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THE CLONK PHENOMENON – A LOAD CHANGE REACTION TO BE BALANCED IN TERMS OF COMFORT AND ENGINE RESPONSE

J.-W. BIERMANN*, A. REITZ and T. SCHUMACHER

Department of Vehicle Acoustics, Institute of Automotive Engineering (ika), University of Technology, Aachen, Germany

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ABSTRACT–The customers demand of a good vehicle agility consists of a quick reaction of the vehicle with the actuation of the throttle pedal on one hand and a high comfort level of vibration and noise within the vehicle on the other hand, which means the reduction of disturbing side effects. In order to achieve a satisfactory compromise it is necessary to gain a deeper understanding of the complex, high dynamic vibrations system "vehicle / drive train". For several years the ika has been carrying out such detailed vehicle investigations and test bench measurements in addition to comprehensive CAE analysis for various research projects in partnership with different vehicle manufacturers.

KEY WORDS : Drive train NVH, Clonk, Shuffle, Load change reaction, Engine responce

1. INTRODUCTION

The development of new vehicles is influenced by the demand of reduced fuel consumption and exhaust emissions. Besides those dominant development criteria, a more intense customer comfort claim regarding noise and vibrations characteristics of vehicles has been observed in recent years. New vehicle presentations that have been made at automobile exhibitions show that the fun of driving a car appears to be a serious reason for purchasing a car. Accordingly, an increase of engine torque can be found in newly developed engines to realize a good agility. Thus, a situation emerges for the vehicle engineer in which a well balanced com-promise between sometimes opposing targets has to be found. The drive train is a main point of interest in this case. The main drive train components (engine, clutch, transmission, shafts, joints and wheels) present a complex, rotational- and bending vibrations system, which causes numerous disturbing NVH-phenomena.

In Figure 1 the most known phenomena are shown. In the following, "shuffle" and "clonk" will be explained in more detail. In contrast to the other NVH phenomena both of these are excited by a sudden load change. This results, for example, via sudden throttle actuation or de-actuation (tip in – back out) as well as engaging the clutch.

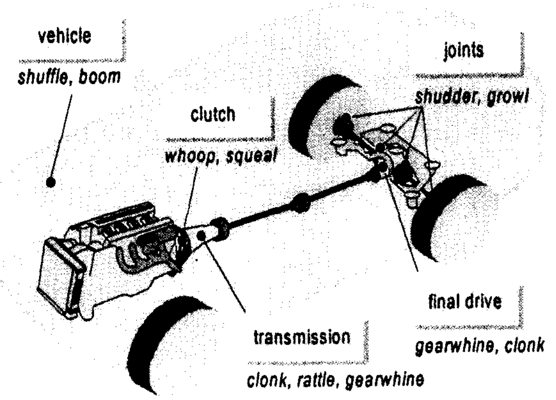

Figure 1. NVH phenomena caused by the drive train.

Figure 2 shows the shuffle and clonk phenomena in principle.

Shuffle is a longitudinal vibration of the entire vehicle excited by the oscillation of the flywheel against the wheels. The frequency range is between 2 and 8 Hz.

The sudden change of the engine torque leads to the back-lash afflicted components thrashing against one another (see also Figure 2). The result of this exchange of impulse is a metallic, disturbing noise known as clonk. The customer increasingly desires a vehicle

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* *Corresponding author.* e-mail: Biermann@ika.rwth-aachen.de

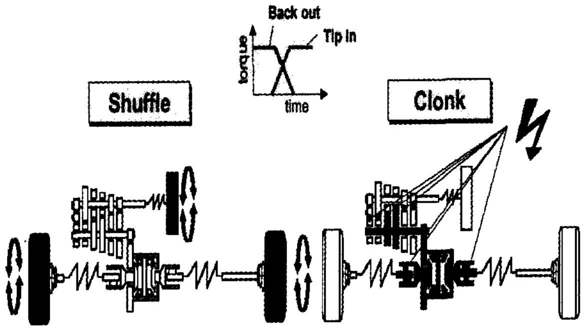

Figure 2. Phenomena of "shuffle" and "clonk".

with a sporty character. This especially means the agility of the vehicle, i.e. a quick response of the engine. Therefore a conflict of interests is pre-programmed into the arrangement of the "vehicle/ drive train" system.

With the aid of measurement results this is clarified in Figure 3. The vehicle acceleration, the angular displacements of each drive train component and the interior noise are all represented for a full throttle acceleration manoeuvre. Vehicle A reacts with a distinctive shuffle movement with the sudden actuation of the throttle pedal. The angular displacement of the individual drive train components shows the superimposed vibration movement in the rotating drive train. The initial impression of the engine response to the throttle actuation is good; but disturbing is the clonk impulse which is clearly audible within the interior of the vehicle.

