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FAKULTA STROJNÍHO INŽENÝRSTVÍ
ÚSTAV AUTOMOBILNÍHO A DOPRAVNÍHO INŽENÝRSTVÍ

FACULTY OF MECHANICAL ENGINEERING
INSTITUTE OF AUTOMOTIVE ENGINEERING

COMPONENTS TESTING IN AUTOMOTIVE INDUSTRY

TESTOVÁNÍ KOMPONENT V AUTOMOBILOVÉM PRŮMYSLU

BAKALÁŘSKÁ PRÁCE
BACHELOR'S THESIS

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ZADÁNÍ BAKALÁŘSKÉ PRÁCE

student(ka): Miroslav Tovaryš

který/která studuje v **bakalářském studijním programu**

obor: **Strojní inženýrství (2301R016)**

Ředitel ústavu Vám v souladu se zákonem č.111/1998 o vysokých školách a se Studijním a zkušebním řádem VUT v Brně určuje následující téma bakalářské práce:

Testování komponent v automobilovém průmyslu

v anglickém jazyce:

Components Testing in Automotive Industry

Stručná charakteristika problematiky úkolu:

Náplní práce je zpracování dostupného přehledu používaných přístupů k testování komponent v automobilovém průmyslu.

Cíle bakalářské práce:

Cílem je zpracovat přehled problematiky testování automobilových komponent zejména s ohledem na

- druhy a rozdělení prováděných testů
- metody zkoušení
- používaná zkušební zařízení
- způsoby vyhodnocení a používané softwarové vybavení
- možnosti snížení nákladů na testování a akcelerace testů

V závěru práce na základě dostupných informací zhodnoťte současný stav a vyslovte se k trendům a dalšímu možnému vývoji v této oblasti.

Seznam odborné literatury:

[1] Online Engineering Reliability Resources [online], 2008, poslední revize 17.10.2008. Dostupné z: <http://www.weibull.com/>

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[4] SCHWAB, H. L., DODSON, B. L. Accelerated Testing: A practitioner's Guide to Accelerated and Reliability Testing. Society of Automotive Engineers, 2006. ISBN 978-0-7680-0690-2.

Vedoucí bakalářské práce: Ing. Pavel Ramík

Termín odevzdání bakalářské práce je stanoven časovým plánem akademického roku 2008/2009.

V Brně, dne 20.11.2008

L.S.

prof. Ing. Václav Píštěk, DrSc.
Ředitel ústavu

doc. RNDr. Miroslav Doupovec, CSc.
Děkan fakulty

Abstrakt:

Tato bakalářská práce se zaměřuje na testování komponent v automobilovém průmyslu. Nabízí přehled testovacích metod, jejich základní popis a popis testovacích zařízení. V práci jsou také zmíněny CAD systémy, metoda konečných prvků a zrychlené testy, které slouží ke snižování finančních nákladů na testování pomocí omezování počtu testů nebo zkracování testovacích časů. Principy těchto nástrojů jsou zde stručně popsány. Závěr práce shrnuje důvody, které ženou vývoj testovacích metod kupředu.

Klíčová slova:

Testování komponent, testovací metody, automobilový průmysl, zrychlené testy, snižování vývojových nákladů

Abstract:

The bachelor's thesis is aimed at testing of components produced by automotive industry. It yields an overview of testing methods, their basic description and description of used testing devices. In the thesis are also mentioned CAD systems, Finite Element Methods and accelerated tests, which are employed to reduce costs of testing process by eliminating the number of tests or by shortening the test-times. The basic principles of all these tools are briefly described. The conclusion of the thesis summarizes the reasons why developing of the testing is so important.

Key words:

Component testing, test methods, automotive industry, accelerated tests, design cost reduction

Bibliografická citace VŠKP dle ČSN ISO 690

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Prohlášení

Prohlašuji, že jsem tuto bakalářskou práci vypracoval samostatně. Při práci jsem vycházel jsem z pokynů vedoucího bakalářské práce, vlastních znalostí, odborných konzultací a odborné literatury.

V Brně dne: ……………….. Podpis: …………………………….

Poděkování

Mnohokrát děkuji všem členům mé rodiny za veškerou jejich podporu. Dále děkuji svému vedoucímu práce za jeho pomoc, udělené rady a obětovaný čas.

Content

1. Introduction

Traditionally, testing was carried out by the vehicle manufacturers and often involved hundreds of expensive prototype vehicles. But car companies will do less and less testing of new designs. Instead they already ask their suppliers to prove a component will last through the life of the vehicle. So the suppliers of the vehicle parts are expected to do the testing themselves, but without the benefit of the vehicles. That means them to calculate and then simulate conditions of laboratory tests as if the component would be mounted and tested in a prototype vehicle. The car parts suppliers are naturally trying to reduce expenses. As it is expensive for vehicle manufacturers to make prototype vehicles it is expensive to make a prototype of every new design of a component. Today this is not necessary. Modern software for 3D digital design is very sophistic and it could have finite element method integrated. That gives the designer the opportunity to make a digital 3D model of the component and after defining the forces actuating to it could be applied the finite element method, which calculates the stress distribution and plastic strain distribution. The designer can immediately see if the construction is designed right or has to be modified. After having a satisfactory construction the prototype of the component are made for realization of real tests. The result of this designing procedure is very effective and helps to reduce development costs. The target of this thesis is to bring basic overview of the test methods and tools, which help to increase their efficiency.

2. Automotive parts design – present approach and used methods

The designers use computers and design software with all its advantages simplifying the design process. Today’s approach in component design is to make a 3D digital model, make virtual analyses and eventually modify the concept. Next stage is the production of prototypes intended for providing the tests. The prototype can be made by conventional technique or by rapid prototyping. After the test results evaluation is the design corrected or goes straight to the production line.

