# Clutch and Operation as a System

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## Introduction

New technologies and increasing demands for comfort, require increased total system thinking, also in the area of clutches and clutch actuation. In addition, the automotive industry requires system suppliers in this area, who can optimize the functional chain in practical ways.

LuK has taken on the task of understanding the theory of the clutch operation, including the dynamics, and of improving it from the pedal to the transmission input.

This presentation will examine the individual load transferring components and how the driveaway performance is improved by tuned interaction and how the actuation force can be reduced.

## General Goal

The clutch manufacturer is required to develop an optimal pedal solution with the clutch parameters (Figure 1).

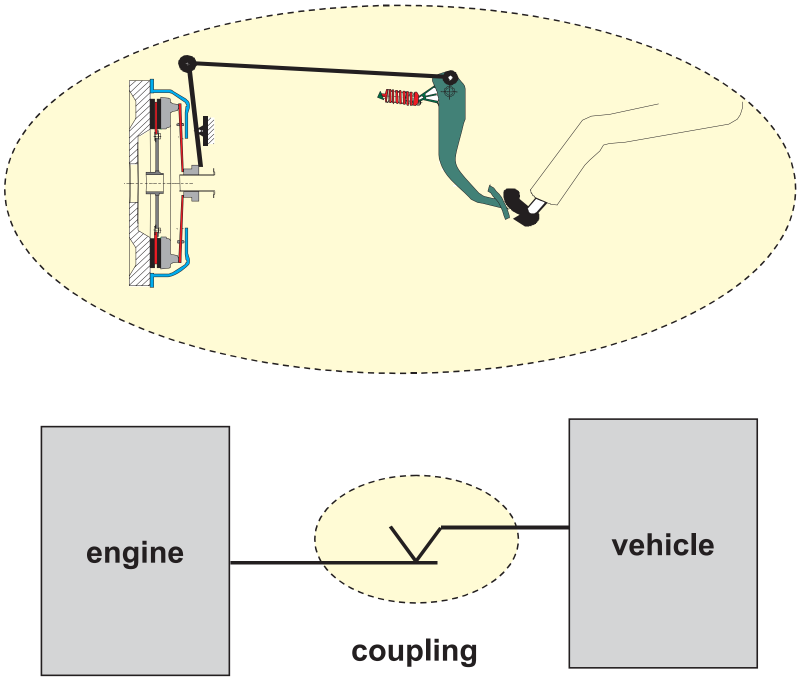

Figure 1: Clutch / operation set-up

For the driver, this should provide a vehicle with a clutch that is guaranteed to have

- flawless release behavior,
- favorable actuation pedal force and pedal travel characteristics,
- noise- and vibration-free actuation, and
- a good modulation behavior during driveaway and shifting.

The clutch manufacturer can only influence a part of the major parameters to meet the above demands.

Hence, it is apparent that optimal function is only achieved if the entire functional chain is considered.

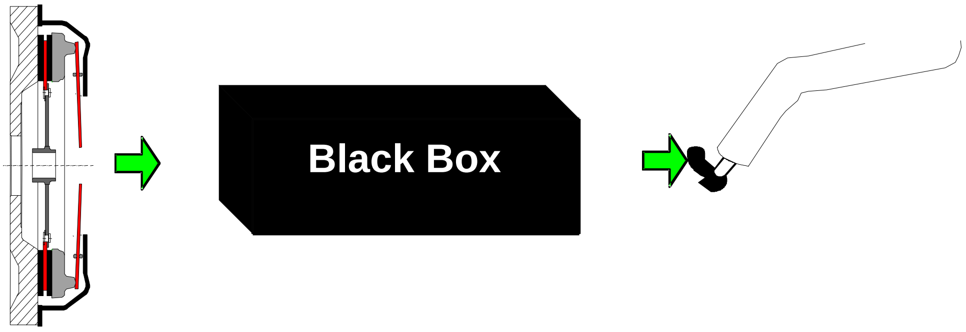

Figure 2 : Previous consideration of the release system by the clutch manufacturer

Only if all part functions of the clutch system are tuned to one another in a practical way and if the influences from the engine and chassis are considered, can a first class overall function of the clutch system be expected.

The overall view must be guaranteed by this system consideration, which was complicated thus far by the different requirements of the car manufacturers for the engine, transmission and chassis.

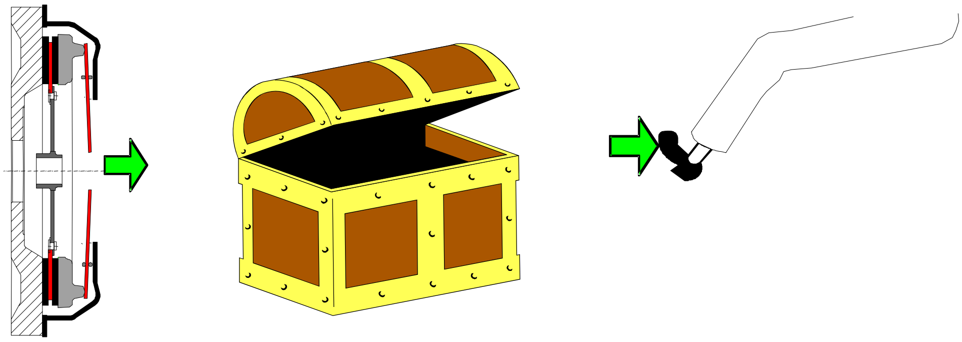

Figure 3 : Consideration of the release system by LuK

The previous black box "release system" (Figure 2) should be broken down, with the intent of better exploiting the potential of clutch and actuation and hence of optimizing the system overall.

Therefore, a few years ago, LuK established a team of five engineers who took on this task and determined a series of new effects. The most important parameters to influence the entire system will be summarized below.

## Elasticity in the Clutch / Operation System

Figure 4 illustrates the travel transmission function “release travel over pedal travel” of an actuation system. The ideal curve as well as a measurement at room temperature (green line) and in warm operating conditions (red line) are shown; deviations from the ideal curve represent the travel losses of the release system. The increased elasticity of the release system as a function of the temperature leads to a significant shift in the clutch separation point towards the end of pedal travel.

