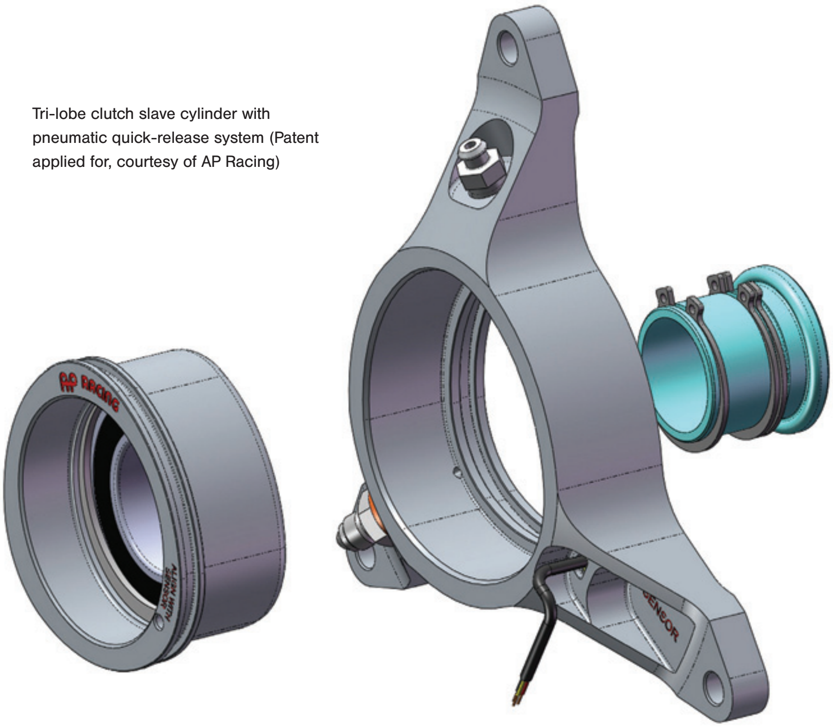
For the greatest level of thermal stability, the material of choice is usually carbon-carbon, as it has a very predictable and consistent coefficient of friction even at high temperatures. The coefficient of thermal expansion for carbon is also low. As a car waits at the start, the clutch is typically held partially engaged (just before the bite point) so heat builds up in the material. If there is sufficient expansion in the disc stack, the car can be launched unintentionally, as the plates' cumulative thermal expansion is enough to engage the clutch more fully. The primary benefit of using a carbon-carbon type material is its superior thermal stability, with heat having a minimal impact on its coefficient of friction, and having minimal thermal expansion in comparison to other materials that experience greater changes.

Clutch plates are typically rigid carbon types for single-seater circuit racing, but variations occur for other race series. Any series with roots in a production car is more likely to use a one- or two-plate clutch, with paddle-type plates to reduce inertia by removing material from the larger radius. While circuit racing tends to desire stiff plates for efficiency and low mass, heavy duty off-road applications may tend towards a sprung centre, to smooth or cushion otherwise harsh fluctuations in torque through the drivetrain.

Clutch control

Actuating the clutch may be achieved by a simple cable, but more commonly a hydraulic system is used, and often an electronically controlled pneumatic system will be used to actuate the master cylinder of the hydraulic circuit (mimicking the driver's pedal input but allowing paddle shifts to be installed on vehicles without electro-hydraulic systems). At higher race series the pneumatic system gives way to an electro-hydraulically controlled system, should the level of technology and budget be available.

While launch control was permitted in Formula One, and crank height was unregulated, the aim was to produce as small a diameter clutch as possible, allowing the crank centreline to be lowered to benefit centre of gravity. With a smaller diameter clutch, however, although inertia is reduced, 'feel' or driver control becomes practically impossible, so a launch control system is needed to take over from the ▶



Tri-lobe clutch slave cylinder with pneumatic quick-release system (Patent applied for, courtesy of AP Racing)

driver. With the banning of launch control and a prescribed minimum crank height, both the potential and the desire to produce a smaller clutch has waned, with most Formula One teams reverting to a larger (though still petite) 97.5-99.0 mm clutch, bringing benefits in terms of controllability and wear.

For clutch control systems, typically the slave hydraulic piston is mounted concentrically to the output shaft, using a spider-type arrangement (reaching over and around the clutch to mount to the engine or gearbox). Recent innovation in this field has seen the development of a 'non-cylindrical' slave piston, the benefit of which is a tri-lobe shaped piston that need not rely on seal friction to prevent its axial rotation. With the piston unable to rotate, a much lower friction piston seal can be used, allowing greater feel and control of the clutch by the driver.

