Hydrostatic- mechanical power split transmission for locomotives

Subtitle: A new CVT approach in high power applications

Dipl.-Ing. **Heinz Aitzetmüller**, VDS Getriebe GmbH, Wolfern/ Austria;

Abstract

Continuously variable transmissions based on the principle of hydrostatic mechanical powersplit have been on the market in agricultural applications for more than a decade.

In high power Diesel driven locomotives there are available two drivetrain systems; the hydrodynamic transmissions and Diesel- electric drives. There are also some applications with pure hydrostatic drives in shunting locomotives.

VDS Getriebe GmbH has worked out a continuously variable transmission system for Diesel locomotives up to 1800 kW based on the principle of hydrostatic- mechanical power split. The transmission consists of a CVT module with pure hydrostatic drive at low speed and two powersplit gears shifted at synchronous rotation speeds. There are foreseen two range gears, the first for operation below 60 kph, the second range for speeds up to 130 kph. Shifting from one range to the next is done with torque interruption and electronic synchronisation by proper control of the hydrostatic power branch.

Additionally a forward/ reverse gearset is foreseen at transmission output for achieving same functionality in both directions.

Due to the specific configuration, the required drawbar pull is achieved with reasonable hydrostatic units available for mobile applications. The big advantage in comparison to hydrodynamic transmissions is the significantly improved efficiency, especially at low speeds. The transmission is designed to achieve maximum drawbar pull of 30 tons and maximum speed above 130 kph.

Introduction

Automatic driveline systems with pure hydrostatic drives or torque converter define the state of the art in municipal vehicles, construction machines, handling machines and similar applications.

In agric tractors continuously variable transmissions based on the principle of hydrostatic mechanical power split have proved their reliability by more than a decade. Fendt was the first company to offer a CVT tractor in 1996, the VARIO 260.

In the meantime several new CVT systems have come to market in agricultural applications, like the ZF ECCOM, ZF S-Matic, JohnDeere AutoPowr, MALI WSE/ WSG, SAME Orchard Transmission CVT, VALTRA CVT, CNH . During the BAUMA fair in April 2010 in Munich there were also shown CVT prototypes for construction machines, primarily for wheel loaders with engine power above 120 kW.

Figure 1: Caterpillar CVT

Figure 2: ZF CVT with double yoke hydro

Figure 3: Dana/ Bosch Rexroth CVT

All these CVTs mentioned are based on the principle of hydrostatic mechanical power split targeting at best functionality and efficiency with acceptable production costs.

Diesel driven locomotives are either equipped with pure electric drives or with hydrodynamic transmissions. In just a few shunting locomotives hydrostatic drives are used.

Requirements locomotive transmissions

Diesel locomotives are used primarily for shunting operations in train stations and for transport of freight trains. The maximum speed during shunting is limited to about 60 kph. For transport operations 120 kph is required.

New driveline concepts need to fulfil following requirements:

- Fully automatic operation
- Continuous drive close to the slipping limit between wheel and rail
- Quick reduction of output torque if wheel slip is recognized
- Best technical reliability
- Best efficiency during shunting and transport operation
- Exact positioning of the locomotive
- Soft pull and push operation
- High service life intervals
- Useable for multi- locomotive operation
- Same performance and operability in both directions
- High continuous brake power

Taking into account these requirements, VDS has worked out several concepts of hydrostatic- mechanical powersplit approaches. Finally a CVT concept called VSP – Variable Stepped Planet was designed assuming an installed Diesel engine power of 1800 kW, which is shown on the following pages.

VSP transmission concept

The VSP transmission concept is working on the principle of hydrostatic mechanical power-split with pure hydrostatic drive at low speeds and two powersplit gears. Gear shifting within the CVT module is done by overlapping shifting at synchronous rotation speeds. Overlapping shifting means, that two clutches are engaged simultaneously at synchronous speeds. So there is no torque interruption during the shifting process. There can be used dog clutches as well as friction clutches as shifting elements.