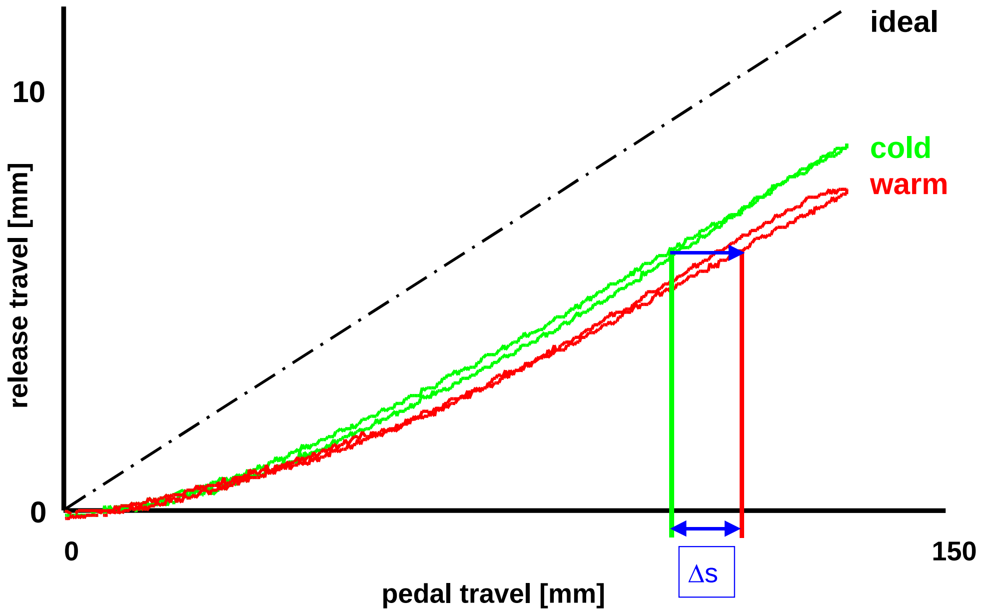

Figure 4: Measurement of the release travel when cold / warm

The transmission function of the entire release system can essentially be described by a single ratio and elasticity.

In order to determine the loss portions of the individual actuation components, as well as the dependence of these losses on temperature, the representation illustrated in Figure 5 was used for the entire system analysis.

The travel losses on the pedal (x axis) present for the defined release force on the clutch (y axis) are shown here. Hence, for maximum release force, the loss travel increases from 30% of the total pedal travel to 55% in warm conditions.

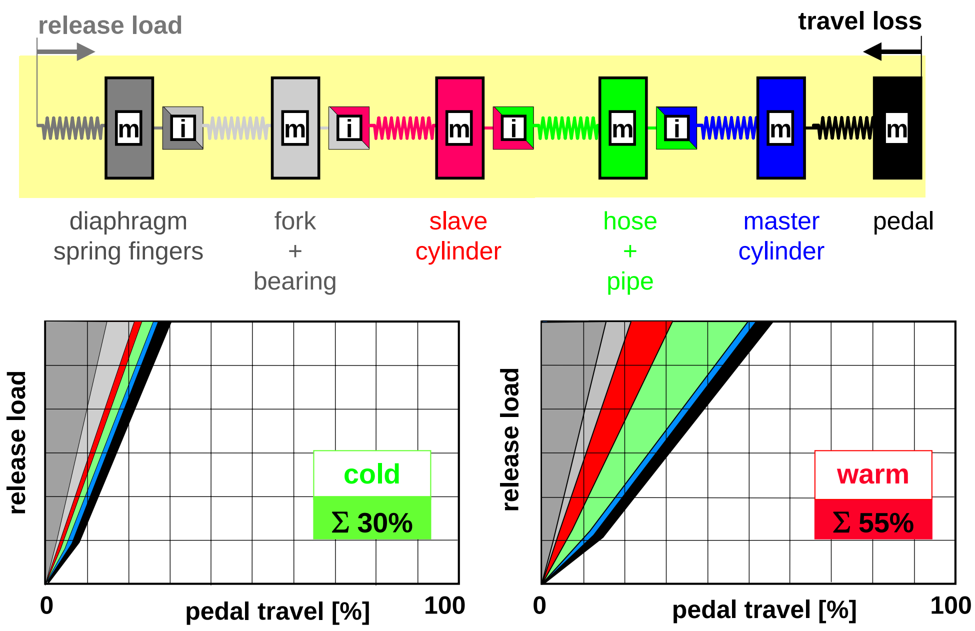

Figure 5: Elasticity's (reduced to pedal travel, cover stiffness not shown)

The illustration of individual elasticity's, reduced to the pedal travel, shows which elasticity's influence the total travel loss the most.

Depending on the quality of the system, the travel loss amounts to up to half of the pedal travel. The components (diaphragm spring fingers, release fork) located on the high force level and low ratio stage have the most influence on the position of the coupling points, hence on the beginning of the torque build-up and on the separation behavior. At the same time, it is apparent how the elasticity's change due to temperature. In the above example, the components – slave cylinder and hydraulic line – exhibit the most potential for improvement.

With this illustration, it is possible to usefully evaluate the different elasticity's in the mechanical system, the semi-hydraulic system and the central hydraulic system.

A comparative consideration can also be made with the frictions in the entire system. The combination of both considerations allows for the study of the influences of force and travel hysteresis.

## Vibrations in the Clutch / Operation System

There are more ways to identify pedal vibrations and actuation noises (e.g., eek, whoop, scratch, etc.) than for almost any other phenomenon. This provides a clear indication that the types of excitation and the vibration transmission are numerous for this type of complex system.

Examples for excitations of vibrations in the system clutch and operation are:

- Axial or bending vibrations from the crankshaft and flywheel
- Unperpendicular release bearing
- Vibrations of the engine-transmission assembly
- Alignment between engine and transmission
- Actuation alignment

To understand the entire vibrational system, to separate the various influence variables and to be able to represent the corresponding remedies in both computation and practice, the entire system was set up as a vibration model at LuK.

