REVIEW OF CURRENT STATE OF KNOWLEDGE ON DURABILITY TESTS PERFORMED ON ELECTROMAGNETIC SHAKERS

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Summary

This work provides an overview of the research, which uses electromagnetic shakers for durability tests. The application spectrum is relatively wide as the variety of sample components is large. Such research are carried out for the needs of many industries from automotive, heavy industry to the aerospace industry. Element of the research may be representative geometry or the real component. Interesting examples are the studies carried out on samples loaded with extra weight or fatigue tests of flare dispenser on AH-1W helicopter. The use of electromagnetic shakers for fatigue tests operative to derive results a much larger ranges of cycles (above 10^9) while reducing test time. Moreover, the possibility of testing real components cannot be overestimated, since it reduces the errors associated with the simplification of the geometry.

Keywords: fatigue tests, state of the art, electromagnetic shakers, frequency domain

PRZEGLĄD AKTUALNEGO STANU WIEDZY Z ZAKRESU BADAŃ TRWAŁOŚCIOWYCH REALIZOWANYCH NA WZBUDNIKACH ELEKTROMAGNETYCZNYCH

Streszczenie

Niniejsza praca stanowi przegląd badań, które wykorzystują wzbudniki elektromagnetyczne do wyznaczania trwałości zmęczeniowej. Spektrum aplikacji tej metody jest stosunkowo szerokie, tak jak różnorodność elementów poddawanych takim testom. Badania te są prowadzone na potrzeby wielu branż od przemysłu motoryzacyjnego, przemysłu ciężkiego do przemysłu lotniczego. Elementem badań może być geometria reprezentatywna dla danego układu lub rzeczywisty element maszyny. Ciekawym przykładem są badania przeprowadzone na próbkach obciążonych dodatkową masą lub badania dotyczące poziomu trwałości systemu obronnego śmigłowca wojskowego AH-1W. Zastosowanie wzbudników elektromagnetycznych do realizacji badań zmęczeniowych umożliwia uzyskiwanie wyników dla znacznie większej liczby cykli (ponad 10^9 cykli), jednocześnie zmniejszając czas trwania badania. Co więcej, możliwość testowania rzeczywistych elementów jest nie do przecenienia, ponieważ redukuje błędy związane z uproszczenia geometrii.

Słowa kluczowe: badania zmęczeniowe, obecny stan wiedzy, wzbudniki elektromagnetyczne, dziedzina częstotliwości

1. INTRODUCTION

Development of techniques for determining the fatigue life occurs with the development of industry and new manufacturing techniques, because the operational performance of machines and equipment are moved towards critical values. Particular attention should be given to the computation time, which in the case of complex systems is long. Therefore methods are being developed which do not require carrying out complex calculations in the time domain - are becoming increasingly popular computational methods in the frequency domain [1] - [4]. The use of electromagnetic shakers in place of the traditional testing machines takes place in the automotive, heavy machinery industry, energy industry, transport and aerospace industry.

Tests carried out using electromagnetic shakers has the ability to conduct tests on the actual structural elements - which in the case of traditional tests is not possible. The use of a properly prepared handle allows you to test any geometry - the only limitation is the excited mass of the system (depending on the size of the inductor). Standard equipment of measuring stand should also include control and generating devices an input signal and accelerometers placed on the analysed geometry. Control of such defined measurement system should be carried out in a feedback loop to ensure constant load conditions. Sample solution was proposed by Abdullah in his work [5].

Electrodynamics system are also a component of some commercial test systems used for typical fatigue tests on laboratory specimens. Such as the MTS machine Tytron 250 enables testing under dynamic and static loading conditions a wide range of materials and also simple components. A particular area of research carried out at the MTS machines: Tytron 250 and Acumen devices for bio-medical materials and medical equipment. The main advantage of this solution is the possibility to carry out tests in higher frequencies. But in respect of servo hydraulic machines such kind of equipment have less power.

The use of this type of testing systems have advantages. First of all, there is the possibility of the direct numerical simulation comparison with the result of the experiment. Verification of computational model is simplified, moreover, identification of the appearance of fatigue damage can be performed on the finished element before putting it into exploitation - is reduced in this way the possibility of failure, which has great significance in aerospace industry in case of significant from the point of view of safety components.