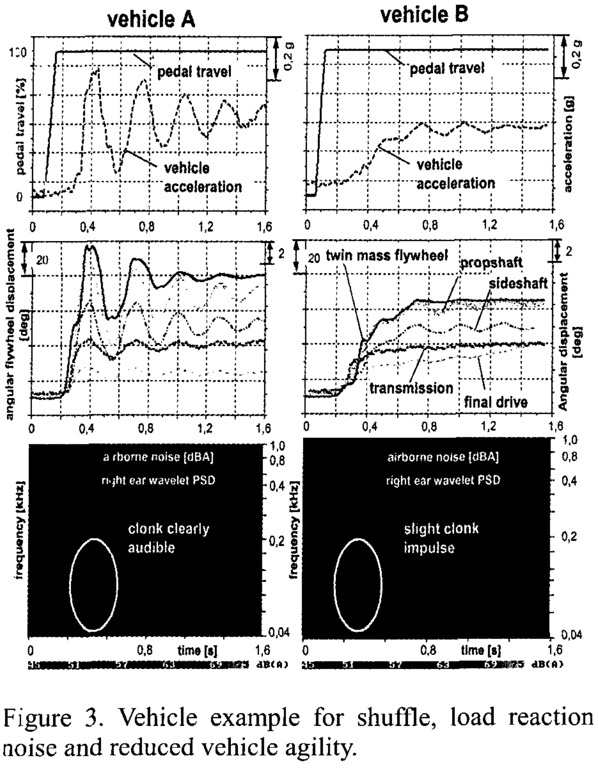

Figure 3. Vehicle example for shuffle, load reaction noise and reduced vehicle agility.

With vehicle B, neither a shuffle or an unpleasant clonk noise occurs. However, in comparison with vehicle A the agility of the vehicle, i.e. the reaction of the vehicle upon quick actuation of the throttle pedal, is not satisfactory. At the moment the majority of the vehicle manufacturers are intensively busy solving this conflict of interests. Over the past few years at the ika investigations for different. European vehicle manufacturers have been and continue to be carried out in the form of road tests, test bench investigations and computer simulations for both front and rear wheel drive vehicles.

2. MEASUREMENT AND ANALYSIS OF THE VIBRATION SYSTEM "VEHICLE / DRIVE TRAIN"

In order to be able to reach a satisfactory compromise between NVH comfort and vehicle agility, a deep understanding of the complex vibration system "vehicle/ drivetrain" is required, as well as a thorough understanding of the interdependent individual parameters that influence the drive train system. Figure 4 shows the most important system parameters that influence NVH and agility using a rear wheel drive vehicle as an example.

The excitation of the vibration system is caused by the engine torque that is influenced by for example manifold pressure, ignition and injection. The vibration

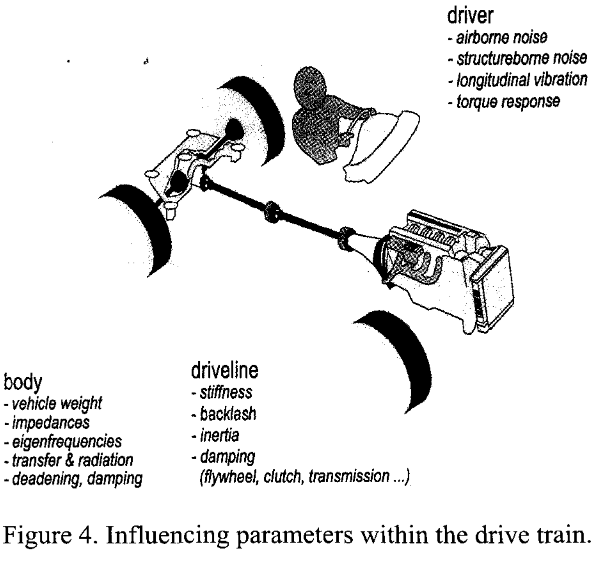

Figure 4. Influencing parameters within the drive train.

characteristics of the system itself are determined via the inertia mass, component stiffness, damping coefficient and the backlash of the drive train components (i.e. flywheel, clutch, transmission,). Relevant for the vehicle rating is the perception of the driver. Most important are the air-borne noise, the longitudinal vibration of the vehicle and the engine response.

For the acquisition of the fundamental data the ika carries out detailed measurements of the drive trains. The results are stored in a corresponding database, so that it is possible to compare different vehicles.