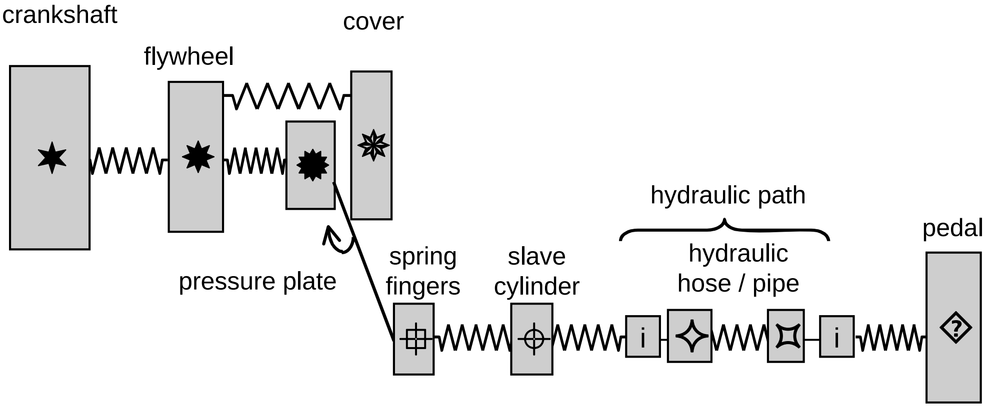

Figure 6: Vibration model

In the following case, this model provides information that is representative of many problems that can be solved in this way.

A strong, high-frequency and pedal travel-dependent actuation noise occurred in one vehicle.

A natural frequency analysis of the vibration model results in a correspondence of the cover natural frequency and the frequency of a standing wave in the fluid column of the hydraulic travel, which leads to good noise transmission in the release system.

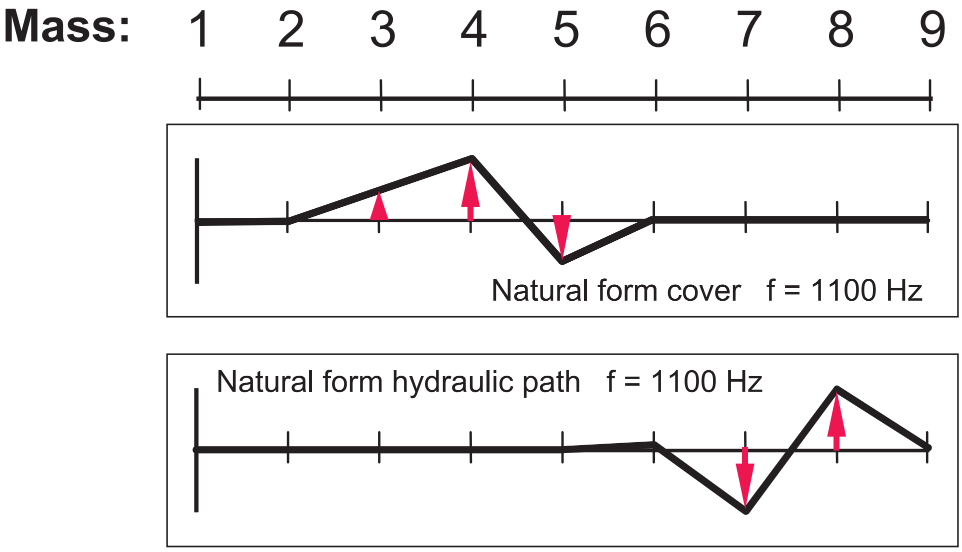

Figure 7: Natural modes of the release system

The natural mode of this standing sound wave in the fluid corresponds for a mechanical system to a string clamped on both ends.

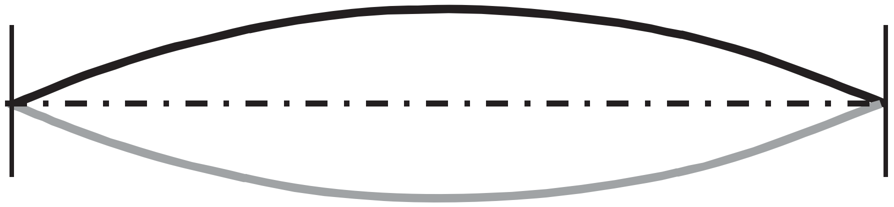

Figure 8: Natural mode of a clamped string

Theoretically, this can be avoided by detuning the two frequencies, thus by changing the cover stiffness or the length of the hydraulic line. In the above case, the steel hydraulic line was lengthened by approx. 20 cm, which is the simplest solution. This solution completely eliminated the actuation noises, without having a negative effect on the elasticity in the release system.

This example illustrates how vibrations, that are excited and transmitted in the clutch and release system, can be described and how improvements can be developed using the simulation program. The critical areas of the individual components were shown. For the pressure plate for example, the simulation program also considers a release travel-dependent natural frequency, because of the surrounding springs. Remedies can be provided depending on the problem by using a “soft connection” for the pressure plate.

The effects of the crankshaft dynamics (axial and bending vibrations) or excitations from out of perpendicular release bearings (“slanted position of the diaphragm spring”) result in reactions on the clutch that are recognized in the timeframe through simulation and thus, can also be prevented. Hence, it is possible to depict the influences of friction and damping. The simulation makes it possible to design the damping elements in the pressure plate as well as to define the friction and damping equipment in the hydraulic or mechanical actuation system.

The “rapid engagement” procedure can also be simulated. In addition to friction and damping, the distribution of the masses and ratios in the release system play a decisive role here.

## Clutch Modulation During Driveaway

Changes to the driving profile due to a higher proportion of city driving or traffic jams, or major changes to the entire vehicle, lead to a critical evaluation of the driveaway performance in many vehicles, particularly at idle.

Significant changes to the entire vehicle that stress the clutch and release system layout with regard to modulation are:

- Small capacity, super-charged engines that reach a high maximum torque, but have low idle torque.
- High maximum engine torque's result in high clutch torque's and high release forces.
- Lowering the idle speed as well as reducing the engine-side rotating masses decrease the flywheel energy during driveaway.
- New injection technologies (particularly for diesel engines) change the engine speed stability during driveaway.
- Clutch systems with reduced forces offer potential in assembly standardization, in the area of clutch and release systems with lower release system ratios.
- The introduction of longer axles results in an increase of the effective vehicle mass reduced to the transmission input shaft.

An added difficulty is that vehicles have predominantly been subjectively classified as having either good or poor driveaway performance, because there were no objective parameters and insufficient measurement and simulation options to describe the driveaway characteristics.

Problems during driveaway are generally attributed to the clutch because it connects the “rotating engine mass” and the “standing vehicle mass”. The factors influencing driveaway characteristics and how these factors can be measured and evaluated using measurement and simulation, will be illustrated below.

