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ANALYSIS OF THE PLANETARY GEAR OF RAVIGNEAUX TYPE AND ITS APPLICATION IN AGRICULTURAL TRACTORS

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Summary. This paper presents two variants of the planetary gear of Ravigneaux type. An analysis of the power flux through the gear on the particular speeds was derived and its usefulness in the agricultural tractors was discussed

Key words: agricultural tractor, planetary gear, power flux analysis

INTRODUCTION

The planetary gear unit Ravigneaux [Studziński 1973] in the standard version (two variants) consists of one full planetary series with the ring gear toothed internally, and the second non full planetary series, which contains the input sun gear and the planet long pinion interpenetrated with the pinion of the full planetary series. View of the planetary gear unit Ravigneaux is presented in Fig. 1 [Berger 2003], and kinematics diagram in Fig. 2.

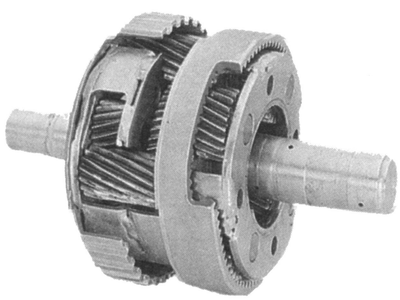

Fig. 1. View of the planetary gear unit Ravigneaux

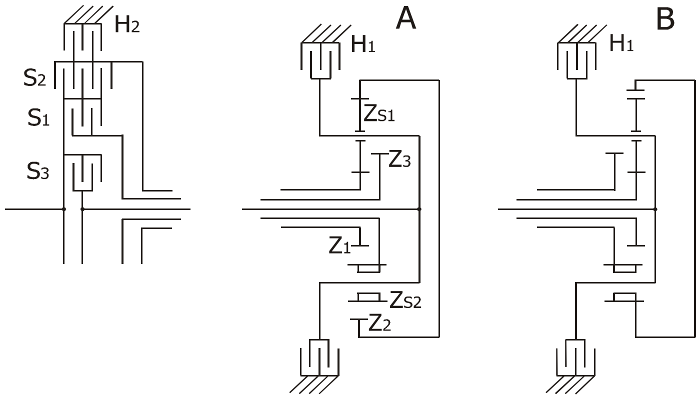

Fig. 2. Ravigneaux gear system in the two basic variants: A and B

The system enables to obtain four speeds forward and one speed reverse. It is controlled by a system of three clutches and two brakes. During the shifting of the speeds (Table 1) from the first to the third during driving forwards, all the time one of the clutches (S_1) is closed and the following are switched successively: two brakes (H_1) and (H_2) and the clutch (S_2). The fourth speed (with the ratio lower than one) is obtained by closing of the clutch (S_2) and the brake (H_2), which are not used on the lower speeds (necessity of switching two elements at the same time). On the reverse speed one brake (H_1) and one clutch (S_2) are closed. The power is taken from the ring gear. This type of unit is used widely in automatic gearboxes in passenger cars.

Table 1

	Speed 1	Speed 2	Speed 3	Speed 4	Reverse
Clutch S_1	X	X	X		
Clutch S_2			X (B)		X
Clutch S_3			X (A)	X	
Brake H_1	X				X
Brake H_2		X		X	

ANALYSIS OF THE PLANETARY GEAR OF RAVIGNEAUX TYPE

In the result of stopping and coupling of various elements in the gear on the particular speeds, the power flux has different character for the successive speeds and it has an influence on its mechanical efficiency [Müller 1971]. For that reason the power flux was determined for particular speeds with taking into account the separation for the part transmitted by the transportation movement (no losses) and the part transmitted by the relative movement, so by the gears (with losses) [Żebrowski, Żebrowski 1987].

The power transmitted by an element ‘x’ can be noted as (1):

$$N_{wx} = M_x \cdot \omega_{wx} \tag{3}$$

and its component transmitted with the transportation movement:

$$N_{ux} = M_x \cdot \omega_0 \tag{2}$$

and its component transmitted with the relative movement:

$$N_x = M_x \cdot \omega_x \tag{1}$$

where:

M_x – torque transmitted by the element ‘x’,
ω_x – angular velocity of the element ‘x’,
ω_0 – transportation angular velocity of the element ‘x’ (angular velocity of the cage of the planetary gear, in which the element ‘x’ is mounted),
$\omega_{wx} = \omega_x - \omega_0$ – relative angular velocity of the element ‘x’.

