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The simulation of the dynamic behaviour for an elastic mechanical transmission of passenger car

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Abstract. In the last years the engine-transmission system was optimized substantially with the purpose to obtain advanced dynamic performances. The transmission must cooperate with the propulsion system in a perfect way to obtain maximum acceleration performances and a low fuel consumption. This paper presents an extensive study of the acceleration performances of an automobile equipped with a mechanical transmission, the study is accomplished through numerical simulation. The numerical simulations were made with the Matlab-Simulink program. The article analyses the dynamic behaviour of an elastic mechanical transmission. The obtained results are similar with the results given by the constructor. The conclusion of the study is that the simulation model presented in this paper can be successfully used for all the automobiles equipped with a mechanical transmission for a fast analyse of the acceleration performances, as well can be used to optimize these performances.

1. Introduction

The functioning of the passenger car in operating conditions takes place in wide limits for the vehicle speed, the payload and for the quality of the roads [7]. For the study of the acceleration performances an important factor is the engine speed characteristic of the engine. The maximum acceleration performances are obtained when the engine is working at the total load [6]. Similar researches of the dynamic performances simulation are presented in the papers [2, 8]. The friction modelling constitutes the base of all clutch models. Examples of friction models (hyperbolic tangent model) are presented in paper [1, 4]. A hard task is solving the model equations including friction elements, because the adaptive time step methods integrating zero crossing detection are not achievable for real-time fruition [3].

The automobile acceleration performances can be estimated with the acceleration characteristic. The acceleration characteristic can be assessed through the variation of the acceleration time reported to the passenger car speed at total load, as well can be assessed using the variation of the acceleration distance reported to the passenger car speed at total load. An automobile with a very good acceleration it is capable to increase his speed in very short space of time. The importance of the acceleration results from the fact that the time of travelling with uniform speeds are relatively low. The acceleration characteristics can be settled by way of using the software programs for modelling and simulation (Matlab-Simulink, AMESim, etc), as well by experimental way using the dynamometric stand, and also the special tracks for researches can be used. Obtaining the acceleration performances through the experimental method implies a direct measuring of the parameters, that involves costs for the materials and some special conditions for researches, especially in case of operating on a track. The benefits of using modelling and simulation programs are: low costs in comparison with the experimental method, does not need the presence of the vehicle, neither the special measuring devices, and the time for obtaining the results of the acceleration performances is significantly reduced.

2. The model presentation

For the modelling and simulation process of the acceleration performances there were implemented mathematical equations in the Matlab-Simulink program. To implement the mathematical equations in an easier way and further to insert the numbers, the global model was divided in more sub models, every sub model representing a subsystem from the engine-transmission system of the vehicle subjected to the simulation (Figure 1).

