# HYBRID GEARS IN FARM TRACTORS

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**Summary**. The objective of this work was to present the newest generation of hybrid gearboxes being in use in the agriculture tractors. Kinetic schemes were presented and the operation principles of these devices were described. The work contains also a set of tables and graphs that compare different types of hybrid gearboxes by the criteria of their efficiency and the velocities that can be reached by tractors on the particular gearshifts.

Key words: farm tractor, transmission, hybrid gearbox

## INTRODUCTION

Velocities used in tractors during various agricultural works have the following values: less than 1 km/h on the so called creeping gears, between 4 and 12 km/h (during working on the main tasks which the tractor was designed for, usually with the highest towing forces), up to 30 or 40 km/h or even 50 km/h dependently on the tractor's design and the traffic regulations. The forces acting on the tractor also vary in a wide range. These depend on the type of work and conditions that the tractor is faced with. For that reason the towing force can change from value zero (e.g. work with a spraying machine), to the maximal force value, which is equal to the critical value of the traction adhesion (e.g. during ploughing).

Tractors are usually faced with several contradictory requirements, e.g. on one hand it is required, that the tractor should work properly from the agricultural point of view (e.g. constant deepness of the tool, the lowest possible skid of the driving wheels), had low fuel consumption. And on the other hand it is usually required that it had the highest possible velocity of work, has high towing efficiency and moreover the mechanical wear of the tractor unit was the lowest possible. A very important issue nowadays is the protection of natural environment (limiting of the toxic content in the exhaust gases, obtained thanks to working with the optimal range of an engine's characteristic, reduction of noise by lowering of the maximal rpm of the engine).

The effects of the tractor's unit work depend on, among other things, the chosen ratio of the transmission system. In accordance to this fact the most proper transmission should be used in the tractor dependently on the working conditions and the particular purpose.

When we take into account the character of the work of a farm tractor and the universal characteristics of engines, the ratio spread of the gearbox should range around forty. It comes from the fact that the tractor should be able to work with maximal and minimal velocities when the rpm of the engine are close to the nominal value [Żebrowski and Żebrowski 1997, Szydelski 2004]. It is the result of the situation that in the agricultural work, the low gears are usually utilized with the accessories that require the additional power from the power take-off shaft (PTO). The slow velocities, at which the tractor is driven on these gears, must be adequate to the velocities of the accessories' operation. And the engine should work with the nominal rpm in order to ensure the nominal standardized angular velocity of the power take-off shaft (PTO) [23]. For these reasons the following solutions are used [Dajniak 1985, Fendt: Fav. 816..., Renius 1992, Knechtel *et al.* 1997, Lang *et al.* 1998, Reiter 1998, Renius 1999, Pfab H. 2003, Żebrowski and Żebrowski 2003, Resch 2004]:

- stepped ratio gearboxes,
- hydrodynamic gearboxes,
- hybrid gearboxes.

For the ratio spread reasons (in the middle-weight and heavy tractors) the number of speeds in the stepped and hydrodynamic gearboxes, shifted in the classical way, is larger than twenty. And in the case of the gearboxes with the gear shifts performed under loading ('power-shift' type) the number of speeds is around twenty. It allows for a proper selection of the ratios gradation, it ensures an adequately low velocity of the first gear (even below 1 km/h) and it allows to reach the maximal speed of the top gear (access gear, max 50 km/h) [Fendt: Fav. 900, Jarchow and Blmenthal 1998, John Deere Ciagniki s. 6020.....].

The requirements mentioned above would be met in the easiest way by the gearboxes with the continuous change of the gears. The existing gears of these types – manual and hydrodynamic (and electric), because of their features (especially mechanical efficiency), are not possible to be directly implemented in the agricultural tractors.

### HYBRID GEARBOXES

In order to obtain the continuously variable gear ratio within the required spread, during transmission of high power, and with ensuring high reliability and durability of the transmission unit, the largest manufacturers implement particular models of their tractors with the hybrid gear boxes in their newest generation [Case IH CVT 1998, Aitzetmüller h. 1999, Claas Xerion, Fendt: Fav. 900..., John Deere Ciągniki s. 6020..., Lang *et al.* 1998, Pohlenz 1999].

They consist of the gears connected in parallel: hydrostatic with the continuous change of the gear ratio and stepped manual gearbox.

The operational principle of these gearboxes lies in dividing of the power provided by the engine into two power-fluxes configured in parallel through the stepped mechanical gear and through the hydrostatic gear. The ratio of the divided flux of the power depends on the shifted gear in the mechanical gear and settings of the hydrostatic gear. The fluxes are combined on the summating shaft, which plays a role of the gearbox's output shaft.