On the shakers are implemented basic tests on standard and customized samples. In the literature was described by Ghielmetti in [6] an example implementation of the standard fatigue tests based on the stand of the electromagnetic exciter being applied to the source of the excitation forces.

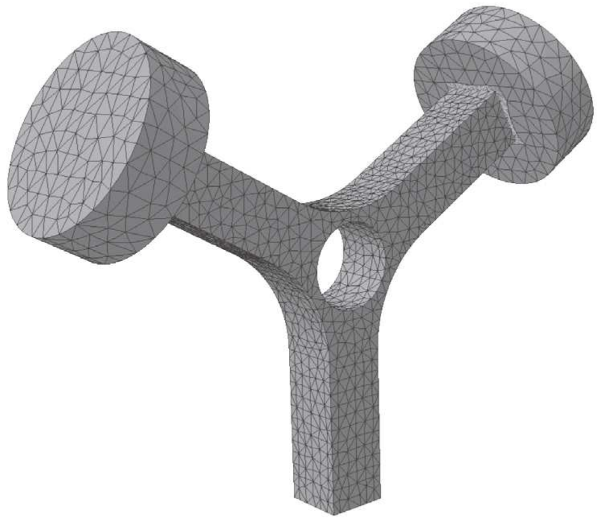

Fig. 1. Numerical model of specimen used by Česnik et al. [7]

Moreover, electromagnetic shakers are used in the dynamic analyses examined elements - determining the frequency response of the analysed systems and resonant frequencies. Practically throughout every industry such tests are performed. Starting from the automotive industry to the high-tech industry.

2. DURABILITY TESTS PERFORMED ON ELECTROMAGNETIC SHAKERS

As can be appreciated parts of equipment and machinery during the service life are subjected to loads varying in time of the random type. Fatigue testing of actual structural components are the domain resorts strongly cooperating with the industry. The main issue under consideration is to assess the durability test components of machines and equipment subject to this type of load. Such a signal can be interpreted as a sine wave with an amplitude variable in time.

2.1 DURABILITY TESTS IN AUTOMOTIVE ON HEAVY GROUND VEHICLES AND TRANSPORTATION

The phenomenon of fatigue is common among ground vehicles. Vehicles composed of a plurality of components that generate vibration, moreover, move along over uneven surfaces which further introduces a random multiaxial load to the loads generated by the rotating parts of the engine and the vibrations coming from the associated components [8].

In [3] Nguyen presented a method for determining the fatigue life in the frequency domain using a multi-factor Monte Carlo simulation. The conversion history of a random load on the distribution of power spectral density function of load leads to a significant increase in computational efficiency with respect to the calculation carried out in the time domain.

Fatigue tests were performed using the test excitation geometry and the course of the load as shown in Fig. 2. For the verification the described calculation algorithm. Method Monte Carlo Simulation (MCS) based on Palgren-Miner hypothesis provides results with the best correlation with the data from the experiment. Conventional spectral methods (Dirlik [2]) are five times more conservative than the MCS method.

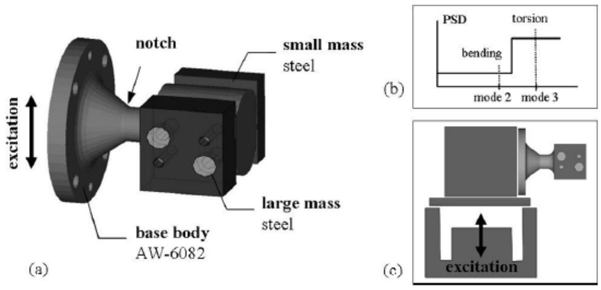

Fig. 2. (a) Demonstrator, (b) PSD load spectrum, (c) Experimental setup [3]

Fatigue damage in ground vehicles are a frequent cause of failure. Damage are subject not only elements of active suspension or engine rotating parts due to the load which they are subjected. An important problem is the failure of lead acid batteries, which are created during service life of the vehicle. These damages are damages fatigue. This problem is widely described in [9], where the authors have analysed cause of a failures.

