Article citation info:
KOSOBUDZKI M. The use of acceleration signal in modeling proces of loading an element of underframe of high mobility wheeled vehicle. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2014; 16 (4): 595–599.

Mariusz KOSOBUDZKI

THE USE OF ACCELERATION SIGNAL IN MODELING PROCES OF LOADING AN ELEMENT OF UNDERFRAME OF HIGH MOBILITY WHEELED VEHICLE

WYKORZYSTANIE SYGNAŁU PRZYSPIESZENIA DO MODELOWANIA OBCIĄŻENIA ELEMENTU USTROJU NOŚNEGO POJAZDU KOŁOWEGO WYSOKIEJ MOBILNOŚCI*

High mobility wheeled vehicles have been built with use materials with limited strength and durability. Usually total costs in life cycle of this kind of technical systems are significant, so the necessity of planning proper way of maintenance is highly desirable. Common ways of describing ultimate work capacity are based on profile ground tests (PT tests) and extrapolation of theirs results for the whole period of maintenance. That methods give biased results caused by among others differences in use and maintenance conditions. The useful methods in permanent tracking of state changes of critical units of vehicle have been exploring and algorithms to forecast the durability of vehicle that are the basis of pHUMS have been designed [11]. In the paper models that have been use to describe the way of loading in frequency domain were presented and a proposal of the new model for tracking a loading of an element of underframe of high mobility wheeled vehicle was proposed.

Keywords: *high mobility wheeled vehicle, maintenance potential, acceleration signal, pHUMS.*

Pojazdy, w tym pojazdy wysokiej mobilności budowane są z materiałów, które mają ograniczoną wytrzymałość. Często koszty cyklu życia takich pojazdów są bardzo wysokie, stąd pojawia się szczególna potrzeba planowania racjonalnej eksploatacji takich obiektów. Powszechnie stosowane metody badawcze wyznaczające docelowy zasób pracy opierają się na przyspieszonych badaniach przebiegowych i ekstrapolacji wyników na cały przewidywany okres eksploatacji. Metody takie są obarczone jednak błędami, wynikającymi między innymi z różnicy warunków prowadzenia badań przebiegowych od rzeczywistych warunków eksploatacji. Poszukiwane są metody ciągłego śledzenia zmian wytrzymałości zespołów krytycznych oraz podejmowane są próby opracowania algorytmów wykorzystywanych do prognozowania trwałości pojazdu będące podstawą systemów pHUMS. W artykule przedstawiono przegląd modeli stosowanych do opisu przebiegu obciążenia w dziedzinie częstotliwości oraz przedstawiono autorską metodę śledzenia rzeczywistych warunków eksploatacji wraz z wynikami prognozowania trwałości wybranego elementu ustroju nośnego pojazdu wysokiej mobilności.

Słowa kluczowe: *pojazd kołowy wysokiej mobilności, potencjał eksploatacyjny, pHUMS.*

Introduction

Carrying out diagnostic of technical system on a basic level before use it there is a common task for every one user. In many enterprises and organization there is an obligation encompassed in law regulations [33]. Permanently carrying out diagnostic of technical system with proper use it has a significant positive influence on a safety of maintenance system [12] and on a durability assumed in life cycle [13]. The next important condition there is a conformity of assumed maintenance requirements with real, what allows to achieve expected service life for which work capacity reaches threshold value, what was presented in the picture 1.

If a real maintenance conditions are in conformity with assumed one technical system achieves forecasted and declared work capacity (curve 1 in the picture 1). If a real maintenance conditions are unfortunately more severe the system do not achieves declared work capacity (curve 3 in the picture 1). Otherwise, if a real maintenance conditions are not harsh the system's work capacity is exceeded (curve 2 in the picture 1). The assessment of assumed and real lost of maintenance potential is carried out with use e.g. diagnostics procedures. This is one of reasons that development of diagnostics tools and knowledge is desirable to be broadened. So, the on-board diagnostic systems are used more and more often.