2.1. Virtual design - CAD systems

Computer-aided design (CAD) means using the computer for the process of designing. Nowadays are used two types of CAD systems:

2.1.1. 2D CAD system

2D CAD systems provide creating of figures and curves, the output are technical drawings. In 1980’s the 2D CAD developed very quickly and substituted the traditional pencil-paper drafting. Today is 2D CAD used mainly for making relatively simple technical drawings or for modifying drawings generated from 3D models and the 3D CAD is substituting the 2D CAD. That is because today, the digital model is a source of data in applications like virtual testing, rapid prototyping and CNC machining and there is very often no need to make technical drawings of the components.

2.1.2. 3D CAD system

3D CAD systems serve for designing 3D solid and surface digital models. The advantage is that the designer can observe the virtual model from all the angles and easily recognize its real shape. When designing some mechanism or structure, the designer can assemble the parts together by assembly tool. Each component of the assembly is defined fixed or movable. The result is an assembly, which moves in way the real assembly would. That allows the designer to inspect if the required functionality is reached. Very important is the function detecting the overlapping. The designer can immediately see which parts are colliding and in which way. So the designer can modify the parts and assemble them together again for another inspection.

2.1.3. Features of CAD systems used in mechanical engineering

There are many different 3D CAD systems available. For example Autodesk Inventor is one of them. Like the others (Pro/Engineer, SolidWorks, CATIA) it has Content Center, which simplifies the work by offering an easy access to often-used parts like bolts, nuts, bearings etc. Another feature is the creation of welded constructions. It is able to define preparation, creation and postweld operations. It is also able to provide the weldment analysis. Inventor has also other features that rapidly simplify the design of sheet metal parts and parts made of plastic. [1] In CAD systems FEM is usually implemented to help the designers with recognizing the critical points and possible mistakes in construction.

Important fact in usage of 3D systems is the combination of CAD software in with the Internet, which brings new type of designing. In 1989 for the first time was this combination (CATIA software + computers connected by a net) used for designing Boeing 777. 238 teams of engineers from all over the world were working on this huge project. Though every team solved its own task, all the data were shared and provided to other teams. Cooperation of this kind, only at smaller projects is quite common now days. [2]

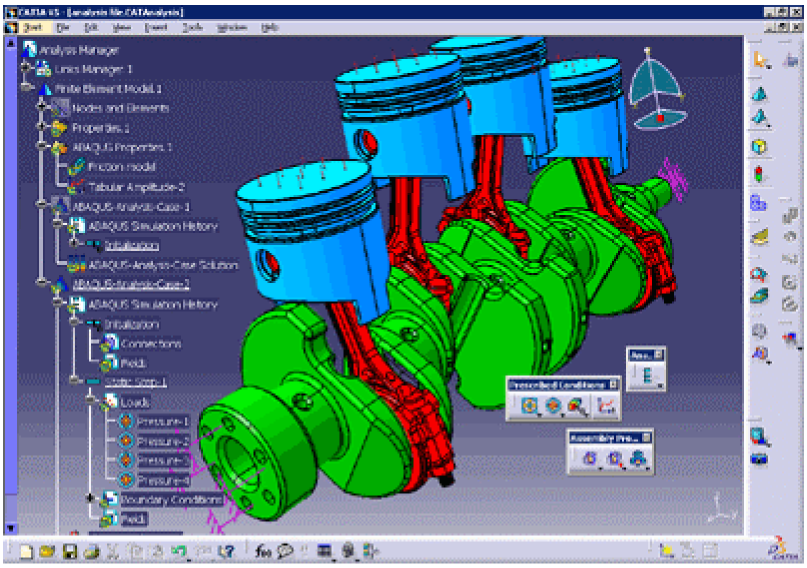

Fig. 1. Assembly of a crankshaft, piston-rods and pistons, CATIA software [3]

2.2. Computational simulations

The designer is charged with responsibility for a new component or structure development. He faces many important decisions while designing something new. The target is a component, which will be able to stand all the given claims. But the designer can’t be absolutely sure that the component is not overlarge. Today the designers have very powerful tool. The Finite Element Method (FEM) enables the constructor to verify his ideas and solutions. The FEM is able to analyze the component during the process of designing. Finite Element Method is a numerical method, which solves the system of equations describing the properties and loading of the component. Well-known FEM software are: ABAQUS, ANSYS and NASTRAN.

The principle of FEM is the mesh discretization of a continuous domain to elements. Properties of every element are described by functions. And the whole component is then described by a system of thousands or even millions equations.

2.2.1. The process of FEM analysis

The first step is to choose models of evaluating, material, loading etc. Then the geometrical model of the component has to be transferred from 3D CAD systems. The data file has to be transformed first to match the FEM software. Some of the FEM applications are integrated in CAD systems already. Then there is no problem with transformation of the file format and with the transfer. After the geometry has been transferred it has to be simplified. That means elimination of recesses, threads and small radiuses. They are unnecessary for the solution and they would extend the time of evaluation. Now these parameters have to be chosen: type of elements, material and its properties and real constants. Then are established degrees of freedom and boundary conditions. The last to be entered is information about loads (force, press and torque). Depending on result concernment is chosen the mesh relevance. Time needed for the calculation depends on mesh density, size of the analyzed component and the type of analysis. The results are presented as tables, graphs and pictures. [4]

