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Hybrid Transmission with Simple Planetary Gear

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Abstract
This article discusses the aspects of expansion of layout and operation possibilities of land vehicles by means of continuously variable transformation and transfer of torque without interruption in torque delivery upon using of electric generator and electric motor in combination with planetary gear. Design and kinematic possibilities of hybrid transmission with simple three-link planetary gear are presented. Continuously variable transformation and transfer of torque in hybrid transmission of land vehicles are reviewed. This article describes operation of hybrid transmission with simple three-link planetary gear implemented as follows: drive only by internal combustion engine; drive only by electric motor; simultaneous drive by internal combustion engine and electric motor. Technical and economical assessment of hybrid transmission with simple three-link planetary gear is given gear.
Keywords: Hybrid transmission, electric generator, electric motor, simple planetary gear, planet carrier, sun gear, epicyclic wheel, design, kinematics.

INTRODUCTION

Hybrid transmissions on the basis of electric machines and mechanic reducers are widely applied. These facilities provide operation of internal combustion engine (ICE) in optimum mode with minimum fuel consumption and emission of harmful exhaust gases. Planetary gears of small sizes and weight can best meet the requirements to reduce metal intensity of machines [2].

SIMPLE PLANETARY GEAR

Simple PG (planetary gear) is comprised of three links (Figure 1): sun gear (***a***) - No. 7, epicyclic wheel (***b***) - No. 16, and planet carrier (***h***) No. 18 with satellite gears - No. 21. PG is characterized by internal parameter $K = Z_b / Z_a = 1{,}5 - 5$, which equals to the ratio of teeth number of epicyclic wheel Z_b to teeth number of sun gear Z_a. The minimum value K is restricted by minimum sizes of satellite gears, the maximum value is restricted by those of sun gear [1].

Design and Kinematics of Hybrid Transmission with Simple Planetary Gear

Figure 1 illustrates kinematic layout of hybrid transmission with simple three-link PG.

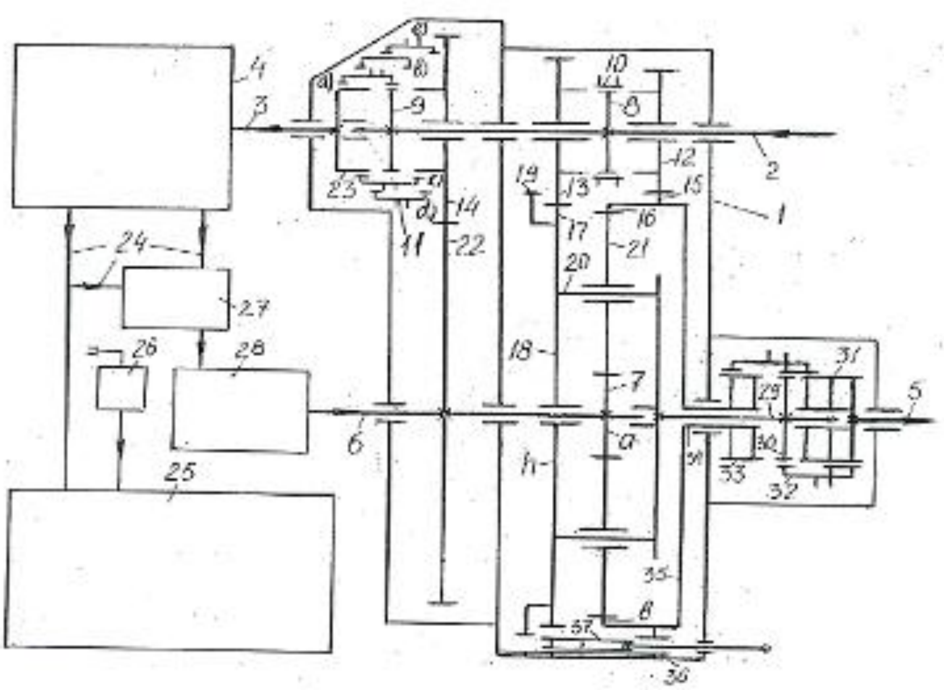

Figure 1. Kinematic layout of hybrid transmission with simple three-link planetary gear upon torque input and output from one reducer side – from the right.