Additionally, in case of usage the military vehicles methods that would allowed to track the level of lost of maintenance potential within

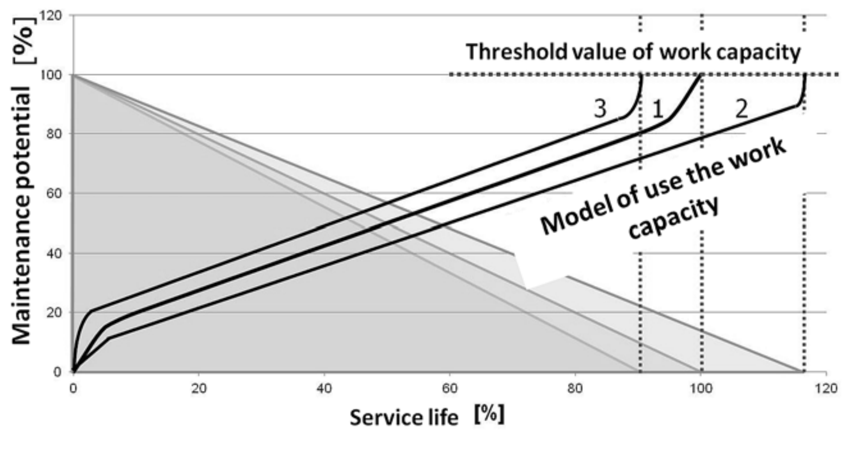

Fig. 1. Linear model of lost of maintenance potential

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** approved maintenance model are desirable with assumption that high level of residual work capacity increases generally reliability and availability of a vehicle. Today the measure of this potential there is mileage and year of production [13]. The basis of valuation the value of total work capacity of a vehicle are profile ground tests. That tests should modeled the future maintenance conditions in the best possible way [15, 25]. In case of military track vehicles the modeled usage conditions are well correlated with real (this kind of vehicles have been used mainly on a training grounds). In case of military wheeled vehicles differences are significant [27]. The influence on that comes from many sources, e.g. length of chosen sort of roads, velocity of drive in comparison to real maintenance conditions. The largest vehicle manufacturers have been carried out their own tests on parametric profile ground tests, where road sections are normalized [21]. Still the up to date problem is how to track permanently drive conditions and assess their influence on the lost of maintenance potential of the vehicle.

In military because of tactics reasons methods to acquire, gather and convert data that would allowed to assumed with some probabilistic level if a vehicles selected to march from position A to B are able to accomplish the task (e.g. pHUMS as an element of Battlefield Management System). In other words if a vehicle will reach the destination (the risk of battlefield damages are not taken into calculations). Now this kind of systems dedicated for military wheeled vehicles to track the real road conditions and offer a list of the most reliable vehicle are in progress (e.g. in USA and UK). Unfortunately, published information in this subject is very few. There is known system (e.g. SoMat eDAQ from nCode International) that could be used for infantry fighting vehicle STRYKER (this is an example of vehicle with very high battlefield value that could not be substituted by different one). In this case mathematical model of the system was not published.

According to the norm [21] a vehicle is treated as a complex oscillating object which analysis is a very difficult task in the whole. So, the analysis have been reduced to point a critical elements of a vehicle and to established theirs threshold values of work capacity. If values are exceeded the vehicle should be withdrawn from maintenance system.

After carried out the mentioned above decomposition of a vehicle the one of the most loaded elements is the underframe [29]. Taking into consideration the published information about the way of reacting the underframe on forces coming from road conditions [16, 27], the highest strain in its elements are caused by its torsion. What is more, the torsional flexibility of an underframe is more significant than its bending flexibility. That leads to the conclusion that the underframe of high mobility wheeled vehicle should be a high enough fatigue strength. In the paper the way of assessment the lost of maintenance potential restricted to only one element of underframe of high mobility wheeled vehicle is presented. This element was treated as an reference one.

2. Modeling the loading of underframe

Modeling the way of loading an mechanical system taking into consideration its fatigue strength if loaded randomly could be divided into two main groups of methods. The first one is focused on calculating cycles of loading to create e.g. histogram of amplitude of stress (strain) [4, 7, 18, 19, 20, 32]. The second one uses statistic parameters approximated with use a power probability density function of loading (e.g. of displacement, velocity or acceleration) [3, 4, 20, 31, 32].

