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CVT Simulation on the Dynamic Engine Test Bed

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1. Introduction

The development of Continously Variable Transmissions (CVT) is currently a major focus in the automotive industry. The advantage of this transmission concept compared to manual or automated shift transmissions is the simple mechanical design and the reduced work load on the human driver. By utilizing the continously variable gear ratio the engine and transmission can be easily optimized for the desired behaviour, for example fuel consumption or power. Out of many mechanical designs to realize a continously gear ratio, e.g. hydraulic acts or friction gears, the looping principle is now commonly used for the small and medium power range (see figure 1). This design is well developed and combines the advantages of low noise and acceptable mechanical efficiency.

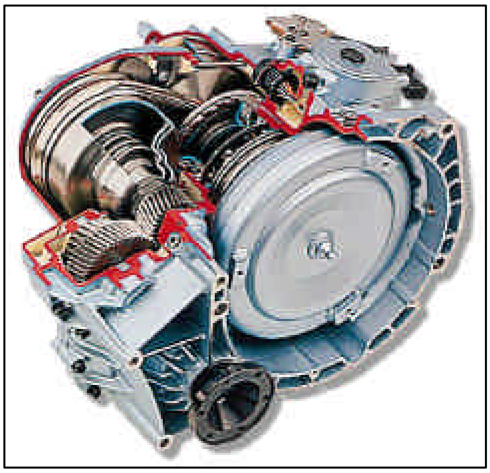

Fig. 1 ZF Ecotronic

Following the actual development trends the market demands now also test beds, which can simulate the dynamic behaviour of CVT gearboxes. Using highly dynamic dynamometers and sophisticated control and simulation methods the AVL List GmbH is the worldwide leading supplier in the field of transmission and vehicle simulation on the dynamic engine test bed (see figure 2).

By combining the test bed control and simulation unit EMCON / ISAC with the open simulation software MATLAB / SIMULINK[1] a maximum of safety on the test bed and at the same time maximum flexibility and openess in the transmission and vehicle simulation can now be provided.

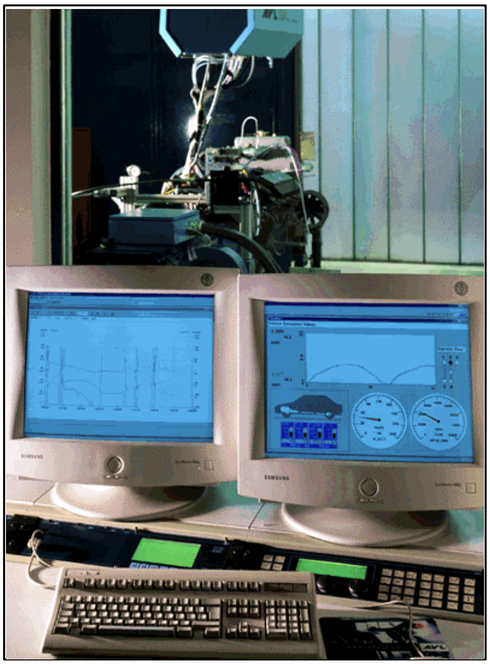

Fig. 2 Highly-dynamic engine test bed with AVL ISAC 300

2. CVT – Model

For the existing test bed environment a real time model was developed with MATLAB / SIMULINK , which can simulate the dynamic behaviour of a CVT gearbox very close to reality. The model is calculated with a fixed step length of 4 milliseconds, which is equal to 250 Hz aquisition frequency and has a user-friendly graphical user interface (GUI) to input

[1] MATLAB / SIMULINK are registered trademarks of The Mathworks Inc.

the model parameters. Because of the strong demands on the real time capability of the simulation model some simplifications in the modelling had to be done. In figure 3 the basic structure of the model is shown, consisting of a gear ratio controller for the variator using 2 dimensional characteristics, two shafts as spring-damping elements, a start clutch with two inertias and the final drive. The modular design of the model allows the use of different start clutch models which can be placed at different locations within the transmission model.