Fatigue tests were not focused to determine the durability given in the number of cycles or during exploitation time. Were focused whereas on identifying spots of damage within the lead-acid battery. The tests were performed using the extortion in three directions on the shaker Electrodynamic Vibration System SD-2200-9/DA-10 (Fig. 3). Shaker has the possibility to change his position - vertical and horizontal position in which it is possible to implement extortion in the x and y direction.


Fig. 3. View of the Electrodynamic Vibration System [9]

Was adopted in attempt constant oscillation frequency - 16.7 Hz and amplitude of vibration at the level of 4mm. In addition, the battery for 20h was periodically switched current of 3.75 A. Tests lasted until the tension. The test was stopped when the voltage reading across the battery terminals reached zero. Localized was formation of cracks place, it occurs on the border of the mechanical connections (Fig. 4).

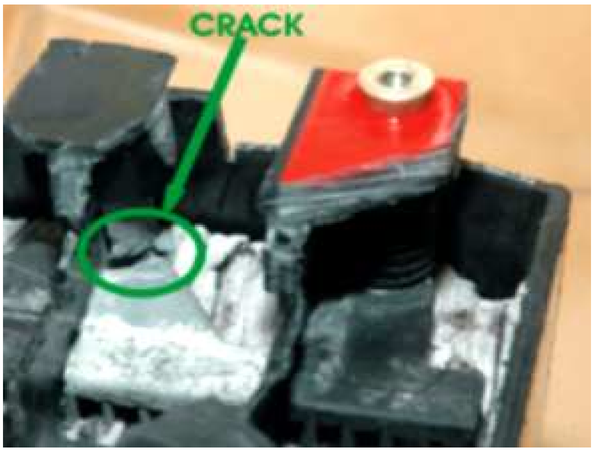

Fig. 4. View of damaged battery without lid [9]

In this paper Shafiullah [10] has been widely described approach using cantilever beam which is part of the reference for fatigue tests using elements of ground vehicles, which was designed to confirm the calculation methodology developed. In this paper Shafiullah applied exciter rather than hydraulic the electromagnetic. Developed substitute geometry should be characterized by a number of factors: the corresponding natural frequency (7.25 Hz), which is characteristic for ground vehicle suspension systems. Furthermore, geometry test should have a low tendency to vibrate in the transverse directions - because of the manner of excitation. Developed substitute beam has been presented in Fig. 5.

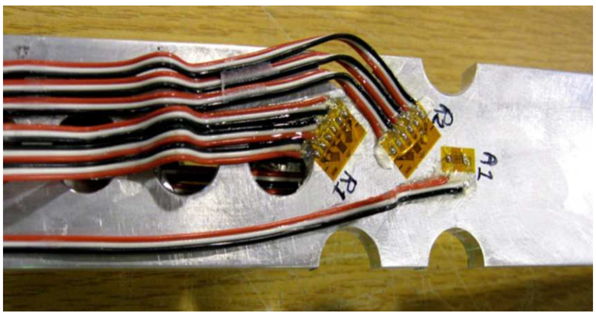
Fig. 5. Attached strain gauges and their locations at the designed beam [10]

2.2 FATIGUE TESTS PERFORMED FOR AERONAUTIC AND AEROSPACE INDUSTRY

Elements of gas turbine engines that are in a rotating motion are particularly vulnerable to high-cycle fatigue caused by dynamic forces caused by vibration as a consequence of the movement of the rotor with high rotational speed. The additional loading is generated by the flowing air stream through the engine. Failures of any high speed rotary elements (jet engines rotors, etc.), may be highly dangerous in its consequences for passengers, flight crew and equipment in the area of failure, for this reason should be reduced the possibility of their occurrence during the service life.

For fatigue test can also be used a real object. In particular, in the aerospace industry, where tested are small, but important parts, such as blades of gas turbine engines. It is also conducting fatigue tests on components of a much larger size. This is conditioned only by the size of the shaker and adequately realized data acquisition.