The ratios of the gearbox with the particular speeds were determined with the Willis’ formula:

– On the first speed (the gearbox operates analogically to the cylindrical gear) the ratio can be noted as follows:

$$i_1 = \frac{z_2}{z_3} \tag{4}$$

and the efficiency:

$$\eta_1 = \eta_{032} = \eta_z^2 \eta_w \tag{5}$$

where:

η_z – efficiency of the external gear,
η_w – efficiency of the internal gear.

– On the second speed the ratio is equal to:

$$i_2 = \frac{\omega_3}{\omega_2} = i_{32}^0 - \frac{\left(1 - i_{32}^0\right) \cdot i_{12}^0}{1 - i_{12}^0} \tag{6}$$

where:

$$i_{12}^0 = -\frac{z_2}{z_1}, \qquad i_{32}^0 = \frac{z_2}{z_3} \tag{7}$$

The power flux on the second gear is the most complicated among the cases of all the speeds. The determined scheme of the powerflux is presented in Figure 3.

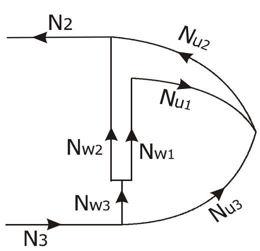

Fig. 3. Power flux scheme for the second speed

On the basis of the introduced scheme of the power flux the following formula of the efficiency was derived:

$$\eta_2 = \eta_{32} = \frac{N_2}{N_3} = \frac{i_{12}^0}{i_{12}^0 - i_{32}^0}\left(1 - \frac{1 - i_{32}^0}{1 - i_{12}^0}\eta_{031}\right) + \frac{1}{1 - i_{12}^0}\eta_{032} \tag{8}$$

where:

$$\eta_{031} = \eta_z^3, \qquad \eta_{032} = \eta_z^2 \eta_w \tag{9}$$

– On the third speed the closed clutches block the planetary system which implies that the ratio is $i_3 = 1$ and no power losses in the gears occur.
– The ratio of the fourth speed can be noted as:

$$i_4 = \frac{\omega_0}{\omega_2} = \frac{i_{12}^0}{i_{12}^0 - 1} \tag{10}$$

Figure 4 presents the scheme of the power flux with the fourth speed

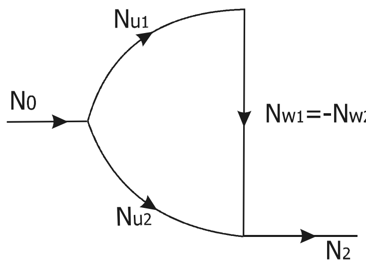

Fig. 4. Power flux scheme on the fourth speed

The efficiency on the fourth speed is as follows:

$$\eta_4 = \eta_{02} = \frac{\eta_{012}\left(1 - i_{12}^0\right)}{1 - \eta_{012} i_{12}^0} \tag{11}$$

where:

$$\eta_{012} = \eta_z \eta_w \tag{12}$$

The ratio of the reverse speed (cylindrical gear case) can be noted as:

$$i_W = \frac{\omega_1}{\omega_2} \tag{13}$$

and the efficiency:

$$\eta_W = \eta_{12} = \frac{N_2}{N_1} = \eta_{012} \tag{14}$$

The described Ravigneaux systems are used also in the agricultural tractor's gear-boxes.

APPLICATION OF THE PLANETARY GEAR RAVIGNEAUX TYPE IN AGRICULTURAL TRACTORS

The Ravigneaux systems in the tractor's garboxes have many applications [Żebrowski and Żebrowski 2000]. In Figure 5 an example of the system is presented, which was used by the Case manufacturer [Materials of CASE IH].

