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CVT for Input Power above 300 kW

For high power agricultural tractors, continuously variable power-split transmissions are optimal for evenly increasing the pulling force to and transmitting full engine power in a fuel-optimal rpm range. The continuously variable transmission presented here with input power > 300 kW is based on the ZF-Eccom 3.5 transmission system in series and covers an essential range of articulated steered vehicles with increased capacity data. The wide ratio spread of the transmission allows simultaneously for high initial pulling power and with 40 kph for transport tasks at a reduced consumption-optimal engine rpm.

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Keywords

High-powered tractors, continously variable transmission (CVT)

Literature

[1] *Lober, M.*: Traktoren mit stufenlosen Getrieben / Tractors with Stepless Transmission. VDI Berichte Nr. 1636, 2001
[2] *Pohlenz, J.*: Neue stufenlose ZF-Traktorengetriebebaureihe „Eccom" im Leistungsbereich von 75 bis 220 kW. VDI Berichte Nr. 1393, 1998
[3] *Pohlenz, J., und K. Grad* : CVT-System für den Großflächeneinsatz. VDI Berichte Nr. 1855, 2004

Tractors for large-scale farming area applications are usually characterized by four similarly large wheels and/or, on a case-by-case basis, track-type drives. Steering of such vehicles is achieved by means of an articulated steering, four-wheel steering or differential steering, which allows for tight turning radiuses despite their large tire sizes.

With the designed static weight distribution, high tractive performance can be achieved by such vehicle concepts in field applications. As a result, tractive power exceeds the performance of standard tractors with front-wheel drive assist by far, especially in the range above 300 kW.

Vehicle Application Profile and Handling

The typical working profile for an articulated tractor with approximately 95 % share in overall application time comprises:

Subsoiling:	< 6 kph
Plowing and chiseling:	8 - 9 kph
Cultivator/disc harrow:	12 kph
Direct seeding:	8 – 15 kph

In the particular speed range from 6 - 15 kph excellent transmission efficiencies are required within the optimum engine speed range. The time share for reversing is rather low; usually it will be needed during attaching implements and manoeuvring. Sometimes, correspondingly lower tractive forces are needed when compacting ensiling material. A maximum reverse speed of 14 kph is sufficient. The transport share is of minor importance; in general a top travel speed of 40 kph will be sufficient for driving back and forth to the work site.

Performance data for the transmission input		
Nominal engine speed:		$n_{nominal}$ = 2000 rpm
Input power:		P = 330 kW
Driving speed and traction forces		
for typical axle ratios/tire sizes:		
Forward:	v = 50 kph	n_{input} = 2000 rpm
	v = 40 kph	n_{input} = 1600 rpm
Reverse: Standard	v = 14 kph	$n_{nominal}$
Optional:	v = 40 – 50 kph	
Traction force forward:		FT = 240 kN
Traction force reverse:		FT = 210 kN

Table 1: Main CVT capacity data

Operation of such vehicles is effected in a highly comfortable manner by means of electrically controlled levers and pedals with many additional automatic functions, which enable an optimum work result and help to relief the driver to a major extent. Automatic guidance systems, for example, can increase the acreage worked by reducing overlapping in soil cultivation and can help to reduce the amount of seeds and fertilizers used.

For attaining high crop yields and avoiding soil compaction "timeliness of operation" is especially important. In order to cultivate vast areas in this brief, suitable time period, continuously variable transmission systems (CVT), which are integrated in superordinate vehicle control systems, offer the best potential for maximum productivity of articulated steered vehicles in large-scale farming area applications.

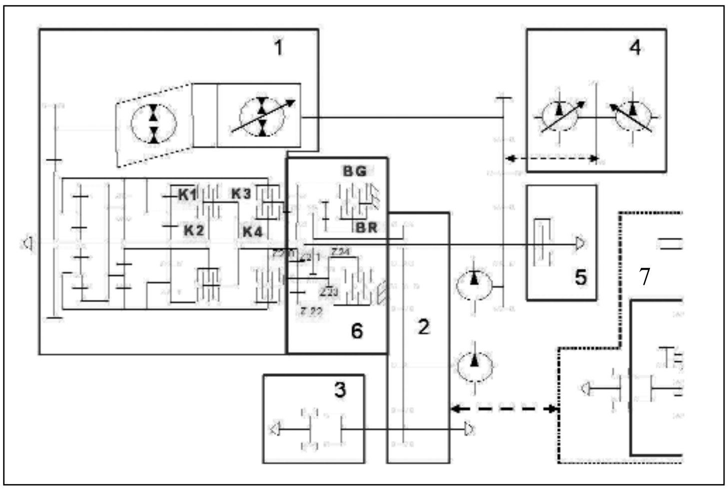

Fig. 1: CVT-transmission scheme

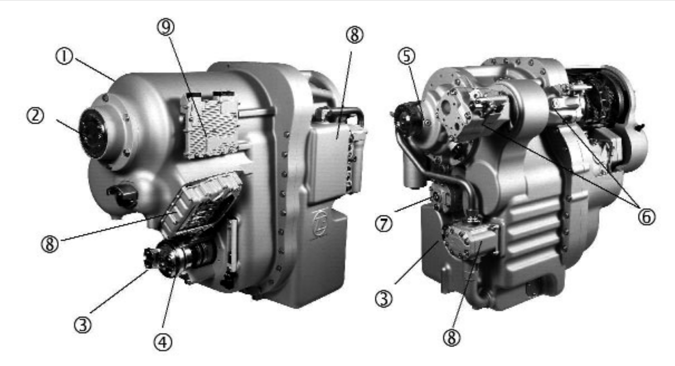

Fig. 2: Front and rear view of CVT transmission

CVT Performance Benefits

Gear shifts under load in the field generate acceleration jerks at the wheel which, particularly under difficult soil conditions, may lead to additional slippage and traction loss and will, consequently, limit the effective working speed.

