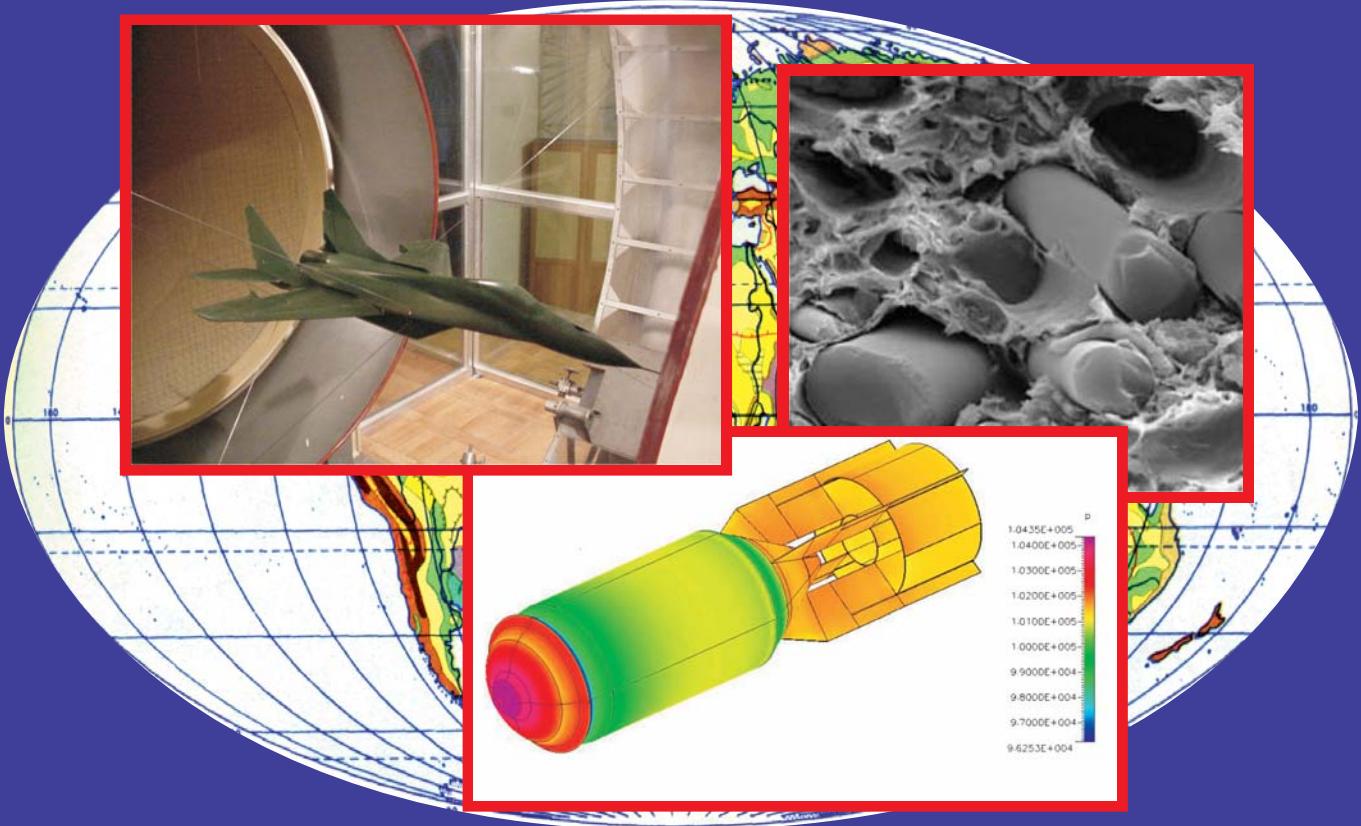


EKSPOLATACJA I NIEZAWODNOŚĆ MAINTENANCE AND RELIABILITY



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W SKRÓCIE - ABSTRACTS

DAILYDKA S., LINGAITIS L. P., MYAMLIN S., PRICHODKO V.: **Model matematyczny wahań przestrzennych wagonu pasażerskiego;** EiN nr 4/2008, s. 4-8.

Dla komfortu podróżnych i dla zapewnienia trwałości części i zespołów taboru kolejowego niezbędnym jest wybór racjonalnych parametrów zawieszenia podwozia, t.j. ustalić racjonalne stosunki pomiędzy dwoma elementami sztywności stopni zawieszenia i tłumienia drgan. Niniejszy artykuł jest przeznaczony dla stworzenia przestrzennego modelu matematycznego, gdy istnieje zawieszenie z dwoma stopniami i różnymi elementami sztywności. Opracowany system równań posiada 52 stopnie swobody. Przedstawiony model matematyczny może być stosowany dla ustalenia rzeczywistych obciążen dynamicznych wagonów pasażerskich i przez to do wyboru racjonalnych parametrów krótkich zawieszeń.

HONG-ZHONG H., ZHI-JIE L., YANFENG L., YU L., LIPING H.: **A warranty cost model with intermittent and heterogeneous usage;** EiN nr 4/2008, s. 9-15.

Estimation of warranty servicing costs during the product life cycle is of great importance to the manufacturers. Earlier research has usually assumed that the product is in continuous use and the usage intensity is the same for all buyers. This paper deals with the problem of estimating the expected warranty cost for the case where the item usage is intermittent and of heterogeneous usage intensity over the product life cycle when sales occur continuously. The failure of the item is dependent on the number of times, the duration the unit has been used and the usage intensity. Also, the product sales depend on product price and design quality. We consider repairable and nonrepairable items and obtain results for the free-replacement warranty (FRW) and Pro-rata Warranty (PRW) policy. Furthermore, the models consider the influences of price level, investment growth and warranty execution effects for the expected warranty costs. It also incorporates the cash flows of warranty reserve costs at any time intervals during the product life cycle. A numerical example is given to illustrate the application of the models.

LIŠČÁK Š.: **Zagadnienia techniczne związane z transportem osób niepełnosprawnych;** EiN nr 4/2008, s. 16-18.

W artykule stwierdzono, że zdolność poruszania się ludzi jest nieodzowną częścią naszego życia. Właściwe planowanie oraz zintegrowany system transportu są bardzo ważne dla zapewnienia ludzkiej potrzeby poruszania się. Celem transportu jest więc zapewnienie wysokiej jakości usług dla wszystkich ludzi, także niepełnosprawnych. Wymaga to dostosowania technicznego przystanków oraz pojazdów do osób niepełnosprawnych. Artykuł omawia także inne wymagania techniczne stawiane środkom transportu z uwzględnieniem osób niepełnosprawnych.

KYUREGHYAN Kh., PIEKARSKI W.: **Analiza wyznaczenia rozkładu ciśnienia w lożysku korbowym;** EiN nr 4/2008, s. 19-24.

Praca przedstawia analityczną metodę wyznaczenia rozkładu ciśnienia oleju w lożysku korbowym, stanowiącego rozwiązanie równania Reynoldsa. Odpowiednie warunki brzegowe rozważano adekwatnie do modelu klasycznego ślimgowego lożyska poprzecznego zgodnie z parametrami technicznymi, charakteryzującymi lożysko wału korbowego silników S-4002/4003 stosowanych w ciągnikach rolniczych. Celem pracy było przeprowadzenie analizy porównawczej teoretycznych parametrów charakteryzujących pracę lożyska ślimgowego, jako wartości parametrów sygnału diagnostycznego. Równanie Reynoldsa (przy stałym współczynniku lepkości dynamicznej) metodą rozdzielenia zmiennych, sprowadzono do układu równań różniczkowych zwyczajnych, ostateczne rozwiązanie zapisano w postaci ogólnej.

KRIŽANOVÁ A.: **The current position and perspectives of the integrated transport systems in Slovak Republic;** EiN nr 4/2008, s. 25-27.

The paper deals with current state of integrated transport systems in the Slovak Republic (SR). There is an analysis of legislative framework of transport system (ITS), description of ITS attributes, advantages and disadvantages of ITS operating in SR in the paper. The paper also points out underlying technical conditions necessary for existence of ITS, which should be established in SR in order to increase the number of ITS projects in cities and regions in SR.

CHE-HUA LI: **Particle Swarm Optimization Fuzzy Systems for the Age Reduction Imperfect Maintenance Model;** EiN nr 4/2008, s. 28-34.

This research includes two topics: (1) the modeling of periodic preventive maintenance policies over an infinite time span for repairable systems with the reduction of the degradation rate after performing an imperfect preventive maintenance (PM) activity; (2) the parameter estimation of failure distribution and the restoration effect of PM from the proposed PM policy for deteriorating systems. The concept of the improvement factor method is applied to measure the restoration effect on the degradation rate for a system after each PM. An improvement factor is presented as a function of the system's age and the cost of each PM. A periodic PM model is then developed. The optimal PM interval and the optimal replacement time for the proposed model can be obtained by minimizing the objective functions of the cost rate through the algorithms provided by this research. An example of using Weibull failure distribution is provided to investigate the proposed model. The method is proposed to estimate the parameters of the failure process and the improvement effect after each PM by analyzing maintenance and failure log data. In this method, a PSO-based method is proposed for automatically constructing a fuzzy system with an appropriate number of rules to approach the identified system. In the PSO-based method, each individual in the population is constructed to determine the number of fuzzy rules and the premise part of the fuzzy system, and then the recursive least-squares method is used to determine the consequent part of the fuzzy system constructed by the corresponding individual. Consequently, an individual corresponds to a fuzzy system. Subsequently, a fitness function is defined to guide the searching procedure to select an appropriate fuzzy system with the desired performance. Finally, two identification problems of nonlinear systems are utilized to illustrate the effectiveness of the proposed method for fuzzy modeling.

DAILYDKA S., LINGAITIS L. P., MYAMLIN S., PRICHODKO V.: **Mathematical model of spatial fluctuations of passenger wagon;** EiN nr 4/2008, s. 4-8.

To ensure passenger comfort as well as the durability of the components of rolling stock, it is necessary to determine the rational parameters of chassis suspension, i.e. rational relations between rigidity and vibration inhibition elements of the two stages of chassis suspension. The article describes a spatial mathematical model of a two-stage suspension that has different rigidity elements. The equation system created has 52 degrees of freedom. The model presented in this article can be employed to establish the real dynamic load of passenger wagons and to determine the rational parameters of resilient suspension.

LIŠČÁK Š.: **The technical problems connected with the transport of the disabled peoples;** EiN nr 4/2008, s. 16-18.

This article deals with mobility as the necessary part of our life. The transport integration and planning are very important for providing sustainable mobility. In view of this aim the high-quality services have to be offered to passengers also for the disabled peoples. It includes also bus stops, vehicles suitable for disabled persons. This article presented the other technical conditions for the transport means which must carry the disabled peoples either.

KYUREGHYAN Kh., PIEKARSKI W.: **Analysis of determining pressure distribution in crank bearing;** EiN nr 4/2008, s. 19-24.

The paper presents an analytical method of determining oil pressure distribution in a crank bearing, which makes a solution of the Reynold's equation. Proper boundary conditions were considered according to the classic model of a radial slide in agreement with technical parameters typical for the crankshaft bearing of S-4002/4003 engines used in agriculture tractors. The goal of this work was to conduct a comparative analysis of theoretical parameters characterizing the work of the slide bearing as the value of the diagnostic signal parameters. By using the method of separation of variables, the Reynold's equation (with constant coefficient of dynamic viscosity) was brought to the system of ordinary differential equations, and the ultimate solution was written in general form.

KRIŽANOVÁ A.: **Obecna pozycja i perspektywy zintegrowanego systemu transportu w Republice Słowackiej;** EiN nr 4/2008, s. 25-27.

W artykule zaprezentowano aktualny stan zintegrowanego systemu transportu na terenie Republiki Słowackiej. Zaprezentowano także analizę podstaw prawnych, rodzaje oraz zalety i wady tego systemu transportu. Artykuł prezentuje także podstawowe warunki techniczne, jakie muszą być spełnione i ustalone w Republice Słowackiej aby w miastach i lokalnych regionach wzrosła liczba zintegrowanych systemów transportowych.

W SKRÓCIE - ABSTRACTS

Kujan K.: **Wyznaczanie liczebności pomiarów odchylek geometrycznych w statystycznej ocenie procesu;** EiN nr 4/2008, s. 35-41.

W artykule przedstawiono analizę metod wyznaczania liczebności próbki jednostek wyróbów wymaganych do statystycznej oceny procesu obróbk. Omówiono metody ustalania liczebności próbki oparte na pojęciu zmiennej standaryzowanej, na wartości krytycznej statystyki t-Studenta i na analizie graficznej wartości krytycznych statystyki t. Dodatkowo przeprowadzono praktyczną weryfikację analizowanych metod uwzględniając w badaniach ocenę wartości średniej i oszacowanie odchylenia standardowego odchylek geometrycznych. Wyniki analiz i badań przedstawiono w postaci graficznej i tabelarycznej.

STASIAK P.: **Nowa koncepcja samochodowych fotelików dla dzieci ze względu na zastosowany system bezpieczeństwa uczestników ruchu drogowego;** EiN nr 4/2008, s. 42-48.

W artykule zostały przedstawione zagadnienia dotyczące budowy samochodowych fotelików dla dzieci, obecnie dostępne rozwiązania konstrukcyjne oraz metodologię badań, która jest podstawą do dopuszczenia fotelika do sprzedaży. Szczególną uwagę poświęcono kryteriom służącym ocenie systemów bezpieczeństwa zamontowanych w foteliku. Wskazano również tendencje pojawiające się przy konstruowaniu nowych urządzeń.

WRONA J., WRONA R.: **Wybrane zagadnienia wpływu napraw powypadkowych nadwozi na bezpieczeństwo drogowe;** EiN nr 4/2008, s. 49-54.

W opracowaniu przedstawiono problem oceny wpływu napraw powypadkowych nadwozi samochodów osobowych na bezpieczeństwo drogowe. Artykuł podnosi kwestie eksploatacji pojazdów i ich napraw oraz zwraca uwagę na istniejące braki w krajowym systemie dopuszczenia do ruchu nadwozi po naprawach. Publikacja uwzględnia też potrzebę regulacji prawnych i wykonawczych procedur dopuszczania pojazdów do ruchu po wcześniej wykonywanych naprawach.

WAŻNY M, JASZTAL M, SZAJNAR S.: **CFD-Fastran – narzędzie do numerycznej analizy oplotu obiektów przez strumień powietrza;** EiN nr 4/2008, s. 55-62.

W niniejszym artykule przedstawiono sposób wykorzystania specjalizowanego oprogramowania CFD-Fastran do wspomagania procesów projektowania i realizacji prac badawczych obejmujących tematykę związaną z zagadnieniami oplotu ciał przez strumień powietrza. Opisano proces rozpoznawania walorów użytkowych przedstawionego programu oraz zilustrowano jego wykorzystanie na przykładach konkretnych obiektów technicznych. Poniższy materiał przedstawia fragmenty prac badawczych prowadzonych przez autorów niniejszego opracowania. Z uwagi na charakter tychże prac prezentowane wyniki nie zawierają szczegółowych danych.

HROMÁDKO J., HÖNIG V., MILER P.: **Applications of NRTC cycle to determine a different fuel consumption and harmful emissions caused by changes of engine's technical conditions;** EiN nr 4/2008, s. 63-65.

The main topic of the paper is to determine different fuel consumption and harmful emissions caused by engine's changes of technical conditions. The change of technical condition of combustion engine at any working point of engine proves different change of fuel consumption and production of harmful emissions. Therefore it is necessary to compare two technical conditions to determine the same engine load. For this purpose the special simulation programme of engine load in Non-Road Transient Cycle (NRTC) was created.

BARA M., SKONECZNY W., KAPTACZ S.: **Tribologiczne właściwości ceramiczno-węglowych warstw powierzchniowych otrzymywanych w elektrolitach o różnej zawartości grafitu;** EiN nr 4/2008, s. 66-70.

W pracy przedstawiono tribologiczne właściwości kompozytowych warstw powierzchniowych tlenek glinu-grafit. Warstwy otrzymano metodą elektrolytyczną, w elektrolitach o różnym stężeniu grafitu. Wytworzone warstwy skojarzono z tworzywem PEEK/BG w ruchu posuwisto-zwrotnym, w warunkach tarcia bez-smarowego. Przedstawiono rezultaty badań współczynnika tarcia pary ślizgowej i zużycia masowego tworzywa. Celem określenia mikrogeometrii powierzchni warstw tlenku glinu oraz warstw tlenek glinu-grafit przeprowadzono badania struktury geometrycznej powierzchni za pomocą profilografometru stykowego, przed i po teście tribologicznym. Zaprezentowano również obrazy struktury i morfologii powierzchni warstw tlenek glinu-grafit oraz tworzywa PEEK/BG wykonane przy zastosowaniu elektronowej mikroskopii skaningowej.

Kujan K.: **Determination of the number of geometric deviation measurements in statistical evaluation of a process;** EiN nr 4/2008, s. 35-41.

The article presents an analysis of the methods of determining the size of a sample of product units required for the statistical evaluation of the process of machining. Discussed are sample size determination methods based on the concept of standardized variable, the critical value of Student's t-statistic, and the graphic analysis of critical values of the t statistic. Additionally, a practical verification of the analyzed methods was conducted, taking into account the estimate of the mean value and the estimation of the standard value of geometric deviations. The results of the analyses are presented graphically and in tabular form.

STASIAK P.: **New idea of child car seat according to new safety system of participants of road traffic;** EiN nr 4/2008, s. 42-48.

In following article some issues of Child Restraint Systems (CRS) construction were presented, esp. currently available design solutions and methodology of the research (which is the basis of granting the type approval before introducing CRS to the market). There were also discussed criteria of evaluating safety systems in CRS. New tendencies of designing new facilities which have already been introduced were also pointed out.

WRONA J., WRONA R.: **Selected problems of the influence of crash body repairs on road safety;** EiN nr 4/2008, s. 49-54.

The paper presents the problem of the evaluation of the influence of crash body repairs on road safety. It raises the issue of vehicle operation and repairs, and draws attention to existing gaps in the national system of granting type approvals for repaired car bodies. The paper also takes into consideration the need for legal regulations and executive procedures regarding type approval of repaired vehicles.

WAŻNY M, JASZTAL M, SZAJNAR S.: **CFD-Fastran – software package for numerical analysis of flow around a body by the air stream;** EiN nr 4/2008, s. 55-62.

The manner of use special software CFD-Fastran for computer aided design and study of flow around a body has been presented in this paper. Authors described process of CFD-FASTRAN virtues recognition and presented examples of using this program for selected technical objects. Presented material describe fragments of studies carried out by the authors. Taking into consideration subject matter of this studies presented results don't include detailed data.

BARA M., SKONECZNY W., KAPTACZ S.: **Tribological properties of ceramic-carbon surface layers obtained in electrolytes with a different graphite content;** EiN nr 4/2008, s. 66-70.

The paper presents the tribological properties of composite aluminium oxide-graphite surface layers. The layers were obtained by the electrolytic method, in electrolytes with a different graphite concentration. The produced layers were coupled with a PEEK/BG material in reciprocating motion, under lubricant-free friction conditions. The results of research regarding the coefficient of a friction couple wear and mass wear of the material are presented. In order to determine the microgeometry of the aluminium oxide layers' surface and of aluminium oxide-graphite layers, investigation was conducted of the geometrical structure of the surface using a contact profilographometer before and after a tribological test. Images are also presented in the paper showing the structure and surface morphology of aluminium oxide-graphite layers and the PEEK/BG material, taken using scanning electron microscopy.

NAUKA I TECHNIKA

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MODEL MATEMATYCZNY WAHAŃ PRZESTRZENNYCH WAGONU PASAŻERSKIEGO MATHEMATICAL MODEL OF SPATIAL FLUCTUATIONS OF PASSENGER WAGON

Dla komfortu podróżnych i dla zapewnienia trwałości części i zespołów taboru kolejowego niezbędnym jest wybór racjonalnych parametrów zawieszenia podwozia, tj. ustalić racjonalne stosunki pomiędzy dwoma elementami sztywności stopni zawieszenia i tłumienia drgań. Niniejszy artykuł jest przeznaczony dla stworzenia przestrzennego modelu matematycznego, gdy istnieje zawieszenia z dwoma stopniami i różnymi elementami sztywności. Opracowany system równań posiada 52 stopnie swobody. Przedstawiony model matematyczny może być stosowany dla ustalenia rzeczywistych obciążen dynamicznych wagonów pasażerskich i przez to do wyboru racjonalnych parametrów krótkich zawieszeń.

Słowa kluczowe: wagon, zawieszenia, stopień, stopień swobody, wibracje, tłumienie, przesuw, sztywność

To ensure passenger comfort as well as the durability of the components of rolling stock, it is necessary to determine the rational parameters of chassis suspension, i.e. rational relations between rigidity and vibration inhibition elements of the two stages of chassis suspension. The article describes a spatial mathematical model of a two-stage suspension that has different rigidity elements. The equation system created has 52 degrees of freedom. The model presented in this article can be employed to establish the real dynamic load of passenger wagons and to determine the rational parameters of resilient suspension.

Keywords: wagon, suspension, stage, degree of freedom, vibration, inhibition, shift, rigidity.

1. Introduction

When examining various dynamic processes, huge importance falls to vibration inhibition systems. For those systems to operate efficiently, it is necessary to determine their rational parameters. When talking about parameters of railway chassis, it is necessary to determine rational relations between rigidities of two stages of chassis suspensions, just as rational relations between inhibition parameters of these stages.

To solve the abovementioned tasks, the present article described a mathematical model for determination of spatial fluctuations of chassis.

2. Description of Structural Schemes

When making a mathematical model for determination of spatial vibrations of railway rolling stock chassis with two stages of suspension, we referred to a calculation scheme, close to carriages KVZ-CH11, Y-32 and 68-7007 [1, 3, 4]. In these carriages, vertical loads are transmitted through sliders of beam located above the resilient suspension. In case of structures of non-cradle carriages, they also transmit horizontal, longitudinal

and transverse forces. In structures with a cradle, a pin is used for this purpose. To reduce shock load in pin node and sliders, it is planned to install resilient-viscous (rubber) elements there. Thus, in the structures in question, it is necessary to take into consideration the shifts of the beam above suspension in respect of the bodywork in longitudinal and transverse direction and when chassis is coiling.

The beam above chassis is linked to carriage frame by means of non-cradle structure, through a spring of increased resilience, which creates restorable moments for mutual shifts of beam and carriage in all the directions, and in cradle-type structures this function is performed by the cradle. We must also take into consideration that in case of mutual horizontal shifts in structures of above-suspension beam and carriage cradle, resilient leads operate as well.

In axle-box node, resilient-dissipative elements allow the carriage frame and axle-wheel pair shifting in respect of each other in all the direction. In some carriages, leads are mounted here.

3. Creation of Mathematical Model

Chassis calculation scheme with the said carriages constitutes a system consisting of 9 solid bodies (bodywork, 2 beams above suspension, 2 carriage frames, 4 pairs of axle-wheels) (Fig. 1).

The followings marks will be conferred (see Fig. 1): x , y , z – shifts of system bodies along road axis (x – jerks), across road axis (y – lateral shift) and along the vertical (z – jumps); θ , ϕ , ψ – angle shifts around the axes x (θ – lateral swing), y (ϕ – longitudinal swing) and z (ψ – soiling). Positive sliding shifts take place along respective axes, and positive angle shifts – counter clockwise, when looking from positive direction of respective axis (Fig. 1). Positive shifts for bodywork with centre of mass in point C are shown.

Further bodywork shifts will be marked without index. Index i ($i=1,2$ – carriage number) – carriage frame, index $i'j$ – the beam above suspension, index in ($m=1, 2$ – number of axle-wheel pair in carriage) – axle-wheel pairs, $pmik$ ($k=1$ – left according to direction of movement, $k=2$ – right side of wagon) – in points of wagon to wheels contact. The calculation scheme takes into consideration recalculated road masses in points of wheels to wagon contacts, which shift in to directions – horizontal across road axis and according to the vertical.

Total number of shifts is equal to:

$$9 \cdot 6 + 2 \cdot 8 = 70$$

Let's review the system relations:

- Between bodywork and the beams above suspensions, mutual shifts are possible in horizontal, longitudinal and transverse direction, also when coiling, i.e. jumps, lateral and longitudinal swing of beams are determined from respective shifts of bodywork:

$$\left. \begin{array}{l} z_{i^3} = z + (-1)^i l\varphi, \\ \theta_{i^3} = \theta, \\ \varphi_{i^3} = \varphi, \end{array} \right\} \quad (1)$$

where l is half of chassis base;

- Longitudinal swing of axle-wheel pairs is expressed as their jerk (slips are determined when calculating forces of pseudo-slippage):

$$\varphi_{im} = \frac{x_{im}}{r} \quad (2)$$

where r is the radius of wheel rolling circle;

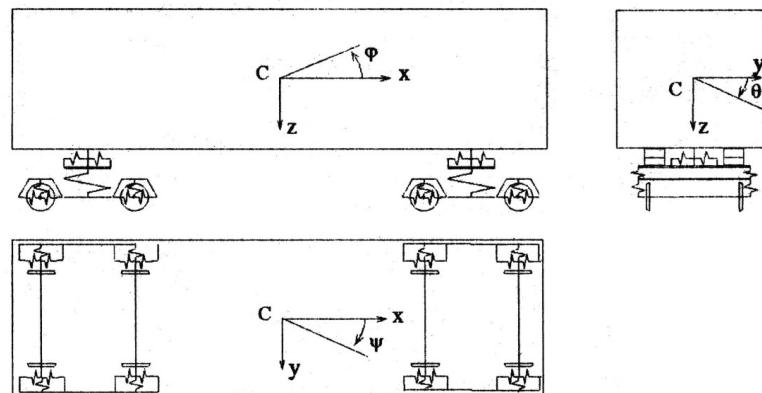


Fig. 1. Calculation Scheme for Chassis with Two-Stage Suspension

- Wheels move without breaking away from rail:

$$z_{pmik} = z_{im} + (-1)^k b_2 \theta_{im} + \Delta r_{imk} - \eta_{i'mk} \quad (3)$$

where b_2 is half of the distance between wheel rolling circles in transverse direction; Δr_{imk} is change of wheel rolling radius in case of lateral axle-wheel shift; $\eta_{i'mk}$ is the ordinate of road's vertical inequalities.

Thus we make (introduce) 18 equations of relation. It means that the system has $70-18=52$ degrees of freedom. Let's write down the summarised coordinates:

- Bodywork shifts:

$$q_1 = z, \quad q_2 = \varphi, \quad q_3 = \theta, \quad q_4 = y, \quad q_5 = \psi$$

- Shifts of carriage frames:

$$q_n = z_i (n=6,7), \quad q_n = \varphi_i (n=8,9), \quad q_n = \theta_i (n=10,11),$$

$$q_n = y_i (n=12,13), \quad q_n = \psi_i (n=14,15),$$

- Shifts of axle-wheel pairs:

$$q_n = z_{im} (n=\overline{16, 19}) \quad q_n = \theta_{im} (n=\overline{20, 23})$$

$$q_n = y_{im} (n=\overline{24, 27}) \quad q_n = \psi_{im} (n=\overline{28, 31})$$

- Shifts of beams above suspensions:

$$q_n = y_{i^3} (n=32, 33) \quad q_n = \psi_{i^3} (n=34, 35)$$

- Rail impress (reaction) in the points of contacts with wheels:

$$q_n = y_{pmik} (n=\overline{36, 43})$$

- Jerks of system bodies:

$$q_n = x_i (n=44,45) \quad q_n = x_{i^3} (n=46, 47)$$

$$q_n = x_{im} (n=\overline{48, 51}) \quad q_{52} = x$$

Static pressure:

- Wheel to rail:

$$D_{no} = \frac{m_y g}{8}$$

where m_y is the weight of entire chassis; g is free fall acceleration;

- To resilient elements of central suspension:

$$D_{\tilde{n}o\ddot{o}} = \frac{(m + 2m_i)g}{4}$$

where m is bodywork weight; m_i , m_t is the weight of the beam above suspension;

- To resilient elements of axle-box suspension:

$$D_{\tilde{n}oa'} = \frac{(m + 2m_i + 2m_o)g}{8}$$

where m_o is weight of carriage frame.

When determining inertia parameters it is assumed that the carriage weight:

$$m_{o\ddot{a}\ddot{e}} = m_o + m_i + 2m_e$$

and the chassis weight:

$$m_{y'} = m + 2m_{o\ddot{a}\ddot{e}}$$

Total static bend of resilient suspension is determined from the following formula:

$$f = f_{\ddot{o}} + f_{a'}$$

where $f_{\ddot{o}}$ and $f_{a'}$ are static bends of first and second stages of resilient suspension:

$$f_{\ddot{o}} = \frac{P_{\tilde{n}o\ddot{o}}}{k_{\ddot{o}}} \quad f_{a'} = \frac{P_{\tilde{n}oa'}}{k_{a'}}$$

where $k_{\ddot{o}}$ is recalculated rigidity of central suspension; $k_{a'}$ is rigidity of axle-box suspension.

Let's review mutual shifts of all the bodies of the system. Markings of geometrical parameters included into shift expressions are described in detail in [1].

