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Holistic Methodology for Generating Customer-Related Testing Profiles for Electrified Powertrains

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Summary

The intensification of the development process with respect to shorter development periods and cost savings while simultaneously increasing the number of product characteristics and proceeding electrification of the powertrain leads to new challenges regarding the approval of vehicle components. The reliability requirement in customer-use in combination with the requested product liability has to be considered as well as a reduction of warranty and goodwill costs. This paper describes a methodology which permits the definition of customer representative test requirements from vehicle down to component level at any maturity level under consideration of all powertrain topologies or degrees of electrification.

Keywords: testing processes, Battery, BEV (battery electric vehicle), ICE (internal combustion engine), HEV (hybrid electric vehicle), reliability

1 Introduction

Durability testing of components or modules in the powertrain area is usually conducted on dynamometers. For this matter test programs including time acceleration factors are performed which replicate the operating loads arising during real life. In this way, the same strain caused in a few hundred hours test bench run occurs as in several hundred thousand kilometres in customer-use. The characteristics of these test programs are based on years of experience acquired by the vehicle manufacturer or the supplier industry. They have usually lead to a reliable component design and testing in the past generations of conventional powertrains and could therefore be applied for future generations. However, the adhered safety clearance to the strain in customer-usage and thus the degree of over- or under-dimensioning of the components remains unknown. A closer link to customer load spectra in real life should be pursued when there is no accurate knowledge about the customer usage and especially in consideration of the proceeding electrification, the demand to lightweight design and focusing on improvements in energy efficiency already in the process of development [1]. The aims of systematic testing are to detect the component´s loads in customer-use in form of representative load spectra and to convert them into concentrated test cycles.

2 State of the Art

The ”Road2Dyno“-Methodology, which converts real driving data to test procedures for component and powertrain testing, is already established in the context of conventional powertrain layouts. This methodology consists of the modules shown in Fig. 1.

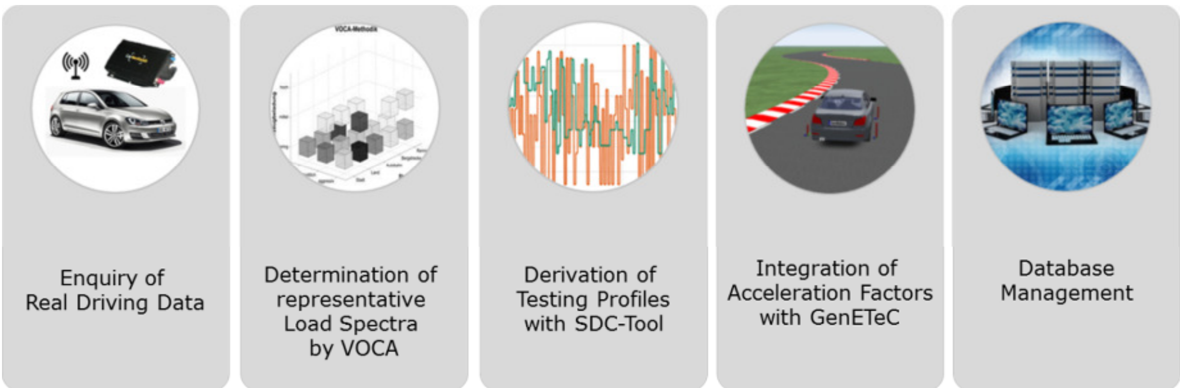

Figure 1: Workflow of the “Road2Dyno”-Methodology

To identify the customer loads from real driving data, it is necessary to perform a precise analysis of the required durability and component loads in customer-usage. Thereby it is fundamental to consider different usage markets, statistical verified recordings of driver and driving behaviour, a sufficient number of subjects and observed mileage and a long time monitoring for a period of a year at best to examine all environmental influences from e.g. different weather conditions.

In the next step the **V**ehicle **O**perating **C**ondition **A**nalysis (VOCA) is performed in order to evaluate the interaction of the driver with the vehicle and environment [2], [3]. VOCA is based on the 3F-methodology, originally developed at the Institute of Automotive Engineering at the University of Braunschweig [4], [5].

To identify the representative load spectrum the already analysed data is then scanned on the basis of a damage matrix in terms of liability of selected components of the powertrain and compared with the load capacity, which e.g. was determined by Wöhler fatigue tests. In this comparative evaluation of component damage usually the linear damage accumulation hypothesis according to Palmgren and Miner is used [6]. The damage accumulation hypothesis assumes that each load-cycle is associated with defined durability consumption for a given amplitude [7]. For a variety of components in the vehicle sector, whose durability is not predictable due to lack of Wöhler fatigue tests, testing is the only way for a proof of reliability [8].

