Types of transmissions

For decades, the world of transmissions was quite simple: there were either manual transmissions or torque converter transmissions. The further developments within these groups were predominantly related to providing a greater number of gears. In recent years, however, the picture has changed drastically (Figure 1).

First of all, CVT transmissions entered the market and have achieved their highest level of popularity in Asia. Then came the first wet double clutch transmissions, which will be followed in the near future by dry double clutches since there is a demand for their higher efficiency.

Work is also progressing on a large number of hybrid concepts. In one group, the hybrid function can be seen almost as an add-on to one of the existing transmission concepts.
The structure of other hybrid concepts means that they are only appropriate in conjunction with one or even two electric motors, such as in the Toyota Prius.

Whichever transmission concepts are ultimately successful, a link between the engine and transmission will always be required that can smooth out the irregular running of the internal combustion engine. With very few exceptions, such as in transmissions with "Geared Neutral" capability, it is also necessary to have a facility for decoupling the engine and transmission, in other words a clutch.

Engine technology has also undergone considerable development in recent years. Torques have increased significantly, especially in diesel engines (Figure 2).

![Engine Torque Chart](image)

**Fig. 2 Increase in engine torque, based on the example of a 6 cylinder 3.0 litre diesel engine**

With the introduction of new combustion processes, gasoline engines seem to be following suit. As a result, the gasoline engine is coming to resemble the diesel engine in many respects, but this unfortunately also extends to the issue of irregularity.

The situation can be generally summarized as follows:

Engine torques are increasing, while in some cases the number of cylinders is decreasing for reasons of fuel consumption, leading to a considerable increase in irregularity of engine speed. Since efficiency is also improving, each reduction in friction and losses in the drive train is accompanied almost automatically by an increase in sensitivity to chatter and boom. The isolation levels of current conventional torsion dampers are no longer adequate and more effective solutions must be found.

In manual transmissions, the dual mass flywheel (Figure 3) has become established, at least for higher motorizations. Over a number of years, it was possible to achieve sufficient isolation of vibrations to meet comfort requirements.
In the case of torque converter automatic transmissions, it was sufficient to run with torque converter slippage in the critical lower speed ranges, so the torsion damper in the torque converter did not need to cover these speed ranges.

Since the focus has now shifted massively to fuel consumption and CO2 emission, vibration damping through high levels of slippage and over wide speed ranges is no longer appropriate. Torque converter structures closer to the dual mass structure are therefore under development.

Figure 4 shows such a multi-function torque converter. The outer shell is the primary flywheel mass. Everything within this is decoupled by means of the torsion damper and forms the secondary mass. This gives excellent isolation of vibrations even at very low speeds (Figure 5).
The structure of course allows the normal torque converter operation that is required at least during starting and gear changes, when the lock-up clutch is opened. In addition, optional mounting of a further clutch allows "Idle Disconnect", a complete separation of the engine and transmission during idling. The slippage losses that normally occur while the vehicle is stationary can be significantly reduced as a result.

In manual transmissions, movement to the dual mass flywheel is already substantially complete. There are increasingly frequent signs, however, that the levels of isolation provided by the dual mass flywheel are no longer sufficient due to increased engine power and drive train efficiency. As a result, it is already necessary to improve isolation of vibrations.

Once again, the essential technological advance in manual transmission applications appears similar to that which occurred in the introduction of the dual mass flywheel.

One of the few remaining possibilities for improving isolation further is an absorber effect. An absorber is normally an elastically suspended mass where the spring rate is selected in order to match the natural frequency of the mass to the frequency to be absorbed. Such an absorber would only be effective at a specific speed, but what is required is a broad band effect that adapts to the relevant speed. This can be achieved if the mass is mounted on the rotating dual mass flywheel as a pendulum.

With a normal pendulum, the resonance frequency is, in accordance with the formula

\[ \omega = \sqrt{\frac{g}{l}} \]

dependent only on acceleration due to gravity and the length of the pendulum. In the centrifugal pendulum, acceleration due to gravity is replaced by centrifugal acceleration

\[ a = r \, \Omega^2 \]

where \( r \) is the radius and \( \Omega \) the speed.

The absorber frequency of the centrifugal pendulum is determined as

\[ \omega = \sqrt{\frac{r \, \Omega^2}{l}} = \Omega \sqrt{\frac{r}{l}} \]
The absorber frequency is thus directly proportional to the speed. By selecting \( r \sqrt{r} \), it is possible to select an order, such as 2nd order in the four-cylinder engine, that is then eliminated over the entire speed range.

