

*EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017*

Holistic testing strategies for electrified vehicle powertrains in the product development process

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Summary

Regarding the new influences throughout the electrification of the vehicle powertrain compared to the conventional one this paper discusses the necessity to develop a holistic test strategy. Within this strategy a new developed test element supporting the integrative testing on powertrains is presented. The following contents have been created throughout the avocational doctorate of the first named author.

Keywords: powertrain, testing processes, HEV (hybrid electric vehicle), standardization, strategy

1 Introduction

The validation branch of the v-model has a major importance as it significantly influences the time-, cost- and quality- amounts within the product development process. In the field of powertrain engineering, longstanding empirical knowledge was gained for testing conventional vehicle powertrains. Through the electrification of the powertrain, the topology, the range of functions and even the usage behavior have changed. Also the complexity of the powertrain system increased and must still be validated and tested regarding its functionality and durability. This leads to new challenges for the validation and requires adjustments of the test strategies for vehicle powertrains that were used so far.

This paper presents a method to develop a holistic test strategy for a hybrid- and electrical vehicle powertrain. In order to avoid misunderstandings of used terms, it is necessary to create a standard understanding of them. Therefore, a nomenclature is defined and described. Furthermore, a definition of a holistic test strategy is provided. The focus here is on the powertrain and not on its single subsystems. Subsequently, the four steps of the method are introduced and the current results are presented. Finally, a new developed test element within the holistic test strategy is introduced. It is supporting the integrative testing on powertrains.

3 Nomenclature

A standard understanding of used terms in the field of powertrain engineering is the basis to develop and describe a holistic testing strategy.

Because this field encloses a big area of studies, it leads to the current fact, that same terms have different meanings depending on the viewing angle of the professional focus, as [1], [2] and [3] expose. The research literature exhibits a gap here [4]. Therefore, a nomenclature is defined and described. A part of the full nomenclature is illustrated in Figure 1 and listed below.