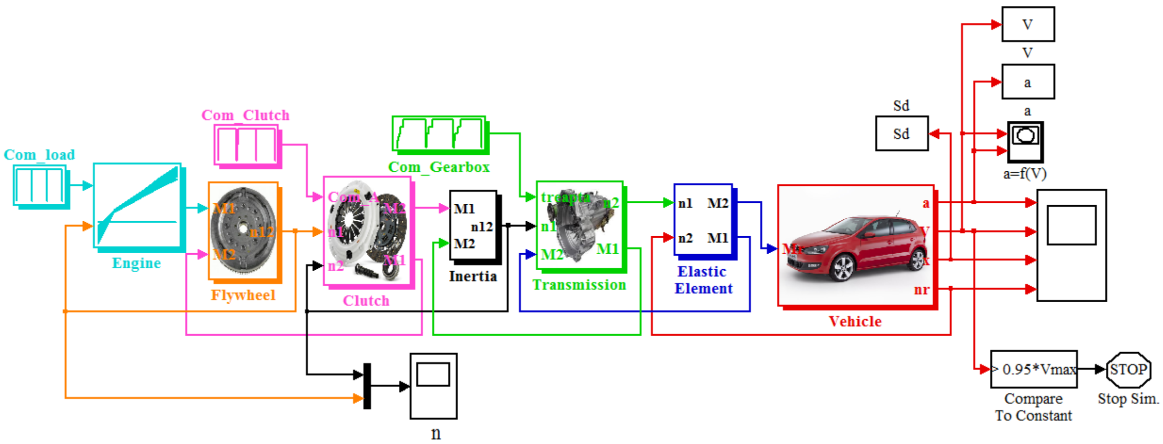

Figure 1. The global model simulated for the acceleration study

The engine was implemented through a mathematic function of two variables, with the load and engine speed variables starting from the maximum load characteristic given by the constructor, that was further modelled for partial loads and for the engine brake regimes (Figure 2). The torque at partial load was obtained from the full load torque, correlated with the throttle valve angle. When the accelerator pedal is complete depressed (100%), this corresponds to the engine full-load curve, and when the accelerator pedal isn't depressed (0%), this corresponds to the engine thrust characteristic curve [6].

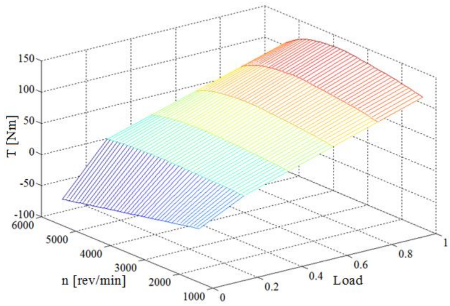

Figure 2. The engine speed characteristic of the engine for partial loads and engine braking digitized for the vehicle subjected to simulation

The acceleration performances study for the simulated vehicle were used a series of mathematical equations presented in the papers [5, 9]. Starting from the wheel traction balance:

$$\frac{dv}{dt} = \frac{F_t - (R_{rul} + R_a)}{\delta \cdot m} \text{ [m/s}^2\text{]} \tag{1}$$

where: $\frac{dv}{dt}$ represents the vehicle acceleration;

δ – influence coefficient for the rotating masses;

m – vehicle mass;

F_t – traction force;

R_{rul} – rolling resistance;

R_a – air resistance.

The acceleration time and distance have been solved by using the following equations:

$$t_d = \int_{v_0}^{v} \frac{dv}{a} \text{ [s]} \quad \text{and} \quad S_d = \int_{v_0}^{v} \frac{v \cdot dv}{a(v)} \text{ [m]} \tag{2}$$

The yield of the gearbox was considered variable in each gear, with a slight increase in superior gears. For determine the variation of the velocity according to the acceleration time, the duration of the change was assumed constant and equal to one second.

3. Simulation results

In the figures 3, 4, 5 and 6 the simulation results obtained with the Matlab-Simulink program are presented. In figure 3 the vehicle speed variation reported to the acceleration time is presented. Following the simulation, the vehicle gets to 100 km/h in approximately 12.4 s, and gets to 80 km/h in about 8.6 s (Figure 3).

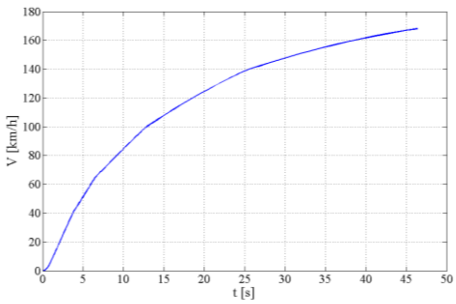

Figure 3. The vehicle speed variation reported to the acceleration time

It is noted that as when the car's speed increases and the start-up time is increasing. So a passenger car has a good start when it is arriving as high a speed as possible. It is noticed that when the starting space increases, the start time is increasing. So a car has a good start up space when it is covering a large space in a short time.
The acceleration performances given by the constructor are in table 1, and the performances obtained following the simulation in table 2.

Table 1. Acceleration parameters [10].

