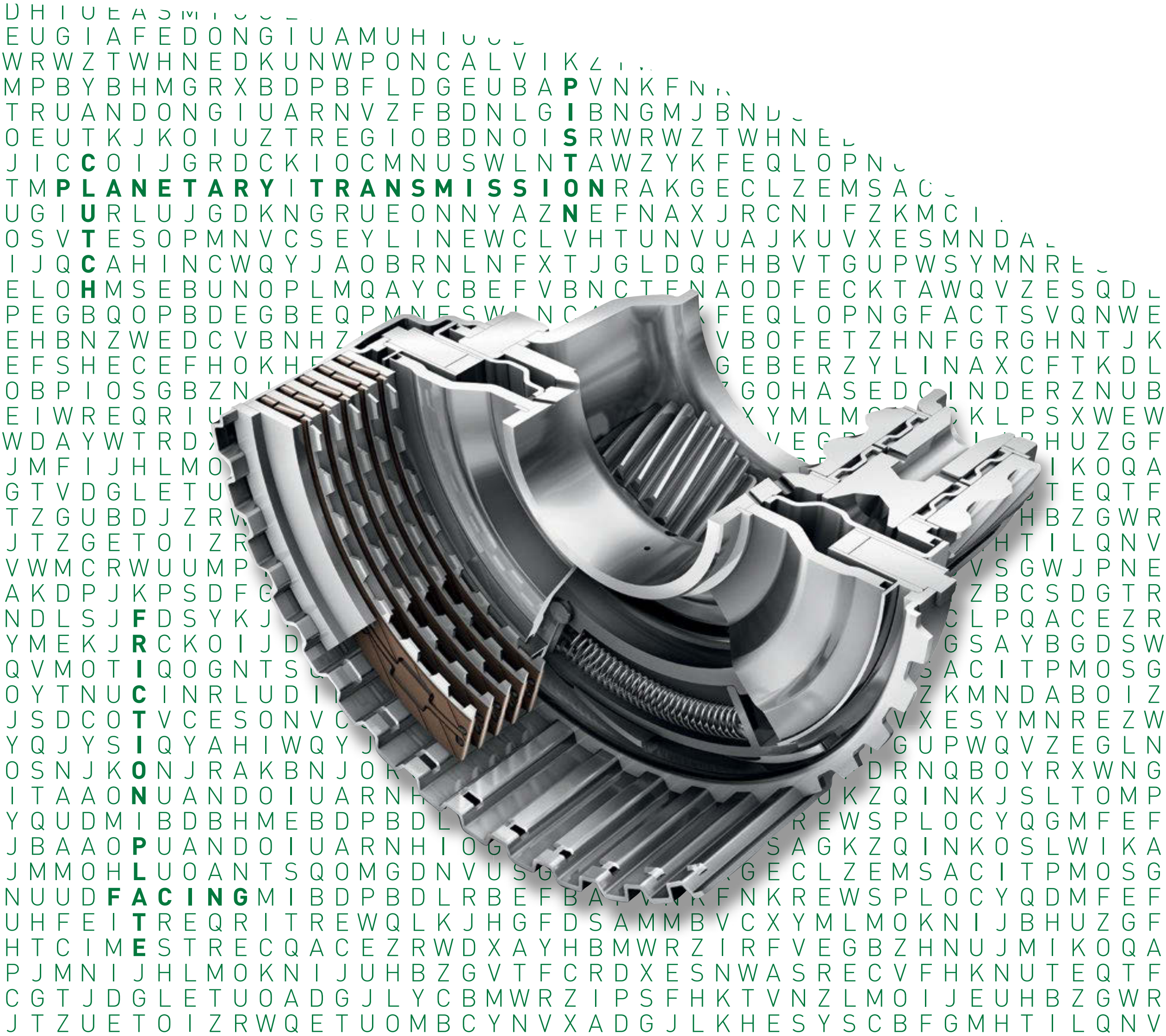
PISTON
CLUTCH
PLANETARY TRANSMISSION
FRICTION PLATE
FACING

Turning New Directions: Surprising Potentials in Planetary Transmissions

Part 2: Shifting clutches

Jeff Hemphill
Philip George
Vural Ari
Chris Luipold
Patrick Lindemann
Greg Copeland