During setting off under high load from standstill, continuously variable transmissions make a continuous wheel force at consistent slip and thus a good traction build-up process - also at difficult soil conditions - available for attaining the working speed. In the working range, the engine can be kept very exactly at its performance limits within the optimal fuel consumption speed range, since the CVT responds to load variations in a continuously variable manner by means of ratio changes. At the corresponding efficiency levels and thanks to this system behaviour, the CVT achieves advantageous fuel consumption and improved work output values in comparison to full-powershift transmissions.

Investigations by Lober [1] concerning the traction efficiency of tractors equipped with CVT show values, which are almost in the range of the values of vehicles with partial powershift transmissions.

In the following section, a CVT is presented for application in articulated tractors which, as the most powerful version, is derived from the ZF-Eccom product range (*Tab. 1*).

CVT Transmission Setup

In the case of the continuously variable transmission part (1), we are dealing with the well-known power-split, hydromechanical transmission structure with four mechanical speed ratios and a hydrostatic variator with low displacement volumes from the ZF Eccom CVT series [2] (*Fig. 1*).

(1) Continuously variable power-split transmission – ZF Eccom series
(2) Output drive gear box
(3) dog-clutch for engagement of front drive axle
(4) Loadsensing-pump drive
(5) PTO clutch (optional)
(6) Stepped planetary gear shuttle transmission
(7) Alternatively: Claw clutch shuttle unit in countershaft design

Shuttle Transmission Options

Shuttle Transmission – Stepped Planetary Gear (6)
The shuttle transmission unit (6) (*Fig. 1*) comprises a planetary gear set, which is made up by a sun gear (z24) and three planet gears (z23) decelerated by the multi-disc brake BR; the entire set, stepped planetary gear as indicated, is directly connected to the output planetary gear set P4. Thanks to this arrangement and with the brake BR closed, the multi-disc clutches K1/K2 can be engaged in a seamless manner for the two reverse ranges at a reversing speed of up to 14 kph. Vehicle standstill is not required for shuttling.

Shuttle Transmission – Alternative: Claw clutch shuttle unit in countershaft design (7)
The transmission setup selected is very flexible, to the extent that instead of the stepped planetary gear, a shuttle transmission in countershaft design can be implemented at the output drive gear box. In the case of this shuttle version, the driving direction is shifted by means of a dog clutch. The shuttle shift is carried out during a temporary vehicle standstill. As a result of the depicted allocation, upon demand, reverse speeds of up to 50 kph are obtainable.

Design of Claw Clutch
The form-locking clutch is closed by means of a hydraulic piston and opened via a disc spring package as soon as the pressure piston is vented. In combination with the selected dog geometry, this functionality ensures safe driving direction engagement / disengagement. The described shuttle shift system enables a highly compact design which, as an option, can be implemented via the output drive gear box variance with an unmodified transmission installation space.

CVT Transmission Design

CVT Design Basis
For an input power > 300 kW, the design basis for the continuously variable transmission is the reinforced planetary gear set of the ZF-Eccom 3.5 transmission described under [3] in combination with a suitably sized hydrostatic unit in back-to-back design.

Design Characteristics (Fig. 2)
(1) Transmission design for frame-type vehicles
(2) Input via cardan shaft
(3) Output via cardan shaft to the axles
(4) Output to front axle can be engaged during standstill by means of dog clutch
(5) As an option, the PTO clutch can be mounted with an integrated PTO brake.
(6) Life pump drive for working and steering hydraulics
(7) Output for emergency steering pump
(8) CVT transmission pump and hydraulics
(9) On-site electronics

The main dimensions are shown in *Fig.3*. Alternatively, center distances can be adapted to the vehicle's installation space by means of housing modifications within a range of 480 - 510 mm.

On-Site Electronics

The transmission is equipped with an on-site electronic control unit.

Functional features
- Transmission and electronics form one functional unit.
- The hardware is suitable for off-road operation conditions.
- The transmission's actuator and sensor system is directly wired to the on-site electronics box (minor wiring effort in the vehicle).
- The electronics control all CVT functions; upon demand, a vehicle controller can be integrated.
- Optimally fine tuned to CVT with the typical transmission calibration data.
- Communication via CAN interface, no direct I/O.
- Network connected with the OEM vehicle controller.

System features
- Networked with a vehicle-engine-transmission control unit driving strategies which are known from standard tractors equipped with CVT can be applied.
- In particular combining an automatic guidance system with a CVT in power-control driving mode allows for exploiting maximum productivity of these vehicles.

Fig. 3: Dimensions