Don’t Stop – Shift on Fly

Abstract

Since decades, modern agricultural tractors have experienced a strong development in drive train and gearbox technologies. Common technologies like power shift transmissions and hydromechanical power-split gearboxes (CVT) have found their way in almost every high-end agricultural tractor. Farmers around the world highly appreciate the comfort and power density of such transmissions.

Tractors smaller 70 hp are mainly used in and manufactured for the Asian market. But also in the European market, tractors within this hp-range are widely used in vegetable and fruit plantations, while in North America they are used for landscaping. Especially the European market demand for tractors with comfortable and high efficient transmissions, similar as in higher hp-ranges, is increasing. Tractors within this hp-range are normally equipped with mechanical (synchronized and / or stand-still) or hydrostatic transmissions with medium-pressure axial piston units.

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Hydrostatic transmissions are continuously variable, but usually there need to be at least a second mechanical gear ratio, to cover the required speed range. This second gear ratio can only be shifted when the tractor is not moving (@ 0 km/h). Usually this is sufficient for the majority of tractors, but does not quite fulfill customer requirements such as:

- Continuous variable speed thoughout the entire speed range (continuous acceleration)
- Simple handling (semi- or full automatic gear shift)
- Fast shift during travel
- High efficiency as with high-pressure variable axial piston pump and axial piston motor

The Rexroth Shift on Fly (SoF) offers a solution which eliminates the disadvantages of the state of the art 2-speed hydrostatic transmissions.

The pump / motor combination from Rexroth together with a high-end controller and corresponding software allows the driver to easily shift gears semi-automatically in a given window with a “push of a button” or the gear shift occurs fully automatically.

Fig. 1: Tractor test machine for Shift on Fly

Transmissions

The state of the art hydrostatic transmission for small tractors < 70 hp has a 2-speed stand still gearbox with medium-pressure variable axial piston units in closed circuit, where the pump displacement is variable and the motor displacement is fixed.

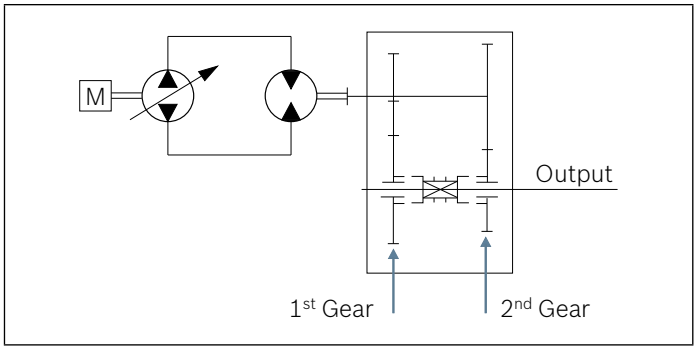

Fig. 2: 2-speed hydrostatic transmission

The disadvantage of such a solution is that a gear shift can only be done when the tractor is not in motion. The hydrostatic transmission is always engaged and must be deactivated for the gear shift. To interrupt the torque transmitted by the hydraulic motor, the vehicle has to come to a standstill (0-speed). Only then the driver can shift gears as required.

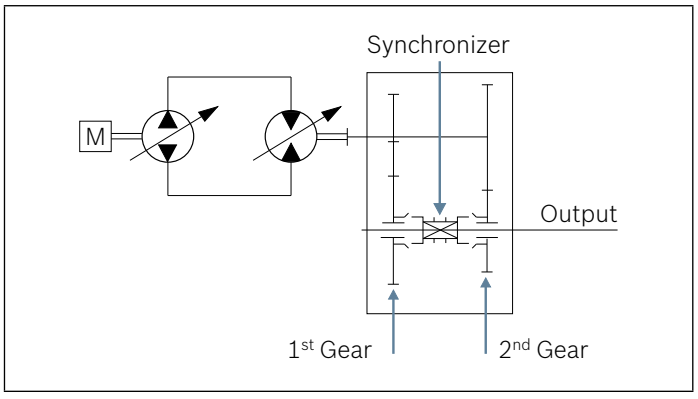

Fig. 3: 2-speed hydrostatic transmission with SoF

In contrast to the state of the art the new Rexroth solution covered a 2-speed hydrostatic transmission with SoF.