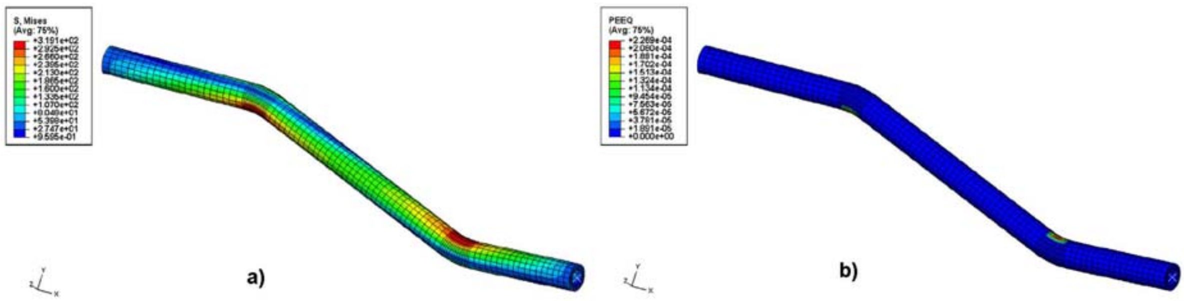

Fig: 2 Cyclically loaded steering link: a) stress distribution; b) strain distribution [5]

2.3. Rapid prototyping

Rapid prototyping is a method of making prototypes. This method can produce very complicated prototype or a model in very short time. While producing model using conventional methods like milling and turning work would cost a lot of time and money, rapid prototyping is cheap and very fast. The start point of this process is a digital 3D model. The digital model can be made by a designer on computer or by 3D scanning of an existing component. Then the output data has to be generated. The output data are sent to the device providing the construction of the solid model. The basic principle of rapid prototyping is adding material of the model layer by layer. There are three types of rapid prototyping varied by the base material.

2.3.1. Liquid based

The method is based on solidification of the liquid after being lightened by ultra violet light. The solidification process runs on the surface of the liquid. When one layer is done the table supporting the model drops down, so the model is sunk close to the surface of the liquid and another layer can be made.

2.3.2. Solid-based

Each layer is cut out of sheet material and joining of all the layers together completes the model. Another type of solid-based prototyping method melts the base material and forms the particular layer by extruding the material through a movable nozzle. After cooling down the material hardens. The material is laid on layer by layer.

2.3.3. Powder-based

This technique uses high power laser to fuse particles of base material into 3D object. The solid layer is made on the surface of a powder bed. After finishing each of the layers the powder bed lowers down by one layer thickness and the process is repeated. [6]

2.3.4. Usage of components made by rapid prototyping method

Rapid prototyping deals with wide range of materials. So if the right material is chosen the models produced by this method can be used for testing. The results of the tests are compared with FEM data. If the tests discover any mistake in design of the component, the designer modifies the digital model and new component for testing can be made in few hours.

3. Automotive component testing - types of tests

The most important types of testing:

- Tests of functionality
- Static load tests
- Fatigue (life) tests
- Vibration tests
- Wearing tests
- Environmental tests

3.1. Static load tests

Components are tested under static load to proof that the specimen can stand requested loads. This requested load is usually the maximum level of the load, which could be reached by normal use of a vehicle.

3.1.1. Static tests

The tested specimen is placed in an overload frame. This overload frame is a solid, very rigid structure, which has to be able to stand high levels of forces and torques acting in different directions and in different areas of the frame at one moment, while maintaining its shape and dimensions. Mostly used are re-configurable frames, their advantage is the possibility of an efficient setup for each tested component or a structure. The overload frame is fitted with hydraulic actuators and load distribution mechanisms operated by load control system consisted of computers with special software. Hydraulic actuators are developing the testing loads actuating to the specimen like press, tensile and torsion. The load control system also records the applied loads using load cells. In case of registration of an excessive deformation or load tracking problems, the testing device safely unloads the component. Other recorded quantity is strain scanned by strain gauges, which are attached in areas of interest.

3.1.2. Static overload testing

This test is used to simulate infrequently occurring maximum static loads which occurrence could cause damages like permanent deformation, cracks or even complete damage of the component. These maximum loads are results of unpredictable situations, overloading the vehicle or any other misuse.

Fig.3. Overload frame [7]

3.2. Fatigue (life) tests

Life tests are the most important tests provided during designing new components and after the start of their production. These tests simulate the loading affecting a component throughout its normal usage in a “real life” period. So the component is cyclically loaded with force or torque, whose levels are slightly higher then the mean values of service loads. The test is used to set the reliability and the life cycle of the specimen. Data gained from these tests are also helping in the process of designing the component. They can be used as a proof of a right choice in selecting material. The designer can also reach the optimum weight and a shape of the component, when knowing, which part of the component is able to hold out the load without a danger of failure and which is not. For the maker of the component is also not reasonable to produce a part, whose life is notably longer, than a life of a whole structure in which the component is mounted. Production of such a component means rising the price of the vehicle and could be also time-consuming. The tests provided after the start of batch production act as a control of observance of the right production technology. Since the production technology could have an outstanding influence over the nature of the component.

3.2.1. Fatigue testers

For fatigue tests are used Electro-hydraulic testers. The testers are constructed for initialization of forces from 1kN up to 100MN at frequency range from 10^{-2}Hz up to 1kHz. If the tester is equipped with an environmental chamber, then the specimen can be tested for fatigue in special conditions like an extreme temperature, high humidity, etc.

The tested component is connected to the electro-hydraulic motors so that they are affecting the component in the same way it is affected at service. The number of used hydro-motors depends on the composition of the specimen and it’s loading. While the tested component is loaded lots of data is scanned by strain gauges, like deformations, forces and stresses.

Fig.4. Fatigue testers, VW-Wolfsburg [9]

3.2.2. Variable loading

The major reason for carrying out variable amplitude loading tests is the fact that a prediction of fatigue life under this complex loading is not possible by any cumulative damage hypothesis. The fatigue life estimation can be enumerated by few different methods.

3.2.2.1 Estimation of fatigue life

For the purpose of fatigue life experiences must be gained by such tests, which allow us to derive real damage sums by comparing Woehler- and Gassner-lines, Fig. 5.