Mutual shifts between bodywork and the beam located above suspension:

- In pin zone, in longitudinal and transverse horizontal directions:

$$\left. \begin{aligned} A_{\phi\ddot{o}i} &= x + h_{\phi}\varphi - x_i \\ A_{\phi\ddot{y}i} &= y - h_{\phi}\theta - (-1)^i l\psi - y_{i^3} \end{aligned} \right\} \quad (4)$$

- Between sliders in longitudinal and horizontal transverse directions:

$$\left. \begin{aligned} A_{cxik} &= x + h_c\varphi - (-1)^k b_c\psi - x_{i^3} + (-1)^k b_c\psi_{i^3}, \\ A_{cyik} &= y - h_c\theta - (-1)^i l\psi - y_{i^3}. \end{aligned} \right\} \quad (5)$$

Respective forces are calculated from the following formulas:

$$\left. \begin{aligned} S_{\phi xi} &= k_{\phi\ddot{o}} A_{\phi xi} + \beta_{\phi\ddot{o}} \dot{A}_{\phi xi}, \\ S_{\phi o'i} &= k_{\phi\ddot{o}o'} A_{\phi o'i} + \beta_{\phi\ddot{o}o'} \dot{A}_{\phi o'i}, \\ S_{\tilde{n}\ddot{o}ik} &= k_{cx} A_{\tilde{n}\ddot{o}ik} + \beta_{cx} \dot{A}_{\tilde{n}\ddot{o}ik}, \\ S_{\tilde{n}\ddot{y}ik} &= k_{cy} A_{\tilde{n}\ddot{y}ik} + \beta_{cy} \dot{A}_{\tilde{n}\ddot{y}ik}. \end{aligned} \right\} \quad (6)$$

Mutual shifts between carriage frame and the beam above suspension in all the directions (deformations of resilient sets of suspension):

$$\left. \begin{aligned} A_{\tilde{o}\ddot{o}ik} &= x_{i^3} - (-1)^k b\psi_{i^3} - x_i + (-1)^k b\psi_i, \\ A_{\tilde{o}\ddot{y}ik} &= y_{i^3} - y_i, \\ A_{\tilde{o}\ddot{z}ik} &= z + (-1)^i l\varphi + (-1)^k b\theta - z_i - (-1)^k b\theta_i, \\ A_{\tilde{o}\ddot{\psi}ik} &= \psi_{i^3} - \psi_i. \end{aligned} \right\} \quad (7)$$

Respective resilient forces will be as follows:

$$\left. \begin{aligned} S_{\tilde{o}\ddot{x}ik} &= k_{\ddot{o}x} A_{\tilde{o}\ddot{x}ik}, \\ S_{\tilde{o}\ddot{y}ik} &= k_{\ddot{o}y} A_{\tilde{o}\ddot{y}ik}, \\ S_{\tilde{o}\ddot{z}ik} &= k_{\ddot{o}z} A_{\tilde{o}\ddot{z}ik}, \\ S_{\tilde{o}\ddot{\psi}ik} &= k_{\ddot{o}\psi} A_{\tilde{o}\ddot{\psi}ik}. \end{aligned} \right\} \quad (8)$$

Mutual shifts between carriage frame and the beam above suspension in vibration amortisation zone:

$$\left. \begin{aligned} A_{\tilde{o}\ddot{y}ik}^{\ddot{a}} &= y_{i^3} - y_i, \\ A_{\tilde{o}\ddot{z}ik}^{\ddot{a}} &= z + (-1)^i l\varphi + (-1)^k b_{ai}\theta - z_i - (-1)^k b_{ao}\theta_i \end{aligned} \right\} \quad (9)$$

In force hydro-absorbers:

$$\left. \begin{aligned} S_{\tilde{o}\ddot{o}'ik}^{\ddot{a}} &= \beta_{\ddot{o}o'} \dot{A}_{\tilde{o}\ddot{o}'ik}, \\ S_{\tilde{o}\ddot{z}ik}^{\ddot{a}} &= \beta_{\ddot{o}z} \dot{A}_{\tilde{o}\ddot{z}ik}, \end{aligned} \right\} \quad (10)$$

where $\beta_{\ddot{o}o'} = \beta_{\ddot{o}} \cos^2 \alpha_{\ddot{a}}$, $\beta_{\ddot{o}z} = \beta_{\ddot{o}} \sin^2 \alpha_{\ddot{a}}$, inclination angle of hydro-absorber towards horizontal plane:

$$\operatorname{tg} \alpha_{\ddot{a}} = \frac{h_{\ddot{o}o} - h_{\ddot{o}e} - h_{\ddot{a}o}}{b_{\ddot{o}o} - b_{\ddot{a}i'}}$$

Let's write down mutual shifts and forces arising in leads of the central suspension:

$$\left. \begin{aligned} A_{\tilde{o}\ddot{a}ik}^{\ddot{i}} &= \tilde{o}_{i^3} - (-1)^k b_{i\ddot{o}}\psi_{i^3} - \tilde{o}_i + (-1)^k b_{i\ddot{o}}\psi_3, \\ A_{\tilde{o}\ddot{y}ik}^{\ddot{i}} &= y_{i^3} - y_i, \\ A_{\tilde{o}\ddot{z}ik}^{\ddot{i}} &= z + (-1)^i l\varphi + (-1)^k b_{i\ddot{o}}\theta - z_i - (-1)^k b_{i\ddot{o}}\theta_i \end{aligned} \right\} \quad (11)$$

Respective forces will be as follows:

$$\left. \begin{aligned} S_{\tilde{o}\ddot{o}ik}^{\ddot{i}} &= k_{\ddot{o}\ddot{o}}^{\ddot{i}} A_{\tilde{o}\ddot{o}ik}^{\ddot{i}} + \beta_{\ddot{o}\ddot{o}}^{\ddot{i}} \dot{A}_{\tilde{o}\ddot{o}ik}^{\ddot{i}}, \\ S_{\tilde{o}\ddot{o}'ik}^{\ddot{i}} &= k_{\ddot{o}\ddot{o}'}^{\ddot{i}} A_{\tilde{o}\ddot{o}'ik}^{\ddot{i}} + \beta_{\ddot{o}\ddot{o}'}^{\ddot{i}} \dot{A}_{\tilde{o}\ddot{o}'ik}^{\ddot{i}}, \\ S_{\tilde{o}\ddot{z}ik}^{\ddot{i}} &= k_{\ddot{o}z}^{\ddot{i}} A_{\tilde{o}\ddot{z}ik}^{\ddot{i}} + \beta_{\ddot{o}z}^{\ddot{i}} \dot{A}_{\tilde{o}\ddot{z}ik}^{\ddot{i}}. \end{aligned} \right\} \quad (12)$$

In case of beam shift restriction in respect of carriage frame in longitudinal and transverse horizontal directions, in the central suspension, after elimination of respective spaces $A_{\tilde{o}\ddot{o}0}$, $A_{\tilde{o}\ddot{o}'0}$ forces emerge, where rigidity and energy dissipation in the structure itself are already assessed. These forces arise during movement of the top beam in respect carriage in the sliders zone:

$$\left. \begin{aligned} A_{\tilde{o}\ddot{x}ik}^{\ddot{e}} &= x_{i^3} - (-1)^k b_c\psi_{i^3} - x_i + (-1)^k b_n\psi_i, \\ A_{\tilde{o}\ddot{y}ik}^{\ddot{e}} &= y_{i^3} - y_i, \end{aligned} \right\} \quad (13)$$

exceeding, under absolute value, the $A_{\tilde{o}\ddot{o}0}$, $A_{\tilde{o}\ddot{o}'0}$.

These forces may be expressed as follows:

$$\left. \begin{aligned} S_{\tilde{o}\ddot{x}ik}^{\ddot{e}} &= \begin{cases} 0, \\ k_{\ddot{o}\ddot{o}}^{\ddot{e}} (A_{\tilde{o}\ddot{x}ik}^{\ddot{e}} - (-1)^k A_{\tilde{o}\ddot{x}0}) \beta_{\ddot{o}\ddot{o}}^{\ddot{e}} \dot{A}_{\tilde{o}\ddot{x}ik}^{\ddot{e}}, \end{cases} \\ S_{\tilde{o}\ddot{y}ik}^{\ddot{e}} &= \begin{cases} 0, \\ k_{\ddot{o}y}^{\ddot{e}} (A_{\tilde{o}\ddot{y}ik}^{\ddot{e}} - (-1)^k A_{\tilde{o}\ddot{y}0}) \beta_{\ddot{o}y}^{\ddot{e}} \dot{A}_{\tilde{o}\ddot{y}ik}^{\ddot{e}}, \end{cases} \end{aligned} \right.$$

$$\left. \begin{array}{l} \dot{a}\tilde{e}\tilde{e}e|\Delta_{\tilde{o}xik}^{\tilde{e}}| \leq \Delta_{\tilde{o}x0}; \\ \dot{a}\tilde{e}\tilde{e}e|\Delta_{\tilde{o}xik}^{\tilde{e}}| > \Delta_{\tilde{o}x0}; \\ \dot{a}\tilde{e}\tilde{e}e|\Delta_{\tilde{o}yik}^{\tilde{e}}| \leq \Delta_{\tilde{o}y0}; \\ \dot{a}\tilde{e}\tilde{e}e|\Delta_{\tilde{o}yik}^{\tilde{e}}| > \Delta_{\tilde{o}y0}. \end{array} \right\} \quad (14)$$

Let's write down the mutual shifts between carriage frame and axle-wheel pair:

$$\left. \begin{array}{l} \Delta_{a'ximk} = x_i - (-1)^k b_i \psi_i - x_{im} + (-1)^k b_i \psi_{im}, \\ \Delta_{a'yimk} = y_i - (-1)^m l_i \psi_i - y_{im}, \\ \Delta_{a'zimk} = z_i + (-1)^m l_i \phi_i - x_{im} + (-1)^k b_i \theta_i - z_{im} - (-1)^k b_i \theta_{im}, \\ \Delta_{a'\psiimk} = \psi_i - \psi_{im}. \end{array} \right\} \quad (15)$$

In axle-box suspensions of some carriages, absorbers of dry friction vibrations are installed, having rubber elements that simulate the viscous friction. Therefore, in general case, the forces acting in axle-box suspension will be:

$$\left. \begin{array}{l} S_{a'ximk} = k_{a'\tilde{o}} \Delta_{a'ximk} + \beta_{a'\tilde{o}} \dot{\Delta}_{a'ximk} + F_{a'\tilde{o}} \text{sign}(\dot{\Delta}_{a'ximk}), \\ S_{a'yimk} = k_{a'\tilde{y}} \Delta_{a'yimk} + \beta_{a'\tilde{y}} \dot{\Delta}_{a'yimk} + F_{a'\tilde{y}} \text{sign}(\dot{\Delta}_{a'yimk}), \\ S_{a'zimk} = k_{a'\tilde{z}} \Delta_{a'zimk} + \beta_{a'\tilde{z}} \dot{\Delta}_{a'zimk} + F_{a'\tilde{z}} \text{sign}(\dot{\Delta}_{a'zimk}), \\ S_{a'\psiimk} = k_{a'\tilde{\psi}} \Delta_{a'\psiimk} + \beta_{a'\tilde{\psi}} \dot{\Delta}_{a'\psiimk} + F_{a'\tilde{\psi}} \text{sign}(\dot{\Delta}_{a'\psiimk}), \end{array} \right\} \quad (16)$$

where $F_{a'}$ is amplitude values of dry friction forces:

$$\begin{aligned} F_{a'\tilde{o}} &= f_{a'\tilde{o}} \cdot P_{\tilde{n}o\tilde{o}'} & F_{a'\tilde{o}'} &= f_{a'\tilde{o}'} \cdot P_{\tilde{n}o\tilde{o}'} \\ F_{a'\tilde{z}} &= f_{a'\tilde{z}} \cdot P_{\tilde{n}o\tilde{o}'} & F_{a'\tilde{\psi}} &= f_{a'\tilde{\psi}} \cdot P_{\tilde{n}o\tilde{o}'} \end{aligned}$$

Mutual shifts and forces emerging in leads of axle-box stage:

$$\left. \begin{array}{l} \Delta_{a'ximk}^{\tilde{i}} = x_i - (-1)^k b_{i\tilde{o}} \psi_i - x_{im} + (-1)^k b_{i\tilde{o}} \psi_{im}, \\ \Delta_{a'zimk}^{\tilde{i}} = y_i - (-1)^m l_i \psi_i - y_{im}, \\ \Delta_{a'zimk} = z_i + (-1)^m l_i \phi_i + (-1)^k b_{i\tilde{o}} \theta_i - z_{im} - (-1)^k b_{i\tilde{o}} \theta_{im}. \end{array} \right\} \quad (17)$$

$$\left. \begin{array}{l} S_{a'ximk}^{\tilde{i}} = k_{a'\tilde{x}} \Delta_{a'ximk}^{\tilde{i}} + \beta_{a'\tilde{x}} \dot{\Delta}_{a'ximk}^{\tilde{i}}, \\ S_{a'yimk}^{\tilde{i}} = k_{a'\tilde{y}} \Delta_{a'yimk}^{\tilde{i}} + \beta_{a'\tilde{y}} \dot{\Delta}_{a'yimk}^{\tilde{i}}, \\ S_{a'zimk}^{\tilde{i}} = k_{a'\tilde{z}} \Delta_{a'zimk}^{\tilde{i}} + \beta_{a'\tilde{z}} \dot{\Delta}_{a'zimk}^{\tilde{i}}. \end{array} \right\} \quad (18)$$

The leads and fasteners, installed in axle-box suspension, limit the shifts of carriage frame in respect of axle-wheel pair on horizontal plane in longitudinal and transverse directions. Let's mark as $\Delta_{a'\tilde{o}}$, $\Delta_{a'\tilde{o}'0}$ the respective spaces, in the limit of which the resilient sets of axle-box suspensions operate. After elimination of these spaces, it is necessary to assess the coefficients of rigidity and viscous friction of the structure. Shifts and forces arising after elimination of these spaces will be as follows:

$$\begin{aligned} \Delta_{a'ximk}^{\tilde{e}} &= \Delta_{a'ximk}, \\ \Delta_{a'yimk}^{\tilde{e}} &= \Delta_{a'yimk}, \end{aligned} \quad (19)$$

$$\begin{aligned} S_{a'ximk}^{\tilde{e}} &= \begin{cases} 0, \\ k_{a'\tilde{o}} [\Delta_{a'ximk}^{\tilde{e}} - (-1)^k \Delta_{a'x0}] \beta_{a'\tilde{o}} \dot{\Delta}_{a'ximk}^{\tilde{e}}, \end{cases} \\ S_{a'yimk}^{\tilde{e}} &= \begin{cases} 0, \\ k_{a'\tilde{y}} [\Delta_{a'yimk}^{\tilde{e}} - (-1)^k \Delta_{a'y0}] \beta_{a'\tilde{y}} \dot{\Delta}_{a'yimk}^{\tilde{e}}, \end{cases} \end{aligned}$$

$$\left. \begin{array}{l} \dot{a}\tilde{e}\tilde{e}e|\Delta_{a'ximk}^{\tilde{e}}| \leq \Delta_{a'x0}; \\ \dot{a}\tilde{e}\tilde{e}e|\Delta_{a'ximk}^{\tilde{e}}| > \Delta_{a'x0}; \\ \dot{a}\tilde{e}\tilde{e}e|\Delta_{a'yimk}^{\tilde{e}}| \leq \Delta_{a'o'0}; \\ \dot{a}\tilde{e}\tilde{e}e|\Delta_{a'yimk}^{\tilde{e}}| > \Delta_{a'o'0}. \end{array} \right\} \quad (20)$$

Forces, acting the axle-wheel pair in the contact zone, are usually determined using the Carter theory [3].

For making differential equations of fluctuation system, we will use the sort 2 Lagrange equation:

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{q}_n} \right) = Q_n \quad (21)$$

where O' is kinetic energy of the system; q_n is summarised coordinates; Q_n is respective summarised forces.

General expression of kinetic energy:

$$\begin{aligned} T = & \frac{1}{2} \left[a_x \dot{z}^2 + a_{\phi} \dot{\phi}^2 + a_{\theta} \dot{\theta}^2 + a_y \dot{y}^2 + a_{\psi} \dot{\psi}^2 + \right. \\ & + a_x \dot{x}^2 + \sum_{i=1}^2 (a_{zi} \dot{z}_i^2 + a_{\phi i} \dot{\phi}_i^2 + a_{\theta i} \dot{\theta}_i^2 + a_{yi} \dot{y}_i^2 + \\ & + a_{\psi i} \dot{\psi}_i^2 + a_{xi} \dot{x}_i^2 + a_{yti} \dot{y}_i^2 + a_{\psi ti} \dot{\psi}_i^2 + a_{xiti} \dot{x}_i^2) \\ & \left. + \sum_{i=1}^2 \sum_{m=1}^2 (a_{zim} \dot{z}_{im}^2 + a_{\theta im} \dot{\theta}_{im}^2 + a_{yim} \dot{y}_{im}^2 + a_{\psi im} \dot{\psi}_{im}^2 + \right. \\ & \left. + a_{xim} \dot{x}_{im}^2) + \sum_{i=1}^2 \sum_{m=1}^2 \sum_{k=1}^2 a_{ypimk} \dot{y}_{pimk}^2 \right] \quad (22) \end{aligned}$$

Let's make differential equations of system fluctuations. We will insert the expression of kinetic energy (22) into sort 2 Lagrange equation (21) and obtain the following system of differential equation:

$$a_n \ddot{q}_n = Q_n \quad (n = \overline{1, 52}) \quad (23)$$

For integration of this system of differential equations, a program is made.

Analogous mathematical models are made also for chassis of other rolling stock [3, 4]. With the help of mathematical model presented here, broad theoretic research was done in the field of passenger wagon spatial fluctuations. The research was made in speed range from 20 to 200 km/h for various road sections. These calculations greatly contributed to creation of new-class passenger wagons in Kriukovo factory [5].

4. Conclusion

We have presented mathematical model for description of spatial vibrations in four-axle passenger wagon with various types of carriages having two-stage resilient suspension. This model can be successfully employed to examine dynamic loads of passenger wagons and, at the same time, it allows determining rational parameters of both resilient stages of carriages.

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A WARRANTY COST MODEL WITH INTERMITTENT AND HETEROGENEOUS USAGE

Estimation of warranty servicing costs during the product life cycle is of great importance to the manufacturers. Earlier research has usually assumed that the product is in continuous use and the usage intensity is the same for all buyers. This paper deals with the problem of estimating the expected warranty cost for the case where the item usage is intermittent and of heterogeneous usage intensity over the product life cycle when sales occur continuously. The failure of the item is dependent on the number of times, the duration the unit has been used and the usage intensity. Also, the product sales depend on product price and design quality. We consider repairable and nonrepairable items and obtain results for the free-replacement warranty (FRW) and Pro-rata Warranty (PRW) policy. Furthermore, the models consider the influences of price level, investment growth and warranty execution effects for the expected warranty costs. It also incorporates the cash flows of warranty reserve costs at any time intervals during the product life cycle. A numerical example is given to illustrate the application of the models.

Keywords: Warranty, intermittent use, usage intensity, product sales.

1. Introduction

A warranty is a seller's assurance to a buyer that a product is or shall be as represented. It may be considered to be a contractual agreement between buyer and seller who are entered into upon sale of the product [1]. The warranty is considered to be the representation of the product quality. It can also be used as a very important marketing tool. Servicing warranty involves additional cost to the manufacturers and greatly influences their profit. So the manufacturer needs to create a warranty reserve fund before the product sale. If the manufacturer is too conservative and sets aside too much reserve fund, he will lose more investment repay opportunity. And if he is too risky, he will reduce the profit and even go bankrupt. Thus, an efficient warranty cost analysis is important to a company's production management and profitability.

Because of its importance, warranty cost analysis has received a lot of attention of many researchers. The handbook by Blischke and Murthy [1] is a collection of research papers dealing with warranty. A general treatment of warranty cost analysis can be found in [2-6] and the references cited therein. Dimtrov [7] modeled the virtual failure rate by considering the repair as the age-reducing or age-accelerating repair factor in the warranty cost analysis. Ja [8] estimated the warranty costs during the life cycle of a product under nonrenewable minimal repair warranty policy, based on a selected level of confidence. The model assumes the repair costs depend on the product age. Chukova evaluated related expected costs using alternating renewal process to model renewing free replacement warranties and non-renewing free replacement warranties in [9] and [10]. The models both allowed for non-zero repair time and associated cost with it. Mitra [11] investigated warranty programs that offer customers the option to renew warranty, after an initial period, for a certain premium. The paper explored the effect of such programs on market share and warranty costs. Reference [12] obtained the probability distributions of the manufacturer's rebate, cost, revenue and profit during a product cycle, under a combination free-replacement/pro-rata warranty policy, with the incorporation of the customer repurchase behavior under warranty. Balcer [13] derived moments of the user's replacement cost over time under

renewing pro-rata and non-renewing free-replacement policies. Jun [14] presented discounted warranty cost models for repairable series systems under free repair policy and pro-rata warranty policy. Dimtrov [15] modeled warranty claim as a marked point process and obtained particular results for non-stationary Poisson purchase process with periodic intensity function. Balachandran [16] dealt with warranty cost estimation of the product consisting of several components using Markovian approach. Markovian states are defined dependent on the number of failures of each component. The model assumes the failure rate constant. These examine a variety of warranty policies for both repairable and nonrepairable items. A review and summary of warranty analysis can also be found in [17-18]. Murthy [19] deals with the administration aspects of warranty.

In the models studied so far, it is implicitly assumed that the item is in continuous use. However, this is normally not the case and many items are used intermittently over the warranty period and the life of the item, such as television, rice cooker, microwave oven etc. The failure rate of an item when in use can be different from that when idle. In order to evaluate the warranty costs from a realistic viewpoint, we should study the failure models under various usage patterns. Murthy [20] studied the unit expected warranty cost during the warranty period for the item used intermittently and the duration of usage each time is often very small in relation to the time between usages. The item usage is modeled as a point process and the item failure is characterized by a discrete distribution and relates to the number of times the current unit has been used. They characterized the life of an item by usage number at failures. Murthy [21] further assumed that the item used intermittently can be either in use (U) or idle (I) and transitions between U and I in a random manner which is modeled by a continuous-time Markov chain. They obtained the expected warranty cost and assumed the transitions rate between the two states to be constant. Kim [22] assumed that the usage intensity varies across the buyer population. The failure rate was modeled as a function of the usage intensity and the expected warranty cost during the warranty period for the unit item was obtained. They considered the usage intensity was modeled as continuous and discrete random variables.

This paper develops the total warranty cost model during the product life cycle for continuous sales process of items used intermittently. The product sales are assumed to be dependent on product price and design quality. The item can be either in use or idle and the failure depends on the number of times, the duration and the usage intensity the unit has been used. The usage intensity varies across the population of users and is modeled as a continuous random variable. This model considers the influences of price level, investment growth and warranty execution effects and obtains the cash flows of warranty costs at any time intervals during the product life cycle. The outline of the paper is as follows. Section 2 deals with the model formulation of the usage pattern and failure. In section 3, we model the expected warranty cost sold for FRW and PRW policy during the product life cycle. A numerical example is given in Section 4 to illustrate the proposed models and make a contrast with continuous usage model. Finally, in Section 5, we conclude with a brief discussion of some extensions for future investigation.

2. Model Development

Notations:

c	Unit product cost, not including warranty cost
p	Unit product sale price, including warranty cost
w	Duration of warranty period
U	Usage intensity (random variable)
$G(u)$	Usage distribution function
$g(u)$	Usage intensity function
$c(t)$	Refund amount when the item fails under Pro-rata Warranty Policy (PRW)
$F(t)$	Distribution function for the first time to failure
$f(t)$	Probability density function associated with $F(t)$
$r(t)$	Failure rate function associated with $F(t)$
$p_i(t,u)$	Probability that the Markov chain $X(t)$ is in state i at time t conditional on the usage rate u , $0 \leq i \leq 1$
$\omega(w)$	Expected warranty cost per unit for a warranty period w
θ	Investment growth rate
ϕ	Expected change rate in the general price level
L	Product life cycle
$g(t,w)$	Warranty execution function for a warranty period w at time t
c_r	Expected minimal repair cost per failure for repairable product
$q(t)$	Sale rate at time t , $0 \leq t \leq L$
$v(\tau)$	Warranty return rate at time t , $0 \leq \tau \leq L + w$
$Q(t)$	Accumulated sales volume in $[0,t]$
$Y(t)$	Age of the unit at time t , $0 \leq Y(t) \leq t$
$\tau(Y(t))$	Duration for which the consumer has used the current unit, $0 \leq \tau(Y(t)) \leq Y$
$N(Y(t))$	Number of times the current unit has been used over the interval $[t - Y(t), t]$
$E[\tau(t)]$	Expected using duration during the interval $[0,t]$
$E[N(t)]$	Expected number of the item used during the interval $[0,t]$

2.1. Product Warranty Strategy

Many types of warranty policies have been used because of their importance. Blischke and Murthy [1] introduced a classification and definitions of various warranty strategies. In this paper, we consider the free replace-repair policy (FRW) and pro-rata warranty policy (PRW) which are defined as follows:

(1) *Free Replacement-repair Policy* (FRW): Under the policy, the seller agrees to repair or provide replacements or repair for failed items free of charge up to a time W from the time of the initial purchase. Typical applications of FRW are consumer products, ranging from inexpensive to relatively expensive items such as automobiles, refrigerators, TVs, electronic components, and so forth.

(2) *Pro-rata Warranty Policy* (PRW): Under the policy, the seller agrees to refund a fraction of the purchase price if the item fails before time w from the time of the initial purchase. The refund can be either a linear or nonlinear function of $w-t$, which defines the linear PRW and nonlinear PRW. The linear PRW applies to relatively inexpensive nonrepairable products such as batteries, tires, ceramics, and so on. The nonlinear PRW usually uses quadratic rebate function. The refund amount can be given as

$$c_1(t) = \begin{cases} \alpha(1-t/w)p, & 0 \leq t < w \\ 0, & \text{otherwise} \end{cases} \quad 0 < \alpha \leq 1 \quad (1a)$$

or

$$c_2(t) = \begin{cases} \alpha(1-t/w)^2 p, & 0 \leq t < w \\ 0, & \text{otherwise} \end{cases} \quad 0 < \alpha \leq 1 \quad (1b)$$

where $c_1(t)$, $c_2(t)$ are the refund amount when the item fails.

2.2. Product usage model

Different consumers have heterogeneous usage intensity for their different own characteristics to a product. For example, the usage intensity (in terms of load and frequency of usage per unit time) of a domestic washing machine varies depending on the size of the family and being used in various situations, such as hospital or at home. So the usage intensity across the buyer population is different. This is also true for many other domestic and industrial products. The product failure depends on the usage intensity and this in turn has an important influence on the expected warranty cost.

In this paper, we refer to the models presented by Kim and Djamanudin [22]. The usage intensity is modeled as a random variable with a distribution function $G(u)$ and density function $g(u)$ which characterizes the different usages across the user population. Conditional on the usage intensity $U=u$, the product failure distribution is given as $F(t,u)$. And $r(t,u)$ is the failure rate function associated with $F(t,u)$, which is given by

$$r(t,u) = k\delta(u)r_0(t,u) \quad (2)$$

where $k(>0)$ is a scale factor to reflect the usage intensity influence. $r_0(t,u)$ is failure rate for a initial design, which may be continuous case as reference [22]. We consider the case of intermittent usage in this paper, which will be obtained in the section 2.3, and $\delta(u)$ defines the effect of the usage intensity to the product which is modeled as

$$\delta(u) = \begin{cases} 1 & u_{min} \leq u \leq u_0 \\ (\frac{u}{u_0})^\varepsilon & u_0 < u \leq u_{max} \end{cases} \quad (3)$$

with $\varepsilon \geq 1$ and u_0 as the additional design parameters which represents the product quality.

The product is assumed to be used intermittently. As a result, at time t , $0 \leq t \leq w$, the product can be either in use (U) or idle (I). The transitions from I to U and form U to I occur in a random manner [21]. So we model the transitions by a two-state continuous time Markov chain formulation $X(t)$. Here

$X(t)=1$ if the item is in use at time t and $X(t)=0$ if the item is idle. Conditional on the usage rate $U=u$, the probabilities

$$\{X(t+\delta t) = j \mid X(t) = i\}, 0 \leq i, j \leq 1$$

are given by the following matrix:

$$X(t) \begin{cases} 1 & \overbrace{\lambda_1(u)\delta t \quad \lambda_1(u)\delta t}^{X(t+\delta t)} \\ 0 & \lambda_0(u)\delta t \quad 1 - \lambda_0(u)\delta t \end{cases}$$

We assume that the consumer uses the unit soon after purchase, i.e., $X(0)=1$.

2.3. Product failure model

We assume that the item is new at $t=0$, i.e., $Y(t)=t$. The item failure rate is dependent on the item historical usage condition. We refer to the models presented by Murthy [21]. Given the usage intensity u , we assume the failure rate is constant when the item is idle and the failure rate depends on the usage history of the current unit when the unit is in use [21]. Conditional on the usage rate u , the failure rate function G when the unit is in use is a linear function of the form

$$\begin{aligned} r_0(t, u \mid \tau(t), N(t), X(t)=1) &= G(Y(t), \tau(Y(t)), N(Y(t))) = \\ &= \theta_0 + \theta_1 t + \theta_2 \tau(t) + \theta_3 N(t) \end{aligned} \quad (4)$$

where $\theta_i, 0 \leq i \leq 3$ are nonnegative constants.

On removing the conditioning, we have

$$r_0(t, u \mid X(t)=1) = \theta_0 + \theta_1 t + \theta_2 E[\tau(t)] + \theta_3 E[N(t)] \quad (5)$$

From the theory of Markov chains [25], we have

$$E[\tau(t)] = \frac{\lambda_0(u)}{\lambda_0(u) + \lambda_1(u)} t + \frac{\lambda_1(u)}{(\lambda_0(u) + \lambda_1(u))^2} (1 - e^{-(\lambda_0(u) + \lambda_1(u))t}) \quad (6)$$

Similarly [21], we have

$$E[N(t)] = \frac{\lambda_0(u)\lambda_1(u)}{\lambda_0(u) + \lambda_1(u)} t + \frac{\lambda_0(u)\lambda_1(u)}{(\lambda_0(u) + \lambda_1(u))^2} (1 - e^{-(\lambda_0(u) + \lambda_1(u))t}) \quad (7)$$

The failure rate when the item is idle is given by

$$r_0(t, u \mid X(t)=0) = \varphi, \quad (\varphi > 0) \quad (8)$$

$\varphi \leq \theta_0$, which ensures that the failure rate when idle is always less than the failure rate when in use.

Using Eqs. (5) and (8), we have

$$r_0(t, u) = r_0(t, u \mid X(t)=1)p_1(t, u) + r_0(t, u \mid X(t)=0)p_0(t, u) \quad (9)$$

where $p_i(t, u)$, $0 \leq i \leq 1$ is the probability that the Markov chain $X(t)$ is in state i at time t . From the theory of Markov chains [21, 25], we have

$$p_1(t, u) = \frac{\lambda_0(u)}{\lambda_0(u) + \lambda_1(u)} + \frac{\lambda_1(u)}{\lambda_0(u) + \lambda_1(u)} e^{-(\lambda_0(u) + \lambda_1(u))t} \quad (10a)$$

$$p_0(t, u) = \frac{\lambda_1(u)}{\lambda_0(u) + \lambda_1(u)} - \frac{\lambda_1(u)}{\lambda_0(u) + \lambda_1(u)} e^{-(\lambda_0(u) + \lambda_1(u))t} \quad (10b)$$

Using Eqs. (5-8) and (10) in (9), we have

$$\begin{aligned} r_0(t, u) &= \frac{1}{\lambda_0(u) + \lambda_1(u)} \{ \lambda_0(u)[\theta_0 + \theta_1 t + \theta_2 E[\tau(t)] + \theta_3 E[N(t)]] + \lambda_1(u)\varphi \} \\ &+ \frac{\lambda_1(u)}{\lambda_0(u) + \lambda_1(u)} e^{-(\lambda_0(u) + \lambda_1(u))t} \{ \theta_0 - \varphi + \theta_1 t + \theta_2 E[\tau(t)] + \theta_3 E[N(t)] \} \end{aligned} \quad (11)$$

Using (11) in (2), we have $r(t, u)$. On removing the conditioning, the failure rate is given by

$$r(t) = \int_{u_{\min}}^{u_{\max}} r(t, u) dG(u) \quad (12)$$

Finally we can obtain $F(t, u)$ and $f(t, u)$ using the relationship

$$F(t, u) = 1 - \exp \left\{ - \int_0^t r(t, u) dt \right\}$$

and

$$f(t, u) = r(t, u) \exp \left\{ - \int_0^t r(t, u) dt \right\} \quad (13)$$

2.4. Warranty Execution Function

In warranty cost analysis, it is usually assumed that the warranty is fully claimed at the time of product failure, which is within the warranty period. In practice, the assumption is not always valid. For example, a consumer may develop dissatisfaction for the product and prefer to change brands rather than to exercise warranty. A customer may purchase some other product cheaper than the cost of repurchase of the same product using the warranty right [23].