While the installation of pull-type actuation clutches is relatively straightforward, the disassembly for servicing can be difficult, with internal snap rings now impossible to access and remove. For this reason, many installations are forced to use a push-type actuation method. As part of the tri-lobe slave cylinder, a new system has now been incorporated that uses a compressed air input from a workshop airline to disengage the requisite snap rings, and allow easy removal of the system (for which a patent has been applied).

Clutch baskets

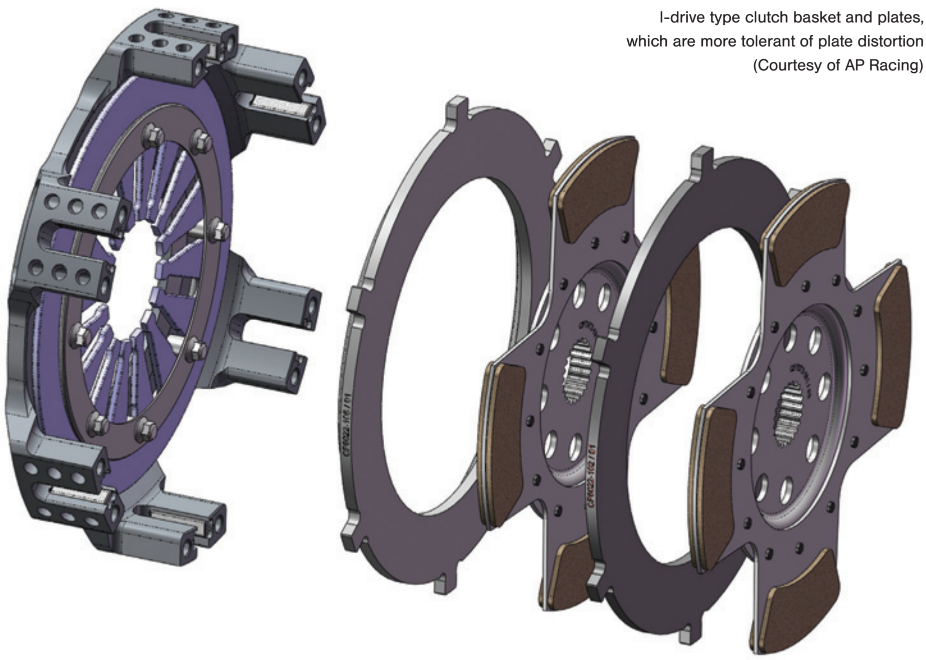
Clutch baskets are typically manufactured from a machined aluminium alloy, which is then hard anodised for wear performance, while higher temperature applications such as Formula One use titanium alloys for the basket. Engagement of the basket with the friction discs is achieved by slotting the friction discs to accept the legs of the basket (as can be seen in the figure on page 63). While this works well, if steel plates become over-heated or distorted, they can tend to pinch the basket leg, sticking and preventing proper clutch actuation. To combat this issue, a new system is appearing on the market, using a male tab on the plate that runs within a track inside the basket leg. The track has an I-shaped profile, with two low-friction liners on which the plates run. This improves clutch feel, while also preventing a distorted plate from jamming too readily.

Torque converters

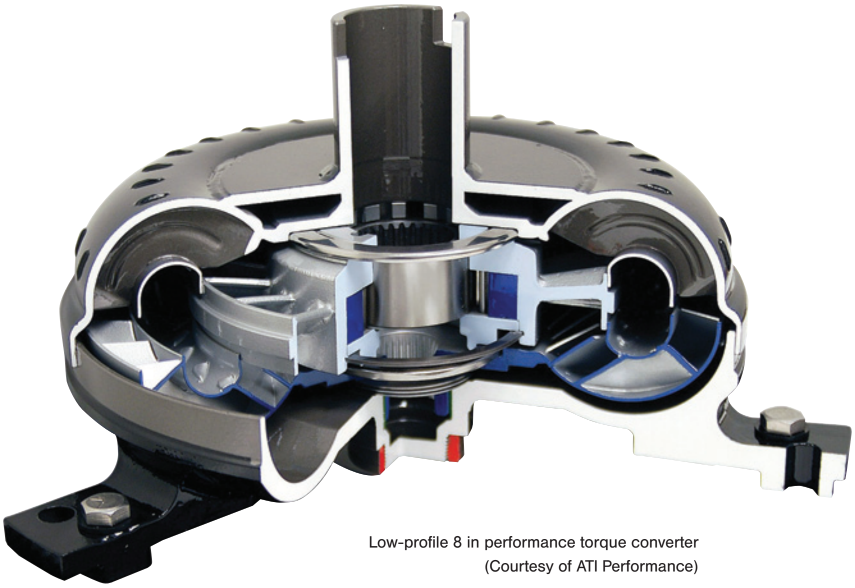
As an alternative, or in addition, to a friction clutch, a torque converter may also be used. An enclosed unit that relies on a hydraulic working fluid to transfer engine power, it can either replace a traditional clutch (in the case of roadcar automatic transmissions) or be used in addition, to smooth and absorb the extreme torque spikes seen in drag racing. Their ability to multiply the engine's torque delivery and achieve an aggressive but mechanically sympathetic launch makes them highly popular in drag racing circles.