The reducer housing supports 1 contain the coaxially installed input shaft 2 and the driving shaft 3 of the electric generator 4; the input shaft 5 and the driving shaft 6 of the sun gear 7 (a) are installed in parallel to them. Two gear rings 8 and 9 are positioned on the input shaft 2, the three-position shifting clutch 10 is installed on the gear ring 8 and the five-position shifting clutch 11 is positioned on the gear ring 11, in addition, three cylindrical gears 12, 13 and 14 are positioned loosely. The shifting clutch 11 can provide five positions: a) it couples the gear ring 9 with the gear ring 23 of the shaft 3; b) and d) - neutral state; c) ot couples the gear ring 14 with the gear ring 23 of the shaft 3; e) it couples the gear ring 9 with the gear ring 14. Near the first gear ring 8 the gears 12 and 13 are positioned, they are engaged with the tooth cylindrical wheels 15 of the epicyclic wheel drive 16 (b) and 17 of the planet carrier drive 18 (h) with the additional gear ring 19. On the axles 20 of the planet carrier 18 (h) the satellite gears 21 are positioned engaged with the sun gear 7 (a) and the epicyclic wheel 16 (b). Near the second gear ring 9 the gear 14 is positioned engaged with the teeth cylindrical wheel 22 of the shaft 6 of the sun gear drive 7 (a) and the gear ring 23 of the shaft 3 of the electric generator drive 4, which interacts via the electric circuits 24 with the battery 25, equipped with the power supply 26, and via the control unit 27 with the electric motor 28 of the shaft 6 of the sun gear drive 7 (a). It is recommended to apply the high-speed electric AC generator 4 with rectifier. On the shaft 29 of the planet carrier 18 (h) the one-position ring 30 is mounted, positioned between the three-position gear ring 31 of the output shaft 5 with the three-position shifting clutch 32 and the two-position gear ring 33 mounted on the sleeve shaft 34 of the housing 35 of the epicyclic wheel wheel 16 (b), inside the reducer housing 1 the gear ring 36 is mounted equipped with three-position clutch 37 of shutdown of the planet carrier 18 (h) via the supplemental gear ring 19 or the epicyclic wheel 16 (b) via the cylindrical wheel 15 of its housing 35.

Simple three-link PG can provide 7 gears in reducing modes and 3 gears in summing modes when the torque is transferred to two links and took off from the third one [1].

Summation possibilities of PG for our case are described as follows:

$$\boldsymbol{n_h = U_{ha}^{b}\, n_a + U_{hb}^{a}\, n_b = n_a/(K + 1) + (n_b\, K)/(K + 1);}$$

$$\boldsymbol{n_b = U_{bh}^{a}\, n_h + U_{ba}^{h}\, n_a = n_h\,(K + 1)/K - n_a\,/K;}$$

where $\boldsymbol{n_a}$, $\boldsymbol{n_h}$, $\boldsymbol{n_b}$ are the rotation frequencies of sun gear, planet carrier and epicyclic wheel in rpm, respectively [1].

Operation of hybrid transmission with simple three-link PG can be implemented by means of several methods: I. Drive only by ICE the via input shaft 2. II. Drive only by the electric motor 28 via the shaft 6. III. Drive simultaneously by ICE and electric motor. The drive of the electric generator 4 for power supply to battery can be provided at the 1-st and 2-nd modes by the five-position clutch 11 in the (a) position.

