THE ESTIMATION OF FRICTION DEGREE IN THE CONTINUOUSLY VARIABLE TRANSMISSION

ОЦЕНКА СТЕПЕНИ ТРЕНИЯ В ПЕРЕДАЧЕ С НЕПЕРЕРЫВНОЙ ПЕРЕМЕНОЙ

Jerzy JANTOS, Prof. D.Sc. Eng, Jarosław MAMALA, Ph.D., Andrzej BIENIEK, M.Sc. Eng.[3]
Opole University of Technology, ul. Mikołaczyka 5, 45 – 271 Opole, Poland
E-mail: jantos@po.opole.pl, E-mail: mamala@po.opole.pl, E-mail: abieniek@po.opole.pl

Abstract: *The metal belt tension in the continuously variable transmission is one of the most important factors where decides about energetic loses and power train durability. In this paper the mathematical model and the tests results are depicted. It is improved the reliable estimation of friction grow degree is possible, but the measure of additional quantities, shown in this paper is indispensable. The presented method could be used to the new control algorithm synthesis. The test bench results of the belt tension influence on fuel consumption and pollutant emission in the NEDC cycle are also presented.*

KEYWORDS: CONTINUOUSLY VARIABLE TRANSMISSION, BELT TENSION, PASSENGER CAR

1. INTRODUCTION

The analysis of European passenger cars market (fig.1) show, that **m**anual **t**ransmission – (MT) is the most often used solution.

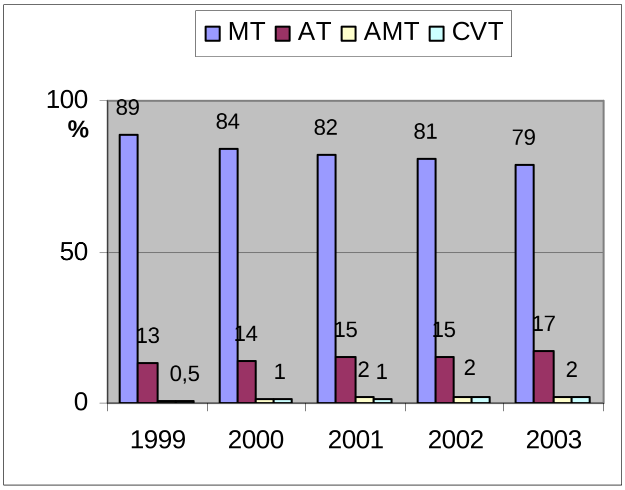


Fig.1. The market share of different transmission solutions in Europe [5]

It can be seen the systematical sale increase of vehicles equipped with automatic transmission. The most often there are the hydro mechanical units - **a**utomatic **t**ransmission (AT). Last years however growths the interest in **a**utomated **m**echanical **t**ransmissions (AMT) and also in **c**ontinuously **v**ariable **t**ransmissions (CVT).
From the comparison shown on figure 2 it results, that the CVT can improve the fuel consumption and vehicle acceleration.

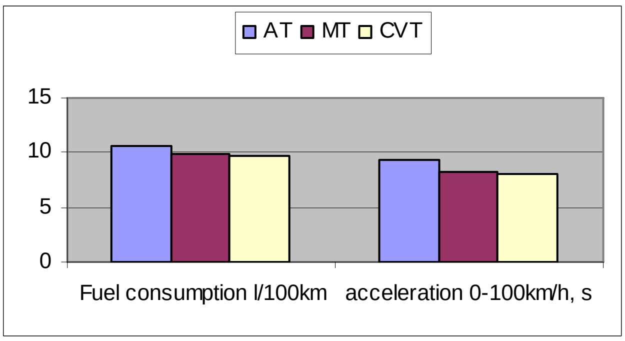


Fig.2. Fuel consumption (MVEG cycle) and dynamic properties (0-100 km/h) comparison in Audi A6 2.8 vehicle equipped with AT, MT and CVT [4]