The factors involved in driveaway can be classified as shown in Figure 9:

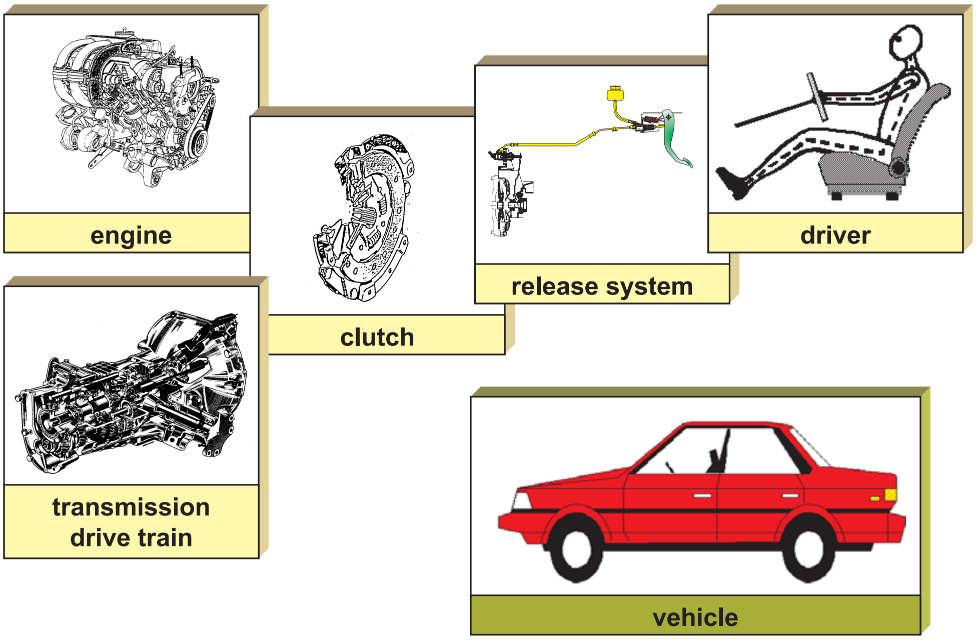

Figure 9 : Influencing parameters during driveaway

In practice, the clutch is almost always proven to be a part of the influencing variables. Various measurement and simulation options were developed at LuK in order to better understand, evaluate and effect positive changes in the individual factors and their interactions.

The driveaway performance of three vehicles will be compared and studied as an example of this systematic procedure. Three different vehicles with similar piston displacement, but with different actuation systems, are used.

To conduct this study, the vehicles **A**, **B** and **C** are broken down into their corresponding sub-systems (clutch, release system, engine, vehicle).

First the clutch is considered. This corresponds to the current “classic” scope of the task of a clutch manufacturer with regard to its options for influencing driveaway characteristics.

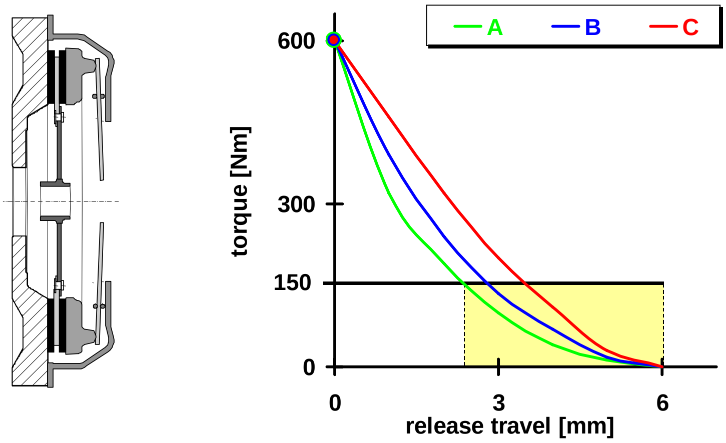

Figure 10 : Clutch torque as a function of the release travel

Figure 10 illustrates the three fundamental clutch torque curves (**A** / **B** / **C**), which all lead to the same maximum clutch torque with the same release travel.

Clutch **C** is shown here as having the steepest characteristic in the torque range (≤ 150 Nm) that is decisive for driveaway. Clutch **A** is shown having the shallowest. Hence, clutch **A** would initially be classified as the easiest to control.

These three clutches were installed and measured in the corresponding vehicles.

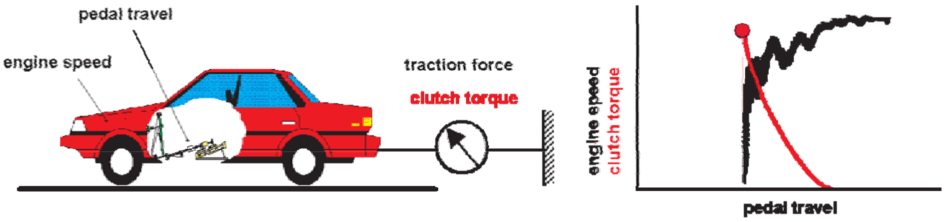

Figure 11 : Determination of characteristic values during engagement to describe the release system

To determine the influence of the actuation system, the clutch is engaged by a spindle unit, which acts upon the clutch pedal; the vehicle is fixed by means of a load cell. This load cell records the torque build-up of the clutch as a function of the pedal travel, which is influenced accordingly by the ratio and the elasticity of the release system. As this measurement is taken, the engine speed is also measured. The engine behavior as well as the level of the stall torque attained when closing the clutch at different speeds while in idle provides information about the quality of the engine and the engine control.

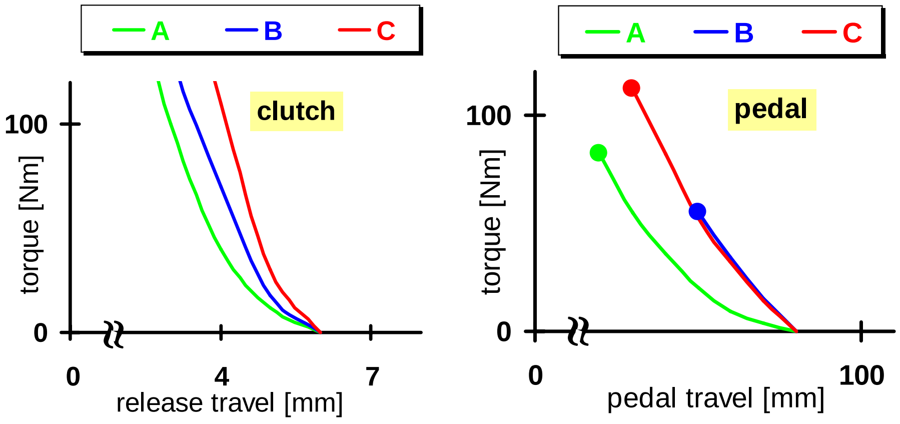

Figure 12: Clutch torque over release travel and pedal travel

Figure 12 (right) illustrates curves **A, B** and **C** of the three different clutches with the applicable release systems in the vehicles. The curves show the modulation travels for the clutch torque on the pedal. All three curves are standardized to the same engagement point, and thus all have the same pedal travel at zero torque. The curve runs over the pedal travel up to the “STALL torque” attainable at idle, at which point the engine stalls. This value is indicated as a bold dot.