Firstly, static measurements of the physical parameters are established, such as inertia, stiffness and backlash of all of the involved drive train components. Figure 5 depicts the torsional stiffness of a complete manual transmission from a rear wheel drive passenger vehicle. The sharp rise in the torsional angle can be easily identified with higher gear selection. The corresponding torsional stiffnesses produce different vibrational behaviour within the individual gear ratios.

Afterwards, the dynamic vibrational characteristics are investigated with the support of on-road tests and special test benches (Reitz et al., 1999). Within these tests the rotational and longitudinal vibrations of the drive train components are recorded simultaneously using a high resolution measurement equipment. The positions of the various measurement sensors are shown in Figure 6, using an example of a vehicle with front wheel drive.

The rotational vibrations within the drive train are determined at six positions so that there is adequate information about the rotational vibration characteristics within the whole drive train system. In addition the opening of the throttle plate, the air pressure in the intake manifold, the ignition signal and injection process of each cylinder are recorded in order to asses the torque configuration.

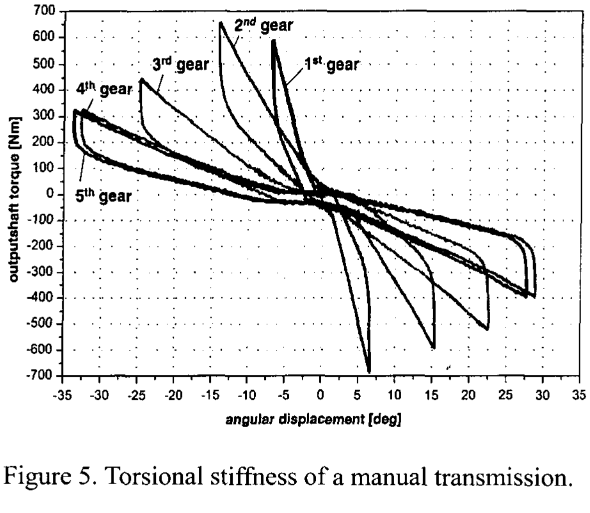

Figure 5. Torsional stiffness of a manual transmission.

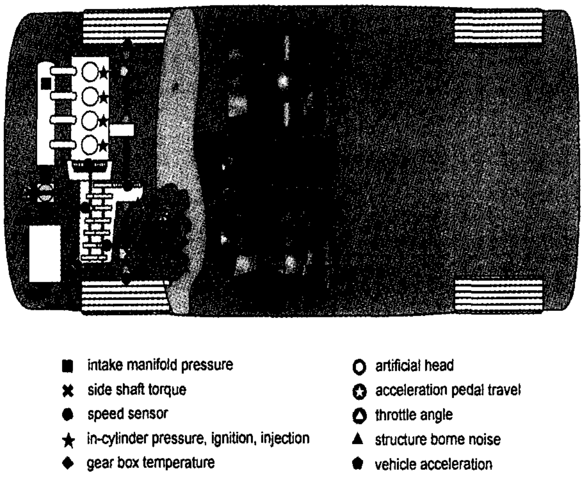

Figure 6. Overview of the measurement positions.

To assess the comfort relevant NVH phenomena the longitudinal vibration of the vehicle and the air-borne noise within the passenger compartment, with the aid of the artificial head, are recorded. This provides an additional possibility of subjective evaluation of noise phenomena. In Figure 7 the results for a road measurement on a compact size passenger car are shown as the vehicle is suddenly accelerated from a trailing throttle.

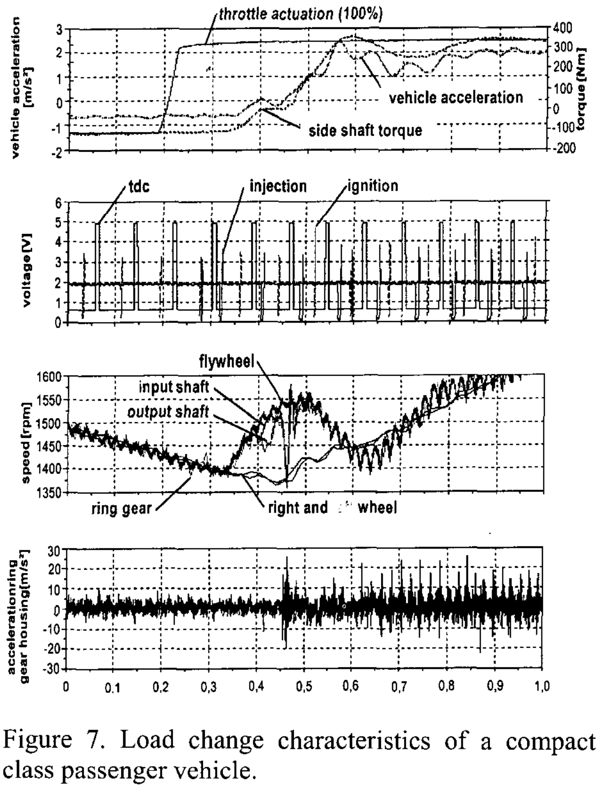

Figure 7. Load change characteristics of a compact class passenger vehicle.

