TRANSMISSION FLUIDS FOR HEAVY-DUTY VEHICLES

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ABSTRACT

In order to further improve the performance and efficiency of automatic power-shift transmissions for heavy-duty applications such as trucks and construction equipment, transmission fluid development is an important activity. There are several different approaches on how to design and lubricate power-shift transmissions. With the correct selection of lubricant extended drain in combination with increased efficiency will result in a reduction of life-cycle cost, and at the same time reduce the environmental impact of the vehicles.

In this paper different transmission fluids, with a focus on ATFs, are presented together with some of their respective advantages and disadvantages. Fluid performance in several different areas such as shear stability, frictional performance and gear protection are presented. Also, industry trends in the ATF market regarding standards and product diversification are discussed from a global OEMs point of view, including information on Volvo's approach to transmission oil specifications.

INTRODUCTION

The commercial vehicle industry is currently facing several challenges related to vehicle efficiency and emission regulations combined with increased demands for performance.

To meet these demands modern transmissions with improved efficiency are introduced to the market, however many of the improvements would not be possible without good transmission fluids. Recently, significant resources have been invested in the area of transmission fluid development by the truck and construction equipment industry.

Some of the demands placed on the transmission fluid are;

- The transmission fluid must be able to protect the machine elements of the transmission, such as gears and bearings, even when the energy density is increased.
- The fluid must have good durability with respect to oxidation, shear stability and friction performance to enable extended drain intervals.
- The fluid should contribute to improved efficiency by enabling lower viscosity and lower torque dependant losses.
- The fluid shall posses desired friction characteristics to enable improved shift comfort while maintaining a high level of friction in the clutches.

In order to meet the different demands different OEMs (Original Equipment Manufacturer) have chosen different fluid technologies with different pros and cons.

The aim of this paper is to present some differences between fluid technologies for automatic power-shift transmissions and discuss OEM challenges related to development of new fluids and the diversification seen on the transmission fluid market.

Transmission fluid market

In the transmission fluid market there is a lack of accepted standards. In the past GM Dexron® used to be the standard many OEMs relied on, however this have changed since GM made most of their standards obsolete at the end of 2006. There are indeed ongoing activities to establish new ATF standards, most active at the moment are probably JAMA (Japan Automobile Manufacturers Association) with the JASO ATF Performance Criteria [1]. There are also some activities within SAE ILSAC [2, 3], but the progress is slow.

That means that there currently are no widely accepted global lubricant standards for automatic transmissions, which have resulted in a diversification of the automatic transmission fluid market. Since there are no accepted standards different OEMs have to specify the fluids by themselves, even though performance demands are often similar non matching viscosity criteria (among others) are make it impossible to make market general fluids.

Due to the vast number of different products in the market, with differences in viscometrics, durability and friction, the end user face a difficult task in choosing the correct fluid. This have resulted in that OEMs tend to restrict extended warranties to customers purchasing own branded fluids, i.e. the factory fill fluid becomes the service fill fluid as well.

For a global OEM such as Volvo the current market situation introduces several difficulties. The vehicle fleet are primarily equipped with in-house made transmissions, but many vehicles also use transmissions made by suppliers. If the suppliers' fluid specifications are different additional fluid types needs to be provided to the end user. Another problem is that while some transmissions require a high spec fluid other transmissions might be able to use it but might not get any advantage by using the more expensive fluid in terms of extended drain interval.

To cope with the transmission fluid demands Volvo have established new ATF standards to support our different operations. Currently there are three different performance levels specified;

- Volvo Transmission Oil 97340, low cost ATF for applications with low demands, such as old transmissions and power-steering system [4].
- Volvo Transmission Oil 97341, reasonably shear stable ATF meeting performance demands of most new transmission designs for normal drain interval [5].
- Volvo Transmission Oil 97342 (to be launched in late 2008), high performance ATF for new transmission designs optimized for improved efficiency and long drain interval.

The targets for the new fluid development have been that;

- The fluids shall reduce the environmental impact by increased drain and reduced fuel consumption.
- The fluids shall be possible to use in all Volvo Trucks and Volvo Construction Equipment.
- The fluids shall be back serviceable to older equipment.
- The fluids shall be globally available.

In addition different performance and cost targets were included in the process.