2.1. Model of analyzing the load in time domain

If the loading is stationary and known in advance (e.g. parametric profile ground test) for load modeling various methods of counting amplitudes of a load could be used what correspond to strain or stress. The best known methods are as follow [8, 32]:

One-parameter methods:

– Level Crossing Counting,
– Peak – Valley Counting,
– Range Counting,

Two-parameter methods:

– Three-points Rainflow Cycle Counting [1] (standard ASTM E1049 [9]),
– Four-points Rainflow Cycle Counting [10].

2.2. Model of analyzing the load in frequency domain

If the loading is unknown in advance (real maintenance conditions) the way of loading should be analyzed with use a statistical methods [5, 32]. That models of loading use a various distribution of a random variable and they are presented often as a Power Spectral Density function (PSD), what is depicted of load energy distribution with correlation of frequency [6, 17]. Good point of that methods is possibility of analyzing the load without the necessity of recording a long samples. This is a very important advantage if testing a demonstrator of a new technical system or a prototype.

The quality analyzing of a spectrum of load could be done with use a statistical parameters characterizing its PSD function. The basic parameters are: the mean , the rate of zero upcrossing E, the rate of peak crossing , the irregularity factor and the spectral width parameter [8, 17, 23]:

$$\mu = M_0 \tag{1}$$

$$E\left[0^+\right] = \sqrt{\frac{M_2}{M_0}} \tag{2}$$

$$E\left[P^+\right] = \sqrt{\frac{M_4}{M_2}} \tag{3}$$

$$\gamma = \frac{E\left[0^+\right]}{E\left[P^+\right]} = \frac{M_2}{\sqrt{M_0 M_4}} \tag{4}$$

$$\lambda = \sqrt{1-\gamma^2} \tag{5}$$

The value of the spectral width parameter λ allows to assess, if analyzing signal is rather narrow-band ($\lambda \rightarrow 0$), or wide-band ($\lambda \rightarrow 1$). The mentioned above parameters are calculated with use a low orders moment (up to the 4th) of one-sided PSD function of loading.

If there is a necessity of analyzing the load signal in a quantity way the methods allowing to point the number and the range of amplitude of signal are desirable. In this case the correlation of a spectral signal to the methods of amplitude counting have been developed [23, 26].

To calculate the fatigue life there is necessary to count the number of fixed amplitude of loading (strain or stress). The representation of loading is e.g. histogram. If the signal of loading is wide-band, its analyzing directly from the PSD function is impossible. So, to gain histogram of amplitude of loading time signal could be simulated by series of random signals if their spectrum is established and the Inverse Fast Fourier Transform (IFFT) is possible. The time of lasting simulation should be long enough to take into account all kinds of load what occurs seldom but have significant influence on fatigue life.

To express number of cycles of loading and to connect them with a value of amplitude the Probability Density Function (PDF) could be used when the loading signal would be treated as a random process [17].

In the time domain Probability Density Function $PDF_X(x)$ characterizing the random process $X(t)$ which means that signal reaches some value is defined as follow:

$$PDF_X(x) = P\left[x \le X(t) \le x + dx\right] = \frac{\sum_{i+1}^{k} dt_i}{T} \tag{6}$$

where: $P[X(t)]$ – the probability, that random process $X(t)$ would occurred, T – time interval of observation, dt_i – the step of time of observation random process $X(t)$.

The shown above relationship is valid when time internal of observation ($T \to \infty$), and the step of time of observation ($dt_i \to 0$). That means infinite long measurements what is impossible in practice.

If the analyzed signal of loading is stationary, random and Gaussian, it is represented by a mean value μ_X, standard deviation σ_X, variance σ_X^2 and root mean square RMS. Additionally, if the signal is ergodic, that parameters are constant in time.