The next step in the methodology includes the generation of synthetic driving cycles with the SDC-Tool (**S**ynthetic **D**riving **C**ycle-Tool) on the basis of the VOCA-data shortened by the execution of the linear damage accumulation hypothesis for each of a selection of characteristic components.

This package of driving cycles is then used as input data for a vehicle simulation whose results can be speed/load cycles for component or complete powertrain test benches. Possible interferences can be detected by a recalculation of VOCA.

Defined time acceleration factors can be implemented by combining significant load cycles with an automated algorithm performed in the GenETeC-Tool (**Gen**erator for **E**ndurance **Te**sting **C**ycles-Tool). With this iteration step time- and thus cost-optimal testing can be pushed on with a simultaneous adjustment of testing profiles, which are developed and adapted over time, to a more customer-usage-based character.

Since the specified methodology is based on the need to collect the necessary real driving data with production vehicles, the last step of the methodology is to ensure the findings, to be accessible to all developers and to transfer them to future vehicle concepts. Therefore a holistic database management system was set up that is usable and user-friendly at once.

3 Transfer to Electrified Powertrains

In the development process of electrified powertrains the arising customer load spectra often remain unknown and are therefore based on hypotheses and simulations without correct knowledge of input data. For this reason APL transferred the well-established “Road2Dyno”-Methodology to electrified powertrains, considering all stages of electrification respectively hybridisation from conventional vehicles with internal combustion engines (ICE) exclusively, Mild Hybrid, Full Hybrid and Plug-In Hybrid Electric Vehicle (PHEV) to Battery-Electric Vehicles (BEV), according to Fig. 2. In addition to conventional vehicles all subsystems like new gearbox designs, the electric motor, the power electronics and batteries with all their requirements in terms of packaging, cooling system and voltage level have to be examined in the design and approval processes, especially when going beyond requirements from legislator and other associations. The methodology permits the definition of customer representative test requirements from vehicle down to component level and even below at any stage of maturity under consideration of all powertrain topologies or degrees of electrification.

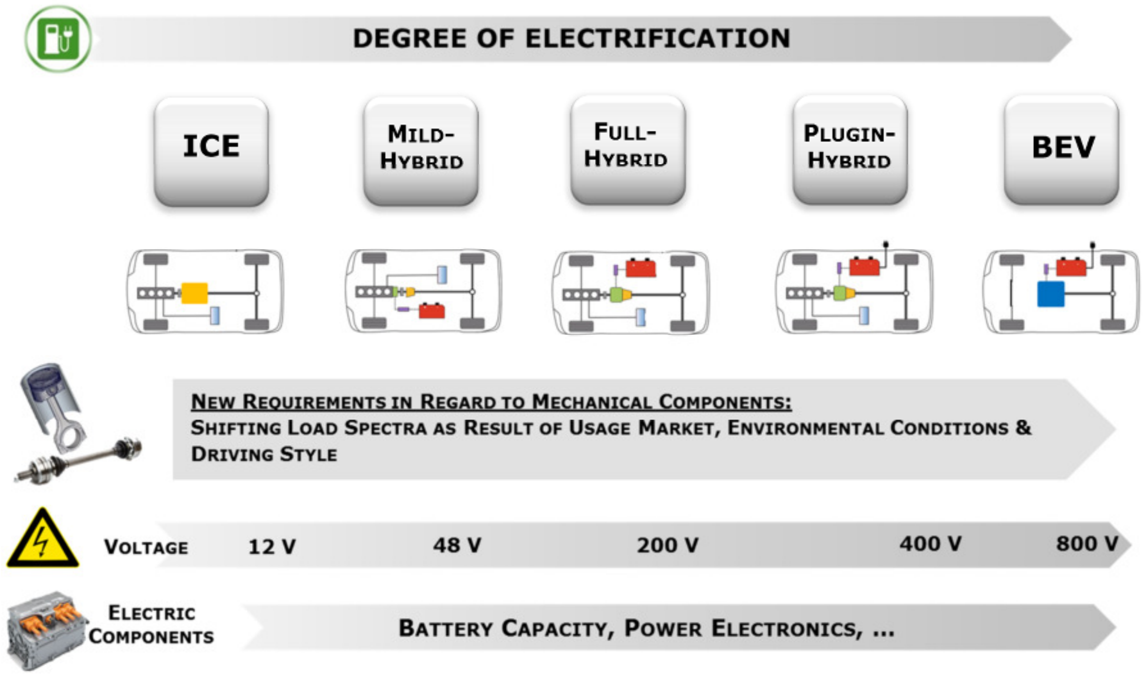

Figure 2: Powertrain Layouts

3.1 Acquisition of real-world driving data

According to the drafted ”Road2Dyno“-Methodology, the first and one of the key steps is the acquisition of real-world driving data of vehicles with electrified powertrain.