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Drivers for change

The wet friction shifting clutch was developed in the 1930's and has been very successful [1]. Multi-plate wet clutches are used in large volumes not only for shifting automatic transmissions and CVT's, but also as launch devices in some CVT and DCT transmissions. The early development of this technology was so successful that it has met the needs of industry with relatively few changes in basic construction for many years [2].

Current trends in the market however, are placing new demands on shifting clutches. The number of speeds in automatic transmissions is increasing dramatically, as shown in Figure 1. The demand for improved shift comfort is likewise stronger than ever. The push for sustainable mobility continues to increase and includes the environmental effects of manufacturing processes. Finally, fuel economy standards are rising steeply around the world, making drag torque and mass reduction ever bigger problems.

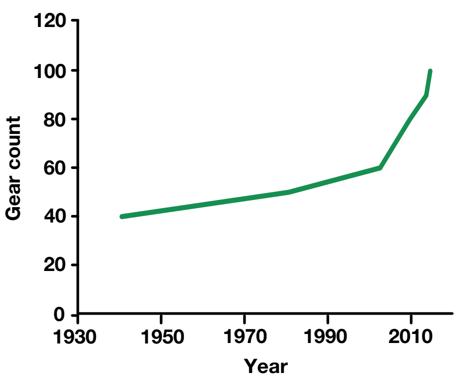

Figure 1 Increasing number of speeds in planetary automatic transmissions over time

Controllability and drag

Multi-plate wet friction clutches are subject to a paradox: Low lift-off gaps improve controllability while large lift-off gaps help reduce drag torque. The controllability is influenced by the two-stage nature of the pack characteristic. That is, the piston must first close the lift-off gap against little significant resistance and then clamp the pack to provide torque capacity. A typical clutch pack schematic can be seen in Figure 2.

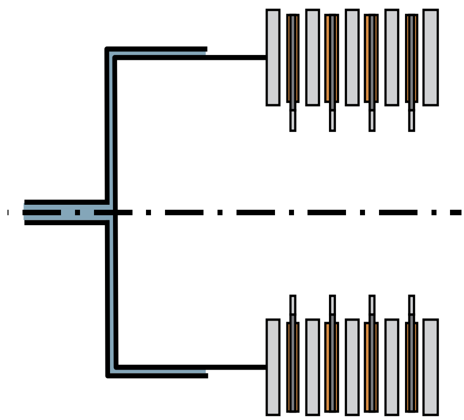

Figure 2 Schematic representation of a clutch pack

Since the axial movement of the piston to close the gap is 1-3 mm while the compression of the pack is 0.1-0.3 mm, the bulk of the oil volume used to actuate the piston in dedicated to closing the lift-off gap. However, the piston area has to be sufficient to allow it to generate enough clamping force to provide the needed torque. This means that it is normally a slow process to close the gap. Furthermore, the transmission controller has no way of knowing when the gap is closed.

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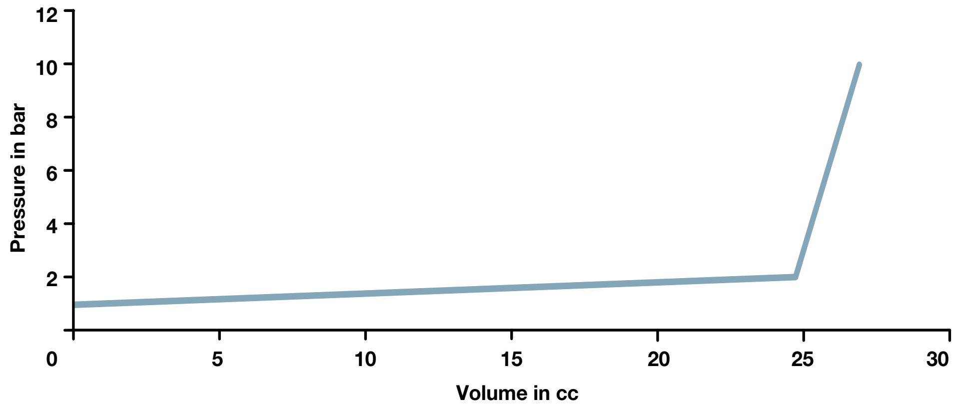