The Rexroth SoF is a special 2-speed shift transmission combined with a high-pressure (up to 450 bar nominal) hydrostatic transmission in closed circuit consisting of a high-pressure variable pump A4VG of swashplate design and a high-pressure variable motor A6VM of bent-axis design (Fig. 4 and 5).

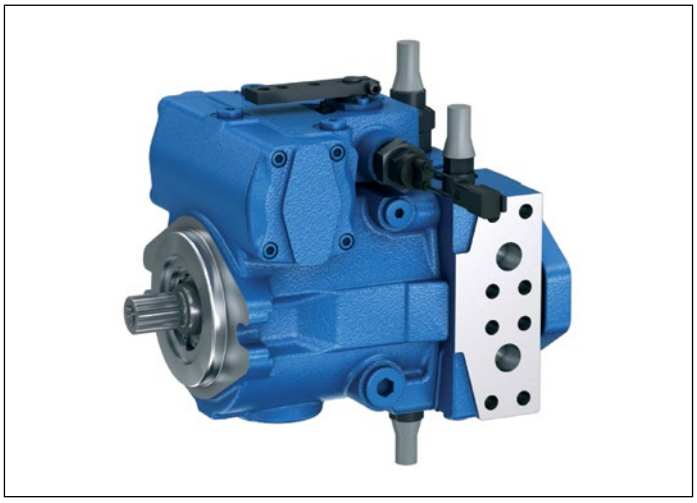

Fig. 4: High-pressure variable pump A4VG of swashplate design

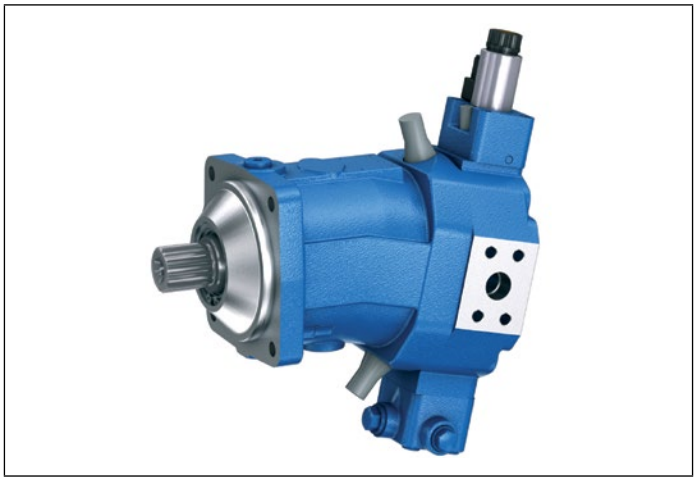

Fig. 5: High-pressure variable motor A6VM of bent-axis design

The Bosch Rexroth solution

The key to the Bosch Rexroth solution is the bent-axis design motor with electro-proportional control, which can swiveled to zero displacement (V_g = 0 cm^3/rev).

At zero displacement (V_g = 0 cm^3/rev) the transmitted hydraulic motor torque is 0 Nm. This means that the 2-speed transmission input torque is also zero and shifting becomes possible in that condition. The difference between transmission input and output speed, is equalized with a synchronizer and supported by the speed of the hydraulic motor in a downshift condition.

Pump description

A high-pressure variable pump of swashplate design, type A4VG is used for the hydraulic power source.

Several control options are available for this pump. The unit can be either controlled via an EP (electric proportional control), DA (hydraulic control, speed-related) or HW (hydraulic control, mechanical servo) plus DA, optional with dedicated electronic hard- and software package.

In this specific application, an automotive speed control is realized. The gas pedal is mechanically connected to the pump control module. Additional, there is a hand lever which controls the diesel engine speed. This lever is friction controlled and overrides the foot controlled gas pedal. This option allows adjusting the diesel engine speed independently from the travel speed.

Motor description

A high-pressure variable motor of bent-axis design with an EP is used to transmit the torque to the transmission and allows a wider speed range than a fixed motor. Bosch Rexroth special design feature allows the motor to go from maximum to zero displacement (V_g = 0 cm^3/rev). In a zero displacement condition, no torque is transmitted.