System **A** still shows the shallowest torque curve over the pedal travel. The torque curves **B** and **C** are practically identical along the pedal travel due to the higher release system ratio of vehicle **C**.

Hence, systems **B** and **C** now pose identical requirements on the driver and on the engine, although the applicable clutches are laid out very differently along the release travel (see Figure 12, left).

The engine influences result from the STALL torque achieved. Vehicle **C** has the highest engine torque available at idle. Vehicle **B** reaches only half this value, therefore stalls more easily during driveaway.

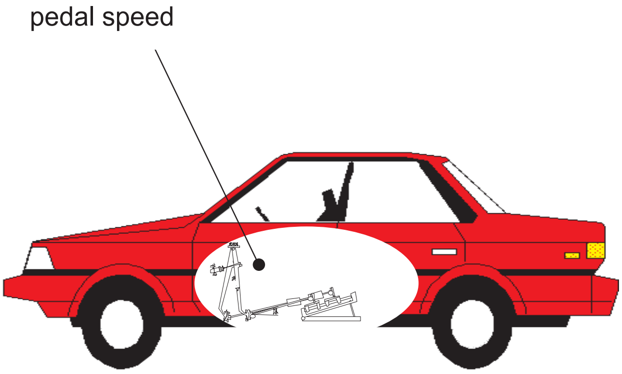

Figure 13 : measurement of driveaway characteristics

This is confirmed by the driveaway measurement (Figure 13), in which the clutch is engaged by a spindle unit connected to the clutch pedal. The vehicle, however, is not fixed. The limit engagement speed [mm/s] determined in this test - at which the vehicle is still able to drive away at idle - provides a characteristic value upon which vehicles could be compared objectively with regard to driveaway performance.

Studies conducted so far on 20 different vehicles at LuK show that a good subjective evaluation (> Rating 6) is achieved after a limit engagement speed of 25 mm/s. At higher limit engagement speeds, the vehicle drives off without any problems.

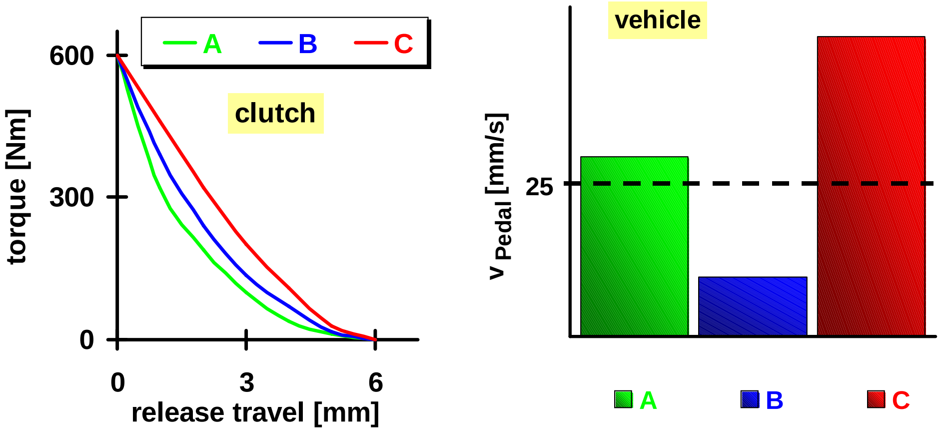

Figure 14: Comparison of the clutch torque, pedal limit speed

Figure 14 illustrates the maximum engagement speeds possible on the clutch pedal of the three comparison vehicles. Vehicle **C** was subjectively rated with Rating 10, vehicle **B** with Rating 3, vehicle **A** with Rating 7. This corresponds to the characteristic value achieved in the driveaway performance test. The result is initially surprising because a better driveaway performance had been expected in vehicle **A** than in vehicle **C**, based on the clutch characteristic curves. This further proves that it is wrong to design the individual components without considering the entire vehicle.

The band width from 5 mm/s to 60 mm/s, i.e., from rating 1 to rating 10, for all of the pedal limit speeds measured so far on different vehicles shows that there is a need for action here.

The information obtained from these measurements is sufficient to systematically compare vehicles and to dispose of the subjective evaluation technique.

In order to replicate the behavior of the real driver and of the real actuation speed on the clutch pedal, basic observations were carried out at LuK. The extent to which ergonomic considerations and the characteristic of the pedal force curve influence the engagement process were studied.

The following experiment comes to mind (Figure 15).

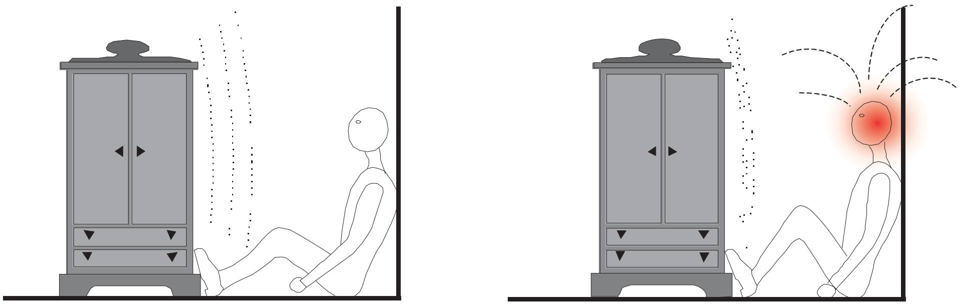

Figure 15 : Simple ergonomic consideration

Although equal displacement forces are required in both cases, in the seated position on the left, subjectively less exertion is required than on the right. From this biomechanical perspective, the “controlled variable” necessary for actuation in the following consideration was not assumed to be pedal force on the foot, but rather the torque at the hip point.

To this extent, the driver’s leg is thus a part of the release system. The weight of the leg acts as a preload on the pedal.