A fluid coupling forms the basic principle of a torque converter, and consists of a toroidal housing, within which rotate a half-toroidal pump and turbine, with the addition of a stator blade ring being the defining feature between a fluid coupling and a torque converter. Perhaps the easiest way to imagine the principle of operation for a fluid coupling is to think of two desk fans, placed face to face; if one is switched on, the other begins to turn and eventually reaches a similar speed to the powered fan. A fluid coupling operates on this principle, but within an enclosure using a transmission fluid rather than air.

If the difference in speed between the pump and turbine is large



I-drive type clutch basket and plates, which are more tolerant of plate distortion (Courtesy of AP Racing)



Low-profile 8 in performance torque converter (Courtesy of ATI Performance)

then some of the working fluid leaves the turbine and swirls counter to the direction of rotation, creating a drag effect and lowering efficiency. A torque converter adds a static ring with aerofoils that direct the excess fluid back into the pump side in the same direction as the rotation, improving efficiency. As the pump and turbine speeds equalise, fluid hits the reverse side of the stator blades, disengaging an overrun clutch and allowing the stator to freewheel, effectively becoming a fluid coupling again. The designed angle of the stator blades determines the point at which the switchover occurs, and is usually set at the crossover in efficiency between operating as a torque converter and a fluid coupling.

Once the initial business of launch is complete, and the difference in pump and turbine speeds is relatively small, then an hydraulically activated lock-up clutch can be used to mechanically join the two together, eliminating slip, reducing the heat input to the working fluid and maximising the torque transfer. For drag racing this is typically after the first half of the track has been completed, with the best torque multiplication possible; the converter is then locked up for the rest of the run. Lock-up is achieved by a friction clutch with up to five plates to cope with up to 3000 bhp; engaging this clutch results in zero slip and at the most extreme can cut large differences in input/output speeds from up to 1000 rpm down to zero.

For racing use, torque converter turbines/pumps are furnace brazed, with vanes TIG-welded in place; generally an aftermarket cast cover is used, and all bearings uprated to high-quality roller bearings.

Typical automatic transmission fluids tend to be replaced with a synthetic specialist alternative, usually based around a Ford Type F specification, but blended to provide the best properties. An SAE 10 weight fluid is likely to be used for qualifying runs, or lower-power cars, rising to SAE 30 to cope with greater power delivery. The viscosity affects the torque converter's behaviour, hydraulic line pressure and the transmission cooler pressure, so it needs to be considered carefully.

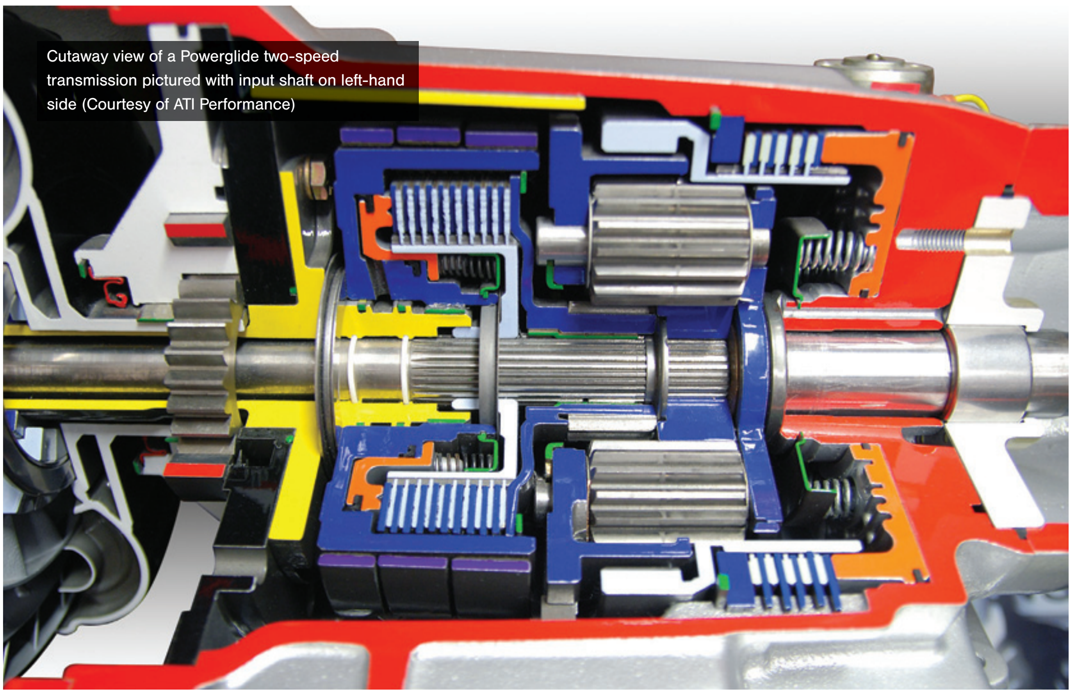
Although a torque converter will suffer a decrease in efficiency compared to a friction clutch, modern units can boast up to 98% efficiency, and their use brings other advantages in torque smoothing and handling power delivery for drag racing engines providing in excess of 3000 bhp.