The individual curves in the diagram at the top show the position of the throttle plate, the torque curve on one side shaft as well as the longitudinal vibration of the vehicle. Noteworthy, is the break in the drive torque of the side shaft at zero transition; this will be further investigated later on.

The second diagram shows the ignition impulses as well as the period of the fuel injection for the first cylinder. In addition the top dead centre (tdc) point is also recorded. During deceleration there is no injection. This starts after application of the throttle plate. An electronic control intervention regarding the influence of the shuffle characteristic is not distinguishable.

The third diagram shows the rotational speed curves of the flywheel, transmission input and output shafts, differential ring gear and both right and left wheels. The transmission ratios are taken into account, i.e. the curves are related to the transmission input shaft. This clarifies the reaction characteristics of the vibration system "vehicle/ drive train". The flywheel rotational speed allows the second engine order to be recognized. At 0,35 sec the speed curves of the individual components deviate from one another. This is caused by the torsional stiffness and backlash of each component. At time 0.45 sec the zero transition of the sideshaft torque is finished as shown in the diagram above. Simultaneously a strong impulse exchange inside the drivetrain occurs as demonstrated in the third diagram. This is the root cause of the corresponding clonk impulse which is clearly visible in the structure borne noise signal at the ring gear housing (see the diagram below). As this example shows, a detailed analysis of the transient vibrational characteristics of the system "vehicle/ drive train" can be obtained with the aid of high resolution, simultaneous recording of all relevant measurement data.

3. ACQUIRING A WELL BALANCED COMPROMISE

The influence of individual parameters upon the vibrational characteristics are best investigated with the aid of a suitable simulation tool in addition to the expensive and time intensive test bench measurements. Different modelling approaches have been made in order to illustrate vehicle/drive train systems (Fan, 1994; Bencker, 1998). Figure 8 shows a simplified model that is used at the ika for the investigation of low frequency shuffle (Hagerodt, 1998).

This model essentially contains the moment of inertia of the engine, the vehicle wheels (inc. vehicle mass), gearbox gears and the differential. In addition the stiffness of the clutch, side shafts, vehicle tyres and the meshing of the teeth between the gears are also considered. For the investigation of low frequency vehicle shuffle it is not necessary to use a more detailed model.

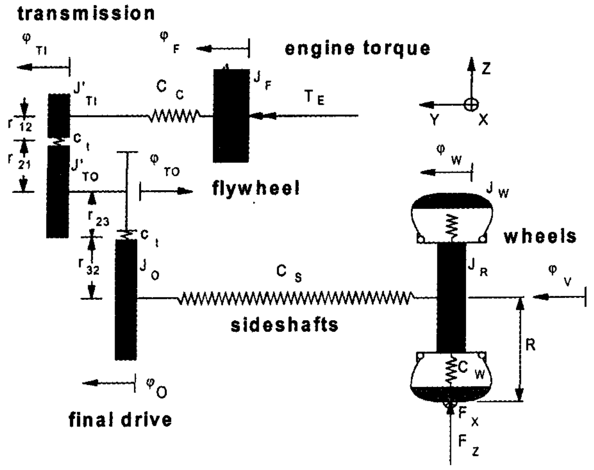

Figure 8. Simplified drive train model for shuffle investigation.

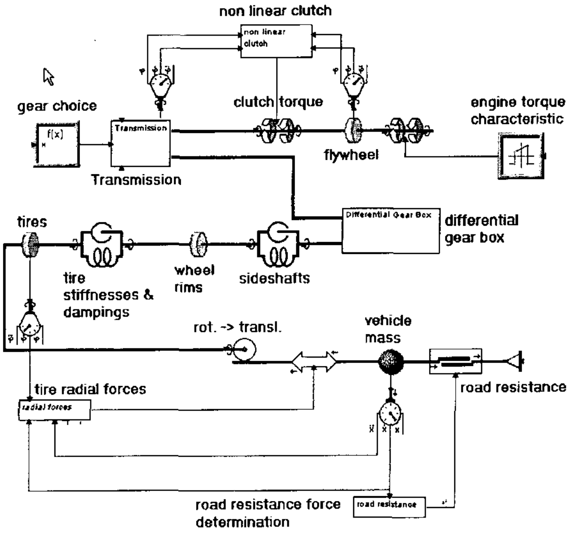

Figure 9. ITI–SIM computer model for shuffle investigations.