Witek in his works [11], [12] comprehensively took issue with the determination of fatigue crack initiation and fatigue life estimation of the compression section of the blades in the turbine engine. The most important from the point of view of this paper is the experimental approach implemented by Witek fatigue tests. As an active element of the measuring system was used the electromagnetic exciter with a specially prepared mounting bracket that allows adequate attachment of the blades. The measurement system and crack front described by Witek shown in Fig. 6 and Fig. 7. Before starting the fatigue test was carried out identification of the resonance frequencies (for transverse vibrations) in order to this value for begin frequency fatigue test. The research was carried out at a controlled amplitude using an optical microscope. The intensity of vibration given by the shaker moving head was variable in the range of 5-25g.

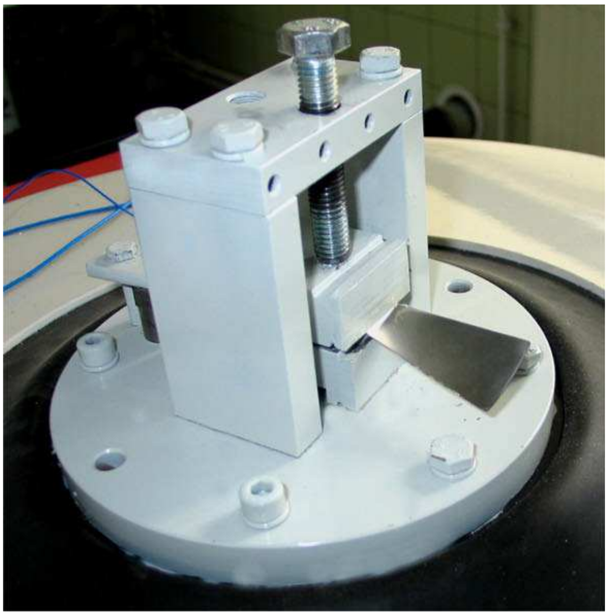

Fig. 6. View of the blade mounted on the movable head of the shaker [11]

Glued structural connectors are widely used in aerospace, automotive and in the civil engineering, mainly due to their high fatigue strength in comparison with other mechanical connecting elements joining methods, such as riveting and welding.

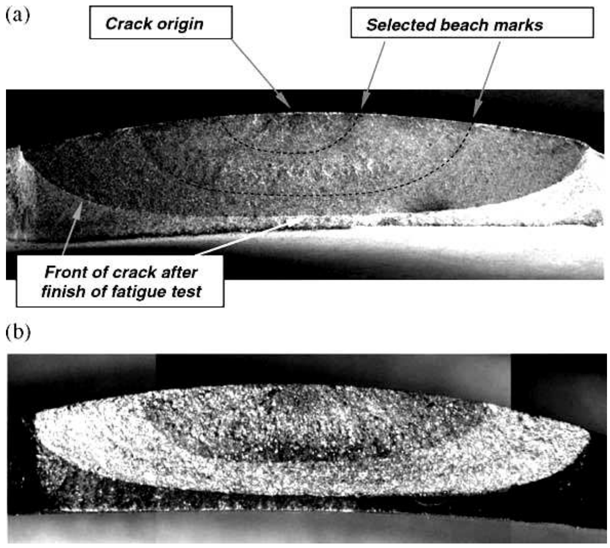

Fig. 7. Shape of crack front in advanced phase of fatigue (8x 10^5 cycles), (a) optical view (b) microscope view [11]

Elements of this type are also characterized by a predominance of the design and manufacturing process. However, fatigue damage in this type of connections is a topic that requires a better understanding. Du and Shi in [13] propose solution that uses the electromagnetic exciter with appropriately designed mounting bracket for enabling fatigue testing multiple joints at the same time which significantly reduced the duration of fatigue tests. Diagram of the apparatus for performing vibration fatigue testing of glued joints samples shows Fig. 8.

Fig. 8. View of the blade mounted on the movable head of the shaker [13]

The measurement system presented above is symmetric, uses two electromagnetic shakers. Between them is a fixed assembly tower, to which samples are augmented at a depth of 10mm at a connection portion of the steel, analogy part of aluminium connection is fixed on an additional element for achieving the vibrations through the shaker. Characteristic of the measuring system provides for application forcing vibration in a direction perpendicular to the connecting layer.