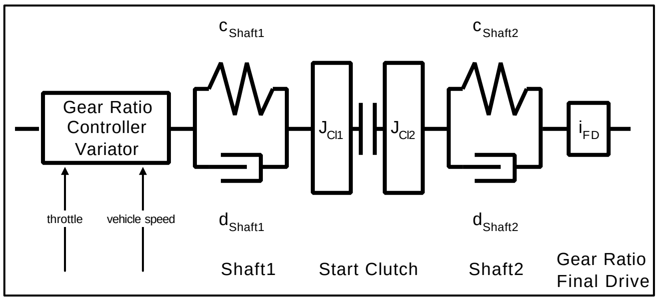

Fig. 3 Structure of the transmission

In the described example model a multiple disc clutch is used, which is positioned between variator and final drive to avoid torque peaks on the transmission output side. In figure 4 the Simulink - model of the start clutch is shown.

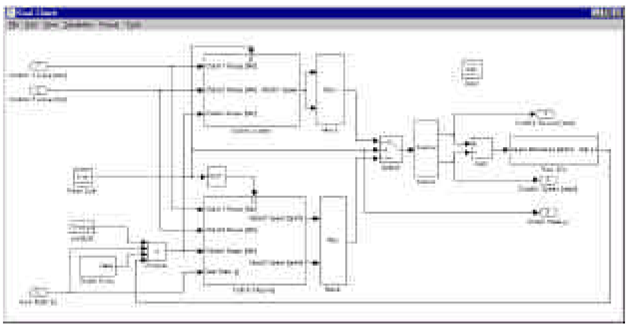

Fig. 4 Model of the start clutch

3. Comparison Measurement - Simulation

In order to prove the quality of the transmission model the calulated values have been compared with the measured values in the real vehicle. These data were taken from a Honda Civic CVT, which was also used as reference for the example model.

In figure 5 ff. are two wide open throttle accelerations (WOT) shown, the first in select lever position D, the second in lever position S. The vehicle is accelerated in lever position D from standstill at time t=0.1 seconds with 100% throttle position until time t=50 seconds and coast then with 0% throttle position to standstill. From time t=107 seconds to standstill the foot brake is used. After selection of lever position S again a WOT is performed, starting at time t=112 seconds. The coastdown starts at time t=150 seconds, the foot brake is activated at time t=190 seconds. For comparison between simulation and measurement the data for vehicle speed, engine speed and variator ratio have been selected. The red curves are from the measurement, the blue curves are from the simulation.

After setting of throttle position to 0% at time t=50 seconds the reduction of the variator ratio to overdrive (i=0,45) can be seen in figure 6. After reaching a vehicle speed of 50 km/h the ratio change towards starting from rest (i=2,47). In lever position S a different variator characteristic is used with an increased ratio for starting from rest, which allows higher engine speed and faster acceleration times.

In figure 7 the resulting engine speed is shown, the jump at time t=50 seconds after setting the throttle position to 0% is due to the fact, that the variator controller tries to control the engine speed to a lower level, which is constrained by the mechanical design to a certain level. At a vehicle speed of approx. 160 km/h the lowest engine speed in overdrive is approx. 3.700 rpm. The second jump at time t=83 seconds is due to the corresponding variator ratio. The same is true for the curve in the second part with lever position S. In figure 8 the resulting engine speed is plotted over the vehicle speed.