This condition allows a gear shift.

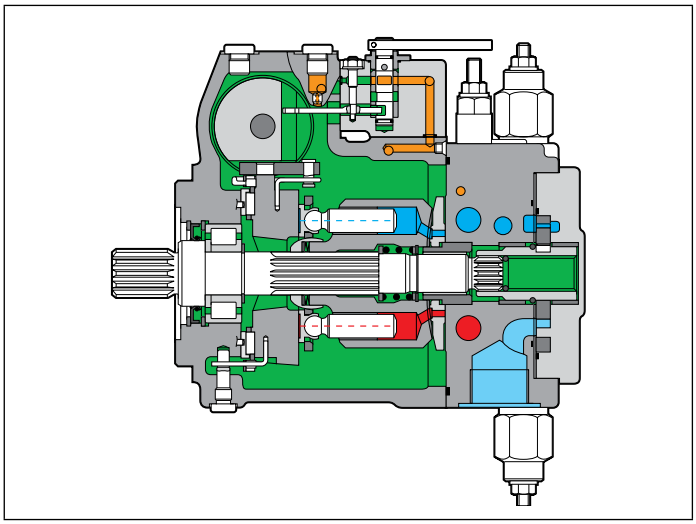

Fig. 6: Variable axial piston pump A4VG

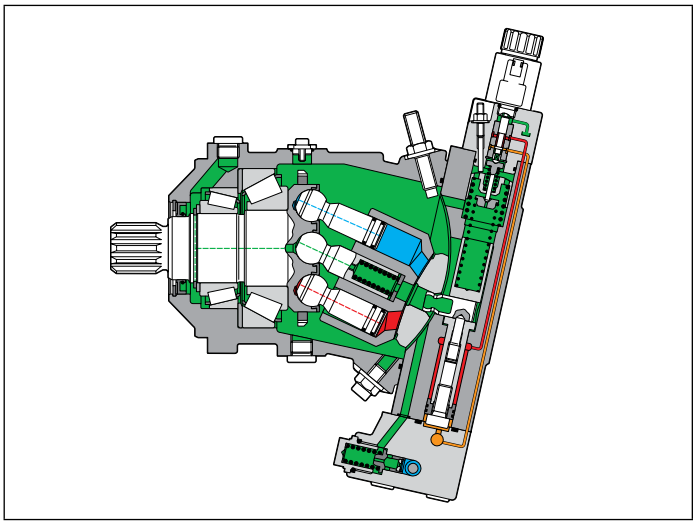

Fig. 7: Variable axial piston motor A6VM

Controller

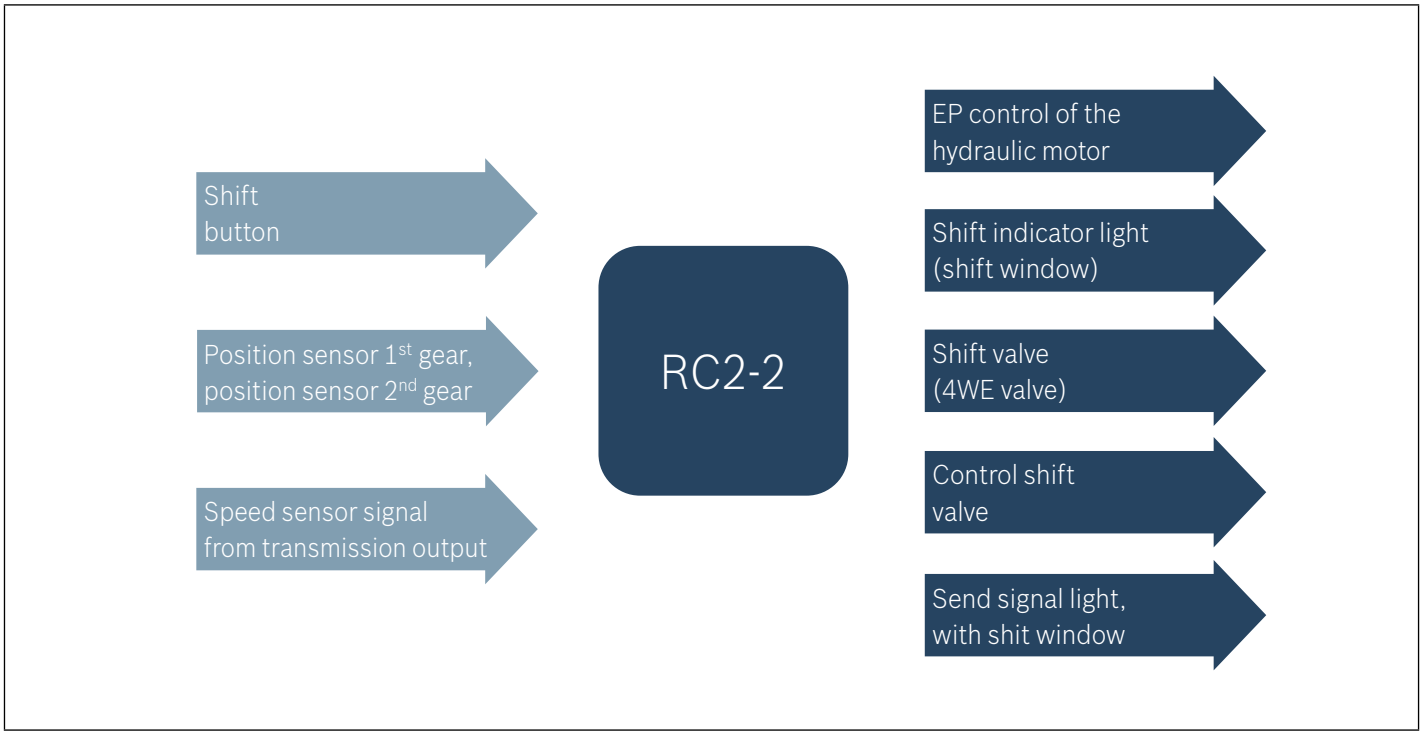

Fig. 8: Controller

The Rexroth BODAS controller RC2-2 is a 16 bit microcontroller, especially developed to suit mobile applications. The main functions of the RC2-2 controller are drive and shift depending on the input