Modern approaches of vehicle suspension durability evaluation at early stages of development

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Abstract. Ensuring demanded service life of a vehicle is a relevant engineering problem. Currently, resolving this problem is heavily complicated. Modern tendencies of automotive industry assume shortened development cycle for new vehicles and sustaining wide lineup of cars for manufacturers. Performing long-term durability testing of vehicle subsystems is becoming limited. Meanwhile, methods of laboratory testing, which provide higher acceleration degree of damage accumulation in comparison with testing on proving ground, are progressing. Virtual simulation methods, which allow analyzing and optimizing a new design at early development stages, are becoming widespread as well. Modern durability analysis methods, based on laboratory testing and virtual analysis, and load cycle generation methods, used for testing and simulations, are considered. Some points are noted, such as an extensive use of described methods of durability research among foreign car manufacturers, and the relevance of developing this kind of durability evaluation methodology for the Russian automotive industry.

Introduction
Ensuring failure free service life of a vehicle, like any machine, is a relevant engineering problem. In recent years, resolving this problem is heavily complicated by the factors caused by the world automotive market conditions and carmakers competition.

One of the factors, which determine progress of automotive industry, is shortening a development cycle for new vehicles, in average, from 48 to 25 months. Acceleration of vehicle development is explained by both constant vehicle lineup expansion and shortening the period of model generation change. These tendencies are noticeable on the example of Volkswagen AG. Volkswagen Golf’s model cycle decreased from 9 to 4 years generation to generation. Since 1950’s, the Volkswagen lineup has been broadening from 3 to, at the lowest estimate, 18 models for today [1]. It worth noting that each car model has a number of configurations, which may vary with powertrain and drivetrain type, and available active or adaptive chassis systems, which have an impact on contact patch forces.

Shortened duration of new vehicles development and sustaining a lineup diversity demand an optimization for each stage of the engineering process. One of the optimization way is wide implementation of means of simulation analysis to ensure targeted service properties of vehicle subsystems and components. Meanwhile, duration of on-road testing program is reducing.

In current conditions ensuring the chassis durability is of a particular interest. The complexity of development and evaluation of suspension is based on the purpose of a suspension in a vehicle.
vehicle’s service, a suspension is transmitting loads, arising from contact patches, to a vehicle body, damping sprung and unsprung mass oscillations caused by loads and road profile and conceiving reaction loads from drivetrain components. Fatigue properties of suspension arms are highly important for ensuring preassigned service life. According to this, the article is mostly dedicated to suspension durability analysis. The provisions given in the article may also be applicable to other components and subsystems analysis.

Methods of accelerated durability testing are based on providing damaging effect on vehicle subsystems, which is equal to impact, accumulated during service life. On proving ground, acceleration of damage accumulation is achieved by the driving cycle, scaled to target service life mileage. The number of tracks and single obstacles (events), order and driving mode of events determine the driving cycle. Driving route also includes connection roads for moving between tracks, wherein the severity of damaging impact caused by connection roads is negligible. Other circumstances, which affect on proving ground testing duration, are shift-based operation hours of test drivers and weather conditions.

Russian automotive industry enterprises practice performing this kind of testing for prototypes, which are to be prepared in last engineering stages. Meanwhile, the companies have not developed own principles of durability evaluation at early development stages, in contrast to foreign car manufacturers. All leading carmakers perform strength and fatigue assessment of new design before the first vehicle prototypes being built. Utilized research methods for this kind of assessment ensure demanded information value of detected failures and comparison with supposed service mileage. Implementation of this approach involves development of unique methodologies and use of cutting-edge testing equipment.

Ways of laboratory testing
The most effective way of chassis durability analysis at the design and development stage is performing semi-natural testing on a state-of-the art test rig. Advantages of laboratory testing are:

- Ability to be performed at any vehicle development stage for rapid obtaining accurate results of failure detecting;
- Vehicle units and subsystems might be used as a research object as well as a vehicle assembly;
- Providing control and monitoring of input loads signals and physical system response signals;
- Ability to rapid identification of weak points of vehicle design, damage propagation and components properties degradation;
- Repeatability of testing and statistical data accumulation;
- Providing continuous loading of object during a testing cycle;
- Providing higher degree of load severeness needed to accelerate damage accumulation [2].

With optimized input and continuous test rig operation, duration of laboratory fatigue testing can be up to 10 times less than duration of durability testing on proving ground.