Parameter	Time (s)
Acceleration 0 - 80/100 km/h	8/12.1
Acceleration 0 - 400/1000 m/s	18.1/33.4
Acceleration 80 - 120 km/h	18

Table 2. Acceleration parameters.

Parameter	Time (s)
Acceleration 0 - 80/100 km/h	8.6/12.4 s
Acceleration 0 - 400/1000 m/s	18.6/33.7 s
Acceleration 80 - 120 km/h	16.3 s

Figure 5 presents the partition for the fifth gear obtained following the simulation. The increase of the speed from 80 km/h up to 120 km/h in the fifth gear, has been made with a partition time of 16.3 s. Following the simulation, the vehicle covers 400 m with 120 km/h, in 18.6 s and 1000 m, with 148 km/h, in 33.7 s (Figure 4 and Figure 6).
Figure 7 presents the moment of the gear shifting for an elastic mechanical transmission. With yellow colour is represented transmission speed and with violet colour the engine speed (Figure 7).
Figure 8 presents the acceleration characteristic for a mechanical transmission (a) and for an elastic mechanical transmission (b). The conclusion is that the maximum value obtained for the acceleration is in the first gear, then the acceleration decreases as we shift to higher gears.

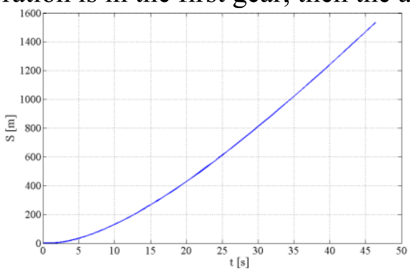

Figure 4. The acceleration distance reported to the acceleration time

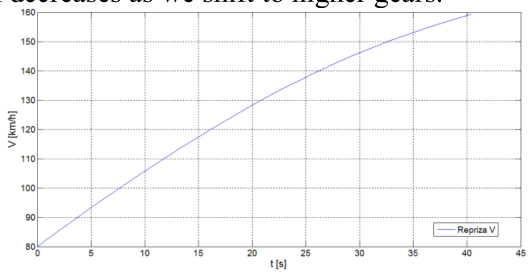

Figure 5. Partition in the fifth gear

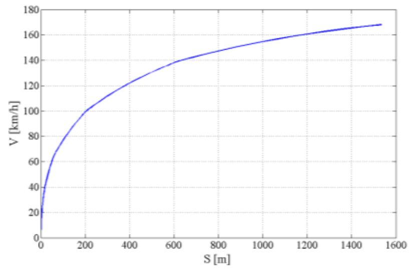

Figure 6. Speed variation reported to the acceleration distance

In the fifth gear, we get to the maximum speed, but the acceleration is zero. In our case the acceleration is annulled at the speed of approximately 180 km/h (Figure 8). Because in the first gear the transmission ratio has the greatest value, the traction force in the tire contact patch increases, so we obtain an increased acceleration, accordingly a limited adherence is needed. For the elastic transmission (Figure 8.b), the elastic oscillations are reduced as we shift to higher gears, the most oscillations are registered in the first gear. The elastic oscillations appear following the elasticity decreasing of the drive shafts, through the introduction of an elastic element. As the rigidity of the drive shafts is lower (meaning that the elasticity of the axles grows) the more oscillations appear. The acceleration characteristics depends on the clutch engagement mode.