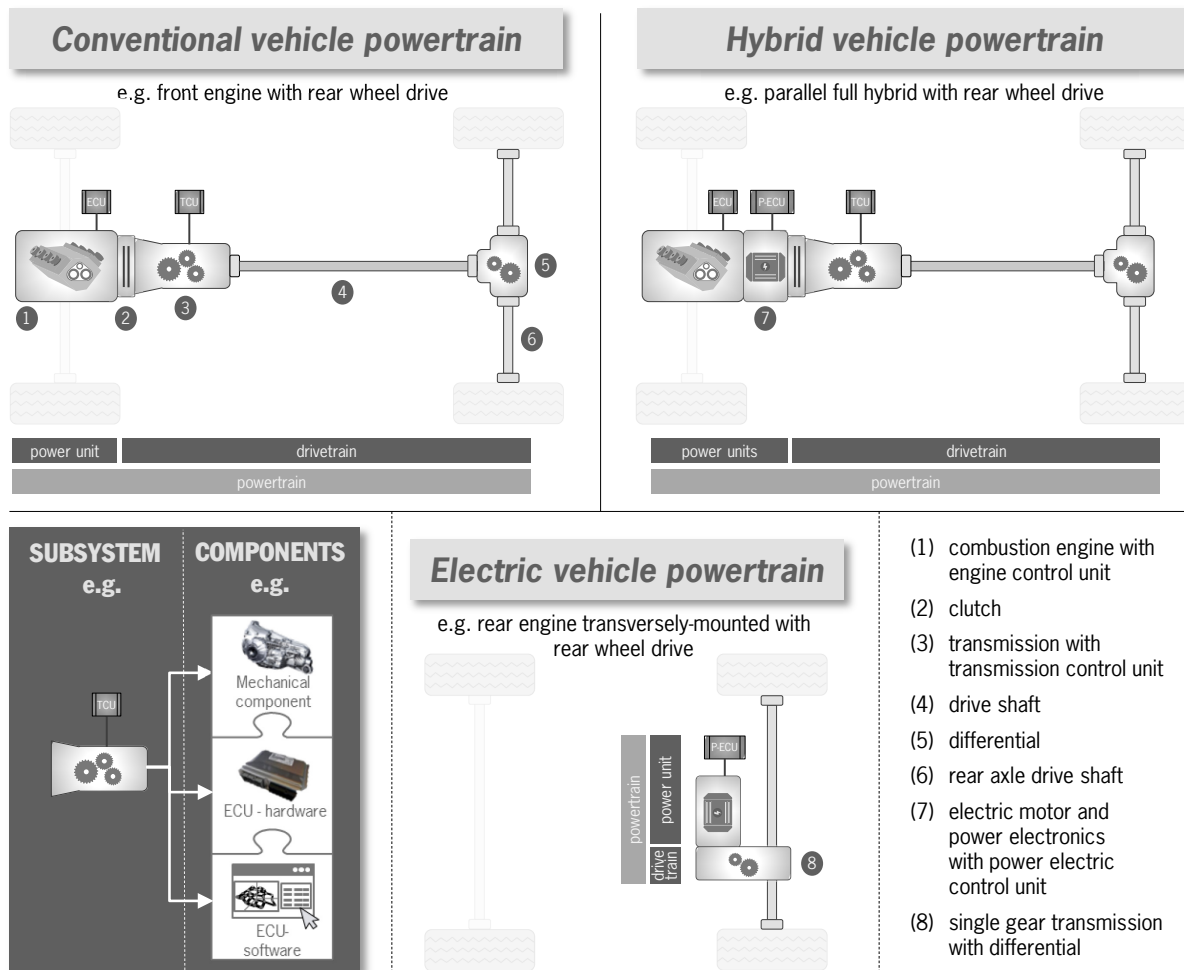


Figure 1: Illustration of the nomenclature

- **powertrain:** combination of subsystems, which deliver drive from the power unit up to the wheel flange. The following applies: powertrain = power unit(s) + drivetrain; Therefore, powertrain and drivetrain are not used as synonyms.
- **power unit(s):** subsystem(s) of the vehicle powertrain, which generate and provide torque and rotational speed. For example, a combustion engine including its engine control unit (ECU hardware and software) or an electric motor including its power electric control unit (P-ECU hardware and software).
- **drivetrain:** combination of subsystems, which transmit and/or convert torque and rotational speed up to the wheel flange.
- **subsystem:** is a functioning intrinsically system. It shall consist of single components.

- **component:** is a mechanical or mechatronic element. They contribute to the complete functionality of the subsystem. Components of a hybrid vehicle powertrain are e.g. P-ECU (hardware), P-ECU (software), and the power electronics (as the mechatronic component).
- **system levels:** For describing the test system level of a test object in a holistic test strategy, four different system levels are established and combined with the v-model:
 - 1. level: vehicle level
 - 2. level: powertrain level
 - 3. level: subsystem level
 - 4. level: component level

4 Method to develop a holistic test strategy

A holistic test strategy for vehicle powertrains is a guideline that is used to validate the vehicle powertrain regarding the functionality and durability throughout the product development process. It is displayed in form of a testing road map.

A test strategy is then a holistic one, when it is focusing the powertrain instead of each subsystem. This is a top down instead of a bottom up approach. Furthermore, all five core questions as shown in Figure 2 need to be answered coherently. The research literature provides a selection of test strategies for subsystems [4]. A few, like [5] and [6], give an approach to describe a holistic test strategy for the powertrain, but do not meet the aforementioned criteria.