In order to compare values of samples $X(t_1), X(t_2)$ of signal $X(t)$ in time interval $\Delta t = t_2 - t_1$, the function of autocorrelation $R_X(t) = E[X(t_1)X(t_2)]$ is used. The mean value and standard deviation are independent of time. There is a possible to write:

$$E\left[X(t_1)\right] = E\left[X(t_2)\right] = \mu_X; \quad \sigma_X(t_1) = \sigma_X(t_2) = \sigma_X \tag{7}$$

The correlation coefficient ρ of two samples $X(t)$ is defined as follow:

$$\rho = \frac{R_X(\tau) - \mu_X^2}{\sigma_X^2}; \ (0 \le \rho \le 1) \tag{8}$$

If $\rho = 1$ there is a perfect correlation and if $\rho = 0$ there is no correlation. When the time interval , the correlation is equal to :

$$R_X(\tau) = \mu_X^2 + \sigma_X^2 = E[X^2] \tag{9}$$

In case of analyzing the signal in frequency domain, the time signal should be transform with use a Fourier transform. The function of $PDF_X(x)$ is:

$$PDF_X(x) = \frac{1}{\sqrt{2\pi\sigma_X}} \exp\left[-\frac{1}{2}\left(\frac{x - \mu_X}{\sigma_X}\right)^2\right]; \ (-\infty \to x \to +\infty) \tag{10}$$

where: μ_X, σ_X – mean value and standard deviation accordingly.

The Fourier transform of stationary random signal $X(t)$ usually does not exist because the relation is not meet [17]:

$$\int_{-\infty}^{\infty} \left|X(t)\right| dt < \infty \tag{11}$$

In this case the function of autocorrelation $R_X(t)$ normalized to zero mean value is transform. The Fourier transform is given by:

$$R_X(t) = \int_{-\infty}^{\infty} S_X(\omega) e^{i\omega t} d\omega \tag{12}$$

where: $S_X(\omega)$ – density function of normalized random process $X(t)$.
If $t = 0$, then:

$$E\left[X^2\right] = R_X(t) = \int_{-\infty}^{\infty} S_X(\omega) d\omega = \sigma_X^2 \tag{13}$$

If the normalized and stationary random process $X(t)$ is considered the area under curve of density function $S_X(\omega)$ is equal to its root mean square (RMS). Practically frequencies only from one-sided of the curve are consider $\langle 0;\infty \rangle$ and express in Hz. Than the density function of $S_X(\omega)$ is transformed to different form $W_X(f)$, named Power Spectral Density (PSD):

$$E\left[X^2\right] = \sigma_X^2 = \int_0^{\infty} W_X(f) df \tag{14}$$

where: $f = \dfrac{\omega}{2\pi}$.

For the functions $S_X(\omega)$ and $W_X(f)$ exists the first and second derivatives:

$$\sigma_{\dot{X}}^2 = \omega^2 S_X(\omega) = (2\pi)^2 f^2 W_X(f) \tag{15}$$

$$\sigma_{\ddot{X}}^2 = \omega^4 S_X(\omega) = (2\pi)^4 f^4 W_X(f) \tag{16}$$

The function $W_X(f)$ is described by a set of spectral characteristic; among others by a spectral moments M_m and irregularity factor γ [3, 32]:

$$M_m = \int_0^{\infty} f^m W_X(f) df \tag{17}$$

$$\gamma = \frac{M_2}{\sqrt{M_0 M_4}} \tag{18}$$

Usually only a few characteristic are used: $M_0, M_1, M_2, M_4, \gamma$.

Taking into consideration the width of a spectrum of the process they are divided into narrow-band, broad-band and bimodal [26]. The loading of underframe is rather broad-band. In the papers there are mathematical models proper to describe fatigue strength in quantitative way in frequency domain using broad-band random signal. That models could be divided into three groups [17, 28]:

- models of fatigue strength using the hypothesis of damage cumulation dedicated for narrow-band spectrum corrected by some coefficient for broad-band,
- analytical models designing a probability density function with use a Ritz distribution function allowing to count loading cycles,
- models of probability density function (PDF) using a combination of various statistical distributions of loading.