A study on the driver seat position is illustrated in Figure 16. The comparative consideration of two different seat positions shows the extent to which this torque can be influenced by ergonomic considerations for the same pedal force characteristic. Seat position 1 leads to a sharp drop-off in the torque characteristic curve. It is easy to imagine that the driver cannot modulate the pedal with this sharply dropping or rising gradient as well as with a horizontal torque curve.

Therefore, the seat position must also be considered in the future.

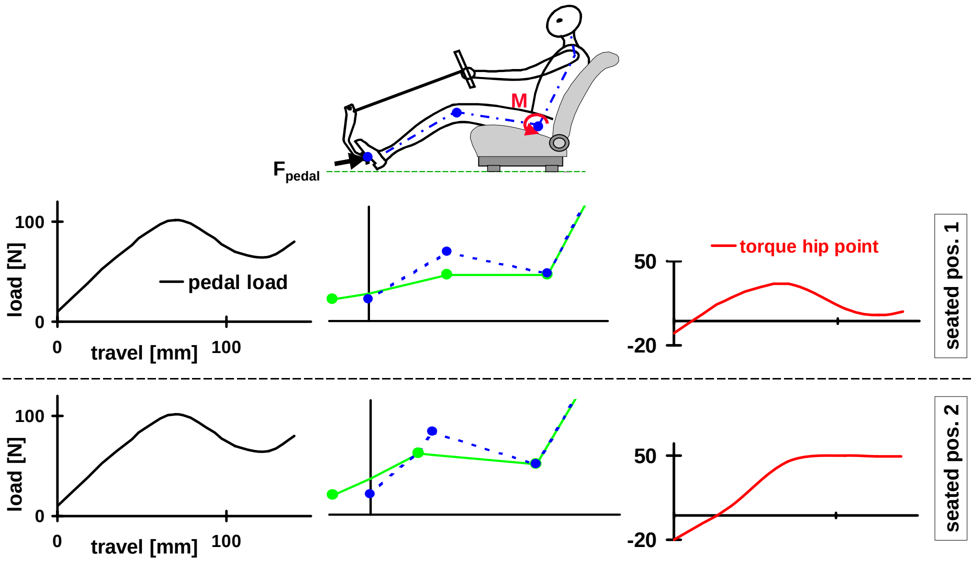

Figure 16 : Simple driver model

All of the influential parameters described for engine speed control via the clutch, the release system and up to the drive train were combined by LuK into a single simulation program. The reliable torsion vibration calculation program was used as the basis. This allowed for an important step to be taken in the simulation of real driveaway processes. With this simulation tool, it is now possible to vary and evaluate each of the factors that influence the driveaway performance listed in Figure 9.

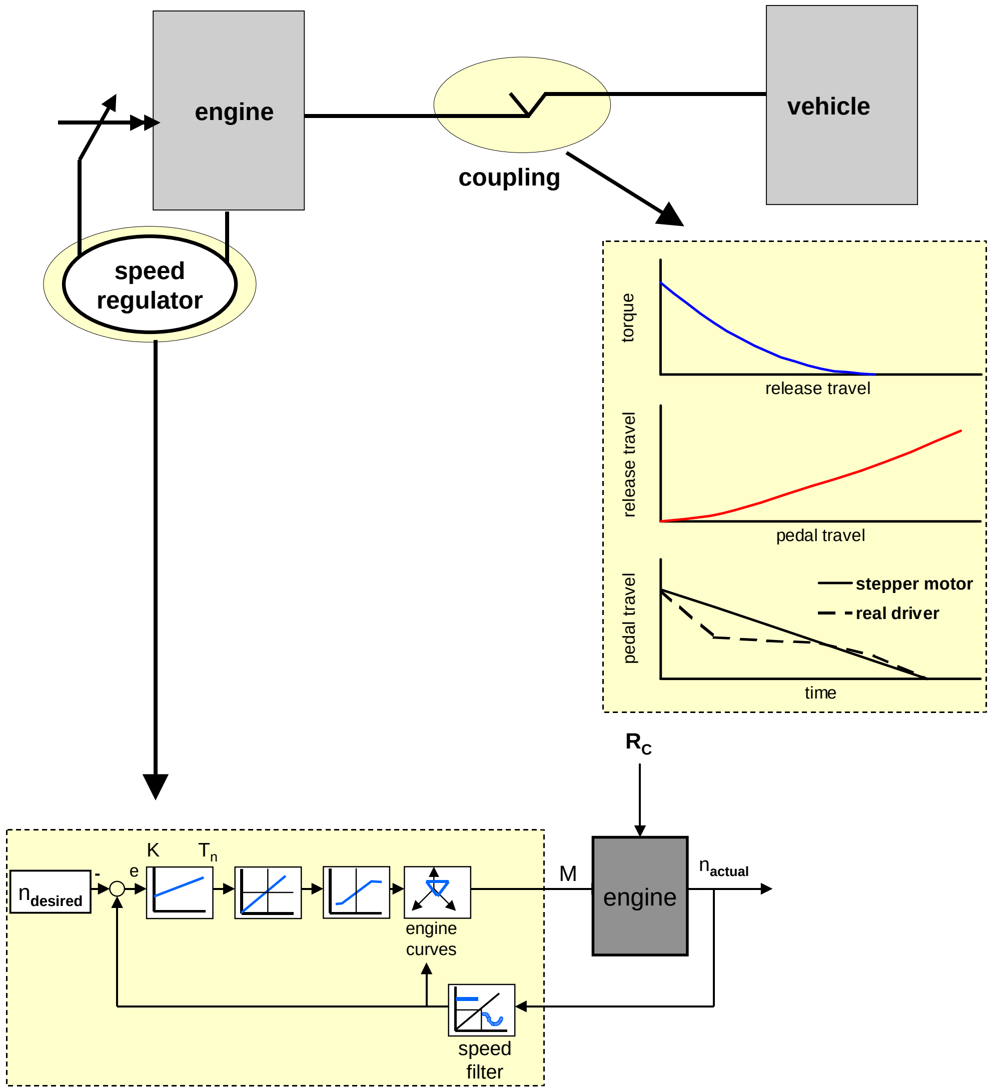

Figure 17 : Simulation model of the driveaway process

Figure 17 illustrates the individual program modules. The friction coupling depicts the interface between the engine and the vehicle. Hence, it represents the function of clutch, release system and driver. Elasticity's, ratios and frictions of the release system are integrated at this point.