For covering the required speed ranges in both directions, there are also considered a forward reverse gearset and a high/low range gear at transmission output. Shifting forward and reverse and high/ low is done by dog clutches with torque interruption and electronic synchronization of rotation speeds.

Additionally a hydrodynamic brake is considered linked to the transmission input shaft. So full braking power can be provided from maximum speed down to standstill.

The transmission scheme is shown in figure 4.

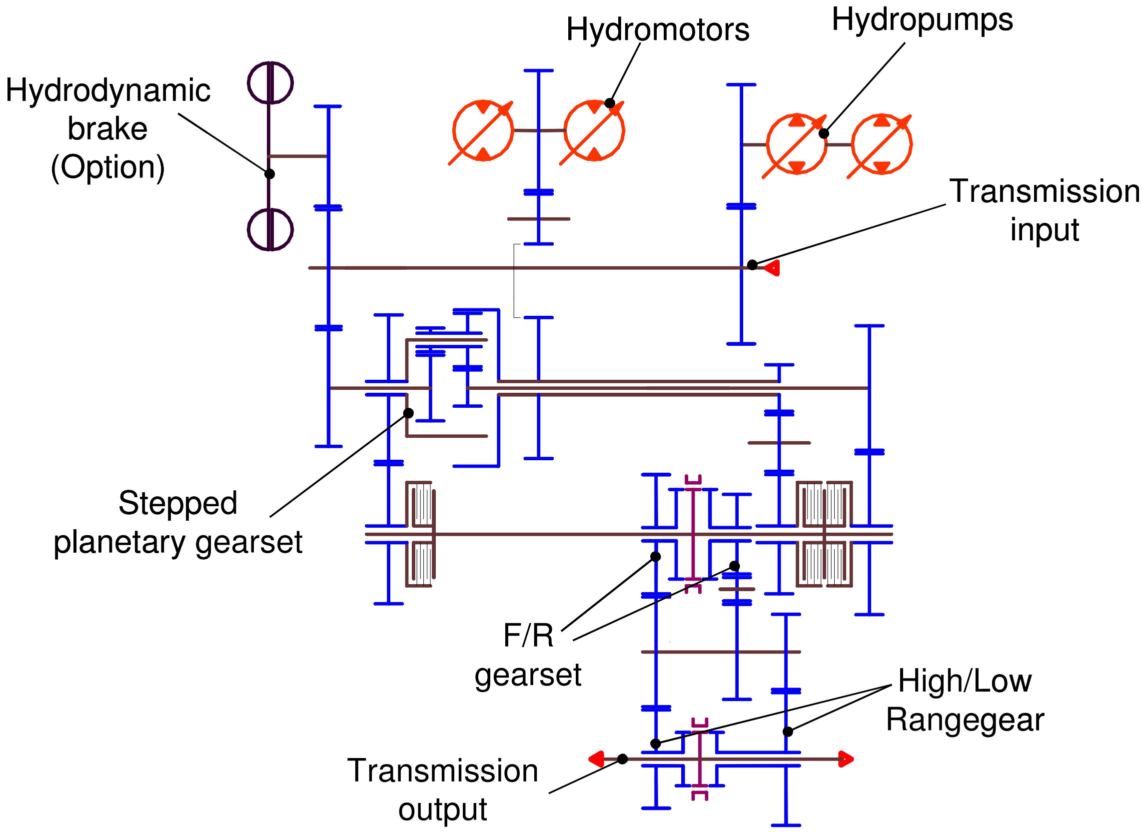


Figure 4: Scheme of VSP transmission for high power Diesel locomotives

Functional description VSP transmission

The key component of the VSP transmission is a double planetary set with stepped planets. The component arrangement is shown in figure 5. Sun gear 1 is connected to the transmission input shaft and is rotating according to the engine speed. Sun gear 1 is meshing with the planets P1a, which are connected to the planets P1b. The planets P1b are meshing with the ring gear H2 and with the sun gear S2. The ring gear H2 is driven by the hydrostatic motors and is rotating according to the speed defined in the hydrostatic power branch. By variation of the swashplate angle in the hydropumps, which are permanently driven by the combustion engine, the speed of the hydromotors is adjusted.