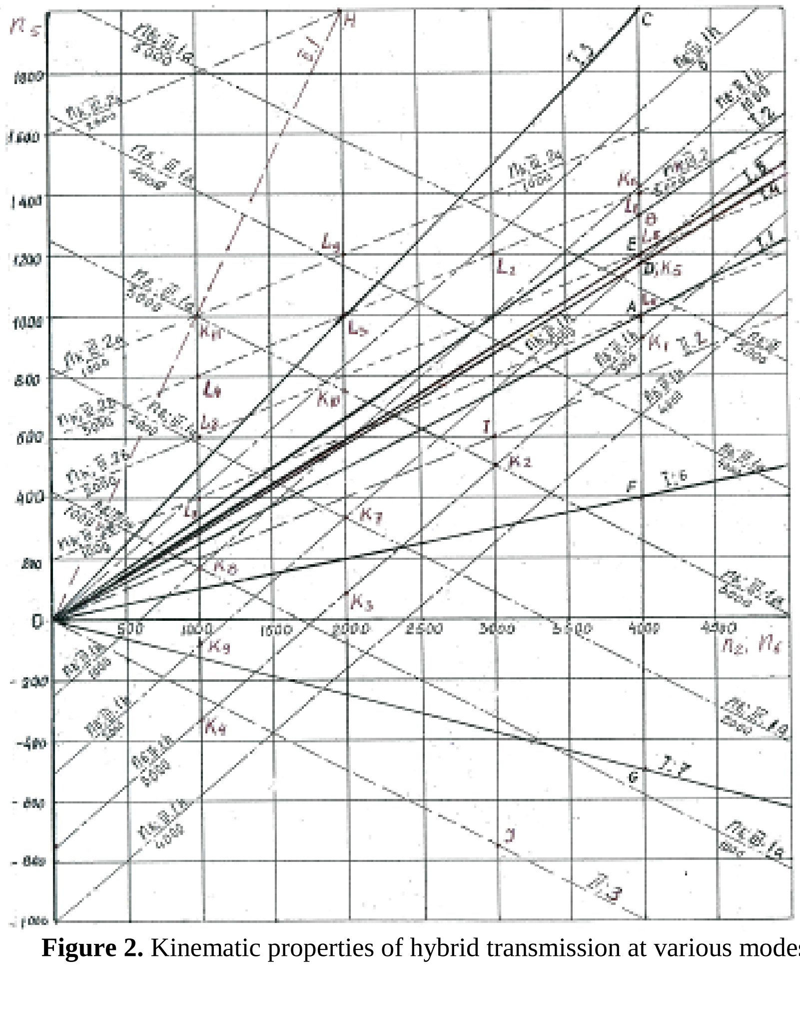

Figure 2. Kinematic properties of hybrid transmission at various modes.

Figure 2 illustrates kinematic properties of hybrid transmission at various modes. Abscissa shows rotation frequency of the input shaft 2 or the shaft 6 of the electric motor 28. Ordinate shows rotation frequency of the output shaft 5.

Operation of Hybrid Transmission Driven by Internal Combustion Engine

The first method is presented by seven solid lines starting at the origin: Point 0. From top to downward: I.3; I.2; I.5; I.4; I.1; I.6, and I.7. Only ICE can provide several operation modes:

Mode I.1. The cylindrical gear 12-15 (Figure 1) onto locked PG. The clutch 11 in neutral position c) or d). The PG is locked by the clutch 32 engaging the ring gears 33 of the sleeve shaft 34 of the housing 35 of the epicyclic wheel 16 (b) and 30 of the shaft 29 of the planet carrier 18 (h). The right wide internal gear ring of the clutch 32 (upper position) locks the gear ring 30 with the gear ring 31 of the output shaft 5. The torque from the input shaft 2 via the gear ring 8 and the clutch 10 in the right-side position is transferred by the cylindrical couple 12-15 to locked PG and by the clutch 32 to the output shaft 5. If $n_{\text{in}} = n_2 = 4000$ rpm; $U_{\text{cyl 12-15}} = 4{,}0$; then the rotation frequency of the output shaft is $n_{\text{out}} = n_5 = =4000/4 = 1000$ rpm. In Figure 2 this value is on the line I.1 in Point A.

Mode I.2. The cylindrical gear 13-17 onto locked PG. The torque from the input shaft 2 via the gear ring 8, the clutch 10 in the left-side position, by the cylindrical couple 13-17 is transferred to the locked PG and by the clutch 32 to the output shaft 5. If $n_{\text{in}} = n_2 = 4000$ rpm; $U_{\text{cyl 13-17}} = 3{,}0$; then the rotation frequency of the output shaft is $n_{\text{out}} = n_5 = 4000/3 = 1333{,}3$ rpm. In Figure 2 this value is on the line I.2 in Point B.

Mode I.3. The cylindrical gear 14-22 onto locked PG. The clutch 10 in neutral position. The torque from the input shaft 2 via the gear ring 9 and the clutch 11 in the position e), by the cylindrical couple 14-22 is transferred to the locked PG and by the clutch 32 to the output shaft 5. If $n_{\text{in}} = n_2 = 4000$ rpm; $U_{\text{cyl 14-22}} = 2.0$; then the rotation frequency of the output shaft $n_{\text{out}} = n_5 = 4000/2 = 2000$ rpm. In Figure 2 this value is on the line I.3 in Point C.

Mode I.4. Summing mode, when we supply torque to the sun gear (a) and the planet carrier (h), with subsequent taking off from the epicyclic wheel (b). The torque from the input shaft 2 via the gear ring 9, the clutch 11 in the position e), by the cylindrical couple 14-22 is transferred to the shaft 6 and the sun gear 7 (a), which rotate the satellite gears 21, also from the input shaft 2 of the gear ring 8 by the clutch 10 in the left position, by the cylindrical couple couple 13-17 is transferred to the planet carrier 18 (h), which by the axles 20 moves the satellite gears 21. Combined force from two links of the PG is transferred to the epicyclic wheel 16 (b), via the housing 35 to the sleeve shaft 34 and the gear ring 33. The clutch 32 in the middle position transfers the increased torque from the gear ring 33 to the gear ring 31 and the output shaft 5, which rotates at lower speed. If $n_{\text{in}} = n_2 = 4000$ rpm; K = 4,0; $U_{\text{cyl 14-22}} = 2{,}0$; $U_{\text{cyl 13-17}} = 3{,}0$; then the rotation frequency of the output shaft is $\boldsymbol{n_b = n_h (K + 1)/K - n_a /K}$ = (4000/3) (5/4) – (4000/2)/4 = 1666,7 – 500 = 1166.7 rpm. U = 4000/1166,7 = 3.43. In Figure 2 this value is on the line I.4 in Point D.

