

Real Time Simulation on Test Benches under Realistic Service Conditions

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Abstract (optional)

A system for test bench control has been developed in a cooperation with the Daimler AG Transmission Test Center, the Computing Faculty at the University of Applied Sciences, Ulm, Steinbeis Transfer Center „New Technologies in Traffic Engineering“, and Steinbeis Transfer Center „Traffic Engineering.Simulation.Software“. This test bench control system makes it possible to simulate driving maneuvers under representative loads on the drive train components and take into account demands of electrified drive train systems. Because of the strongly nonlinear behaviour and relatively long reacting time, the test bench control system was realized with an online simulation as an IMC regulator. We will show that the model of the control path necessary for this is sufficiently exact so that the required simulation suitability can be achieved. The test bench control using online simulation has been rolled out on the drive train test benches at Daimler AG's Transmission Test Center.

Kurzfassung

In Zusammenarbeit mit dem Triebstrangprüffeld der Daimler AG, der Hochschule Ulm, Fakultät Informatik, dem Steinbeis Transferzentrum Neue Technologien in der Verkehrstechnik, Ulm sowie dem Steinbeis Transferzentrum Verkehrstechnik Simulation Software wurde ein System zur Prüfstandssteuerung entwickelt, das es erlaubt, realistische Fahrmanöver unter repräsentativen Belastungen der Antriebsstrangkomponenten

vorgeben und Anforderungen von elektrifizierten Antriebssystemen zu berücksichtigen. Auf Grund des stark nichtlinearen Verhaltens und relativ großer Totzeiten wurde die Prüfstandssteuerung mittels Online-Simulation als IMC-Regler realisiert. Es wird gezeigt, dass das dazu notwendige Modell der Regelstrecke ausreichend genau ist, so dass die gewünschte Simulationsgüte erreicht wird. Die Prüfstandssteuerung mittels Online-Simulation wird im Triebstrangprüffeld der Daimler AG auf den Antriebsstrangprüfständen ausgerollt.

1 Aim of the test bench control system

In their passenger vehicles, Daimler AG predominantly uses drive trains which they have developed and produced themselves. Software development and application is one of their core competences. Throughout the whole development process, all drive train components are tested on the test benches according to the production phase. The general term “drive train components” includes parts, component groups, aggregates or whole drive trains with hybrid transmissions or alternative driving mechanisms. The control test is a central part of any category. For each category of the drive train components, there are special tests to be carried out on the test bench.

The total drive train test including the test bench check is extremely complex. Because it is here that the whole drive train from the combustion engine including hybrid components, automatic transmission or manual gear box, power divider, articulated shaft, axle drive and auxiliary consumer are tested as is the vehicle itself. The drive train test has to live up to the demands for durability as well as function. With regard to the development process and the degree of maturity of the aggregate, the focus is first of all on the function test followed by the durability guarantee using pre-tested components. When carrying out the drive train test, it is presumed that the aggregates have been pre-tested and are therefore worthy of the test.

The purpose of the drive train test on the test bench is to project realistic driving maneuvers under representative loads of the drive train components. As a consequence of the representative load, the corresponding loads on the drive train components are provided almost automatically for the evaluation of reliability, fatigue life [11, 12] and in exceptional cases in the drive train test of fuel consumption. When choosing a suitable system, the control systems already in use at Daimler, play an important role, see [1]. The common drive train testing on test benches is done mainly with the help of the output speed / pedal value closed loop control. The new test procedure was carried out as an additional support system

to a test bench control already in use and is shown as a test bench control by means of an online simulation. [3].

The test bench control system by means of online simulation takes into account the following aspects.

- Detailed drive train model with all important drive train components
- Simulation of the target speed based on the route (the target speed simulation differentiates here between the speed intervals as compared to the indicated speed in a journey on public roads.)
- The driver model aims to achieve this target speed taking into account route data such as slope, curvature and speed, as well as driver interaction such as gear limitations or selection of changed driving programs
- Feedback of the reactions shown by the drive train being tested into the online simulation
- Through the learning cycles, the online simulation learns the particular characteristics of the test assembly in a fully automated way.
- The test programs can be transferred to the various test bench control systems

The potential of using the system construction kit:

- Simulations dependent on the traffic flow can pay a part in ascertaining the diversity of the conditions of use [9]
- Systems for measuring the route data speed up the transfer of road tests on the test bench
- Damage accumulation analysis for finding out the use-related loadings of the drive train components as well as the focusing on the critical component collectives. [6]
- Effective realistic fatigue life estimation of the drive train components [7]
- Analysis of highly dynamic processes such as gear changes in automatic gear boxes enable us to make a prognosis on the function, comfort and fatigue life [5]
- Comparison of new transmission concepts in realistic operating conditions [4]

After a successful prototype phase, the test bench control system by means of online simulation was established as a standard test process at Daimler AG and rolled out on the drive train test benches. The main focus of this presentation is the control oriented implementation of the test bench control system by means of online simulation.

2 Real time system for the online simulation

The drive train simulation winEVA, which was used here for the test bench control system by means of online simulation, represents the components of the drive train, each component in a single block which is simulated according to the cause and effect principle. The calculation times of this system are not generally synchronous to real time. Therefore if different test benches systems are used, the real-time capability has to be obtained with a real-time box. To do this, the calculation time of the online simulation must be slowed down accordingly.

2.1 Test bench control system

The aim of the classic test bench control system is, among other things, to control, activate and monitor:

- the safety systems such as the alarms or conditions requiring a shut-down or in critical situations the activating of fire extinguishers,
- the auxiliary systems such as the supply of fuel, radiator fluid, air, electricity supply
- the communications and bus systems including the residual bus simulation,
- the measuring systems,
- the transfer and regulation of the default values etc

Part of the test bench control system is the default unit which copies the program sequence, the so-called control program, and transfers it onto the test assembly.

In this case here, when we talk about the test bench control system by means of online simulation, we are referring to this default unit. Compared to the road tests, the test bench control system by means of online simulation generally represents the driver's role. The aim of the default unit and therefore of the online simulation, is to follow a given speed curve, taking into account various parameters. In order to do this, the simulation has constantly to create a balance of the forces between the driving resistances resulting from the gradient, air, rolling and acceleration resistances, and the tensile force from the drive train caused by the driving pedal. The principle of the drive train test bench control system is shown simplified in diagram 2 (without the brake).