Transmission fluid types

There are several different fluids commonly used in heavy-duty transmissions;

ATF: ATF fluids have been adopted by many heavy-duty transmission producers such as

Volvo, Allison, Voith and Dana. The specifications are often based on passenger car requirements such as GM Dexron® or Ford Mercon. Different additions to the original specifications are however added. For example the Volvo Transmission Oil 97341 specification is based on the obsolete Dexron® III-G spec but with added requirements on shear stability and friction characteristics. Another example is Allison TES-389 which is based on the Dexron® III-H spec but with added requirements on seal tests.

UTTO: UTTO (Universal Tractor Transmission Oil) or THF (Tractor Hydraulic Fluid) are used primarily in agricultural applications and construction equipment by transmission producers such as John Deere and Case. Some common standards for UTTO type fluids are Volvo Transmission Oil 97303, WB101 and John Deere J20C. The UTTO fluids are generally heavily friction modified to counteract brake-squeal.

TO-4: TO-4 fluids are primarily used in construction equipment transmissions by manufacturers such as Caterpillar and Komatsu. The TO-4 fluids are typically mono-grade fluids giving them very good shear stability but also a very low VI due to the lack of viscosity index improvers.

RESULTS AND DISCUSSION

In this section data from various tests are presented with the aim to highlight some differences between different fluid technologies with focus on ATFs.

<u>Viscosity and shear stability</u>

Regarding viscometrics there are different approaches seen from different OEMs. Some work towards lower viscosity to reduce losses while some commercial vehicle manufacturers see the need to increase viscosity to maintain the film thickness at higher transmission operating temperatures.

Generally Dexron® III ATF fluids have very high VI (over 200 for fresh fluids) but they have poor shear stability. Typical shear losses in viscosity for a non shear stable Dexron® III ATF can be up 40%. The shear down will not only lower the viscosity, the VI is also reduced. New high performance ATF are much more shear stable but with a lower VI (approximately at 150).

There are different methods to measure shear stability for lubricants, one of the most common are the KRL20h (CEC L-45-99) [6]. Figure 1 shows measured viscosity at 100°C for a Volvo Transmission Oil 97341 and a Volvo Transmission Oil 97342 in a 1000h transmission dyno test under maximum load. There is good correlation between the viscosity in the ATFs after 1000h dyno test and the KRL 20h values for the ATFs, the transmission test final viscosities are 5.1cSt/5.8cSt compared to the KRL20h value of 5,3cSt/5.6cSt.

The shear stability of UTTOs are generally similar to ATFs but there are shear stable products available at the market.

In the case of manufacturers using TO-4 fluids the viscometrics (low VI) make it necessary to specify different viscosity grades for different climates or seasons. The shear stability are however very good (also a result of no VII or very low concentration).

<u>Friction</u>

Figure 2 presents friction measurements from a Volvo clutch dyno, similar to SAE#2 but bigger in size. Of primary interest are the friction level and the shape of the rooster tail, i.e. the torque at the end of engagement which is highlighted in the figure. This portion of the curve is dependant on the fluid properties.