CVT used in passenger cars most often transfer the engine torque on the friction way. To do that it is a thrust force between cooperating parts needed. Behalf on transmission efficiency and durability the thrust force value should be regulated [2]. Because the metal friction parts can be destroyed in case of slip, the selection of right thrust force value is the one of most difficult tasks. Big operating conditions differentiation, many disturbances and also difficulties in measurement of some dimensions [6] causes that the estimation of friction degree is uncertainly. Owing to this uncertainty, it is a big (about 30%) thrust force excess applied compared with theoretical or experimental defined bottom limit value [7, 9].
Although there are well known many cases where the CVT is damaged through excess slip. Enlargement of safety coefficient value

(1) $$k_s = \frac{T_{\max}}{T},$$

Where $T_{\max}$ - upper limit torque value; T - CVT pulley torque,

raised the transmission work safety but causes with bigger mechanical and hydraulic loses. Also the durability of CVT decreases. So it is an objective necessity to reliable estimation of friction degree in CVT. In this paper the selected problems connected with friction degree estimation in push belt CVT are considered.

2. THRUST FORCES IN CVT

2.1. The value of CVT safety coefficient

The torque transfer in CVT is possible through friction connection between belt and pulleys. The demanded friction torque value can be achieved only on the way of thrust force generation. The demanded axial thrust force value can be calculated from the equation [8]

(2) $$A_d = \frac{k_s T}{2\mu\, r \cos\beta},$$

Where r – pulley wrapped radius; β – pulley angle.
This value is dependent among others of friction coefficient value (μ).
To aim of qualify the influence of thrust force value on the Powertrain performances the test bench investigations has been done. The test object was Fiat Punto II Speed Gear.

Fig.3. Test bench

The investigations on the test bench were done for nominal (k_s=1.3) and enlarged (k_s=2.3) value of transmission safety coefficient. In every of passed cycles (UDC, EUDC, NEDC) significant fuel consumption (fig.4), in case of enlarged thrust forces in CVT, was recorded.

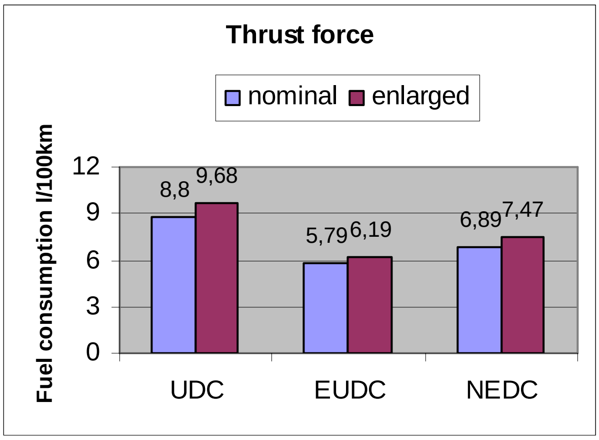
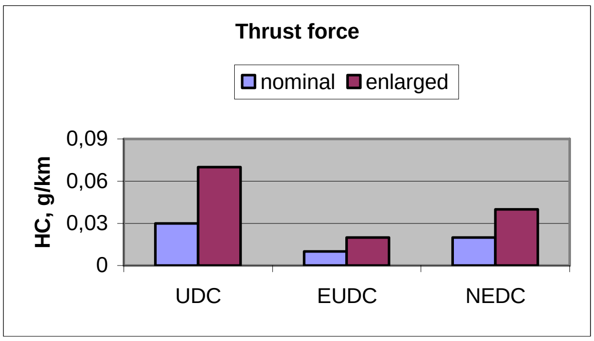


