CONTINUOUSLY VARIABLE TRANSMISSION FLUID

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SUMMARY
A new chapter of passenger car automatic transmissions has been written with the new, modern continuously variable transmission from Audi. Consequently a special tailor-made lubricant was developed by CASTROL. This new fluid has been designed to ensure safe power transmission in the LuK chain variator with a minimum required hydraulic pressure in the pulley sets to help achieving a high efficiency. Challenging the fluid has to offer a high steel-to-steel coefficient of friction in the variator and low losses in all the other lubricating contacts like bearings, gears and seals. This has been achieved in selecting a fully synthetic base oil approach. The fluid lowers the operating temperatures and has an extremely high thermal stability required due to very high contact temperatures in the wet start-up clutch. High oil flow in the system increases the importance of air release to ensure proper operation of the hydraulic pump. The presence of the electronic control in the housing and therefore within the oil is an additional requirement where in contrast to the above the lubricant should behave totally passive. This comprehensive set of requirements was covered by a new synthetic CVT fluid developed in simultaneous engineering with the OEM, the variator manufacture, the friction plate manufacture and the electronic control manufacture.

Keywords: Castrol, CVT, synthetic fluid, lubricant, Audi multitrionic, quality control

1 INTRODUCTION
The drivers for new transmission concepts in passenger cars are comfort, performance and fuel consumption. Due to the increase of traffic the comfort advantage of automatic transmission is becoming more and more considered by the customers in upper mid-class vehicles like Audi A6, BMW 5-series etc. This trend will be seen as well in the smaller car segments.

The customer acceptance today is limited by the loss of performance and the fuel consumption penalty he pays with 4-speed or 5-speed automatic transmissions. An important step towards combining comfort with performance and fuel saving is the introduction of a modern continuously variable transmissions (CVT).

To achieve this a totally new concept was developed by Audi - the Audi multitrionic®.

Based on the first car application of the LuK chain a high torque transmission without fixed transmission ratios enables to operate the car in the most appropriate working regime to achieve lowest fuel consumption or highest engine output depending on the driver demand. Quick response between these operating points is achieved with no shift shocks, which leads to an incredible comfort experience.

One very important engineering component in this transmission is the Continuously Variable Transmission Fluid (CTF). This paper describes the requirements and achievements of the fluid.

Only a tailor-made lubricant allows consequent exploitation of the transmission concept. Even though there are a lot of similarities to conventional automatic transmission fluids (ATF) the key requirements cannot be fulfilled satisfactory by an ATF.

2 KEY REQUIREMENTS FOR THE LUBRICANT
As all the power from the engine has to be transferred via steel-to-steel friction in the variator this plays the key role in the design of the lubricant. Other than that the wet start-up clutch, the hydraulic pump system, the gears, the bearings and the seals do require special fluid performance to work at their optimum performance.
The variator is a very high shearing lubricating contact for the oil. The shear stress is higher than that of a hypoid gear. The output temperatures from the clutch are extremely high which requires extraordinary thermal stable fluids. Additional requirements as there are

- suitable and stable friction characteristics
- good low temperature viscometrics
- good air release and foam behaviour
- good corrosion protection
- good seal compatibility
- no interaction with electronic compounds
- low bearing wear
- good extreme pressure (EP) performance
- good protection against pitting

complete the list of key requirements. The performance in these areas will be discussed in more detail in the following.

Before doing that it needs to be highlighted that nearly in all these areas the existing standard test methods and rigs did not describe the required performance of a CVT. Large part of the fluid development was spent on the fundamental research to understand the appetite of the transmission and to reproduce it in simple tests on a rig or in the lab. Only after having that in place it was possible to optimise the fluid performance.

3 FLUID PERFORMANCE DETAILS

3.1 Steel-to-Steel Friction

As screening tools the SRV (oscillating ball on plate contact) and a modified Timken machine were used to compare the metal-to-metal coefficient of friction under various loads, temperatures and sliding speeds. The friction increases with load and temperature and decreases with speed. Within the operating window little dependence of temperature and load could be achieved.

![Optimum Steel-to-Steel Friction](image)

This steel-to-steel friction needs to be stable throughout the whole lifetime of the fluid. Extreme oxidation tests in labs as well as on rigs demonstrate little to no change of the steel-to-steel friction.