For drag racing applications, the torque converter is typically coupled to a longitudinal gearbox, with normally either two or three speeds, and with the power transmission ratios achieved by an epicyclic gear arrangement. Changing gear is achieved by the use of either plate friction clutches or band brakes (which use hydraulic pressure to clamp around the circumference of a drum). In low gear, the high-gear drum is held with pressure on a Kevlar-lined band around its exterior. In order to shift to high gear, the pressure on this band is released, while the high gear ten- to 12-plate friction clutch is engaged.

Sequential transmissions

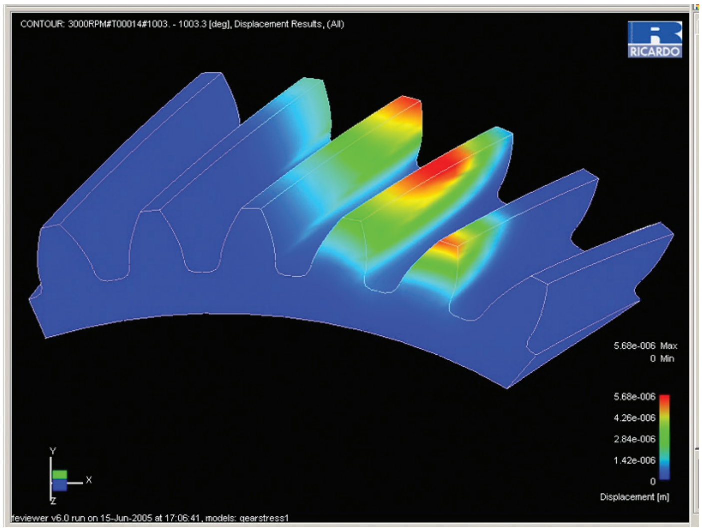
The use of clutches to select a ratio is fairly unique to drag racing/automatic transmissions, while normal practice for most racecars – be they circuit- or rally-based – is through the use of straight spur gears, engaged by drive dogs and selected by a rotating drum/selector fork arrangement. This well-established technology provides a sequential transmission that is highly efficient and lightweight. While spur gears experience high forces due to the instantaneous meshing of each tooth across their width, there is virtually no side load, which is of great benefit to reducing the weight of shafts, bearings and casings.

Helical gears are preferred in a roadcar setting for reduced noise, vibration and harshness, and while their progressive engagement is smoother and quieter, the side loads created mean ▶



Cutaway view of a Powerglide two-speed transmission pictured with input shaft on left-hand side (Courtesy of ATI Performance)

Ten- to 12-plate high-gear engagement clutch from a Superglide 4, capable of handling up to 3000 hp (Courtesy of ATI Performance)



Example of gear tooth stress/displacement, from a gear design analysis package (Courtesy of Ricardo)

thrust bearings have to be used, so are rarely seen in motorsport.

The fundamental technology behind the sequential transmission has changed very little; there is however a continual challenge of reducing the packaging space required, and installing the transmission in the most beneficial manner for aerodynamics, space and weight distribution or centre of gravity.