One of the most used approaches of performing accelerated laboratory testing of a vehicle frame structure is use of a hydropulsator N-post rig (figure 1). Input load of this facility determined as a wheel platforms vertical displacement, independent from each other, which imitates load and kinematic factors exposure on a vehicle. Emerging normal wheel loads makes a significant contribution to damage accumulation. However, lack of complicated impact of wheel forces and torques as well as reactive loads produced by drivetrain torques makes this approach imperfect for a complete identification of weakest points in a suspension design. According to this, described type of laboratory testing is suitable only for frame structure fatigue analysis.
Independent fatigue testing of each component with uniaxial load has the similar issue. Testing facilities, used for this purpose, are unable to provide such loading conditions with critical cross-sections of a component to be loaded in the same way as during vehicle service. In addition, there is a risk to overload other cross-sections, which can lead to component failure to be not similar to the same one happened in a vehicle assembly.

To avoid mistakes described above, 6 degree-of-freedom multichannel spindle-coupled testing systems (figure 2) were developed for suspension assembly testing. These test rigs allow setting contact patch forces and torques (up to 12 inputs for one axle), reaction loads from drivetrain units, steering and active/adaptive suspension systems operation. Laboratory testing on a spindle-coupled facility can provide high accuracy of damage accumulation and full information about weakest points of design and identify components properties changing during the test.
Methods of suspension module accelerated durability testing with a spindle-coupled rig have been confirming their efficiency since the first implementation of them. Thanks to deserved recognition, these test rigs are widely adopted by the leaders of the world automotive industry, such as Porsche Engineering and Magna. Spindle-coupled test rigs find an application for military and racing cars development as well (figure 3).

![Figure 3. HMMWV mounted on a spindle-coupled test-rig](image)

The most advanced testing equipment allow considering a negative impact of environment on vehicle units durability. This impact is simulated via supply of a mix of water and salts to an object periodically during the testing cycle.

**Computer-aided engineering methods of durability analysis**

As the development cycle of new vehicles is constantly shortening, CAE software becomes more widespread for engineering tasks. Making simulation analysis of vehicle performance properties allows to identify weaknesses of a design before first prototypes to be assembled and tested, that helps to avoid undesirable material and financial resources spending. Additional advantage of using CAE tools is the fact that numerical calculation is the only element of fatigue design process, which provides well-controlled certainty and accuracy [3].

Multibody system models are used for calculation of suspension parts loads regarding the impact of wheel loads. The main advantages of MBS models are functionality of a detailed physical object properties description, simplicity of properties editing and event simulation. An MBS model of a vehicle or a suspension subsystem allows considering suspension kinematics, linear and non-linear properties of spring, dampers and bushings, and the operation of existing active or adaptive systems of suspension control.

Suspension loading simulation can be performed with a numerous approaches. The simplest way is to simulate operation of a suspension on a virtual multichannel test rig. This approach is noticeable with the fact that physical object testing results can be compatible with calculation results that allows an MBS model accuracy improvement. Improvement of a model accuracy can be achieved with an iterative editing of properties of suspension components [4]. If it is necessary, an MBS-model can be
sophisticated with a detailed description of testing equipment used for performing of physical object testing (figure 4) [5].

Some leading companies of an automotive industry use approaches of simulation of full vehicle assembly driving through proving ground tracks and single obstacles. This way of performing a load calculation is the most advanced, but at the same time has higher demands to be implemented. It is necessary to have a number of virtual copies proving ground tracks, obtained with laser scanning technologies. Quality of responded wheel loads is provided by high-accuracy frequency-dependent tyre model, which is able to perceive loads from the road surface in the whole contact patch, not in one contact point. The FTire model is widely used format of this kind of tyre model [6]. In addition, the driver model used in an MBS software can have limits of driving path choice and maximum longitudinal and lateral accelerations to be achieved. It is a very tricky point of simulation of events, which assumes driving on the grip limits. As a result, vehicle chassis can be underloaded, and the targeted chassis service life could not be checked. In the end, higher computation capacity is demanded for this kind of simulation in comparison to a suspension assembly load simulation. As the number of simulated events is not necessary restricted, automatized event formation is preferable.

Estimation of damage accumulation has several approaches as well. The most accurate way is implementing “flexible” parts (e.g. suspension arms) into an MBS-model after being prepared by methods of finite element modelling. Stress and strain of these parts under load is determined as a sum of linear deformation according to eigen modes of parts. Calculated time-dependent stress-strain state is exported to fatigue analysis software. Approach of estimation of pseudodamage accumulation, where stress-strain state replaced by loads on component, is also acceptable [3].

For car manufacturers and engineering centers, which are working on their method of virtual analysis of chassis durability, development of a detailed MBS-model of suspension modules with flexibility of suspension arms is sufficient.