The clutch is thus closed by the driver or by a spindle system (see measurement) at the pedal with “pedal travel over time” input. This function can also assume any characteristic, for example, the influence of force and travel hysteresis on the driveaway performance, during reversal of the pedal movement direction, can be realized.

The engine speed control can be achieved in two different ways. The speed can be controlled by means of a PI or PID regulator or the speed can be controlled by means of the real engine map. In this case, the controller is subject to the dependencies on the throttle position, speed and torque that are specified in the map.

Currently, the data to replicate the engine controls in the simulation model on the vehicle are obtained by a simple test. To do this, the reaction of the engine is measured when subjected to defined torque jumps, similar to the tractive force measurement in Figure 11. Furthermore, this allows for a comparative consideration of the engine controls independent of the clutch.

Figure 18 and Figure 19 illustrate two examples. The quality of the engine control can be determined from the engine’s reactions to the torque jumps.

Figure 18 shows strong engine speed oscillations after each torque jump. The engine in Figure 19 exhibits short breaks in the speed, however, adjusts immediately thereafter.

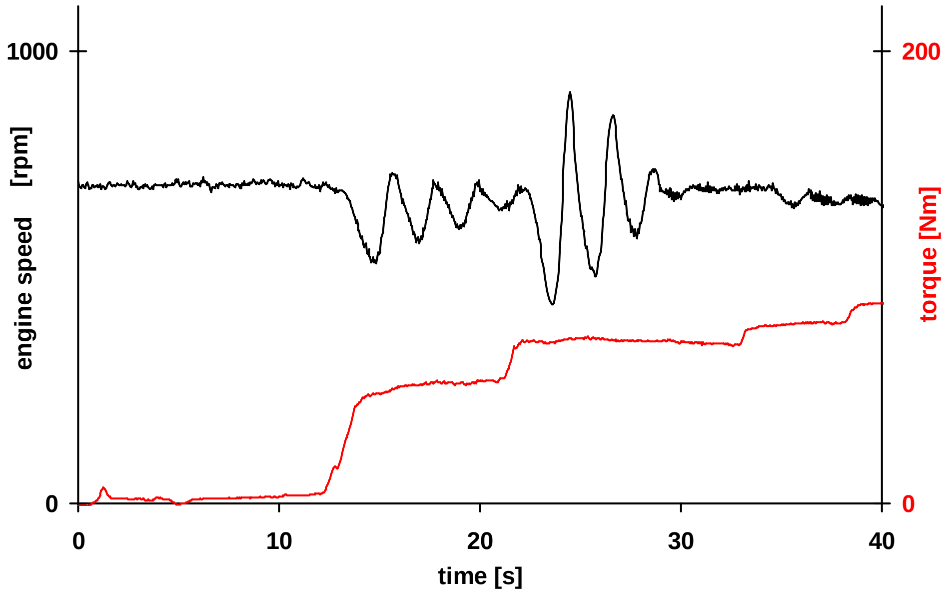

Figure 18 : Identification of an idle controller (Vehicle 1)

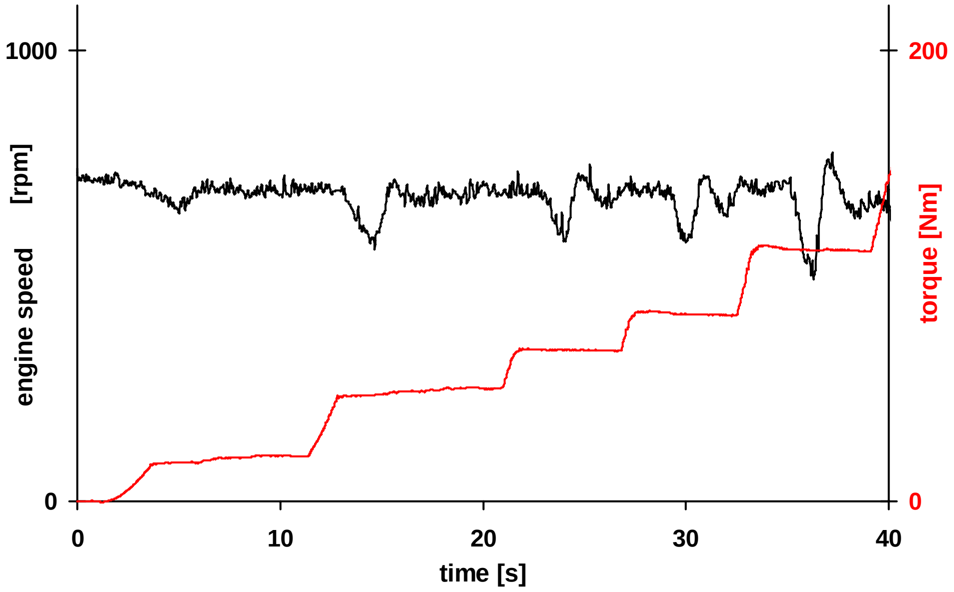

Figure 19 : Identification of an idle controller (Vehicle 2)

Of course, the engine control with all of its special cases can only be mapped and influenced with limited accuracy. However, concrete suggestions on how the driveaway characteristics of a vehicle can be improved can be made based on the simulations.

The other influences from the drive train and release system can be simulated very precisely and can be evaluated with regard to their influence.

Several examples are illustrated in Figure 20 to Figure 22. A real vehicle was used as the basis. Three different engine controls were simulated for the variations.

The limit engagement speed on the clutch pedal (PGEG), which is shown as the y-axis in the bar chart, was evaluated. The limit engagement speed should lie above the limit value of 25 mm/s so that the engine will not stall too easily during engagement.