In the present case, the utilisation of a data acquisition device in customer cars was selected for recording real customer driving behaviour. It was important to ensure that the customer is not restricted in his normal vehicle use despite the knowledge of measurement technique in the vehicle. Therefore, the integration of additional sensors, possibly even in the field of vision of the driver, was out of question. Instead, the decision was made on a simple data logger, which was not visible to the vehicle user and only reads from the vehicle´s CAN-Bus and thus uses the vehicle-specific sensors as well as the existing communication between the control units. Only a GSM antenna is visible which transmits the collected driving data to a central server at regular intervals.

Years of experience with vehicle measurements showed that only a few measuring signals are sufficient to adequately describe the real use of the vehicle and the interaction of the driver with the vehicle and the environment for the question of the load spectra survey. The most important signals which were also basis for the following description of the methodology, are shown in Table 1.

Table 1: Measured Signals for VOCA

Signal	Frequency (Hz)
Engine Speed (ICE)	2
Engine Torque (ICE)	2
Engine Speed (E-Motor)	2
Engine Torque (E-Motor)	2
State of Charge (SOC)	2
Vehicle Speed	2
Accelerator Pedal Position	2
Gear	2
Steering Angle	2
GPS Altitude	2
Longitudinal Acceleration	10
Lateral Acceleration	10

The signals were stored in the dedicated frequency in packages per trip for optimal access. For the further analysis all trips can be merged and then observed as a complete dataset or as individual trips in order to investigate single events. It is explicitly mentioned that recording of GPS coordinates was abandoned for privacy reasons.

3.2 Data analysis to determine representative load spectra

The aim of the data analysis to be carried out following the data collection is to derive as comprehensive and detailed information and connections as possible regarding the driving and usage behaviour. From this information, robust load spectra balances can then be generated at component level.

Using only basic signals, as shown in Table 1, that accurately describe real vehicle usage and load, such as vehicle speed, accelerations, gear, engine speed, and so on, it was possible to perform a differentiation of the collected driving data with the help of an offline applicable algorithm which is the basis for VOCA, with regard to vehicle condition, driving distance and interaction of the driver with the vehicle taking into account all relevant influences. An online analysis of the data was not required by viewing components of the powertrain without the need for the driver's influence in real-time, as it may be useful in the context of driver assistance systems. In spite of the recording of periodic driving data, a relatively low-cost data logger suited to the computer performance was used for simple data storage, so that the number of subjects could be increased by corresponding cost savings. The result of the data analysis is the systematic and distinct allocation of the route, driving style and vehicle state at every time of the trip, in addition to the storage of load numbers and event counters. With the help of a damage matrix which could be used to assign potential causes of damage and relevant load spectra to each component to be viewed in the powertrain, representative components could be selected and the representative load spectra could be derived on the basis of the classification into the customer clusters using the damage accumulation hypothesis.

In the context of investigations with electrified powertrains a classic subdivision in the manners of driving ("conservative", "average" and "aggressive") was chosen for the driver, as shown in Fig. 3 for an exemplary battery electric vehicle (BEV).

