MODELING OF CONTINUOUS VARIABLE POWER SPLIT TRANSMISSION IN A HYBRID ELECTRIC VEHICLE

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SUMMARY
The latest research are trying so hard in order to find something that can minimise the cost of fuel efficiency and reduce quantity of smoke that comes from internal combustion engine, because the sources of oil – fuel they are getting smaller and smaller and criteria for protection environment every day they are more roughness. That is why one of the goals that we mention above it's to come up with the hybrid electric vehicle. If on of those vehicle we use continuous variable power split transmission which make continuously variable transmission ratio, then as result is minimized the cost of fuel efficiency and quantity of smoke.
In this research they are analyzed the characteristic parameters for continuously variable power split transmission which is using for hybrid electric vehicle and through mathematic model and own worked out programme code in MATLAB, they are analyzed the transmission ratio versus driving pulley contact angel φ and torques versus continuous variable transmission ratio (i_{CVT}).

Keywords: Hybrid electric vehicle, continuous variable transmission, planetary gear, split, torques, transmission ratio, etc.

1. INTRODUCTION

Power train for vehicle from internal combustion engine to differential it can be realized through: mechanical gearbox, automatic gearbox, and lately through continuously variable transmission which are known as **variator**.
Continuously Variable Transmission (CVT) which provides a continuously variable transmission ratio between the power source (internal combustion engine or electric motor) of a vehicle and wheels drive and give in possibility that engine works in optimum boundary and give in optimum torque for wheels drive. However, from the limit of power train in long term they didn't apply to the industry of automobile, just because of limit of power train from belt.
In order to improve capacity of power train for continuously variable transmission with belt they build continuously variable transmission (CVT) which is combination with planetary gear (PG), which use principal power split and known as "Continuously variable power split transmission - CVPST" (Figure 1). For distinguish from continuously variable transmission, power train through belt at continuously variable power split transmission, are controlled by computer-electronically.

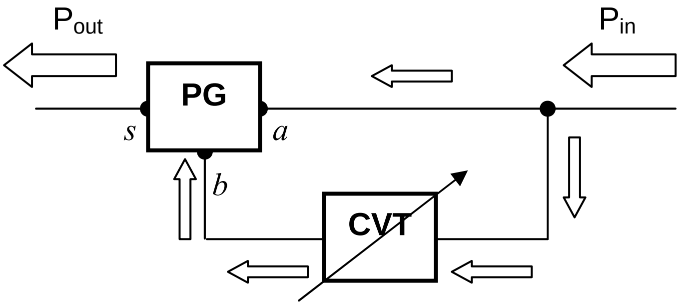

Figure 1. Schematic of Continuously variables power split transmissions

Power split principally has enabled that continuously variables power split transmissions be used as gearbox in vehicle with larger displacement engine.

2. MODEL OF CONTINUOUS VARIABLE POWER SPLIT TRANSMISSION IN A HYBRID ELECTRIC VEHICLE

As we mention above, continuous variable power split transmission introduced combine planetary gear with continuous variable transmissions.
Planetary gear is type **1AI** and consist: sun gear (z_a), ring gear (z_b), planet gear (z_g) and planetary carrier (s), while continuous variable transmissions consist from: driving pulley (a), driven pulley (c) and variable belt drives (b), (Figure 2).