Many factors influence customer behavior in exercising warranties such as the warranty time, warranty attrition due to costs of executing the warranty, the product class, the form of reimbursement, change in product preference, the consumer's geography position, and so on. The form of the weight function describes warranty not full execution factors. The execution function is usually to be a decreasing function of time. Patankar and Mitra [28] examined two examples of the conditional warranty execution weight function. They modeled the heterogeneity in consumer behavior in warranty execution with random variables and investigated its impact towards expected warranty cost. Liu [29] obtained the estimating warranty costs model for continuous sales process of nonrepairable products under pro-rate warranty policy, which modeled the warranty execution with deterministic and random variables. In this paper, we refer to the models presented by Liu [29], which is given by Eqs. (14) and is shown in Fig.1 when $k=0.5$.

$$g(t, w) = -\frac{k}{w^2} t^2 + 1 \quad 0 \leq t \leq w \quad (14)$$

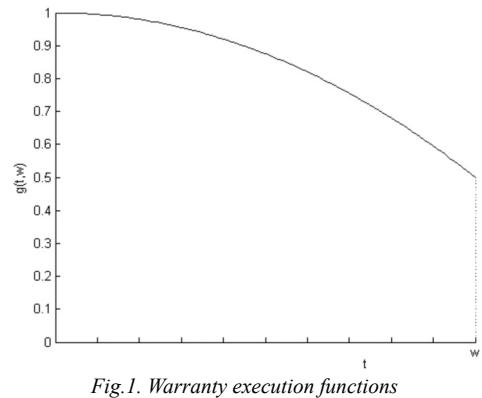


Fig.1. Warranty execution functions

2.5. Product Sale Model

In order to estimate the total expected warranty cost (and, ultimately, total profit) for a product, it is necessary to model the product sales as well. Many factors are involved in the product sale, such as the product class, quality, price, post-sale service, and the rival circumstance and so on. Many models express-

ing sales through time as a function of these factors have been developed. A demand model that explicitly considers warranty as a factor has been proposed by Glickman and Berger [26]. Demand is assumed to be a decreasing function of price and an increasing function of w . Bass and Bruce [27] presented an epidemic model which has been used to explain the penetration of many consumer durables in the American market. The Bass model assumes that there are two basic kinds of purchasers, innovators and consumers who are sensitive to the actions of their peers. In this paper, we assume the demand is a decreasing function of price and an increasing function of the product quality parameter u_0 , and the sales model is given by

$$q(t) = \frac{dQ(t)}{dt} = ku_0^a P(t)^{-b} \left[1 - \frac{Q(t)}{Q_M} \right] \left[\psi + \frac{Q(t)}{Q_M} \right] \quad (15)$$

$$Q(0) = Q_0$$

where $q(t)$ is the demand rate function, and $a, b, k > 0$. The interpretation of the parameters of this model is as follows: k is a scale factor to reflect the competitor and other environmental influence, such as the number of potential consumers, the consumer purchasing power, etc. a represents the design usage intensity elasticity; and b is price elasticity. $P(t)$ denotes unit sale price at time t (Marketing variable). The square brackets reflect the concept of sales as a diffusion process involving innovators and imitators as in the Bass model (see reference [27]). The parameter ψ reflects the relative influence of innovators.

The total sales during the product life cycle $Q(L)$ is given by

$$Q(L) = Q_0 + \int_0^L q(\tau) d\tau \quad (16)$$

with Q_0 is a parameter which captures the past experience at $t=0$, from research and development and pilot plant operation.

3. Warranty cost models during the life cycle

When an item is returned for rectification under warranty, the manufacturer incurs many costs, such as transportation cost, handling costs of warranty, material cost and labor cost, etc. We aggregate all of these costs into a single cost termed “warranty cost” for each claim. Because some of the costs are uncertain, this cost is a random variable [1]. The number of claims over the warranty period depends on the product quality, warranty policy and the type of rectification action used and these in turn determine the warranty costs. This paper considers repairable and nonrepairable items under FRW and PRW policy and minimal repair action for repairable items.

3.1. Warranty cost model under Free Replacement Warranty Policy (FRW)

3.1.1. Non-repairable product

For non-repairable product, let $M(t,u)$ denote the expected number of failures during the interval $[0,t]$, $0 \leq t \leq w$ conditional on $U = u$. From the renewal theory [25], we have

$$M(t,u) = F(t,u) + \int_0^t M(t,u) dF(t,u) \quad (17)$$

Removing the conditioning

$$M(t) = \int_{u_{\min}}^{u_{\max}} M(t,u) dG(u) \quad (18)$$

The warranty execution weight function that reflects not full execution factors is given by Eqs. (14). The warranty return rate $v_1(\tau)$ at time τ is given by

$$v_1(\tau) = \int_a^b q(\tau-t) g(t,w) dM(t) \quad (19)$$

where the lower and upper limits of the integral are as given in Table 1.

Thus the total expected warranty reserve costs in $[\tau, \tau+dt]$ can be evaluated by

$$h_1(\tau) = c \int_a^b q(\tau-t) g(t,w) e^{-(\theta+\phi)\tau} dM(t) \quad (20)$$

where the limits of the integral are the same as those given in Table 1.

Tab. 1. Lower and upper limits a, b for the integral

	a	b	Interval
$L \leq w$	0	τ	$0 \leq \tau \leq L$
	$\tau - L$	τ	$L < \tau \leq w$
	$\tau - L$	w	$w < \tau \leq L + w$
$L > w$	0	τ	$0 \leq \tau \leq w$
	0	w	$w \leq \tau \leq L$
	$\tau - L$	w	$L < \tau \leq L + w$

From Eqs. (20), the expected warranty costs in $[\tau_0, \tau_1]$ is given by

$$\int_{\tau_0}^{\tau_1} h_1(\tau) d\tau \quad (21)$$

3.1.2. Repairable product

For a repairable item, we consider the failed item is repaired minimally. For other rectification action, we can also obtain the models according to the models presented by Blischke and Murthy [1]. Under such a repair, the failure rate of the product after repair is the same as that just before the failure. Let $S(t,u)$ denote the expected number of failures during the interval $[0,t]$, $0 \leq t \leq w$ conditional on $U = u$. $S(t,u)$ is given by

$$S(t,u) = \int_0^t r(t,u) dt \quad 0 \leq t \leq w \quad (22)$$

By removing the conditioning

$$S(t) = \int_{u_{\min}}^{u_{\max}} dG(u) \int_0^t r(t,u) dt \quad 0 \leq t \leq w \quad (23)$$

The warranty execution weight function, which reflects not full execution factors, is given by Eqs. (14). The warranty return rate $v_2(\tau)$ at time τ is given by

$$v_2(\tau) = \int_a^b q(\tau-t) g(t,w) dS(t) \quad (24)$$

where the limits of the integral are the same as those given in Table 1.

Thus the total expected warranty reserve costs $h_2(\tau)$ in $[\tau, \tau+dt]$ can be evaluated by

$$h_2(\tau) = c_r \int_a^b q(\tau-t) g(t,w) e^{-(\theta+\phi)\tau} dS(t) \quad (25)$$

where c_r is expected minimal repair cost per failure for repairable product and the limits of the integral are the same as those given in Table 1.

The expected warranty costs in $[\tau_0, \tau_1]$ is given by

$$\int_{\tau_0}^{\tau_1} h_2(\tau) d\tau \quad (26)$$

3.2. Warranty cost model under the Pro-rata Warranty Policy (PRW)

Under PRW policy, the fraction refunded is a function which is given by Eqs. (1a) or (1b).

The product failure probability is given by

$$f(t) = \int_{u_{\min}}^{u_{\max}} f(t, u) dG(u) \quad (27)$$

The warranty execution weight function that reflects not full execution factors is given by Eqs. (14). The warranty return rate $v_3(\tau)$ at time τ is given by

$$v_3(\tau) = \int_a^b q(\tau - t) f(t) g(t, w) dt \quad (28)$$

The lower and upper limits for the integral $v_3(\tau)$ and $h_3(\tau)$ are given at Table 1. Thus the total expected warranty reserve costs $h_3(\tau)$ in $[\tau, \tau+d\tau]$ can be evaluated by

$$h_3(\tau) = \int_a^b q(\tau - t) f(t) g(t, w) c(t) e^{-(\theta+\phi)\tau} dt \quad (29)$$

From Eqs. (29), the expected warranty costs in $[\tau_0, \tau_1]$ is given by

$$\int_{\tau_0}^{\tau_1} h_3(\tau) d\tau \quad (30)$$

3.3. The unit product's expected warranty cost

The total warranty cost during the product life cycle is the sum of warranty cost for $Q(L)$ units. Since $Q(L)$ is large, according to the central limit theorem the total warranty cost can be approximated as being normally distributed with mean $Q(L)\omega(w)$ [25]. Thus the unit product's expected warranty cost during the life cycle can be evaluated by

$$\frac{\int_0^{L+w} h(\tau) d\tau}{Q(L)} \quad (31)$$

In general, it is not possible to derive analytical expressions for $M(t)$, $S(t)$ and the complex nature of the integrand for other equation. In this case, numerical integration methods can be used to evaluate the expected warranty reserve costs.

4. Illustrative example

4.1. Cost analysis for product used intermittently under FRW policy

First, we consider the warranty cost analysis for the repairable product under the free replacement policy as an example. We assume the usage intensity is given by a Gamma distribution with parameter α , i.e.

$$g(u) = \begin{cases} \frac{1}{\Gamma(\alpha)} u^{\alpha-1} e^{-u} & u > 0 \\ 0 & u \leq 0 \end{cases} \quad (31)$$

where

$$\Gamma(\alpha) = \int_0^\infty u^{\alpha-1} e^{-u} du$$

Let $\alpha = 2$. That is, $\Gamma(\alpha) = 1$, $g(u) = ue^{-u}$. We assume $\lambda_0(u) = \lambda_1(u) = u$, $u_0 = 1$, $k = 1$, $\varepsilon = 1$, $u_{\min} = 0$, $u_{\max} = 3$. So

$$\delta(u) = \begin{cases} 1 & 0 \leq u \leq 1 \\ u & 1 \leq u < 3 \end{cases}$$

For the sales rate model given by (15), let $\alpha = 0.5$, $b = 2$, $k = 2 \times 10^8$, $\psi = 0$, $Q_0 = 200$, $Q_M = 6000$, $L = 5$ years. We consider the case that the price is constant, i.e. $p(t) = p = 200$. So the sales model during the product life cycle is given as

$$q(t) = 5 \times 10^3 u_0^{0.5} (1 - Q(t)/6000)^{Q(t)/6000}$$

The sales rate function is shown in Fig.2 when $u_0 = 1$.

For failure model, let $\theta_i = 0.1$, $0 \leq i \leq 3$, $\varphi = 0.05$.

Using (6) and (7) in (11), we have $r_0(t, u)$. Using (2), (22) and (23), we have $S(t)$.

Thus from (24), we can obtain the expected warranty return rate during the product life cycle. The sales function and the corresponding warranty return rate functions are shown in Fig.2 for $w = 1$ year, $u_0 = 1$. From Fig. 2, the peak of the warranty return rate function lags the peak of the sales function, since failed products are returned in some periods after sales. From the warranty return rate, the expected number of failed unit returned for repair in any time periods can be evaluated.

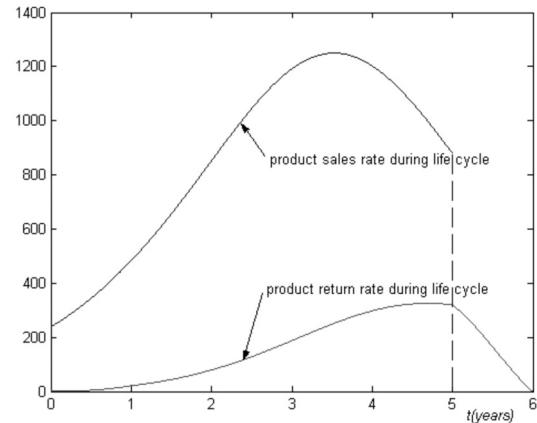


Fig. 2. Sales rate and warranty return rate during the product life cycle ($w=1$, $u_0=1$)

From the market experimental data [5], we let $\theta + \varphi = 0.1$. From (25), (26) and (31), we can obtain the expected warranty cost results. Table 2 shows the unit discounted expected warranty cost $\omega(w)$ and the total discounted warranty costs for a product with a life cycle of $L = 5$ for various values of w and u_0 . Management may use information in Table 2 to select the warranty period w and the design parameter u_0 . Given the life cycle of the product, the amount to be needed for warranty costs may be determined for a selected value of w . If the budgeted warranty costs are identified, a corresponding warranty period and the design parameter u_0 could be estimated. For example, for a product with a life cycle of $L = 5$ years, if a budget for expected warranty costs not to exceed $1500c_r$, the selected warranty period could be 1 year for various design parameter u_0 .

To study the sensitivity of the design parameter u_0 on the amount of required warranty costs, several values of u_0 are selected. Table 2 shows warranty costs for values of $u_0 = 1.0, 1.5, 2.0, 2.5$ respectively for different values of w . For example, for a product with a life cycle of $L = 5$ years, the expected warranty cost per unit for a warranty period $w = 1$ reduces from $0.3804c_r$ for $u_0 = 1$ to $0.1673c_r$ for $u_0 = 2$, which represents an decrease of about 56.0%. Higher values for u_0 are the result of better design and will cost more design expenses, so this may help us choose more better design plan when we know design expenses for various u_0 .

From (25), (26), the expected total warranty costs in a particular time period can be evaluated. The expected warranty costs in the various one-year intervals for $w = 1$ year, $u_0 = 1$ are given in Table 3. For example, in the second year of the warranty costs totally $39.0c_r$ will be paid.

Management may use the information in Table 2 and 3 to store appropriate cash for the warranty. As expected with an increase in the warranty period, warranty costs increase, but at different rates depending on the warranty period. For a 50% increase from 1 year to 1.5 years in warranty period, warranty costs would increase by approximately 82.6% for $u_0 = 1.5$. Such information could be used to determine the magnitude of the warranty parameter and the design parameter u_0 in order to maximize the expected profit.

4.2. Cost analysis for product used continuously under FRW policy

Now, we evaluate the expected warranty cost for continuous usage under FRW policy in order to make contrast with the intermittent usage case.

We assume the product initial design failure rate is given by

$$r_0(t, u) = 0.2 + 0.2t \quad (32)$$

We take the other parameters or equations as Section 4.1. Using (32), (2), (22) and (23), we have $S(t)$.

From (25), (26) and (31), we can obtain the expected warranty cost results for product used continuously with a life cycle of $L = 5$ for various values of w and u_0 , as showed in Table 4.

From Table 2 and Table 4, we can see the expected warranty cost has a large decrease from the continuous usage to intermittent usage. For example, the expected warranty cost per unit for a warranty period $w = 1$ and $u_0 = 1.5$ reduces from $0.4002c_r$ for continuous usage to $0.2281c_r$ for intermittent usage which represents an decrease of about 43.0%. If the manufacturer sets aside reserve fund according to the earlier research estimating warranty

cost model for product used intermittently, he will overestimate the warranty cost and lose more investment repay opportunity.

5. Conclusions

Warranty cost models for the case where the item is used intermittently over the product life cycle is considered in this paper. The model assumes that the usage intensity varies across the population of users and the failure of item is dependent on the number of times, the duration and the usage intensity the unit has been used as opposed to earlier models where the usage is continuous and the users are same. We consider both repairable and nonrepairable items under the FRW and PRW policy and the product sales depend on product price and design quality. Also, this model considers the influences of price level, investment growth and warranty execution effects and studies the cash flows of warranty reserve costs at any time intervals during the product life cycle, which is very important for the product management and post-sale service for the manufacturers. The models can be used to compute different sale programs and warranty policies and plan cash budget and service facilities for the product used intermittently.

This paper assumes that the product can be either in use or idle. In fact, the product can be multi-state. For example, this unit can be used either in the normal specified mode of usage or in an abnormal mode. The failure rate in abnormal use is much higher than in normal use. And the failure caused by the use in an abnormal mode is not within the warranty. Thus the warranty for the multi-state product could be a further research topic of interest.

Tab. 2. The expected warranty costs for product intermittently used

		$\omega(w)$				The total expected warranty cost, $Q(L)\omega(w)$			
w	u_0	1.0	1.5	2.0	2.5	1.0	1.5	2.0	2.5
0.5	0.1515c _r	0.0902c _r	0.0657c _r	0.0532c _r	702.25c _r	485.16c _r	374.45c _r	311.27c _r	
1	0.3804c _r	0.2281c _r	0.1673c _r	0.1365c _r	1762.9c _r	1227.1c _r	953.63c _r	797.85c _r	
1.5	0.6917c _r	0.4165c _r	0.3066c _r	0.2513c _r	3206.2c _r	2240.1c _r	1748.0c _r	1469.2c _r	

Tab. 3. The expected warranty costs in the various one-year intervals during the life cycle ($w = 1$ year, $u_0 = 1$, $L = 5$)

Time interval (Year)	0-1	1-2	2-3	3-4	4-5	5-6
Expected warranty costs	5.83c _r	39.0c _r	100.2c _r	172.6c _r	202.74c _r	95.7c _r

Tab. 4. The expected warranty costs for product continuously used

		$\omega(w)$				The total expected warranty cost, $Q(L)\omega(w)$			
w	u_0	1.0	1.5	2.0	2.5	1.0	1.5	2.0	2.5
0.5	0.2674c _r	0.1589c _r	0.1155c _r	0.0936c _r	1239.5c _r	854.46c _r	658.51c _r	547.02c _r	
1	0.6695c _r	0.4002c _r	0.2930c _r	0.2389c _r	3103.3c _r	2152.6c _r	1670.4c _r	1397.0c _r	
1.5	1.2204c _r	0.7334c _r	0.5402c _r	0.4431c _r	5656.4c _r	3945.1c _r	3079.7c _r	2590.9c _r	

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ZAGADNIENIA TECHNICZNE ZWIĄZANE Z TRANSPORTEM OSÓB NIEPEŁNOSPRAWNYCH

THE TECHNICAL PROBLEMS CONNECTED WITH THE TRANSPORT OF THE DISABLED PEOPLES

W artykule stwierdzono, że zdolność poruszania się ludzi jest nieodzowną częścią naszego życia. Właściwe planowanie oraz zintegrowany system transportu są bardzo ważne dla zapewnienia ludzkiej potrzeby poruszania się. Celem transportu jest więc zapewnienie wysokiej jakości usług dla wszystkich ludzi, także niepełnosprawnych. Wymaga to dostosowania technicznego przystanków oraz pojazdów do osób niepełnosprawnych. Artykuł omawia także inne wymagania techniczne stawiane środkom transportu z uwzględnieniem osób niepełnosprawnych.

Slowa kluczowe: transport, techniczne problemy, osoby niepełnosprawne.

This article deals with mobility as the necessary part of our life. The transport integration and planning are very important for providing sustainable mobility. In view of this aim the high-quality services have to be offered to passengers also for the disabled peoples. It includes also bus stops, vehicles suitable for disabled persons. This article presented the other technical conditions for the transport means which must carry the disabled peoples either.

Keywords: transport, the technical problems, the disabled peoples.

1. Introduction

Disabled persons form important and still growing part of society and the number of them will increase in the process of growing older population. At average 10 % of European Union population are disabled persons (50 million). The disabled person group includes people with physical and sensual disability, learning disturbances, with mental problems.

Transport and environment accessibility is very important for providing access to work, school and it enables to disabled persons to participate in the society life, to provide goods and services, to enjoy the social contacts with friends and family, to move free and independently within the urban or country area. If the accessibility is not provided for disabled persons in the same way as for healthy people, the disabled persons are underprivileged. Transport and environment accessibility is the basic right. It increases the independency of disabled persons and their active integration to the life of society.

The transport and environment accessibility is not only useful for disabled persons but also for other persons with limited capability of mobility, also for older people, parents with children, people with temporary disablement [1]. And also for people with large baggages. The good practice examples have shown that the transport system and environment accessibility increases the number and frequency of service users what is very important from the commercial point of view.

The mobility is the necessary part of our life for economy and also for the leisure time. Its negative impact influences our life. There are still more traffic congestions. The overflowed traffic arteries and congestions become the part of our everyday life. The scientists have already discovered the relation between the economic growth and the need of mobility. Simply with growing level of living the transport grows too. The globalization, increasing internationalization of economy and integration of Central European and East European countries generates the new requirements for transport system efficiency. The changes

of transport policy, transport management and infrastructure are necessary. It is also important to decrease the energy input with increasing transport volumes what will have the positive influence on the environment.

On the other side the increasing transport volumes have the negative impact on the environment and cause the decrease of quality of life. The transport consumes the same volume of energy as the industry production. There is also the problem with limited capacity of infrastructure. For reduction of these negative impacts the new conceptions of transport have to be discovered. The research and development has the important role in this part. The innovative research policy has the important task to change the relation between the transport, economy and environmentalism.

2. The mobility and planning of the integrated transport system

The urban and transport planning has many synergic effects. The coordination role is very important because it puts together the landscape planning with transport planning and it enables to create the integrated approach to these problems and it provides the integration of different transport modes. The factor of strong political lead is applied on the regional level [2,4]. It allows the coordination and planned development to the different transport modes what creates the compact system focused on user. The regional planning gives the possibility of direct subsidies to the suitable investment. This is the way how the means of public transport can be competitive with the individual transport.

The regional view of this problem allows to see the connection between the land utilization and transport planning and effectively creates the new formulas of land development which will increase the role of public transport and decrease the dependence on the individual transport.

The main reason of integration is untransparency and in-

efficiency of the state-of-the-art when many of citizens prefer individual transport because it is difficult to orientate in the tangle of transporters, time tables and prices. The integrated transport system means the providing of public transport when the different transport modes cooperate and create the transparent system with integrated tariff, transport conditions and regular intervals between links. The next stages could include the coverage of the rest of region in 5 years. Integrated system has 7 advantages: the unified tickets, integrated prices, season tickets, regular departures, possibilities of changes, improvement of services and improvement of awareness.

3. The social exclusion in transport area

Some persons are excluded from the system of easy availability. Our task is to eliminate the barriers to the mobility.

The sustainable mobility development for everyone is the global aim. This aim is achieved by the basic specific and operational targets.

The operational targets are the concrete tools which the specific aims are realized with. In the mobility programme there is mainly:

- 1) the creation of barrier free lines which will allow to all citizens the free and safe move by all means of transport,
- 2) the connection of barrier free lines with regional transport systems and overregional corridors,
- 3) the abidance by rules of free and safe moving for all the citizens in the case of all new constructed buildings and transport systems, including their repairs and reconstructions.

The mobility programme represents the complex of preventative measures in term of system elimination of all kinds of barriers, offers verified methodological processes for good-quality processing of proposals for making accessible all the transport chains (traffic roads, means of transport, objects for providing the services and information systems), increases the safety of traffic and also:

- 1) eliminates the most serious causes of accidents in traffic,
- 2) solutes the question of safe access to the labour market, development of human resources and increases the competitive advantage of labour force and improves the quality of mobility for all citizens,
- 3) creates conditions for integration of social excluded citizens,
- 4) limits the negative influences of transport to environment by supporting the integrated transport systems,
- 5) influences the thinking of citizens in relation to free and safe moving of people with limited

4. Types of services and vehicles

There is a wide spectrum of vehicle services including intercity transport, haulage, express and private services or services intended for excursions, domestic or abroad holiday. It is supposed that there is the corresponding infrastructure for this spectrum which is formed not only by terminals and stations but also by infrastructure for tourists [5]. There are also many variation of vehicles. Most of vehicles for tourists or for haulage are highbed. But many of intercity services use lowbed vehicles. The access of highbed buses for people on wheelchairs

is difficult, only with elevator, the new design has been created and the people on wheelchairs have the places near the bus driver on the relatively low position. Where the using of elevator is possible, it is placed on the side of vehicle in the front of back axle, or in the back of vehicle. Also the conditions for entry/exit in the terminal or station have to be considered.

Bus stations and railway stations are located in the city centre or close to it or in the multimodal changing stations (airports). The factors which should be considered include:

- sidewalks which are enough wide for access of people on wheelchairs, 2 m are recommended,
- cross-fall max. 2,5 %,
- controlled zebra crossings across the highly frequented roads, tactil warming surfaces, suitable acoustic and tactual signals,
- the access of roads and sidewalks to the railway station,
- clear directional marking to the railway station and if it is necessary, the using of tactful surfaces as the assistance for people with impaired vision,
- well-kept sidewalks with good street illumination.

It should be possible to separate the places for entry/exit for highbed and lowbed buses within the station and on many other places including the village and city locations. There is a lot of experiences with providing the infrastructure for lowbed buses. The key parts of design are:

- the area of entry. There are the slight differences in the opinions of the height of entry area. 160 mm is recommended (GB, Norway), 160 – 200 mm (Germany, France), 240 mm in Germany (Euskirchen), but the low access angle is required because the risk of bus damage increases.

Free barrier public transport in Germany features that the optimal maximum of horizontal and vertical gap between the kerb of entry area and the entry to the bus is 50 mm. Maximal values which are suitable for people on wheelchairs without any help are 50 mm vertical and 100 mm horizontal or 100 mm vertical and 50 mm horizontal.

5. The bus stop equipment and location on the street

There are several possibilities for bus stop: on the street side, on the parking space or on the places which enter to the roadway. The first possibility is the simplest and the most used. Sometimes it is criticized for the complication of traffic flow but in fact the traffic delay is minimal. The stop on the parking space does not solve this problem but it has some other disadvantages. For example more space is required and also the access to the traffic flow is more complicated for bus. The passengers waiting on the bus stop can be at risk from the front parts of bus. These parking spaces are not considered as suitable for parking.

The stops as places which enter to the roadway will be also influence the traffic, but there are some possibilities when the design could be suitable. On the roads which have a lot of space for parking on the side the using of this type of bus stop eliminates the parking in the space of the bus stop. In the country areas the parking space is recommended because of less frequented traffic and so the less risk of accidents.

The essentials of bus stop:

- possibility for seating,
- protection from the weather (rain),

- ticket machines,
- service information,
- bins,
- public telephone,
- illumination,
- possibility of call for assistance.

In the country, bus stops do not have all these essentials. We propose they would consist of following components:

- heightened entry area: dimensions should be determinated by the type of vehicle, e.g. for one door lowbed intercity buses – 3 m long and 2 m wide, for highbed buses 3 m long a 3 m wide. The entry area is expected to be longer than 3 m for passengers to be able to entry/exit the vehicle from/on paved area, but the length should be less (1,5 m),
- illumination of waiting area,
- timetable, bus column and information,
- possibilities for sitting.

There should be the seats, shelter and the bin on each bus stop in the small cities and suburban areas. The stops in centers should have all the components. The timetable and information about services should comprise the indicators of other bus services in surroundings, and also the map. The seating capacity should be determined by utilization rate of bus stops. The shelter should consist of space for at least one man on the wheelchair.

The people with fragile health, older people and disabled persons feel the extremum of temperature more intensively than the young healthy persons. This is the reason why the waiting zones should be sheltered even in the case of less used bus stops. The sitting is very important too. For many disabled persons every minute of waiting is very uncomfortable, tiring and sometimes painful. There should be the sitting places in the space of bus stations. The seating should be 470-480 mm high, with resting place form hands about 200 mm above the level of

seating. The recommended width is minimally 500 mm. The substandard seating should be 700 mm high and 550 – 600 mm wide. The space for people on the wheelchair is the necessity.

6. Conclusion

Despite of the great progress which has been done in the development of transport technologies, design or in the area of policy and legislation, the transport and environment accessibility is still limited in European Union.

European Union has accepted the legislation and initiatives in the transport area including to understand and meet needs of disabled persons. This is the result of the intensive campaign realized by European Disability Forum which was focused on providing distinguishing problems of disabled persons in all areas of European legislation.

In the area of environment the EU institutions refuse to apply pressure in the form of legal obligations because they reach behind the EU competences. Despite of it the initiatives exist in the European legislation which includes the environment accessibility in relation to the similar treatment in work, standards for elevators, health and safety.

New member states have the duty to implement the European policy and legislation through the changes in their national legislation from 1st May 2004. It is important that the organizations of disabled persons in the new member states and access countries lob at their governments with aim to provide the knowledge and implementation of requirements of EU regulation and direction associated with the accessibility of disabled persons.

This document gives the summary of regulations in the area of transport; environment and sustainable development of policies formed by the EU institutions and includes also the summary of relevant legislation initiatives. It is the help for the change of thinking and culture that separate the disabled persons from everyday life.

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ANALIZA WYZNACZENIA ROZKŁADU CIŚNIENIA W ŁOŻYSKU KORBOWYM

ANALYSIS OF DETERMINING PRESSURE DISTRIBUTION IN CRANK BEARING

Praca przedstawia analityczną metodę wyznaczenia rozkładu ciśnienia oleju w łożysku korbowym, stanowiące rozwiązanie równania Reynoldsa. Odpowiednie warunki brzegowe rozważano adekwatnie do modelu klasycznego ślimakowego łożyska poprzecznego zgodnie z parametrami technicznymi, charakteryzującymi łożysko wału korbowego silników S-4002/4003 stosowanych w ciągnikach rolniczych. Celem pracy było przeprowadzenie analizy porównawczej teoretycznych parametrów charakteryzujących pracę łożyska ślimakowego, jako wartości parametrów sygnału diagnostycznego. Równanie Reynoldsa (przy stałym współczynniku lepkości dynamicznej) metodą rozdzielenia zmiennych, sprowadzono do układu równań różniczkowych zwyczajnych, ostateczne rozwiązywanie zapisano w postaci ogólnej.

Słowa kluczowe: łożysko poprzeczne ślimakowe, smarowanie hydrodynamiczne, równanie Reynoldsa, równanie Riccatiego, analiza diagnostyczna.

The paper presents an analytical method of determining oil pressure distribution in a crank bearing, which makes a solution of the Reynold's equation. Proper boundary conditions were considered according to the classic model of a radial slide in agreement with technical parameters typical for the crankshaft bearing of S-4002/4003 engines used in agriculture tractors. The goal of this work was to conduct a comparative analysis of theoretical parameters characterizing the work of the slide bearing as the value of the diagnostic signal parameters. By using the method of separation of variables, the Reynold's equation (with constant coefficient of dynamic viscosity) was brought to the system of ordinary differential equations, and the ultimate solution was written in general form.

Keywords: radial slide bearing, hydrodynamic lubrication, the Reynold's equation, the Riccati's equation, diagnostic analysis.

1. Wprowadzenie

Diagnostyka techniczna oceny procesu zużycia mechanizmu korbowego przy dynamicznym obciążeniu łożyska, jest ściśle związana z oceną stanu technicznego węzła czop-panewka. W procesie eksploatacji silnika spalinowego zwiększa się luz w łożysku korbowym, co powoduje stopniowe ubywanie cieczy smarującej, związanej bezpośrednio ze zmianą geometrii klinu olejowego. Zmiany ekstremalnych wartości temperatury i momentów obrotowych sił tarcia wewnętrz łożyska, a stąd wynikający rozkład ciśnienia oleju w łożysku korbowym jest jednym z najważniejszych teoretycznych instrumentów służącym do wykrycia awaryjnych stanów pracy układu korbowego.