Mode I.5. Summing mode, when we supply torque to the sun gear and the epicyclic wheel, then take off from the planet carrier. The torque from the input shaft 2 via the gear ring 9, the clutch 11 in the position e), by the cylindrical couple 14-22 is transferred to the shaft 6 and the sun gear 7 (a), which rotates the satellite gears 21, also from the input shaft 2 via the gear ring 8 by the clutch 10 in the right-side position, the cylindrical couple 12-15 is transferred to the epicyclic wheel16 (b), which also rotates the satellite gears 21. Combined force from two links of the PG is transferred to the axles 20, the planet carrier 18 (h), the shaft 29, the gear ring 30. The clutch 32 in the right-side position (below) transfers the increased torque from the gear ring 30 to the gear ring 31 and the output shaft 5, which rotates at lower frequency. If $n_{\text{in}} = n_2 = 4000$ rpm; $U_{\text{cyl 14-22}} = 2{,}0$; $U_{\text{cyl 12-15}} = 4{,}0$; K = 4,0; then the rotation frequency of the output shaft is $n_{\text{out}} = n_5 = \boldsymbol{n_h = n_a/(K + 1) + (n_b K)/(K + 1)}$ = = (4000/2) /5 + (4000/4)(4/5) = 400 + 800 = 1200 rpm. U = 4000/1200 = 3.33. In Figure 2 this value is on the line I.5 in Point E.

Mode I.6. The cylindrical gear 14-22 plus PG in reducing mode $\boldsymbol{U_{ah}^{b} = K+1}$. The superscript «b» indicates at stopped PG link - the epicyclic wheel 16 «b», the subscripts – to the input links «a» - the sun gear 7 (a) and output «h» of torque – the planet carrier 18 (h). The epicyclic wheel 16 «b» is stopped by the clutch 37 in the right-side position engaging the gear ring 36 of the housing 1 and the cylindrical teeth wheel 15 with the housing 35. The torque from ICE via the input shaft 2, the gear ring 9 and the clutch 11 in the position in the position e) is transferred via the cylindrical gearing 14-22 to the shaft 6, the sun gear 7 (a), the satellite gears 21 and rotates by the axles 20 the planet carrier 18 (h) with regard to the stopped epicyclic wheel 16 «b» at lower rotation frequency but with increased torque. If we assume that K = 4.0; then the rotation frequency of the planet carrier 18 (h) and the driven shaft 5 will be 5 times lower than that of the sun gear 7 (a), which is determined by the rotation frequency of the input shaft 2. If the rotation frequency of the input shaft 2: $n_{\text{in}} = n_2 = 4000$ rpm; $U_{\text{cyl 14-22}} = 2.0$; then $n_{\text{out}} = n_5 = (n_2 / U_{\text{cyl 14-22}})/(\text{K}+1) = (4000/2)/5 = 400$ rpm. In Figure 2 this value is on the line I.6 in Point F.

Mode I.7. The cylindrical gear 14-22 plus PG in reducing mode $\boldsymbol{U_{ab}^{h} = - K}$. The superscript «h» indicates at stopped

PG link - the planet carrier 18 (h), the subscripts – to the input links «a» - the sun gear 7 (a) and output «b» of torque – the epicyclic wheel 16 «b». The planet carrier 18 (h) is stopped by the clutch 37 in the right-side position engaging the supplemental gear ring 19 of the cylindrical wheel 17 of the PG planet carrier drive 18 (h) with the housing 1 of the reducer. The torque from ICE via the input shaft 2, the gear ring 9 and the clutch 11 in the position e) is transferred via the cylindrical gearing 14-22 to the sun gear 7 (a), the satellite gears 21 and rotates by the axles 20 the epicyclic wheel 16 «b» with regard to the stopped planet carrier 18 (h) in reverse direction at lower rotation frequency but with increased torque. If we assume that the rotation frequency of the input shaft 2: $n_{in} = n_2 = 4000$ rpm; $U_{cyl\ 14\text{-}22} = 2.0$; then $n_{out} = n_5 = 4000/(2\times4) = - 500$ rpm. The minus sign indicates at reversing of rotation of the output link with regard to the input. In Figure 2 this value is on the line I.7 in Point G.