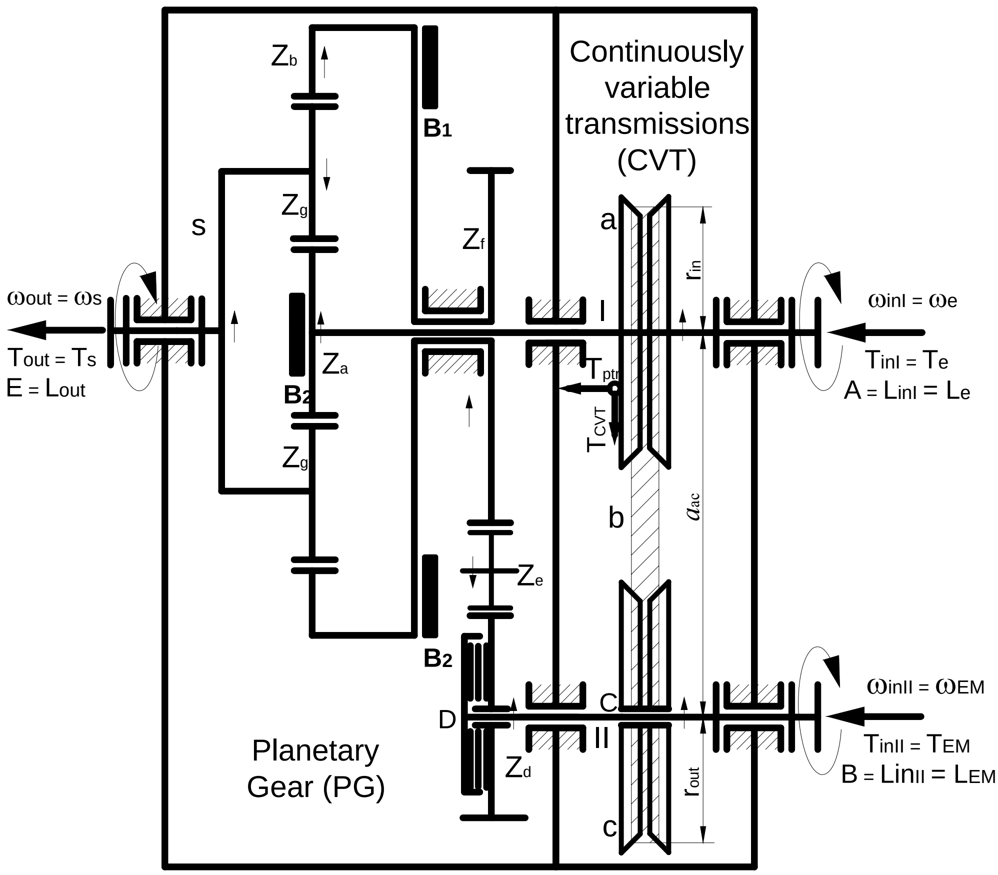

Figure 2. Model of continuously variables power split transmissions.

This system of power train in a hybrid electric vehicle allow to work in six working options, depending on the demand of driver and electronic units, which realised with fixing gears: sun gear (z_a), ring gear (z_b), through brakes: (B_1) and (B_2) and clutches: A, B C, D, E (Figure 2).
In order to achieve better transmission ratio of this power train, this system should have the optimum number of teeth gears: (z_a), (z_b), (z_d) and (z_f) and radius of driving (a) and driven pulley (c) which determines the range of continuously variable transmission ratio.

2.1. Transmissions ratio

Transmissions ratios in power train system at the hybrid electric vehicle it's a very important factor to adjust and determine the speed of movement of the vehicle.
In order to determine the continuously variable transmission ratio, first should be determined equation which represent versus radius of driving (a) and driven pulley (c). Radius of driving (r_{in}) and driven pulley (r_{out}) are variable therefore, they are necessary to make equation between relations arising from Figure 3. For this case when the distance between axis, conically pulley are constant (a_{ac}=constant).

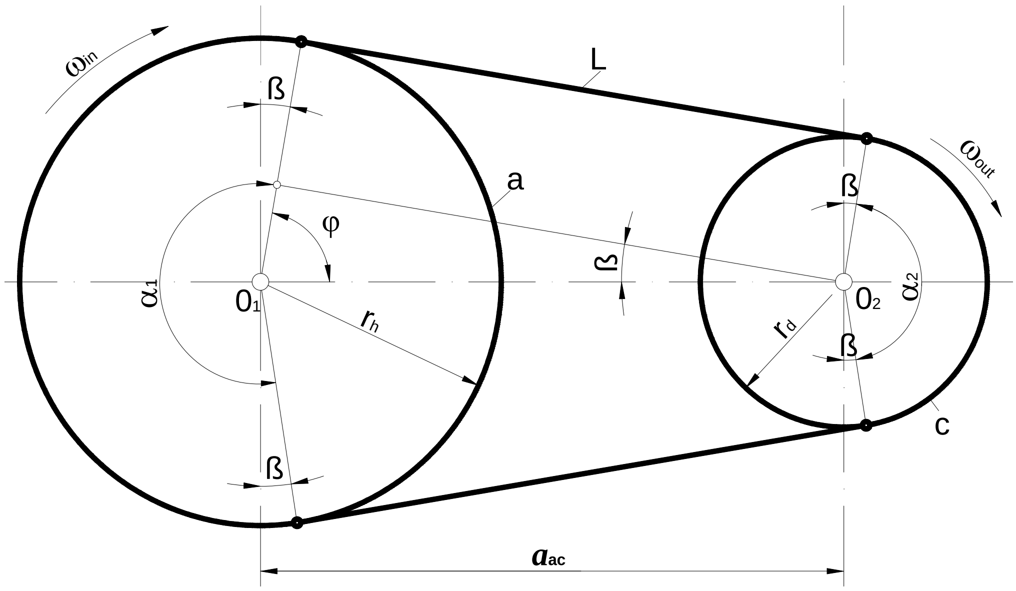

Figure 3. Geometrical size of continuously variable transmission

The length of belt (L) is determined by equation:

$$L = \pi(r_{in} + r_{out}) + 2 \cdot \beta(r_{in} - r_{out}) + 2 \cdot a_{ac} \cdot \cos\beta \qquad \text{... (1)}$$