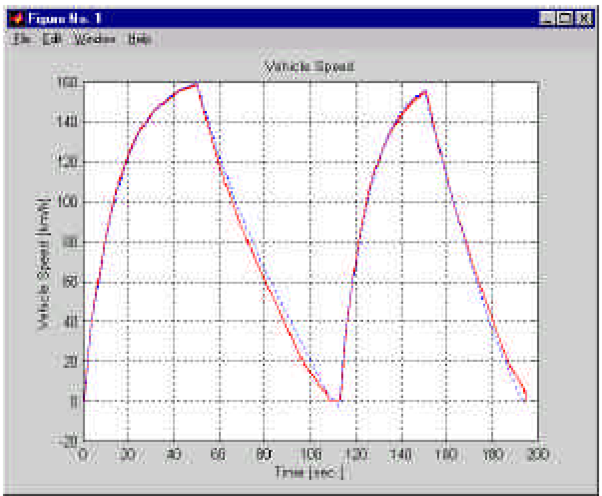

Fig. 5 Vehicle speed over time

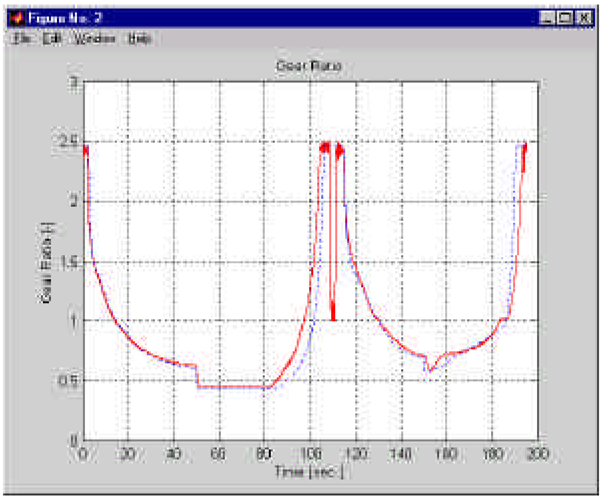

Fig. 6 Variator ratio over time

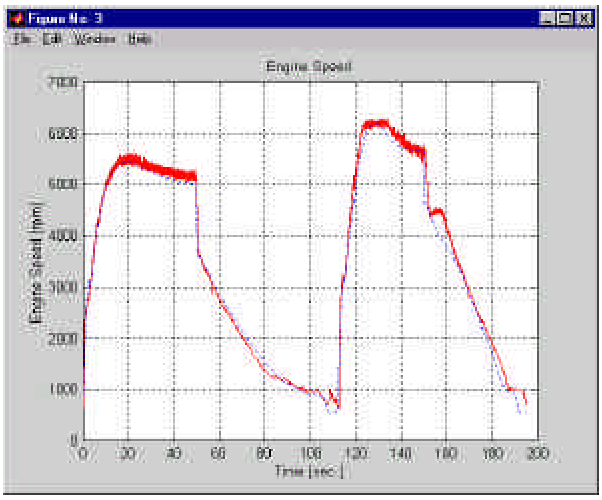

Fig. 7 Engine speed over time

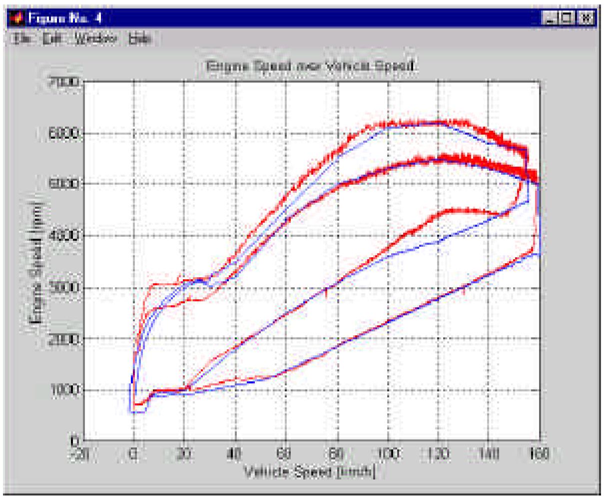

Fig. 8: Engine speed over vehicle speed

4. Conclusion

The ideal vehicle transmission with optimal calibration of engine and transmission can only be one with continously variable gear ratio. The development progress during the last years for this type of transmissions will result in an increasing acceptance of CVT in the world market. It will be necessary to utilize the existing potentials for optimization and to put it in production solutions, in order to establish CVT type transmissions besides conventional manual and automatic transmissions. Clearly the latest CVT designs have overcome problems of the long existing types on the market.

The dynamic engine test bed with its driver, transmission and vehicle simulation and its available versatile measurement systems for power, emissions and fuel consumption plays an important role in the calibration of the complete powertrain with combustion engine and CVT gearbox. Besides the realistic simulation of already build transmissions is the simulation of new CVT concepts on the dynamic engine test bed another step in the reduction of the development time of new vehicle powertrains.