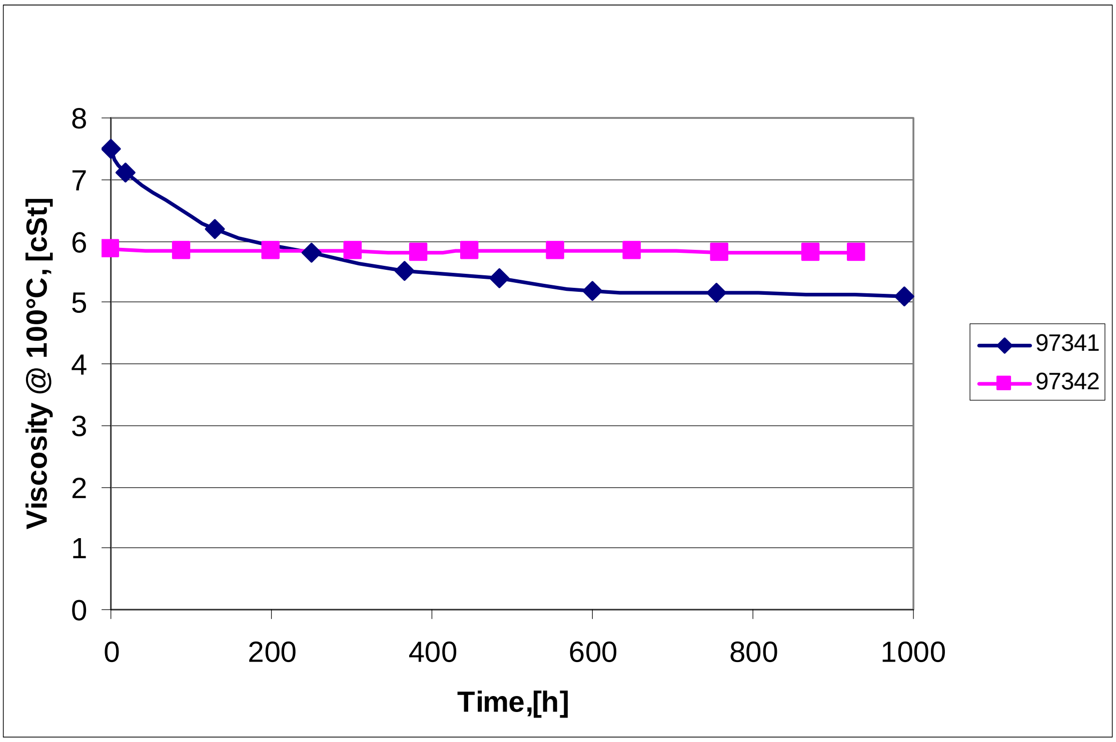

Figure 1. Oil viscosity as a function of test time for two different ATFs from a transmission dyno test.

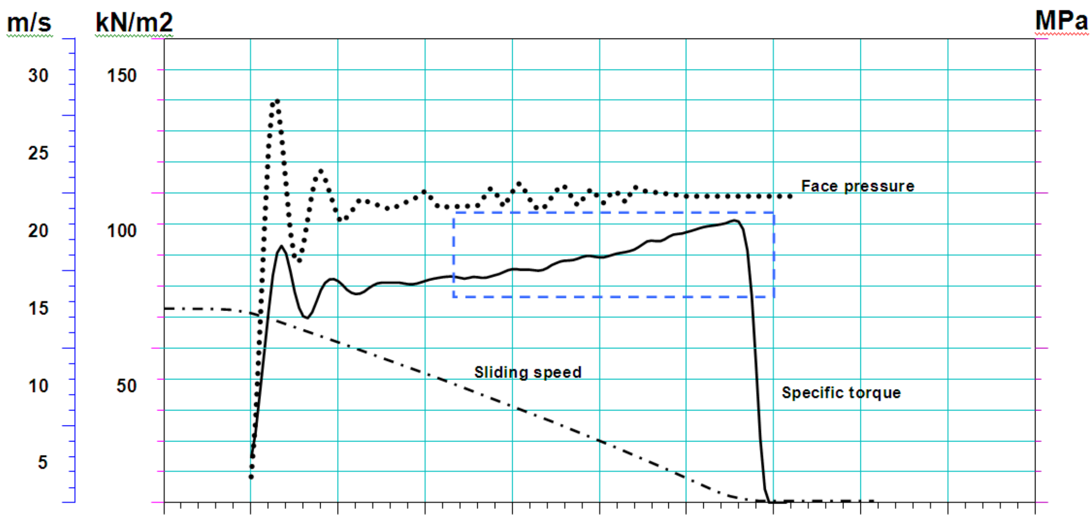

Figure 2. Typical clutch engagement for a ATF measured by a Volvo clutch dyno.

Figure 3 presents friction curves from the rooster tail region, outlined in the previous figure, for the different fluids described in section 1.2. All fluids were tested in combination with an organic friction lining commonly used in construction equipment transmissions. In this case the ATF and TO-4 are similar, but as expected from the formulation the highly friction modified UTTO fluid shows a lower friction level but a more favourable curve shape with respect to anti-shudder properties.