Equation for radius of driving (r_{in}) and driven pulley (r_{out}) in function of angle (φ), the belt length (L) and axis distance (a_{ac}) assigned by expressions:

$$r_{out} = \frac{L - 2 \cdot a_{ac} \cdot [(\pi - \varphi) \cdot \cos\varphi + \sin\varphi]}{2 \cdot \pi} \qquad \text{... (2)}$$

$$r_{in} = \frac{L - 2 \cdot a_{ac} \cdot [(\pi - \varphi) \cdot \cos\varphi + \sin\varphi] + 2 \cdot \pi \cdot a_{ac} \cdot \cos\varphi}{2 \cdot \pi} \qquad \text{... (3)}$$

Continuously variable transmission ratio (i_{CVT}) in function of angel (φ), it's determined by expression:

$$i_{CVT} = \frac{r_{out}}{r_{in}} = \frac{L - 2 \cdot a_{ac} \cdot [(\pi - \varphi) \cdot \cos\varphi + \sin\varphi]}{L - 2 \cdot a_{ac} \cdot [(\pi - \varphi) \cdot \cos\varphi + \sin\varphi] + 2 \cdot \pi \cdot a_{ac} \cdot \cos\varphi} \qquad \text{... (4)}$$

Continuously variable power split transmission ratio (i_{CVPST}), it's determined by equations:

$$i_{CVPST} = \frac{\omega_e}{\omega_s} = \frac{i_{CVT} \cdot (1 + i_{ab}^s)}{i_{ab}^s \cdot i_{CVT} + i_{fd}} \text{ ose} \quad \text{... (5)}$$

$$i_{CVPST} = \frac{z_f \cdot (z_b + z_a) \cdot \{L - 2 \cdot a_{ac} \cdot [(\pi - \varphi) \cdot \cos\varphi + \sin\varphi]\}}{z_f \cdot \{L - 2 \cdot a_{ac} \cdot [(\pi - \varphi) \cdot \cos\varphi + \sin\varphi]\} + 2 \cdot \pi \cdot a_{ac} \cdot z_b \cdot z_d \cdot \cos\varphi}.$$

2.2. Torque

Engine torques ($T_e = T_{inI}$) it's split in shaft I and part of the torque which is transmitted through continuously variable transmission (T_{CVT}), while the rest of the torque (T_{ptr}) it's transmitted directly to sun gear (z_a):

$$T_{inI} = T_e = T_{CVT} + T_{ptr} \quad \text{... (6)}$$

Torque in continuously variable transmission (T_{CVT}), respectively in sun gear (z_a) of planetary gear (T_{ptr}), assigned according to expressions [5]:

$$T_{CVT} = T_{inI} \cdot \frac{i_{fd}}{i_{ab}^s \cdot i_{CVT} + i_{fd}} \quad \text{... (7)}$$

$$T_{ptr} = T_a = T_{inI} \cdot \frac{i_{ab}^s \cdot i_{CVT}}{i_{ab}^s \cdot i_{CVT} + i_{fd}} \quad \text{... (8)}$$

3. ESTIMATE CHARACTERISTICS PARAMETER OF CONTINUOUS VARIABLE POWER SPLIT TRANSMISSION IN A HYBRID ELECTRIC VEHICLE

To realize the goal in this research was using the program code in MATLAB, to calculate characteristic parameters for the power transmission system, respectively in continuously variable power split transmission in a hybrid electric vehicle.
The program is designed when we change inputs values we will get required characteristics in output, while the obtained results in this research are presented in graphical form and are given their comments.