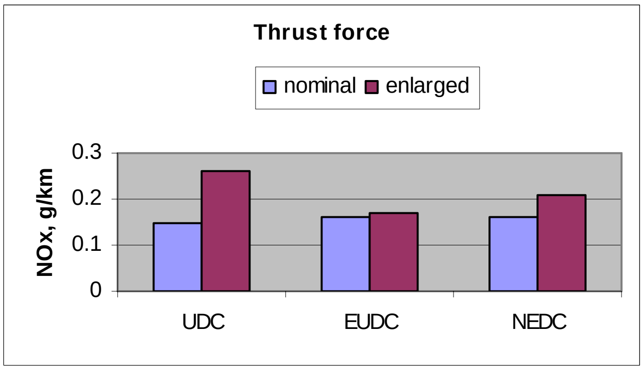
Fig.4. Fuel consumption in driving cycles

Enlarge value of k_s courses also with greater pollutant emission (fig.5).

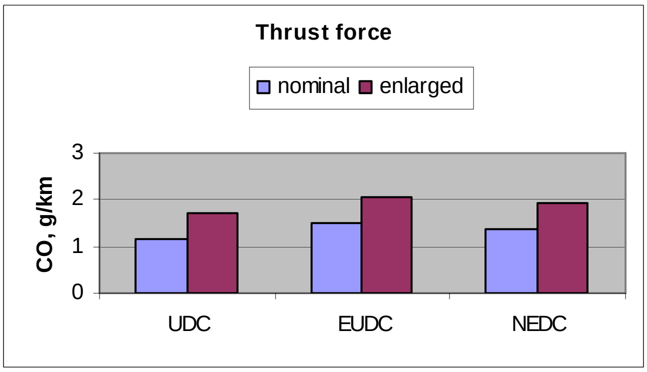
a)



b)



c)



Rys.5. HC, NO_x and CO emission in driving cycles

So we can say that keeping the real value of k_s on the right level is important from energetic and ecological point of view, in passenger car powertrain.

2.2. Analytical considerations

The further considerations have been done with help of simple mathematical description consistent with Euler's theory, where the band force is given with equation [1]

(3) $F_1 = F_2 e^{\mu'\alpha}$.

Where F_1, F_2 – forces in driving and driven belt part; α – pulley wrapped angle; $\mu' = \mu_T / \sin\beta$.

The axial thrust force describes equation

(4) $A = \dfrac{1}{2\sin\beta\cos\beta}\int_0^\alpha F d\alpha$,

Taking into account division of wrapped angle (α) on a slip (α_p) and rest angle, we obtain

$$(5)\ A_1 = \frac{F_2\left[\mu' e^{\mu'\alpha_p}\left(\alpha_1-\alpha_p\right)+e^{\mu'\alpha_p}-1\right]}{2\mu'\sin\beta\cos\beta},$$

$$(6)\ A_2 = \frac{F_2\left[\mu'\left(\alpha_2-\alpha_p\right)+e^{\mu'\alpha_p}-1\right]}{2\mu'\sin\beta\cos\beta}.$$

The thrust forces ratio is given as

$$(7)\ \frac{A_1}{A_2}=\xi=\frac{\mu' e^{\mu'\alpha_p}\left(\alpha_1-\alpha_p\right)+e^{\mu'\alpha_p}-1}{\mu'\left(\alpha_2-\alpha_p\right)+e^{\mu'\alpha_p}-1}.$$

It can be seen that the thrust forces ratio is dependent on friction coefficient and the values of wrapped and slip angels. Introducing relative slip angle

$$(8)\ \alpha_r=\frac{\alpha_p}{\alpha},$$

and taking equations describing wrapped angles (α_1, α_2) as a function of geometrical values (l – the belt length, a – CVT axis distance) and transmission ratio (i_T)

$$(9)\ \alpha_1=\pi+\frac{2\left(1-i_T\right)\cdot\left(l-2a\right)}{\pi\cdot a\cdot\left(i_T+1\right)},$$

$$(10)\ \alpha_2=\pi-\frac{2\left(1-i_T\right)\cdot\left(l-2a\right)}{\pi\cdot a\cdot\left(i_T+1\right)},$$

the thrust forces ratio can be shown as a function on figure 6.