# HYBRID GEARBOX OF FENDT VARIO TRACTOR

The speeds of stepped gearboxes can define, dependently on the design, the ranges of the tractor's velocity (e.g. Fendt Vario – two ranges: heavy work and transport work) (Fig. 1, 2, 3) [Fendt: Fav. 900..., Żebrowski and Żebrowski 1993, Szydelski 2002] or can be used in order to obtain the required spread of the ratio changeable continuously (Fig. 5, 9, 12, 14)



Fig. 1. Kinetic scheme of the hybrid transmission of the tractor Fendt Vario [Żebrowski and Żebrowski 1993]



Fig. 2. Theoretical evolution of the efficiency in the domain of the velocity in the first range [Stockmar *et al.* 2003]



Fig. 3. View of the hybrid gearbox transmission of the Fendt Favorit Vario 924 type [Szydelski 2002]

The principle of the operation is that, the stepped ratio gear (planetary) shifted automatically has the gear's ratios designed in the way that on a particular shift of the planetary gear, the lowest ratio of the gearbox is referenced to the highest ratio of the gearbox on the higher shift. However, the shifting of the gears is accompanied by changes in the mechanical efficiency of the gearbox (Fig. 2, 9, 12, 14).

# HYBRID GEARBOXES: 'ECCOM TRANSMISSION' IN THE DEUTZ FAHR AGROTRON TRACTOR AND 'STEYR S-MATIC' IN THE CASE IH SERIES CVX TRACTOR

Figure 2 presents the design of 'Eccom transmission' gearbox by ZF Passau GmbH applied in tractors of Deutz Fafr Agrotron models: TTF 1130, 1145, 1160 developing power: 107, 123, 175 and 220 kW [Pohlenz 1999]. Figure 3 depicts the solution Steyr S-Matic proposed by Steyr-Daimler-Puch AG [Case IH CVT 1998, Aitzetmüller h. 1999] manufacturer for tractor produced by Case IH in series CVX (power 101–141 kW). Presently both companies were united with the new name ZF Steyr GmbH. Both of the gearboxes have 4-speed, planetary gears but with differences in the design details [Lang *et al.*1998].

In the Steyr S-Matic gearbox, claw clutches were used. The clutches: K1, K2, K3, K4, KF, KR are toothed elements.



Fig. 4. Kinetic scheme of the hybrid gearbox 'Eccom transmission' mounted in Deutz Fafr Agrotron TTF 1130, 1145, 1160 tractors



Fig. 5. Distribution of the angular velocity in the domain of the tractor's velocity









Fig. 7. View of the hybrid gearbox 'Eccom transmission' mounted in Deutz Fafr Agrotron TTF 1130, 1145, 1160 tractors



Fig. 8. Kinetic scheme of the Steyr S-Matic gearbox by Steyr-Daimler-Puch AG mounted in tractors Case IH series CVX [Case IH CVT 1998, Aitzetmüller 1999]



Fig. 9. Course of the mechanical efficiency on the successive gears in the domain of velocity in the Steyr S-Matic gearbox [Seeger 2001]



Fig. 10. View of the Sreyr S-Matic gearbox [Żebrowski and Żebrowski 1996]

## HYBRID GEARBOX OF XERION TRACTOR BY CLASS MANUFACTURER

Another design was used in the tractor Xerion manufactured by Class (Fig. 11, 12). It implements a 4-speed planetary gear configured in series with a 2-speed gear in the way that allows to get eight speeds [Class Xerion, Sauer 1998, Ivantysynova 2000, www.dspace.de].

Range	Power transmission	Gear rate	Running velocity	Running velocity, km/h	
			km/h	for $Nh = 0 \%$	
1	hydrostatic	~ 15.82	0-1.11	-	
2	Hydrost. & mech.	15.82-9.94	1.11-1.85	1.7	
3	Hydrost. & mech.	9.94-5.69	1.85-3.08	2.8	
4	Hydrost. & mech.	5.69-3.42	3.08-5.13	4.6	
5	Hydrost. & mech.	3.42-2.05	5.13-8.56	7.7	
6	Hydrost. & mech.	2.05 - 1.23	8.56-14.30	12.9	
7	Hydrost. & mech.	1.23-0.74	14.30-23.80	21.4	
8	Hydrost. & mech.	0.74-0.44	23.80-39.6	35.7	

Table 1. Velocity ranges on the particular gear ratios

The column in the Table 1 for Nh = 0% represents the velocities of the tractor when the hydrostatic gear does not transmit any power. It is referenced to the maximal efficiency for the particular speed.