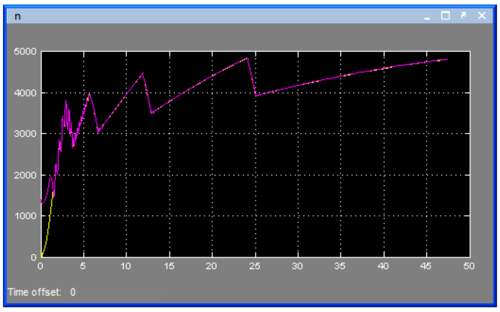

Figure 7. The moment of the gear shifting for an elastic mechanical transmission

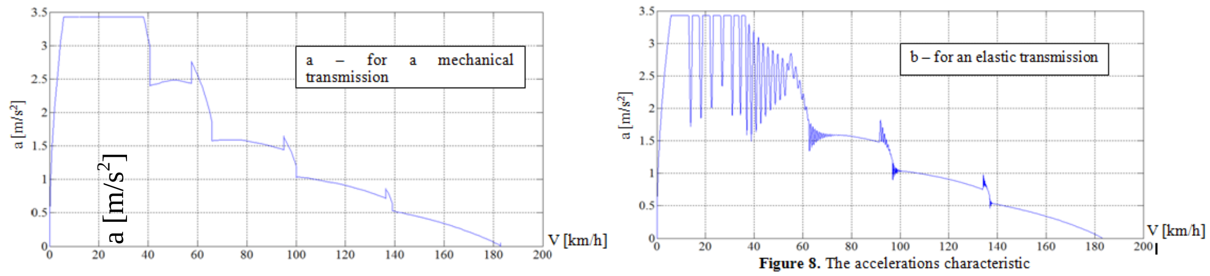

Figure 8. The accelerations characteristic

4. Conclusions

The model made for the acceleration performances study in Simulink can be used for all the vehicles with mechanical transmission and can be easily adapted for the CVT, DCT or automated transmissions. This model can be considered valid because the acceleration performances obtained following the simulation are satisfactory compared with the acceleration performances given by the constructor (for example the relative error $S_{d\ 1000}$ is approximately 0,8%). The acceleration of the passenger car, generally characterizes its dynamic qualities. High acceleration involves the increasing of the average speed of exploitation. The acceleration qualities are the main performances of the vehicles, having a direct influence on traffic safety, average speed and market success, especially in the case of cars and motorcycles.

References

[1] Andersson S, Soderberg A, Bjorklund S 2007 *Friction models for sliding dry, boundary and mixed lubricated contacts* (Tribology International), 40, pp. 580–587

[2] Alexa O, Ilie C O, Vilău R, Marinescu M and Truţă Marian 2014 *Using Neural Networks to Modeling Vehicle Dynamics* (Applied Mechanics and Materials Trans Tech Publications, Switzerland), ISBN 978-3-03835-272-3, Vol 659 pp 133-138, doi:10.4028/www.scientific.net/AMM.659.133

[3] Bachinger M, Stolz M and Horn M 2014 *Fixed step clutch modeling and simulation for automotive real-time applications* (American Control Conference ACC, Publisher IEEE, Portland, OR, USA), DOI: 10.1109/ACC.2014.6858933, pp. 2593-2599

[4] Băţăuş M., Maciac A. Oprean I M and Vasiliu N 2011 *Automotive clutch models for real time simulation* (Proceedings of the Romanian Academy, Series A: Mathematics, Physics, Technical Sciences, Information Science, The Publishing House Proceedings of the Romanian Academy), Vol 12, No 2, pp 109-116

[5] Guzzella L, Sciarretta A 2005 *Vehicle propulsion systems – Introduction to modeling and optimization*" (Berlin, Germany) ISBN-10 3-540-25195-2

[6] Naunheimer H, Bertsche B et al *Automotive Transmissions – Fundamentals, Selection, Design and Application* (SpringerVerlag, Berlin, Heidelberg), 2nd edition, ISBN 978-3-642-16213-8

[7] Tabacu I 1999 *Mechanical Transmissions for Passenger Car* (Technical Publishing House, Bucharest, Romania), ISBN 973-31-1340-9, romanian Language

[8] Vilău R, Marinescu M, Alexa O et al 2014 *Diagnose method based on spectral analysis of measured parameters* (Advanced Materials Research Trans Tech Publications, Switzerland) ISBN 978-3-03835-255-6, Vol 1036, pp 535-540, doi:10.4028/www.scientific.net/AMR.1036.535

[9] Wallentowitz H 2004 *Lecture longitudinal dynamics of vehicles*", 4th Edition, Aachen, Germany

[10] ***Technical Specifications VW Polo