signals. As soon as the transmission operates in the shift window condition, the controller activates the shift indicator light.

As soon as the driver activates the shift button, the controller sends a signal to the shift valve (Fig. 8 and 9).

Either one of the two solenoids will be energized and the coupling cylinder will shift from 1st to 2nd gear or vice versa.

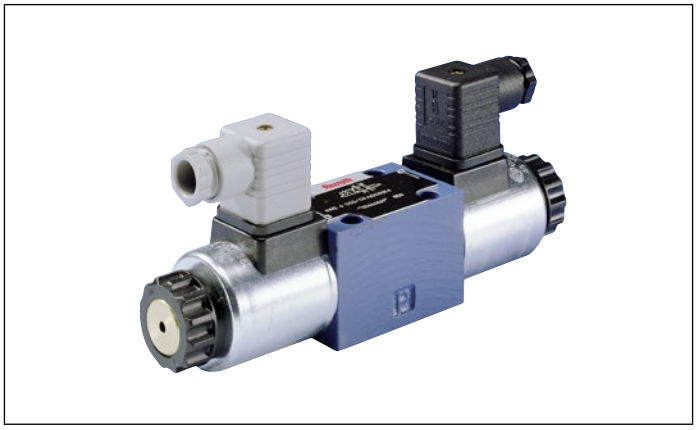

Fig. 9: Shift valve 4WE6

Shift strategy (control algorithm)