According to many authors [2, 3, 17, 22, 32, 34, 35] the quantity model fitted well to narrow- and broad-band spectrum of loading is model of Dirlik using an empirically design combination of exponential and Rayleigh distribution:

$$PDF_D = \frac{1}{2\sqrt{M_0}}\left[\frac{D_1}{Q} e^{-\frac{Z}{Q}} + \frac{D_2 Z}{R^2} e^{-\frac{Z^2}{2R^2}} + D_3 Z e^{-\frac{Z^2}{2}}\right] \tag{19}$$

$$x_m = \frac{M_1}{M_0}\sqrt{\frac{M_2}{M_4}} \tag{20}$$

$$\gamma = \frac{M_2}{\sqrt{M_0 M_4}} \tag{21}$$

$$Z = \frac{1}{2\sqrt{M_0}} \tag{22}$$

$$D_1 = \frac{2\left(x_m - \gamma^2\right)}{1+\gamma^2} \tag{23}$$

$$D_2 = \frac{1-\gamma - D_1 + D_1^2}{1-R} \tag{24}$$

$$D_3 = 1 - D_1 - D_2 \tag{25}$$

$$Q = \frac{1,25\left(\gamma - D_3 - \left(D_2 R\right)\right)}{D_1} \tag{26}$$

$$R = \frac{\gamma - x_m + D_1^2}{1-\gamma - D_1 + D_1^2} \tag{27}$$

This model allows to design a probability density function PDF of amplitude of loading (what is comparable to Rainflow method) if the power spectral density PSD of loading is known (e.g. PSD of recorded acceleration signal).

3. Durability analysis of underframe of high mobility wheeled vehicle

The method presented in point 2.2 of designing PDF based on calculated PSD function used to assess the durability of a tubular cross-bar of underframe of high mobility wheeled vehicle [12]. There was established that the torsional stiffness of underframe of a vehicle is linear. The theoretical fatigue life of a cross-bar was calculated with used a common formulas [14, 24] taking into consideration linear hypothesis of Palmgren – Miner (PM). The algorithm of calculating the durability was presented in the picture 2. The recorded quantity was acceleration measured in the four corners of underframe: a_{PP}, a_{PT}, a_{LT} i a_{LP}, [15] what allowed after double integration to assess the outcome torsion of underframe: h_{out}. In case to validate the theoretically assessed results the electric resistance wire strain gauge to measure the torsion of cross-bar was used according to the algorithm presented in the picture 3.

In the table 1 an example of fatigue life assessment of selected cross-bar of an underframe was presented. The loads were recorded during a profile ground tests of a vehicle in a parametric vehicle test center.

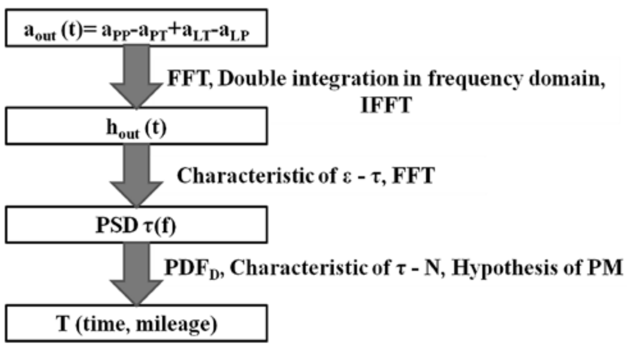

Fig. 2. Algorithm of fatigue life assessment with use an acceleration signal

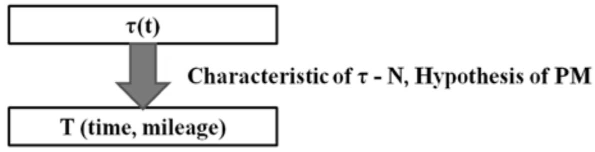

Fig. 3. Algorithm of fatigue life assessment with use an electric resistance wire strain gauge

Table 1. Results of fatigue life assessment of the cross-bar

Off-road, velocity V=30 [km/h]		
	strain gauge	sensor of acceleration
Fatigue life [h]	1075500	1425000
Durability [km]	32000000	42750000
Off-road, velocity V=14 [km/h]		
	strain gauge	sensor of acceleration
Fatigue life [h]	25200	13400
Durability [km]	353000	190000
Embedded rock, velocity V=9 [km/h]		
	strain gauge	sensor of acceleration
Fatigue life [h]	9900	9400
Durability [km]	89000	84500
Embedded rock, velocity V=5 [km/h]		
	strain gauge	sensor of acceleration
Fatigue life [h]	7900	5500
Durability [km]	40000	27200
Road "wave", (wheels displacement up to 500 [mm]), velocity V=4 [km/h]		
	strain gauge	sensor of acceleration
Fatigue life [h]	66	55
Durability [km]	240	220