In Figure 9 the corresponding simulation model is shown. For the model approach ITI®-SIM is used as CAE Software. For the investigation of higher frequency phenomena, such as clonk, more detailed models were substituted, in which the individual drive train components are depicted in more detail.

In extensive simulation investigations the influence of engine and drive train parameters on the shuffle characteristics of the vehicle were analysed. Regarding

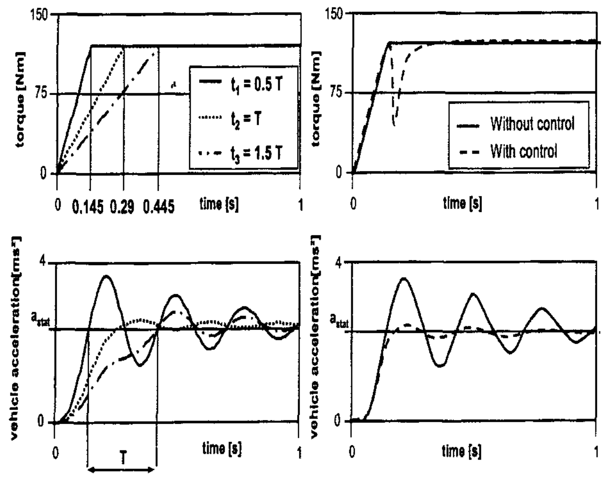

Figure 10. The influence of torque on the shuffle characteristic of a passenger vehicle (Hagerodt, 1998).

this matter, the impact of the torque increase upon the acceleration of a passenger vehicle is shown in Figure 10 as an example.

In the top left of the diagram three different engine torque increases are depicted; the resulting vehicle accelerations are shown underneath. It is obvious that the middle of the three engine torque increases is a compromise between adequately reduced shuffle movement as well as sufficient agility of the vehicle. The other two set-ups result in either a non-acceptable shuffle characteristic or a reduced agility of the vehicle. With the aid of this example the first measure can be identified, i.e. the time periods for engine torque build-up and shuffle frequency should be the same. The right hand side of the figure shows again the engine torque increase with the shortest period and the resulting unacceptable shuffle characteristic. In order to reduce the vehicle shuffle a control of engine torque is undertaken. Shortly before reaching the maximum value the torque is held back for a short duration so that the shuffle movement of the vehicle can be suppressed. The agility of the vehicle is now better than in the previously described set-up.

Figure 11 shows an example of a vehicle in which a well balanced compromise was found. The left hand side of the picture shows again vehicle A with a good agility but an uncomfortable shuffle behaviour and a clearly audible clonk noise within the passenger compartment. In comparison with vehicle A vehicle C, in the right hand side of the figure, has an adequate vehicle gility and also a good shuffle behaviour and no audible clonk. This result was obtained using a specific control set-up of the engine torque.

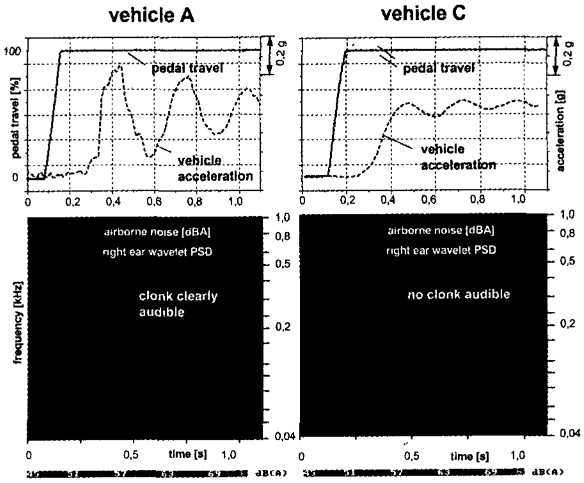

Figure 11. Example of a well balanced vehicle set-up.

4. CONCLUSION

Up until now, the investigations at ika have shown that the control of engine torque is a major parameter in order to design a well balanced vehicle regarding NVH comfort and longitudinal dynamics. But it is also worth noting that the physical characteristics (backlash, stiffness etc.) of the different components within the drive train must not be neglected. Engine and drive train characteristics should not be designed separately. In order to achieve a well balanced compromise between NVH-comfort and vehicle agility both of these aspects have to be taken into account in the same way.

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