Performing simulation analyses allows effective optimization of durability evaluation at early stages of vehicle development in terms of testing duration and quality of results. Combined durability research with both laboratory testing and simulation analysis ensure high accuracy of results. Vehicle testing on proving ground remains necessary at further development stages as well as semi-natural testing for more detailed failures research.

Load cycle formation
Additional testing duration reducing in comparison with testing on proving ground tracks is provided by use of shorter load cycles with higher values of loads, which ensure damage value to be equal to damage accumulated during service life of vehicle. Load cycle is a set of load signals, which describe

Figure 4. A suspension test rig based on the hexapod concept model used in an MBS software can have limits of driving path choice and maximum longitudinal and lateral accelerations to be achieved. It is a very tricky point of simulation of events, which assumes driving on the grip limits. As a result, vehicle chassis can be underloaded, and the targeted chassis service life could not be checked. In the end, higher computation capacity is demanded for this kind of simulation in comparison to a suspension assembly load simulation. As the number of simulated events is not necessary restricted, automatized event formation is preferable.

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contact patch forces and reaction forces caused by drivetrain loads. Approaches of load cycle formation are:

- Editing previously recorded load signals on tracks based on accelerated durability testing driving cycle;
- Determination of artificial (synthetic) signals based on vehicle properties, targeted service life and service conditions rate.

Initial set of signal could be obtained during a driving cycle of accelerated durability testing on proving ground, performed by vehicle, comparable with a new vehicle under development. Adjustment of recorded loads is conducted by scaling according to weight, size and other properties of a new car.

Obtained signals are necessary to be optimized to ensure the same damage accumulation for less duration. It is possible with excluding of parts of signal, which cause a small amount of damage. Thus, signals of driving on connection roads during the driving cycle can be removed completely. In addition, there a plenty of amplitude-based and frequency-based methods of signal editing. Choice of signal processing method depends on the impact on a vehicle. Amplitude-based methods are used for description the signal as a rainflow cycle counting or range pairs of load. Frequency-based methods allows determining input signal based on vehicle properties as an oscillation system. Special attention is required to wheel load data processing because of their simultaneous influence, and synchronicity of load impact is crucial to be saved [3].

Utilizing a synthetic load cycle allows achieving the highest degree of laboratory testing acceleration and ensure expected value of damage accumulation during service life. Synthetic signal consists of a number of sinusoidal signals with determined frequency and amplitude. Synthetic load cycle must take into account such demanded information as type of a vehicle, service conditions rate, expected service mileage, weight properties, stiffness and damping properties of a suspension, etc. According to the correlation of synthetic load cycle with supposed service conditions of a vehicle, the cycle can be generated with achievement of scaling possible number of important load signals in the limits of linear deformation of parts (Hooke’s Law) [3]. It means that artificial load cycle can provide much more severe impact than proving ground tracks, so it allows reducing the time of testing performing. Use of synthetic load cycle may exclude a road load data recording phase with similar cars, but it is necessary to approve a creditability of determined load cycle with a reliable statistic data of vehicle service in different conditions.

**Conclusion**

Current level of technology development suppose use of a variety of vehicle fatigue evaluation methods at early stages of development. This article reflects generalized concepts of existing methods of accelerated durability laboratory testing, simulation analysis and load cycle formation.

Leading car manufacturers and engineering centers are developing or have already had own methodologies of fatigue evaluation. These methodologies are a commercial secret and cannot be found in a public domain.

FSUE “NAMI” has a broad experience in performing accelerated durability testing of vehicles on roads of “NICIAMT” proving ground. Meanwhile, described approaches of chassis durability analysis at early development stages have not been embodied yet by Russian scientists and researchers. Development the methodology, which reflects service conditions on roads of Russia, can be useful for being utilized by Russian manufacturers and foreign car makers, which want to keep competitive performance on Russian automotive market, as well.

To sum up, development and implementation of accelerated durability testing methodology of a vehicle based on virtual and semi-natural experiment technologies is a relevant and highly sought
scientific and engineering problem for Russian automotive industry. In addition, problems, which are to be resolved, are:

- Increasing efficiency of fatigue research results;
- Shortening duration of laboratory testing in comparison with road testing;
- Ensuring the possibility of road testing replacement on laboratory testing;
- Reduction of material and human resources for preparation physical objects for testing.

Taking into account all the advantages and disadvantages of described approaches, possible methodology of accelerated durability evaluation at early development stages can have a good potential with these methods:

- The method of synthetic load cycle formation for chassis;
- The method of performing virtual experiments with a highly detailed MBS-model of a suspension assembly;
- The method of performing semi-natural testing of a suspension assembly on the multichannel spindle-coupled test rig.

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