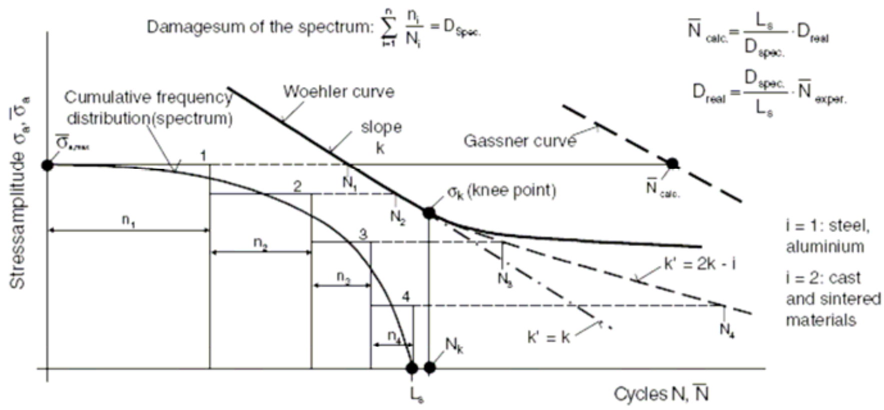

Fig.5. Modification of the Stress-Cycle curve and calculation of fatigue life [11]

Applying because of its simplicity still the mostly used Palmgren–Miner-Rule modified by Haibach, the damage content of a spectrum with the size *Ls* (sequence length) can be determined

$$\sum\left(\frac{n}{N}\right)_i = D_{spec} \quad (1)$$

n – number of tests; N – number of cycles under constant amplitude loading; D_{spec} - damage content of a spectrum

and with this value the real damage sum is calculated from the experimental results:

$$D_{real} = \frac{D_{spec}}{L_s}\overline{N}_{\exp} \quad (2)$$

D_{real} – real damage sum; D_{spec} - damage content of a spectrum; L_s – sequence length (number of cycles); N_{exp} – number of cycles under variable amplitude loading

A broad investigation on cumulative fatigue displays the scattering of the real damage sum over almost three decades, Fig. 6. About 90% of all results are below the conventionally used value *D* = 1.0, i.e. a fatigue life estimation with *D* = 1.0 is in these cases at the unsafe side.

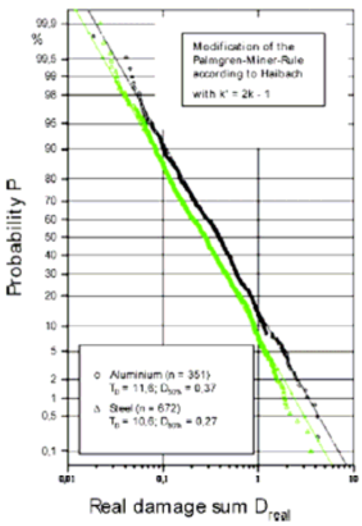

Fig. 6. Real damage sum distribution [11]

This knowledge gives the reason for usage of variable tests. These tests are important both for the investigation of cumulative behavior of components and for proving the component durability. For reasonable results an adequate load-time history must be given. Therefore the applied load-time history corresponding specifically for each tested specimen is usually gained from specimen’s service load-time histories.

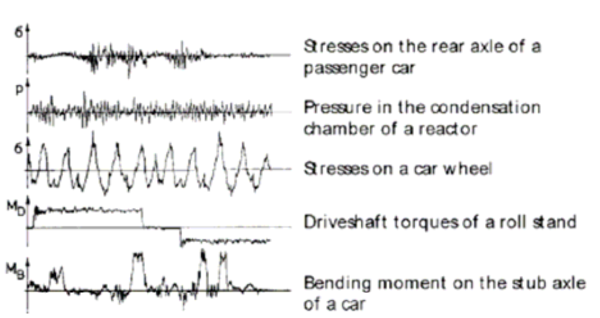

Fig. 7. Examples of load time histories [11]

For a laboratory fatigue test, the load-time history has to be edited, because of containing intervals with small amplitude cycles. These small amplitudes do not induce any damage. Therefore their simulation is pointless and they can be removed. This shortened signal then consists of only damage causing cycles. For the signal editing are used algorithms, specially designed for this purpose. These algorithms are applying the local strain parameter and linear damage rule for eliminating small amplitude cycles while retaining the original sequence of the cycles. [11]

3.2.2.2 Wavelet Bump Extraction (WBE) algorithm

The WBE algorithm is adjusted for editing the load-time history by locating the fatigue damaging events. The result of this process is a shortened mission signal. For realistic simulation stays the sequence of the load cycles unchanged.

The first stage of the algorithm decomposes the original signal into wavelet levels. That is procedure equivalent to dividing the original vibration energy among the wavelet levels. Next the wavelet groups are created. Each of them represents one frequency region. Then is calculated a trigger level for every wavelet group is. The trigger level represents a boundary between damaging and non-damaging values of stress. So the purpose of the trigger level is to identify the bump borders. Once the bumps from each wavelet group are located and can be assembled into the final mission signal. [12]