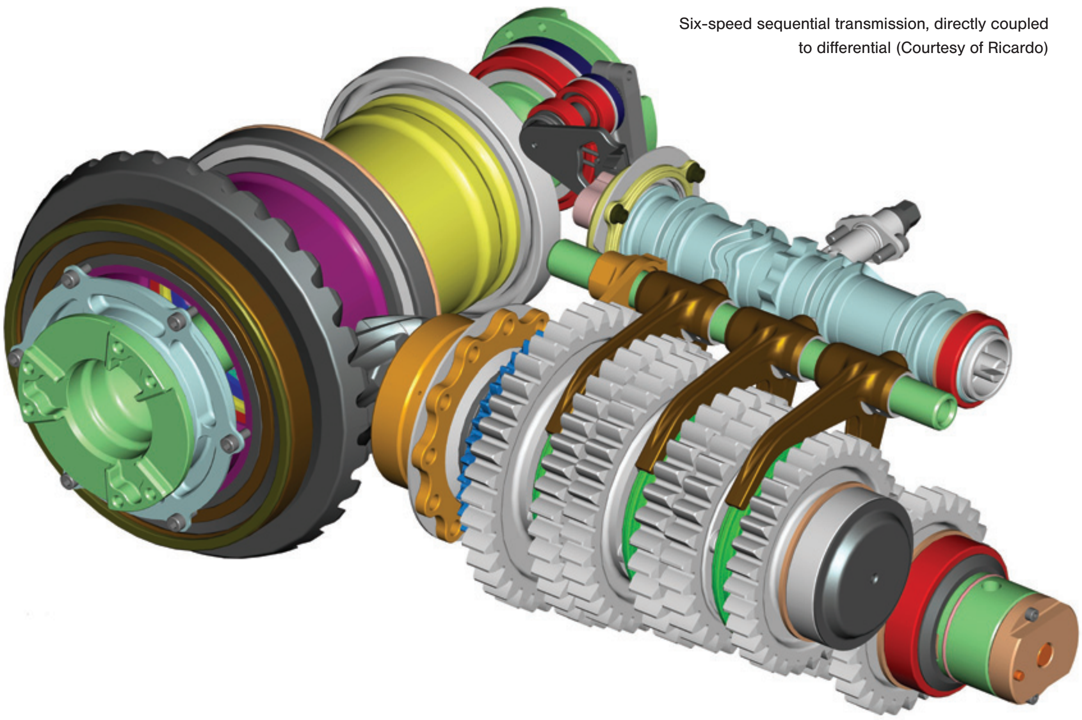
Gears

The design of a gear set usually begins with a tailored analysis package, which not only evaluates the stresses on the gears but defines fillet clearances, land width, contact ratios and so on to provide an optimised profile for a chosen design life or stress limit. While most manufacturers maintain their own particular philosophy on tooth geometry, the development of stress calculation software is beginning to have an impact, providing new insight into the interactions present. At least one gear manufacturer interviewed for this article has found a new approach to certain very heavily stressed gear applications on the basis of such analysis, pushing to extend gear life more so than reducing weight.

Once a set of ratios and geometry has been defined, 2D drawings, along with 2D and 3D CAD files, feed into the manufacturing process. This process varies according to the lead time and budget available, with annealed gear blanks typically cut by hobbing, soft grinding or wire cutting depending on the features present, and 3D features such as drive dogs machined from CAD data by milling. Cut gears are then heat treated and casehardened, with a possible post-heat treatment grinding that may be specified if the budget is available, ensuring complete geometric accuracy free from the effects of any thermal distortions.

Any heavily stressed gear will usually receive a two-stage controlled shot-peening process, using various metallic, ceramic or organic media, along with precise controls on velocity, and masks that control which areas are to be treated. The first stage is intended to introduce a surface/subsurface compressive stress, to counter the tensile stress experienced during operation and so reduce the net stress present and increase fatigue life. Depending on application, it may be desirable to induce this compressive stress anywhere between zero and up to 0.2 mm below the surface; a deeper residual stress requires more energy from the peening process, so it relies on heavier or larger media particles or higher velocities. The first stage therefore reduces the surface finish of the gear, and is usually followed by a second shot peening using finer media to smooth the surface.

Surface nitriding or carburising (casehardening) processes are also useful for increasing surface ▶



Six-speed sequential transmission, directly coupled to differential (Courtesy of Ricardo) hardness, and are performed by heating the gears in a nitrogen-rich atmosphere, after the hardening and tempering heat treatments. A fuller account of potential surface treatments of gears and other components can be found in *RET* 57 (September/October 2011).