Figure 3 Pressure vs. volume for a typical shifting clutch

This can lead to torque errors if the controller doesn't guess accurately. A pressure vs. volume characteristic is shown in Figure 3.

The usual solution to this problem is a pre-fill strategy. The controller keeps a look-up table of time to touch point for given temperatures and furnishes a very high flow to close the gap. When it's time estimate is reached, the flow is reduced and torque control takes over. If there is a torque error, the controller can adapt the time in the table. This method works but gives rise to several errors.

The drag is improved by a larger lift-off gap, since it is largely viscous drag and the shear forces in the oil are smaller in larger gaps. A measurement of a clutch pack with various lift-off gaps is shown in figure 4. It is also important to keep in mind that each clutch has a different tolerance situation. Therefore, the nominal drag may be acceptable but the maximum drag can be significantly higher.

Another factor which can raise clutch drag is plates sticking together, even though there is a lift-off gap. This can happen because the oil between the friction material and the steel plate forms a

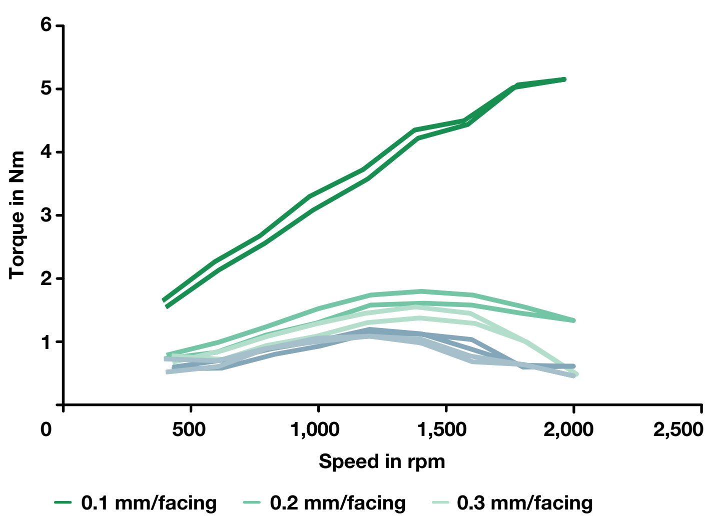


Figure 4 Multi-plate clutch drag for various lift-off gaps

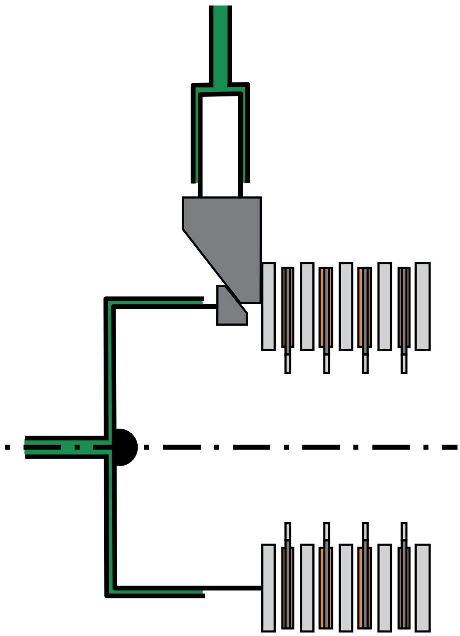


Figure 5 Two-stage clutch apply mechanism

seal which allows atmospheric air pressure to hold the plates together.