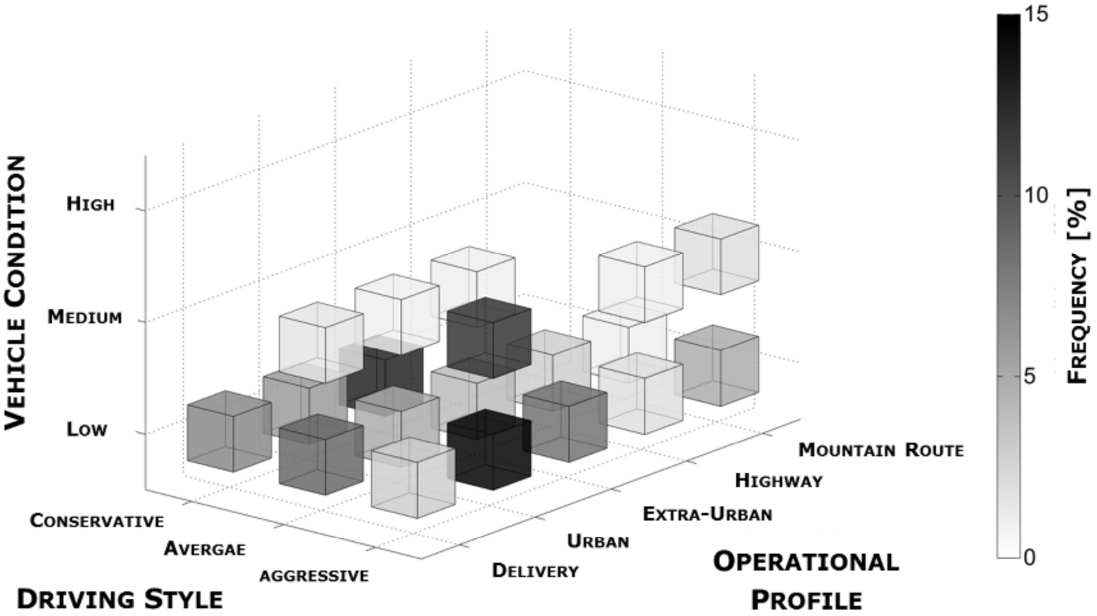

Figure 3: Example of VOCA

For the characterisation of the condition of the vehicle multiple distinguishing features are possible. However, the vehicle load is usually the only factor that is shortly changeable by the customer. So here the load groups "low" (driver only), "medium" (driver, front passenger and luggage), "full“ (gross vehicle weight) were chosen. The operational profile can be characterised by means of traffic flow in terms of velocity profile, traffic density, road parameters, weather conditions, degree of expansion of roads and road gradient and of course the customer´s use [9]. This influence is integrated into "delivery" for delivery traffic characterised by short distances and many start/stop-events, "urban", "extra-urban", "highway" and "mountain road" as a distance profile in the detection algorithm.

The overview in Fig. 4 of the main modules of an electrified powertrain shows the development requirements in general, which are simultaneously the main modules of the damage matrix to be regarded in the analysis process with VOCA.

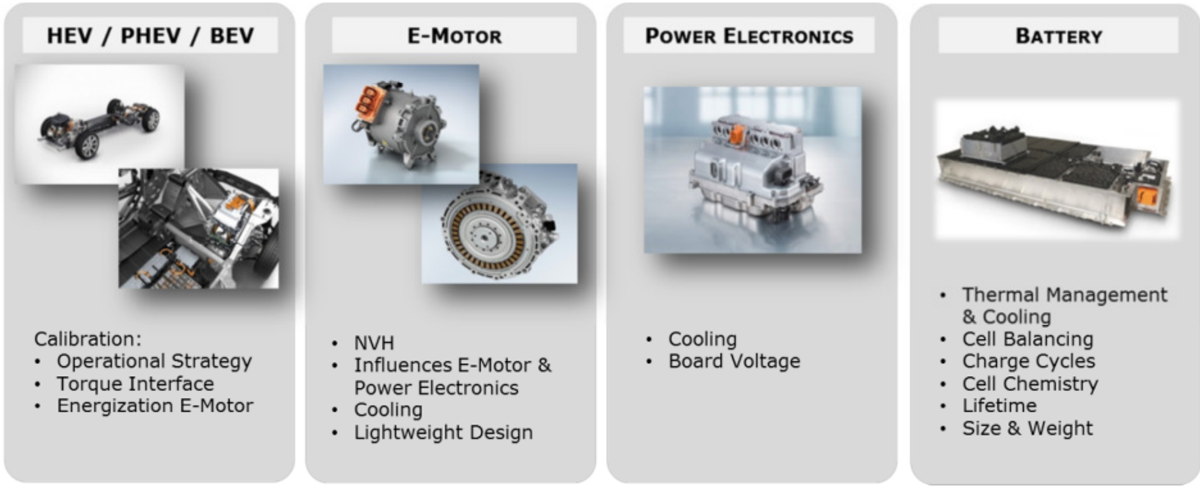

Figure 4: Powertrain subsystems and components

When starting the transfer of the “Road2Dyno”-Methodology to electrified powertrains it was useful in a first approach to shift knowledge from conventional powertrain components to similar components of electric powertrains by e.g. considering bearings of electric motors which are stressed by completely different loads under different boundary conditions. An extract of the corresponding damage matrix is shown in Fig. 5.