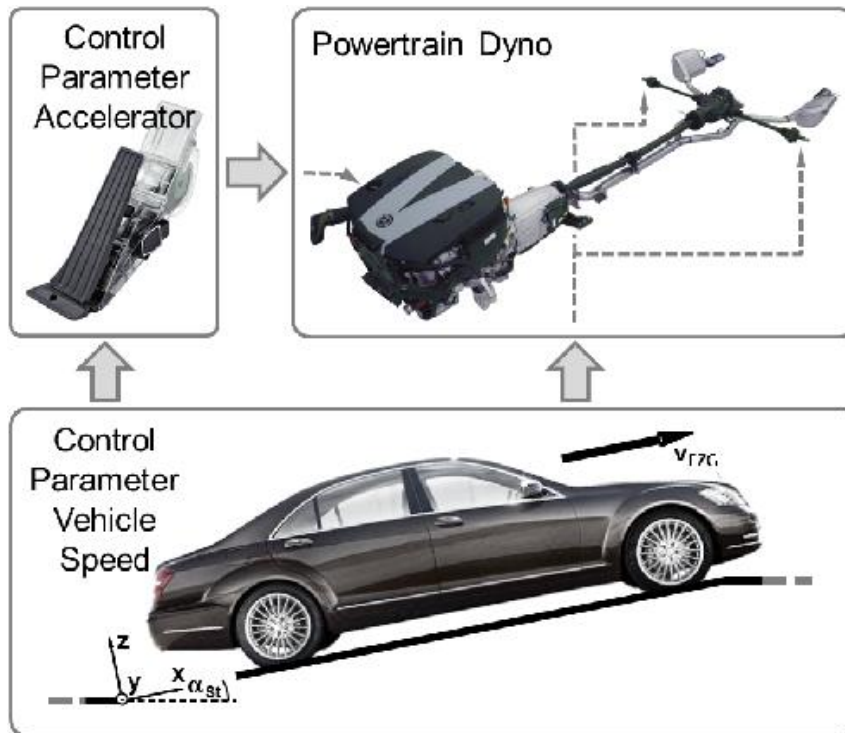


Diagram 2: Schematic illustration showing what the test bench (Dyno) control system does

2.2 Test bench control system as a closed-loop control

The following section makes clear the concept of the test bench control system by means of online simulation as opposed to the usual test bench control and also shows the different types of control systems.

Definition:

- Controlling is the procedure in a system by which one or more input variables influence the output variables based on the functions of the system [16].
- Regulating is a process by which the control variable is constantly measured and compared to the reference variable. Then, based on this comparison, the necessary changes are made through the actuating variable to be in accordance with the reference variable. [16].

2.2.1 Classification of the governor

A governor suitable for this particular exercise needs to have the following characteristics [3]:

- Time invariant: A system is time invariant if it reacts independently to a stimulus when this occurs. The system here is not time invariant.

- Follow up control: The test bench control system is a sequence control. This can be seen because a certain speed curve has to be followed. With a sequence control we recommend a feed-forward control.
- Linearity: The system in the test bench is a non-linear system because individual components are non-linear. It is also not feasible to make it linear because the operating points are constantly changing.
- Causality: The causality means that a particular value of an input variable only influences the behavior of the system in the following time steps. Causality exists in this system.
- Reaction time (Totzeit) system with a very long reaction time: When analyzing the reaction time, it is important to consider the ratio between the reaction time and the rise time (Anstiegszeit) of the step response.
- $T_{\text{Totzeit}} / T_{\text{Anstiegszeit}} \ll 1$
Here we are dealing with a reaction time system.

2.2.2 Simple setting

In order to do justice to the demands mentioned in chapter 2.1, the test bench control could be designed as a typical regulator [13], as shown in Diagram 3.

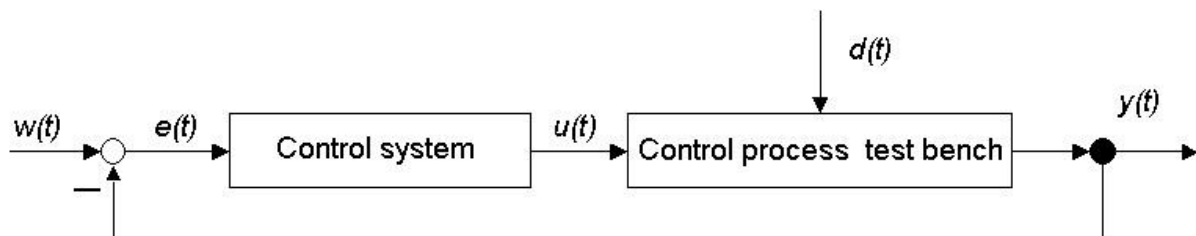


Diagram 3: Test bench control as a closed-loop control

$w(t)$ the set point, in this case the provided speed curve.

$e(t)$ the control deviation.

$u(t)$ the actuating variable, the driving pedal setting in the test bench control.

$d(t)$ the disturbance variable, in the test bench control the sum of provided driving resistances and the reduced mass to be accelerated. These are not really unknown disturbance variables because it was possible to calculate them from the vehicle data, the speed curve and the route data.

$y(t)$ the controlled process variable, in this case the driving speed.

2.2.3 Control system with feed-forward control

Since in the test bench control we are dealing with a follow-up control (speed path) and not a fixed command control, it is often necessary to re-control the system quickly. This can be achieved with a feed-forward control [14], as shown in diagram 4.

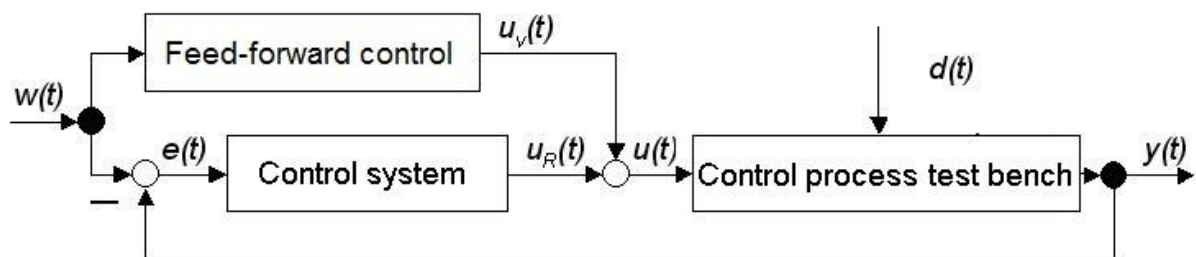


Diagram 4: Test bench control as a control system with a feed-forward control

$u_v(t)$ is the share of the actuating variable from the feed-forward control.