Rozkład ciśnienia oleju w łożysku korbowym (łożysko poprzeczne ślimakowe, można wyznaczyć jako rozwiązanie uogólnionego równania Reynoldsa.

$$\frac{\partial^2 P(x,z)}{\partial z^2} + \frac{\partial^2 P(x,z)}{\partial x^2} + \frac{3e \sin x/R}{Rc(1 - e \cos x/R)} \cdot \frac{\partial P(x,z)}{\partial z} = 0 \quad (1)$$

Gdzie: c - luz promieniowy [mm], e - mimośrodowość względna, R - promień czopa [mm].

Równanie (1) jest niejednorodnym równaniem różniczkowym o pochodnych cząstkowych, przy czym stopień jego złożoności zależy od wyboru warunków początkowych i brzegowych oraz od charakterystyki funkcji przedstawiających lepkość dynamiczną cieczy smarującej i wartości zużycia łożyska. Szczegółową analizę różnicznych warunków brzegowych oraz analitycznych własności lepkości dynamicznej i funkcji zużycia łożyska, można znaleźć w [2, 7, 9]. W związku z powyższym, w zagadnieniach diagnostycznych najczęściej posługujemy się przybliżonymi rozwiązaniami (1) lub rozwiązaniami zakładającymi znane *a priori* właściwości funkcji zużycia łożyska [2, 6, 7, 9].

1. Introduction

Technical diagnostics of the process assessment of crank mechanism wear with dynamic bearing load is closely connected with the technical state assessment of pin-liner knot. During using a combustion engine, clearance in the crank bearing increases what results in gradual decreasing of liquid lubricant, directly associated with the change of oil wedge geometry. The changes of extreme temperature values & turning moments of friction force inside the bearing, and hence resulting the oil pressure distribution in crank bearing is one of the most important theoretical instruments used for detecting emergency states of the crank system work.

The oil pressure distribution in crank bearing (radial slide bearing, might be determined as a solution of generalized Reynold's equation

$$\frac{\partial^2 P(x,z)}{\partial z^2} + \frac{\partial^2 P(x,z)}{\partial x^2} + \frac{3e \sin x/R}{Rc(1 - e \cos x/R)} \cdot \frac{\partial P(x,z)}{\partial z} = 0 \quad (1)$$

where: c - radial clearance [mm], e - relative eccentricity, R - pin radius [mm].

The equation (1) is a composite differential equation with partial derivatives, where its complexity grade depends on choice of initial & boundary conditions and on function characteristics presenting absolute viscosity of liquid lubricant and value of bearing wear. The specific analysis of various boundary conditions and analytical qualities of absolute viscosity & bearing wear functions, one can find in [2,7,9]. That being so, in diagnostic issues most often we use approximate solutions (1) or solutions assuming known *a priori* of properties of bearing wear function [2,6,7,9].

Zgodnie z założeniem [3], zależność

$$U(t) = -\frac{g(t)}{f(t)} + f^{-2}(t) \left(C - \int \frac{f'(t)}{g(t)f^2(t)} dt \right)^{-1} \quad (12)$$

jest ogólną całką równania (11), gdzie funkcje $f(t)$ i $g(t)$ spełniają następujące warunki:

$$\frac{f'(t)}{g(t)} = -\frac{2R}{t^2+1} \left[\frac{t^2 + \frac{1-\varepsilon}{1+\varepsilon}}{t^2+1} \right]^{\frac{3\varepsilon}{\varepsilon}} \quad (13)$$

$$\frac{g'(t)}{f(t)} = \frac{2RK^2}{t^2+1} \left[\frac{t^2 + \frac{1-\varepsilon}{1+\varepsilon}}{t^2+1} \right]^{\frac{3\varepsilon}{\varepsilon}} \quad (14)$$

Powyższy układ równań za pomocą prostych przekształceń, można przedstawić w uproszczonej formie:

$$f'(t)g'(t) = -\frac{4R^2K^2}{(t^2+1)^2} f(t)g(t) \quad (15)$$

$$g'(t)g(t) = -K^2 \left[\frac{t^2 + \frac{1-\varepsilon}{1+\varepsilon}}{t^2+1} \right]^{\frac{6\varepsilon}{\varepsilon}} f'(t)f(t) \quad (16)$$

Stąd rozwiązania układu spełniające równanie (11) można wybrać z rodziny funkcji

$$g(t) = \left(\frac{C_3}{t^2+1} + C_4 \right) f(t) \quad (17)$$

$$f(t) = \left[\frac{C_5 t^2}{t^2+1} \right]^{\frac{R^2 K^2 - \frac{3\varepsilon}{\varepsilon}}{\varepsilon}} + C_6 \quad (18)$$

Po obliczeniu wartości stałych C_3 - C_6 i po wstawieniu funkcji (17) i (18) do równań układu (15), (16), otrzymujemy ogólne rozwiązanie równania (11) o postaci:

$$U(t) = \left[\frac{t^2+1}{t^2} \right]^{\frac{R^2 K^2 - \frac{3\varepsilon}{\varepsilon}}{\varepsilon}} \cdot \left[-\frac{1}{t^2+1} + \left[\frac{t^2+1}{t^2} \right]^{R^2 K^2} \left(C + R^2 K^2 \left(\sum_{i=1}^{R^2 K^2} \binom{R^2 K^2}{i} \frac{1}{it^{2i}} - \ln t^2 \right)^{-1} \right) \right]$$

Ostateczne rozwiązanie równania (8) stanowi funkcja

$$T(x) = \left[\frac{\operatorname{tg}^2 x/2R + 1}{\operatorname{tg}^2 x/2R + \frac{1-\varepsilon}{1+\varepsilon}} \right]^{\frac{3\varepsilon}{\varepsilon}} \left[\frac{\operatorname{tg}^2 x/2R + 1}{\operatorname{tg}^2 x/2R} \right]^{R^2 K^2} \cdot \left[-\frac{1}{\operatorname{tg}^2 x/2R + 1} + \left[\frac{\operatorname{tg}^2 x/2R + 1}{\operatorname{tg}^2 x/2R} \right]^{R^2 K^2} \left(C + R^2 K^2 \left(\sum_{i=1}^{R^2 K^2} \binom{R^2 K^2}{i} \frac{1}{it^{2i}} - \ln \operatorname{tg}^2 x/2R \right)^{-1} \right) \right]$$

Po przeprowadzeniu elementarnych uproszczeniach rozwiązanie równania (8) zapisujemy w następującej postaci:

$$T(x) = \left[\sin^2 x/2R + q \cos^2 x/2R \right]^{\frac{3\varepsilon}{\varepsilon}} \left[\sin^2 x/2R \right]^{-R^2 K^2} \left[-\cos^2 x/2R + \left[\sin^2 x/2R \right]^{R^2 K^2} \Psi_{R,K}^{-1} \left(x/2R \right) \right] \quad (19)$$

gdzie: $q = \frac{1-\varepsilon}{1+\varepsilon}$

$$\Psi_{R,K} \left(x/2R \right) = \left(C + R^2 K^2 \left(\sum_{i=1}^{R^2 K^2} \binom{R^2 K^2}{i} \frac{1}{it^{2i}} - \ln \operatorname{tg}^2 x/2R \right) \right) \quad (20)$$

According to assumption [3], dependence

$$U(t) = -\frac{g(t)}{f(t)} + f^{-2}(t) \left(C - \int \frac{f'(t)}{g(t)f^2(t)} dt \right)^{-1} \quad (12)$$

is a general equation integral (11), where functions $f(t)$ & $g(t)$ meet the following conditions:

$$\frac{f'(t)}{g(t)} = -\frac{2R}{t^2+1} \left[\frac{t^2 + \frac{1-\varepsilon}{1+\varepsilon}}{t^2+1} \right]^{\frac{3\varepsilon}{\varepsilon}} \quad (13)$$

$$\frac{g'(t)}{f(t)} = \frac{2RK^2}{t^2+1} \left[\frac{t^2 + \frac{1-\varepsilon}{1+\varepsilon}}{t^2+1} \right]^{\frac{3\varepsilon}{\varepsilon}} \quad (14)$$

Above equation system with the use of simple transformations might be presented in a simplified form:

$$f'(t)g'(t) = -\frac{4R^2 K^2}{(t^2+1)^2} f(t)g(t) \quad (15)$$

$$g'(t)g(t) = -K^2 \left[\frac{t^2 + \frac{1-\varepsilon}{1+\varepsilon}}{t^2+1} \right]^{\frac{6\varepsilon}{\varepsilon}} f'(t)f(t) \quad (16)$$

Hence the system solutions realizing equation (11) can be chosen from the family of functions

$$g(t) = \left(\frac{C_3}{t^2+1} + C_4 \right) f(t) \quad (17)$$

$$f(t) = \left[\frac{C_5 t^2}{t^2+1} \right]^{\frac{R^2 K^2 - \frac{3\varepsilon}{\varepsilon}}{\varepsilon}} + C_6 \quad (18)$$

After calculating constant values C_3 - C_6 & placing functions (17) & (18) in the system equations (15), (16), we receive general solution of the equation (11) in the form of:

Ultimate solution of the equation (8) makes the function

After conducting elementary reductions the equation solution (8) we write in the following form:

where: $q = \frac{1-\varepsilon}{1+\varepsilon}$

$$\Psi_{R,K} \left(x/2R \right) = \left(C + R^2 K^2 \left(\sum_{i=1}^{R^2 K^2} \binom{R^2 K^2}{i} \frac{1}{it^{2i}} - \ln \operatorname{tg}^2 x/2R \right) \right) \quad (20)$$

Rozwiązywanie równania (7) na mocy zależności (19) zapisuje się następująco:

$$A(x) = C' \exp \left\{ \int T(x) dx \right\} \quad (21)$$

Wzory (19) i (20) można zapisać również w postaci:

$$\begin{aligned} T(x) &= \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] \\ \Psi(x/R) &= C + R^2 K^2 \left[\sum_{i=1}^{R^2 K^2} \binom{R^2 K^2}{i} \frac{1}{i} \cdot \left(\frac{1 + \cos x/R}{1 - \cos x/R} \right)^i - \ln \frac{1 - \cos x/R}{1 + \cos x/R} \right] \end{aligned} \quad (19a)$$

Ogólne rozwiązywanie równania (1) otrzymujemy na mocy wzorów (21), (8), (7), (6):

$$P(x, z) = p_0 + C_1 z + C_2 + \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \sum_{K=1}^{\infty} (C_{1K} e^{Kz} + C_{2K} e^{-Kz}) \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] \quad (22)$$

gdzie stałe C_1 , C_2 , C_{1K} oraz C_{2K} można wyznaczyć z warunków brzegowych (2) - (4).

3. Wyznaczenie stałych oraz konstrukcja rozwiązania

Przy uprzednio przyjętych warunkach brzegowych (2) otrzymujemy zależności

$$C_1 \frac{L}{2} + C_2 = 0$$

oraz

$$C_{2K} + C_{1K} e^{KL} = 0$$

stąd mamy

$$C_2 = -C_1 \frac{L}{2} \quad C_{2K} = -C_{1K} e^{KL}$$

stąd zależność (22) można zapisać następująco:

$$P(x, z) = p_0 + C_1 z - C_1 \frac{L}{2} + \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot \sum_{K=1}^{\infty} C_{1K} (e^{Kz} - e^{KL}) \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] \quad (23)$$

Następnie zastosujemy warunek brzegowy (3) do rozwiązań (23) otrzymując

$$P_w = p_0 - C_1 \frac{L}{2} + \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot \sum_{K=1}^{\infty} C_{1K} (1 - e^{KL}) \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] \quad (24)$$

Pochodna cząstkowa funkcji (23) względem zmiennej z oraz zależność (24) zastosowana do warunku brzegowego (4) pozwala otrzymać następującą tożsamość

$$\begin{aligned} C_1 + \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot \sum_{K=1}^{\infty} C_{1K} K (1 + e^{KL}) \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] &= -\frac{3\pi a^4 (p_z - p_w)}{4c^3 \eta L (1 - \varepsilon \cos x/R)^3} = \\ &= -\frac{3\pi a^4}{4c^3 \eta L (1 - \varepsilon \cos x/R)^3} \left\{ p_z - p_0 + C_1 \frac{L}{2} - \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot \sum_{K=1}^{\infty} C_{1K} (1 - e^{KL}) \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] \right\} \end{aligned} \quad (25)$$

Solution of the equation (7) in virtue of dependence (19) is written in the following way

$$A(x) = C' \exp \left\{ \int T(x) dx \right\} \quad (21)$$

Formulas (19) & (20) might be written also in the form of

General solution of the equation (1) we receive in virtue of formulas (21), (8), (7), (6):

3. Determining constants & the structure of solution

With former accepted boundary conditions (2) we receive dependences

$$C_1 \frac{L}{2} + C_2 = 0$$

and

$$C_{2K} + C_{1K} e^{KL} = 0$$

therefore we have

$$C_2 = -C_1 \frac{L}{2} \quad C_{2K} = -C_{1K} e^{KL}$$

hence dependence (22) might be written like this:

$$P(x, z) = p_0 + C_1 z - C_1 \frac{L}{2} + \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot \sum_{K=1}^{\infty} C_{1K} (e^{Kz} - e^{KL}) \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] \quad (23)$$

Next we use boundary condition (3) for solution (23) receiving

$$P_w = p_0 - C_1 \frac{L}{2} + \left[\frac{1 - \varepsilon \cos x/R}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot \sum_{K=1}^{\infty} C_{1K} (1 - e^{KL}) \cdot \left[-\frac{\sin^2 x/R}{4} \cdot \left(\frac{1 - \cos x/R}{2} \right)^{-(R^2 K^2 + 1)} + \Psi_{RK}^{-1}(x/R) \right] \quad (24)$$

Partial derivative of function (23) toward variable z and dependence (24) used to boundary condition (4) implicates the following identity

Stąd otrzymujemy

$$C_1 = -(p_z - p_0 + C_1 \frac{L}{2} \frac{15\pi a^4}{2c^3 \eta L}), \quad C_1 = -\frac{\Delta_L}{1 + \frac{L}{2} \Delta_L} (p_z - p_0)$$

gdzie :

$$\Delta_L = \frac{15\pi a^4}{2c^3 \eta L}$$

Wykorzystując otrzymane wyrażenie dla stałej C_1 według równania (24), można wyznaczyć stałą C_{11} następująco:

$$C_{11} = -\frac{3\Delta_L \Gamma_L (p_z - p_0) C_1}{(1 + \varepsilon)^{\frac{3\varepsilon}{\varepsilon}} \left[1 + \frac{1 + \varepsilon}{1 - \varepsilon} C_1 e^L + \Gamma_L \left(\frac{(1+3\varepsilon)^2}{1-\varepsilon^2} \left(\frac{4\Gamma_L - \varepsilon^2 \Delta_L}{3\Delta_L} \right) \cdot (e^L - 1) \right) \right]} \quad (26)$$

gdzie w mianowniku wyrażenia (26) pominieliśmy składniki sumy o wartościach rzędu ε^4 oraz przyjęliśmy założenie

$$\Gamma_L = \frac{1 - \varepsilon^2}{1 + 3\varepsilon} \Delta_L (e^L - 1) \quad (27)$$

Analogicznie można wyznaczyć wartości współczynników $C_{12}, C_{13}, \dots, C_{1K}$, jednak należy zauważać, iż wartości wymienionych współczynników są wielkościami powyżej rzędu ε^4 .

4. Wykorzystanie analitycznego rozkładu zmiany ciśnienia oleju jako sygnału diagnostycznego

Analiza parametrów sygnału diagnostycznego lożysk wału korbowego podczas pracy silnika, wymaga przeprowadzenia niezbędnych pomiarów między innymi prędkości obrotowych, obciążenia wału korbowego oraz względnego spadku ciśnienia oleju. W. Piekarski [4,5] przedstawił przykład sporządzania pomiarów sygnału diagnostycznego względnego spadku ciśnienia oleju lożyska korbowego w aspekcie diagnostyki technicznej.

Wyniki badań parametrów sygnałów diagnostycznych (S_j) otrzymano drogą pomiarów względnego spadku ciśnienia oleju na urządzeniu pomiarowym ze zwężką pomiarową przy trzech prędkościach obrotowych silnika: 600, 1600, 2000 obr/min. dla 6 punktów pomiarowych wyznaczonych czasem pracy silnika dla (100, 500, 900, 1300, 1700, 2100 godzin pracy).

Szczegółowa ocena stanu podsystemu korbowego została dokonana przy zastosowaniu złożonego zestawu pomiarowego, wykorzystującego sygnał ciśnienia oleju P_N wewnętrz lożyska korbowego na płaszczyźnie symetrii panewki (plaszczyna $z = 0$) w 6 charakterystycznych punkach (punkty $x = \frac{\pi RN}{3}$, gdzie $N = 0,1,2\dots5$) przy czym $P_0 = p_w$. Zatem parametr sygnału diagnostycznego przekazywanego z urządzenia pomiarowego opiera się na liczbowej wartością gradientu ciśnienia, którą można porównać z wartością teoretyczną otrzymaną z rozkładu ciśnienia (23) następująco:

$$\frac{\partial P}{\partial z} \left(\frac{\pi RN}{3}, 0 \right) = C_1 + \left[\frac{1 - \varepsilon \cos \frac{\pi N}{3}}{1 + \varepsilon} \right]^{\frac{3\varepsilon}{\varepsilon}} \cdot C_{11} \left(1 + e^{\frac{L}{R}} \right) \cdot \left[\Psi_{R1}^{-1} \left(\frac{\pi N}{3} \right) - \frac{\sin^2 \left(\frac{\pi N}{3} \right)}{4} \left(\frac{1 - \cos \left(\frac{\pi N}{3} \right)}{1 + \varepsilon} \right)^{-(R^2+1)} \right]$$

W szczególności na wlocie lożyska otrzymujemy wartość

$$\left[\frac{\partial P}{\partial z} (0,0) \right]_w = C_1 + \left(\frac{1 - \varepsilon}{1 + \varepsilon} \right)^{\frac{3\varepsilon}{\varepsilon}} C_{11} \left(1 + e^{\frac{L}{R}} \right) \Psi_{R1}^{-1} (0) = C_1 + \frac{1 + \varepsilon}{\varepsilon R^2} \left(\frac{1 - \varepsilon}{1 + \varepsilon} \right)^{\frac{3\varepsilon}{\varepsilon}} C_{11} \left(1 + e^{\frac{L}{R}} \right)$$

Hence we receive

$$C_1 = -(p_z - p_0 + C_1 \frac{L}{2} \frac{15\pi a^4}{2c^3 \eta L}), \quad C_1 = -\frac{\Delta_L}{1 + \frac{L}{2} \Delta_L} (p_z - p_0)$$

where :

$$\Delta_L = \frac{15\pi a^4}{2c^3 \eta L}$$

Using a received expression for constant C_1 according to equation (24), one can determine constant C_{11} in the following way:

$$\Gamma_L = \frac{1 - \varepsilon^2}{1 + 3\varepsilon} \Delta_L (e^L - 1) \quad (27)$$

Analogically we can determine values of coefficients $C_{12}, C_{13}, \dots, C_{1K}$, however it should be noticed that the values of mentioned coefficients are quantities above the order ε^4 .

4. Using the analytical change distribution of oil pressure as a diagnostic signal

The analysis of diagnostic signal parameters of crankshaft bearings during engine work, needs carrying out necessary measurements such as rotational speed, crankshaft load and relative oil pressure drop. W. Piekarski [8, 11] presented an example of measuring diagnostic signal of relative oil pressure drop of crank bearing in the aspect of technical diagnostics. The research results of diagnostic signals parameters (S_j) were obtained by measurements of relative oil pressure drop in measuring device with inlet at 3 engine speeds: 600, 1600, 2000 rev/min. for 6 measuring points determined by time of engine work for (100, 500, 900, 1300, 1700, 2100 work hours).

Specific assessment of crank subsystem condition was carried out by applying a complex measuring set using the signal of oil pressure P_N inside crank bearing on the symmetry plane of bearing (plane $z = 0$) in six characteristic points (points

$x = \frac{\pi RN}{3}$, where $N = 0,1,2\dots5$), with $P_0 = p_w$. Therefore the parameter of diagnostic signal transferred from the measuring device is based on numerical value of pressure gradient, which can be compared to the theoretical value obtained from pressure distribution (23) in that way:

Particularly at the bearing inlet we receive the value

5. Podsumowanie i wnioski

Wymagania odnośnie postępu eksploatacyjnego zaczynają być coraz częściej dostrzegane i formułowane. Stwierdzono bowiem, że efektywność gospodarowania obiektami technicznymi obniża w wielu przypadkach wysokie nakłady eksploatacyjne, przekraczające nierzaz nakłady z tytułu projektowania i wytwarzania. Wysokie nakłady eksploatacyjne można zmniejszyć przez poprawę jakości obiektów technicznych, a także warunków ich użytkowania i obsługiwanego. W tym celu niezbędne jest dążenie do racjonalnej, opartej na naukowych podstawach eksploatacji obiektów technicznych.

Warunki współpracy podsystemu funkcjonalnego tłok – pierścień – cylinder oraz podsystemu korbowego czop – panewka decydują o niezawodnym działaniu silnika. Pogorszenie warunków współpracy tych podsystemów w wyniku procesów zużycia prowadzi do przedwczesnego zużycia silnika, a jeszcze przedtem do znacznego wzrostu zużycia paliwa i oleju oraz zwiększenia trudności w jego rozruchu.

Główne zagadnienie analizowane w pracy w związku z formułowaniem własnej metody postępowania w badaniach, było związane z możliwościami opisu fizycznych zjawisk zużycia zachodzących w podsystemie korbowym czop – panewka, wyznaczonych metodami oceny przebiegu zmian szczelności w podsystemach funkcjonalnych silnika. Dotychczasowy stan wiedzy o zagadnieniach procesów zużycia i związany z tym problem zmian szczelności podsystemu funkcjonalnego czop – panewka nie pozwalał na jednoznaczne i szczegółowe określenie zależności między cechami ich stanu a wartością parametrów sygnałów diagnostycznych.

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5. Summing up & conclusions

Requirements concerning operational progress are becoming noticed and formulated more often. It has been stated that efficiency of managing technical objects in many cases decreases high operational costs exceeding often designing & manufacturing expenditures. High operational costs might be decreased by improving technical objects quality and also conditions of using & operating them. In order to do that it is necessary to pursue a rational, scientifically-based operation of technical objects.

Conditions of cooperation between the functional subsystem ‘piston-rings- cylinder’ and the crank subsystem ‘pin-bearing’ decide about a reliable engine work. Worsening of cooperation conditions of these subsystems as a result of wear processes leads to an early engine wear, and before that to a significant increase of fuel & oil consumption and bigger difficulties in its starting.

The main issue, analysed in the project concerning formulation of own conduct method in research, was connected with possibilities of describing physical wear effects proceeding in the crank subsystem ‘pin-bearing’. They were determined by the assessment methods of change course of tightness in the engine functional subsystems. Current knowledge of the wear processes issues and the problem of tightness changes in the functional subsystem ‘pin-bearing’ have not allowed to determine a clear & detailed dependence between their state qualities and the value of diagnostic signals parameters.

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OBECNA POZYCJA I PERSPEKTYWY ZINTEGROWANEGO SYSTEMU TRANSPORTU W REPUBLICE SŁOWACKIEJ

THE CURRENT POSITION AND PERSPECTIVES OF THE INTEGRATED TRANSPORT SYSTEMS IN SLOVAK REPUBLIC

W artykule zaprezentowano aktualny stan zintegrowanego systemu transportu na terenie Republiki Słowackiej. Zaprezentowano także analizę podstaw prawnych, rodzaje oraz zalety i wady tego systemu transportu. Artykuł prezentuje także podstawowe warunki techniczne, jakie muszą być spełnione i ustalone w Republice Słowackiej aby w miastach i lokalnych regionach wzrosła liczba zintegrowanych systemów transportowych.

Slowa kluczowe: Transport publiczny, zintegrowany system transportu.

The paper deals with current state of integrated transport systems in the Slovak Republic (SR). There is an analysis of legislative framework of transport system (ITS), description of ITS attributes, advantages and disadvantages of ITS operating in SR in the paper. The paper also points out underlying technical conditions necessary for existence of ITS, which should be established in SR in order to increase the number of ITS projects in cities and regions in SR.

Keywords: Public transport, Integrated transport systems.

1. Introduction

There is necessity to take different look at state, region and city transport policy due to factors such as expanding transport requirements, increasing number of congestions, negative impacts on quality of life. This new approach, with goal to meet requirements of sustainable transport and functional usage of both city and regional area, must clearly accept elimination of negative factors, such as pollution of air, increasing risk of transport accidents with their negative impacts, waste of time public transport etc.

Although there is broad array of tools for state interventions in transport market with aim to eliminate mentioned negative impacts. According to the project "TRANSPLUS" [7] the following three types of integrated transport and regional politics are especially effective:

- upgrading of infrastructures for short distances,
- reducing of automobile transport,
- improving of public passenger transport services.

Upgrading of infrastructures for short distances

This policy is focused on development of localities with possibilities for moving of pedestrians and cyclists with no necessity to use cars, and thus encouraging of using alternative transport systems. It covers building of hierarchical whole-city cyclic network in an attractive environment connecting important localities and social facilities. It requires both building of an information system providing enough information on lines connecting various parts of the city dedicated to pedestrians and cyclists and establishing of conditions respecting pedestrians and cyclists.

Reducing of automobile transport

This policy is focused on limiting of undesired entrances of cars into urban areas. It covers reducing of negative impacts on noise, air quality, safety and aesthetic of cities, parking slots and regulation of entrances of private cars into public areas.

Improving of public transport services

This policy is focused on new structure of settlements oriented on using public transport. In other words it is oriented on concentration of urban growth and sub-centres around nodes and public transport corridors and renovation of railway stations and their surroundings. Improving of public transport services should increase availability of public transport in existing settlements by either renovation or expanding lines for light trains and trams or continual development of systems of tram and bus lines in smaller cities. Important and effective solution is integration of different transport modes with aim of providing public transport services of high quality, comfort, speed and frequency, in other words development of integrated transport systems [8].

2. Integrated transport system and legislative framework in Slovak Republic

Integrated transport system is a perspective solution in regional transportation. Responsibility of regional governments for securing regional transportation is not directly imposed by law. It is indirectly imposed by the law on local government [1], in which there is specified that a local government is responsible for general development of particular region and needs of its inhabitants by executing of the following activities:

- forming and executing of programme of economic, social and cultural development of given region of local government,
- undertaking of planning activities relating to region,
- development of preconditions for optimal arrangement of relations among settlements and other elements of given region.

There have been delegated some responsibilities from state bodies onto local governments in SR. Among others those relating to transport are the following ones [2]:

- relating to railways and trams:
 - approving of prepositions of schedules and its modification

- cations before its publishing,
- executing of delegated state competencies relating to trams.
- relating to road transport:
 - Granting and cancelling of transport licences in interstate regular bus transport,
 - Approving of schedules in interstate regular bus transport,
 - Signing of agreements on public transport in general interest with operators and paying off losses resulting from its operation (by signing of the agreement the operator commits to meet obligations to public).

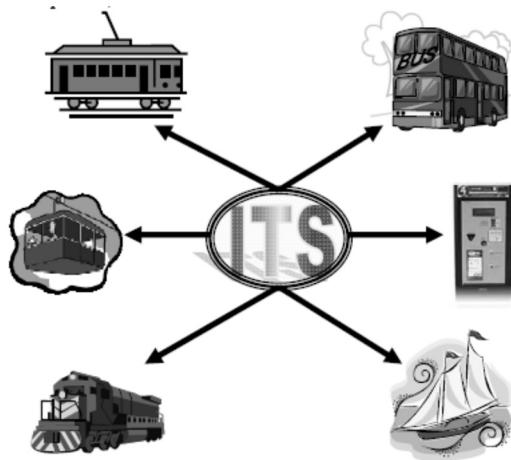


Fig. 1. The range of the integrated transport system

Different range of responsibilities in railway and road transport evokes that public transport in SR is regulated in each mode by specific legislative framework [4]. There is a specific law for road public transport and specific law for railway public transport. It means that a transport operator providing transport services in both railway and road transport has to follow at least 2 acts: Railway Act and Act on road transport.

These two Acts cover the issue of integrated transport system, but there is no single act dedicated to all aspects of providing transport services in an integrated transport system.

3. Integrated transport systems in the Slovak Republic

Integrated transport system is a system of transport operation designed for a specific area by public transport consists of various transport modes or covers lines of several operators within which passengers are transported according to unified both transport and tariff conditions.

ITS from the operator point of view:

In ITS transport is provided by various transport means: railways, tube, trams, buses, cableways and boats. Integration may also cover bikes and cars through Park & Ride or Bike & Ride. Transport services in ITS can provide various operators. However, schedules for particular lines within ITS should be optimised regardless which operator operates a given line. Degree and way of integration differs in ITS projects.

We can say that current urban transport systems and regional and domestic passenger railway transport have characteri-

ties of ITS. However, ITS is usually called transport systems either developed by extending existing system of public passenger transport into remote areas or by integration of more traditional transport systems in particular cities (urban transport, railway transport, intercity transport).

Currently, there are zone and sectional tariffs usually applied in ITS. It means that the covered area is divided into sections. If the area is divided into circles then there is agglomeration in the middle. If the area consists of more agglomerations then they made zones and among zones there is inter-zone transport.

ITS from a customer point of view:

From a customer point of view an integrated transport system means integration of schedules, transport conditions and tariffs. Customers are allowed to travel on single ticket and on the same conditions by different modes of transport. ITS is mostly developed in agglomeration with aim to increase inhabitants' quality of life and offer them frequent, high quality, speedy and comfortable transport.

Results of increasing of quality of life are the following ones [9]:

- decreasing of level of noise,
- decreasing of amount of air pollutants,
- decreasing of costs of building new infrastructure for automobiles,
- increasing of safety,
- increasing of travel comfort.

Essential conditions for establishing of ITS:

- preferences for ITS transport vehicles over automobiles,
- jointly used and shared information system for all transport modes,
- shuttle transport services and timetables (regular and easily remembered intervals of arrivals and departures),
- unified tariffs,
- railway transport is the bone of ITS complemented by bus transport (parallel railway and bus transport lines are eliminated).

There have been operated the following integrated transport systems in the Slovak republic:

- Integrated transport system of Bratislava "BID",
- Regional integrated transport system of Žilina "ŽRIDS",
- Integrated transport system of Košice "KIDS".

These transport systems are located in the three biggest cities (according to number of inhabitants): Bratislava, Košice, Žilina.

Integrated transport system of Bratislava :

The first attempt to develop an integrated transport system in Bratislava was undertaken in 2001. It allowed passengers to buy a ticket for tram with a coupon for railway and bus transport. ITS is operated through cooperation of railway operator Železničná spoločnosť Slovensko, public passenger road operator Slovenská autobusová doprava providing both local and interstate transport services, and operator Dopravný podnik Bratislava, providing public urban transport services. At present, BID covers urban, intercity, and local public passenger road transport and passenger railway transport in Bratislava. It allows traveling on single ticket of operator Dopravný podnik Bratislava bought with a coupon of BID. BID has proved to

be an effective solution and now Bratislava tries to eliminate parallel lines. Since March 2008 the possibility of travelling on single ticket will become reality. In 2009 BID is planning to expand to Trnava district, to the Czech and Austrian republic, and integrate dispatchers of engaged operators.