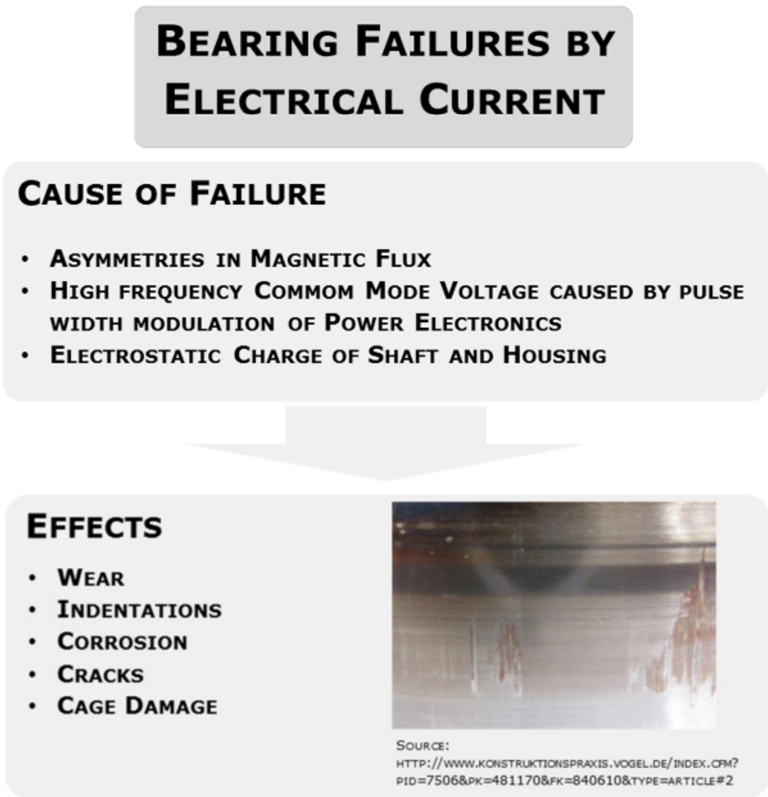

Figure 5: Extract of Damage Matrix of Electric Motors

3.3 Derivation of Testing Profiles

The previously determined combination of the operational profile, the driving style and the vehicle condition, which is regarded as representative of a component of the powertrain and thus causes the greatest stress over the vehicle´s lifetime, now provides the basis for generating a representative testing profile. The challenge is to derive a short and repeatable profile for test benches from the collected driving data. For this purpose, an algorithm has been developed which uses the classified driving data as an input database and generates a representative testing profile, the so called **S**ynthetic **D**riving **C**ycle, by statistically regarding the characteristic route parameters. In the settings of the SDC-Tool the user can adjust basic parameters like cycle length or if it is required other VOCA-combinations of the input data.

In the next step, this synthetic driving cycle is used as a vehicle speed profile to be computed with a well-adjusted vehicle simulation environment. The result of this virtual test can, for example, be a speed/load-profile which can directly be implemented on a transient test bench with reduced automation complexity and without the need for a real-time computer with an online vehicle simulation.

The described procedure can also be used in an even earlier stage of the development process. In the vehicle simulation environment several vehicle components can be varied with little effort, and the effects on the resulting load spectra can be evaluated by a corresponding analysis if a prototype for a hardware test is not yet available. Further application possibilities include comparisons of different calibrations, influence analysis of the driver or driving route types on the durability of powertrain components

3.4 Integration of Acceleration Factors with GenETeC

Because of one synthetic driving cycle and therefore one speed/load-profile for every damage mechanism in the next step the number of repeats of each cycle and the integration of acceleration factors has to be considered. If all analysed driving cycles are to be merged into a complete testing profile, overlaps of load spectra which also can chase other damage mechanisms must be taken into account and only the enveloping load spectra must be considered. For this purpose the tool **Gen**erator for **E**ndurance **Te**sting **C**ycles (GenETeC) was developed. Basis for the GenETeC-algorithm, as shown in Fig. 6, are all driving cycles which represent the damage mechanisms to be considered on the one hand. On the other hand the intersection between the testing profile with acceleration factor, the real driving load spectra and the design criterion must be regarded.