$u_R(t)$ is the share of the actuating variable from the closed-loop control.

In this way the required characteristics of robustness and disturbance compensation of the control system could be combined with the quick reverse control. The feed-forward control should be selected so that the command variable $w(t)$ can be updated as quickly as possible on the test bench route. The control system makes sure that the disturbance $d(t)$ and the effect of the model uncertainty is compensated for.

2.2.4 Control system with feed-forward control and disturbance variable switch

A disturbance variable compensation is a further improvement to the test bench control. In the test bench control system, the disturbance variable is known. The disturbance variable is taken from the calculated driving resistance factors. This information can therefore be used as an actuating variable and can be added to the closed-loop control before the results measured at the end of the control path are available. A closed-loop control with a disturbance variable switch is shown in diagram 5.

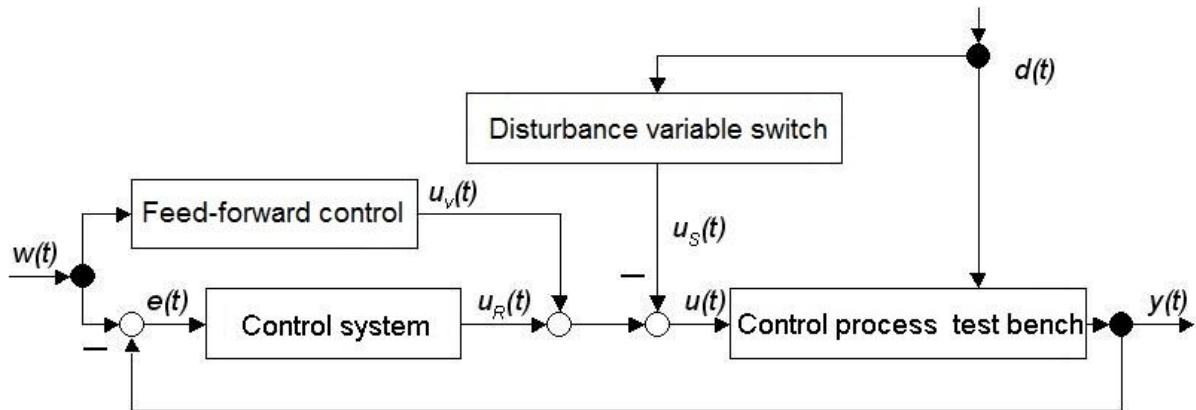


Diagram 5: Test bench control as a closed-loop control with a feed-forward control and a disturbance variable switch

$u_s(t)$ is the share of the actuating variable, which is compensated by the disturbance variable.

For a closed-loop control with a disturbance variable switch, the governor only has to be active during the dynamic interim procedure because the disturbance variable is completely compensated for by the disturbance variable switch.

2.2.5 IMC-Governor

A further improvement to the test rig control system can be made by installing an IMC governor. (Internal Model Control) [13]. In the closed-loop controls described until now, the information included in the model regarding the behaviour of the control path in the selection of the control parameters has not been mentioned and the control system does not include the model.

It is recommended, however, to use the test bench model as a model in the closed loop and to use the drive train parameter as a closed loop parameter.

The inner closed loop can have dynamic characteristics and show the control path realistically as a model, making a feed-forward control superfluous.

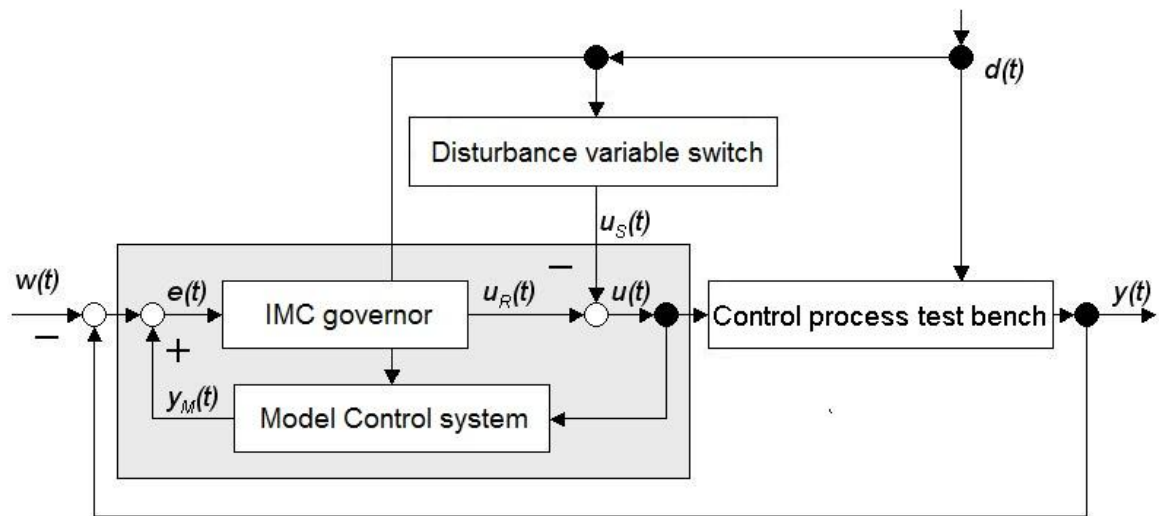


Diagram 6: Test bench control as an IMC governor

$y_M(t)$ is the control variable of the model of the control path (test bench model).

If the test bench model was now to show the same behaviour as the test bench itself,

$$\text{Model}_{\text{control path}} = \text{control path}_{\text{test bench}}$$

then the outer control deviation $y(t) - w(t)$ would disappear since the control deviation would be completely compensated for by the inner control loop. The inner control loop could therefore be considered as a forward control. The deviation variable switch naturally remains the same as in the previous models. This construction is shown in diagram 7.