Regional integrated transport system of Žilina:

In 2003 there started a cooperation among municipalities Žilina and Rajec and a railway operator Železničná spoločnosť Slovensko and urban public passenger operator Dopravný podnik Žilina with aim to develop ITS in the city Žilina. ITS in Žilina is based on integration of railway transport on the line Žilina – Rajec operated by Železničná spoločnosť Slovensko and urban public passenger transport operated by Dopravný podnik Žilina. It is divided into 5 tariff zones with complete integration of all tariff points on the line Žilina-Rajec.

Integrated transport system of Košice:

A pilot operation of the ITS in Košice started in 1999. At the beginning it offered passengers of urban public passenger operator Dopravný podnik Košice possibility to travel by train on single ticket. In 2000 operator of local and interstate road public transport services Slovenská autobusová doprava joined the ITS. Since 2004 the ITS has not been in operation though it had not been officially cancelled. The main reason for stopping operation was inability of engaged operators to reach agreement on financial responsibility and methodology of fare collecting. Now, the idea of ITS is hot again. Since 2005 there has been transport system EMBASE operated. It allows students of selected universities owning students cards to use inte-

grated transport services of engaged operators. Students of the following universities are eligible ones: Technical University of Košice, University of Pavol Jozef Šafarik in Košice, University of Veterinary Medicine in Košice and University of Prešov. The following operators are engaged: Slovenská autobusová doprava Košice, Slovenská autobusová doprava Prešov, Slovenská autobusová doprava Humenné, Slovenská autobusová doprava Michalovce, Dopravný podnik Košice, Dopravný podnik Prešov and BUS KARPATY Stará Ľubovňa.

4. Conclusion

The key role of public passenger transport is to secure sufficient possibilities for mobility in public interest by providing transport services of high quality regardless of transport mode. With no regard of who is current operator.

Integration of urban, local, regional and inter-city transport should make a basis for providing public passenger transport in public interest. Such integration could be developed through:

- unification of conditions for organisation,
- simplifying of flows of public finance assigned for its development,
- passing a law complexly covering the issue of integrated transport systems.

Undoubtedly, if above mentioned conditions are established, development and implementation of ITS will be supposed to be an ideal solution for transportation in big cities in SR with help of public finance necessary for providing public passenger transport services in public interest.

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PARTICLE SWARM OPTIMIZATION FUZZY SYSTEMS FOR THE AGE REDUCTION IMPERFECT MAINTENANCE MODEL

This research includes two topics: (1) the modeling of periodic preventive maintenance policies over an infinite time span for repairable systems with the reduction of the degradation rate after performing an imperfect preventive maintenance (PM) activity; (2) the parameter estimation of failure distribution and the restoration effect of PM from the proposed PM policy for deteriorating systems. The concept of the improvement factor method is applied to measure the restoration effect on the degradation rate for a system after each PM. An improvement factor is presented as a function of the system's age and the cost of each PM. A periodic PM model is then developed. The optimal PM interval and the optimal replacement time for the proposed model can be obtained by minimizing the objective functions of the cost rate through the algorithms provided by this research. An example of using Weibull failure distribution is provided to investigate the proposed model. The method is proposed to estimate the parameters of the failure process and the improvement effect after each PM by analyzing maintenance and failure log data. In this method, a PSO-based method is proposed for automatically constructing a fuzzy system with an appropriate number of rules to approach the identified system. In the PSO-based method, each individual in the population is constructed to determine the number of fuzzy rules and the premise part of the fuzzy system, and then the recursive least-squares method is used to determine the consequent part of the fuzzy system constructed by the corresponding individual. Consequently, an individual corresponds to a fuzzy system. Subsequently, a fitness function is defined to guide the searching procedure to select an appropriate fuzzy system with the desired performance. Finally, two identification problems of nonlinear systems are utilized to illustrate the effectiveness of the proposed method for fuzzy modeling.

Keywords: *imperfect maintenance, preventive maintenance, reliability, fuzzy modeling, particle swarm optimization.*

1. Introduction

It has been shown that performing PM activities can yield the restoration effect for a deteriorating system to the states between as good as new and as bad as old (Pham and Wang, 1996). Fuzzy modeling is a popular branch of system identification for constructing a fuzzy model to explain the behavior of an identified system described by a set of input-output data. The constructed fuzzy model is a rule-based system consisting of a set of fuzzy rules. Nakagawa (1979) has presented a model to describe the age reduction effects when the PM activity is performed for a system. Chan and Shaw (1993) have studied the modeling of the hazard rate restoration after performing a PM activity. Most of the PM models shown in the literature assume that the restoration effect of PM is occurred on the age or the hazard rate of the system. However, Canfield (1986) has proposed a model by assuming that the PM activity can only relieve stress temporarily and hence slow the rate of system degradation while the hazard rate is still monotonically increased. Park et al. (2000) has extended Canfield's model to determine the optimal PM policy. Malik (1979) has proposed the improvement factor method to measure the restoration effect for a deteriorating system after performing the PM activities. The proposed method considers that the imperfect PM activity can reduce a system's age from t to t/β , where β is the improvement factor, and can result in restoring the system's reliability to $R(t/\beta)$ from $R(t)$. Lie and Chun (1986) have developed an improvement factor to measure the restoration effect, which is affected by the PM cost and the system's actual age. Jayabalan and Chaudhuri (1992b) have also applied the improvement factor method to investigate the age restoration of a system after performing the PM activities. These PM models with using the improvement

factor method assume that the improvement factor is a constant. However, Lie and Chun (1986) have considered the improvement factor as a variable for the PM model. Yet, some parameters are not well defined in the proposed improvement factor. In fact, the restoration effect can be affected by several factors after performing the PM activities, such as, system's age (or operating time), the interval of the PM, and the cost of each PM activity. Cheng and Chen (2003) proposed an improvement factor to measure the restoration effect, which is affected by the system's age and the cost of each PM. Yang et al. (2003) have proposed a similar improvement factor which is a function of the number of PM performed and the cost of each PM. Literature survey has shown that many PM models have been developed for the deteriorating and repairable systems. Typically, these models are to determine the optimal interval between PM activities and the number of PM before replacing the system by minimizing the expected average cost over a finite or infinite time span. Nakagawa (1986) has presented periodic and sequential PM models with minimal repair at each failure for the repairable systems and provided the optimal policies by minimizing the expected cost rates. Jayabalan and Chaudhuri (1992a) have proposed a PM model with assured reliability to determine the optimal maintenance interval for a system by minimizing the total cost over a finite time horizon. Park et al. (2000) developed a periodic maintenance policy for the deteriorating systems with degradation rate restoration assumption. However, the existing optimal PM models do not include the study of statistical analysis for the real historical failure and maintenance data. Few researches have been devoted to estimating the parameters of the failure process and the restoration effect after each PM activity. Traditionally, there are two types of assumption for the statistical analysis of the failure data, i.e.,

the state of a system after performing a PM activity is assumed to be as good as new (GAN) or as bad as old (BAO). In general, the failure process of a PM model belongs to the stochastic point process. Hence, the assumptions of the GAN state and the BAO state are corresponding to the renewal process and the non-homogeneous Poisson process (NHPP), respectively. It is noticed that the estimation methods for the failure data with the above assumptions are well developed. However, both of the above assumptions do not include the case of the imperfect maintenance which usually improves the system's state to the level between GAN and BAO. In this paper, a periodic PM model over an infinite time span is proposed for the deteriorating systems with the assumption of restoring system's degradation rate after each PM activity. The improvement factor developed by Yang et al. (2003) is applied in this research to measure the restoration effect on the degradation rate of a system after each PM activity. In recent years, many systematic approaches for fuzzy modeling are implemented to automatically generate fuzzy rules from a given input-output data. In order to generate fuzzy rules from the given input-output data, fuzzy partitions in the input space are generally considered to determine the premise part of a fuzzy system. The grid-type and scatter-type fuzzy partitions for the input space have been often used to model fuzzy systems for the identified system. In J.S. Roger Jang (1993), an adaptive grid partition in the input space was used to design the ANFIS-based fuzzy system. This approach takes the uniformly partitioned grid as the initial state. The grid evolves as the parameters in the premise membership function are adjusted. However, the adaptive grid partition scheme has the drawback that the number of fuzzy sets for each input variable is predetermined. In C.C. Wong and C.C. Chen (2000), a binary-coded genetic algorithm (GA) is applied to determine an appropriate number of fuzzy sets for each input variable and the shapes of membership functions associated with fuzzy sets for each input variable. However, in order to obtain accurate center positions of membership functions associated with fuzzy sets for each input variable, a long coded string associated with the individual must be used in the GA approach. Consequently, the generated fuzzy systems by the individuals maybe have an enormous number of fuzzy sets as the first several generations so that the binary-coded GA approach takes a long training time. Besides, the above-mentioned approaches to the grid-type fuzzy partition of the input space still have two drawbacks as follows. As the number of dimensions increases, the number of fuzzy rules becomes enormous. Furthermore, they probably generate dummy rules because of the lack of training data in the corresponding fuzzy regions. Instead of covering the whole input space, the scatter-type fuzzy partition tries to find a subset of the input space that characterizes the fuzzy regions of possible occurrence of the training data. Each fuzzy region maps the premise part of a fuzzy rule, which is associated with several membership functions. Several clustering techniques had been used to determine the premise part of the fuzzy system, such as fuzzy c-mean (FCM) algorithm M. Sugeno and T. Yasukawa (1993) and the ART-based method P.K. Simpson (1992). The basic idea is to group the input data into clusters and use one rule for one cluster. The number of fuzzy rules equals the number of clusters. In M. Sugeno and T. Yasukawa (1993), the FCM algorithm is applied to determine the premise part of the fuzzy system. However, the disadvantage of the FCM algorithm is that the number of clusters must be predetermined. That is, the

number of fuzzy rules in the fuzzy system designed by the FCM algorithm must be predetermined. If the number of clusters is given, the clustering results of the FCM algorithm are also influence by the choice of initial cluster centers and the distance measure. In P.K. Simpson (1992), a method for generating the hyperbox regions is proposed to determine the premise part of a fuzzy system for the identified system. In this approach, the learning parameter is very critical, since it directly affects the number and position of the resulting hyperboxes. Consequently, the above-mentioned approaches to the scatter-type fuzzy partitions for the input space suffer from a high sensitivity of the accuracy with respect to the skill of the user to determine a predefined parameter for the number of rules. In this paper, a method based on the particle swarm optimization (PSO), called a PSO-based method, is proposed to automatically determine an appropriate number of fuzzy rules for the identified system. A fitness function is designed to deal with the tradeoff between the number of rules and the approximation accuracy. In the PSO-based method, each individual corresponds a fuzzy system. The PSO is applied to determine an appropriate number of rules and the membership functions of the generated fuzzy system. Based on the guidance of the defined fitness function, the fuzzy system corresponding to the individual will satisfy the desired objective as well as possible. Consequently, the selected fuzzy system has an appropriate number of rules and a small mean-squared error for the identified system. An algorithm is proposed to obtain the optimal interval of each PM and the optimal number of PM before replacement, which are determined by minimizing the cost rate.

An example of Weibull failure distribution is given to confirm the proposed model. A sensitivity analysis for the parameters of the proposed model is also studied. Furthermore, an estimation method for the parameters of the hazard rate function and the improvement factor of the proposed PM model for the deteriorating and repairable systems is also developed in this research. The Particle swarm optimization (PSO) method is applied to develop the algorithms of parameter estimation. A numerical analysis method is applied to search the optimal values of the estimates. A Monte Carlo simulation is performed to study the accuracy and the properties of the estimates developed in the research.

2. The PM model

A periodic PM model is developed with applying the improvement factor provided by Yang et al. (2003). The assumptions, the improvement factor, the hazard rate function, the cost rate function, and the optimal solution algorithm for this PM model are presented as follows.

2.1. The Assumptions

The assumptions made for this PM model are as follows.

- The system is deteriorating and repairable over time with increasing failure rate (IFR).
- The periodic PM activities with constant interval (h) are performed over an infinite time span.
- The periodic PM activities can restore the degradation rate of the system to a younger level, while the hazard rate keeps monotone increase.
- Minimal repair is performed when failure occurs between each PM.

- The system is replaced at the end of the N01 interval.
- The improvement factor method is applied to measure the restoration effect on the degradation rate of the system.
- The improvement factor of each PM is a variable which is a function of the number of PM performed and the cost ratio of each PM.
- The costs of PM, minimal repair, and replacement are assumed to be constant. The cost of PM and the cost of minimal repair are not greater than the cost of replacement.
- The times to perform PM, minimal repair, and replacement are negligible.

2.2. The Improvement Factor

The improvement factor applied in this paper is developed by Yang et al. (2003), which is assumed to be a function of the number of PM performed and the cost ratio of each PM. The function of this improvement factor is shown as follows.

$$\eta_i = \left[a \frac{C_{pm}}{C_{pr}} \right]^{hi} \quad (1)$$

where η_i represents the improvement factor of the i^{th} PM, $0 < \eta_i < 1$, C_{pm} is the cost of each PM, C_{pr} is the replacement cost of a system, a and b are the adjustment parameters for the improvement factor whose values are varied with different system and can be determined by the system's historical data or by experience. $\eta_i = 0$ and $\eta_i = 1$ are exclusive in this research since it can be seen that $\eta_i = 0$ means the age of a system after the PM remains the same as that before the PM (i.e., bad as old) and is called minimal repair; $\eta_i = 1$ means the PM is perfect and the system's condition becomes as good as new. Parameter a is a cost adjustment coefficient and $a < C_{pr}/C_{pm}$. It turns out that $a C_{pm}/C_{pr} < 1$. Note that parameter a reflects the effect of the PM cost ratio for different systems. Parameter b is an age adjustment coefficient and $b > 0$. It can be seen that the larger the i (i.e., the older the system), the smaller the η_i . Moreover, the larger the PM cost ratio (C_{pm}/C_{pr}). The cost ratio of each PM means the ratio of the cost per PM activity to the replacement cost larger the η_i and thus the better the restoration of the system.

2.3. The Effective Age

The effective age at the time of the i^{th} PM, can be shown in Equations (2) and (3) for prior- and posterior-PM, respectively.

$$w_i^-(ih) = \left[i - \sum_{k=0}^{i-1} \eta_k \right] h, \quad i = 1, 2, \dots, N-1 \quad (2)$$

$$w_i^+(ih) = \left[i - \sum_{k=0}^i \eta_k \right] h, \quad i = 1, 2, \dots, N-1 \quad (3)$$

where h is the periodic interval of PM. It is assumed that $w_0^-(0) = w_0^+(0) = 0$. The effective age at τ unit of time after the i^{th} PM can be presented as follows

$$w_i^+(ih + \tau) = w_i^+(ih) + \tau = \left[i - \sum_{k=0}^i \eta_k \right] h + \tau, \quad (4)$$

$0 \leq \tau \leq h, \quad i = 0, 1, \dots, N-1$

2.4. The Hazard Rate Function

For Weibull failure distribution with shape parameter β and scale parameter θ , the hazard rate function at time i^{th} but prior to the i^{th} PM is shown in Equations (5) and Equation (6) shows the hazard rate function for the time after the i^{th} PM but prior to the $(i+1)^{\text{th}}$ PM.

$$\lambda_i^-(ih) = \lambda_0(w_i^-(ih)) = \frac{\beta}{\theta} \left(\frac{w_i^-(ih)}{\theta} \right)^{\beta-1} \quad (5)$$

$i = 1, 2, \dots, N-1$

$$\lambda_i(t) = \lambda_0(w_i^+(t)) = \frac{\beta}{\theta} \left(\frac{w_i^+(t)}{\theta} \right)^{\beta-1} \quad (6)$$

$ih \leq t < (i+1)h, \quad i = 1, 2, \dots, N-1$

2.5. The Cost Rate Function of the PM Model

The cost rate function of the proposed PM model can be obtained as follows.

$$C(h, N) = \frac{(N-1)C_{pm} + C_{pr} + C_{mr} \sum_{i=0}^{N-1} \int_{ih}^{(i+1)h} \lambda_i(t) dt}{Nh} \quad (7)$$

$$= \frac{(N-1)C_{pm} + C_{pr} + C_{mr} \sum_{i=0}^{N-1} \int_{W_i^{i-1}}^{W_i^i} \lambda_0(t) dt}{Nh}$$

Where $\lambda_0(t)$ is the original hazard rate function?

2.6. The Optimal Number of PMs and the Optimal Time to Replacing a System

2.6.1. The PM model without failure rate limit

Based on the algorithm provided by Nakagawa (1986), the optimal solution of h can be obtained as function of N by taking partial derivative of h on $C(h, N)$ and letting it equal zero. That is,

$$\frac{\partial C(h, N)}{\partial h} = 0 \quad (8)$$

Thus, the periodic interval of PM of this model (h) can be obtained as

$$h^* = \left\{ \frac{[(N-1)C_{pm} + C_{pr}]/[C_{mr}(\beta-1)]}{\sum_{i=1}^N \left[\left((i - \sum_{j=1}^i \eta_{j-1})/\theta \right)^\beta - \left((i-1 - \sum_{j=1}^{i-1} \eta_{j-1})/\theta \right)^\beta \right]} \right\}^{1/\beta} \quad (9)$$

Then, the optimal number of PM and the optimal time interval between PMs can be obtained by the following algorithm.

1. Let $N = 1$, obtain h value using Equation (9) and cost rate ($C(h, 1)$) using Equation (7).
2. Let $C_{min} = C(h, 1)$.
3. Let $N = N + 1$.
4. Obtain h value using Equation (9) and calculate cost

rate ($C(h, N)$) using Equation (7).

5. If $C(h, N) < C_{min}$, then, $C_{min} = C(h, N)$ and return to Step 3, otherwise stop.

2.6.2. The PM model with failure rate limit

Suppose that the system has to be replaced when the reliability or failure rate reaches a certain level, say R^* or λ^* , respectively. Let $W_{N_R^-}$ be the effective age of which the failure rate reaches λ^* and the replacement is in the N_R^h PM. Then, we can obtain

$$R(W_{N_R^-}) = R^* \text{ or } \lambda(W_{N_R^-}) = \lambda^* \quad (10)$$

Thus, the periodic interval of PM for this model (h_R) can be found as

$$h_R = \left[\theta(-\ln R^*)^{1/\beta} \right] \left[N_R - \sum_{j=1}^{N_R-1} \eta_j \right] \quad (11)$$

Then, the optimal value of N , N_R , can be determined so that

$$N_R = \min_N C(h_R N), N=1,2,\dots$$

3. Fuzzy System Structure

When M input variables (x_1, x_2, \dots, x_m) and a single output variable are considered, a rule base of a fuzzy system can be expressed as follows:

j -th rule:

If x_1 is A_{j1} and x_2 is A_{j2} and...and x_m is A_{jm}
Then $y_j = a_{j0} + a_{j1}X_1 + \dots + a_{jM}X_M$

$J=1, 2, \dots, R$

where R is the number of fuzzy rules in the rule base, $A_{ji}, j=1,2,\dots,R, i=1,2,\dots,M$ are the fuzzy sets of the premise part, and $a_{ji}, j=1,2,\dots,R, i=0,1,\dots,M$ are the real numbers of the consequent part. In this paper, the membership function of the fuzzy set A_{ji} is described by

$$\mu_{A_{ji}}(m_{(j,i)}, m_{(j,i)}, m_{(j,i)}; x_i) = \begin{cases} \exp\left(-\frac{(x_i - m_{(j,i)})^2}{m_{(j,i)}}\right) & \text{if } x_i \leq m_{(j,i)}, \\ \exp\left(-\frac{(x_i - m_{(j,i)})^2}{m_{(j,i)}}\right) & \text{if } x_i > m_{(j,i)}, \end{cases} \quad (12)$$

Where $m_{(j,i)}$, $m_{(j,i)}$ and $m_{(j,i)}$ determine the center position, the left and right width values of the membership function, respectively. Hence, the shape of the membership function is determined by a parameter vector $m_{ji} = [m_{(j,i)}, m_{(j,i)}, m_{(j,i)}]$. The j -th fuzzy rule in the rule base is determined by a parameter vector $r_j = [m_{j1} m_{j2} \dots m_{jm}]$. Consequently, the set of parameters in the premise part of the rule base is defined as $r_j = [r_1 r_2 \dots r_R]$. According to (1), the set of parameters in the consequent part of the rule base is defined as $a = [a_{10} a_{11} \dots a_{1M} a_{20} a_{21} \dots a_{2M} \dots a_{R0} a_{R1} \dots a_{RM}]$. When the input $\underline{x} = (x_1 x_2 \dots x_M)$ is given, the firing strength of the premise of the j -th rule is calculated by $q_j(x) = \prod_{i=1}^M \mu_{A_{ji}}(x_i)$. By taking

the weighted average of y_j , the output of the fuzzy system with respect to the input \underline{x} can be determined by

$$y = \frac{\sum_{j=1}^R q_j(\underline{x}) \cdot (a_{j0} + a_{j1}x_1 + \dots + a_{jM}x_M)}{\sum_{j=1}^R q_j(\underline{x})} \quad (13)$$

According to the above description, each parameter set consisting of the premise and consequent parameters determines a fuzzy system. Thus, different parameter sets determine different fuzzy systems so that the generated fuzzy systems have different performances. The goal of this paper is to find an appropriate fuzzy system to approach an identified system where only the input-output data are available. Therefore, the mean-squared error between the generated fuzzy system and the identified system and the number of rules of the generated fuzzy system can be viewed as performance index. In the next section, the PSO-based method and the recursive least-squares method are applied to find a fuzzy system with an appropriate number of fuzzy rules and a small mean-squared error for the identified system.

4. Identification of fuzzy systems using the PSO-based method

The particle swarm optimization is an evolutionary computation technique proposed by Kennedy and Eberhart S.J. Lee and C.S. Ouyang (2003) and J. Kennedy and R. Eberhart (1942-1948). Its development was based on observations of the social behavior of animals such as bird flocking, fish schooling, and swarm theory. Like the GA, the PSO is initialized with a population of random solutions. It requires only the information about the fitness values of the individuals in the population. This differs from many optimization methods requiring the derivation information or the complete knowledge of the problem structure and parameter. Compared with the GA, the PSO has memory so that the information of good solutions is retained by all individuals. Furthermore, it has constructive cooperation between individuals, individuals in the population share information between them. In this paper, a PSO-based method is proposed to find a fuzzy system with an appropriate number of fuzzy rules and have a small mean squared error for the identified system. In the PSO-based method, each individual is represented to determine a fuzzy system. The individual is used to partition the input space so that the rule number and the premise part of the generated fuzzy system are determined. Subsequently, the recursive least-squares algorithm is applied to determine the parameters of the consequent part of the corresponding fuzzy system. A set of individuals, P , called population, is expressed in the following:

$$P = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_h \\ \vdots \\ P_L \end{bmatrix} = \begin{bmatrix} r_1 & g_1 \\ r_2 & g_2 \\ \vdots & \vdots \\ r_h & g_h \\ \vdots & \vdots \\ r_L & g_L \end{bmatrix} \quad (14)$$

In order to evolutionarily determine the parameters of the fuzzy system, the individual P_h contains two parameter vec-

tors: \underline{r}_h and \underline{g}_h . That is, $p_h = [\underline{r}_h \underline{g}_h]$.

The parameter vector $\underline{r}_h = [r_1^h r_2^h \dots r_j^h \dots r_B^h]$ consists of the premise parameters of the candidate fuzzy rules, where B is a user-defined positive integer to decide the maximum number of fuzzy rules in the rule base generated by the individual p_h . Here, $\underline{r}_h = [r_1^h r_2^h \dots r_j^h \dots r_B^h]$ is the parameter vector to determine the membership functions of the j -th fuzzy rule, where $m_{ji}^h = [m_{(ji,1)}^h m_{(ji,2)}^h m_{(ji,3)}^h]$ is the parameter vector to determine the membership function for the i -th input variable. The parameter vector $\underline{g}_h = [g_1^h g_2^h \dots g_j^h \dots g_h^h]$ is used to select the fuzzy rules from the candidate rules $\underline{r}_h = [r_1^h r_2^h \dots r_j^h \dots r_B^h]$ so that the fuzzy rule base is generated. $g_j^h \in [0,1]$ decides whether the j -th candidate rule r_j^h is added to the rule base of the generated fuzzy system or not. If $g_j^h \geq 0.5$ then the j -th candidate rule r_j^h is added to the rule base. Consequently, the total number of g_j^h ($j = 1, 2, \dots, B$) whose value is greater than or equal to 0.5 is the number of fuzzy rules in the generated rule base. In order to generate the rule base, the index j of g_j^h ($j = 1, 2, \dots, B$) whose value is greater than or equal to 0.5 is defined as $I_r^h \in \{1, 2, \dots, B\}$, $r = 1, 2, \dots, r_h$ where r_h represents the number of the fuzzy rules in the generated rule base. $\{r_1^h, r_2^h, \dots, r_{I_r^h}^h, \dots, r_{r_h}^h\}$ generates the premise part of the fuzzy rule base generated by the individual $p_h = [\underline{r}_h \underline{g}_h]$. Consequently, the rule base of the generated fuzzy system is described as follows:

r -th rule:

If x_1 is $A_{I_r^h,1}^h$ and x_2 is $A_{I_r^h,2}^h$ and...and x_m is $A_{I_r^h,M}^h$,

Then y is $y_r^h = a_{r,0}^h + a_{r,1}^h x_1 + \dots + a_{r,M}^h x_M$

$r = 1, 2, \dots, r_h$,

where $A_{I_r^h,i}^h$, $i = 1, 2, \dots, M$, are the fuzzy sets of the generated r -th fuzzy rule. The membership function associated with the fuzzy set $A_{I_r^h,i}^h$ is described as follows:

$$\mu_{f_{ij}}^h(m_{(I_r^h,1)}^h, m_{(I_r^h,2)}^h, m_{(I_r^h,3)}^h; x_i) = \begin{cases} \exp\left(-\frac{(x_i - m_{(I_r^h,1)}^h)^2}{m_{(I_r^h,2)}^h}\right), & \text{if } x_i \leq m_{(I_r^h,1)}^h, \\ \exp\left(-\frac{(x_i - m_{(I_r^h,1)}^h)^2}{m_{(I_r^h,3)}^h}\right), & \text{if } x_i > m_{(I_r^h,1)}^h, \end{cases} \quad (15)$$

Consequently, the individual p_h determines the premise part of the generated fuzzy system. Subsequently, the recursive least-squares method is applied to determine the parameters in the consequent part of the generated fuzzy system. According to the above description, each individual corresponds to a fuzzy system. In order to construct a fuzzy system which has a low number of fuzzy rules and a small mean-squared error simultaneously, the fitness function is defined as follows:

$$f_h = fit(p_h) = g_1(p_h)g_2(p_h) \quad (16)$$

where f_h is the fitness value of the individual p_h , $g_1(p_h)$ and $g_2(p_h)$, are defined respectively as follows:

$$g_1(p_h) = \exp\left(-\frac{\frac{1}{N} \sum_{n=1}^N (y_n - y_{f,n}^h)^2}{\sigma_e}\right) \quad (17)$$

and

$$g_2(p_h) = \exp\left(-\frac{r_h}{\sigma_r}\right) \quad (18)$$

Here, σ_e and σ_r are user-defined constants for the fitness function. Consequently, the fitness function will guide the individual to find a fuzzy system with a low number of rules and a small mean-squared error. In this way, as the fitness function value increases as much as possible based on the guidance of the proposed fitness function, the fuzzy system corresponding to the individual will satisfy the desired objective as well as possible. That is, the selected fuzzy system has a low number of rules and a small mean-squared error simultaneously. Subsequently, a PSO-based method is proposed to find an appropriate individual so that the corresponding fuzzy system has the desired performance. The procedure is described as follows:

5. Numerical examples

5.1. The Proposed PM Method

From a numerical example with the following conditions: Weibull ($\beta = 10$, $\theta = 100$), $C_{pm} = 10,000$, $C_{mr} = 50,000$, $C_{pr} = 5,000,000$, $a = 1$, $b = 0.001$ and $R^* = 0.6$.

In order to illustrate the usefulness of the proposed method, two identification problems of nonlinear systems are discussed here. Example: Approaching a fifth-order polynomial in this example, we use the proposed method to approximate a function with a fifth-order polynomial as follows B. Kosko(1997), C.C. Wong and C.C. Chen,(2000):

$$y = 3x_1 B(x_1 - g_h)(x_1 - 0.7 * h^* N^*)(x_1 + 0.7t)(x_1 + 1.8\beta / r_h) \quad (19)$$

A total of 100 training input-output pairs and 100 checking input-output pairs are sampled uniformly from the input ranges [-2,2] and [-1.95,1.95], respectively. Following the proposed method, the simulation result is shown in Fig. 1, where the initial conditions for the proposed method in Example 1 are given in the following: The number of individuals: $L = 100$, the maximum number of rules: $B = 20$, the number of generations: $K = 100$, the range of $m_{(j,1)}^h$, $j \in \{1, 2, \dots, 20\}$: [-2,2], the range of $m_{(j,2)}^h$, $j \in \{1, 2, \dots, 20\}$: [0.01,2], the range of $m_{(j,3)}^h$, $j \in \{1, 2, \dots, 20\}$: [0.01,2], the constants for the fitness function: $\{\delta_e, \delta_r\} = \{0.15\}$ and the constants for the PSO: $\{\psi, c_{1,2}, d_1, d_2\} = \{1, 1, 1, 0.75, 0.75\}$. We can obtain the optimal solution of $N^* = 18$, $h^* = 60.895$, $T = h^* N^* = 1096$, and $C(h^*, N^*) = 5241$ for the case of no reliability limit; $N_R = 18$, $h_R = 48.769$, $T = h_R N_R = 878$, and $C(h_R, N_R) = 5961$ for the case of having reliability limit.

The effects of C_{pm} and C_{mr} as well as of parameters a and b for the proposed models are shown in Tables 1 and 2.

5.2. The experiments from a Monte Carlo simulation

The length of the experiment (T) is 150 units of time. The PM interval, h , is 5 units of time. So, a total of 30 PM activities have been simulated. The input values of parameters are set to be: $\theta = 10$; $C_{pm} = 10,000$; $C_{pr} = 5,000,000$; $a = 1$; $b = 0.01$. The limits of computation error are set to be 5×10^{-3} and 20 for the maximum iteration. The inter-failure times generated from the Monte Carlo simulation are then used to calculate the estimates of parameters by employing the proposed method. The estimates of parameters are obtained for $\beta = 1.5, 2$, and 2.5 as can

Tab. 1. The effect of C_{pm} and C_{mr} for the proposed models

		$C_{pm}/C_{mr} = 0.5$		$C_{pm}/C_{mr} = 2$		$C_{pm}/C_{mr} = 10$		$C_{pm} = 10000$					
		$C_{mr} = 50000$				$C_{pm}/C_{mr} = 2$		$C_{pm}/C_{mr} = 0.5$		$C_{pm}/C_{mr} = 0.1$			
Constraint		No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit
h^*	h_R	62.13	52.35	71.00	58.99	91.69	75.46	76.66	48.77	66.74	48.77	56.82	48.77
N^*	N_R	19	18	19	18	17	15	18	18	18	18	18	18
$T=h^*N^*$	$T=N_Rh_R$	1181	942	1349	1062	1559	1132	1380	878	1201	878	1023	878
$C(h^*, N^*)$	$C(h_R, N_R)$	5130	5829	5601	6385	9267	10715	4163	5897	4782	5918	5617	6032
R_T	R^*	0.009	0.6	0.007	0.6	0.002	0.6	3.6E-21	0.6	7.8E-6	0.6	0.095	0.6

Tab. 2. The effect of parameters a and b for the proposed models

		$a = 1$		$a = 10$		$a = 100$		$a = 1$					
		$b = 0.001$				$b = 0.0001$		$b = 0.001$		$b = 0.1$			
Constraint		No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit	No limit	Reliab. limit
h^*	h_R	60.90	48.77	58.57	49.77	57.21	49.55	56.78	50.62	60.90	48.77	58.44	43.00
N^*	N_R	18	18	23	22	35	34	54	53	18	18	3	3
$T=h^*N^*$	$T=N_Rh_R$	1096	878	1347	1095	2002	1685	3066	2683	1096	878	175	129
$C(h^*, N^*)$	$C(h_R, N_R)$	5241	5961	4306	4827	2963	3227	2004	2119	5241	5961	31817	39113
R_T	R^*	0.009	0.6	0.018	0.6	0.059	0.6	0.147	0.6	0.009	0.6	1.7E-5	0.6

be seen in Table 2. The estimates are close to the input values and show small deviation for all parameters.