Fig. 11. Hybrid gearbox used in the Xerion tractor manufactured by Class [www.dspace.de]: a) kinetic scheme of the HN8 gearbox, b) view of the Xerion hybrid gearbox



Fig. 12. Distribution of mechanical efficiency of the Xerion hybrid gearbox on the particular gear ratios

In the Xerion tractors by Class, it is possible to switch between so called operation modes, which automatically control the work. The following modes are available [Class Xerion]:

- to adjust the tractor's speed by keeping constant angular velocity of the engine ('lever strategy'),

- to adjust the tractor's speed by changing the angular velocity of the engine, with limiting of the maximal speed by means of the control lever on the gearbox ('acceleration pedal strategy'),

- keeping of the constant work velocity for various angular velocities of the engine ('constant velocity strategy'),

- operation on a defined constant output power level ('constant power strategy').

## HYBRID GEARBOX 'AUTOPOWR' IN JOHN DEERE SERIES 7020 TRACTOR

The John Deere manufacturer implemented in the tractors series 7020 (engines power 125–147 kW) the gearbox IVT called 'AutoPowr', which enables varying of the velocity from 0,05 km/h (50 m/h !) to 42 or 50 km/h [John Deere...].



Fig. 13. Kinetic scheme of the hybrid gearbox IVT 'AutoPowr' manufactured by John Deere and mounted in 7020 series tractors

The gearbox consists of planetary gear connected in parallel with hydrostatic gear. The planetary gear has two speeds forward and one reverse and is operated by two wet multiple-disc clutches and one brake. The hydrostatic gear has a variable delivery pump and a constant absorbing capacity of the turbine (both of the units have the same maximal unitary delivery). The principle of the gear operation is that, with the clutch KL closed, when the hydrostatic gear works with the maximal negative ratio, the cage of the planetary gear, which gives the power feed, does not rotate (the tractor does not move). Increasing of the gear ratio to the value zero and then a further increase to its maximal value, result in a growth of the tractor's velocity. A further increase of the tractor's velocity is continued after opening of the clutch KL and closing of the clutch HL and successive decreasing of the hydrostatic ratio to the minimal value (negative ratio by the maximal delivery of the pump).

### COMPARISON OF THE HYBRID GEARBOXES

In all of the variable-speed transmissions presented in this paper, the phenomenon of the total mechanical efficiency variation occurs (Fig. 2, 9, 12, 14). It is the result of two facts. The first is the existence of variations in the efficiency of the hydrostatic gear dependently on its actual ratio, and the second is variation of the power flux efficiency through the planetary gear, which comes from the direction of the power flux and its partition for the power transmitted by the relative movement and for the power transmitted by the transportation movement.



Fig. 14. Comparison of the gearboxes' efficiency: Steyr S-Matic mounted in the Case IH tractors series CVX, and HN8 mounted in the Xerion tractor manufactured by Class [Lang *et al.*1998]

Gearbox type	Fend Vario	Steyr S-Matic	Claas HM8	ZF Eccom	Jon Deere IVT
				transmission 1.5	"AutoPowr"
Input power, kW	190	125	140	107	125 - 147
Pump type	Variable axial	Variable axial	Variable axial	Variable axial	Variable axial
	piston pump in	piston pump in	piston pump in	piston pump in	piston pump in
	bent axis design	swash plate	swash plate	swash plate	swash plate
		design	design	design	design
Control range	From +45° to	±20°	±20°	±20°	±45°
Displacement	-30°				
volume		57 cm	$28 \text{ cm}^3$	$28 \text{ cm}^3$	$160 \text{ cm}^3$
	$233 \text{ cm}^3$				
Motor type	Variable axial	Axial piston	Axial piston	Axial piston	Axial piston
	piston motor in	motor in swash	motor in swash	motor in swash	motor in swash
	bent axis	plate design	plate design	plate design	plate design
Number	2	1	1	1	1
Control range	From - 0° to	Fixed displace-	Fixed displace-	Fixed displace-	Fixed displace-
Displacement	+45°	ment	ment 16 [cm <sup>3</sup> ]	ment	ment
	$2 \text{ x} 233 \text{ cm}^3$	$57 \text{ cm}^3$		$28 \text{ cm}^3$	$160 \text{ cm}^{3}$
Number of gears	2	4	8	4	2 + 1R
Shifting method	Synchromesh	Gear clutch	Gear clutch	Multiplate clutch	2 Multiplate
					clutch + 1 brake
Number of	1	3	2	4	1,5
planetarny gears					
Davana aaan	Nagativa aminal	Diamatamar as an	Devening coor	Daviancia o coor	Dlan atomax, anon
Reverse gear	negative swiver	Planetarny gear	Reversing gear	Reversing gear	Planetarity gear
Manimum tantus		500/	D	Energy 20 (c. 450/	500/
Maximum nydro-	100%	50%	Ranges I: 50%	From 30 to 45%	50%
static power ratio			other ranges 33%		
INN NH Q A C 1	22:50	0004165	1 7 9 9 4 6 7 7	0 0 10 00	10.25
Nh = 0 At forward	32150	2,9; 8,4; 16,5;	1,7; 2,8; 4,6; 7,7;	3; 9; 18; 36	10; 35
speed, km/h		30,9	12,9; 21,4; 35,7		$(V_{max} = 42)^*$