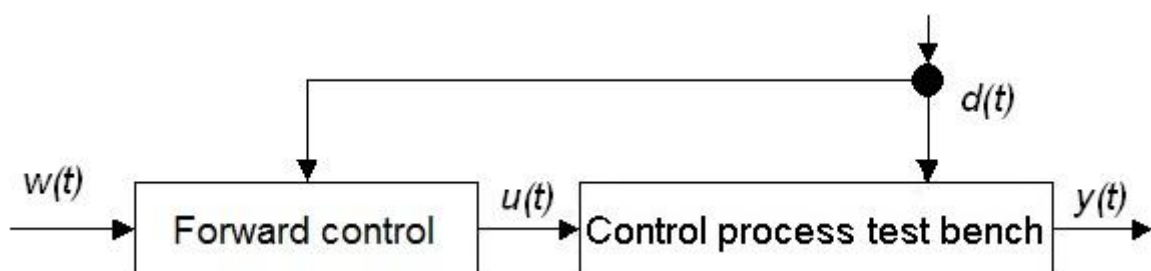


Diagram 7: Test bench control as a forward control

2.2.6 Selecting the suitable control procedure

As already described in section 2.2.1, this system does not fulfill all the requirements of a stable control system. Above all, the long reaction time of the system is a particular challenge. Up to a ratio of 0.3 the systems are still controllable [15]. The ratio in this system

is at times above 1. That means that this system can no longer be controlled with normal methods.

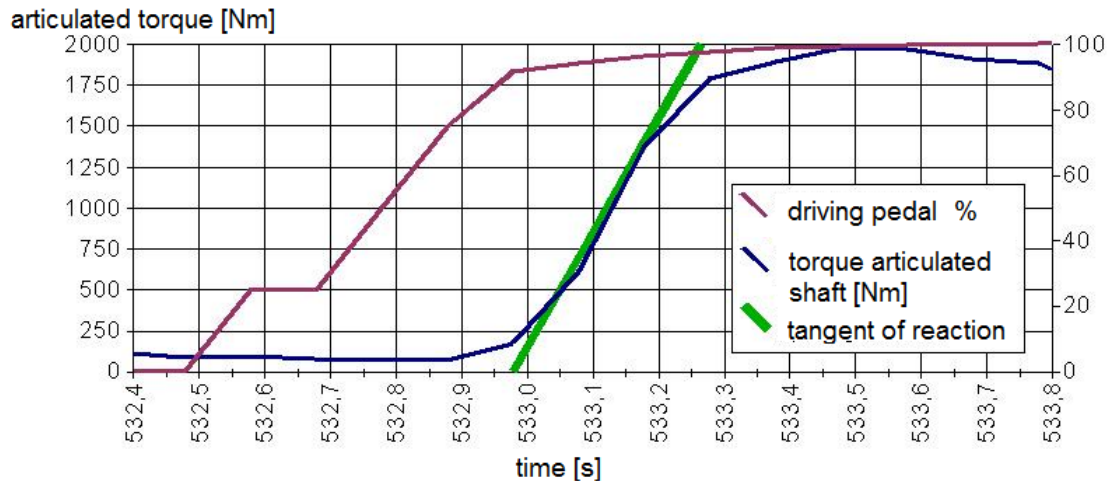


Diagram 8: Step response: articulated shaft as reaction on a gas pedal step.

In diagram 8 we can see the response of the test bench to a fast gas pedal change from zero to full throttle. Although we are really dealing with a slope shaped signal here, we will describe it from now on as a step response since the speed in which it changes is very fast. For the step response analysis we are not using the speed which represents the control value, but the articulated shaft torque. In this case here, the speed would not be very significant, as it is an integrated variable.

With full throttle acceleration, the acceleration with which the drive train reaches a particular target speed is important. The articulated shaft torque is used as a control variable since it is directly connected to the acceleration and later becomes an important factor in the fatigue life calculation of the component. The ratio between the reaction time and the rise time of the step response in diagram 8 is calculated as follows:

$$T_{\text{Totzeit}} = 532,97[\text{s}] - 532,65[\text{s}] = 0,32[\text{s}]$$

$$T_{\text{Anstiegszeit}} = 533,26[\text{s}] - 532,97[\text{s}] = 0,29[\text{s}]$$

$$T_{\text{Totzeit}}/T_{\text{Anstiegszeit}} = 1,1$$

The ratio 1.1 is much too large and no test bench control system with a conventional governor will accept it.

2.3 Construction of the test bench control system

As explained previously, the test bench cannot be controlled with a conventional governor. The governor should therefore take the vehicle data as the control parameters since these are known at the time of the change of the drive train on the test bench. If we were to use a conventional governor then the parameter of the governor would have to be re-determined each time. The non-linearity and the time invariance can be compensated for to some extent by the IMC governor with only a slight error. But the reaction time cannot be compensated for. As shown in the previous chapter this is far too long in relation to the rise time. For this reason the closed-loop control should be carried out as a forward control with an ideal model. Diagram 9 shows the current construction of the test bench control system.