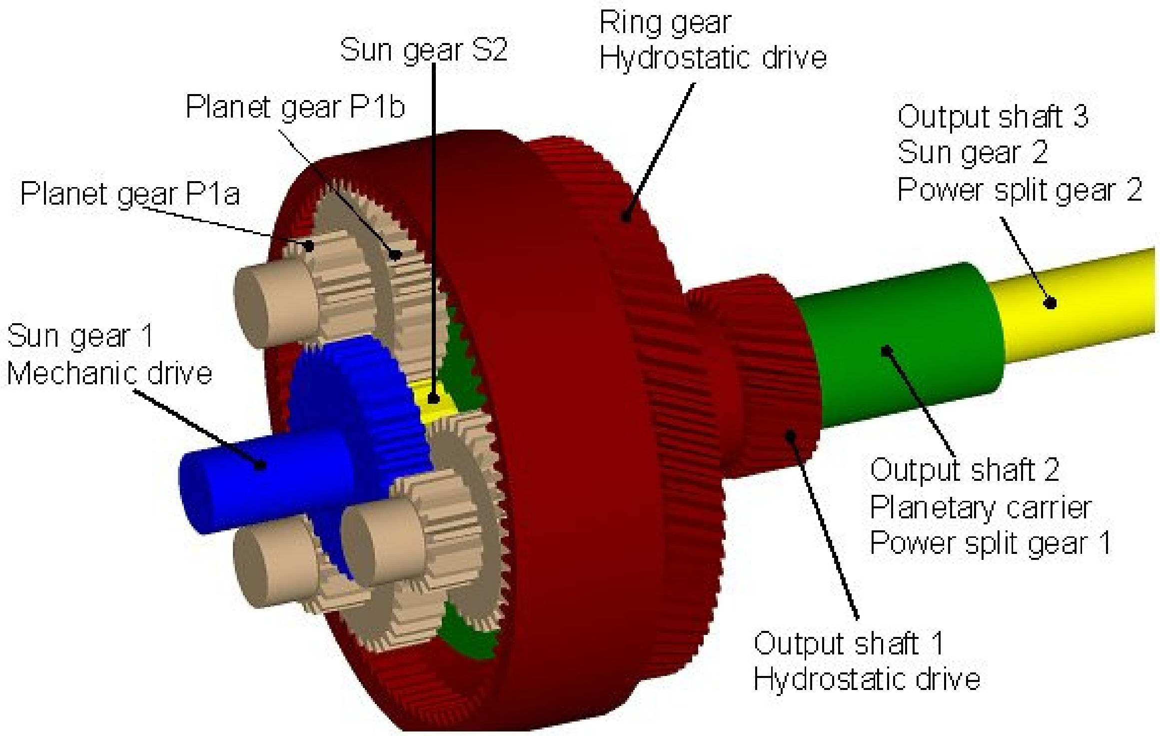


Figure 5: VSP planetary gearset

Due to the arrangement shown and the gear ratios defined there is achieved continuous variation of transmission output speed within one pure hydrostatic gear and two powersplit gears. Pure hydrostatic drive is available from -8 kph to +8 kph.

At 8 kph there is done an automatic shifting to powersplit gear 1, which covers the speed up to 29 kph. The speed variation is done by changing the speed in the hydromotor from maximum speed in one direction to maximum speed in the opposite direction. At 29 kph shifting is done again at synchronous speed from powersplit gear 1 to powersplit gear 2.