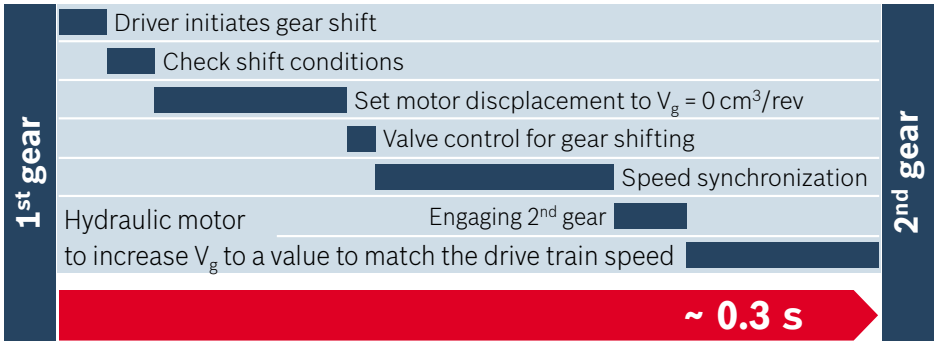

Fig. 10: Shift strategy 1st to 2nd gear

1st to 2nd gear

When starting the tractor in motion usually the driver selects the 1st gear. As soon as the speed is inside the desired range (shift window), an indicator light gives a signal to the driver in order to initiate the gear-shift. Pushing the shifting button, the following steps will happen within milliseconds:

- The transmission output speed will be checked
- Hydraulic motor displacement will be set to V_g = 0 cm³/rev
- Shift valve (4WE6) will receive a signal from the controller (RC2-2)
- Transmission input and output speed will be synchronized by the synchronizer
- The 2nd gear will be engaged
- The hydraulic motor displacement will be increased up to a value to match the required transmission input speed

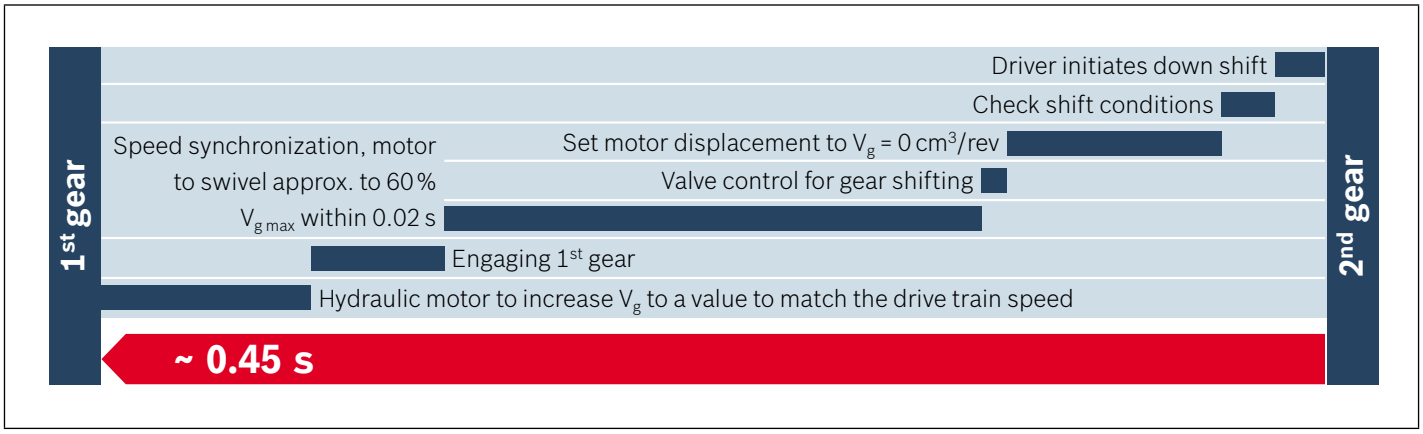

Fig. 11: Shift strategy 2nd to 1st gear

2nd to 1st gear

The driver initiates downshift.

Transmission output speed will be checked

Hydraulic motor displacement will be set to V_g = 0 cm³/rev shift valve (4WE6) will receive a signal from the controller (RC2-2)

The hydraulic motor will upstroke within a few milli seconds to about 60 % maximum displacement in order to support the synchronization and then back to V_g = 0 cm³/rev. Transmission input and output speed will be equalized by the synchronizer

1st gear will be engaged

The hydraulic motor displacement will be increased up to a value to match the required transmission input speed