Figure 6 shows a design for the oscillating masses. Figure 7 shows the improved isolation of vibrations. Volume application of dual mass flywheels with these centrifugal force pendulums is planned over the coming years.

**Centrifugal Pendulum Absorber:**

speed adaptive damper

**Fig. 6 Pendulum Absorber**

![Centrifugal Pendulum Absorber: speed adaptive damper](image)

![Fig. 6 Pendulum Absorber](image)

**Fig. 7 Isolation gain with centrifugal pendulum absorber**

A similarly significant step towards improved isolation of vibrations will also be necessary in torque converter transmissions. These are driven by the same engines.

In fact, isolation can be improved in a similar way in the torque converter. A centrifugal force pendulum matched to the main exciter arrangement (Figure 8) almost completely
eliminates torsional vibration (Figure 9). The lock-up clutch can then be closed at significantly lower speeds, without impairing comfort, in order to allow better fuel consumption.

![Pendulum Absorber](image)

**Fig. 8 Pendulum absorber in torque converter**

![Graph](image)

**Fig. 9 Measurement of torsional vibration of differential in 4th gear**

**The clutch**

Almost all transmission types require, in addition to the torsion damper, a means of separating the engine from the rest of the drive train. In order to fulfil this function, it is possible to use wet or dry clutches, either of which can be justified on certain grounds.

Dry clutches predominate in manual transmissions, while clutches and brakes are heavily integrated in the planet sets in automatic transmissions and it would be extremely difficult to achieve a dry area in the middle of the oil environment. Nevertheless, tests have been carried out repeatedly on using dry clutches since their slippage and actuation losses are quite simply lower.

While the allocation of roles was clear in classical transmissions, there have been long discussions as to which clutch system would be more suitable in double clutch transmissions (Figure 10).
Fig. 10 Double Clutch Transmission

Essentially, the two most important characteristics were in conflict:
The better efficiency of a dry clutch against the better cooling in wet clutches.

Today, it has been defined fairly clearly up to what limits dry clutches can be used to advantage and from which point wet clutches become necessary. The limit is at about 300 Nm and depends on vehicle mass, the selected 1st gear ratio and a series of other parameters. The application range of both clutch types will depend strongly in future on how the specific disadvantages can be reduced or eliminated.

In the dry clutch, cooling is under investigation. Ventilation of the clutch housings is relatively simple when large quantities of frictional energy are present. Since excessive water and contamination could enter if the clutch housing were open permanently, a temperature-controlled flap is advisable and allows air exchange at high temperatures (Figure 11).

Fig. 11 Clutch temperature with open housing
The rotating clutch itself acts as a ventilator, so temperatures in the clutch housing can be reduced by approx. 50% and the number of immediately consecutive hill starts can be significantly increased.

The strength of the wet double clutch (Figure 12) is the oil cooling of the friction discs.

Figure 12 Wet and dry double clutch

However, this does not allow infinitely long slippage times in the clutch since the normal oil cooling devices can only give cooling of close to 10 kW from the oil sump. The oil supply requires a continuously running pump that must fulfil widely varying requirements. This can only be achieved by a poor compromise when using a pump and will probably not be designed this way in future projects on fuel consumption grounds, since the efficiency of torque converter transmissions has also improved. The wet double clutch transmission appears gradually to be losing its significant consumption advantage over the torque converter transmissions. Separation of actuation and cooling therefore appears inevitable.

Figure 13 shows a wet clutch that can be actuated, like dry clutches, by a clutch release bearing. The associated actuator can be driven electromechanically or via a hydraulic powerpack in which the oil pump is only driven for short periods to fill an oil reservoir.

In each case, the aim must be to develop actuators that only require positioning energy when clutches are to be actuated. Since hydraulic rotary transmission leadthroughs always show leakage, they are not the first choice.
Cooling oil can be provided using a low pressure pump that, due to its low power consumption, can be driven directly via the internal combustion engine (Figure 14). Such concepts can significantly improve the efficiency of the wet double clutch.
Summary
Figure 15 shows the efficiency of different transmission concepts.

As expected, the manual transmission shows the lowest losses. The new torque converter transmissions show continuous improvement in efficiency. They thus come close to the wet double clutch transmissions, which must themselves be further optimized. The dry double clutch transmission retains its lead in terms of consumption for automatic transmissions and almost matches the efficiency of manual transmissions.

In terms of consumption, however, these automatic transmissions will impact significantly on the manual transmission since the issue is not simply one of efficiency but also relates to achieving shifting points favourable to fuel consumption, which can only be achieved by sophisticated software assistance.

*Fig. 15 Electrical actuation for advanced transmission systems, efficiency and performance*