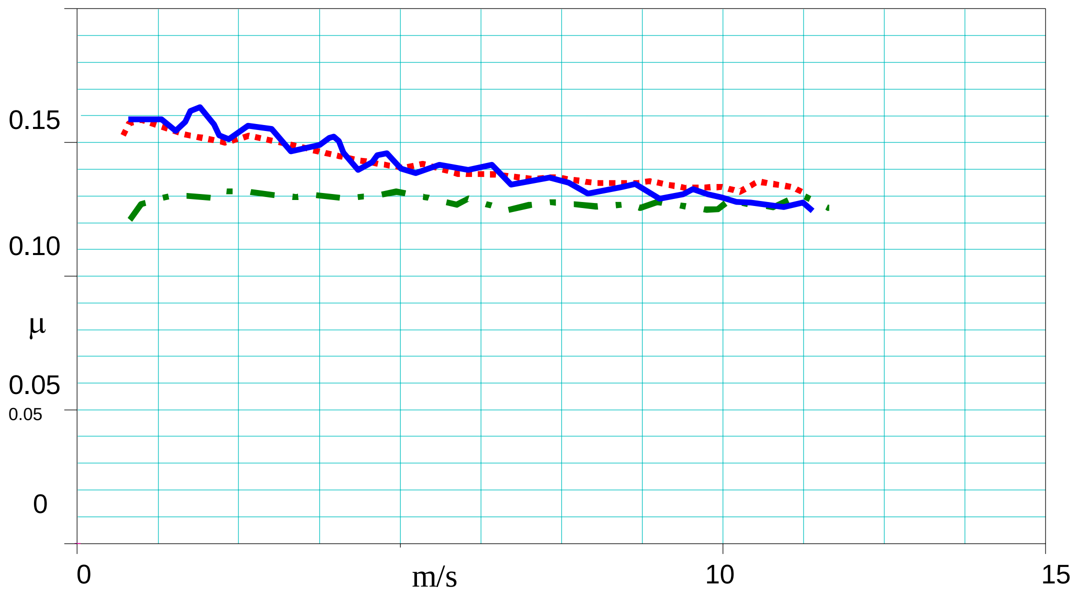

Figure 3. Friction traces for different lubricants. Blue line=ATF technology, red dotted line=TO-4, green dash-dotted line=UTTO.

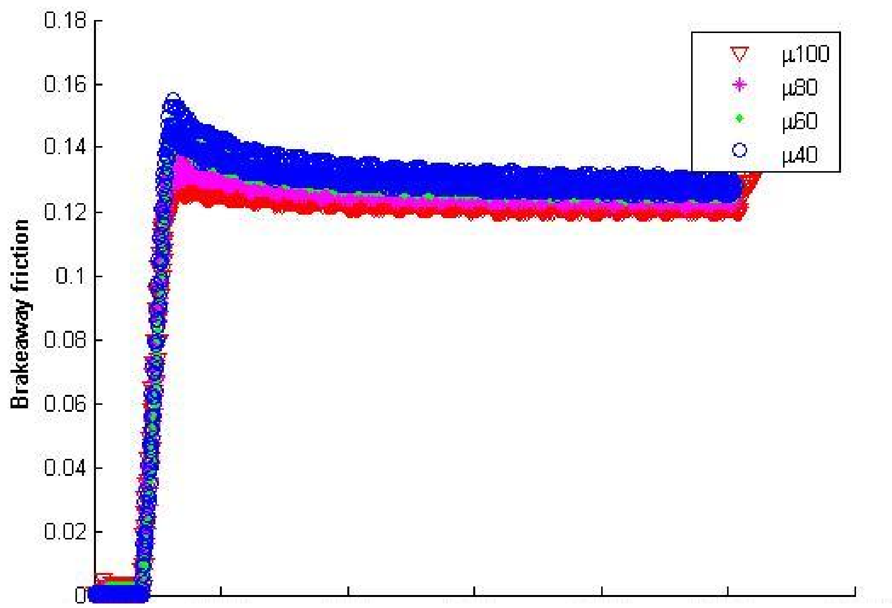

Figure 4. Brake-away friction for a ATF at 40, 60, 80 and 100°C.

Except for a low friction level, another drawback of UTTOs compared to ATFs is presented in Figure 4 and Figure 5. The figures present brake-away friction behaviour for a ATF and a UTTO at different temperatures measured in the Limited Slip Clutch Test Rig [7, 8]. As seen in the figures the ATF shows a limited influence from temperature. The UTTOs brake-away friction on the other hand is strongly influenced by temperature as seen in Figure 5. This makes it harder to control the transmission since the temperature influence has a significant influence on the clutch performance and therefore needs to be included in the clutch control algorithms.