It is important to consider this for the clamping force of the pulleys. In contrast to known CVTs on the market a controlled hydraulic pressure dependent on the operating conditions was the target for this transmission. The graph shows the required axial clamping force at different transmission ratios. With the synthetic CTF it was achieved to be about 15-20% below this requirement, which gives additional safety against chain slippage and room for reduction of hydraulic pressure.

![Axial Pressure Significant Below Design Requirement](image)

3.2 Clutch Friction Characteristics

The decision to use a wet start-up clutch leads to a very spontaneous response to the driver's performance demand. For the fluid it creates the need to have an increasing coefficient of friction with increasing sliding speeds. This so called positive friction characteristic is extremely important to avoid shudder. The driver will easily observe shudder by noise and vibrations.

![Positive Friction Characteristics for the Clutch](image)

The perfect fit between friction material and oil is required to achieve stable friction characteristics even after severe thermal and oxidative stress of oil and clutch plate.

3.3 Viscosity and Shear Stability

The compromise between high efficiency and wear led to the use of a 7.5 mm²/s @ 100°C fluid as most popular for ATFs. It was shown that there are interesting advantages using a 6 mm²/s fluid, which might be considered for future fluid generations.

The shear stress of a CVT is that high that a conventional ATF loses about 35% of its viscosity within 40,000 km. The synthetic CTFs will not lose more than 5% viscosity over the lifetime of the transmission, which can be well described by a 100 hours taper roller bearing test.
Under the high shear and high contact temperatures in the variator contact the HTHS viscosity remains significant higher than that of a conventional ATF.

3.4 Low Temperature Performance

The viscosity at low temperature is very important to describe the ability to pump the hydraulic oil under arctic conditions in the starting mode. The Brookfield viscosity of the synthetic CTF is significantly lower than even today's part synthetic ATFs used in European 5-speed ATs.

The real pump ability is not fully described with the Brookfield measurement. An in-house pump test is much better featuring reality.

3.5 Air Release and Foam Behaviour

Due to the very high oil flow required to cool the variator and the wet clutch the fluid has under some operating conditions only 15-20 seconds to rest in the oil sump before it starts to circulate again. This means that the air pulled into the oil when sprayed onto the variator has only little time to release. All available air release tests do not describe the right amounts of air volume in the oil and the time period that is important. A special air-release additive system could be found that reduces the air in oil content significantly.

But as the air content in the transmission is around 10-30% various tests have been used and finally a unique test apparatus was developed to create realistic air contents and measure it.
3.6 Thermal and Oxidative Stability

As mentioned before, the high temperatures being generated especially in the clutch under severe load conditions like towing a trailer uphill requires a very high thermal oxidative stability. Even after 384 hours at 160°C oil temperature with continuous air pouring into the oil, the viscosity hardly changes and no sign of oil degradation is seen.

3.7 EP and Pitting Protection

Typical ATF offer an EP performance characterised by a failure load stage in the A/8.3/90 FZG scuffing test of around 8 to 10. The new synthetic CTF achieves a failure load stage of 12, which gives sufficient protection. A higher EP performance will result in less oxidation stability and lower metal-metal friction in the variator.

More important is the protection against pitting on the pulleys and gears. The synthetic CTF offers here maximum performance in the FZG PT C/9/90 test. It runs up to the end of the test at 300 hours.

3.8 Reduction of Energy Losses

Even though a high metal-metal friction is required to keep the hydraulic work in the variator low, it is possible to reduce operating temperatures e.g. in bearings as demonstrated in the axial ball bearing (ARKL).

A reduction of torque loss could as well be shown in the gears using a modified FZG rig.

4 QUALITY CONTROL SCHEME

As demonstrated, a lot of the special performance of the synthetic CTF is due to its tailor-made friction characteristics both in the variator as well as in the clutch. This can hardly be described by the element contents of the additives and the oil. Therefore, it is needed to control friction properties and air-release by functional tests.

The table and the flow chart give an impression of the effort put into the quality control to ensure the performance of the oil.

5 CONCLUSIONS

The CTF is an integral part of a modern CVT, which can only do its job perfectly when designed from the very beginning in a simultaneous engineering. A lot of know-how generation was required to understand the appetite of the application and optimise the fluid performance accordingly. The quality control goes far beyond the established processes to ensure the required fluid performance.