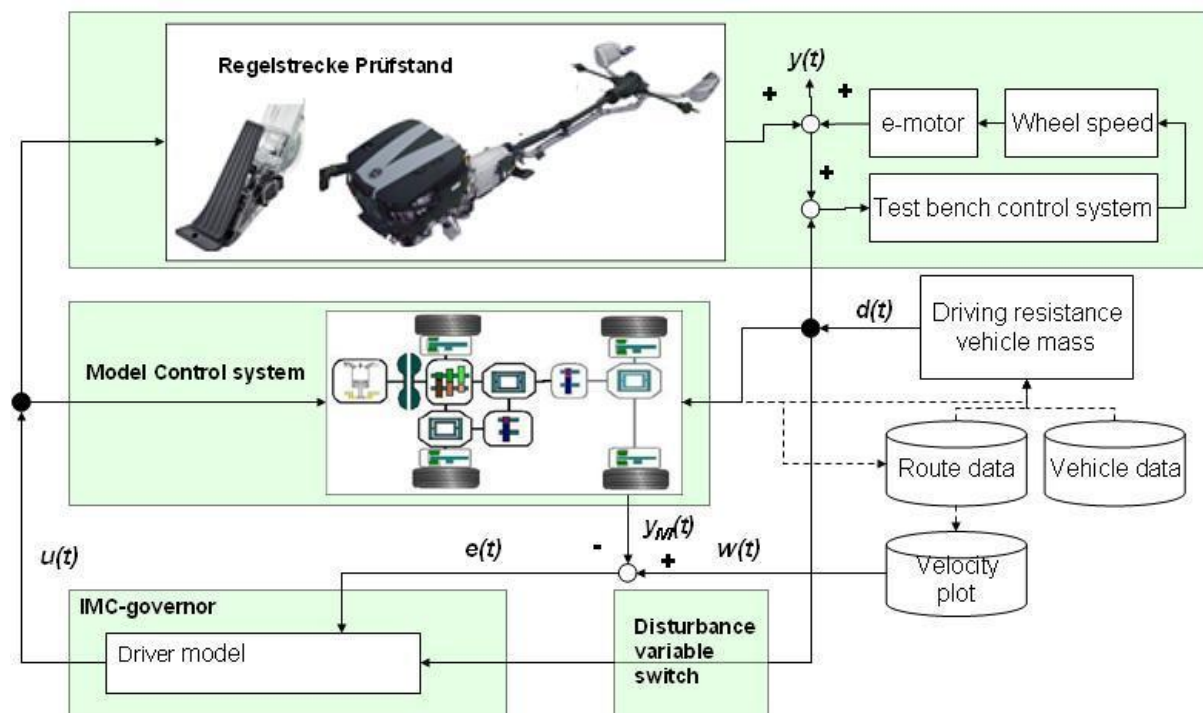


Diagram 9: Test bench control as an IMC governor

- $w(t)$ Reference variable $w(t)$ is the wheel speed (\cong driving speed) at a determined position. The change of the position results with the speed information from the control path model. It could, however, also result from the test bench control path
- $d(t)$ The disturbance variable $d(t)$ is the driving resistance and the vehicle mass to be accelerated. The driving resistances are determined from the
- route data (slope of the route, road curvature)

- model of the control path (driving speed) and
- vehicle data (vehicle mass, c_w -value, cross-section surface, roll resistance factor).

$y_M(t)$ Control variable $y_M(t)$ is the wheel speed of the test bench model.

$e(t)$ Control discrepancy $e(t)$ is the discrepancy between the presumed speed curve and the simulation speed curve.

$u(t)$ The actuating variable $u(t)$ is the driving pedal setting which is given by the IMC closed-loop control and forwarded to the model of the control path and the test bench.

$y(t)$ The control variable $y(t)$ is the wheel speed of the test bench which would usually close the outer control circle. However, this does not happen in this case because the model of the control path corresponds with the test bench and therefore the test bench closed-loop control can be used as a forward control.

The controlled loop control system is the test bench with all mechanical and control-technical components, together with the complete mechanical assembly (engine, transmission axles and articulated shaft).

The control-technical construction consists of all internal closed-loop controls, measuring systems, real-time computers with their software and the associated closed-loop control algorithms as well as the braking system (e-engines or generator). The internal test bench closed-loop control is part of the controlled loop control system since its purpose is to adjust the disturbance variable $d(t)$ over the braking systems correctly, hereby impressing the test bench with a wheel speed. The impressing of the wheel speed here represents the braking or the acceleration of the wheel speed based on the driving resistances and the mass to be accelerated, i.e. the disturbance variables. These disturbance variables are converted into a wheel speed using the pull-force on the axles. For this control purpose it is necessary to have a real-time operating system since the torques coming from the drive train can change very quickly.

The super positioning of the disturbance signal is given the driving resistances and the vehicle mass as disturbance variables $d(t)$ and forwards these values directly to the IMC closed-loop control. Unlike in diagram 6, the super positioning of the disturbance signal is not subtracted from the actuating variable of the IMC closed loop control, but is used internally by the IMC closed-loop control and therefore does not have to be converted into a actuating variable. This means that the super positioning of the disturbance signal is only shown symbolically in this structure.

The model controlled loop control system is the simulation model of the drive train. The IMC closed loop control is the driver model in winEVA which, with the help of the inner control loop of the

IMC closed loop control, gives the actuating variable in such a way that the actuating variable of the model $u(t)$ is equivalent to the reference variable $w(t)$.

2.4 Characteristics for analysing the closed loop control performance

To analyze a control cycle, the following four demands [13] must usually be met.

- Stability
- Disturbance compensation and predetermined value sequence
- Dynamic demands
- Robustness demands

Since the test bench closed-loop control must be used as a forwards control with an ideal model, it must be considered whether we are dealing with an ideal model. In an ideal model all the characteristics of the model behaviour would be exactly the same as those of the control path.

There are two ways of validating the closed loop control performance:

- The first alternative is a direct comparison of the load-time data between the model behaviour and the control path. For example the discrepancies in the load-time data can be quantified using the least mean square error method.
- Most typically, the test bench control system by means of online simulation is used to carry out continuous operation tests. In this way statistical methods become more important because the closed loop control performance can then be evaluated over extended time periods. The statistical counting method, for example the counting of residence time, provides reliable characteristics which do not only assess the behavior of the model for a short time but are reliable for complete long-time tests.

For this reason, the validation of the closed loop control performance is then evaluated using statistical counting methods and the characteristics.

3. Validation of the closed loop control performance

As mentioned in section 2.4, the closed loop control performance is carried out using statistical counting methods and the characteristics. The test run data from a complete long time test is taken into account. This long-time test is over a total length of several 10,000 km and the load represents a mix of customer requirements under stringent conditions. For the

test we used the topology of the latest S-class with a 4-cylinder Diesel engine and NAG2 including stop/start-function. The comparison is based on the IMC-governor with forward control described in section 2.4 without taking into account the extensiveness of the further developments described in sections 4 and 5.

3.1 Residence time collective

Basically the residence time collective of engine and articulated shaft show a very good match between the simulation requirements and the test results. In diagrams 10 and 11 we can see the corresponding revolutions on the x-axis and the corresponding torque on the y-axis. The colours show the residence time of each load point logarithmically. The colouring showing how frequent the load points are approached is important for the evaluation. The darker the red colouring is, the more often the load points were approached and the darker the green colouring is, the less often. Blue areas are off-site and were not approached at all. Using this direct comparison, it can be seen, for example, that the modelling of the area of the engine's braking moment requires improvement. (Compare with diagram 11.)