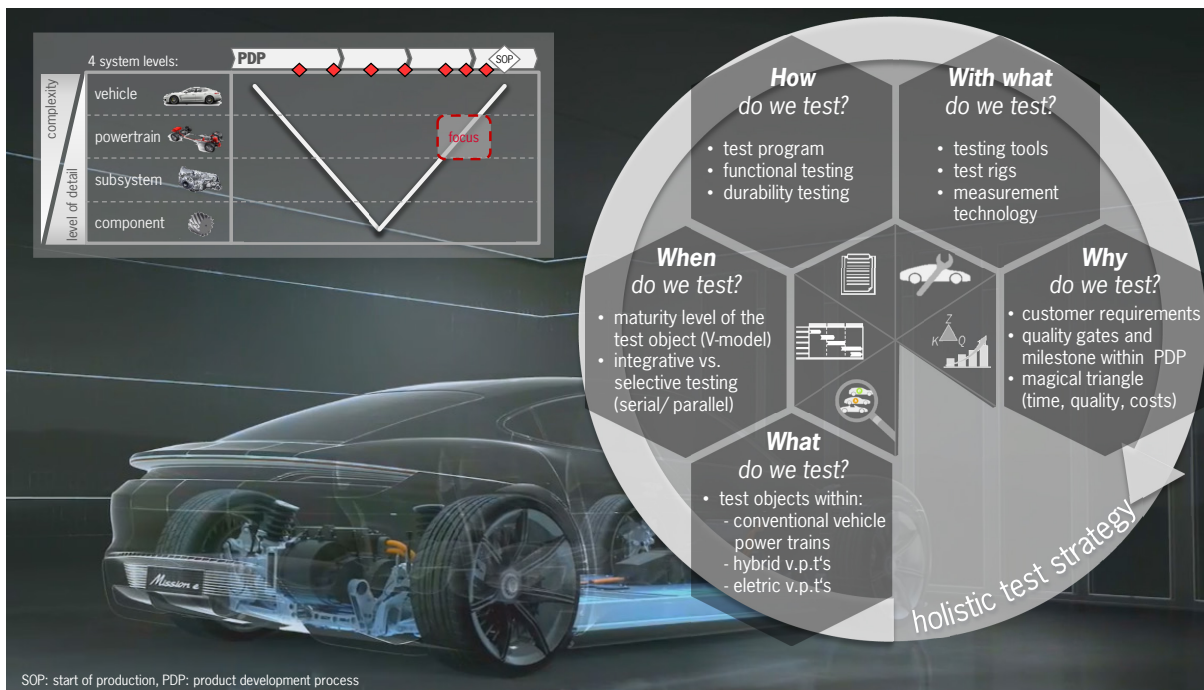


Figure 2: holistic test strategy

By applying the following method, including four steps, a holistic test strategy can be developed:

- Step 1: Analyze the test strategy of a conventional vehicle powertrain by answering the five core-questions (Figure 2).
- Step 2: Perform a requirement determination by a function-analysis for either a hybrid- or electrical vehicle powertrain topology

- Step 3: Overlay the test strategies, identify emerged vacancies and dependencies.
- Step 4: Complete the test strategy by filling up the vacancies with testing methods and display it in form of a testing road map

Previous results for step 1 show a current volume of over 2000 tests.

The strategies that are currently being worked on by using the four aforementioned steps are also being used within the framework of knowledge management. The holistic test strategy displayed in form of the testing road map can be used by developers as a procedural model/ manual in the product development process. By successively integrating the experiences of the developers, not only a know-how protection can be made possible, but also the recirculation of the test knowledge into the development can take place. This is particularly important because there is currently a different know-how level in the development for electrified powertrains than for conventional ones [7]. In the field of electrified vehicle powertrains, very large competencies exist in the individual disciplines on subsystem and component level. On the powertrain level connected know-how must be built up and networked.

4.1 Five core questions

In this broad thematic area the scope must be clear in order to develop the holistic strategy. This is defined as an entrance requirement. In order to derive the application of the core questions, these are explained below:

- **What** do we test?

Within this core question it is necessary to clarify the extent of consideration of the powertrain with regard to its subsystems and, where required, to its components. In the current analysis the powertrain topologies from Figure 1 are considered. The HV battery, the charging technology and stations are just like the tires and brake units not the extent of consideration.

- **When** do we test?

This core question analyzes the maturity levels of the test objects at different times in the product development process. It is important to identify interdependent tests as a qualitative indication so they can be categorized regarding an integrative or selective testing strategy. Therefore it is linked to the core question “How do we test?”.

- **How** do we test?

Within this core question, test programs need to be gathered and categorized regarding their testing focus. For example durability testing, functional testing, misuse testing or testing acoustics or thermodynamics.

- **With what** do we test?

A large toolbox of testing tools is available for realizing and implementing test requirements. These include for example simulation models, test rigs and measurement technologies. As test resources have to follow the trend to be more flexible and not just cover one test application ([8]), the description of several configurations is quite permissible. With this core question not only the analysis of the toolbox but also the categorization is to be carried out to connect the contents to the other core questions. An example categorization of test rigs is shown in Figure 3.

- **Why** do we test?

This core question examines superordinate the customer requirements, quality gates and milestones within the PDP referring to the magical triangle of time, quality and cost factors.

The answers to the core questions combined with the consideration along the product development process result in a holistic test strategy for a vehicle powertrain topology. For this purpose, the v-model is used as a procedural model, which is explained in the following chapter 4.2 - System levels in the v-model.