4. Conclusions

The presented method of usage an acceleration signal of torsion of the underframe allowed to assess the fatigue life and durability of selected element of this unit. If the cross-bar would be treated as an reference unit (Canary approach) the method could be used to track the lost of maintenance potential of the critical unit of the vehicle. The road conditions could influence on the durability of a vehicle very seriously (table 1). The selection of the cross-bar was not random and allowed to easy-to-stick the electric resistance wire strain gauge. So the method was limited only to assess the durability of an underframe in a single point in various road conditions and for various velocities of drive. The results of analysis presented in the table 1 show that selected methods are comparable. The advantage of analysis the load spectrum with use an acceleration signal is that the method does not involve to use an large computational capacities of on-board computer and allows to track the global deformation of the underframe in variable road conditions [30].

If the model FEM of underframe would be built and correlated with the global deformations of the underframe there is possible to calculate the durability in numerical way in any point of the unit (e.g. in the weakest link). And than the track of road conditions with use an acceleration signal and its transformation into the way of lost of maintenance potential of an underframe would be also possible. That would allowed to design pHUMS (prognostic Health and Usage Monitoring System) for the vehicle. Finally the information to take the decision of use a single vehicle and to task it would be more accurate in tactic and operational warfare [11].

References

1. Amzallag C, Gerey JP, Robert JL, Bahuaud J. Standarization of the reinflow counting method for analysis. Journal of Fatigue 1994; 16: 287-293.
2. Benasciutti D, Tovo R. Spectral methods for lifetime prediction under wide-band stationary random processes. International Journal of Fatigue 2005; 27(8): 867-877.
3. Benasciutti D, Tovo TR. Comparison of spectral methods for fatigue analysis of broad-band Gaussian random processes. Probabilistic Engineering Mechanics 2006; 21(4): 287-299.
4. Benvillet A, Łagoda T, Macha E, Niesłony A. Pallin-Luc T, Vittori JF. Fatigue life under non-Gaussian random loading from various models. International Journal of Fatigue 2004; 26: 349-363.
5. Bishop NW. The use of frequency domain parameters to predict structural fatigue. Coventry. University of Warwick, 1988.
6. Bishop NW. Spectral methods for estimating the integrity of structural components subjected to random loading. Handbook of fatigue crack propagation in metalic structures. Elsevier: Science B.V, 1994, 1685-1720.
7. Colombi P, Doliński K. Fatigue lifetime of welded joints under random loading: rainflow cycle vs. cycle sequence method. Probabilistic Engineering Mechanics 2001; 16: 61-71.
8. Dirlik T. Application of computer in fatique analysis. Coventry: University of Warwick, 1985.
9. E-1049, Standard practices for cycle counting in fatigue analysis, ASTM Standards.
10. E-1049-85, Standard practices for cycle counting in fatigue analysis, Philadelphia: Annual Book of ASTM Standards, 1997.
11. Heine R, Barker D. Simplified terrain identification and component fatigue damage estimation model for use in a health and usage monitoring system. Microelectronics Reliability 2007; 47: 1882 - 1888.
12. Jamroziak K, Kosobudzki M, Ptak J. Assessment of the comfort of passenger transport in special purpose vehicle. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2013; 15(1): 25-30.
13. Katalog norm eksploatacji uzbrojenia i sprzętu wojskowego wojsk lądowych, Ministerstwo Obrony Narodowej, Warszawa, Sztab Generalny Wojska Polskiego, 1995.