As presented in paper [14] an element with considerable dimensions - the system of military helicopter rocket launchers - can be fully subjected to the fatigue tests. This is conditioned only by the size of the shaker and adequately realized data acquisition, which will allow the determination of the fatigue life at various locations of analysed structure (Fig. 9). To define problem in such a manner is not possible to use the representative geometry or the samples for the estimation of the fatigue life. The complexity of the shape and the loads that is the element subjected to practically excludes any other method of the research, which would not introduce significant simplifications.

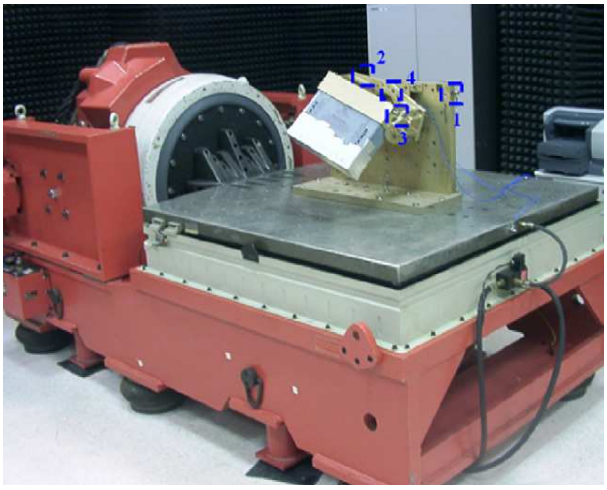

Fig. 9. Fatigue testing of the Chaff/Flare dispenser bracket (x-axis) [14]

The design of the bracket must meet a number of requirements would qualify it as safe. Predominantly takes fatigue analysis but also considers the problem of taking into account the static and modal analysis. The study takes into account the dynamic load characteristics of the helicopter coming from the harmonic components generated by the rotor and the general broadband spectrum random loadings resulting from aerodynamics and resonance of the entire system.

2.3 OTHERS APPLICATIONS

The fatigue tests which are based on electromagnetic shakers are often carried out tests on various geometries. In addition to the individual applications prepared samples can also be loaded with additional mass as is the case in [3], [5], [7], [15]. In these works presented studies which analysed geometrically differentiated samples have been additionally loaded by additive mass. This load is added to generate the desired load condition - close to the real situation or to lower the resonant frequency of the system.

The most widespread fatigue tests using electromagnetic shakers are performing bending fatigue tests, as this is a natural consequence of the uniaxial movements work shakers. You can meet studies, such as Ghielmetti [6], which describes are designed and constructed an innovative positions performing fatigue tests. Ghielmetti described the position based on the electromagnetic shaker equipped with a platform acts as a mounting platform for the tested samples. This position performs research in bending (Fig. 10). In this work are used by the ASTM standardized sample, however, samples may be used practically any shape. The shape is conditioned only purpose of the study and used / available mounting bracket.

Fig. 10. Fatigue test stand developed by Ghelimetti [6]

Possibility of conducting tests in the field of high-cycle (10^4 <n <10^8) and even giga-cycles (n> 10^9 cycles) in the range of resonance frequencies allows the completion of attempt within a few hours what compared to tens of hours when utilizing conventional machines fatigue is very good result. George [16] in his work shows the methodology for conducting fatigue tests for flat samples (Fig. 11). Were taken in this study also attempts to determine the shape of the flat sample to be able to achieve uniaxial and biaxial stress state by applying to the resonant frequency.

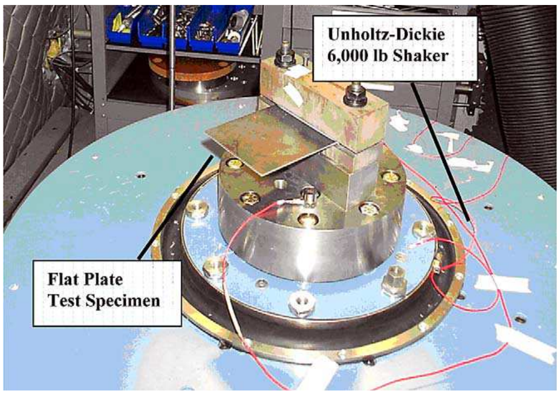

Fig. 11. Experimental set-up presented by George in [16]

This method allows for the detection of fatigue cracks in the test specimen before the crack propagation phase of the material by observation of the sample changes the resonance frequency. This fact can be used by a researcher, whose interests are the mechanisms of initiation and propagation of fatigue cracks.