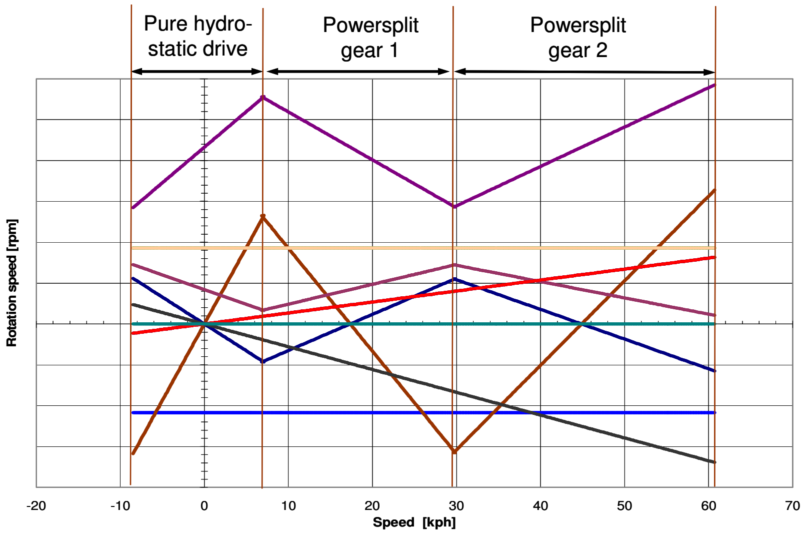
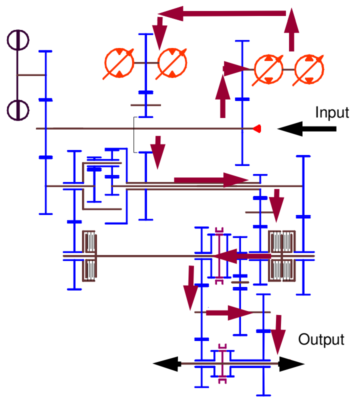
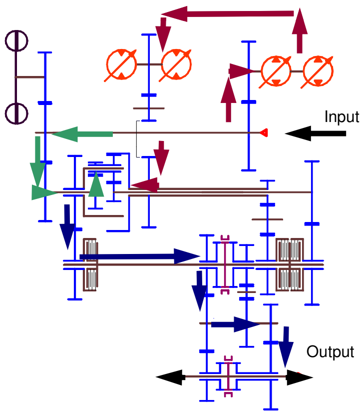


Figure 6: Rotation speeds in VSP components

By changing the speed of the hydromotor again from one direction to the opposite side, maximum output speed in low range is reached, which is close to 61 kph in the example shown. The following sketches show the flow of mechanical and hydrostatic power in the transmission in pure hydrostatic drive and in the powersplit gears.





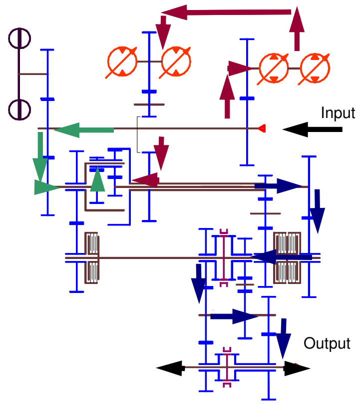


Figure 7: Powerflow pure hydrostatic drive

Figure 8: Powerflow 1st powersplit gear

Figure 9: Powerflow 2nd powersplit gear

Due to the arrangement shown, drawbar pull of 30 tons is achieved with just two 280 cc hydromotors at a maximum pressure difference of 350 bars. The hydropumps are considered to have same maximum displacement as the hydromotors.

The transmission is designed with low and high range gear at transmission output. In low range the maximum speed achieved is above 60 kph, which is sufficient for shunting operations. For running the locomotive in long distance applications at speeds above 60 kph, shifting from low to high range is done with torque interruption and electronic synchronization of shifting elements.

Shifting is foreseen at speeds between 30 and 60 kph. A graph indicating the rotation speeds of the significant transmission components as a function of vehicle speed is shown in figure 10. This graph also gives an indication of the shifting zone from low to high range. Depending on up- or downshift and the load in the system, the exact shifting speed can be varied within a certain speed range. All graphs shown are based on a constant input speed.