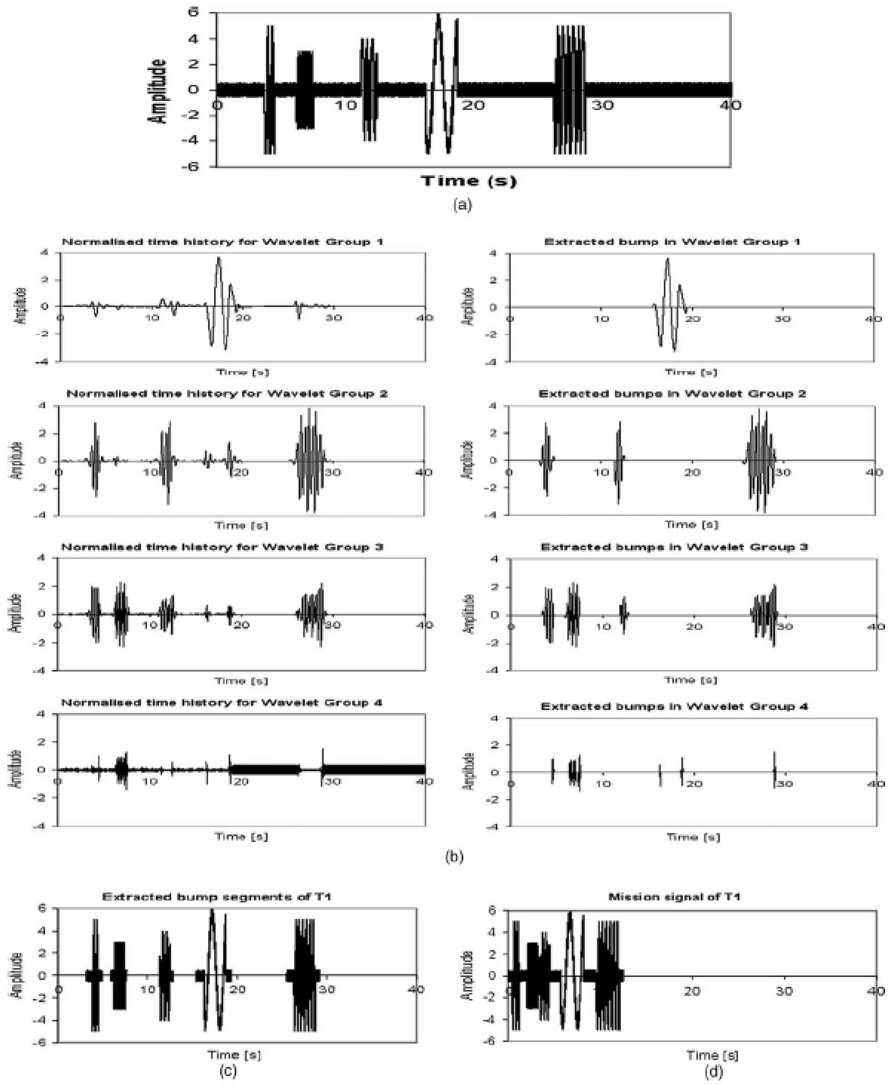

Fig. 8. a) The original time history; b) Time histories in normalized scale of the wavelet groups and the location of bumps; c) The extracted bump segments at their original time positions; d) The mission time history [12]

3.3. Vibration tests

Electric and electronic devices are the most sensitive to vibrations of all the car components. Vibrations usually cause damage to soldered joints or line wires. That’s the reason why vibration tests are mostly carried out to these devices. The tested specimen is fixed to a table of a shaker, which provides vibrations to the tested component to simulate conditions of a driven vehicle.

3.3.1. Mechanical shakers

The oldest type of shakers, which can provides frequency up to 35Hz. The direction of the movement is mainly vertical and the testing frequency is constant.

3.3.2. Electrohydraulic (servohydraulic) shakers

Electrohydraulic shakers are more sophisticated than the mechanical because the produced vibrations can be random and complex also the frequency of vibrations comes up to 200Hz.

3.3.3. Electrodynamic shakers

This type of shakers tests relatively small electronic devices and some other components. The testing frequency can reach 20,000Hz. Majority of electrodynamic vibration tests is provided as single-axis-at-a-time. That's because of satisfaction of purchasers with this kind of test.

3.3.4. Multi-axial shakers

But in real life it is nearly no single axis vibrations. Earlier were multi-axial tests provided as single-axis-at-a-time, today is required simultaneous multi-axis shaking. The reason is simple, if you provide simultaneous test with vibrations in three axes then the time will be one-third in comparison to a single-axis-at-a-time test time. Shakers used to be fabricated only very rarely as multi-axial. But the test laboratories needed to provide multi-axial vibration tests even with the lack of manufactured multi-axial shakers. This problem was solved by an assemblage of more shakers, which could carry out a simulation of multi-axial vibrations. Then the shakers can shake the load in three or even more axes. Fortunately for the test laboratories the number of multi-axial testers is growing. For most applications it its advantageous to buy a fabricated shaker than constructing one's own machine. [13]

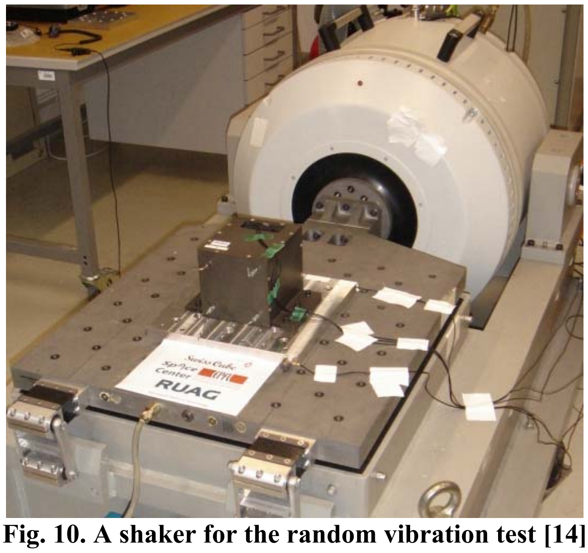

Fig. 10. A shaker for the random vibration test [14]

3.4. Wearing tests

Wearing tests are quite similar to fatigue tests. The specimen is also loaded in a way, which simulates the loading of the component in service. The difference is in monitored quantity. Wearing tests are related to changes of dimensions, geometry, amount of removed material and quality of the surface. The transfer of the load to the component is provided by the same or very similar geometry contact as if the component would be mounted to the vehicle. In case of testing a structure, the wear is monitored on it's separated parts.