Operation of Hybrid Transmission Driven by Electric Motor

In Figure 2 the operation modes of the second approach are highlighted by dotted lines. Only from electric motor – the following operation modes can be provided: 1. Direct transmission by locked PG. 2. Reducing mode $\boldsymbol{U_{ah}^{b} = K+1}$. 3. Reducing mode $\boldsymbol{U_{ab}^{h} = -K}$. Operation of the electric generator 4 from ICW can be provided by the input shaft 2 via the gear ring 9, the clutch 11 in the position a), via the gear ring 23 and the shaft 3. The clutches 10 and 11 are in neutral position and disengage ICE.

Mode II.1. The torque from the electric motor 28 is transferred via the shaft 6 to the sun gear 7 (a), then via the locked PG to the input shaft 5, as in the modes I.1, I.2 and I.3. If the rotation frequency of the electric motor 28 and the shaft 6: $n_{el.mot.} = n_6 = 2000$ rpm; then n_{out} also equals to 2000 rpm. In Figure 2 this value is on the line II.1 in Point H on the upper horizontal line.

Mode II.2. The torque from the electric motor 28 is transferred via the shaft 6 to the sun gear 7 (a) and then as in the mode I.6. If the rotation frequency of the electric motor 28 and the shaft 6: $n_{el.mot.} = n_6 = 3000$ rpm; then $n_{out} = n_5 = 3000/5 = 600$ rpm. In Figure 2 this value is on the line II.2 in Point I.

Mode II.2. The torque from the electric motor 28 is transferred via the shaft 6 to the sun gear 7 (a) and then as in the mode I.7. If the rotation frequency of the electric motor 28 and the shaft 6: $n_{el.mot.} = n_6 = 3000$ rpm; then $n_{out} = n_5 = 3000/4 = - 750$ rpm. In Figure 2 this value is on the line II.3 in Point J at the bottom.

Operation of Hybrid Transmission Driven Simultaneously by Internal Combustion Engine and Electric Motor

In order to supply power to the battery 25 the electric generator can be driven by ICE via the input shaft 2, the gear ring 9 and the clutch 11 in the position "a" via the gear ring 23 and the shaft 3. In Figure 2 these modes are indicated by dashed lines.

Mode III.1. Summing mode, when we transfer the torque to the sun gear (a) and the planet carrier (h), then take off from the epicyclic wheel (c). This mode is described as follows: $\boldsymbol{n_b = n_h (K + 1)/K - n_a /K}$ similar to the mode I.4, only with direct drive to the sun gear from electric motor and not from ICE via the gears 14-22.

The torque from the electric motor 28 is transferred by the shaft 6 to the sun gear 7 (a), which rotates the satellite gears 21, from the input shaft 2 via the gear ring 8 and the clutch 10 in the left-side position, the cylindrical couple 13-17 and transferred to the planet carrier 18 (h), which by the axles 20 moves the satellite gears 21. Combined force of two PG links is transferred to the epicyclic wheel 16 (b), via the housing 35 tot the sleeve shaft 34 and the gear ring 33. The clutch 32 in the middle position transfers the increased torque from the gear ring 33 to the gear ring 31 and the output shaft 5, which rotates at lower frequency.

Rotation frequency of the output shaft can be varied both by ICE and electric motorm or simultaneously by ICE and electric motor. For instance, we vary the ICE rotation frequency: 4000, 3000, 2000 and 1000 rpm.

If $n_{in} = n_2 = 4000$ rpm; $U_{cyl\ 13\text{-}17} = 3{,}0$; $n_{el.mot.} = n_6 = 3000$ rpm; K = 4,0; then the rotation frequency of the output shaft is $n_{out} = n_5 = \boldsymbol{n_b = n_h (K + 1)/K - n_a /K}$

$n_5 = (4000/3)\,(5/4) – 3000/4 = 1666.7 – 750 = 916.7$ rpm. Point K_1.

$n_5 = (3000/3)\,(5/4) – 3000/4 = 1250 – 750 = 500$ rpm. Point K_2.

$n_5 = (2000/3)\,(5/4) – 3000/4 = 833.3 – 750 = 83.3$ rpm. Point K_3.

$n_5 = (1000/3)\,(5/4) – 3000/4 = 416.7 – 750 = - 333.3$ rpm. Point K_4.