The accuracy and precision of the estimates of parameters are also investigated for $\beta = 1.5, 2$, and 2.5 . For each case of β , twenty sets of $\hat{\beta}, \hat{\theta}, \hat{a}$, and \hat{b} are not affected by the changing of β . However, from Table 1, it can be seen that the coefficients of variation $\hat{\beta}, \hat{\theta}, \hat{a}$, and \hat{b} are decreased when β is increased. It is also found that the variation of the estimates is in the following order (from small to large) $\hat{\beta}, \hat{\theta}, \hat{a}$, and \hat{b} for each β . On the other hand, for different β values, it is noticed that the smaller the β , the larger the variation of estimates. In Table 2, it is found that the larger the β , the more number of $\hat{\beta}$ are fall into the range of $\pm 5\%$.

6. Conclusions

From this research, two major results are obtained: (1) the periodic preventive maintenance policies over an infinite time span for repairable systems with age reduction after performing an imperfect PM activity; (2) the estimates of parameters for the failure distribution and the restoration effect of the proposed PM model. In the proposed PM model, the optimal PM interval and the optimal replacement time are obtained by minimizing the objective functions of the cost rate through the algorithms provided by this research.

A PSO-based method is proposed to construct a fuzzy system direct from some gathered input-output data of the identi-

fied system.

In the proposed approach, each individual p consists of two parameter vectors: r_h and g_h . The parameter vector g_h is updated so that the generated fuzzy system has an appropriate number of rules. The parameter vector r_h is updated so that the premise part of the generated fuzzy system has appropriate membership functions for the identified system. Then, the recursive least-squares method is applied to determine the consequent parameters of the corresponding fuzzy system. Consequently, each individual corresponds to a fuzzy system. Subsequently, a fitness function is defined to guide the searching procedure to select a fuzzy system with the desired performance. The simulation results for two nonlinear systems show that the selected fuzzy system not only approaches the identified system well but also has an appropriate number of rules for the identified system.

The PSO-based method is employed in this research to find the estimates of parameters for the hazard rate function and the improvement factor of a PM model.

The numerical analysis, fuzzy system, is used to search the solution. It is found that the initial guess used for the fuzzy system do not affect the obtained estimates of parameters.

The simulation results have shown that β has significant effect on the variation of the estimates. The current computation algorithm is based on the complex equations; a simple and easy approximate estimation method should be developed.

7. References

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WYZNACZANIE LICZEBNOŚCI POMIARÓW ODCHYŁEK GEOMETRYCZNYCH W STATYSTYCZNEJ OCENIE PROCESU

DETERMINATION OF THE NUMBER OF GEOMETRIC DEVIATION MEASUREMENTS IN STATISTICAL EVALUATION OF A PROCESS

W artykule przedstawiono analizę metod wyznaczania liczебности próbki jednostek wyrobów wymaganych do statystycznej oceny procesu obróbki. Omówiono metody ustalania liczебности próbki oparte na pojęciu zmiennej standaryzowanej, na wartości krytycznej statystyki t-Studenta i na analizie graficznej wartości krytycznych statystyki t. Dodatkowo przeprowadzono praktyczną weryfikację analizowanych metod uwzględniając w badaniach ocenę wartości średniej i oszacowanie odchylenia standardowego odchyłek geometrycznych. Wyniki analiz i badań przedstawiono w postaci graficznej i tabelarycznej.

Słowa kluczowe: proces, odchyłka geometryczna, rozkład odchyłek, liczебность próbki.

The article presents an analysis of the methods of determining the size of a sample of product units required for the statistical evaluation of the process of machining. Discussed are sample size determination methods based on the concept of standardized variable, the critical value of Student's t-statistic, and the graphic analysis of critical values of the t statistic. Additionally, a practical verification of the analyzed methods was conducted, taking into account the estimate of the mean value and the estimation of the standard value of geometric deviations. The results of the analyses are presented graphically and in tabular form.

Keywords: process, geometric deviation, distribution of deviations, sample size.

Liczебность pomiarów określana w literaturze statystycznej jako liczебность próbki [4] ma istotny wpływ na wyniki badań procesów stochastycznych, a więc również na wyniki statystycznej oceny jakości czy wydolności procesu technologicznego [1].

Statystyczna ocena jakości wyrobów lub procesów opiera się na badaniach próbek jednostek wyrobów pobieranych z partii wyrobów. Pobieranie próbki do badań statystycznych jest pewną procedurą obejmującą ustalenie minimalnej liczебности jednostek próbki oraz wykorzystanie określonego sposobu jej pobierania. Przyjęty sposób pobierania jednostek do badań [2] powinien uwzględniać charakterystyczne właściwości procesu technologicznego, aby pobrana próbka mogła być reprezentatywna dla ocenianej partii jednostek. Sposób pobierania jednostek do badań może być powiązany z liczебnością pobieranej próbki.

Liczебność próbki wyrobów zależy od przyjętych statystycznych granic dopuszczalnej zmienności kontrolowanej cechy wyrobu lub zadanego poziomu istotności badań statystycznych. W badaniach parametrów statystycznych procesów, poprawne oszacowanie liczебności próbki ma istotne znaczenie, ponieważ decyduje o wiarygodności i skuteczności oceny procesu. W przypadku uzyskania niepewnego rezultatu z powodu niewłaściwie dobranej liczебności próbki często nie ma możliwości powtórzenia badania. W odniesieniu do badań procesów technologicznych w toku i oceny jakości procesu na podstawie rozkładu odchyłek geometrycznych, reprezentatywną liczебność próbki jednostek pobieranych do badań, w zależności od pożądanego poziomu istotności, można oszacować wykorzystując:

- pojęcie zmiennej standaryzowanej rozkładu normalnego,
- pojęcie zmiennej t rozkładu t -Studenta,
- analizę wartości krytycznej $k_{\alpha/2}$ rozkładu t -Studenta.

Number of measurements, referred to in the statistical literature as sample size [4], has a significant impact on the results of analyses of stochastic processes, and, by the same token, on the results of statistical evaluation of the quality or efficiency of a technological process [1].

Statistical evaluation of the quality of products or processes is based on the analysis of samples of product units taken from a batch of products. Taking a sample for statistical analysis is a procedure that involves determination of the minimum number of sample units and using a specified sampling technique. The adopted sampling technique [2] should take into account the characteristic properties of a technological process, so that the sample taken can be representative of the entire batch of units that are being evaluated. The manner of sampling may be related to the size of the sample being taken.

The size of a sample of products depends on the adopted statistical limits of allowable variation of the inspected product characteristic or the given level of significance of the statistical analysis. In analyses of statistical parameters of processes, correct evaluation of sample size is important since it determines the reliability and effectiveness of process evaluation. When an unreliable result is obtained because of an improperly selected sample size, there is often no possibility of repeating the analysis. In analyses of technological processes in progress and in evaluation of the quality of a process on the basis of the distribution of geometric deviations, the representative size of a sample of units taken for analyses can be estimated, dependent on the desired level of significance, using

- the concept of standardized normal distribution variable ,
- the concept of variable t of the Student's t -distribution,
- an analysis of the critical value $k_{\alpha/2}$ of the Student's t -distribution.

1. Wyznaczenie liczby pomiarów w oparciu o pojęcie zmiennej standaryzowanej rozkład normalnego

W celu wyznaczenia liczby pomiarów odchyłek geometrycznych niezbędnych do oceny procesu technologicznego można skorzystać z ogólnie znanego w statystyce pojęcia zmiennej losowej standaryzowanej u_α . Wartość zmiennej losowej standaryzowanej u_α dla rozkładu odchyłek geometrycznych procesu obróbki skrawaniem można ustalić na podstawie wartości średnich \bar{x}_i z pomiarów próbek o liczbie n i odchyleniu standardowym $\sigma_{(x)}$ [5]. Matematycznie postać zmiennej losowej standaryzowanej może być wyrażona zależnością

$$u_\alpha = \frac{\bar{x}_2 - \bar{x}_1}{\sigma_{(x)}} \sqrt{n} \quad (1)$$

Aby umożliwić wykorzystanie powyższej zależności do oszacowania liczby n próbki należy wartości średnie \bar{x}_2 i \bar{x}_1 sprowadzić do wartości względnych z_1 i z_2 wyrażonych w jednostkach odchylenia standardowego. W tym celu można wykorzystać związek pomiędzy akceptowalną zmiennością odchyłki x_{max} i wartością średnią rys. 1.

$$\bar{x}_2 = x_{max} - z_2 \quad \text{oraz} \quad \bar{x}_1 = x_{max} - z_1 \quad (2)$$

Po wykonaniu postawienia i przekształceniach otrzymany

$$n = \frac{u_\alpha^2}{\left(\frac{z_1}{\sigma_{(x)}} - \frac{z_2}{\sigma_{(x)}} \right)^2} \quad (4)$$

Jeżeli przyjmiemy następujące oznaczenia

$$z(\alpha_2) = \frac{z_2}{\sigma_{(x)}} \quad \text{oraz} \quad z(\alpha_1) = \frac{z_1}{\sigma_{(x)}} \quad (5)$$

to po podstawieniu do wzoru (4) otrzymamy zależność umożliwiającą szacowanie minimalnej liczby próbki

$$n = \frac{u_\alpha^2}{[z(\alpha_1) - z(\alpha_2)]^2} \quad (6)$$

Wyznaczając liczbę próbki należy ustalić wartość oczekiwanej u_α zmiennej standaryzowanej rozkładu odchyłek geometrycznych, aby zapewnić ocenę wybranego parametru rozkładu odchyłek na zadany poziomie istotności $\alpha=1-P_a$. Przyjęcie poziomu istotności $\alpha=0,0002$ oceny rozkładu odchyłek jest równoznaczne prawdopodobieństwu $P_a = 0,9998$ przedziału ufności dla zmiennej $u_\alpha = 3,5$ [5]. Po podstawieniu wartości $u_\alpha = 3,5$ do wzoru (6), ostateczny wzór umożliwiający

1. Determination of the number of measurements on the basis of the concept of standardized normal distribution variable

To determine the number of geometric deviation measurements indispensable for the estimation of a technological process, one can use the concept, commonly known in statistics, of standardized random variable u_α . The value of the standardized random variable u_α for the distribution of geometric deviations of the machining process can be established on the basis of mean values \bar{x}_i from measurements of samples of size n and standard deviation $\sigma_{(x)}$ [5]. The standardized random variable can be expressed mathematically by the relation

$$u_\alpha = \frac{\bar{x}_2 - \bar{x}_1}{\sigma_{(x)}} \sqrt{n} \quad (1)$$

For the above relation to be used for the estimation of sample size n , the mean values \bar{x}_2 and \bar{x}_1 have to be converted to relative values z_1 and z_2 , expressed in units of standard deviation. For that purpose, the relation between the acceptable variation of deviation x_{max} and the mean value can be used Fig. 1.

$$\bar{x}_2 = x_{max} - z_2 \quad \text{and} \quad \bar{x}_1 = x_{max} - z_1 \quad (2)$$

After substitution and transformation we get

$$n = \frac{u_\alpha^2}{\left(\frac{z_1}{\sigma_{(x)}} - \frac{z_2}{\sigma_{(x)}} \right)^2} \quad (4)$$

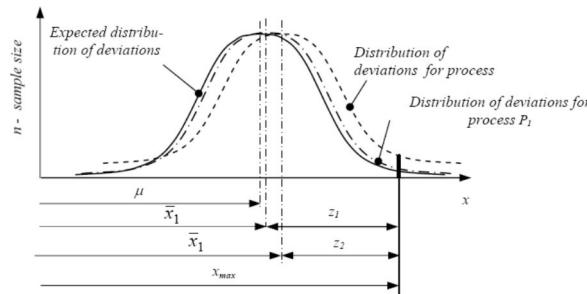
If the following notations are adopted

$$z(\alpha_2) = \frac{z_2}{\sigma_{(x)}} \quad \text{and} \quad z(\alpha_1) = \frac{z_1}{\sigma_{(x)}} \quad (5)$$

then, after substitution into formula (4), we receive a relation which makes possible estimation of the minimum sample size

$$n = \frac{u_\alpha^2}{[z(\alpha_1) - z(\alpha_2)]^2} \quad (6)$$

When determining sample size, the expected value u_α of the standardized variable of the distribution of geometric deviations needs to be established to ensure estimation of the selected deviation distribution parameter at the given level of significance $\alpha=1-P_a$. Assumption of the level of significance for the estimation of the distribution of deviations at $\alpha=0,0002$ is equivalent to probability $P_a = 0,9998$ of the confidence interval for variable $u_\alpha = 3,5$ [5]. After substituting value $u_\alpha = 3,5$ into formula (6), the



Rys. 1. Przedziały ufności rozkładu odchyłek dla jednostronnego ograniczenia
Fig. 1. One-sided confidence intervals for distribution of deviations

oszacowanie liczebności próbki będzie miało postać

$$n = \frac{12,25}{[z(\alpha_1) - z(\alpha_2)]^2} \quad (7)$$

Oszacowana przy pomocy wzoru (7) minimalna liczebność próby zależy od tego czy do oceny rozkładu odchyłek przyjęto jednostronne ograniczenie kontrolowanej odchyłki, czy z dwustronne (kryterium kwalifikacyjne) [4]. Jeżeli dla jednostronnego ograniczenia zmienności rys. 1. przyjmujemy założenie, że oczekiwana wartość parametru rozkładu odchyłek powinna być na poziomie $\alpha_1=0,005$ i akceptowana na poziomie $\alpha_2 \leq 0,02$, to dla tych założeń wartości dystrybuanty [5] rozkładu będą odpowiednio równe

$$P_1 = 1 - \Phi(\alpha_1) = 0,995 \quad P_2 = 1 - \Phi(\alpha_2) = 0,98 \quad (8)$$

Wyznaczonym wartościom dystrybuanty odpowiadają [5] $z(\alpha_1)=2,58$ i $z(\alpha_2)=2,06$. Minimalna liczebność próbki w tych warunkach będzie równa zgodnie ze wzorem (7) $n=45$ jednostek wyrobu.

W przypadku dwustronnego ograniczenia rozkładu odchyłek rys. 2., szczególnie istotnego w kontroli procesów obróbki elementów maszyn, poziomy ufności rozkładu odchyłek można wyznaczyć na podstawie wzorów

$$\begin{aligned} P_1 &= 1 - 2\Phi(0,5\alpha_1) = 0,9975 \\ P_2 &= 1 - 2\Phi(0,5\alpha_2) = 0,99 \end{aligned} \quad (9)$$

Korzystając z dystrybuanty rozkładu normalnego wyznaczonym poziomom ufności odpowiadają odpowiednio $z(\alpha_1)=2,81$ i $z(\alpha_2)=2,33$. Minimalna liczebność próbki przy dwustronnym ograniczeniu właściwości wyniesie zgodnie ze wzorem (7) $n=53$.

W praktyce, wyznaczanie minimalnej liczebności w oparciu o pojęcie zmiennej standaryzowanej rozkładu normalnego można odnieść do zmienności rozkładu odchyłek. Przyjmując, że przedział zmienności rozkładu odchyłek dla procesu ustabilizowanego jest równy

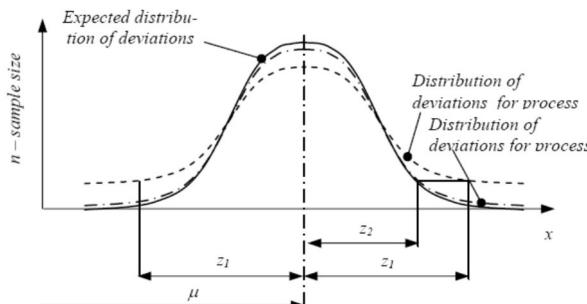
$$T_S = 2u_\alpha \sigma_{(x)} \quad (10)$$

a zmienność rozkładu powodowana zmiennością wartości średniej lub odchylenia standardowego rozkładu odchyłek spełnia warunek

$$z(\alpha_1) - z(\alpha_2) \leq 0,5kT_S \quad (11)$$

to dla przyjętych założeń wzór (6) można sprowadzić do postaci

$$n = \frac{u_\alpha}{[0,5kT_S]^2} \quad (12)$$



Rys. 2. Przedziały ufności rozkładu odchyłek dla dwustronnego ograniczenia
Fig. 2. Two-sided confidence intervals for distribution of deviations

final formula for calculating sample size will have the form

$$n = \frac{12,25}{[z(\alpha_1) - z(\alpha_2)]^2} \quad (7)$$

The minimum sample size, calculated using formula (7) depends on whether a one-sided or a two-sided limit of the inspected deviation was assumed for the estimation of the distribution of deviations (a qualification criterion) [4]. If, for a one-sided variation limit Fig. 1., we assume that the expected value of the deviation distribution parameter should be at the level of $\alpha_1=0,005$ and is accepted at the level of $\alpha_2 \leq 0,02$, then the values of the distribution function [5] for those assumptions will be, respectively,

$$P_1 = 1 - \Phi(\alpha_1) = 0,995 \quad P_2 = 1 - \Phi(\alpha_2) = 0,98 \quad (8)$$

The calculated values of the distribution function [5] correspond to $z(\alpha_1)=2,58$ and $z(\alpha_2)=2,06$. The minimum sample size under those conditions will be, in accordance with formula (7), $n=45$ product units.

In the case of a two-sided limit of the distribution of deviations Fig. 2., which is particularly important in the control of the processes of machining of parts, the levels of confidence for the distribution of deviations can be determined on the basis of formulas

$$\begin{aligned} P_1 &= 1 - 2\Phi(0,5\alpha_1) = 0,9975 \\ P_2 &= 1 - 2\Phi(0,5\alpha_2) = 0,99 \end{aligned} \quad (9)$$

When the normal distribution function is used, the determined levels of confidence correspond to $z(\alpha_1)=2,81$ and $z(\alpha_2)=2,33$, respectively. The minimum sample size for two-sided limitation of properties will be, in accordance with formula (7), $n=53$.

In practice, determination of the minimum sample size using the concept of standardized normal distribution variable can be related to variation of the distribution of deviations. Assuming that the variation interval of the distribution of deviations for a stabilized process equals

$$T_S = 2u_\alpha \sigma_{(x)} \quad (10)$$

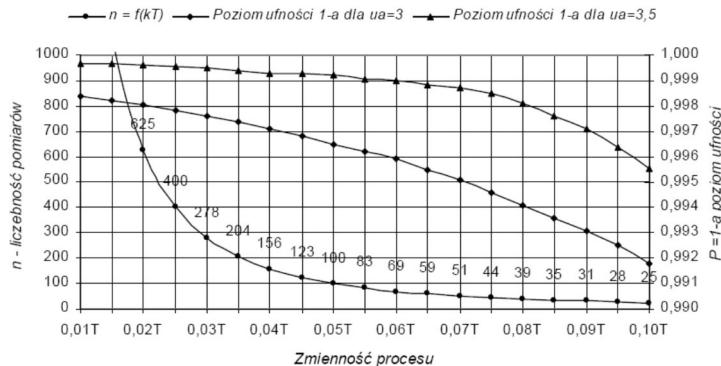
and the distribution variation caused by the variation of the mean value or the standard deviation of the distribution of deviations satisfies condition

$$z(\alpha_1) - z(\alpha_2) \leq 0,5kT_S \quad (11)$$

then, for the adopted assumptions, formula (6) can be re-written in the form

$$n = \frac{u_\alpha}{[0,5kT_S]^2} \quad (12)$$

Korzystając powyższego wzoru przeprowadzono analizę liczebności próbki w funkcji akceptowanej zmienności rozkładu odchyłek dla różnych poziomów ufności. Rezultaty analizy przedstawiono na rys.3.



Rys.3. Liczebność próbki oraz poziomy ufności $P_{\alpha} = 1 - \alpha$ w funkcji akceptowanej zmienności procesu

Fig.3. Sample size and the levels of confidence $P_{\alpha} = 1 - \alpha$ as a function of the accepted variation of a process

Z przeprowadzonej analizy wynika, że dla przyjętej zmiennej standaryzowanej rozkładu oczekiwanej minimalna liczebność próbki zależy tylko od akceptowanej zmienności rozkładu zaobserwowanego.

2. Wyznaczenie liczebności próby w oparciu o pojęcie zmiennej t

Do wyznaczenia oszacowania minimalnej liczebności próbki można wykorzystać także pojęcie zmiennej losowej rozkładu t -Studenta, której postać matematyczną można zapisać

$$t = \frac{|\bar{w} - \mu|}{S_{(\bar{w})}} \leq k_{\alpha,f} \quad (13)$$

Korzystając z zmiennej t można wyznaczyć oszacowanie błędu standardowego średnich z prób o liczebności n , pobranych z partii jednostek wyrobów o oszacowaniu odchylenia standardowego $S_{(\bar{w})}$. Oszacowanie odchylenia standardowego średnich jest równe [5]

$$S_{(\bar{w})} = \frac{S_{(\bar{w})}}{\sqrt{n}} \quad (14)$$

Korzystając z oszacowania odchylenia standardowego średnich można napisać, że maksymalny rozstęp wartości średnich procesu [4] z prób o liczebności n będzie równy

$$\bar{w}_2 - \bar{w}_1 = k_{\alpha} \frac{S_{(\bar{w})}}{\sqrt{n}} \quad (15)$$

Przyjmując założenie, że maksymalny rozstęp wartości średnich z prób powinien być równy k -tej części tolerancji konstrukcyjnej T można napisać

$$\bar{w}_2 - \bar{w}_1 = kT \quad (16)$$

Uwzględniając, że oszacowanie odchylenia standardowego rozkładu odchyłek geometrycznych procesu powinno spełniać warunek

$$T = 6S_{(\bar{w})} \quad (17)$$

wtedy

$$kT = k_{\alpha} \frac{T}{6\sqrt{n}} \quad (18)$$

Using the above formula, an analysis was conducted of sample size as a function of accepted variation of the distribution of deviations for different confidence levels. The results of the analysis are presented in Fig. 3.

It follows from the conducted analysis that, for the adopted standaryzowanej rozkładu oczekiwanej minimalna liczebność próbki zależy tylko od akceptowanej zmienności rozkładu zaobserwowanego.

2. Determination of sample size based on the concept of variable t

To determine the estimation of the minimum sample size, one can also use the concept of the random variable of Student's t -distribution, which can be written in a mathematical form as

$$t = \frac{|\bar{w} - \mu|}{S_{(\bar{w})}} \leq k_{\alpha,f} \quad (13)$$

Using variable t , one can determine the standard error estimator of means from samples of size n taken from a batch of product units with a standard deviation estimator $S_{(\bar{w})}$. The standard deviation estimator of means equals [5]

$$S_{(\bar{w})} = \frac{S_{(\bar{w})}}{\sqrt{n}} \quad (14)$$

Using the standard deviation estimator of means, it can be written that the maximum range of mean values of a process [4] from samples of size n equals

$$\bar{w}_2 - \bar{w}_1 = k_{\alpha} \frac{S_{(\bar{w})}}{\sqrt{n}} \quad (15)$$

Adopting the assumption that the maximum range of mean values from samples should be equal to the k -th part of structural tolerance T , it can be written that

$$\bar{w}_2 - \bar{w}_1 = kT \quad (16)$$

Taking into account that the standard deviation estimator of the distribution of geometric deviations of a process should satisfy condition

$$T = 6S_{(\bar{w})} \quad (17)$$

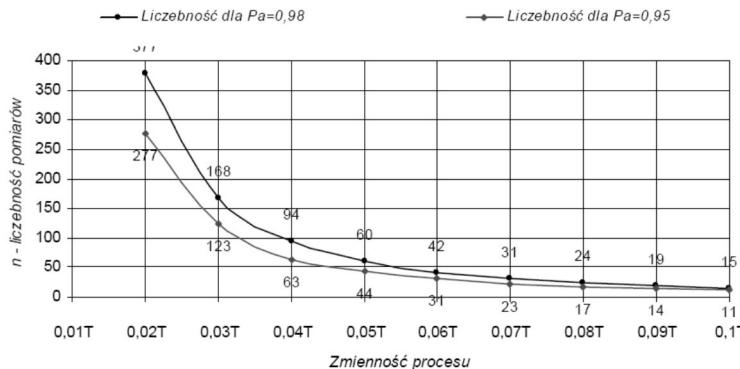
then

$$kT = k_{\alpha} \frac{T}{6\sqrt{n}} \quad (18)$$

Przekształcając wzór (18) można wyznaczyć minimalną liczebność próby na określonym poziomie ufności P_α . Na poziomie ufności $P_\alpha=0,98$ i $P_\alpha=0,95$ minimalną liczebność próby można wyznaczyć ze wzorów odpowiednio

$$n = \frac{0,151}{k^2} \text{ dla } P_\alpha=0,98 \quad n = \frac{0,111}{k^2} \text{ dla } P_\alpha=0,95 \quad (19)$$

Na podstawie powyższych zależności wyznaczono krytyczne liczebności próby n w funkcji k współczynnika maksymalnego rozstępu wartości średnich. Wyniki obliczeń przedstawiono na rys. 4.



Rys. 4. Liczebność próbki dla poziomów ufności $P_\alpha=0,98$ i $P_\alpha=0,95$ w funkcji akceptowanej zmienności procesu
Fig. 4. Sample size for confidence levels $P_\alpha=0,98$ and $P_\alpha=0,95$ as a function of the accepted variation of a process

3. Wyznaczenie liczebności próby w oparciu o analizę wartości krytycznej zmiennej t rozkładu t-Studenta

Oszacowanie liczebności próby można wykonać w oparciu o analizę wartości krytycznej parametru t rozkładu t -Studenta. Wartości krytyczne parametru t można znaleźć w literaturze [5] w postaci stabelaryzowanych wartości liczbowych. Analiza wartości w postaci liczb zestawionych w tabeli jest niewygodna i trudno w ten sposób ustalić oszacowanie optymalnej liczebności próby. Znaczenie wygodniej jest analizować wartości krytyczne parametru t jeżeli zostaną przedstawione w sposób graficzny.

Na rys.5. przedstawiono w sposób graficzny charakterystyki wartości krytycznych $k_{\alpha,f}$ parametru t w funkcji liczby stopni swobody $f = n-1$ dla trzech poziomów istotności α . Na podstawie przebiegu charakterystyk wartości krytycznych $k_{\alpha,f}$ można ustalić oszacowanie liczebności próby. Jako oszacowa-

By re-writing formula (18), we can determine the minimum sample size at a given level of confidence P_α . At the levels of confidence of $P_\alpha=0,98$ and $P_\alpha=0,95$, the minimum sample size can be determined from the respective formulas

$$n = \frac{0,151}{k^2} \text{ for } P_\alpha=0,98 \quad n = \frac{0,111}{k^2} \text{ for } P_\alpha=0,95 \quad (19)$$

On the basis of the above relations, critical sample sizes n were determined as a function of k , the coefficient of the maximum range of mean values. The results of the calculations are presented in Fig.4.

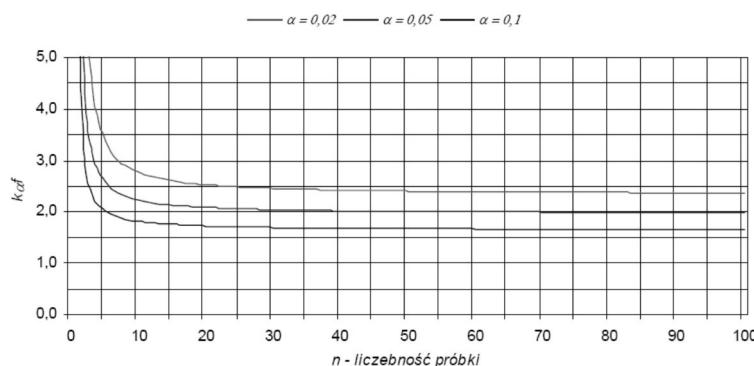
Liczebność dla $P_\alpha=0,98$

Liczebność dla $P_\alpha=0,95$

3. Determination of sample size based on the analysis of the critical value of variable t of Student's t-distribution

Sample size can be determined by analyzing the critical value of parameter t of Student's t -distribution. Critical values of parameter t can be found in the literature [5] in the form of tabulated numerical values. Analysis of values in the form of tabulated numbers is inconvenient, and it is difficult to determine the estimation of the optimum sample size in that way. It is considerably more convenient to analyze critical values of parameter t if they are represented graphically.

Fig.5. is a graphical representation of the characteristics of critical values $k_{\alpha,f}$ of parameter t as a function of the number of degrees of freedom $f = n-1$ for three levels of significance α . Based on the curves of critical values $k_{\alpha,f}$, one can determine the estimation of sample size. The estimation of the minimum sample size is assumed to be such a number n beginning



Rys. 5. Wartości krytyczne $k_{\alpha,f}$ parametru t w funkcji liczebności próbki
Fig. 5. Critical values $k_{\alpha,f}$ of parameter t as a function of sample size

nie minimalnej liczebności próbki należy przyjąć taką liczbę n od której przebieg charakterystyki jest prawie równoległy do osi n . Dla poziomu istotności $\alpha=0,02$ prawie równoległy przebieg zaczyna się od $n=45\div50$, a dla $\alpha=0,05$ od $n=30\div35$ i dla $\alpha=0,1$ od $n=25\div30$.

4. Ocena wpływu liczebności próby na podstawowe parametry statystyczne rozkładu odchyłek

Przedstawiona analiza zagadnienia dowodzi, że istnieje minimalna liczebność próbki, która może zapewnić poprawne oszacowanie parametrów rozkładu odchyłek geometrycznych dla określonego poziomu ufności. Omawiane metody szacowania liczebności próbki nie dają jednoznacznych wartości liczbowych, aczkolwiek dają wartości zbliżone. Należy zaznaczyć, że wybór metody wyznaczania minimalnej liczebności próbki zależy od celu jaki w wyniku badania statystycznego powinien być osiągnięty.

Wyznaczanie liczebności próbki w oparciu o pojęcie zmiennej standaryzowanej zapewnia najwyższe liczebności próbek i z tego względu powinno być stosowane w badaniach odbiorczych, których celem jest skuteczność jakościowej oceny partii wyrobów.