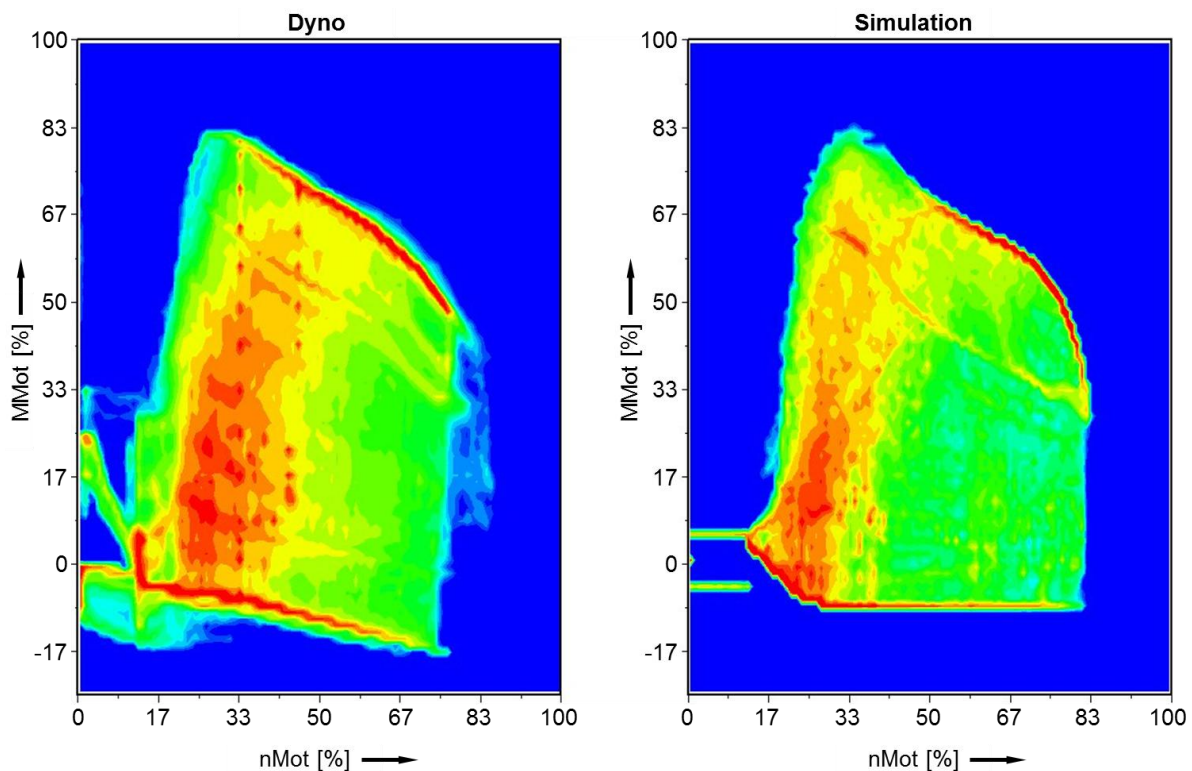


Diagram 10: Residence time counting of the engine rotation speed (nMot) and the engine torque (MMot) for test bench (Dyno) and simulation

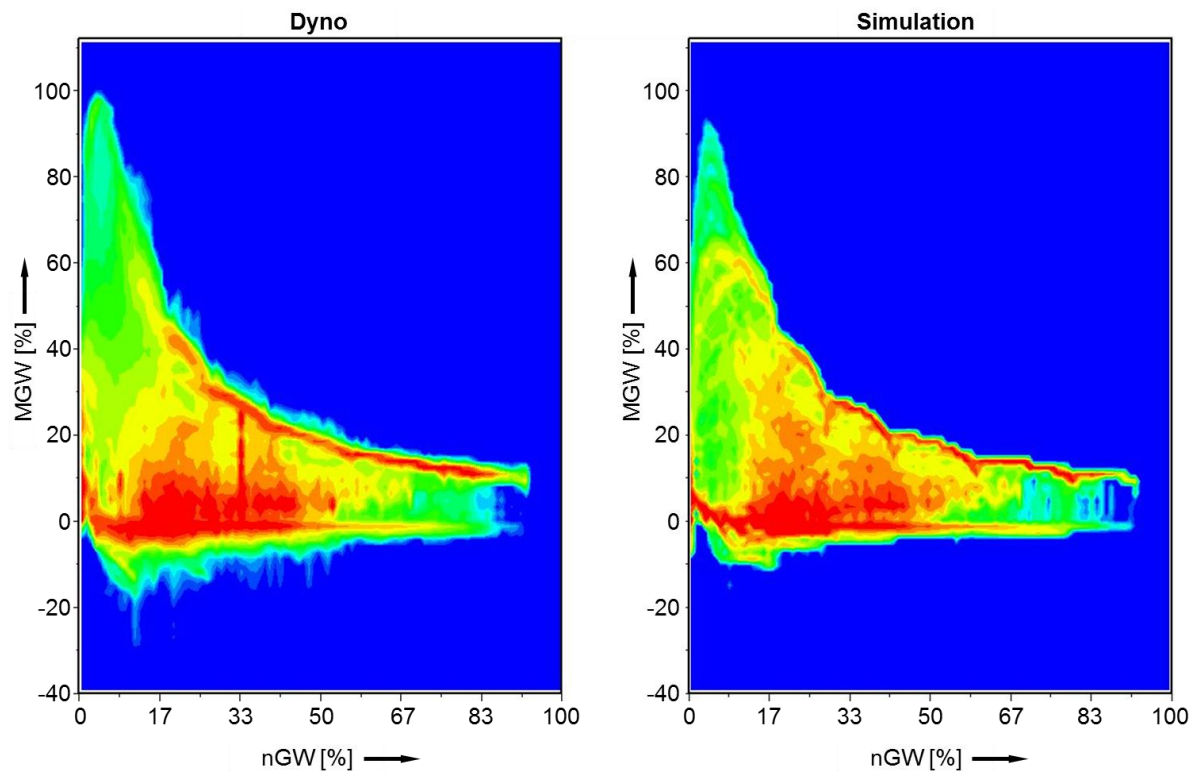


Diagram 11: Residence time counting of the articulated shaft rotation speed (nGW) and the articulated shaft torque (MGW) for test bench (Dyno) and simulation

3.2 Gear distribution

The gear distribution shows the residence time in each gear throughout the test run of the simulation requirements and the test results. You can clearly see the discrepancies in the gear shift program between the simulation requirements and the test results. Basically, the gear distribution is useful in showing where the residence time differs only slightly, above all considering the proportion of neutral positions and the 1st gear of the test set-up have to be added in order to obtain the residence time of the 1st gear of the simulation result. The reason for this is the stop/start system. If this is implemented in the simulation the vehicle stays in 1st gear but in the real set-up it shifts to neutral. Otherwise larger discrepancies can be seen in 3rd gear (compare with diagram 12). This can be explained for by the changed software version in the test set-up without modifying the parameters of the simulation model.