If required, further superfinishing operations (abrasive/chemical-type processes) may be used to provide the ultimate in surface finishing, and are capable of a finish in the region of Ra 0.01 µm for the measured surface roughness. This is particularly desirable in high-load/friction applications such as hypoid or helical gears, which will benefit most from the potential improvement in fatigue life. However, when interviewed for this article, one manufacturer indicated that shot peening or superfinishing are certainly not “the silver bullet for reliability” – while they enable an extension in life, the fundamental base product is the determining factor.

The material of choice for manufacturing gearbox internals is a steel alloy, as no other material can match the specific strength and stiffness which is possible with steels, certainly not for such a reasonable cost. While some manufacturers will specify and develop their own proprietary steel grades, on the whole standard casehardenable aerospace steel alloys such as S156 are the mainstay. The most cost-effective method of controlling material properties on an application-by-application basis is probably through the heat treatment of a known and familiar steel alloy, with a significant range of properties available depending on the regime selected. Manufacturers will typically undertake to develop a specific heat treatment/surface finishing regime if required, using coordinate measuring machines to gauge geometric accuracy, along with destructive testing and measurement of micro-hardness through the gears’ subsurface region.

The current direction of gearbox design is towards improving the functional aspects, rather than particularly shedding weight. Many series now specify minimum gearbox lifetimes, or limit teams’ access to change components, effectively forcing them to last a whole event. Innovative and refined gearbox design that minimises the need to replace or remove components, or reduces the spares inventory required, is now preferable in nearly all race series as manufacturers, competitors and organisers all seek to reduce cost. The use of ‘drop gears’ is particularly useful to trackside time savings, as providing easy access to change a single ratio that impacts the overall final drive ratio of the whole gearbox allows a team to change and evaluate different gear ratios quickly and easily without the need to strip down or even remove the gearbox.

Gearbox casings

For gearbox casings, the material of choice is typically aluminium, produced via a casting route that draws heavily on aerospace expertise. This is probably the most efficient and cost-effective option, as the casting technology and alloys are widely understood. Many highly established gearbox offerings have recently undergone redesigns, updating the aluminium casings to take advantage of new 3D CAD design capabilities, and new thinner sections achievable by aerospace casting techniques.

For higher price tags, some manufacturers will also offer a cast magnesium alloy casing, permitting further weight reductions. The use of magnesium can have some pitfalls though, as some of its more advanced alloys can be difficult to cast, with specialist knowledge and experience being needed during both the design and manufacture stages. The higher cost is not necessarily just material-derived: until the experience has been gained, manufacturers may have to absorb the cost of incurring a much higher scrap rate than with their more established aluminium products.

For the ultimate in weight reduction, the use of carbon fibre gearbox casings with machined titanium bulkheads and inserts are used at the level of Le Mans Prototypes or Formula One. Even at this level though, the benefits must be weighed against the increased complexity, particularly as a move from aluminium or magnesium to carbon fibre reinforced polymer requires a significant investment in development and new knowledge if the expertise is not already available.

At the most expensive end of the spectrum, Formula One and Le Mans cars will often have a completely one-off gearbox design, one which is in effect a semi- or fully stressed chassis component. The mounting of suspension pick-ups and other components such as rear crash structures is a complex job, as it needs to ensure that the case can withstand all the loads involved while contributing to the overall stiffness of the chassis.

For most motorsports, a one-off gearbox is not cost-effective and, depending on the series or installation, the requirements can be quite different. Front-wheel-drive transverse gearboxes rarely need to support suspension loads, while longitudinal drag car transmissions (although not technically a part of the chassis) are under pressure from a desire to reduce flex in the casing, and to provide stronger casings than OEM units to prevent debris reaching the driver in the event of a transmission failure. Many aftermarket suppliers now have new offerings for race transmission cases, either to reduce weight or increase stiffness, providing options for competitors involved in drag racing, rally raid or historic club racing who need improved but cost-efficient performance and reliability over previous OEM units.

In NASCAR, some transmission units have previously used a centre support, a figure eight-shaped insert, mounting two bearings

Aftermarket race transmission, designed to reduce the longitudinal flex found in OEM units (Courtesy of ATI Performance)

Typical clutch plate-based motorsport limited-slip differential (Courtesy of Ricardo)

used to tie the main and layshafts together and prevent the shafts spreading apart through second and third gears. More recently though, improvements to gearbox design have allowed this support insert to be removed, reducing the gear cluster length as well as removing the efficiency losses associated with the additional bearings.