3.1. Power train transmission ratios versus driving pulley contact angel φ

In Figure 4 is presented power train transmission ratios versus driving pulley contact angel φ in a hybrid electric vehicles, respectively, to: continuously variable transmission (i_{CVT}) and continuously variable power split transmission (i_{CVPST}).
From Figure 4 we have for the minimum value of angle (φ_{min}) continuously variable transmission ratio is $i_{CVTmin} = 0.5$, while for the maximum value of angle (φ_{max}) is $i_{CVTmax} = 2.52$. For these extreme values of angle φ, the continuously variable power split transmission ratio has values $i_{CVPSTmin} = 0.9$ and $i_{CVPSTmax} = 2.52$.
For maximum value of angel (φ_{max}) is i_{CVTmax}=$i_{CVPSTmax}$=2.52.
The smaller angel than $\varphi_{min} = 72^0$, respectively the largest angel than $\varphi_{max} = 113^0$ are not taken into consideration, because the efficiency of continuously variable transmission for these values is very low.

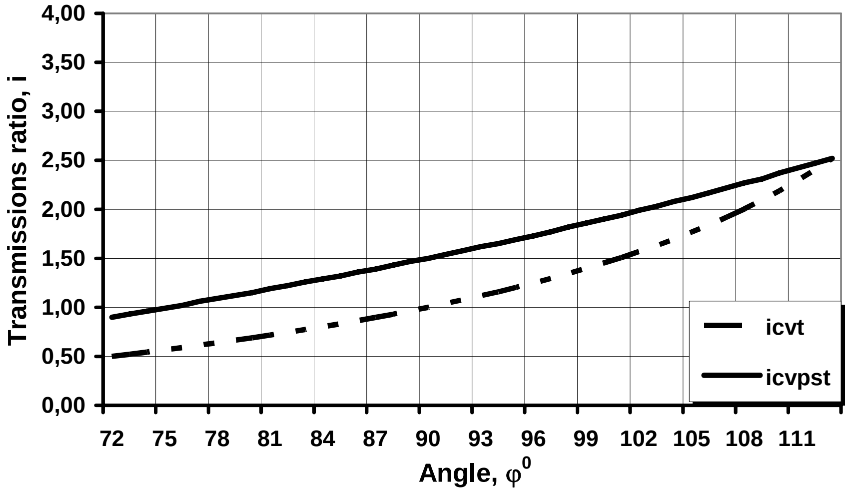

Figure 4. Transmission ratios versus driving pulley contact angel φ

3.2 Engine torques flowing through the belt and gear as functions of continuously variable transmission ratio

In Figure 5 and Figure 6 are shown curves of engine torque ($T_{inI} = T_e$) for internal combustion engine AEB 1.8 i, which is used in passenger car Audi A4. This engine torques is split through the planetary gear (T_{ptr}) and continuously variable transmission (T_{CVT}) as functions of continuously variable transmission ratios (i_{CVT}) for two values of engine speeds: $n_{emin}=800$ *RPM*, $T_{emin}=171$ *Nm* and $n_{Temax}=4000$ *RPM*, $T_{Temax}=186$ *Nm*.

Also at Figure 5 and Figure 6 shows that with increasing transmission ratio $i_{CVT} = 0.5 ... 2.52$ increase torque in planetary gear (T_{ptr}), while decreases in the continuously variable transmissions (T_{CVT}), because $T_{inI}=T_e=T_{ptr}+T_{CVT}$, which makes particular this power train system especially when required to realize the large acceleration.

For $i_{CVT} = 0.5$ the torque are $T_{ptr} = 33.65$ Nm (*19.6 %*) *and* $T_{CVT} = 137.67$ *Nm* (*80.4 %*), respectively $T_{ptr} = 36.52$ *Nm* (*19.6 %*) and $T_{CVT} = 149.38$ *Nm* (*80.4 %*), while for $i_{CVT} = 2.52$ torque are $T_{ptr} = 94.62$ *Nm* (*55.2 %*) and $T_{CVT} = 76.70$ *Nm* (*44.8 %*), respectively $T_{ptr} = 102.67$ *Nm* (*55.2 %*) and $T_{CVT} = 83.23$ *Nm* (*44.8 %*), for $n_{emin} = 800$ and $n_{Temax} = 4000$ *RPM*.

Also, to transmission ratio $i_{CVT} = 2.05$ split torque at planetary gear (T_{ptr}) and continuously variable transmission (T_{CVT}) are equal ($T_{ptr} = T_{CVT}$), respectively *50 %* of engine torque (T_e).