Performance advantages

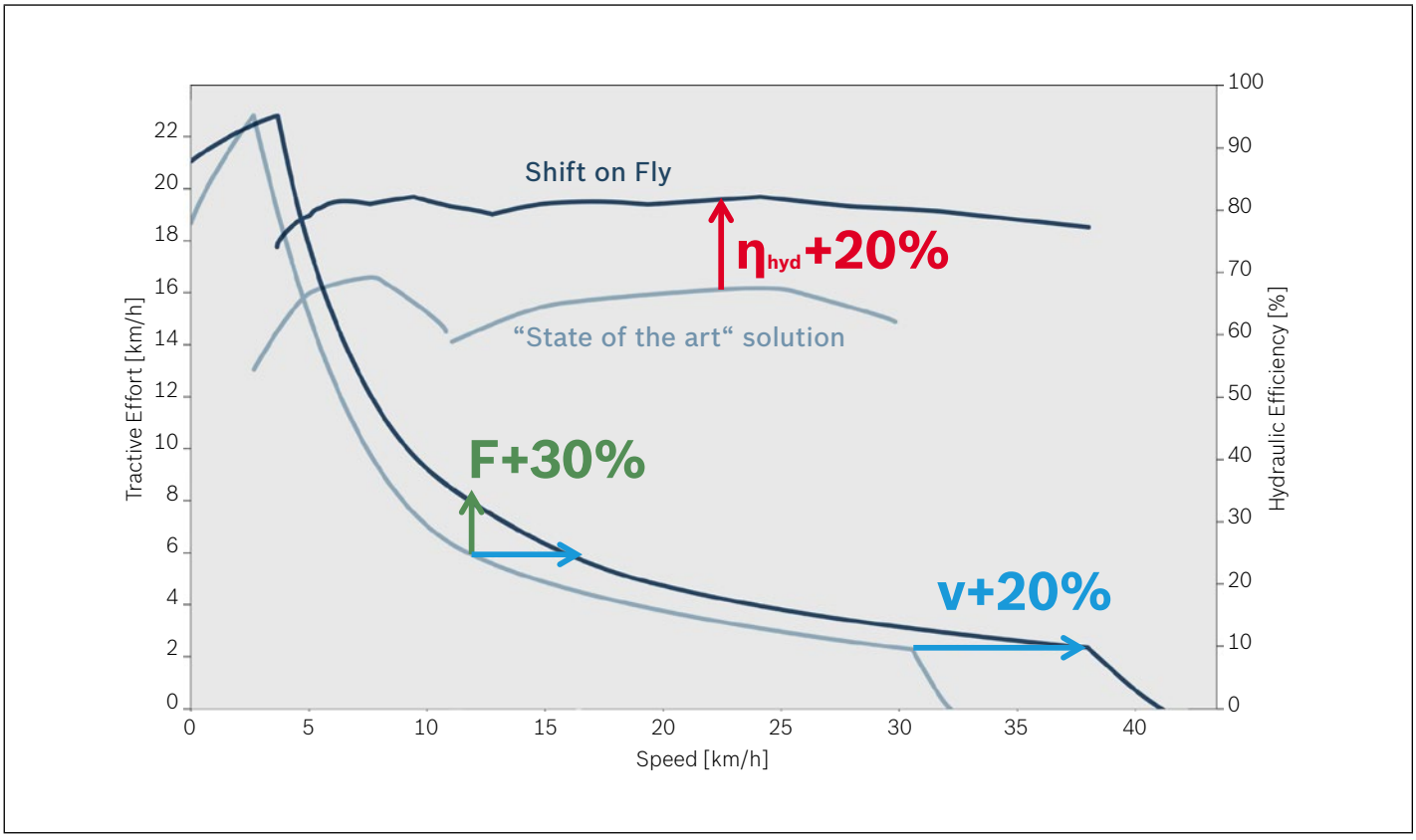

Fig. 12: Performance advantages

Speed range extension

The drive diagram shows that by using a high-pressure closed circuit system with a variable hydraulic motor, a 20% extend of the ratio can be realized. On top of the ratio extend, the high pressure variable units increase the tractive effort up to 30% compare to the state of the art solution.

Efficiency advantages

Comparing the efficiency of both systems, the hydraulic efficiency on the Rexroth SoF solution shows an 20% higher hydraulic efficiency than the "state of the art " solution.