Integrating KERS

The addition of energy recovery systems, be they mechanical flywheel or electrically based, has created a new packaging and integration challenge for gearbox designers. The primary requirement is to integrate the flywheel or motor/generator unit (MGU) to provide the best overall packaging solution with the surrounding components. Where the layout permits, the MGU is often driven directly from the end of one of the gearbox shafts, minimising the level of complexity and number of additional components required (easier to achieve in a transaxle than a longitudinal arrangement). Typically though, the speeds required for an MGU are quite high (about 10,000 rpm), so some level of gearing is needed, and care must be taken to ensure that the gearbox seals can cope with these higher speeds and therefore surface temperatures, with early overheating issues causing seal failures. The correct selection of seal material and geometry is essential, as is ensuring sufficient lubrication to act as coolant.

The development of electromagnetically driven energy recovery systems is an interesting future development in this area, effectively side-stepping the issues of gearbox sealing. The ability to build in a ratio between the gearbox shaft and the magnetically driven rotor also allows the speed to be stepped up without the need for additional gearing or weight.

Differentials

Drive from the gearbox output shaft is usually fed to the differential via a hypoid-type crown and pinion wheel, in the case of a longitudinal gearbox. While straight and helical gear profiles on plain 45° bevel gears are an option, the use of a helical profile cut on a hyperbolic surface (termed a hypoid gear) allows the pinion wheel to be offset from the centreline of the crown gear. This is highly beneficial in circuit racing, particularly for downforce-generating cars with minimal ground clearance, as it allows the gearbox shaft centrelines to be placed as low as possible for centre-of-gravity gains while maintaining the axle's centreline height.

Several differential technologies exist, but while open differentials for example are fine for road use, few if any race series would contemplate their use. By contrast, limited-slip differentials (LSDs) are widespread in racing, but the methods for achieving and managing the level of slip can vary.

Conventionally, LSDs use two friction clutches, either a multi-plate or cone type, with one attached to either axle. The steel plates of the clutch have tangs that engage with the differential case, while the friction plates are splined to the axles; in normal operation the clutches are held engaged by springs. If one wheel loses traction and spins, the clutches hold the two axles together, effectively creating a solid axle and maintaining drive to the wheel with traction still available. During cornering, however, if a difference in torque is created then the clutches are forced to slip, so allowing different wheel speeds. The behaviour of the differential is then a function of the clutch plates/springs used, increasing the torque difference required to allow slip between the wheels by increasing the torque capacity of the clutch (using stiffer springs or more clutch plates).

An alternative to a clutch-based LSD is one using helical gears, rather than bevelled, which resist relative movement and so prevent excessive slip. The design of the helix angle will determine the forces involved and the rate at which torque is biased to the tractive wheel.

Most differentials are passive in their operation – that is, once ramp rates are set, they remain fixed until changes can be made in the garage. While some have a solenoid-actuated function to fix the differential in open, locked or LSD positions, fine control of the diff settings is impossible.

Active differentials use electro-hydraulic control systems to alter the characteristics of the differential during operation. An ECU combines data from the car – wheel speeds, steering angle, yaw and so on – to determine the slip that should be permitted at the differential. Hydraulic pressure can then be used to increase or decrease the clutch's clamping loads and affect the torque capability.

The precise differential technology employed is usually more a function of budget and series regulations. Some series, such as the World Rally Championship, prohibit the use of 'active' differentials, while for others the cost of such systems naturally places a limit on their adoption. Some manufacturers offer passive differentials but with quick-change cartridge-type systems, allowing rapid alterations to settings during testing or practice. With one cartridge installed in the car, another with a different setting can be configured in the garage and then swapped when needed, with a minimum of fuss and lost running time.

Power transmission shafts

The transmission of power from the differential to the wheel hubs – or indeed between gearbox and differential, in the case of a front-engined, rear-wheel-drive car – is achieved by mechanical driveshafts. Traditionally made from solid steel bar, with splines machined at either end, driveshaft development is an excellent area for relatively easy weight reduction, as the shafts can be exchanged or upgraded without for example dismantling a transmission or significantly changing the car's layout.

Specialist manufacturers of composite driveshafts can supply either off-the-shelf replacements for popular roadcars that see use as race chassis/engine combinations, or indeed there is a market for the supply of one-off custom propshafts.

Carbon or glass fibre composite prop or driveshafts offer a significant reduction in rotational inertia and static weight savings (typically up to 60% compared to a standard steel shaft). The reduced inertia offers a significant improvement in the overall drivetrain response, and while the shaft stiffness can be significantly higher, requiring fewer support bearings (for example in the case of a transaxle), the lower inertia can potentially help reduce the vibration effects on surrounding components as well. A composite shaft can be designed to accept in excess of 4000 Nm of torque at up to 9500 rpm, with a temperature range of -20 C to 120 C, and is typically produced and tested to aerospace specifications (where power transfer for flap control and so on is handled via such composite shafts). Shafts are designed to optimise weight and stiffness through specific filament winding patterns to achieve the optimal fibre lay-up within the shaft.