Given these physics a new approach is needed. Since we recognize that the friction pack offers a two-stage characteristic, a two stage mechanism could be used to break the paradox. A schematic of such a mechanism is shown in Figure 5. In this principle sketch, a ramp and crank mechanism are introduced between the piston and the clutch pack. This mechanism is actuated by the main piston and, due to the high ratio of the crank, fills the gap with very little piston travel. This means that a larger lift-off gap can be closed quickly and with little oil demand, avoiding a pre-fill strategy. Furthermore, when the clutch reaches the touch point, very little torque is exerted due to the high ratio of the mechanism. This minimizes torque errors. The pressure over volume curve for a clutch with this mechanism is shown in Figure 6.

The design for a mechanism which can meet these functional requirements is shown in Figure 7.

This mechanism functions as follows: High pressure oil enters the area behind the main piston. The oil enters the rotary actuator through several holes in the main piston. The oil pressure rotates the actuator, which, in turn, rotates the ramp ring. As the ring moves down the ramps, it closes the gap to the friction plates. Once

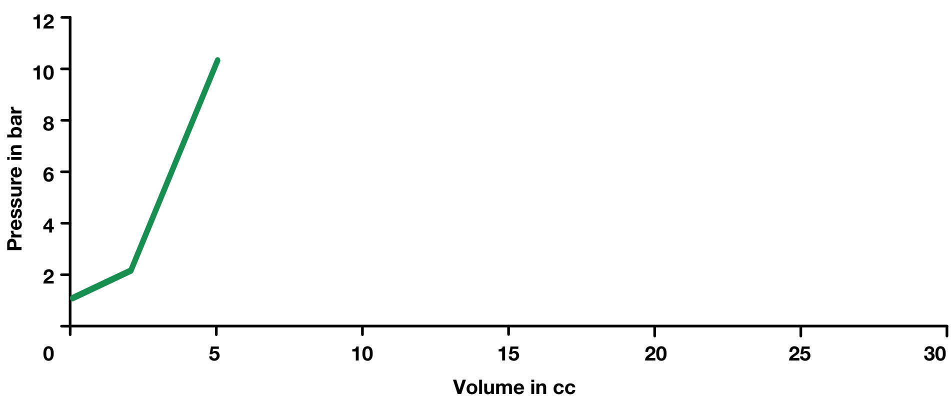


Figure 6 Pressure vs volume characteristic for a clutch with a two-stage mechanism

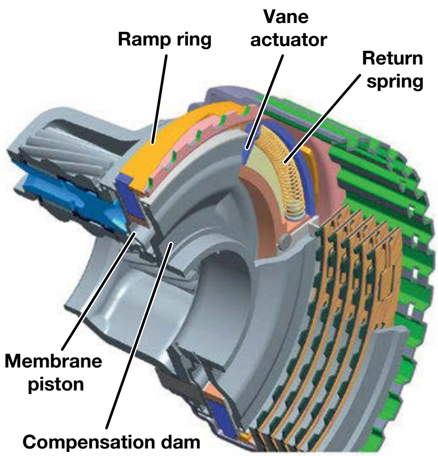


Figure 7 Cross-section of two-stage piston

the ramp ring hits the friction plates, it stops. As oil pressure continues to increase, the main piston now begins to advance. Since the only travel that the main piston needs to make is to compress the clutch pack, it is designed as a membrane piston. this allows the piston to accomplish the roughly 0.3 mm displacement and also allows it to act as its own return spring. The clamping action of the main piston is applied through the rotary actuator. This clamps the actuator closed and provides two additional benefits: The actuator is sealed and the ramp ring is clamped in place, preventing any unwanted adjustment. Figure 8 shows a simulation of this type of clutch versus a normal clutch. Here we can see a faster engagement time, smaller torque error, and a larger lift-off gap.

This leads to the following concrete advantages:

- Allows lift-off gaps of 3 mm or more without shift time penalty.
- Reduces drag torque by allowing such lift-off.
- Reduces oil flow required for clutch actuation, potentially allowing a smaller transmission pump.