Summary

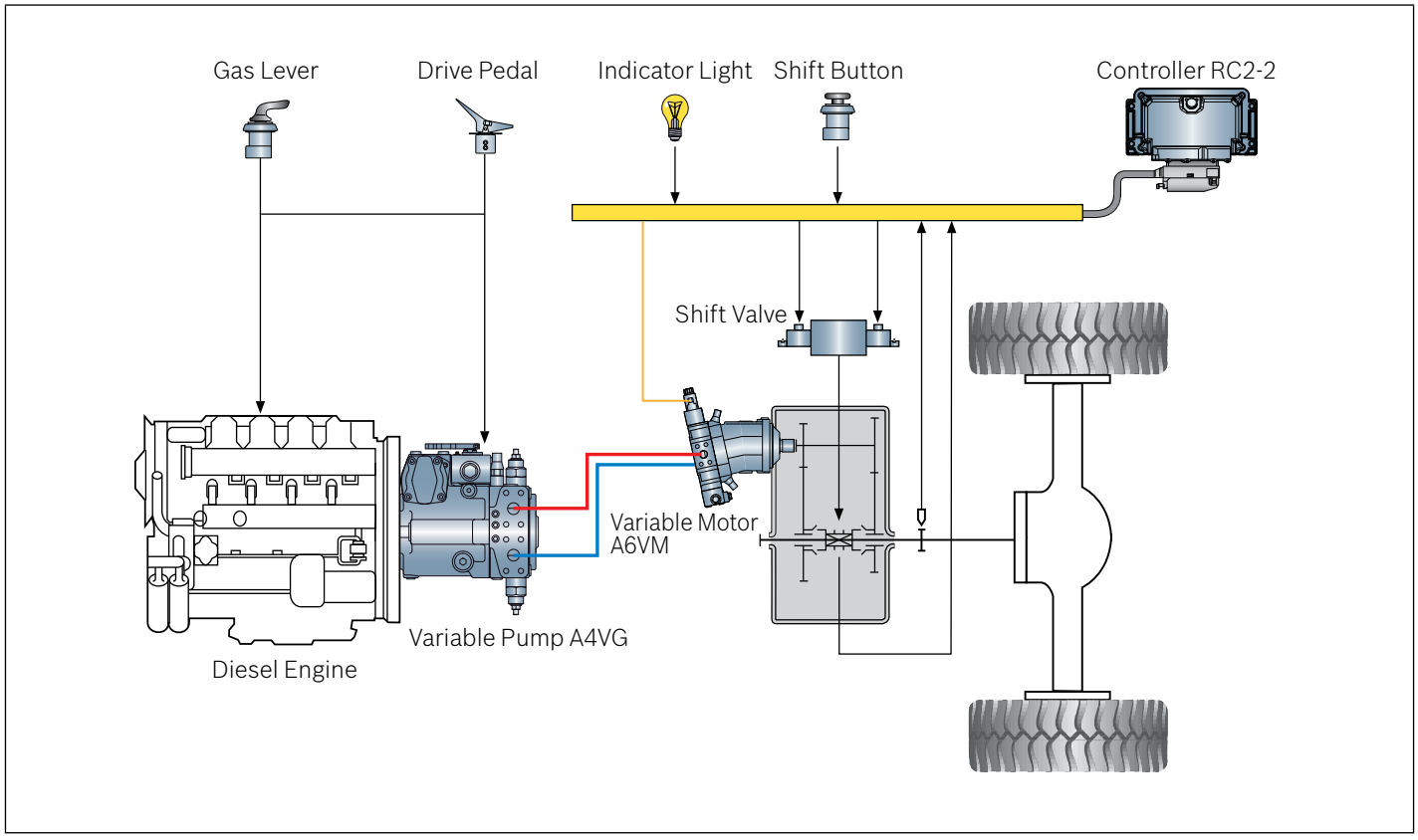

Fig. 13: Shift on Fly (SoF)

Due to the growing population worldwide, the need for more cultivated farm land will Increase. The demand for agricultural tractors even within the small hp-range will increase. Enhanced driving technology, combined with fuel efficiency and comfortable machine operation are the driver for future drive train systems.

Bosch Rexroth perfectly combines with its SoF the advantage from a manual shift gearbox with a closed circuit high-pressure hydrostatic transmission. It is a highly comfortable and highly efficient solution to meet these market requirements.

The SoF solution increases the productivity significantly, due to the fact that the tractor can continuously operate at any desired speed in any given operation point, without stop.