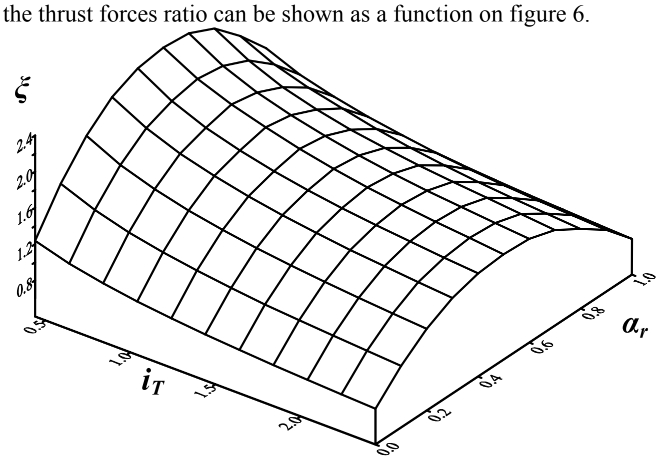


Fig.6. The ratio of trust forces as function of relative slip angle and transmission ratio

Introducing the friction degree coefficient

$$(11)\ k_f=\frac{1}{k_s},$$

after conversions we obtain:

$$(12)\ k_f=\frac{e^{\mu'\alpha_r\alpha}-1}{e^{\mu'\alpha}-1}.$$

Regards on this equations we can say, that the thrust forces ratio value at a given transmission ratio value is connected with friction degree in the CVT.

3. EXPERIMENTAL INVESTIGATIONS

3.1. The control unit modification

In order to calculation of thrust forces ratio the measurement of hydraulic pressure in primary and secondary pulleys was necessary. The series production Fuji Hyper M6 CVT has only one pressure sensor in the secondary hydraulic circuit. The same one has been mounted in the primary hydraulic circuit (fig. 7).

Fig.7. The primary hydraulic pressure sensor

3.2. Results analysis

The measurements results under steady state conditions for different engine speed are depicted on the figure 8.

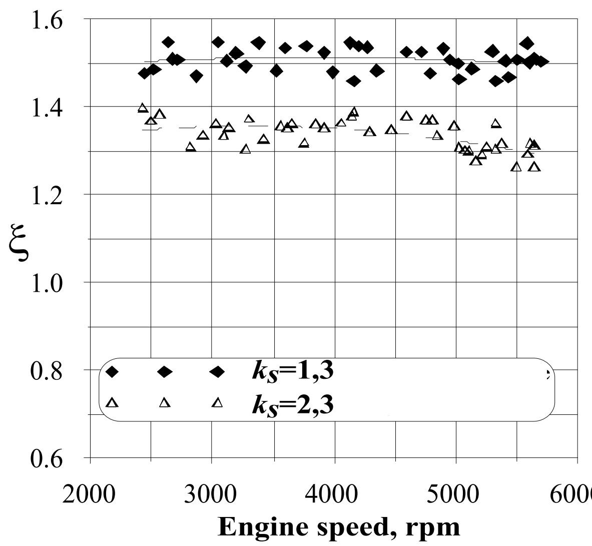


Fig.8. The ratio of thrust forces for different belt tension

It can be seen that in the same work conditions, the value of thrust forces ratio significantly depends on belt tension (friction degree). On the figure 9 the thrust forces ratio determined during UDC/EUDC cycles, for the nominal and enlarged belt tension has been depicted. Also in these conditions, clear differences can be seen on the picture.