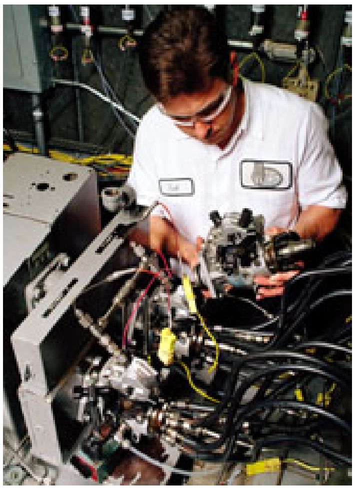

Fig. 11. Wear test of a fuel pump [15]

3.4.1. The wear mechanisms

- Surface fatigue
- Abrasion
- Adhesion

3.4.1.1. Surface fatigue

Surface fatigue is brought about by crack initiation and propagation, which might take place at the surface or in a certain distance below it. That depends on the contact situation and the microstructure of the contacting materials.

3.4.1.2. Abrasion

Abrasion is caused by a hard or sharp particles or protuberances of harder surface moving on a softer surface.

3.4.1.3. Adhesion

Adhesion is brought by friction-welded-micro-joints. Asperities of both surfaces are plastically deformed. The deformation causes heat, which results in welded-micro-joints. The joints separate in the region underneath the contact area. Thus there is material transfer between the surfaces.

3.4.2. Simple form of Archard's Law

The level of wear is diagnosed by measuring the profile of wear track and/or by the amount of removed material. For evaluation of the wear the Archard's Law can be used. Its simplest form is

$$W_n = k \cdot N_n \quad (3)$$

Wn - The amount of material removed by the wear; k - Archard's constant; Nn - normal force.

The *k* constant differs for each type of wear mechanism. [16]

3.5. Environmental tests

Because cars are machines used outside, their parts are exposed to various weather conditions, which could rapidly affect their performance. The conditions like a temperature; humidity, rain and dust levels and many others are varying from a geographical location. For example in the Czech Republic the interval of temperature is about –20˚C in winter up to 70˚C inside the car when exposed to sun. During the tests, these conditions are simulated.

3.5.1. High / Low Temperature test

High / Low Temperature test is a process in which the air surrounding a test specimen is raised or lowered to pre-determined levels. The purpose is to observe the effect of the temperature extremes on the equipment, which may be operating or non-operating. Temperature extremes and rapid temperature transitions are also used to purposely induce failures to determine weak points or latent defects.

3.5.2. Humidity test:

There are typically two types of humidity tests, condensing and non-condensing. Condensing humidity tests consist of temperature cycling in high relative humidity air. The temperature cycling induces the moisture to condense on all surfaces of the test specimen. This is an extremely severe test for electronics. Non-condensing humidity tests are run at a constant temperature, with a high relative humidity, typically higher then 95%. This test is not as severe as the condensing test because the moisture is not in liquid form. This test is much more difficult to perform because the temperature must be tightly controlled to prevent condensation at such a relative humidity.

3.5.3. Salt fog test

A salt fog test subjects test specimens to a fog of water having a high salt content. Usually 5 % sodium chloride solution (NaCl) is sprayed by the jet nozzles using compressed air saturated with humidity thus there is a fine mist evenly distributed in the testing chamber. The fall out of the fog reacts with the surface material of the specimens and cause corrosion depending on the resistance of the surface. On a regular basis the test is provided at a temperature of 30˚C.

There is a big disadvantage of this test. The salt fog test does not determinate the performance of corrosion-resistance. The specimen in salt spray chamber is exposed only to solution of sodium chloride. In service is the component exposed to variety of humidity, temperatures, etc. That means the corrosion process in salt fog chamber is different from the corrosion mechanism in real life. That means, this test can only predict the behavior of the component in service because good performance in salt fog does not guarantee good performance in service.

3.5.4. Combined environmental test

To make tests closer to real loading the combine tests were invented. These tests involve more quantities, which are changed in cycles like cold to hot, wet to dry, presence and absence of different ionic components. The results of these tests serve much better in predicting the behavior of the component in service than single environment tests. [17]

Fig. 12. Environmental chamber [18]

4. Tests acceleration

4.1. Tests acceleration advantages and benefits

The biggest benefit of accelerated tests is unambiguously time saving. The test duration is decreased due to increased stress levels. The time needed for preparations of the accelerated tests is much longer especially when providing the very first one, than the time of setting up normal tests. But by executing more and more accelerated tests and building up one's own know-how the time of preparations drops down remarkably. The reason is the difficulty of selecting the right type and level of the stresses for new component tests. And if the design of the component does not change seriously the modification of the test is quite easy because configuration of the test stays very similar.

The acceleration factor can reach 500, but such a test does not give useful information. Since the acceleration factor increases the verity of results decreases. So it is not possible to accelerate the tests so drastically, but also shorter time saving is money saving.

4.2. Principle and approach

There are two methods of accelerated tests: qualitative and quantitative, which can be provided under constant or variable loading.

4.2.1. Qualitative tests

Qualitative tests are performed mainly on small specimens. The component is exposed to a single high level of stress, to multiple stresses or to time-varying stress. If the component does not survive the test, the product's design has to be modified to eliminate the causes of failure. If the test is designed properly, then it quickly gives valuable data about the failure modes, which could appear during the service of the component. But if the test is not set up properly, then can occur mode of failure, which would not be initialized by the normal use of the component. Qualitative tests cannot give us information about the length of components life, but we get very valuable information about types of possible failures and about levels of loads we can use in quantitative tests.

4.2.2. Quantitative tests

Quantitative accelerated tests are used to quantify the life attributes of the component in normal service. The data gained from the quantity tests give us reliability information like estimation of the probability of failure of the product and mean life under normal use conditions. [19]

4.2.3. Time-independent/dependent loading

The not accelerated tests are provided with constant or variable loads and so are the accelerated ones. For accelerated tests can also be used time-independent or time-dependent loading.