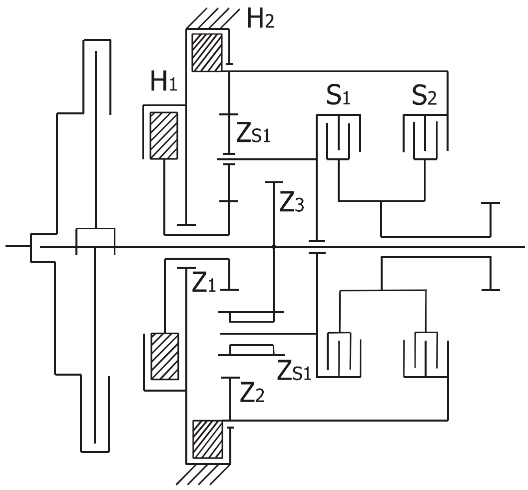

Fig. 5. Scheme of the Ravigneaux system used by Case manufacturer

The power input is on the gear z_3 and the output is from the gear z_2 or on the planetary cage with the assistance of the clutches S_1 and S_2. With the help of the brakes H_1 and H_2 the gears z_1 and z_2 can be stopped. Effectively, the system can provide three speeds forward and one speed reverse. Table 2 shows which elements are closed on the particular speeds.

Table 2

	Speed 1	Speed 2	Speed 3	Reverse
Clutch S_1	X		X	X
Clutch S_2		X	X	
Brake H_1	X	X		
Brake H_2				X

– The ratio of the first speed can be noted as:

$$i_1 = \frac{\omega_3}{\omega_0} = \left(1 - \frac{1}{i_{13}^0}\right) \tag{15}$$

where:

$$i_{13}^0 = -\frac{z_3}{z_1} \tag{16}$$

And the efficiency formula can be derived on the basis of the presented power flux scheme (Fig. 6):

$$\eta_{30} = \frac{N_O}{N_3} = \frac{\eta_0\left(1 - i_{13}^0\right)}{1 - \eta_0 i_{13}^0} \tag{17}$$

where:

$$\eta_0 = \eta_z^3 \tag{18}$$

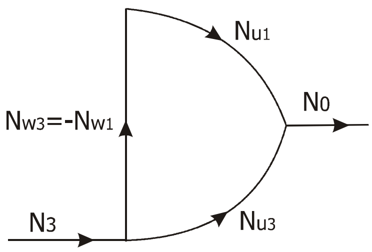

Fig. 6. The scheme of the power flux in the system on the first speed

- On the second gear the ratio, the power flux scheme and the efficiency formula are identical with the second speed of the Ravigneaux system, described previously (8), (9), (Fig. 3).
- On the third speed the closed clutches block the planetary system, which results in the ratio $i_3 = 1$ and results in no mechanical losses on the gears.
- The gear ratio of the reverse speed can be noted as:

$$i_w = \frac{\omega_3}{\omega_0} = 1 - i_{32}^0 \tag{19}$$

The scheme of the power flux on the reverse speed is showed in Figure 7, and the mechanical efficiency of the reverse speed efficiency derived on its basis can be noted as:

$$\eta_w = \eta_{30} = \frac{N_0}{N_3} = \frac{1 - \eta_{032} i_{32}^0}{1 - i_{32}^0} \tag{20}$$

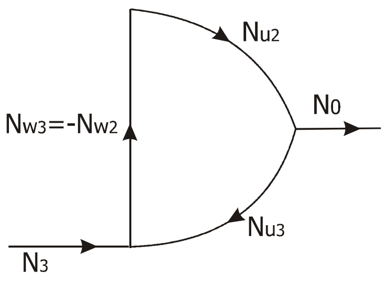

Fig. 7. Scheme of the reverse gear power flux

The determined, with the derived formulas, values of the ratios and efficiencies on the particular speeds (dependently on the teeth number and the gear efficiency) were put into Table 3.

Table 3

	Speed 1	Speed 2	Speed 3	Reverse
Ratio	1.6666	1.2500	1.0000	-1.0000
Efficiency	0.9818	0.9847	1.0000	0.9308

The modified Ravigneaux system is also a part of a 19 speed gearbox 'powershift' type applied by John Deere manufacturer in the tractors of series 7000 (part III) [John Deere Trans. 1992].

Figure 8 represents the scheme of the part of this gearbox. The power input element for the system Ravigneaux (part III) for all the speeds is the planetary cage and the output element is the shaft on which the first sun gear is positioned (z_7 – larger).

In comparison to the classical Ravigneaux system, in the newest version of the gearbox was added the ring gear z_8 (in the previous version there was no gear in this place and the system had a classical configuration). The gears z_8 and z_9 can be stopped with the wet multiple discs brakes and the clutch enables connecting the planetary cage with the gear z_{10}. This solution enables to get three speeds forward and one speed reversed, but in each configuration only one friction element was closed. This feature makes the control of the whole unit simpler as the changes of the speeds require only switching between the friction elements.