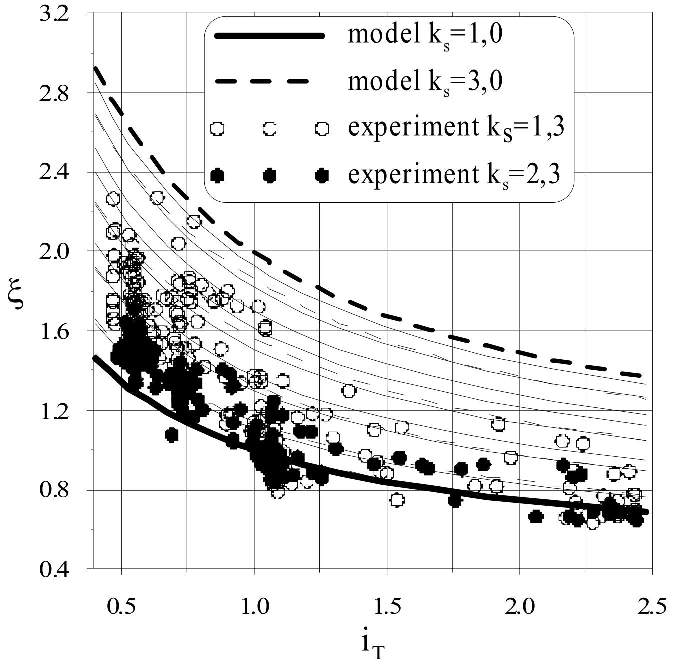


Fig. 9. The ratio of thrust forces in the UDC/EUDC cycles

So we can say that also in unsteady operating conditions it is possible to conclude about friction degree in CVT on the basis of thrust forces ratio observation.

4. CONCLUSION

The presented results show that the estimation of friction degree in CVT on the way of thrust forces ratio observation is possible. The analytical considerations with use of simple mathematical model are good agreed with experimental results. The next step of the investigations should be the synthesis of new control algorithm for the CVT.

REFERENCES

Journal articles

1 BECCARI, A. M. CAMMALLERI *Implicit regulatiion for automotive variators*, Proc Instn Mech Engrs 2001 Vol 215, Part D, 697-708.

2 DOONER, D., H-D YOON, SEIREG A.: *Kinematic considerations for reducing the circulating power effect in gear-type continously variable transmissions*, Proc Instn Engrs 1998, Vol 212 Part D, 463-478.

3 HAHN, J-O., J-W HUR, Y.M. CHO, K.I. LEE *Robust observer-based monitoring of a hydraulic actuator in a vehicle power transmission control system*, Control Engineering practice 10 (2002), 327-335.

4 NOWATSCHIN K., G. HOMMES, H-O. FLEISCHMANN, H. FAUST, T. GLEICH, O. FRIEDMANN *Multitronic- Das neue Automatikgetriebe von Audi -Teil II*, Automoblitechnische Zeitschrift 102(2000) nr 9, 746-753.

Conference articles

5 BEHRENROTH J., GUETER C.: *Aspekte zur Systemarchitektur, Triebstrangregelung und Abstimmung – wie haben Kundenerwartung die Entwicklung des CVT für den neuen Mini beeinflusst*, CVT 2002 Congress Munich, 7th/8th October 2002, VDI-Berichte 1709, s. 195-210.

6 BONSEN B., T. KLAASSEN, K. VAN DE MEERAKKER *Modelling Slip- and Creep mode Shift Speed Characteristics of a Pushbelt Type Continuously Variable Transmission*, International Continuously Variable and Hybrid Transmission Congress, California 23-25 September 2004, 04CVT-3.

7 FAUST H., M. HOMM, Efficiency-Optimized CVT Hydraulic and Clamping System, CVT 2002 Congress Munich, 7th/8th October 2002, VDI-Berichte 1709, 43-58.

8 JANTOS J. *Control of the Transmission Ratio Derivative in Passenger Car Powertrain with CVT*, SAE 2001 World Congress Detriot, Michigan, nr 2001-01-1159.

9 STÖCKL B. *Energy Optimized Pressure Controlled Clamping System for Continuously Variable Chain Transmission"*, International Continuously Variable and Hybrid Transmission Congress, California 23-25 September 2004, 04CVT-14.

ACKNOWLEDGEMENTS

The authors wishes to thank the Polish State Committee for Scientific Research which supported this work in frame of Research Project in years 2003 - 2006.