In Figure 2 these values are on the dashed line $\boldsymbol{n_b}$**;** III.1**h**, 3000 (the speed of planet carrier **h** varies at constant speed of sun gear), originating from Point -750 on ordinate in the bottom part upward from the right.

We vary the electric motor rotation frequency: 2000 and 1000 rpm.

$n_5 = (4000/3)\,(5/4) – 2000/4 = 1666.7 – 500 =1166{,}7$ rpm. Point K_5 on the line $\boldsymbol{n_b}$**;**III.1**h**, 2000 - it corresponds with Point D.

$n_5 = (4000/3)\,(5/4) – 1000/4 = 1666.7 – 250 =1416.7$ rpm. Point K_6 on the line $\boldsymbol{n_b}$**;**III.1**h**. 1000.

We vary simultaneously the rotation frequency of ICE and electric motor: 2000 and 1000 rpm.

n_5 = (2000/3) (5/4) – 1000/4 = 833.3 – 250 = 583.3 rpm.

n_5 = (2000/3) (5/4) – 2000/4 = 833.3 – 500 = 333.3 rpm. Point K_7 on the line $\boldsymbol{n_b}$**;**III.1**h**. 2000.

n_5 = (1000/3) (5/4) – 1000/4 = 416.7 – 250 = 166.7 rpm. Point K_8 on the line $\boldsymbol{n_b}$**;**III.1**h**. 1000.

n_5 = (1000/3) (5/4) – 2000/4 = 416.7 – 500 = - 83.3 rpm. Point K_9 on the line $\boldsymbol{n_b}$**;**III.1**h**. 2000.

It can be seen (Point K_1 – Point K_4 on the line $\boldsymbol{n_b}$**;** III.1**h**, 3000) that the rotation frequency of the epicyclic wheel 16 (b) $\boldsymbol{n_b}$ and the output shaft 5 decreases with decrease in the rotation frequency of the planet carrier 18 (h) $\boldsymbol{n_h}$ at constant rotation frequency of the sun gear 7 (a) $\boldsymbol{n_a}$ and increases (Point K_1, Point K_5 and Point K_4 on parallel lines $\boldsymbol{n_b}$**;** III.1**h**: 3000; 2000; 1000).

The influence of variation of only the rotation frequency of the sun gear 7 (a) $\boldsymbol{n_a}$ at constant rotation frequency of the 18 (h) $\boldsymbol{n_h}$ is illustrated in Figure 2 by dashed lines $\boldsymbol{n_b}$**;** III.1**a,** (Point K_{11}, Point K_{10} and Point K_2) in the left side downward to the right.

n_5 = (3000/3) (5/4) – 2000/4 = 1250 – 500 = 750 rpm. Point K_{10}.

n_5 = (3000/3) (5/4) – 1000/4 = 1250 – 250 = 1000 rpm. Point K_{11}.

Peculiar interest is attracted by the mode with close values of the terms. If $\boldsymbol{n_h (K + 1)/K = n_a /K}$; then $\boldsymbol{n_b = 0}$. At close values of the terms we obtain low rotation frequency of the output shaft – these are lines intersecting abscissa.

Mode III.2. Summing mode of PG operation - by the electric motor 28 and the shaft 6 on the sun gear 7 (a), via cylindrical gear 12-15 to the epicyclic wheel 16 (b), taking off from the planet carrier 18 (h). Similar to the mode I.5 this mode is described as follows: $\boldsymbol{n_h = n_a / (K+1) + n_b K / (K+1)}$, only the drive to the sun gear is directly from electric motor and not from ICE via the gears 14-22.

From the input shaft 2 and the gear ring 8 via the clutch 10 the torque by the cylindrical gear 12-15 is transferred to the epicyclic wheel 16 (b) and the satellite gears 21. From the satellites 21 the cumulative force of the sun gear 7 (a) and the epicyclic wheel 16 (b) is transferred to the axles 20, the planet carrier 18 (h), the shaft 29, the gear ring 30, the clutch 32 (below) in the right-side position, the gear ring 31, and the output shaft 5.