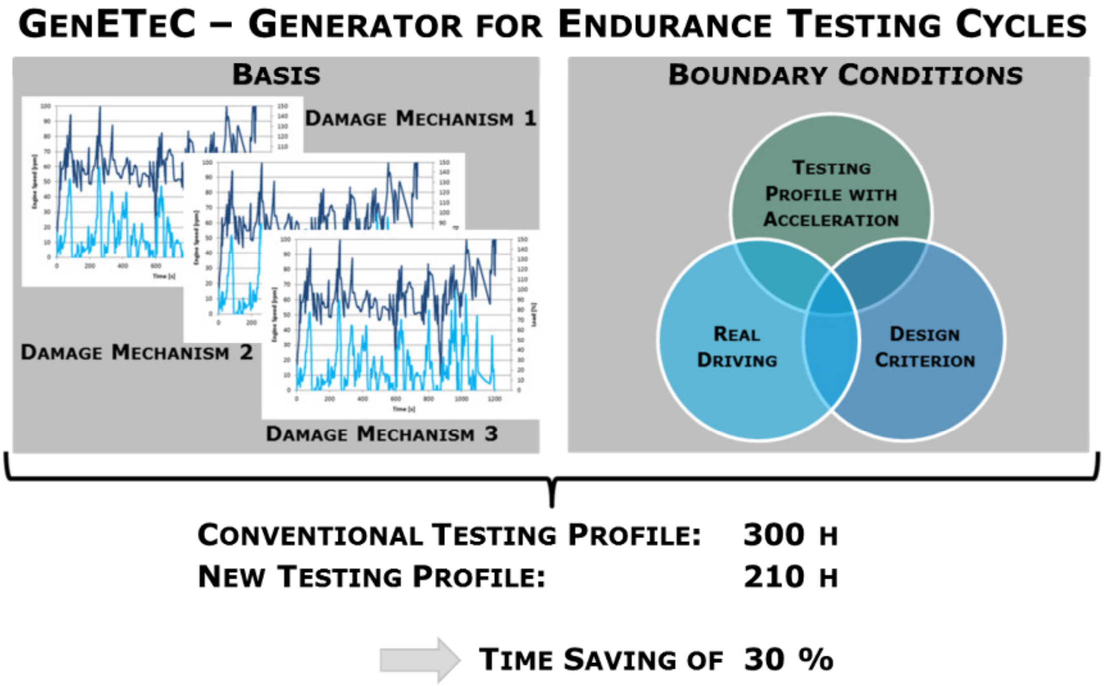

Figure 6: Schema of the benefit of GenETeC

With the help of an optimisation algorithm whose target is an optimal and reproducible testing procedure at shortest testing duration, the testing procedure is calculated. In the given example the originally specified testing profile of a permanent excited synchronous machine could be reduced from 300 to 210 hours including the same damage mechanisms and the same enveloping load spectra with a clear increase of customer representativeness due to the basis of real driving data.

3.5 Database Management

Step five of the drafted methodology is a database management system of the enquired real driving data and also the analysed and classified data from VOCA which is already stored as statistically edited. At this stage it is also necessary to implement automated evaluation and combination algorithms in order to accomplish a database for future powertrain component layout and design and to integrate the methodology´s effort in the whole development process. Therefore it is essential to gain access to the findings and knowledge database for all involved developers at the right stage of the product development process. In the interests of sustainability the enquired real driving data and especially the driving style is processed by a transfer function to make it usable for future vehicle and powertrain concepts.

4 Summary

By the presented approach, a well-defined and customer representative as well as time- and thus cost-optimal testing profile was realized. Recent applications of the methodology showed significant reductions of testing-time of approximately 30% by switching the testing profile to a more customer related and still representing the requested strain including now defined acceleration factors. The correlating testing-costs could be reduced in a similar scale.

The consistent implementation of the methodology even in the early stages of the development process promises extensive savings at simultaneously increased customer representativeness and enhanced utilization of component strength.

In the context of automotive applications and especially electrified powertrains in which nearly all developers of all OEMs and the supplier industry do not have the deep experience for decades in terms of durability and complex usage of powertrain components in real life, the recent approach puts the developers in a position to rate for example the behaviour of different battery cell types depending on its needs and applications in a 48V-Mild-Hybrid System or a 400V+ PHEV or BEV in customer-usage-related conditions by performing reproducible testing procedures on highly developed and conditioned test benches with state-of-the-art measuring systems.

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