Table 2 Comparison sheets of the data characterizing the presented gearboxes.

\* V (km/h) given in accordance to the analysis of the author

In Table 2 the data describing the presented gearboxes are showed [Lang *et al.*1998] with additional data devoted to the case of the IVT 'AutoPowr' by John Deere.

#### CONCLUSIONS

1. The simplest designed gearbox is the one of the Fendt Vario tractor. It consists of one planetary series and the hydrostatic gear containing special hydrostatic units: variable delivery pump and turbines with variable absorbing capacity. The hydraulic units are characterized with large angles of the cylinders blocks (45 deg) and large delivery. However the efficiency of this gear is very low within the range of the low velocities. It results from the fact, that almost all of the transmitted power in the low velocity range is transmitted by hydrostatic gear. In this range the hydrostatic gear has very low efficiency of the pump by the low delivery and low efficiency of the turbine by the low angular velocity).

2. A little bit more advanced but still simple design was chosen in the case of JD 'AutoPowr' transmission gear. It consists of: two planetary series (one of them not full) controlled by means of two multiple disc wet clutches (forward speeds) and one multiple disc brake (reverse speed); hydrostatic gear, containing the pump of variable delivery and turbine of the constant absorbing capacity. Thanks to that solution, the control system of the gear is relatively simple.

3. The gearboxes 'Eccom transmission' and Steyr S-Matic consist of four planetary series but with different configurations. Both of them have four ranges of ratios. The 'Eccom transmission' gearbox is controlled by four multiple discs wet clutches and one multiple discs wet brake. Moreover, the gearbox has one multiple discs wet clutch to drive forward and one clutch of the same type to drive reverse. The Steyr S-Matic gearbox is controlled by four claw-toothed clutches. The forward drive and reverse drive is realized via two toothed clutches. The advantage of using of the toothed brakes and clutches is the lower price of manufacturing and exploitation (no need of the oil delivery for operation), and it increases the mechanical efficiency of the device (no viscous losses on the friction components). In both of the designs, the hydrostatic gears have the same principle of operation. They contain the pumps of variable delivery and the turbine of constant absorption capacity (hydraulic units of classical design, very popular on the market). This kind of the design requires more complicated system of the automatic control.

4. The most advanced mechanical design has the gearbox HN8 manufactured by Class. It consists of four speeds planetary gear connected in a series with two speed cylindrical gear, which give 8 speeds (velocity ranges) in total. Thanks to the fact, that the minimal value of the ratio on each gear is equal to the maximal ratio of the next gear, it was possible to use in the Steyr S-Matic gearbox the toothed clutches. This solution decreases the costs of the manufacturing and exploitation (no need of the oil delivery for operation), and it increases the mechanical efficiency of the device (no viscous losses on the friction components). The hydrostatic gear consists of the classical hydraulic units (pump of variable delivery and the turbine of constant absorption capacity). Moreover, it has the most advanced systems of the automatic control.

5. The hybrid gearboxes are treated as the newest and most advanced solutions on the market and are usually offered as optional equipment for the tractors equipped mostly with traditional gearboxes e.g. normally 'powershift' type. For example the John Deere manufacturer mounts in the tractors series 7020 the 'AutoPowr' gears or proved gearboxes type 'powershift': 'AutoQuad Plus' and 'PowrQuad Plus', which have constant and very high mechanical efficiency on each speed. The 'Powershift' gearboxes have proved their durability and reliability in a large amount of tractors that were manufactured.

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