Rotation frequency of the output shaft can be varied by variation of rotation frequency of both ICE and electric motor, or simultaneously of ICE and electric motor. For instance, we vary the ICE rotation frequency: 4000, 3000, 2000 and 1000 rpm. If we assume that the rotation frequency of the input shaft 2: $n_{in} = n_2$ = 4000 rpm; $U_{cyl\ 12\text{-}15}$ = 4.0; K = 4; then the rotation frequency of the epicyclic wheel 16 (b): n_b = 4000/4 = 1000 rpm; $n_b K/(K+1)$ = 1000 (4/5) = 800 rpm; the rotation frequency of the sun gear 14 (a): n_a =3000 rpm; $n_a /(K+1)$ = 3000/5 = 600 rpm. Rotation frequency of the planet carrier 18 (h), the shaft 29 and the output shaft 5 will be $\boldsymbol{n_h=n_a/(K+1)+n_b\ K\ (K+1)}$=[(3000/5)+(4000/4) (4/5)]=600 + 800= 1400 rpm. Point L_1.

n_5 = [(3000/5)+ (3000/4) (4/5)] = 600 + 600 = 1200 rpm. Point L_2.

n_5 = [(3000/5)+ (2000/4) (4/5)] = 600 + 400 = 1000 rpm. Point L_3.

n_5= [(3000/5)+ (1000/4) (4/5)] = 600 + 200 = 800 rpm. Point L_4.

We vary the electric motor rotation frequency: 2000 and 1000 rpm.

n_5 = [(2000/5)+ (4000/4) (4/5)] = 400 + 800 = 1200 rpm. Point L_5 - coincides with Point E.

n_5 = [(1000/5)+ (4000/4) (4/5)] = 200 + 800 = 1000 rpm. Point L_6 - coincides with Point A.

We vary the rotation frequency of ICE and electric motor: 2000 and 1000 rpm.

n_5 = [(1000/5)+ (1000/4) (4/5)] = 200 + 200 = 400 rpm. Point L_7.

n_5 = [(2000/5)+ (1000/4) (4/5)] = 400 + 200 = 600 rpm. Point L_8.

n_5 = [(1000/5)+ (2000/4) (4/5)] = 200 + 800 = 1000 rpm. Point L_3.

n_5 = [(2000/5)+ (2000/4) (4/5)] = 400 + 800 = 1200 rpm. Point L_9.

In Figure 2 the values L_1 – L_4 are on the flat dashed line $\boldsymbol{n_h}$**;** III.2b, 3000, originating from Point 600 on ordinate in the middle part upward to the right. It can be seen that the rotation frequency of the planet carrier 18 (h) $\boldsymbol{n_h}$ and the output shaft 5 decreases both with decrease in the rotation frequency of the epicyclic wheel 16 (b) $\boldsymbol{n_b}$ at constant rotation frequency of the sun gear 7 (a) $\boldsymbol{n_a}$, and with decrease in the rotation frequency of with the sun gear 7 (a) $\boldsymbol{n_a}$ at constant rotation frequency of the epicyclic wheel 16 (b) $\boldsymbol{n_b}$ (Point L_1, Point L_5 and Point L_6 on parallel flat lines $\boldsymbol{n_h}$**;** III.2b: 3000; 2000; 1000).

RECOVERY

While braking and free running of land vehicle the power flow is transferred in reverse direction; from driving wheels to hybrid transmission. This power flow can be transferred to the generator 4 (Figure 1), and the resulted electric power via the control unit 27 to the battery 25. This can be aided by some modes of the first approach.

Reverse mode I.1. (Figure 1). We lock PG, engaging by the clutch 32 the gear rings: 33 of the sleeve shaft 35, the housing 35 of the epicyclic wheel 16 (b) and 30 of the shaft 29 of the planet carrier 18 (h). The right-side wide internal ring of the clutch 32 (top position) engages the gear ring 30 with the gear ring 31 of the output shaft 5. The torque from the output shaft 5 by the gear ring 31, the clutch 32, the gear rings: 33 of the sleeve shaft 34, the housing 35 of the epicyclic wheel 16 (b) and 30 of the shaft 29 of the planet carrier 18 (h), via locked PG, by the cylindrical couple 15-12, via the clutch 10 in the right-side position, the gear ring 8, the input shaft 2 is transferred to the gear ring 9, and by the clutch 11 in the position a) to the gear ring 23, the shaft 3 and the electric generator 4. If the output shaft 5 rotates with the frequency n_{out} = n_5 = 1000 rpm; $U_{cyl\ 15\text{-}12}$ = 0.25; then n_{in} = n_3 = 4000 rpm. In this mode ICE should be disengaged from the input shaft 2 by means of additional clutch, for instance, freewheel clutch – not shown in Figure 1.

Reverse mode I.2. The torque from the output shaft 5 via locked PG, the planet carrier 18 (h), the cylindrical couple 13-17, the gear ring 8, the clutch 10 in the left-side position is transferred to the input shaft 2, via the shaft 2 to the gear ring 9, via the clutch 11 in the position a) to the gear ring 23, the shaft 3 and the electric generator 4. If the output shaft 5 rotates with the frequency n_{out} = n_5 = 1000 rpm; $U_{cyl\ 17\text{-}13}$ = 0,33; then n_{in} = n_3 = 3000 rpm. In this mode ICE should be disengaged from the input shaft 2 by means of additional clutch, for instance, freewheel clutch.