Liczebność próbki wyznaczona w oparciu pojęcie zmiennej t rozkładu t -Studenta zapewnia również dobre oszacowanie parametrów rozkładu odchyłek geometrycznych.

Metoda wyznaczenia liczebności próbki oparta na analizie wartości krytycznej parametru t rozkładu t -Studenta zapewnia najmniejszą liczebność próbki, dlatego nie powinna być stosowana w przypadkach, gdzie jest wymagana wysoka skuteczność oceny. Z przeprowadzonych badań w tym zakresie wynika, że można korzystać z tej metody przy monitorowaniu parametrów rozkładu statystycznego odchyłek geometrycznych procesu na podstawie kontroli frakcji jednostek.

Porównanie wpływu liczebności próbki n na wartości podstawowych parametrów rozkładu odchyłek geometrycznych procesu zestawiono w tabeli 1. W kolumnie 2 zestawiono wartości średnie zaobserwowanych odchyłek wymiaru E_w od wartości nominalnej d_N (kolumna 1) dla trzech kolejnych cykli badania procesu wyznaczone dla wszystkich jednostek obrabionych powierzchni w danym cyklu. W kolumnie 3 zestawiono wartości średnie zaobserwowanej odchyłki wymiaru dla tych samych warunków ale dla próbek o liczebności $n=62$. Taką liczebność zapewnia metoda oparta na pojęciu zmiennej standaryzowanej rozkładu normalnego przy zmienności procesu równej ok. $0,06T$ rys.3, lub metoda oparta na pojęciu zmiennej t przy zmienności procesu ok. $0,04T$ i poziomie istotności $\alpha=0,05$ rys.4. W kolumnie 4 zestawiono wartości średnie zaobserwowanych odchyłek wymiaru dla trzech próbek o liczebności $n=31$ jednostek wyznaczone w oparciu o analizę wartości krytycznych parametru t rys.5. W kolumnie 5 zawiera wartości odchylenia standardowego dla wszystkich jednostek serii a w kolumnie 7 i 8 odpowiadające im oszacowania odchylenia standardowego wyznaczone dla próbek o liczebności $n=62$ i $n=31$ jednostek.

Analiza i wyniki przeprowadzonych badań jak również rezultaty badań powtarzalności rozkładu odchyłek zawarte w pracy [3] dowodzą, że omawiane metody zapewniają bardzo dobrą skuteczność wyznaczania wartości średniej z próbek o wyznaczonej liczebności. Różnica w oszacowaniu wartości średniej z próbek w odniesieniu do wartości średniej z populacji nie

from which the curve is almost parallel to the axis n . For the level of significance $\alpha=0,02$, an almost parallel curve begins from $n=45\div50$, for $\alpha=0,05$ from $n=30\div35$, and for $\alpha=0,1$ from $n=25\div30$.

4. Assessment of the effect of sample size on basic statistical parameters of distribution of deviations

The presented analysis of the issue proves that there exists a minimum sample size, which can ensure correct estimation of the parameters of distribution of geometric deviations for a specified level of confidence. The discussed methods of estimating sample size do not give unequivocal numerical values yet they provide approximate values. It must be pointed out that the choice of a method for determining the minimum sample size depends on the goal that a statistical analysis is aiming to achieve.

Determination of sample size using the concept of standarized variable ensures the largest sample sizes and for that reason should be used in acceptance tests, which aim at effective assessment of the quality of a batch of products.

Sample sizes determined based on the concept of variable t of Student's t -distribution also ensure good estimation of the distribution parameters of geometric deviations.

The method of determining sample size based on the analysis of the critical value of parameter t of Student's t -distribution provides the smallest sample sizes, which is why it should not be used in cases where high effectiveness of assessment is required. It follows from the research conducted in this regard that this method can be used in monitoring the statistical distribution parameters of geometric deviations of a process on the basis of the control of unit fractions.

A comparison of the effect of sample size n on the values of basic distribution parameters of geometric deviations of a process is presented in Table 1. Column 2 shows mean values of the observed dimension deviations E_w from the nominal value d_N (column 1) for three successive process testing cycles, determined for all units of machined surfaces in a given cycle. In column 3, mean values of the observed dimension deviation have been tabulated for the same conditions, but for samples of size $n=62$. This size is provided by the method based on the standarized normal deviation variable for process variation of ca. $0,06T$ Fig.3, or the variable t method for process variation of ca. $0,04T$ and the level of significance $\alpha=0,05$ Fig.4. Column 4 presents mean values of observed dimension deviations for three samples of size $n=31$ of units determined based on the analysis of the critical values of parameter t Fig.5. Column 5 contains standard deviation values for all units of the series, and columns 7 and 8, the corresponding estimators of standard deviation determined for samples of $n=62$ and $n=31$ units.

The analysis and the results of the conducted studies as well as the findings of the investigations of repeatability of deviation distribution included in article [3] demonstrate that the methods discussed ensure very good effectiveness of determining mean value from samples of defined size. The difference in estimation between the sample mean value compared to the population mean value does not exceed 0.9%. With regard to the estimation of standard deviation, the effectiveness of the discussed methods is sufficient. The difference between the estimation values of sample standard deviation compared to po-

Tab. 1. Zestawienie wyznaczonych parametrów statystycznych rozkładu odchyłek wymiaru E_w procesu dla różnych liczebności n próbek

Tab. 1. A collation of the determined statistical parameters of the distribution of dimension deviations E_w of a process for different sample sizes n

$d_n / \text{nr próbki}$ $d_n / \text{sample no.}$	Wartość średnia E_w Mean value E_w			$\sigma_{(Ew)}$	$S_{(Ew)}$		
	n_{\max}	$n=62$	$n=31$		n_{\max}	$n=62$	$n=31$
89,54/1	0,076	0,074	0,075	0,032	0,032	0,034	0,032
89,54/2	0,076	0,077	0,076	0,032	0,032	0,036	0,036
89,54/3	0,076	0,077	0,075	0,032	0,032	0,035	0,034
1/3 Σ	0,076	0,076	0,07533	0,032	0,032	0,035	0,034

przekracza 0,9%. W odniesieniu do oszacowania odchylenia standardowego skuteczność omawianych metod jest dostateczna. Różnica wartości oszacowania odchylenia standardowego z próbek w odniesieniu do odchylenia standardowego zawiera się w przedziale (6,25÷9,4)%.

Należy podkreślić, że skuteczność oszacowania wartości parametrów statystycznych rozkładu odchyłek geometrycznych zależy od sposobu pobierania jednostek do badań. Sposób pobierania jednostek do badań jest szczególnie ważny w procesach odpowiadających modelom statystycznym typu C i typu A-C, gdzie wartość średnia zmienia się w toku procesu. Procesy obróbki skrawaniem należy zaliczyć do tego typu procesów z uwagi na występowanie zużycia ostrza. Zużycie ostrza jest funkcją nieliniową charakteryzującą się etapami o różnej intensywności zużycia. Sposób pobierania jednostek do badań statystycznych powinien uwzględniać to zjawisko aby wyniki uzyskane z badania próbek o wyznaczonej liczebności były wiarygodne.

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pulation standard deviation is within the range of (6,25÷9,4)%.

It should be emphasized that the effectiveness of estimating the value of the statistical parameters of distribution of geometric deviations depends on the manner in which units are taken for analysis. The manner of sampling is particularly important in processes corresponding to statistical models of type C and type A-C, where the mean value changes in the course of the process. Processes of machining should be counted among this type of processes since they involve wear of the cutting tool point. Wear of the cutting tool point is a non-linear function characterized by stages of different intensity of wear. If the results obtained from the analyses of samples of defined size are to be reliable, this phenomenon needs to be taken into account while choosing a sampling technique.

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NOWA KONCEPCJA SAMOCHODOWYCH FOTELIKÓW DLA DZIECI ZE WZGLĘDU NA ZASTOSOWANY SYSTEM BEZPIECZEŃSTWA UCZESTNIKÓW RUCHU DROGOWEGO

NEW IDEA OF CHILD CAR SEAT ACCORDING TO NEW SAFETY SYSTEM OF PARTICIPANTS OF ROAD TRAFFIC

W artykule zostały przedstawione zagadnienia dotyczące budowy samochodowych fotelików dla dzieci, obecnie dostępne rozwiązania konstrukcyjne oraz metodologię badań, która jest podstawą do dopuszczenia fotelika do sprzedaży. Szczególną uwagę poświęcono kryteriom służącym ocenie systemów bezpieczeństwa zamontowanych w foteliku. Wskazano również tendencje pojawiające się przy konstruowaniu nowych urządzeń.

Słowa kluczowe: fotelik dla dziecka, ISOFIX, homologacja, bezpieczeństwo dziecka.

In following article some issues of Child Restraint Systems (CRS) construction were presented, esp. currently available design solutions and methodology of the research (which is the basis of granting the type approval before introducing CRS to the market). There were also discussed criteria of evaluating safety systems in CRS. New tendencies of designing new facilities which have already been introduced were also pointed out.

Keywords: Child Restraint System (CRS), ISOFIX, type approval, child's safety.

1. Wprowadzenie

Przewożenie dziecka w samochodzie ma szczególne znaczenie, gdy weźmie się pod uwagę specyfikę podróży najmłodszych z pasażerów. Wypadek może spowodować kierujący samochodem lub inni uczestnicy ruchu w sposób całkowicie nieświadomy. Można sobie wyobrazić sytuację, w której na samochód osobowy najeżdża pojazd ciężarowy lub autobus tylko z tego powodu, że kierowca nie widział tegoż samochodu osobowego z powodu ograniczonego pola widzenia z kabiny kierowcy.

Należy również jasno powiedzieć: kierowca i inni dorośli pasażerowie samochodu wsiadają do niego świadomie i – zazwyczaj – zgodnie z własną, nieprzymuszoną wolą uczestniczą w ruchu drogowym, niosącym ze sobą ryzyko doznania urazów lub utraty życia, dziecko natomiast jest pasażerem biernym. Nie może samo decydować, czy chce znajdować się w samochodzie, gdy ten jest w ruchu, ani świadomie przeciw temu za protestować, tym bardziej w świadomy sposób nie jest w stanie zająć swojego miejsca w sposób, który będzie zgodny z intencją producenta użytkowanego fotelika oraz uwzględniający specyfikę samochodu, w którym fotelik ten został zamontowany.

Zapewnienie dziecku odpowiednio skutecznego systemu bezpieczeństwa podczas podróży zależy od jego opiekuna. Opiekun może bowiem zatem zadbać o dobrą ochronę dziecka na kilka sposobów:

1. powinien zapewnić stosowanie specjalnych urządzeń do przewożenia dzieci (co jest wymagane prawem);
2. powinien używać wskazanego urządzenia zgodnie z zaleceniami producenta;
3. powinien prowadzić pojazd, mając na uwadze, że bezpieczeństwo jego podopiecznego zależy głównie od decyzji jakie podejmie prowadząc pojazd.

Ze względu na obszerność przedstawionych wyżej zagadnień w niniejszym artykule autor skoncentruje się jedynie na kwestii konstrukcji urządzeń do przewożenia dzieci, zastosowane bowiem w nich rozwiązania wprost wpływają na to, czy podróżujące w nim dziecko będzie dobrze chronione przed skutkami wypadku drogowego lub kolizji.

1. Introduction

Child's car transportation gets special meaning when we take into consideration specific character of journey of the youngest passengers. An accident could be caused by a driver or other participants of traffic – totally unintentionally. One could imagine a situation when passenger car is crashed by heavy goods vehicle or a bus. Such crash could be caused for example when passenger vehicle is placed out of range of visibility in a bus (or a lorry).

It should be also clarified: a driver and other adults become passengers basing on their intentional choice and – in most cases – conscious will of participation in traffic. Traffic which brings a risk of loss of life or serious injury. Child is a passive passenger, it cannot decide if it want to be inside a car, it cannot protest, and – what's the most important – it is unable to take proper position in child car seat (CRS), which will be in conformity of intention of CRS and car manufacturer.

Providing a child an effective safety system during journey depends only on a child's guardian. A guardian could take care of child's safety on several ways:

1. He or she should ensure using a proper CRS (which is demanded by law);
2. He or she should use a CRS with conformity of demands of its manufacturer;
3. He or she should be aware that, while driving, the safety of his / her charge depends mainly on his /her decision on the road.

Regarding to the fact that issues mentioned above are comprehensive, author will focus in this article on a problem of construction of CRS. Solutions used in CRS influence directly the ability to secure child properly.

Regulamin EKG ONZ nr 44 ze względu na masę dziecka wyróżnia 4 grupy fotelików:

1. grupa 0 (0+) - dla dzieci o masie do 11 kg (13 kg);
2. grupa I - dla dzieci o masie od 9 kg do 18 kg;
3. grupa II - dla dzieci o masie od 15 kg do 25 kg;
4. grupa III - dla dzieci o masie od 22 kg do 36 kg.

W praktyce grupa II i III bazują na przytrzymaniu dziecka pasem bezpieczeństwa dla osób dorosłych. Grupa 0 to tzw. nosidełko/kolyski, w których dziecko podróży w pozycji leżącej.

Najbardziej interesująca z punktu widzenia możliwości konstrukcyjnych jest grupa I. W tych konstrukcjach jest wymagane, aby dziecko było mocowane do fotelika integralnym pasem, niezależnym od sposobu zamocowania fotelika w pojazdzie.

2. Definicja wymagań dotyczących fotelików

Sytuacja wypadku drogowego jest dla dziecka najbardziej niekorzystna ze względu na skutki jakie ta sytuacja może wywołać. Wszystkie systemy bezpieczeństwa biernego, mające zmniejszać ciężkość obrażeń doznanych przez pasażerów, są zaprojektowane z myślą o dorosłej osobie, jej wzroście i masie. Dziecko, gdyby nie fotelik, byłoby całkowicie bezbronne. Konfiguracja pasa bezpieczeństwa nie odpowiada ani masie dziecka ani jego wzrostowi, wytrzymałość i sztywność taśmy pasa jest zoptymalizowana pod kątem dorosłego, a zakres działania poduszek gazowych nie obejmuje przestrzeni, w której znajduje się dziecko podczas jazdy.

Mimo zastosowania specjalnego urządzenia, jakim jest fotelik samochodowy, dziecko nadal jest narażone na olbrzymie opóźnienia, jakie działają na jego ciało podczas wypadku.

Definicja kryteriów, jakie stosuje się do oceny fotelików, znajduje się w Regulaminie EKG ONZ nr 44. Określony jest w nim tzw. „kształt krzywej hamowania” (zależność opóźnienia od czasu), oraz wielkości, jakie powinny zostać zarejestrowane przy pomocy manekina badawczego (serii P).

Ogólne kryteria do oceny spełniania wymagań w zakresie bezpieczeństwa to m.in.:

1. zdolność utrzymania dziecka w foteliku (badanie polega za obróceniu fotelika z zamontowanym manekinem o 360°);
2. wewnętrzne części fotelika powinny być wykonane z materiałów zapewniających rozpraszanie energii; maksymalna wartość opóźnienia po uderzeniu specjalnym impaktem powinna wynosić nie więcej niż 60 g (588,6 m/s²);
3. Podczas hamowania stosuje się np. kryteria:
4. opóźnienie wypadkowe klatki piersiowej (mierzzone za pomocą przetwornika opóźnienia umieszczonego w klatce piersiowej manekina) nie może przekroczyć 55 g (539,6 m/s²);
5. pionowa składowa opóźnienia klatki piersiowej, skierowana od brzucha do głowy (kierunek składowej pokrywa się z osią kręgosłupa manekina, zwrot jest w kierunku głowy) nie może przekroczyć 35 g (343,4 m/s²);
6. głowa manekina użytego do pomiaru nie może przemieścić się poza obszar kontrolny (rysunek 1).
7. dodatkowo sprawdza się stopień penetracji jamy brzusznej za pomocą plastelinowej wkładki, umieszczanej w części jamy brzusznej manekina.

ECE Regulation No. 44 gives 4 groups of CRS (from the mass of a child):

4. Group 0 (0+) – for children of mass to 11 kg (13 kg);
5. Group I - for children of mass from 9 kg to 18 kg;
6. Group II - for children of mass from 15 kg to 25 kg;
7. Group III - for children of mass from 22 kg to 36 kg.

In practice, group II and III are based on restraining child by a safety belt for an adult person. Group 0 contains CRS (carry cots) in which child in prone position.

The most interesting (for the reason of possibilities) is group I. In these constructions of CRS it is required to restrain a child (in CRS) by an integral belt which is independent from restraining of CRS in a car.

2. Definition of requirements concerning CRS

A situation of road accident is the most unfavorable for a child because of effects. All of passive safety systems, which are to decrease a range of injuries, are designed for a height and weight of an adult person. A child without CRS would be completely vulnerable. A configuration of an adult safety belt doesn't fit to a child, neither to its height, neither to its weight. The stiffness and strength of the strap of belt is optimized for an adult; the work range of airbags doesn't cover the area where a child is placed during a journey.

Despite using a special device, which CRS is, a child is still endangered to huge decelerations acting during an accident.

Definitions of requirements used during marking CRS are placed in ECE Regulation No. 44. The Regulation defines the shape of “deceleration curve” (deceleration-time dependence) and parameters which should be registered on crash test dummy (P-series).

General criteria of safety system in CRS are:

1. Ability of CRS to restrain a child inside CRS (full rotation of CRS with a dummy);
2. Inner parts of CRS should be made from materials ensuring appropriate level of energy dissipation (maximum value of deceleration after using special impactor should be no more than 60 g [588,6 m/s²]);
3. During deceleration are used criteria of:
4. Resultant deceleration of chest of a dummy (measured by deceleration transducer) mustn't exceed 55 g (539,6 m/s²);
5. Perpendicular component of chest deceleration from the stomach to the head mustn't exceed 35 g (343,4 m/s²);
6. A head of a dummy mustn't exceed the control area (Drawing No.1);
7. In addition, there is introduced level of stomach penetration. It is measured by plasticine insert placed in abdominal cavity of a dummy.
8. Mentioned above requirements should be completed by criteria determining ability to release a child from CRS by only one operation.

Do powyższych kryteriów należy jeszcze dodać wymaganie mówiące o możliwości uwolnienia dziecka z fotelika po wykonaniu tylko jednej operacji.

3. Analiza wymagań

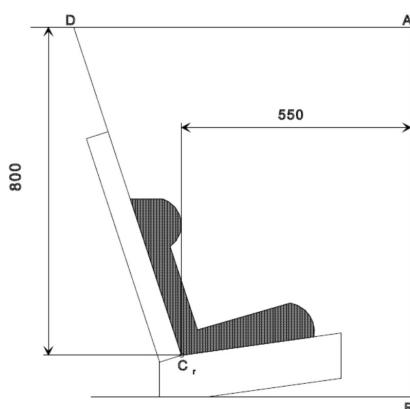
Przyjęło się, że Regulamin będący podstawą do udzielenia homologacji typu (ang. *type approval*) stanowi minimum wymagań, jakie powinien spełniać fotelik dla dziecka, warto jednak krytycznie przyjrzeć się przyjętej metodycy badań i spojrzeć na nią przez pryzmat konstrukcji, które zostały dotychczas wprowadzone do użytku. W praktyce bowiem, większość producentów stara się spełnić jedynie minimum wymagań, tak aby uzyskać dokumenty pozwalające wprowadzić produkt na rynek.

Wymagania stanowią jedynie o zachowaniu się klatki piersiowej dziecka, nic jednak nie jest powiedziane o ocenie dynamicznego zachowania głowy, tj. o opóźnieniach rejestrówanych w głowie manekina, odkształceniu szyi manekina, sile tnącej czy momencie zginającym działającym na odcinek szyjny kręgosłupa dziecka. Analizując proporcje mas poszczególnych części ciała [2] (rysunek 2), można zauważać, że głowa trzyletniego dziecka ma masę dwukrotnie większą niż masa głowy dorosłego człowieka. Dodatkowo należy również zauważać, że dziecko nie ma wykształconej w pełni tkanki mięśniowej ani kostnej, która pozwoliłaby skutecznie przenosić wysokie obciążenia, które działają na głowę i szyję dziecka podczas wypadku.

Regulamin nakłada na konstrukcję fotelika warunek stosowania pasa kroczo-wego. Skutkuje to wymuszeniem konstrukcji pasów integralnych fotelika. Obecnie mają one kształt sześciopunktowej uprzęki, która ma pas kroczo-wy opierający się bezpośrednio o kroce dziecka oraz klamrę spinającą taśmy pasa. Klamra umieszczona jest na brzuchu dziecka.

Można przyjąć założenie, że klamra jako element o bardzo dużej sztywności i twardości (w porównaniu z brzuchem dziecka) może powodować urazy narządów znajdujących się w jamie brzusznej dziecka. Jednakże Regulamin nie stawia w tym przypadku żadnych kryteriów dotyczących rejestracji siły i/lub głębokości penetracji. Spowodowane jest to tym, że nie są obecnie dostępne manekiny dzieci, które byłyby wyposażone w przetworniki rejestrujące właśnie nacisk na kroce czym siłę z jaką zamek penetruje jamę brzuszną.

Obecnie jedyną metodą na sprawdzenie czy konstrukcja zamka nie powoduje zbyt dużego ryzyka urazu stosuje się pomiar penetracji przy pomocy wkładki plastelinowej. Jednakże metoda ta pozostawia wiele do życzenia. Sam pomiar bazuje na każdorazowym umieszczeniu wkładki w ma-



Rys. 1. Obszar kontrolny dla głowy manekina podczas testu dynamicznego [1]

Fig. 1. Control area for a head of a dummy during dynamic test [1]

3. The analysis of requirements

It is accepted that ECE Regulation which is a basis to granting type approval contains a minimum of requirements that CRS should fulfill. But it is reasonable to look into ECE methodology of testing from the point of view of CRS which were introduced to the market.

In practice most of manufacturers want to fulfill only a minimum of requirements in order to complete all of documents which are necessary for introducing CRS to the market.

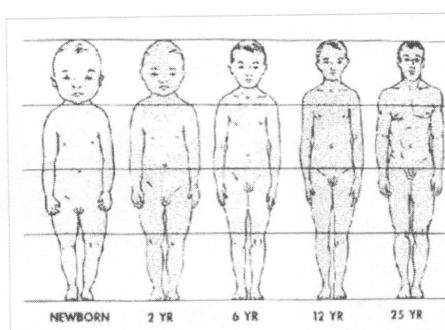
Requirements describe only behavior of chest of a child. There is nothing said about dynamic performance of a head: decelerations registered in the head of a dummy, deflection of a neck, shearing force or bending moment acting on neck section of a spine. After analyzing proportions of different parts of human body [2] (Drawing No.2.) it could be noticed that a head of three-years old child has a weight two times higher than a head of an adult. It is also very important that three-year old child has a muscular and bone tissue not strong enough to withstand dynamic load which affects its head and neck during the impact.

ECE Regulation gives a requirement to use a crotch strap. This statement forces using specific construction of integral belt system. At present this construction is formed as a 6-point harness with crotch strap resting on child's genitals and main buckle. The buckle is placed on a child's stomach.

It could be assumed that the buckle has very high stiffness and hardness (in comparison with child's stomach). A contact of buckle and stomach could be a reason of serious injuries of inner organs. But the Regulation doesn't give any criteria for registering force and/or depth of penetration. It is caused by situation of market of test dummies. At present there is no reliable dummy equipped with transducers measuring pressure on crotch or force of buckle penetration.

Nowadays the only method of testing if the construction of buckle doesn't penetrate the stomach too deep is measurement of penetration by plasticine insert. However this method is not satisfying. During each measurement the insert is placed in abdominal cavity of dummy by a technical service and judgment is given after removing the insert from a dummy. Before giving the judgment the insert could be damaged twice. Reliability of such measurement and its repeatability are controversial.

Another requirement which could be questioned is the way of releasing a child from CRS. The requirement



Rys. 2. Zmiany proporcji ciała dziecka wraz z wiekiem

Fig. 2. Changes of proportions of body vs. age

nekinie przez pracownika placówki technicznej prowadzącej badania, a ocena następuje po wyjęciu wkładki również przez pracownika. Zanim więc zostanie odnotowany wynik badania, wkładka ma możliwość być uszkodzoną dwa razy. Pewność tak przeprowadzonego pomiaru oraz jego powtarzalność jest co najmniej dyskusyjna.

Kolejnym wymaganiem, które można kwestionować jest sposób uwalniania dziecka z fotelika. Kryterium mówi, że musi się to odbyć przy pomocy jednej operacji. W domyśle mowa tu o odpięciu blokady pasów integralnych (poprzez naciśnięcie przycisku zwalniania). Jednakże przy poprawnie wyregulowanym pasie samo odpięcie blokady nie gwarantuje szybkiego usunięcia dziecka z fotelika. W praktyce należy również wyłuzować taśmy, co znaczco wydłuża czas ewakuacji. Należy również zauważać, że gdy ewakuacja odbywa się w sytuacji zagrażającej dziecku utratą życia, może nie być czasu na mocowanie się z mechanizmem regulacji długości taśm.

Na szersze omówienie zasługuje również sama specyfikacja testu dynamicznego. Regulamin przewiduje jedynie badanie, które odwzorowuje wypadek drogowy, który można sklasyfikować jako zderzenie czołowe bez tzw. offsetu¹. Natomiast w rzeczywistości większość wypadków to zderzenia czołowe właśnie z offsetem. Nierzadko również występują zderzenia boczne oraz kombinacja tych dwóch typów zderzeń. Zdarza się również, że zaraz po zderzeniu czołowym następuje drugie zderzenie, boczne lub uderzenie w tył pojazdu. Regulamin jednak takich sytuacji nie przewiduje.

Jako podsumowanie specyfikacji badań należy podać, że badanie dynamiczne fotelika mocowanego pasem bezpieczeństwa dla osoby dorosłej prowadzone jest po uprzednim naprężeniu taśmy pasa siłą 50 daN. W praktyce użytkowej bardzo trudno jest osiągnąć taką wartość naprężenia taśmy (najczęściej nie jest ona w ogóle naprężana).

Kluczowym pytaniem, jakie należy w tym momencie postawić, jest: czy fakt uzyskania przed fotelik homologacji EKG ONZ mówi cokolwiek o możliwościach ochronnych systemu bezpieczeństwa fotelika, w którym codziennie woźimy nasze dzieci?

Słuszną jest teza o konieczności opracowania metody badań homologacyjnych od nowa, tak aby odzwierciedlała rzeczywiste warunki użytkowania fotelika, jak również odtwarzała w większym stopniu rzeczywiste warunki wypadku drogowego.

W celu sprawdzenia rzeczywistej skuteczności systemów bezpieczeństwa używanych w fotelikach dla dzieci, zostało założone międzynarodowe konsorcjum (członkami są automobilkluby z całego świata²), które wykonuje co roku test konsumencki fotelików w centrum testowym ADAC w Niemczech.

Formuła tego testu przewiduje zwiększenie wartości prędkości zderzenia czołowego z 50 km/h na 70 km/h oraz umieszczenie fotelika w nadwoziu samochodu na rzeczywistym fotelu (a nie na standardowym fotelu badawczym, jak to jest w przypadku badań homologacyjnych). Dodatkowo wprowadzono test zderzenia bocznego, wzorowany na procedurze testowej EuroNCAP. Wprowadzono również (z małym współczynnikiem wag) badanie właściwości funkcjonalnych testowanych fotelików.

¹ Offset (ang.) – w terminologii opisującej zderzenia pojazdów określa odległość osi wzdłużnych zderzających się pojazdów

¹ Offset (ang.) – w terminologii opisującej zderzenia pojazdów określa odległość osi wzdłużnych zderzających się pojazdów

² W skład konsorcjum wchodzą organizacje z Austrii, Belgii, Chorwacji, Czech, Danii, Wielkiej Brytanii, Finlandii, Francji, Niemiec, Hong Kongu, Węgier, Irlandii, Włoch, Holandii, Norwegii, Portugalii, Słowenii, Hiszpanii, Szwecji i Szwajcarii.

² Members of consortium are from: Austria, Belgium, Croatia, Czech Republic, Denmark, England, Finland, France, Germany, Hong Kong, Hungary, Ireland, Italy, Netherlands, Norway, Portugal, Portugal, Slovenia, Spain, Sweden and Switzerland.

claims that child should be released by one operation. As an interpretation it could be said that releasing should be made by pressing one button on buckle. However when the harness is properly adjusted, releasing a buckle doesn't guarantee a possibility of fast removing child from CRS. In practice also the harness should be released, but this operation extend time needed for child evacuation. Is also worth to mention that child evacuation acts usually in case of emergency and it could happen that there won't be enough time to release the harness.

Another thing which should be discussed is dynamic test specification itself. The Regulation covers only situation of car accident which could be described as a front impact without the offset¹. But in real accidents most of them are front impacts with offset. Often there are also lateral impacts or combinations of both: front and lateral or back impacts. The Regulations doesn't cover such cases.

As a summary of dynamic test specification it should be mentioned that dynamic test CRS which is restrained in a car by an adult safety belt is performed with pre-tensioning the safety belt with a force of 50 daN. In practice such pre-tension is very difficult to achieve (in most cases belt is without any tension).

Basic question which should be asked is: Does the fact of granting ECE type approval say anything about efficiency of safety system used in particular CRS?

It's highly recommended to work on new methodology of type approval tests in order to keep it as close to real road situations as possible.

In order to check real efficiency of safety systems in CRS an international consortium was established (members of this consortium are motor-clubs from all of the world²). The consortium performs a customer's test once a year in ADAC testing centre in Germany.

Specification of this test increases value of velocity from 50 km/h to 70 km/h and places CRS in real car body on real seat (not on a standard testing seat as it is in type approval test). Additionally there was introduced lateral impact based on the EuroNCAP specification. There was also introduced a test of functionality of CRS (but with low importance).

But all of that doesn't change a fact that ADAC test is performed by using the same equipment as it is in type approval.

Nie zmienia to jednak faktu, że próby te wykonywane są za pomocą tego samego sprzętu, który służy do badań homologacyjnych.

4. Możliwości projektowe

Obecnie, gdy konstruktor staje przed zadaniem zaprojektowania nowego typu fotelika dla I grupy masowej, może skorzystać z dwóch podstawowych koncepcji mocowania fotelika do pojazdu:

1. Fotelik mocowany pasami bezpieczeństwa dla osoby dorosłej.

Zalety: uniwersalność, pasuje do każdego samochodu wyposażonego w trzypunktowy pas bezpieczeństwa dla osoby dorosłej.

Wady: system podatny na błędy użytkownika przy mocowaniu, duże luzy wynikające z rozciągania się taśmy.

2. Fotelik mocowany systemem ISOFIX.

Zalety: szybkie i pewne zamocowanie do pojazdu, duża sztywność konstrukcji.

Wady: wysoka masa całego urządzenia, wysoki koszt końcowy.

Podstawowa konstrukcja wewnętrzna, dotycząca mocowania dziecka w pojeździe do tej pory pozostawała właściwie taka sama: uprząż sześciopunktowa ze wszystkimi jej wadami wskazanymi wcześniej.