Česnik in his works [7] and [17] has been described in detail and carefully conducted tests on unusual samples (Fig. 12) Y-shaped additionally loaded at the free ends of the rings involving an additional mass of the system. This procedure results in extending the inertia in the system under study and results, among others and reduction in the resonance frequency when using discs of different weights and / or other shapes and placing the multi-axis stress state. Shaped in such a way sample has a characteristic stress concentrations points where expected to obtain a fatigue crack.

Fig. 12. Experimental specimen and holdere presented by Česnik in [17]

An interesting work that differs significantly thematically from other described ways to use electromagnetic shakers is Yu work [18]. The author presents research aimed at determining the fatigue life of electronic components subjected to excitations vibrational. durability was determined to the point of failure of electronic circuits connected in series. In addition, data were collected concerning the conduct of load from accelerometers placed on the shaker and of the specimen. The matter under consideration is important because during production, transportation and operation of electronic component are subjected to oscillations and vibrations. In particular, the components used in the automotive industry. The method of conducting tests described by Yu shows Fig. 13.

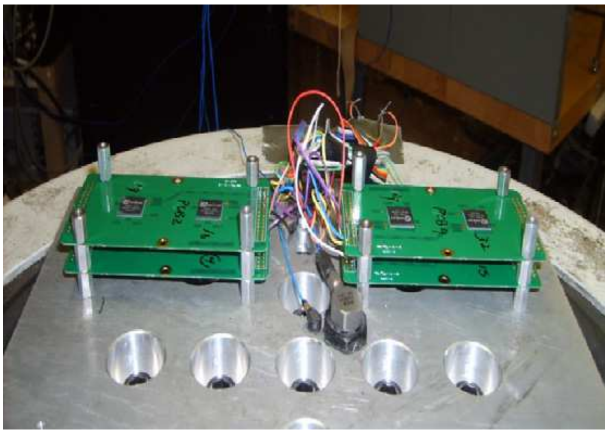

Fig. 13. Experimental set-up presented by Yu in [18]

3. CONCLUSIONS

The variety of scientific disciplines and industrial applications based on the utilization of electromagnetic shakers for cognitive and utilitarian demonstrate that a very good alternative for fatigue tests carried out in the traditional manner. It should be noted at this point that the machines with servo-hydraulic drive and using electromagnetic inductors have some limitations. There is a range of applications, where it is possible to use both types of machines. Testing at high frequencies - greater than 100 Hz - and in the area of the resonance frequencies of the test system is the domain of electrodynamic shakers. In contrast, research that require large displacements and forces are still the domain of hydraulic systems. It can be concluded that electromagnetic shakers will be applied to more and more applications. Construction measurement systems comes down largely to the development of the mounting bracket allows the correct realization of the planned research.

Geometry that can be subjected to fatigue tests on shakers as shown by the examples cited in the work with practically no restrictions (apart from those resulting from the limitations of hardware - the size of shaker and measuring system accessories). Frequently used additional loading elements introduce the test geometry and desired state of deformation changes the frequency range for which resonance occurs towards lower values.

The undeniable advantages resulting from the application of this approach to the study of fatigue combined to the conduct of calculations in the frequency domain is determined to improve the computational efficiency with respect to the corresponding calculation carried out in the time domain. This is due to the great reduction in the amount of input data that must be processed. This is used to transform the history of the load to form a spectral density function of load using the Fourier transform of the autocorrelation function of the load signal [4], [19], [20].

Electromagnetic shakers enable the implementation of actual elements of the tests what have been widely described in various examples in the literature. The use of multi-shaker systems further enhances the research potential for complex mechanical systems and oversized elements in areas such as automotive and aerospace industry such as tests of complete aircraft wings, self-supporting body vehicles.

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