Reverse mode I.3. The clutch 11 in the middle position (c) engages the gear rings 14 and 23 of the shaft 3 of the electric generator drive 4. We lock PG engaging by the clutch 32 the gear rings: 33 of the sleeve shaft 35, the housing 35 of the epicyclic wheel 16 (b) and 30 of the shaft 29 of the planet carrier 18 (h). The right wide internal gear ring of the clutch 32 (upper position) locks the gear ring 30 with the gear ring 31 of the output shaft 5. The torque from the output shaft 5 by the gear ring 31, the clutch 32, via the gear rings: 33 of the sleeve shaft 34, housing 35 of the epicyclic wheel 16 (b) and 30 of the shaft 29 of the planet carrier 18 (h), via locked PG, by the cylindrical couple 22-14, by the clutch 11 in the middle position c) from the gear ring 14 is transferred to the gear ring 23, the shaft 3 and the electric generator 4. If the output shaft rotates with the frequency n_{out} = n_5 = 1000 rpm; $U_{cyl\ 22\text{-}14}$ = 0.5; then n_{in} = n_3 = 2000 rpm.

Reverse mode I.6. PG in reducing mode $\boldsymbol{U_{ah}^{b}}$ **= K+1** plus the cylindrical gear 22-14**.** the epicyclic wheel 16 «b» is stopped by the clutch 37 in right-side position, engaging the gear ring 36 of the housing 1 and the cylindrical teeth wheel 15 with the housing 35. The torque from the output shaft 5 by the gear ring 31, the clutch 32, the gear ring 30, via the shaft 29 is transferred to the planet carrier 18 (h), which by the axles 20 transfers the force to the satellite gears 21. The satellite gears 21 rotate with regard to the stopped epicyclic wheel 16 «b» at increased rotation frequency, and then, by the cylindrical couple 22-14, via the clutch 11 in the middle position c) from the gear ring 14 is transferred to the gear ring 23, the shaft 3 and the electric generator 4. If the output shaft rotates with the frequency n_{out} = n_5 = 1000 rpm; K= 4; $U_{cyl\ 22\text{-}14}$ = 0.5; then n_{in} = n_3 = 10 000 rpm. Variation of the parameters K, U_{cyl} would vary calculated results.

Technical end Economical Assessment of Hybrid Transmission with Simple Planetary Gear

In comparison with similar designs the proposed hybrid transmission provides great operational possibilities in wide range of gear ratios while characterized by more simple arrangement. While using the first approach 6 forward gears and one reverse hear were obtained. The transmission range D, low and top gear ratio, is determined by K, internal variable of PG. The range can be increased by increase in K to 5, D = 6. While using the second approach 3 gears were obtained, using the third approach – 2 gears. Upon the first two approaches the transmission operates as conventional step-by-step gearbox, and the third approach provides continuously variable torque transfer. In order to recover energy at the initial step it would be reasonable to apply the reverse mode I.3, and at low speed – the reverse mode I.6.

CONCLUSIONS

It is possible to select optimum distribution of gear ratios over the range, to use electric motor similar to hydraulic torque converter. Using the plot it is possible to determine the required operation mode of transmission. For instance, it is required to obtain n_5 = 300 rpm at output. Several variants are available: 1. Using the line $\boldsymbol{n_b}$**;** III.1**a, 3000** we obtain $\boldsymbol{n_b = n_h(K+1)/K - n_a/K}$ = n_5 = (3118/3) (5/4) – 4000/4 = 1300 – 1000 = 300 rpm; 2. For the mode I.6 it is required to increase either gear ratio $U_{14\text{-}22}$ or K: n_5=(n_2/$U_{14\text{-}22}$)/(K+1) = (4000/2.67)/5 = 300 rpm; n_5 = (n_2 /$U_{14\text{-}22}$)/(K+1) = (4000/2.0)/6.67 = 300 rpm. K = 5.67 is high; if we apply limitation K=5, then we obtain n_5=(n_2/$U_{14\text{-}22}$)/(K+1) = (4000/2.22)/6.0= 300 rpm at $U_{14\text{-}22}$ = 2.22, and so on.

The proposed design of hybrid transmission with simple planetary gear provides expansion of layout and operation performances of land vehicles, as well as wide range of operation conditions upon operation of ICE in optimum mode.

CONFLICT OF INTEREST

The authors confirm that the submitted data does not contain conflict of interest.

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