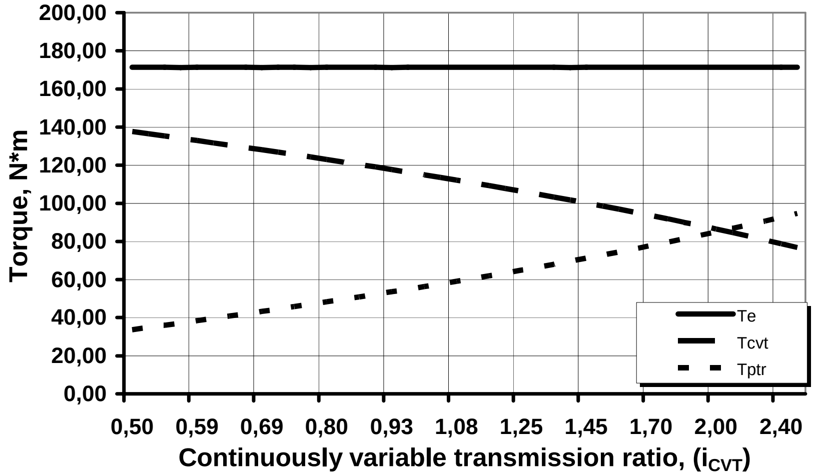

Figure 5. Engine torque (T_e) flowing through the planetary gear (T_{ptr}) and continuously variable transmission (T_{CVT}) as functions of continuously variable transmission ratio (i_{CVT}) for $n_e = 800$ RPM

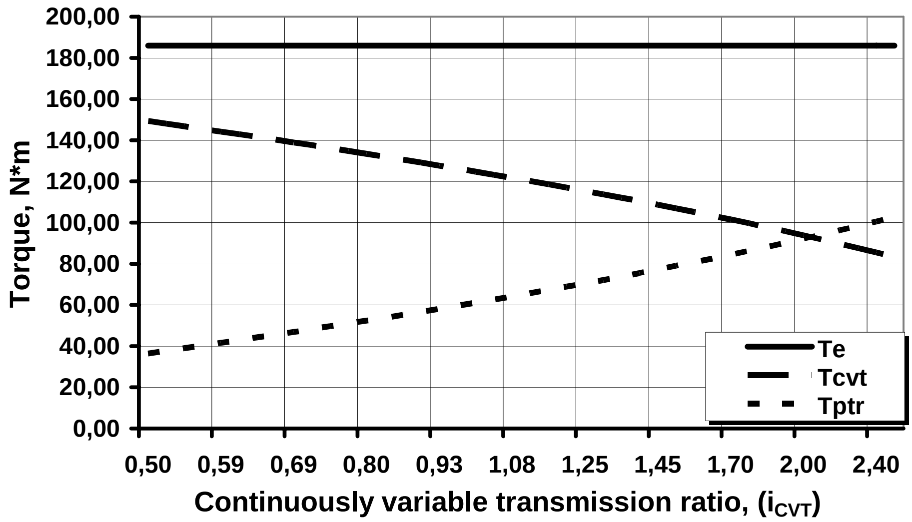

Figure 6. Engine torque (T_e) flowing through the planetary gear (T_{ptr}) and continuously variable transmission (T_{CVT}) as functions of continuously variable transmission ratio (i_{CVT}) for n_{Temax}=4000 RPM

4. CONCLUSION

Based on the results achieved through application program MATLAB for continuously variable power split transmission in a hybrid electric vehicle can be concluded that:

- transmission ratio of power train system increase with increasing angel φ;
- for maximum value of angle $\varphi_{max} = 113^0$ the continuously variable transmission ratio is equal with the continuously variable power split transmission ratio;
- when the engine torque of the internal combustion engine (T_e) is split, torques in planetary gear (T_{ptr}) is increased, while the torque in continuously variable transmission (T_{CVT}) is decreased with increasing continuously variable transmission ratio (i_{CVT});
- For the continuously variable transmission ratio i_{CVT} = 2.05 split torques at planetary gear (T_{ptr}) and continuously variable transmission (T_{CVT}) are equal ($T_{ptr} = T_{CVT}$).

5. REFERENCES

[1] Shpetim Lajqi: Planetary gears combine with continuous variable transmission in Hybrid Electric Vehicle, Master Thesis, Prishtinë, with 12.09.2008.
[2] Prof. dr. Nijazi Ibrahimi: Transmetuesit e Fuqisë, Prishtinë 2005,
[3] Tóth-Nagy, C.; Investigation and simulation of the planetary combination hybrid electric vehicle, Master's thesis at West Virginia University, Mechanical and Aerospace Engineering Department, Morgantown, WV, 2000,
[4] Gisbert Lehner & Harald Naunheimer: Automotive transmission fundamentals, Selections and Design and Application, Studgard, February 1999,
[5] Mucino, V. H., Smith, J. E., Cowan, B. and Kmicikiewicz, M.: A continuously variable power split transmission for automotive applications, SAE Technical Paper No. 970687,