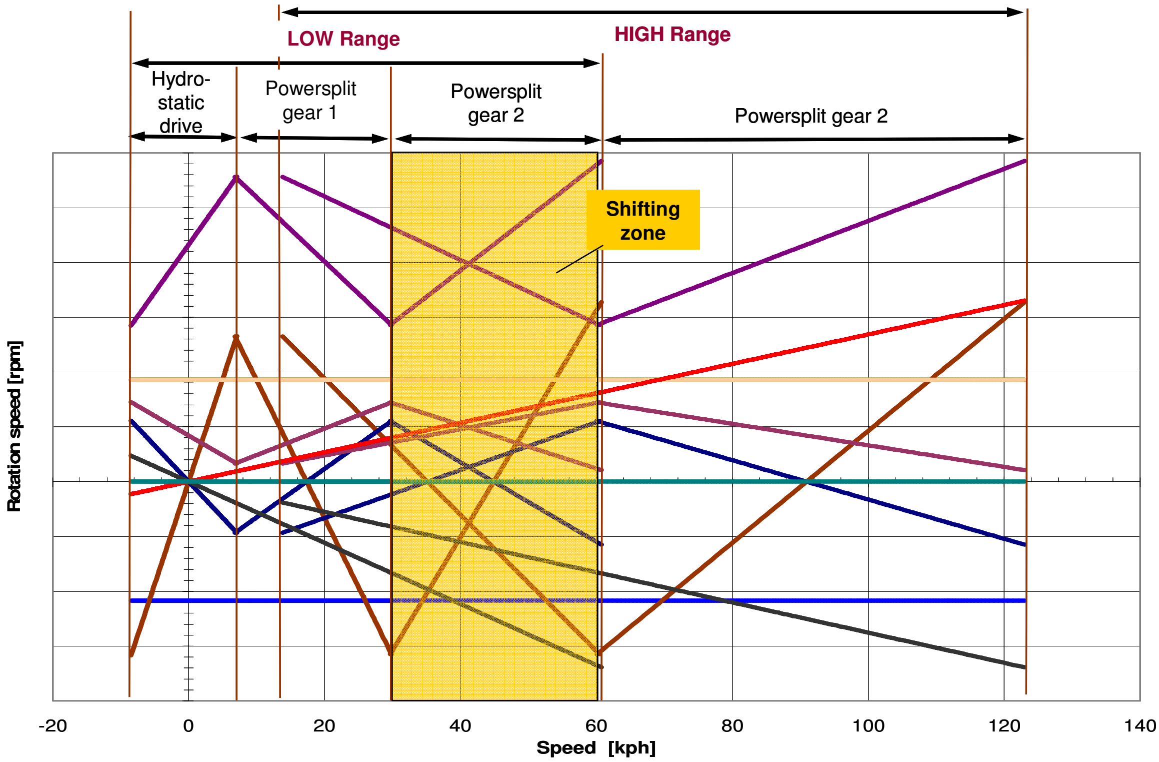


Figure 10: Component speed vs vehicle speed

One of the major benefits of the powersplit system in comparison to hydrodynamic transmission is, that full drawbar pull can be achieved even at low Diesel speed. So especially in shunting operation, when there is a lot of pulling and pushing operation at low speeds, the average Diesel speed can be kept significantly lower than using hydrodynamic transmissions.

Furthermore, if the locomotive runs at high speeds, the transmission efficiency is at high level as a big portion of engine power is transferred by the mechanical branch and only a small power portion is transferred by the hydrostatic branch. Whenever the swashplate angles in the hydropumps are at an angle of 0 degrees, the whole input power is transferred by the mechanical branch only. At these operating conditions, the transmission efficiency reaches maximum values. A graph of the transmission efficiency as a function of vehicle speed is shown in figure 11.