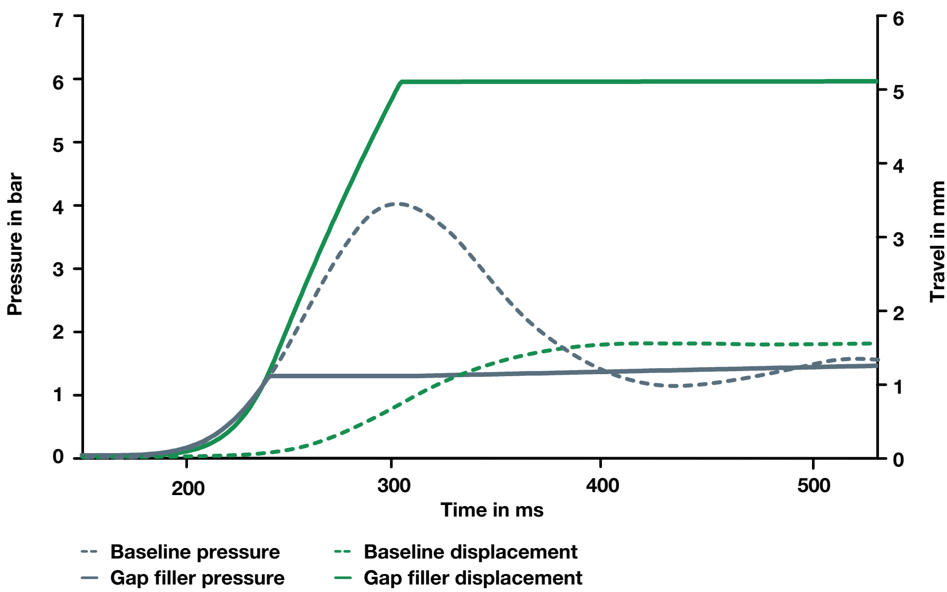


Figure 8 Simulation results of two-stage mechanism vs normal mechanism

- Improves controllability by reducing torque error when reaching the touch point.
- Eliminates the need for tolerance correction in clutch pack assembly.

Friction plate with a built-in separator feature

Now that we have shown a mechanism which can open a larger lift-off gap without penalty, we need to assure that we separate the friction disks in this gap. Over the years, several things have been tried to accomplish this including separator springs, hydrodynamic forces, etc. These concepts usually suffer from tolerance problems and often can space either the friction plates or steel plates but not the one from the other, which is the important interface.

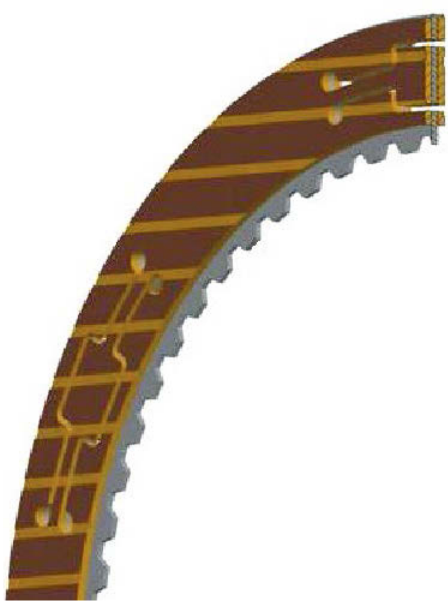


Figure 9 Friction plates with separator feature

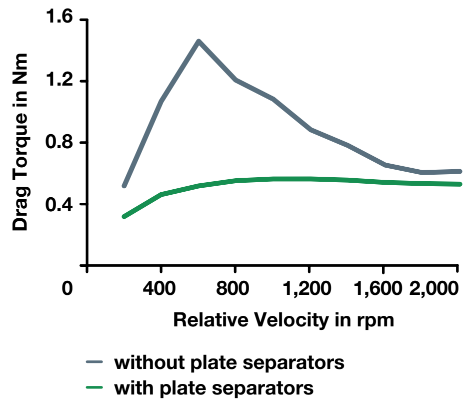


Figure 10 Drag torque measurement with and without plate separators (SAE#2 plates, 0.7lpm, 60C)