While the shaft material itself is certainly proven and capable, composites present an interesting challenge: where a steel shaft may simply be splined, the composite shaft requires a metallic fitting at either end to integrate with the powertrain. While composite bonding may historically have been seen as a risky proposition, the technology is now largely understood, particularly by specialist companies offering several options for either adhesive or mechanical bonding of end fittings. Possibly due to the perception of a joint as a weakness, most CFRP (carbon fibre reinforced polymer) and metallic bonds are conscientiously engineered to be stronger than the shaft material, and will usually be seen to fail within the shaft itself rather than de-bond from an end fitting. Completed shafts are usually tested for both impact and torsion, along with environmental weathering and durability.

Although carbon or glass fibre composite shafts have significant advantages, their use in open-wheel circuit racers has not really taken off. To achieve torsional stiffness with minimal weight, composite shafts must use a much larger diameter when compared to their steel counterparts. This does not bode well for their uptake in aerodynamic downforce-generating formulae, where aerodynamic performance is king. Shafts require a smaller diameter, as they are exposed in the airflow and are rotating, making them aerodynamically rather dirty and undesirable, so they typically use high-strength tubular or solid steel components to minimise the aerodynamic impact. However, the use of composite components in GT or Touring car racing brings significant benefits without the sensitive aerodynamic drawbacks.

Prop or driveshafts typically run at an angle, requiring a joint that allows some misalignment to take place. For driveshafts in particular, the movement of the suspension necessitates the use of constant velocity joints to allow this. Typically a high-strength steel tri-pode is used to mount roller bearing surfaces, which allow the angle of the shaft to change within a designed limit, and this is the largely accepted technology used everywhere from production automobiles through to Formula One. For propshafts, however, the angular misalignments can be smaller but typically remain constant. Traditionally a Hooke's or universal joint will be used to accommodate a large angle, and a splined slip joint used to take up any change in shaft length.

In NASCAR oval racing, mandatory one-piece 4 in diameter tubular steel driveshafts with a minimum wall thickness of 0.065 in (1.65 mm) are specified, along with magnetic steel universal joints/yokes. The development of these shafts is aimed at reducing rotational inertia, achieved primarily by designing out weight in the slip yokes. Designs are destructively tested, with one manufacturer consulted for this article able to claim an impressive zero failure rate in service. ▶

Steel drive shaft to NASCAR regulations with lightweight precision machined steel billet slip yokes (Courtesy of C&R Racing)

SOME EXAMPLES OF TRANSMISSION-RELATED COMPONENT MANUFACTURERS

AUSTRALIA

Albins
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CTG Goodrich
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Elite Racing Transmission
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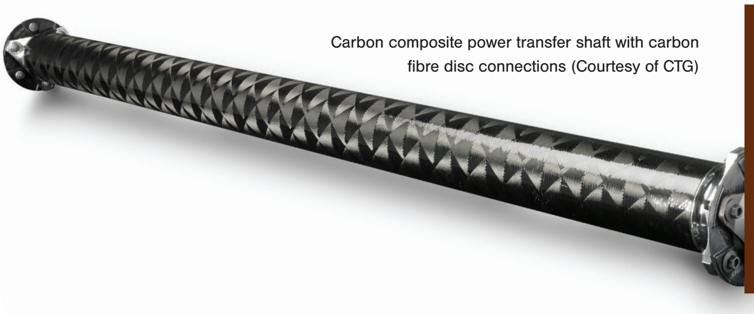
Where small misalignments are involved, an alternative to the usual universal joint is to use a flexible carbon fibre composite disc. The disc mounts between two spider-type flanges, one on either shaft, with the spiders offset from each other such that a small degree of flex in the carbon disc can occur. Although unable to tolerate a misalignment of more than about 2°, these are however a very lightweight solution (each disc weighs of the order of 10 g) for propshafts that do not need to undergo significant movement.

Conclusion

There is a multitude of different technologies within motorsport transmissions, with any one component a subject in its own right. For the time being it seems that the steady optimisation of transmission systems for packaging and ease of maintenance or set-up are becoming increasingly popular. The extension of part life though is the driving factor, with components going from one-race use to being intended for several race weekends or even complete seasons, either as a result of series regulations or simply customer demand. ■



Carbon composite power transfer shaft with carbon fibre disc connections (Courtesy of CTG)

CREDITS

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