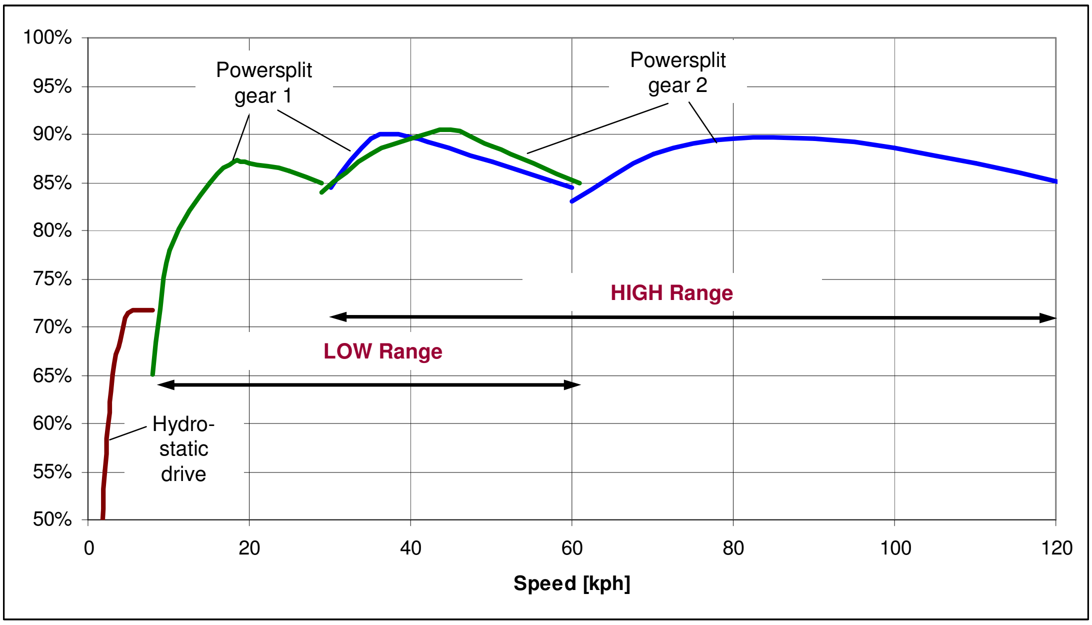


Figure 11: Transmission efficiency vs vehicle speed

A forward/ reverse gearset is foreseen between the CVT module and the high/ low range gear. Shifting the forward/ reverse gearset is done by dog clutches at standstill with electronic supervision of the shifting process.
Due to the high/ low gearset at transmission output, the CVT module and the forward/ reverse gearset can be set to neutral and separated from the output shaft, which gives the opportunity of towing the locomotive without extra lubrication provision.

Design concept

The design concept was aiming at keeping the transmission dimensions within the limits of comparable hydrodynamic transmissions. The hydrostatic components are arranged outside the transmission and can be serviced and exchanged easily in case of malfunction. The dimensions of the hydropumps and hydromotors are within the common limits of mobile applications, that causes significant impact on components costs and availability. There are several suppliers offering hydrostatic components within the power ranges foreseen.
In case of lower installed Diesel power and modified functional requirements, different hydrostatic components can be used.