Figure 9 shows a friction plate with a built-in separator feature. In this design, tabs have been formed in the plate itself and slightly twisted so that the edges of the tabs protrude above the friction material by the amount of the desired lift-off gap. Since these tabs only have line contact with the separator plate, the surface area for viscous drag is dramatically reduced. This cannot be accomplished with other methods, such as “waving” the friction plates. The thin arms on the tab act as torsion springs, allowing the tab to be compressed back in line with the friction material during engagement.

A measurement of a friction pack with and without the plate separators is shown in Figure 10. Here a reduction in drag torque of more than 60 % can be seen. It should be noted that this concept also has a significant tolerance stack-up. However, when using it with the gap filling piston, the additional tolerances do not present a penalty.

Friction Disk Production

The concepts reviewed so far have enabled better performance of a clutch pack in operation. Now we turn our attention to improving the manufacturing process. Friction plates today are made by stamping a steel ring, acid etching the ring, applying adhesive, placing friction paper on the adhesive, clamping between hot, parallel plates, and cutting oil flow grooves if required. This process has several disadvantages:

- Environmentally harmful, and therefore, difficult to dispose of chemicals are used for cleaning the parts and as adhesive.
- The process can be difficult to control especially since friction performance is influenced by the amount the paper is cured during bonding. This means the adhesive and paper must both be cured to the right level in one process.
- Multiple process steps are required to reach the end result.

An improvement can be made by eliminating the adhesive and using a mechanical connection between the paper and the steel. An example of such a construction is shown in Figure 11.

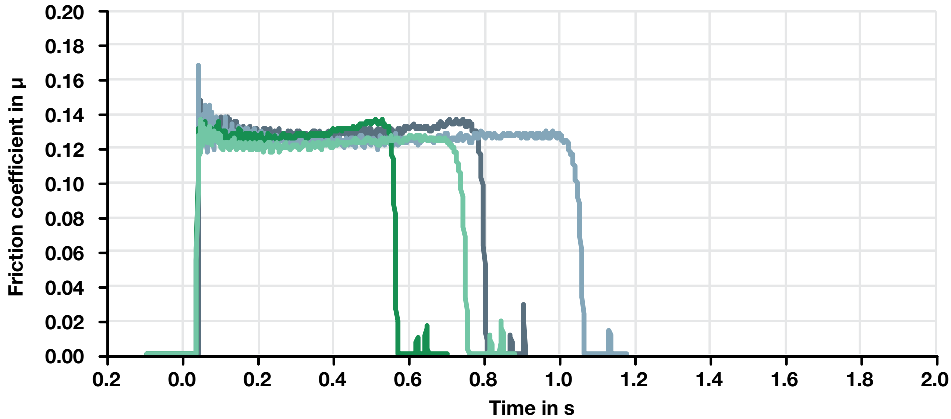
In this design, two thin steel plates are pressed into a paper ring from either side. The steel plates meet at the teeth around the inside diameter and at a series of holes in the middle of the paper ring. At each hole, the steel plates are joined by a coining operation similar to riveting. The resulting pressed grooves provide a mechanical means for transmitting torque from the spline teeth to the paper. They also provide a means for allowing cooling oil to flow.

This design eliminates most of the issues with current production methods.

Figure 11 Composite friction Disk construction

There is no need for adhesive and, therefore, no need for acid to prepare the steel for it. It is much easier to control since only paper curing is involved. It can be a one step process wherein the steel is compressed into the paper, the coining is accomplished, and the paper gets a final cure and flattening. This process can also be much faster than a bonding process since the time required for the adhesive to flow and cure is eliminated.