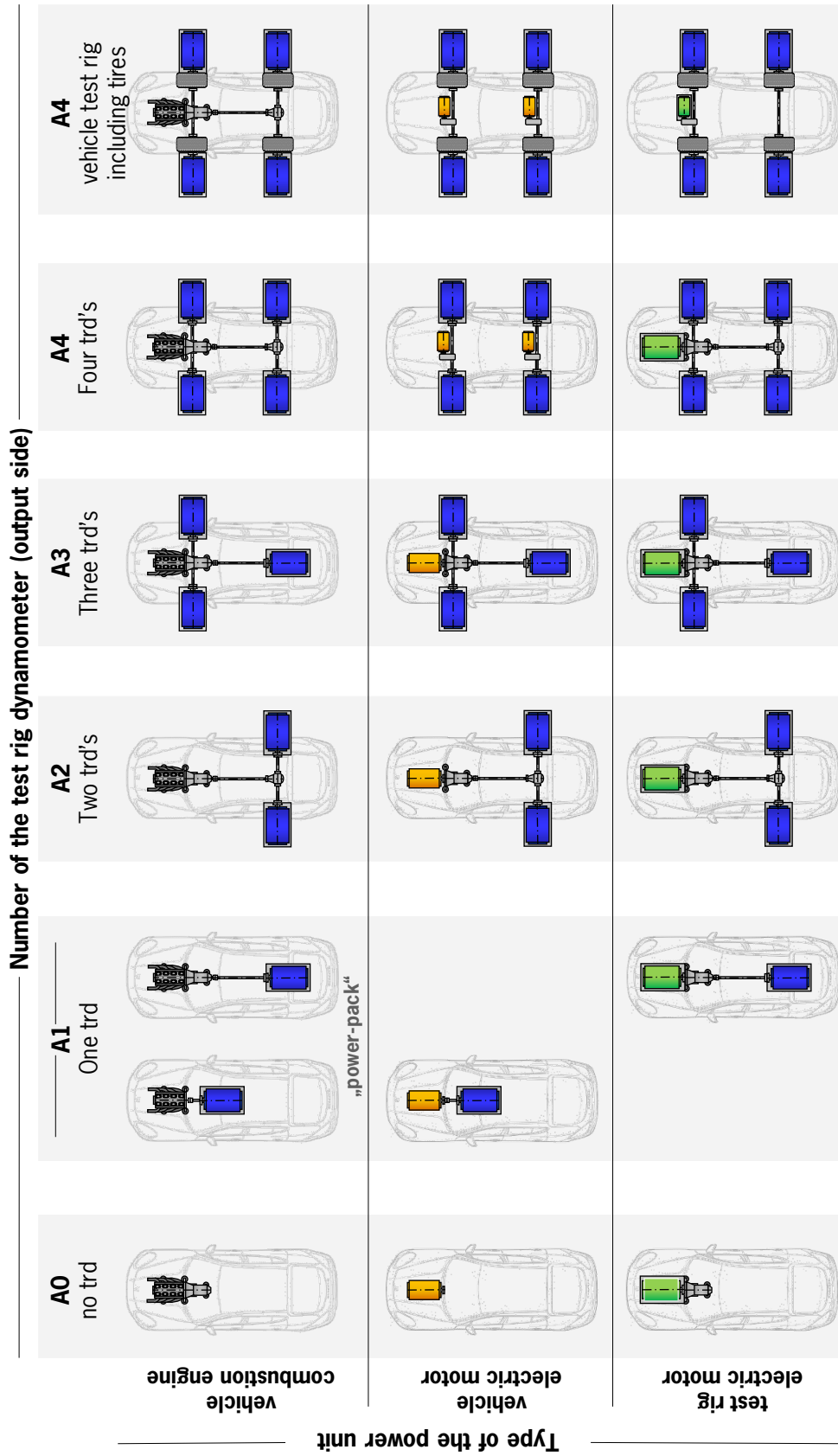


Figure 3: Exemplary categorization of test rigs "With what to test?"

subsystems of the powertrain are deployed (Figure 6). Therefore the powertrain system test is supporting the integrative testing on powertrains.

The focus of the PST is to validate the functionality of the powertrain as a whole system of subsystems. Therefore the developed test catalog is not a continuous program but a sum of different function, interface and network tests. Testing the mechanical durability isn't the focus of this test element.

An important point in the implementation of the PST is that the latest hardware and software is obtainable. Meaning that the powertrain of e.g. the vehicle charge 1 is fully available on a powertrain test rig or on a parts-carrier vehicle. There it is tested before the vehicle of charge 1 is even accessible for testing. This makes frontloading possible. In this case the vehicles of charge 1 receives a powertrain with a higher total maturity level as it is the case when testing in the vehicle level directly after the subsystem level. This results in an expectation for a good project- and part management in order to fulfill this important framework condition.