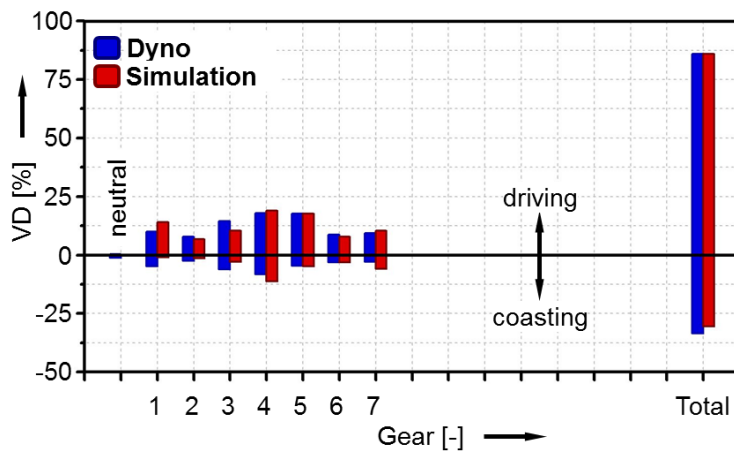


Diagram 12: Gear distribution residence time (VD) for test bench (Dyno) and simulation

3.3 Equivalent full throttle route

The equivalent full throttle route represents the equivalent damage route of the test collective depending on the gear and presuming the elementary miner's rule (no endurance limit) at full throttle. Since a logarithmic weighting takes place here, the differences will be clearly recognizable. The comparison between the simulation requirements and the test results shows that in the test set-up there is a slightly higher full throttle route proportion for nearly all the gears (not in 5th gear) than is presumed in the simulation requirement. (Compare with diagram 13.)

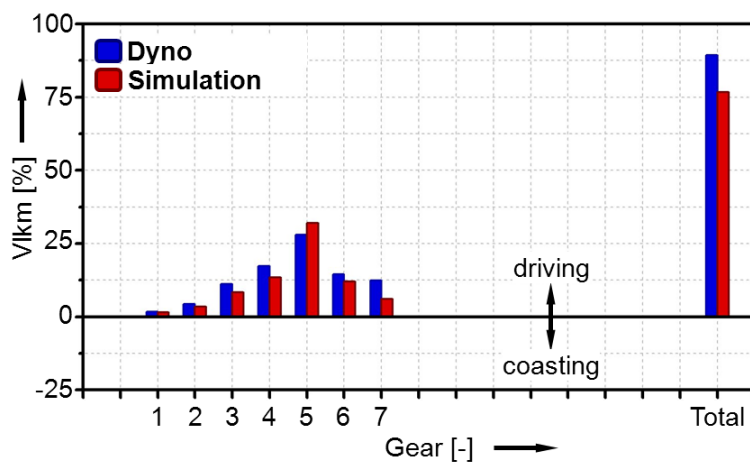


Diagram 13: Equivalent full throttle route (Vlkm) for test bench (Dyno) and simulation

3.4. Roll-over damage

In the roll-over damage the differences in the size of the signal arising because of the logarithmic association between the load amplitude and the damage, become more and more obvious. As opposed to the previous methods, a relative analysis is used here in which the 100 %-line represents the damage equivalence between the simulation requirements and the test results. Values above 100% mean that the test collective is tougher than the requirement and vice versa. Differences worth mentioning can only be found in the 7th gear (Compare diagram 14 and 15.) Considering the total collective, the differences can be considered unimportant.

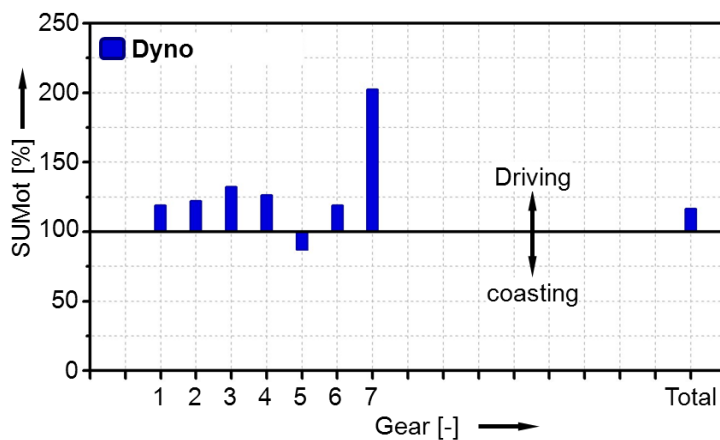


Diagram 14: Rolling over damage to the engine (SUMot) shown relatively

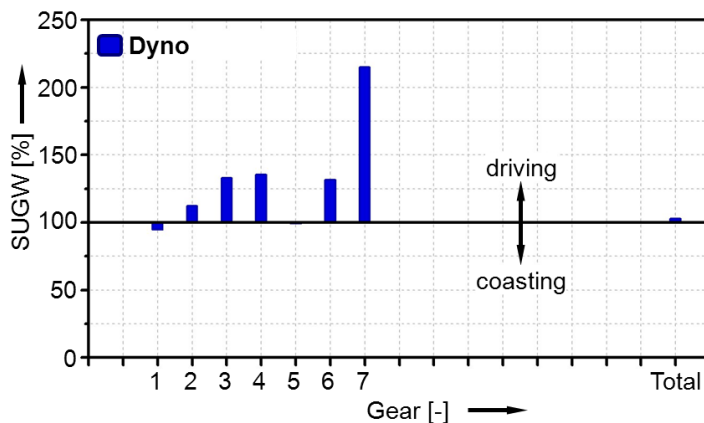


Diagram 15: Rolling over damage to the articulated shaft (SUGW) shown relatively

3.5 Average speed in the gears

As opposed to the load-induced characteristics, the average speeds in the gears indicate the revolution influence on the gear distribution. The average speed shows that the shift program of the test set-up tends to be the longer gears (6 and 7) and remains at higher speed.

Otherwise the discrepancies can be considered slight. In some cases with realistically built gear boxes special circumstances occur during the gear change which result in counts which are not shown in the simulation (compare with diagram 16).