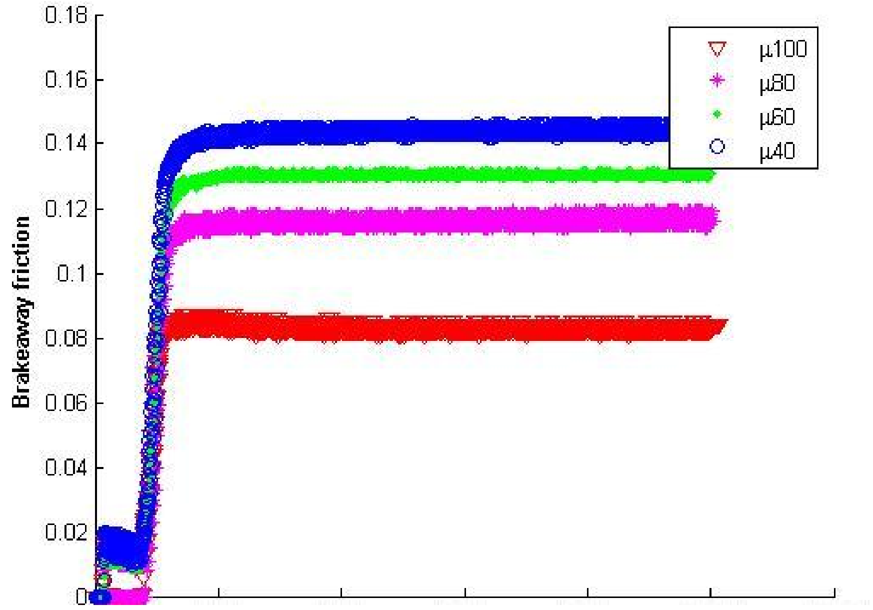

Figure 5. Brake-away friction for an UTTO at 40, 60, 80 and 100°C.

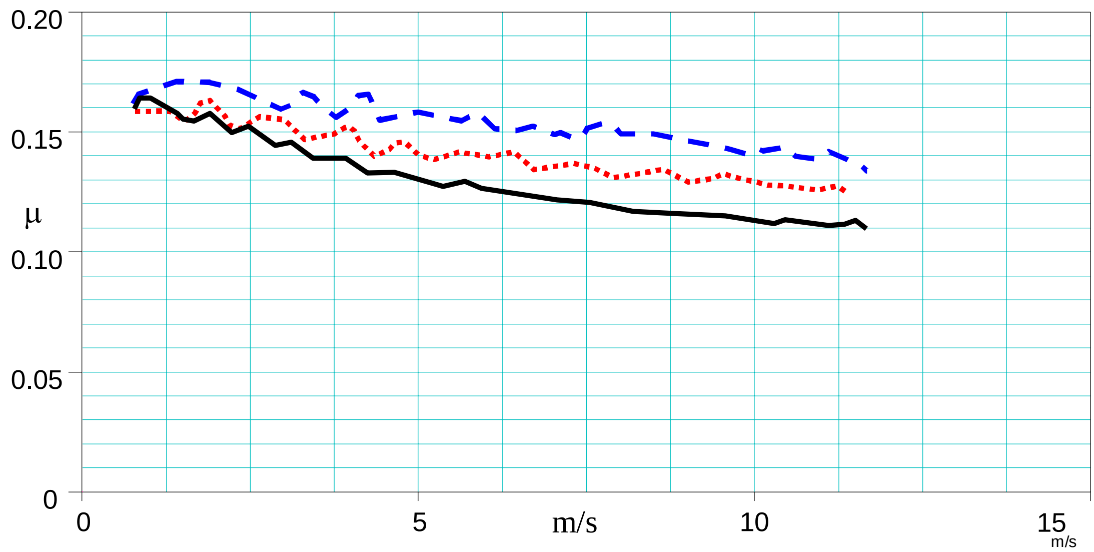

Figure 6. Friction behaviour for three different ATFs. Black line=Older technology, red dotted line=Modern technology for North American market, blue dashed line=Modern technology for Japanese market.

Looking at different ATF technologies there have been significant performance improvement over the last decade or two. Figure 6 presents friction curves for a older technology (late eighties) compared to two different fluids developed in the last few years. It can be seen that the friction properties have improved quite a lot, the friction level is as high or higher and the rooster tail is reduced.