14. Kocańda S, Szala J. Podstawy obliczeń zmęczeniowych. Warszawa: PWN, 1991.
15. Kosobudzki M, Stańco M. Metoda oceny wybranych właściwości pojazdu wysokiej mobilności na podstawie badań przebiegowych, Przegląd Mechaniczny 2014; 2: 32-36.
16. Kosobudzki M. Skręcanie ustroju nośnego samochodu ciężarowo - osobowego wysokiej mobilności podczas jazdy w zróżnicowanym terenie. Zeszyty Naukowe WSOWL 2010; 4(158): 130-139.
17. Lee Y-L, Pan J, Hathaway R, Barklay M. Fatigue testing and analysis. Theory and practice. Burlington: Elsevier Butterworth-Heinemann, 2005.
18. Łagoda T, Macha E, Niesłony A, Muller A. Fatigue life of cast irons GGG40, GGG50 and GTS45 under combined variable amplitude tension with torsion. The Archive of Mechanical Engineering2001; 48(1): 55-69.
19. Macha E, Łagoda T, Niesłony A, Kardas D. Fatigue life under variable amplitude loading according to the cycle counting and spectral methods. Material Science2006; 42(3): 416-425.
20. Macha E, Łagoda T, Niesłony A. Fatigue life calculation by means of the cycle counting and spectra methods under multiaxial random loading. Fatigue and Fracture of Engineering Materials and Structures 2005; 28: 409-420.
21. MIL-STD 810G: Environmental Test Methods and Engineering Guidelines, Department of Defense. USA, 2008.
22. Niesłony A, Macha E. Spectral method in multiaxial random fatigue. Berlin-Heidelberg: Springer-Verlag, 2007.
23. Niesłony A. Comparison of some selected multiaxial random fatigue. Journal of Theoretical and Applied Mechanics 2010; 48(1): 233-254.
24. Niezgodziński ME, Niezgodziński T. Wytrzymałość materiałów. Warszawa: Wydawnictwo Naukowe PWN, 2009.
25. Norma Obronna NO-06-A105. Uzbrojenie i sprzęt wojskowy. Ogólne wymagania techniczne, metody kontroli i badań. Ogólne zasady badań oraz odbioru prototypów i urządzeń produkowanych seryjnie, Ministerstwo Obrony Narodowej, Warszawa, 2005.
26. Passipolaridis V,A, Brondsted P. Fatigue evaluation algorithms: review. Raport Riso-R-1740(EN). Denmark: National Laboratory for Sustainable Energy, Technical University, 2009.
27. Prochowski L. Obciążenia dynamiczne układu nośnego pojazdu mechanicznego. Podstawy prognozowania, weryfikacja doświadczalna. Dodatek do Biuletynu WAT 1982; 12364.
28. Rahman M, M, Ariffin A, K, Jamaludin N, Haron C, H, Baker R, A. Fatigue life prediction of two-stroke free piston engine mounting using frequency response approach. European Journal of Science Research 2008; 22(4): 480-493.
29. Reimpell J, Betzler J. Podwozia samochodów. Podstawy konstrukcji. Warszawa: Wydawnictwa Komunikacji i Łączności, 2008.
30. Rusiński E, Czmochowski J, Pietrusiak D. Problemy identyfikacji modeli modalnych stalowych ustrojów nośnych. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2012; 1(14): 54 - 61.
31. Sherratt F, Bishop N, W, Dirlik T. Predicting fatigue life from frequency domain data. Engineering Integrity 2005; 18: 12-16.
32. Sobczyk K, Spencer BF. Stochastyczne modele zmęczenia materiałów. Warszawa: PWN, 1996.
33. Zasady Oceny Stanu Technicznego Uzbrojenia i Sprzętu Wojskowego w Siłach Zbrojnych RP, Ministerstwo Obrony Narodowej, Bydgoszcz, Inspektorat Wsparcia Sił Zbrojnych RP, 2012.
34. Zhao W, Backer JM. A new stress range distribution model for fatigue analysis under wave loading. Environmental Forces of Offshore Structures and their Prediction. Kluwer: Kluwer Academic Publishers, 1990.
35. Zhao W, Backer JM. On the probability density function of rainflow stress range for stationary Gaussian processes. International Journal of Fatigue 1992: 14(2); 121-135.

Mariusz KOSOBUDZKI
Logistic Departament
General Tadeusz Kosciuszko Military Academy of Land Forces
ul. Czajkowskiego 109, 51-150 Wrocław, Poland
E-mail: m.kosobudzki@wso.wroc.pl