4.2.3.1. Time independent load

Constant stress tests are much easier to be provided. The quantification of constant stress test is also easier. Models for analyzing the data already exist and they are empirically verified. Extrapolation from a constant stress test is more accurate than extrapolation from a time-dependent stress test.

4.2.3.2. Time-dependent load

During the time-dependent tests the level of stress is changing with time. And if the component is affected by varying load the failures occur more quickly. There are four basic models of time varying loads. The first one is step-stress model. The stress load remains constant for a period of time and then it steps to a different stress level where it remains constant for another time interval until next step. The ramp-stress model is very similar. The difference is that when the stress is changing to another level it follows a linear function. Other models are simple constantly increasing function and completely time-dependent stress model.

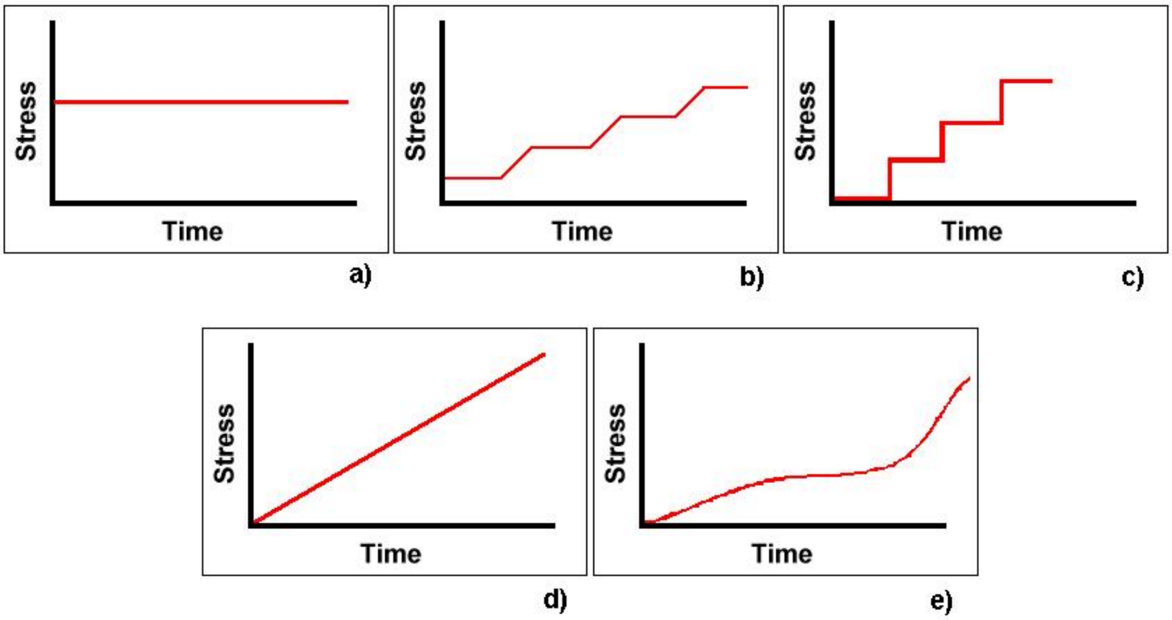

Fig. 13. Graphical representation of: a) constant loading; b) ramp-stress model; c) step-stress model, d) constantly increasing stress model; completely time-dependent stress model [20]

4.3. ALTA

ALTA is probably the most complex software to be used for accelerated tests. The software is equipped with many mathematical models and is able to analyze test data with up to 8 simultaneous stresses. ALTA was designed for quantitative accelerated tests and provides many features

4.3.1. Life-stress models

The spreadsheets support complete and also censored data with up to 8 stress types and data sets can be randomly generated. It also gives a choice of these life-stress models:

Arrhenius: a single stress model that is typically used for the analysis of data from temperature tests.

Eyring: a single stress model that is typically used for the analysis of data from temperature or humidity tests.

Inverse Power Law: a single stress model that is typically used for the analysis of data from tests with non-thermal stresses, such as vibration, voltage or temperature cycling.

Temperature-Humidity: a variation of the Eyring relationship that can be used for the analysis of data from temperature and humidity tests.

Temperature-Nonthermal: a combination of the Arrhenius and IPL relationships that can be used for the analysis of data from tests with two stresses, such as temperature and voltage.

Generalized Eyring: used when temperature and a second non-thermal stress (typically voltage) are the acceleration variables.

Proportional Hazards: analyzes data with up to 8 stress types using the exponential relation. It also allows the use of zero as a stress value, which enables the analysis of data with indicator variables (e.g. on/off or continuous operation).

General Log-Linear: the most general model, which supports the analysis of data with up to 8 stress types and provides the flexibility of specifying the life-stress relation for each stress (such as Arrhenius and Inverse Power) with the use of transformations.

Cumulative Damage: analyzes data with stresses that vary with time. The model now supports multiple time-dependent stresses. [21]

4.3.2. Result data generated by ALTA

After defining the level of stress, which will be affecting the component in service, ALTA calculates the results like acceleration factor, reliability given time, mean life, etc. Naturally it is possible to make transparent plots representing the results of the test. Another very useful function of this software is the test planning utility. Using mathematical models designs ALTA an effective accelerated test by assessing the stress type, method of applying stress, stress levels, number of tested components and a life-stress model.

4.4. An Example of ALTA usage – Automotive Part Test

Within the propagation of ReliaSoft Corporation’s product ALTA published the company examples of the software applications. One of the examples is an accelerated test of automotive part. I am using this example without any changes because it is described briefly and appositely. [22]

Background

Consider a test in which multiple stresses are applied simultaneously to a particular automotive part in order to precipitate failures more quickly than they would occur under normal use conditions. The engineers responsible for the test are able to quantify the combination of applied stresses in terms of a "percentage stress" as compared to typical stress levels (or assumed field conditions). In this scenario, the typical stress (field or use stress) is defined as 100% and any combination of the test stresses is quantified as a percentage over the typical stress. For example, if the combination of stresses on test is determined to be two times higher than typical conditions, then the stress on test is said to be at 200%.