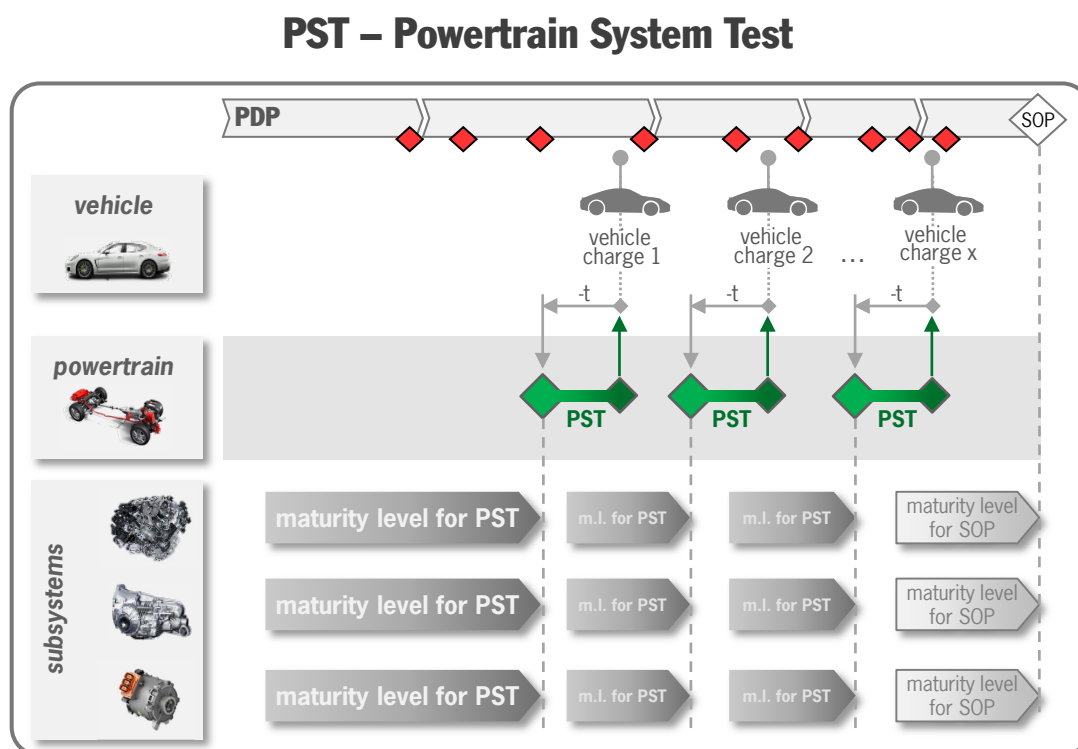


Figure 5: Concept of the powertrain system test (PST)

Figure 6 shows the classification of the PST as a test element in the ascending branch of the v-model. The use of the test tools is not necessarily chronological but partly parallel or overlapping.

The PST will be used systematically for all vehicle powertrain topologies to expand integrative testing at the Porsche AG and is currently in the roll-out phase for the topologies shown in Figure 1:

- **conventional vehicle powertrain:** rear wheel drive (two wheel drive) with a front engine, clutch, automatic transmission, drive shaft, differential and rear axle drive shafts
- **hybrid vehicle powertrain:** rear wheel drive (two wheel drive) with a front engine, clutch, automatic transmission, drive shaft, differential and rear axle drive shafts and an electric motor with power electronics
- **electric vehicle powertrain:** rear wheel drive (two wheel drive) with a rear engine transversely-mounted with an electric motor (including power electronics) and a single gear transmission with differential

6 Conclusion and Outlook

In summary an insight into the nomenclature has been given in the area of the vehicle powertrain development in order to avoid different understandings of used terms in this field. On the basis of this, the need for a holistic test strategy for the further advancement of electrified vehicle powertrains was presented. The holistic test strategies are currently in active development and serve as a guideline for developers. By declaring a component of this holistic strategy, the powertrain system test, the importance and added value for the expansion and the better integration of the powertrain within the product development process are highlighted.

The scope of the holistic test strategies includes the open potential of not only presenting a guideline and approach but also an active project control tool for the vehicle powertrain development. For this purpose, it is necessary to develop a valuation method for the potential risk in the case of non-fulfillment of the strategy content. This could be learnt on risk priority numbers (RPN) known from the quality method “failure mode and effects analysis” (FMEA).

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