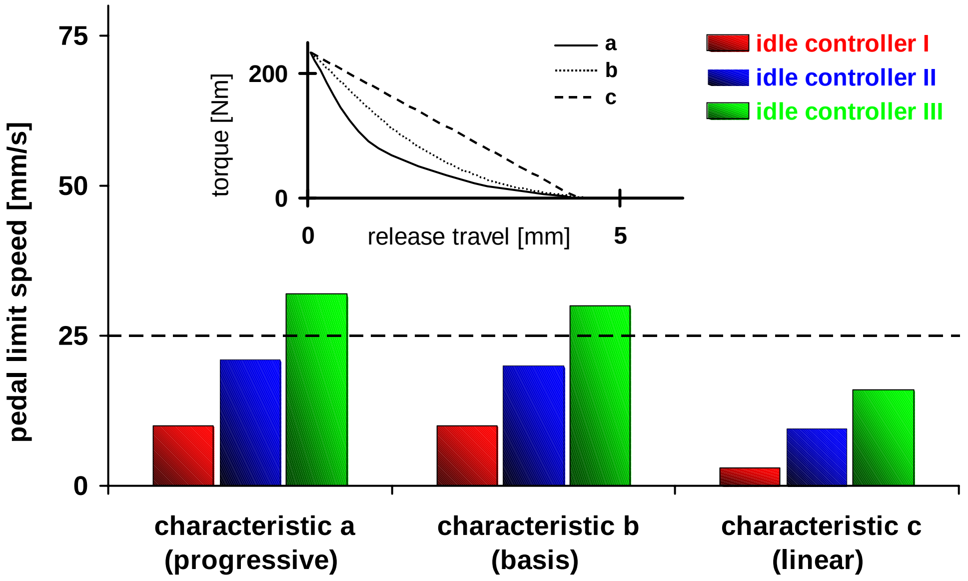

Figure 20: Variation of the clutch torque curve

Figure 20 illustrates the influence of different clutch torque curves. In this case, even the very shallow torque curve in characteristic curve **a** could only have been managed with the control parameters of controller III.

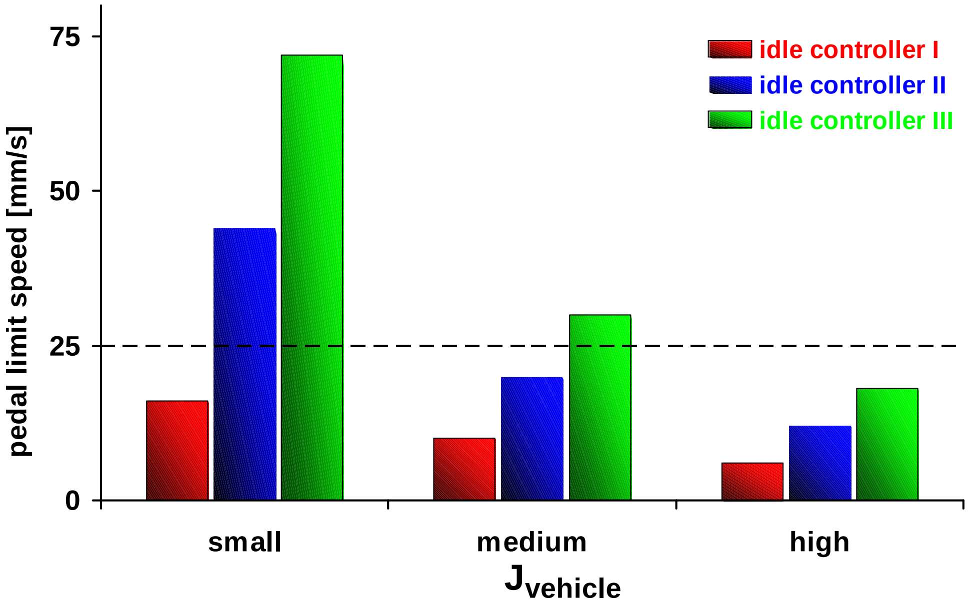

Figure 21: Variation of the reduced vehicle mass

Figure 21 illustrates the influence of the vehicle mass reduced to the transmission input shaft. The translational vehicle mass was converted along with the transmission and differential ratio as well as with the rolling radius of the tires, into a rotary mass. In particular, a “long axle”, which leads to high reduced vehicle mass moments of inertia, leads to driveaway problems here insofar as this was not compensated for by other parameters.

Figure 22 illustrates the influence of the engine side rotating masses on a vehicle’s pedal limit speed. The lower the engine-side rotating mass, the less centrifugal energy available for the driveaway process.

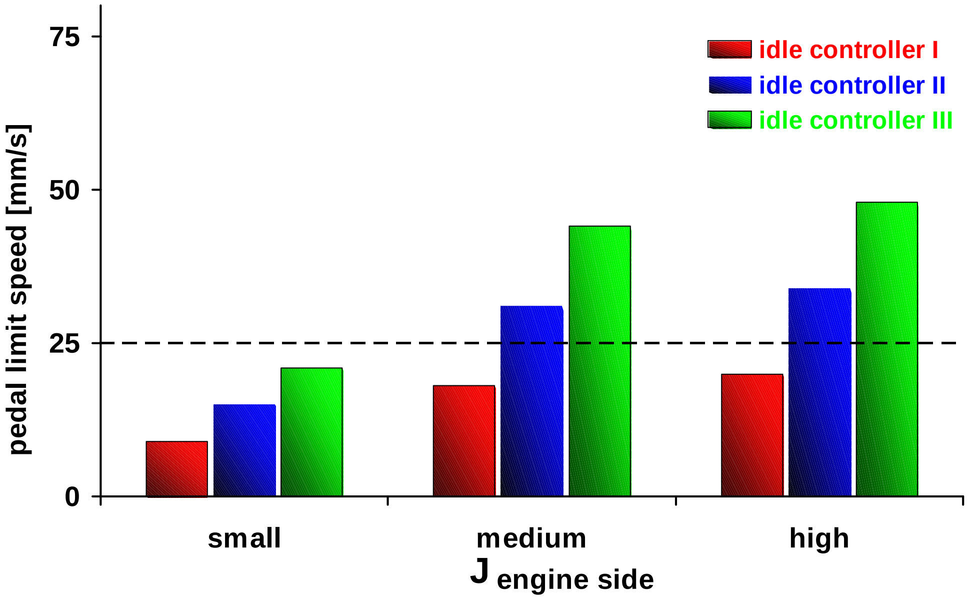

Figure 22: Variation of the engine-side rotating mass

These examples should illustrate that the effect of all of the important parameters were included in the simulation and that predictions can thus be acted upon.

## Summary

The experiences in recent years at LuK show that a rigid separation of the clutch and the release system cannot lead to an optimal, technical solution.

Only by carefully analyzing all of the elements involved in the flow of force from the clutch and release mechanism and considering specific vehicle and engine data, is optimal function of the clutch ensured. A system consideration is almost mandatory.

In the future, project management should be arranged for all clutch optimizations and new designs so that all of the elements in the functional chain are tuned properly with one another.