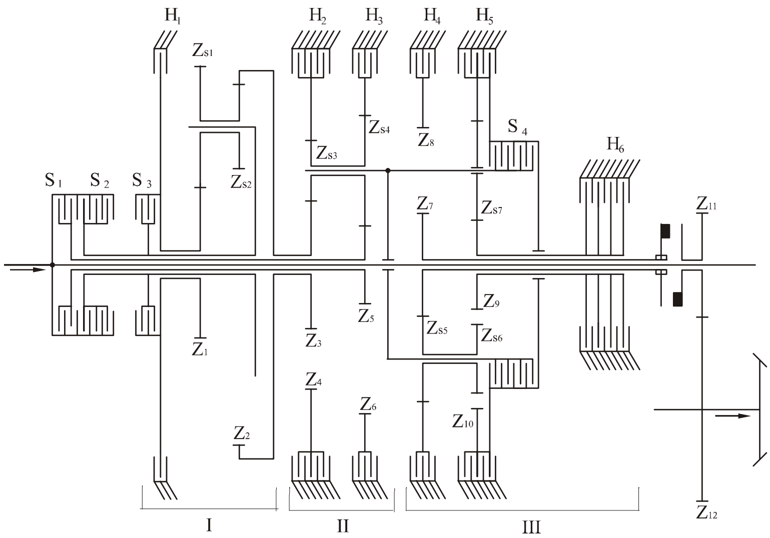

Fig. 8. Scheme of the modified Ravigneaux system as a part of a 19-speed gearbox 'powershift' type applied by John Deere [1992] manufacturer in the tractors of the series 7000 – part III

Table 4 presents which elements are required to be closed for the particular speeds.

Table 4

	Speed 1	Speed 2	Speed 3	Reverse
Clutch S_4	X			
Brake H_4			X	
Brake H_5				X
Brake H_6		X		

The ratios of the particular speeds, the determined schemes of the power fluxes and the derived formulas of the efficiency (dependently on the gear's teeth numbers and the gears efficiencies) are presented below [Żebrowski 2002]:

– First speed:

Ratio $i_1 = 1;$

No mechanical losses occur in the gears (direct speed)

– Second speed:

$$i_2 = \frac{i_{97}^0}{i_{97}^0 - 1}$$

Ratio
$$i_2 = \frac{i_{97}^0}{i_{97}^0 - 1} \tag{21}$$

where:

$$i_{97}^0 = -\frac{z_{s6} z_7}{z_9 z_{s5}} \tag{22}$$

The scheme of the power flux is presented in Figure 9.

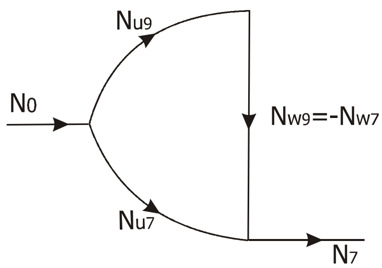

Fig. 9. Power flux scheme on the second speed

Efficiency

$$\eta_2 = \frac{\eta_{079}\left(1 - i_{97}^0\right)}{1 - \eta_{97}^0 i_{97}^0} \tag{23}$$

where:

$$\eta_{079} = \eta_z^3 \tag{24}$$

– Third speed:

Ratio
$$i_3 = \frac{1}{1 - i_{78}^0} \tag{25}$$

where:

$$i_{78}^{0} = -\frac{z_8}{z_7} \tag{26}$$

The scheme of the power flux is presented in Figure 10.

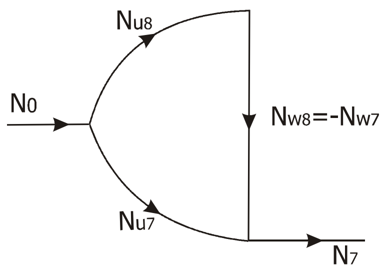

Fig. 10. Power flux scheme on the third speed

Efficiency

$$\eta_3 = \frac{\eta_{078}\left(1 - i_{78}^{0}\right)}{\eta_{078} - i_{78}^{0}} \tag{27}$$

where:

$$\eta_{078} = \eta_z \eta_w \tag{28}$$

– Reverse speed:

Ratio

$$i_w = \frac{1}{1 - i_{710}^{0}} \tag{29}$$

where:

$$i_{710}^{0} = \frac{z_{s5} z_{10}}{z_7 z_{s6}} \tag{30}$$

The scheme of the power flux is presented in Figure 11.