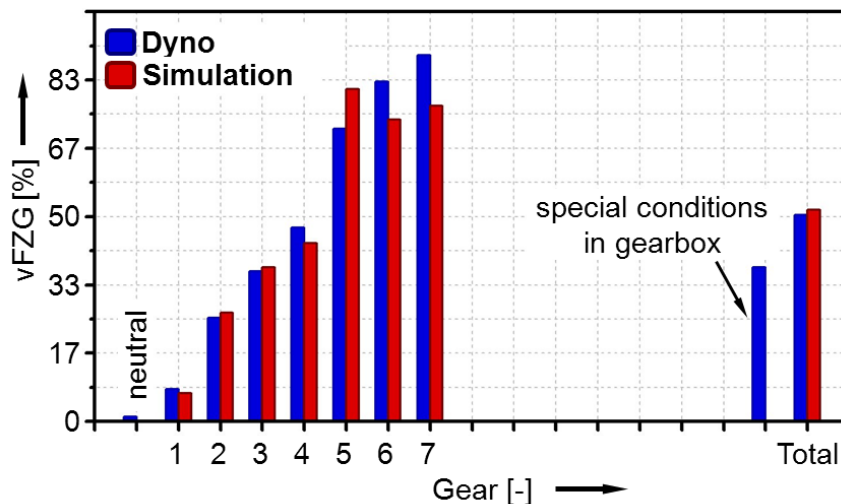


Diagram 16: Average speed (vFZG) in the gears

4. Further development of the test bench control

The comparison of the model data with the control path shows that there are discrepancies but that these are sufficiently small. An important aspect for the test bench simulation in every-day use however, is that the model data can be obtained easily and at a reasonable price.

Initially, the model data can be given based on the extensive component measurements carried out by Daimler. It is therefore possible to create an acceptable starter model. With standardized learn cycles which are driven on the test bench, the differences between the model path and the control path can be recognized and the model data can be corrected if necessary. In particular, it is very simple to determine the link between the pedal value and the torque to obtain a realistic result. This is very important for the simulation accuracy.

5. Looking to the future and summary

The test bench simulation by means of online simulation described here was implemented in 2007 as a prototype for a certain drive train. Since then, this system has proved itself. It is now used on various single-engine and multi-engine test benches for greatly differing drive trains.

The validation of the system described in sections 3 and 4 between the simulation requirements and the test results is shown in the result without using the learning cycles. The improvements to the comparatively simple forwards control by re-feeding the test set-up state variables into the IMC-governor, reduces the differences mentioned here even more. It is elementary that the simulation automatically corresponds to the behaviour of the real set-up without changing its operating strategies.

By developing an internal company system for the drive train test benches, taking into consideration the company's requirements and integrating these into the operational procedure, it was not only possible to obtain considerably better test results for the drive train components, but also to increase the productivity with far fewer shut-downs.

Bibliography

- [1] Klos, W.; Schenk, M.; Schwämmle, T.; Müller, M.; Bertsche, B.:
Antriebsstrangerprobung bei der Daimler AG, Internationales Symposium für
Entwicklungsmethodik, Stuttgart 29.8.2011
- [2] Willmerding, G.; Häckh, J.:
Ein System zur Untersuchung von Fahrzeugantrieben zur Vorhersage von
Fahrleistung, Kraftstoffverbrauch und Lebensdauer unter realistischen
Einsatzbedingungen, Vortrag auf der VDI-Tagung Erprobung und Simulation in der
Fahrzeugentwicklung, 24.6.-25.6.2009, Würzburg
[Erprobung Simulation VDI Würzburg 2009.](#)
- [3] Häckh, J.: Untersuchung und Optimierung der Steuerung von Prüfständen zur
Streckensimulation von Pkw-Antriebssträngen unter realistischen Einsatzbedingungen,
Masterarbeit an der Hochschule Ulm, Fakultät Informatik, Nov. 2007.
- [4] Greiner, J., Dörr, C., Klos, W., Schwämmle, T.: Lastkollektive 7-Gang
Automatikgetriebe W7A700, durchgängige Bewertung und Betrachtung im
Entwicklungsprozess bei Mercedes-Benz, Getriebetagung Friedrichshafen, VDI-
Berichte
- [5] Klos, W.: Gruppenschaltungsansteuerung von Nutzfahrzeuggetrieben, Dissertation
2004, Universität Stuttgart, Institut für Maschinenkonstruktion und Getriebebau Bericht
Nr. 508, ISBN 3-922 823-60-2

- [6] Körner, T; Depping, H; Häckh, J; Willmerding, G.:
Fatigue Life Prognosis for Transmissions based on critical Component Spectrum;
World Automotive Congress FISITA 2002, Helsinki, [Paper Nr.F02V091](#)
- [7] Körner, T.; Depping, H.; Häckh, J.; Willmerding, G.; Klos, W.: Rechnerische
Lebensdauerabschätzung unter Berücksichtigung realer Belastungskollektive für die
Hauptwelle eines Nutzfahrzeuggetriebes, DVM-Tagung Fulda vom 5. bis 6.6. 2002,
VDI Berichte N2. 1689, 2002 Seite 275 - 285
- [8] Willmerding, G.: A Simulation System to study the Working Conditions of Vehicles and
to develop fuel efficient Drivetrains, Publication on the FISITA-Congress 1992,
Institution of Mechanical Engineers, London 1992
- [9] Willmerding, G.: Ein Simulationsmodell für den Autobahnverkehr, Teil 1;
Automobiltechnische Zeitschrift Heft 5/1992
- [10] Willmerding, G.: Ein Simulationsmodell für den Antriebsstrang, Teil 2.
ATZ Automobiltechnische Zeitschrift, Heft 6, 1992
- [11] Willmerding, G.; Jehlicka, E.: Verbrauchsuntersuchungen an Stadtbussen, Zeitschrift
der Nahverkehr 1986, Heft 5 Seite 13-19
- [12] Willmerding, G.; Hoffmann, M.; Rasch, W.; Schicker, R.:
Ermittlung der Einsatzverhältnisse militärischer Radkraftfahrzeuge durch Auswertung
militärischer Übungen; Teil 4: Erfassung der Einsatzverhältnisse hinsichtlich
Beanspruchungen bei der Übung "Große Rochade", *Battelle-Bericht* 1976 .
- [13] Jan Lunze. Regelungstechnik 1, Systemtheoretische Grundlagen, Analyse und Entwurf
einschleifiger Regelung. Springer –Verlag Berlin, 6., korrigierte Auflage, 2007.
- [14] G. Schlüter. Regelung technischer Systeme – interaktiv. Carl Hanser Verlag, München
2001.
- [15] ABB Automation Production. Einführung in die Regelungstechnik. Technische
Information, 30/60-110 DE, 1(1):3, April 2003
- [16] W. Beitz und K.-H. Küttner. Dubbel Taschenbuch für den Maschinenbau. Springer –
Verlag Berlin, 17.,neubearbeitete Auflage, 1990.