The test is set up and run as a step-stress test (i.e. the stresses are increased in a stepwise fashion) and the time on test is measured in hours. The step-stress profile used is as follows: until 200 hours, the equivalent applied stress is 125%; from 200 to 300 hrs, it is 175%; from 300 to 350 hrs, it is 200% and from 350 to 375 hrs, it is 250%. The test is terminated after 375 hours and any units that are still running after that point are right-censored (suspended). Additionally, and based on prior analysis/knowledge, the engineers also state that each hour on test under normal use conditions (i.e. at 100% stress measure) is equivalent to approximately 100 miles of normal driving.

Experiment and Data

The test is conducted and the following times-to-failure and times-to-suspension under the stated step-stress profile are observed (note that XXX + indicates a non-failed unit, i.e. suspension): 252, 280, 320, 328, 335, 354, 361, 362, 368, 375+, 375+, 375+ hr.

After performing failure analysis on the failed parts, it is determined that the failure that occurred at 328 hrs is due to mechanisms other than the ones considered. That data point is therefore identified as a suspension in the current analysis. The modified data set for this analysis is: 252, 280, 320, 328 +, 335, 354, 361, 362, 368, 375 +, 375+, 375+ hr.

The test objective is to estimate the life for the part (i.e. time at which reliability is equal to 99%) at the typical operating conditions.

Analysis

Step 1: Utilizing ALTA 7 PRO, the analyst first creates a new Standard Folio for non-grouped time-to-failure and time-to-suspension data, using "Other" as the stress type and entering 100 as the use stress, and then defines the Stress Profile.

Step 2: Once the profile is defined, the analyst selects the cumulative damage life-stress model (to use a time-varying stress) and the Weibull distribution then selects the Logarithmic (Power LSR) transformation (since the effect of the stress was deemed to be mechanical and more appropriately modeled by a power function) in the Stress Transformation window. The analyst then enters the observed times, their state and a reference to the profile used in the ALTA Data Folio.

Step 3: There are several methods available to ascertain adequacy of fit, including residual plots and use level probability plots, as shown in Fig. 14.

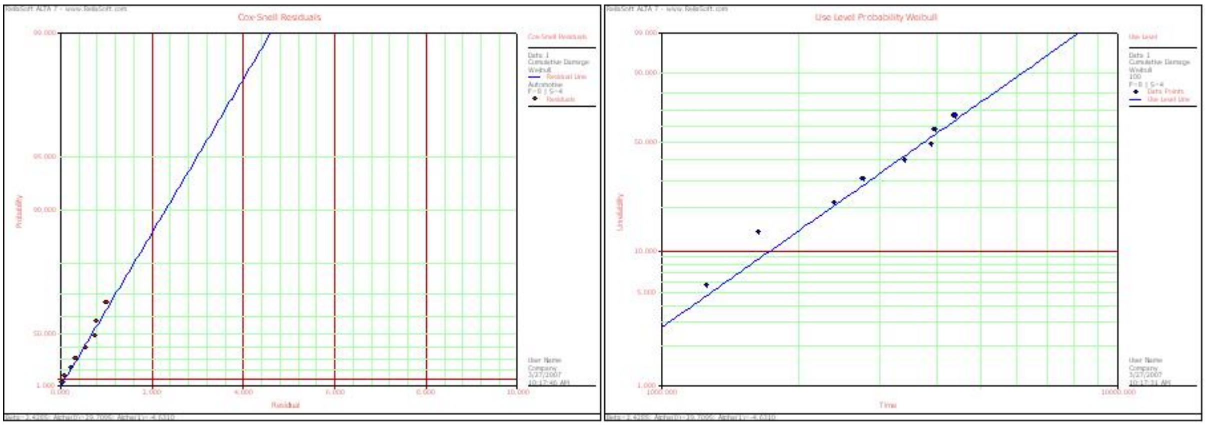

Fig. 14. Residual plots [22]

Step 4: The last part remaining is to determine the B(1) life at the part's use stress level. Using the QCP, the B(1) life is found to be 657 hours. Based on the given multiplier, the B(1) life in miles would then be 657 test-hr*100 (miles/test-hr)= 65,700 miles.

5. Conclusion

This thesis brings an overview of the main types of tests used in automobile industry and their brief description. The purpose of tests is to prove the durability and functionality of the components. The importance of the component testing is represented by a lack of information about types of tests, their setups and equipment providing the tests. For every car company is important to keep bringing new solutions and technologies, because the development in car industry is progressing very quickly. Every delay can cost the position in the market. Therefore all the companies are developing and improving not only their products but also the test techniques. Any success means being ahead of competition and is highly kept as a secret. Because many tests take quite a long time, it is desired to eliminate the test times or even eliminate the number of tests. The first case is solved by accelerated tests. Their providing is not easy and need some experience, especially the setting of the test and evaluation of the results. The reduction of a number of the tests can be realized by using the special software. FEM enables the designers to discover defects of design solution forestall even before the prototype is made. All these procedures help to decrease the time to market and the expenses. And that is what is it all about.

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7. Index of used abbreviations and symbols

2D		Two Dimensional
3D		Three Dimensional
B(1)		Part's life at the use stress level
CAD		Computer Aid Design
D_{real}	[-]	Real Damage Sum
D_{spec}	[-]	Damage content of a spectrum
FEM		Finite Element Method
k	$[mm^3 \cdot N^{-1}]$	Archard's Constant
L_s	[-]	Sequence Length

n	[-]	Number of Tests
N	[-]	Number of cycles under constant amplitude loading
N_{exp}	[-]	Number of cycles under variable amplitude loading
Nn	[N]	Normal Force
WBE		Wavelet Bump Extraction
Wn	[mm^3]	The Amount of Material Removed by Wear