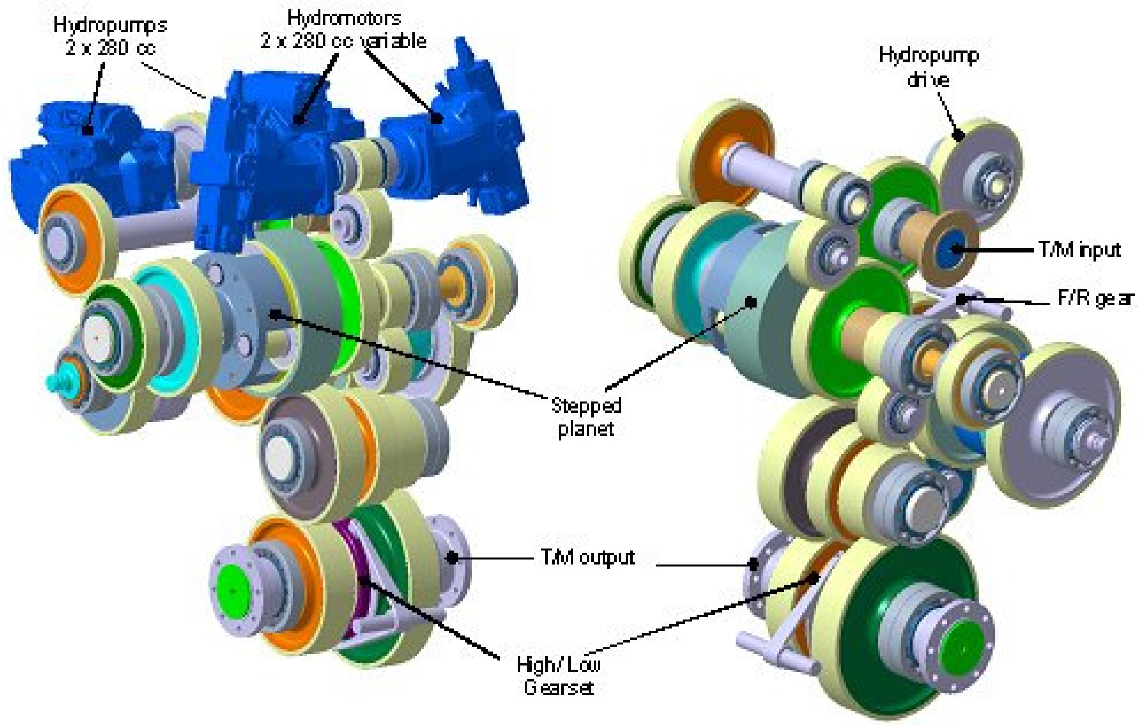


Figure 12: Component configuration VSP transmission

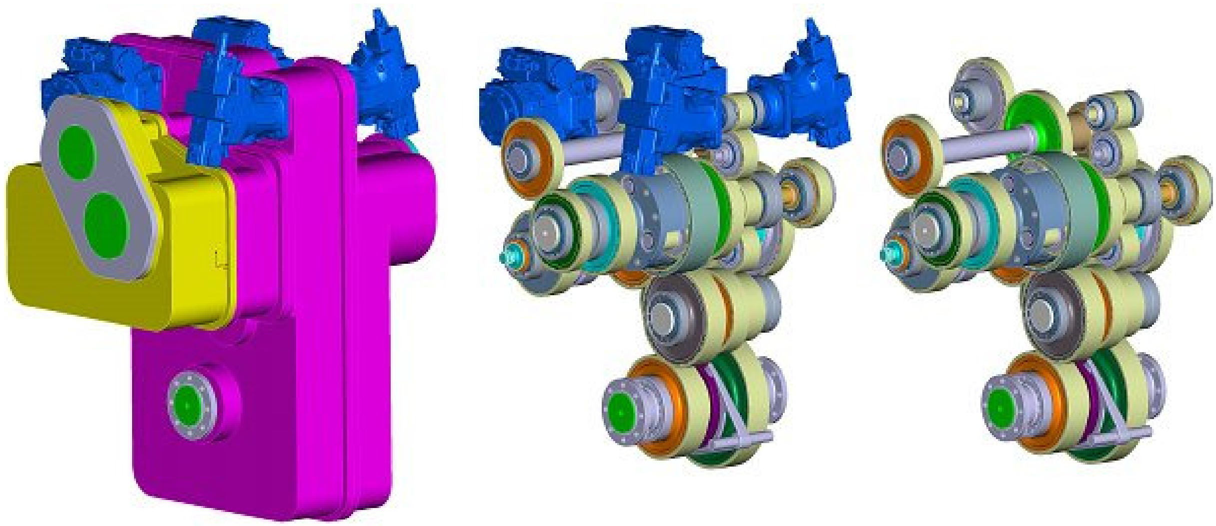


Figure 13: Component configuration VSP transmission

Summary and conclusion

Continuously variable transmissions with hydrostatic mechanical powersplit have become state of the art in agric tractors and are entering more and more applications in construction machines, forestry machines and municipal vehicles.

The VSP transmission concept shows a new CVT approach for a high power application in a Diesel driven locomotive. Due to the reasonable dimensions of the hydrostatic components and the benefits in efficiency this power split system is an alternative to hydrodynamic transmissions.

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