Further advantages include reduction in mass and inertia of the friction plate. This can result in a savings of 0.5 kg in a typical automatic transmission. The method can be used with various friction papers, allowing the same range of friction performance as with bonded plates. In some cases, even better performance can be achieved since the paper is roughly 3 times thicker than in a bonded design. This allows a softer stiffness which is more forgiving to the additives in the oil.



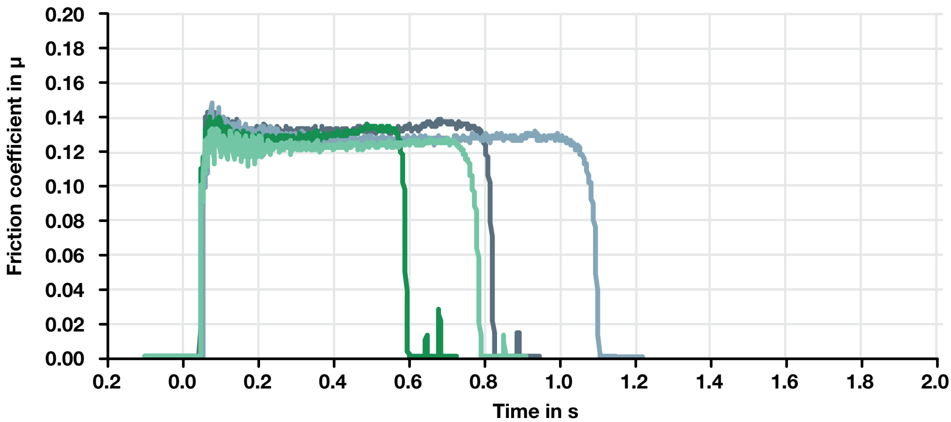


Figure 12 Comparison of friction behavior between composite facing (top graph) and bonded facing (110C, 2,700/3,500rpm, SAE J2490 test profile)

Figure 12 shows a comparison of friction performance between a composite facing and a bonded facing with the same paper and the same total paper thickness. As expected, there is virtually no change in friction behavior. Tests are underway to quantify the advantage of the composite facing compared to typical thickness bonded friction plates. Various groove patterns are possible. In fact, the resulting groove geometry is similar to a pad design, without the intensive processing which is normally needed for that construction. Finally, the design also lends itself to the plate spacers described in the previous section.

Conclusion

The demands on shifting clutches are increasing with the new generation of automatic transmissions and increasing consumer demands. These new requirements can be met by breaking some of the old paradigms of clutch design:

- Creating a two-stage apply characteristic allows better controllability with larger lift-off gaps.
- Plate separators maximize the advantage of this larger gap.
- Eliminating adhesive provides an environmentally friendly production method while decreasing mass and inertia.

Together, these lead to some notable improvements on the vehicle level, such as:

- fuel economy improvement of 1-2 %
- mass reduction of 0.5 kg
- reduced space requirement (see Figure 13)
- shift time improvement of up to 100 ms with reduction in shift shock complaints

These advantages are useful not only in planetary automatic transmissions, but also in CVT and DCT transmissions, which use multiple-plate wet clutches. Even in an 80 year old technology, new ideas can provide new functions and continue to meet the growing demands for fuel efficient mobility.

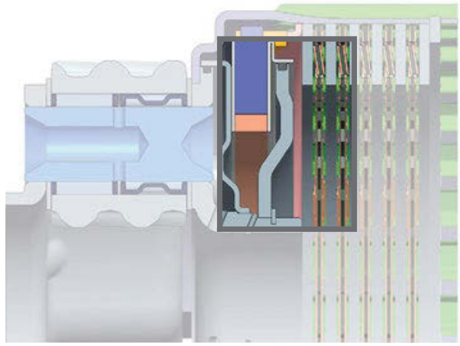


Figure 13 Improved shifting clutch piston assembly compared to conventional piston assembly (red outline)

Literature

[1] Gott, P.: Changing Gears – The Development of the Automatic Transmission, SAE International, 1991

[2] SAE Transmission/Axle/Driveline Forum Committee: Design Practices: Automatic Transmissions, 1994