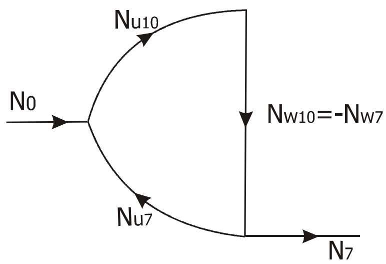

Fig. 11. Power flux scheme on the reverse speed

Efficiency

$$\eta_w = \frac{\eta_{0710}\left(1 - i_{710}^0\right)}{\eta_{0710} - i_{710}^0} \tag{31}$$

where:

$$\eta_{0710} = \eta_z^2 \eta_w \tag{32}$$

Values of the ratios and efficiencies on the particular speeds determined with the presented formulas are presented in Table 5.

Table 5

	Speed 1	Speed 2	Speed 3	Reverse
Ratio	1.0000	0.5576	0.3226	-0.6224
Efficiency	1.0000	0.9799	0.98641	0.9450

On the basis of the presented examples it can be concluded that in the gearboxes for tractors not all the possible speeds are used. Both manufacturers: Case and John Deere, use three speeds forward and one speed reversed but obtained in different ways. The power input is always, whichever speed is realized, on the same element (gear z_1 – Case, planetary cage – John Deere).

In the gearbox from Case two clutches and two brakes are used. On each speed two of the friction elements must be closed but gear shifting is obtained via switching only one friction element. The Ravigneaux system is utilized in the way that the first and the second gears are reducing and the third gear is direct. On the reversed gear the obtained ratio is equal minus one (during the work of the planetary series), which is accompanied by the circulating power phenomenon and decreases the efficiency of the gearbox on that speed in comparison to the internal efficiency of the planetary series. On the forward speeds the total efficiency of the gearbox is higher than the internal efficiency of the planetary series in work.

In the John Deere's gearbox, because of different application of the modified Ravigneaux system, there exist three brakes and one clutch (the design is better from the point of view of the used friction elements). Shifting the speeds is obtained via switching only one friction element. In this case the first speed is direct – the ratio is equal to the one. The rest of the speeds have the ratios lower than one. This solution requires an implementation of the reduction gears in the further part of the transmission system, which have higher ratios than the reduction gears used in the case of the Case manufacturer. Also on the reversed speed the ratio is lower than one, which provokes the occurrence of the circulating power phenomenon. According to this fact the total efficiency of the gearbox on the reverse gear is lower than the internal efficiency of the planetary series working inside. On the forward speeds the total efficiency of the gearbox is higher than the internal efficiency of the planetary series in work.

CONCLUSIONS

1. The presented and analyzed systems of Ravigneaux type gears are transmissions of the 'power-shift' type. Because of the number of speeds and the range of the ratios of the particular speeds (1.323 and 1.250 Case or 1.793 and 1.729 John Deere) they play

the role of primary or final part of the whole gearbox. In the Case's gearbox the Ravigneaux system is the primary part of the whole transmission system that transmits the power to the traditional stepped gear after opening of the clutch (operation ranges). In the case of the John Deere (JD) gearbox, the Ravigneaux system is the final part of the transmission system, which is fed with the power by a 'power-shift' gear. The JD gearbox enables shifting of all the speed under the load.

2. As it was presented in the analysis of the Ravigneaux systems used in tractors, the realization of the speeds in terms of the proper ratios and control of the speeds' shifting is different to the solutions used in the passenger cars (with the exception of the second speed in the Case's system).

3. In the terms of the control, in both of the designs, three forward speeds are used and one reversed speed. The speeds shifting are realized via switching only one friction element.

4. The efficiencies of the systems coming from the losses in the gears, on the forward speeds with the ratio not equal to one, are not lower than 0.98. On the reversed speed both of the gearboxes are characterized by the circulating power, which gives as the result an increase in the planetary gear load and decrease in the efficiency of the systems (0.93 Case and 0.95 John Deere).

5. The most complicated power flux occurs in the case of the second speed in the Case gearbox. However, the efficiency on that speed is high and its value is equal to 0.98.

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