Another area where new ATF technology outperforms older technologies is friction durability, which has been a very important area of improvement especially among Japanese OEMs [9]. Together with better oxidative stability, improved friction durability have been an enabler for fill for life ATFs in passenger cars and extended drain fluids in heavy-duty applications.

Gear protection

Good gear protection is an important property for transmission fluids. One common way to measure gear protection is different FZG methods. For transmission oils the CEC L-07-A-95 (A8,3/90) is commonly used [10]. ‘A8,3/90’ describes the test conditions. ‘A’ stands for ‘A’ profile gear set, 8,3 is the speed, in rps and 90 is the test running temperature in degrees Celsius. The test result are given as, load stage that gives a failure, FLS (Failure Load Stage) 1 to FLS 12. If no failure is obtained after load stage 12 the oil is considered as a 12 pass.

Table 1 shows common FLS for different transmission fluids measured with the CEC L-07-A-95 method. For other type of oils such as hypoid gear oils the A8,3/90 FZG method are not severe enough. The other methods like the CEC L-84-02, A10/16,6R/120 [11]. A profile gears but with half the width is used (10mm), the speed is doubled (16,6 rps) and the rotation is reversed (R) and test temperature 120°C is used. The severity of the test is much higher than for the standard one. A FLS 12 measured with CEC L-07-A-95 corresponds to approximately a FLS 8 for the CEC L-84-02 method.

Table 1. Typical Failure Load Stage for different fluids measured with FZG method CEC L-07-A-95.

Fluid	UTTO	ATF	TO-4
FLS	9-11	10-12	10-11

Even though most OEMs state FZG gear protection demands in their transmission fluid standards the general situation is that this is not sufficient to cover the gear protection properties of the fluid. For this reason a lot of different in-house tests are required, adding to difficulties in comparing lubricant performance ratings.

CONCLUSIONS

Different transmission fluids have been presented together with some of their respective advantages and disadvantages. As can be seen the choice of lubricant is not easy and should be done with care since the transmission lubricant will have a large influence on the performance of the vehicles as well as on life-cycle cost. Based on this type of lubricant evaluations Volvo has chosen to work with ATF technology, and adopted the transmission designs accordingly.

A correct selection of viscosity profile has a huge fuel saving potential in a commercial vehicle, but taking it to far can be very dangerous.

The recent fluid developments have enabled extended drain interval with cost competitive products. In the case of ATFs the durability improvements in shear stability have been the most important one in combination with oxidative stability and friction durability.

With the correct selection of lubricant, extended drain in combination with increased efficiency and reduced service down-time, will result in a reduction of life-cycle cost and at the same time reduce the environmental impact of the vehicle population.

In short;

- Based on performance and availability ATF is the preferred lubricant for next-generation Volvo power-shift transmissions.
- The recent performance improvement of ATFs, especially with respect to shear stability, is a big advantage for heavy-duty transmission applications.

- There is an urgent need for improved industry standards regarding ATF specifications and test methods.

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NOMENCLATURE

POWER-SHIFT TRANSMISSIONS

For heavy-duty applications, especially in construction equipment and agricultural equipment, a big challenge is to maintain traction and torque transmission during gear changes. For this reason manual transmissions have been replaced by power-shift transmissions in most applications. The definition of power-shift is that the gear change is performed without torque interruptions as seen in Figure A1.

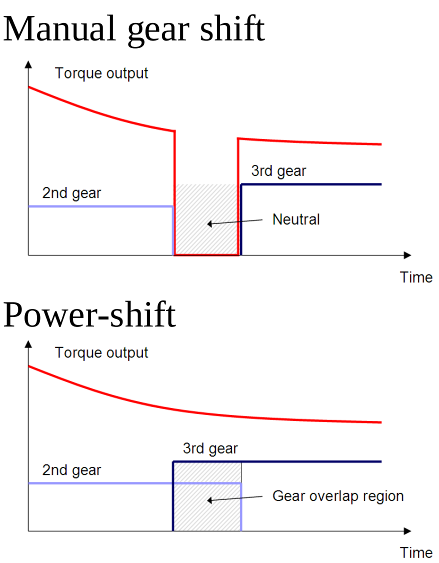

Figure A1. Comparison of torque output and gear ratio for a manual shift vs. a power-shift.