Patrząc na dotychczasowe konstrukcje przez pryzmat testu homologacyjnego można odnieść wrażenie, że obecnie stosowane konstrukcje spełniają wymagania dostatecznie dobrze. Jednakże podstawowe pytanie jakie należy postawić brzmi: w jaki sposób kryterium opóźnienia wypadkowego torsu 55 g (przykładowe wyniki – rysunek 3) przekłada się na faktyczną jakość fotelików ze względu na bezpieczeństwo?

Odpowiadając na postawione do tej pory pytania, należy wziąć pod uwagę fakt, że dotychczas instytucje zajmujące się określaniem wymagań, jak również prowadzące prace rozwojowe nad manekinami, nie dysponują danymi biomechanicznymi ludzkiego ciała. W literaturze brakuje podstawowych danych dotyczących wytrzymałości tkanki kostnej, stawów, narządów wewnętrznych oraz ich odporności na przeciążenia. Co więcej, praktyczne każda próba stworzenia programu badawczego pozwalającego zebrać wymagane dane spotyka się z mnóstwem zarzutów moralnych.

5. Rozwiążanie problemu

Rozwiążania problemu można upatrywać w koncepcji konstrukcji będącej treścią zgłoszenia patentowego nr P-380316. Konstrukcja ta przewiduje wyeliminowanie układu pasów szelkowych na rzecz pasów krzyżowych, które zapewniają rozłożenie obciążzeń podczas wypadku na większej powierzchni oraz wyeliminowanie pasa kroczonego na rzecz dwóch pasów przytrzymujących miednicę dziecka. Co najważniejsze, klamra spi-

4. Design abilities

At present, when constructor is going to start designing a new type of CRS for I group, he or she could use one of two basic solution of restraining CRS in car:

1. CRS restrained by safety belt for adults

Advantages: universality, it fits every car equipped with 3-point safety belt for adults.
Disadvantages: this solution is susceptible to misuse; it has large clearance as a result of tension.

2. CRS restrained by ISOFIX

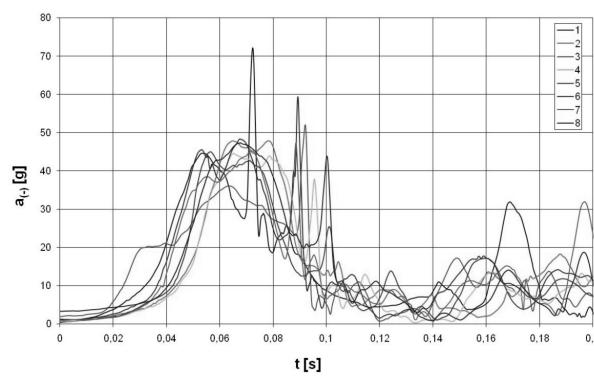
Advantages: fast and reliable fixing in a car, large stiffness of construction.
Disadvantages: large weight of complete device, high production costs.

Basic inner construction of child restraining system is still unchanged: 6-point harness with all its disadvantages mentioned above.

When we look on constructions introduced up to now from the point of view of type approval test, it could be said that constructions introduced to the market fulfill requirements quite well. However basic question in this case will be: how "55 g criteria" of chest deceleration (example results – drawing No.3) is transmitted to real quality of safety systems in CRS?

Before we give answer our questions, we should take into consideration a fact, that institutions that are working on preparing criteria and making research on test dummies don't have accurate biomechanical data of human body. In literature, there is not enough data concerning strength of bone tissue, joints, inner organs and its resistance to deceleration. What's more,

almost every attempt to prepare research in order to get necessary data is contrasted with serious objections.



Rys. 3. Opóźnienia wypadkowe torsu manekina podczas prób dynamicznych

Fig. 3. Result deceleration of manikin chest in dynamic tests

5. Solution of the problem

Solution of the problem of safety of CRS could be found in construction placed in Polish patent application no. P-380316. This construction eliminates classic 6-point harness, and introduces Crossing Belt System (CBS). CBS provides distribution of load (during an accident) on larger area and eliminates a crotch strap. Instead of crotch strap, there are two straps restraining a child's pelvis. The most important in this solution is

nająca taśmy została zamocowana pod powierzchnią siedziska. Dzięki temu zamek nie ma możliwości wejść w kontakt z żadną częścią ciała dziecka – wyeliminowana została możliwość powstania obrażeń spowodowanych klamrą zamka.

Rozwiążanie to eliminuje całkowicie wszystkie elementy, których rzetelne przetestowanie dostępnym sprzętem jest co najmniej kłopotliwe.

Przywołane wyżej rozwiążanie konstrukcyjne jest obecnie wdrażane w nowym typie fotelika dla dzieci przez polską firmę Ramatti. Cykl projektowania, badań oraz wdrażania produkcji objęty jest programem dofinansowania z UE.

Współczesne standardy projektowania wymagają, aby przed uruchomieniem produkcji został wykonany prototyp, który poddawany jest procedurze testowej. Procedura ta powinna stanowić walidację założeń, przyjętych na początku procesu projektowania.

Jako test sprawdzający dla nowej konstrukcji wybrane zostało badanie dynamiczne według Regulaminu EKG OZN nr 44. Mimo jego licznych wad jest to procedura, która jest standardowa i z tego powodu czytelna dla różnych ośrodków badawczych. Pozwala również w prosty sposób porównać między sobą wyniki uzyskane w całkowicie niezależnych ośrodkach badawczych.

Ze względu jednak na specyfikę materiału, z którego został wykonany prototyp, wartość prędkości uderzenia została zmniejszona z 50 km/h do 34 km/h. Obecnie, prawie niemożliwe jest zbudowanie prototypu projektowanego urządzenia (czyli wykonanie kilku sztuk w skali 1:1) w taki sposób, aby użyć materiału, z którego docelowo będzie on produkowany. Wynika to z faktu, że nadawanie tworzywom sztucznym żądanego kształtu odbywa się przy wykorzystaniu specjalnych narzędzi (form wtryskowych), których produkcja jest czasochłonna i bardzo kosztowna. Wykorzystanie tej metody produkcji na etapie prototypu pozbawia sensu ekonomicznego cały proces badawczo-rozwojowy. Stąd też wynika konieczność zastosowania tworzywa, które daje się formować ręcznie, ale należy mieć świadomość, że wytrzymałość mechaniczna tego tworzywa będzie dużo niższa niż materiału używanego docelowo.

Mimo zastosowania słabszego materiału wykonanie testów dynamicznych (nawet ze zmniejszoną prędkością) pozwala ocenić ogólnie zachowanie się nowej konstrukcji, jak również ocenić specyficzne wymagania postawione konstrukcji.

a fact that main buckle is hidden beneath the level of the seat. As a result, there is no possibility to make buckle – stomach contact. Risk of injuries in abdominal area made by buckle is eliminated.

The CBS solution eliminates also all elements which are very difficult to test properly.

The CBS solutions is being introduced to new type of CRS produced by Polish company Ramatti. The whole cycle of design, research and introducing the production is subsidized by EU funds.

Actual standards in design require making a prototype, which will be put into research procedure. This procedure should be a validation of goals set on the beginning of design.

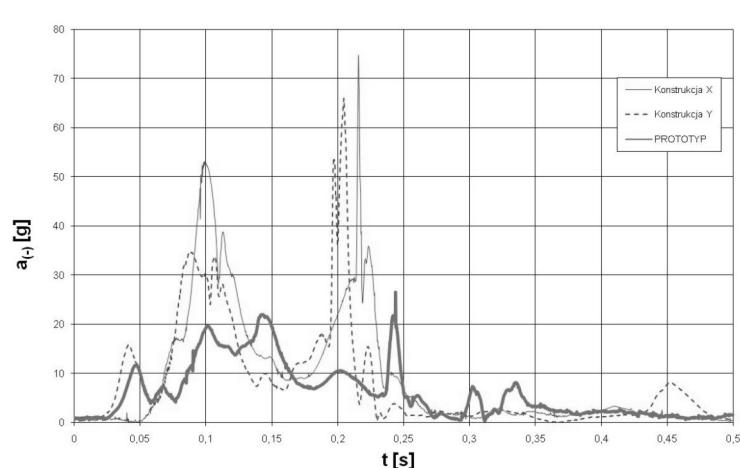
As a final validation of a CBS solution the dynamic test (according to ECE Regulation No. 44) was chosen. Despite its many disadvantages it is a procedure which is standardized and due to this it is comparable with test conducted by many different research organizations. This test gives also the opportunity to compare results from different laboratories.

Regarding specification of material that was used to build a prototype, value of velocity was decreased from 50 km/h to 30 km/h. Nowadays it is almost impossible to build a prototype of new designed CRS (in 1:1 scale) from material which will be used in serial production. It is a result of specification of production: production form plastic requires using special machines and moulds. Preparing machine and mould to use is very expensive and time-consuming. Using method from serial production in order to build a prototype doesn't make an economical sense. That's why it is needed to use hand-forming technology, but it is necessary to keep in mind, that such prototype won't be as strong as it should.

Despite using weaker material, performing dynamic tests (even with decreased velocity) could show general behavior of new construction and evaluate specific demands made before.

During dynamic test also different constructions (available on the market) were tested with the prototype (drawing no. 4). Comparative test is very important on the stage of prototype: profits from introducing new construction could be estimated from the point of view of existing solutions.

Dynamic tests were done in Vehicle Safety Laboratory in Automotive Industry Institute (PIMOT) in Warsaw.



Rys. 4. Opóźnienia głowy manekina podczas próby prototypu oraz konstrukcji standardowych
Fig. 4. Deceleration of a head of dummy during comparative test

Wraz z prototypem poddano badaniu również konstrukcje dostępne w chwili testu na rynku (rysunek 4). Test porównawczy jest na etapie powstawania prototypu bardzo ważny: dzięki niemu można oszacować korzyści jakie wynikają z wdrożenia nowego rozwiązania, poprzez pryzmat obecnie dostępnych dla konsumenta rozwiązań.

Badania wykonano w Laboratorium Bezpieczeństwa Pojazdów Przemysłowego Instytutu Motoryzacji (PIMOT) w Warszawie.

Wyniki uzyskane w tym teście wskazują na znaczne zmniejszenie opóźnień rejestrów podczas próby przez przetworniki umieszczone w manekinie.

6. Podsumowanie

Działania podjęte przez firmę Ramatti można odebrać jako punkt zwrotny w formułowaniu założeń konstrukcyjnych fotelików, wzbogacający system bezpieczeństwa. Opracowane rozwiązania konstrukcyjne oraz sposób prowadzenia prac projektowych jasno wskazuje, że przy konstruowaniu współczesnego fotelika samochodowego dla dziecka najbardziej istotnym elementem tego procesu jest analiza możliwości ochronnych urządzeń tak z punktu widzenia dziecka siedzącego w foteliku, jak i z punktu widzenia pozostałych pasażerów samochodu.

Można się spodziewać, że konstrukcja, która wejdzie do produkcji seryjnej określi nowy punkt odniesienia „bezpiecznej konstrukcji fotelika dla dzieci”.

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Results of this tests point out that decelerations registered by transducers in dummy in prototype were smaller than in other constructions..

6. Summary

All of effort taken by Ramatti company could be a turning point in defining goals in construction of CRS which will improve safety systems. Designed construction and the way of designing and research modern CRS pointed out that the most important element of designing is the analysis of efficiency of safety systems in CRS but from the point of view of child who will be restrained inside the CRS and from the point of view of other passengers.

It can be expected that new construction which will be introduced to serial production will set new reference point of “safe construction of CRS”.

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WYBRANE ZAGADNIENIA WPŁYWU NAPRAW POWYPADKOWYCH NADWOZI NA BEZPIECZEŃSTWO DROGOWE

SELECTED PROBLEMS OF THE INFLUENCE OF CRASH BODY REPAIRS ON ROAD SAFETY

W opracowaniu przedstawiono problem oceny wpływu napraw powypadkowych nadwozi samochodów osobowych na bezpieczeństwo drogowe. Artykuł podnosi kwestie eksplatacji pojazdów i ich napraw oraz zwraca uwagę na istniejące braki w krajowym systemie dopuszczania do ruchu nadwozi po naprawach. Publikacja uwzględnia też potrzebę regulacji prawnych i wykonawczych procedur dopuszczania pojazdów do ruchu po wcześniej wykonywanych naprawach.

Słowa kluczowe: powypadkowe naprawy pojazdów, nadwozie, bezpieczeństwo ruchu drogowego.

The paper presents the problem of the evaluation of the influence of crash body repairs on road safety. It raises the issue of vehicle operation and repairs, and draws attention to existing gaps in the national system of granting type approvals for repaired car bodies. The paper also takes into consideration the need for legal regulations and executive procedures regarding type approval of repaired vehicles.

Keywords: crash body repairs, roda safety.

1. Wstęp

Nadwozie samochodu jest przestrzenną konstrukcją o określonych kształtach, wymiarach i wyposażeniu. Spełnia funkcje i wymagania użytkownika pojazdu z zachowaniem odpowiedniego poziomu komfortu oraz bezpieczeństwa. Budowa nadwozia współczesnego samochodu osobowego zależy od technologii produkcji, spełnia także walory estetyczne i ergonomiczne. Nadwozie pełni również odpowiedzialną funkcję nośnej struktury pojazdu (nadwozie samonośne), do której mocowane są elementy między innymi układu napędowego, zawieszenia oraz układu kierowniczego. Struktura nadwozia powinna chronić kierowcę i pasażerów przed obrażeniami, zatem posiada odpowiednią sztywność ze wzmacnieniami oraz stosowne wyposażenie. Nad opracowaniem nowego nadwozia pracują wykwalifikowani specjalści, niekiedy kilku firm, wyspecjalizowanych w opracowywaniu nowych modeli nadwozi. Schemat procesu tworzenia nadwozia przedstawia rys. 1, a podział nadwozi ilustruje rys. 2.

2. Stan prawny badań technicznych pojazdów

Znaczny wzrost ilościowy pojazdów samochodowych w Polsce i Unii Europejskiej skutkuje potrzebą regulacji prawnych, technicznych, szkoleniowych i organizacyjnych. Stan techniczny pojazdu, w tym jego nadwozia, ma istotne znaczenie dla bezpieczeństwa ruchu drogowego. Powołane zgodnie z prawem o ruchu drogowym¹ placówki upoważnione są do wykonywania badań technicznych pojazdów, wyposażone są w urządzenie i instrukcje dotyczące sposobu i zakresu wykonywanych badań technicznych dopuszczających pojazdy do ruchu na drogach publicznych. Badania diagnostyczne powinny obe-

1. Introduction

A car body is a spatial construction of a particular shape and size, equipped with certain devices. It satisfies vehicle user's requirements and offers certain functions, ensuring adequate level of comfort and safety. Body construction of a modern passenger car is a result of manufacturing technology, but also offers the advantages of aesthetic look and ergonomics. The body also constitutes a load-bearing construction (integral body) to which, for example, power transmission system, suspension, and steering system elements are fixed. The body construction should protect the driver and passengers against injuries, so it is rigid, reinforced and equipped with necessary devices. To develop a new body, a team of qualified professionals, who are specialists in developing new body models, sometimes working for several companies, is engaged. Fig. 1 shows the process of body development, and Fig. 2 shows a classification of bodies.

2. Legal status of vehicle technical inspections

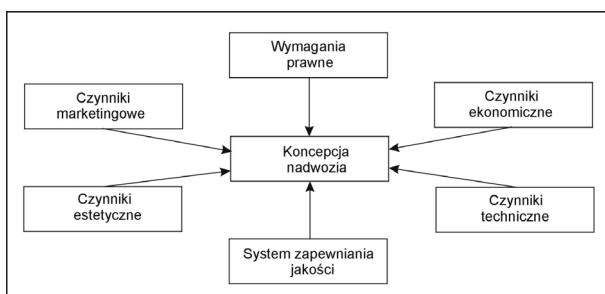
Considerable increase of the number of vehicles in Poland and European Union calls for legal, technical, training, and organizational regulations. Vehicle technical condition, including its body, is important as far as road safety is concerned. Stations appointed pursuant to traffic law provisions¹ authorized to carry out vehicle technical inspections, possess equipment and instructions regarding the method and scope of technical inspections necessary for vehicle type approval. Diagnostic tests should assess technical worthiness and necessary vehicle equipment against valid legal provisions with regard to safety and

¹ Jednolity tekst Ustawy Prawo o ruchu drogowym z dnia 20 czerwca 1997 roku z późniejszymi zmianami.

¹ Consolidated text of the Traffic Law Act dated 20 June 1997 with later amendments.

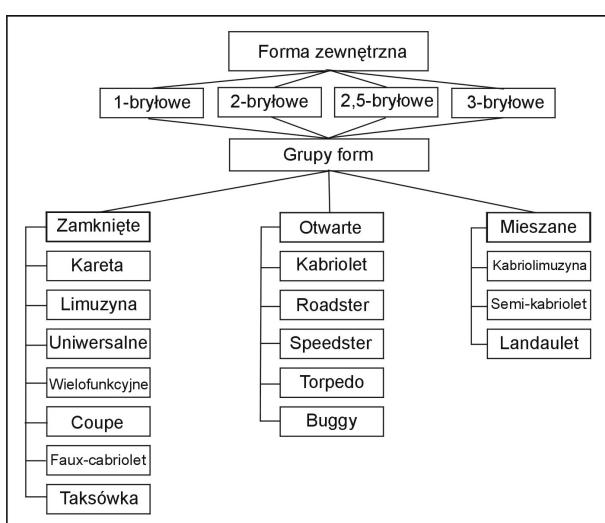
nić zdolność techniczną i zakres niezbędnego wyposażenia pojazdu z obowiązującymi przepisami pod kątem bezpieczeństwa i ochrony środowiska. Procedury diagnostyczne pojazdów różniące się w poszczególnych krajach Unii Europejskiej będą zmierzały do ich ujednolicenia na określonym poziomie badań tak aby badania techniczne były uznawane w krajach Unii Europejskiej. Problem dopuszczenia nowych pojazdów do ruchu na drogach Unii Europejskiej reguluje procedura 70/156/EWG.

Bezpieczeństwo ruchu nie zależy wyłącznie od stanu technicznego pojazdów nowych ale również w dużym stopniu od stanu technicznego pojazdów w całym okresie ich eksploatacji. Dlatego Unia Europejska wydała ramowe wytyczne ujęte procedurą 77/143/EWG, która ustala minimalne wymagania badań regularnych pojazdów wykonywanych okresowo podczas kontroli pojazdów przez państwową lub kontrolowaną przez państwo inną organizację. Oprócz wymienionych powyżej procedur, w poszczególnych państwach członkowskich Unii Europejskiej istnieją krajowe przepisy dotyczące dopuszczenia pojazdów do ruchu, które utraciły wcześniej zdolność techniczną. W niektórych krajach Unii Europejskiej obowiązują dodatkowe i odrębne przepisy dotyczące dopuszczenia do ruchu pojazdów po ciężkich wypadkach. Dotyczy to państw: Belgia, Niemcy, Włochy, Francja, Luxemburg, Hiszpania i Holandia, gdzie wprowadzono przepisy badań naprawionego pojazdu przed ponownym dopuszczeniem go do ruchu drogowego. W Belgii właściciel pojazdu zobowiązany jest do okazania pojazdu naprawionego po ciężkim wypadku terenowej jednostce nadzoru technicznego. Praktykowany jest także w niektórych krajach Unii Europejskiej obowiązek nałożony na towarzystwa ubezpieczeniowe aby zgłaszały szkody wypadkowe w jednostce dopuszczającej pojazd do ruchu. Jednostka ta wzywa właściciela pojazdu do zgłoszenia się z naprawionym pojazdem na specjalny przegląd techniczny. Przepisy powyższe stosowane są w Niemczech i Francji, dotyczą jednak określonej grupy pojazdów i są zróżnicowane w obydwu krajach. Najlepiej system kontroli badań pojazdów powypadkowych funkcjonuje we Włoszech, gdzie istnieje bieżące połączenie z centralnym serwerem ewidencji pojazdów, a diagnosta wykonywane przez siebie czynności wprowadza na bieżąco do serwera. Policja sporządza raport powypadkowy i decyduje czy podczas wypadku zostało ograniczone bezpieczeństwo ruchu pojazdu, jeśli tak to informację ta policja przesyła do jednostki



Rys. 1. Schemat procesu tworzenia koncepcji nadwozia [3]

Fig. 1. Body concept development process



Rys. 2. Klasifikacja nadwozi samochodów osobowych wg kryterium formy zewnętrznej [3]

Fig. 2. Classification of car bodies according to external form criterion

environmental protection. The test procedures differing from one Member State to another will be heading towards unification at a certain test level so as to allow technical inspection to be recognized throughout European Union. The problem of granting type approval for new vehicles in the European Union is solved by the procedure laid down in the Council directive 70/156/EEC.

Road safety does not depend only on the technical condition of a new vehicle, but also on the technical condition of a vehicle during its lifetime. Therefore, the European Union published framework guidelines laid down in the directive 77/143/EEC which determines minimum requirements for regular inspections of vehicles carried out periodically during vehicle checks by a state or state-controlled organization. Apart from the above-mentioned procedures, each Member State has its own regulations with regard to type approval for vehicles which are no longer road worthy. Some Member States implemented additional and separate regulations with regard to type approval for vehicles involved in serious accidents. These regulations were implemented by: Belgium, Germany, Italy, France, Luxembourg, Spain, and the Netherlands, which introduced regulations requiring the repaired vehicle to be checked before granting type approval. In Belgium a vehicle owner is required to submit the vehicle after crash repair to a field technical supervision unit for inspection. Some Member States introduced also a requirement for insurance agencies to report accidents to the institution responsible for granting type approvals. This institution requests the vehicle owner to submit the repaired vehicle for special technical inspection. The above-mentioned regulations are observed in Germany and France but they apply to a certain group of vehicles and are different each country. The functioning of the crash vehicle inspection system is the best in Italy, where the diagnostic station is connected to the central server of vehicle register, and a diagnostician records his activities on the server. The police prepare an accident report and determine whether vehicle operation safety was limited during an accident, and if this is the case, they send this information to the unit granting type approvals called "Motorizzazione" which requests the vehicle owner to submit the vehicle for technical inspection within 30 days. The unit granting type approvals checks vehicle documents and correctness of the repair. If the

dopuszczającej pojazd do ruchu – „Motorizzazione”, ta wzywa właściciela do okazania pojazdu w celu sprawdzenia jego stanu technicznego w ciągu 30 dni. Jednostka dopuszczająca pojazd do ruchu sprawdza dokumenty pojazdu i prawidłowość przeprowadzonej naprawy. W przypadku gdy pojazd nie zostanie przedstawiony do badań nastąpi wygaśnięcie zezwolenia na jego eksploatację.

W Holandii policja jest zobowiązana do zatrzymania dokumentów pojazdu, który uległ wypadkowi, jeśli stwierdzono, że uszkodzeniom uległy części decydujące o bezpieczeństwie ruchu drogowego. Następnie funkcjonariusze policji zgłaszą pojazd do jednostki nadzoru technicznego, która uprawniona jest do badań pojazdów.

W Hiszpanii od 1994 roku wprowadzono przepisy o specjalnym badaniu pojazdów po wypadku, wcześniej jednak policja zatrzymuje dokumenty i przekazuje je kompetentnej jednostce kontroli pojazdów. Podobnie przepisy obowiązują od 1995 roku w Szwajcarii.

W Polsce rzecznawcy samochodowi i biegli sądowi z zakresu techniki motoryzacyjnej i wypadków drogowych w swojej codziennej praktyce spotykają się z pojazdami, które uległy uszkodzeniom w różnym stopniu w wyniku wypadków i kolizji drogowych. Nadwozia tych pojazdów wyposażone były często fabrycznie w strefy kontrolowanego zgniotu, których naprawa budzi kontrowersje, zwłaszcza w kontekście bezpieczeństwa drogowego. W Polsce, pierwszy kontakt z uszkodzonym pojazdem mają funkcjonariusze policji, którzy obsługują zdarzenia drogowe. Policjant może z przyczyn technicznych zatrzymać dowód rejestracyjny (wydając w zamian pokwitowanie), jeśli stwierdzi, że uszkodzony pojazd może zagrażać bezpieczeństwu drogowemu. Często zdarza się, że po wypadku samochód z rozległymi uszkodzeniami przekazywany jest właścicielowi, który w krótkim czasie wykonuje naprawę samochodu w sposób niezgodny z technologią naprawy przewidzianą przez producenta pojazdu. Bardzo często powierzchowna naprawa pojazdu zakrywa uszkodzenia powstałe w czasie danego zdarzenia drogowego, niekiedy także te, które powstały w wyniku wcześniejszych zdarzeń drogowych, a które jednocześnie mogły być przyczyną zaistnienia kolejnego wypadku bądź kolizji drogowej. Zarówno policjant jak i rzecznawca samochodowy bądź biegły sądowy badający pojazd, który uległ uszkodzeniom, nie posiada wszystkich niezbędnych przyrządów służących określaniu rzeczywistego zakresu uszkodzeń, w tym przede wszystkim zwłaszcza geometrii nadwozia. Samochody po wypadku bardzo często są zabezpieczone przez funkcjonariuszy policji w miejscowościach, gdzie również brak jest urządzeńłatwiających badania uszkodzonego pojazdu.

Uszkodzone w wyniku zdarzeń drogowych pojazdy zgłoszane są następnie do firm ubezpieczeniowych, które dokonują (nadal niestety zbyt pobiernie) oględzin oraz przeprowadzają analizę kosztów naprawy. Jak wynika z praktyki, ubezpiecyciele przeprowadzając analizy kosztów napraw uszkodzonych pojazdów bezwzględnie stosują zasadę skrajnej minimalizacji kosztów – kosztów odbudowy pojazdu. Biegli sądowi i rzecznawcy samochodowi w swojej pracy dokonują (a przy najmniej powinni) obliczenia realnych kosztów napraw wynikających z technologii naprawy jaką przewiduje producent danej marki samochodu. Podstawę do wydania opinii stanowią: protokół powypadkowych badań uszkodzonego pojazdu oraz dokumentacja fotograficzna uszkodzeń, jakie sporządza pracownik firmy ubezpieczeniowej odpowiedzialnej za powstałą szkodę.

vehicle is not submitted for inspection, its operation permit will expire.

In the Netherlands the police are required to retain crash vehicle documents if they determine that the elements which should ensure road safety are damaged. Then the police officers report the vehicle to the technical supervision station, which is authorized to carry out vehicle inspections.

In Spain, in 1994, new regulations with regard to special checks of crash vehicles were introduced, but the police are required to retain documents and hand them over to a competent vehicle inspection unit. Similar regulations were implemented in 1995 in Switzerland.

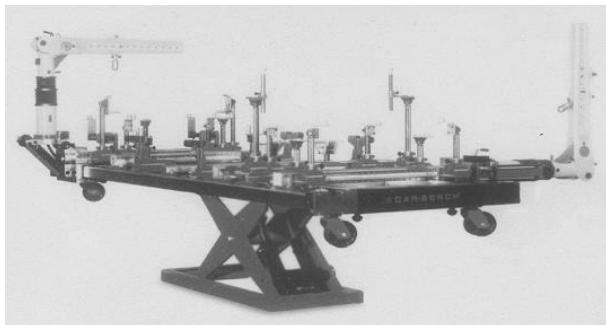
In Poland vehicle experts and expert witnesses in the field of motor industry technology and road accidents every day inspect vehicles damaged in accidents and road collisions to different extent. The bodies of these vehicles were equipped during manufacturing process with controlled deformation zones, the repair of which is controversial, in particular as regards road safety. In Poland, it is the police officers, dealing with road accidents, that first come into contact with a crash vehicle. A police officer may retain the registration certificate (and issue a receipt) due to technical reasons if he decides that the crash vehicle may constitute a hazard to other road users. It is often the case that after an accident a heavily damaged vehicle is returned to the owner, who within short time has the vehicle repaired, contrary to repair technology determined by the vehicle manufacturer. Very often the superficial repair of the vehicle covers damage which occurred during the accident, and sometimes even damage which occurred during previous accidents and which might have been the cause of the following accident or collision. Neither the police officer nor vehicle expert nor expert witness who examine the crash vehicle possess all necessary equipment to determine actual damage, and in particular body geometry. Crash vehicles seized by the police are often kept in areas which also lack equipment necessary for the vehicle inspection.

Vehicles damaged in accidents are reported to insurance companies which conduct (but unfortunately still superficial) inspection and prepare repair cost analysis. As practice shows, insurers, when analysing repair costs of crash vehicles, apply a principle of extreme minimization of vehicle rebuilding costs. Expert witnesses and vehicle experts, when carrying out their tasks, calculate (or at least they should calculate) actual costs of repair which is a part of repair technology determined by the vehicle manufacturer. Their opinion is issued on the basis of: protocol of post-accident inspection of the damaged vehicle and photographs of the damage taken by the insurance agent covering the damage. Vehicle inspection needed for the insurance agency is also superficial, and later repair does not take into consideration the fact that the load-bearing body construction, controlled deformation zones and reinforcements made by the vehicle manufacturer were weakened. So vehicles involved in accidents or collisions are granted type approvals in Poland, because the diagnostician inspecting the vehicle is not aware of the vehicle accident history nor of the numerous repairs. The example given above is quite common. Polish roads are full of old vehicles which were repaired numerous times and whose technical condition constitutes a hazard to road safety.

Another problem are active and passive safety systems vehicles are equipped with. These systems are often damaged in collision or accident. The vehicle superficially repaired or sold

Oględziny pojazdu dla potrzeb firm ubezpieczeniowych także są powierzchowne a późniejsza naprawa nie uwzględnia osłabienia struktury nośnej nadwozia, jego stref kontrolowanego zgniotu czy wzmacnień jakie nadał pojazdowi producent. W rezultacie dopuszcza się w kraju do ruchu samochody, które wcześniej uczestniczyły w wypadku bądź kolizji drogowej, gdyż diagnosta badający pojazd nie zna historii życia pojazdu ani zakresu przeprowadzonych, niekiedy wielokrotnych, napraw. Powyżej przytoczony przykład jest więc zjawiskiem powszechnym. Po drogach naszego kraju porusza się znaczna ilość pojazdów o wieloletnim stażu i po naprawach, a których stan techniczny zagraża bezpieczeństwu drogowemu.

Kolejny problem stanowi wyposażenie pojazdów po naprawie w składniki bezpieczeństwa czynnego i biernego. Wypożyczenie to często ulega uszkodzeniom podczas kolizji lub wypadku. Naprawiony powierzchownie lub odsprzedany w stanie uszkodzonym pojazd i kosmetycznie naprawiony przez nowego nabywcę posiadać może braki w wyposażeniu, np. brak poduszek powietrznych, pirotechnicznych napinaczy pasów bezpieczeństwa, regulatorów położenia reflektorów, zderzaków energochłonnych czy elementów systemu ABS. Pojazdy takie są również dopuszczane do ruchu, ponieważ diagności nie sprawdzają tego wyposażenia pojazdów podeznych badań samochodów w stacji kontroli pojazdów, gdzie zazwyczaj sprawdza się układ jezdny, kierowniczy, hamulcowy oraz oświetlenie pojazdu. Szczególnie groźne jest powszechnie dopuszczanie do ruchu pojazdu z naprawionym wcześniej nadwoziem, o czym diagnosta nie jest informowany, a poza tym nie ma przyrządów do sprawdzenia geometrii nadwozia. Tymczasem na rynku są dostępne urządzenia do naprawy i sprawdzania geometrii nadwozia. Przykłady takich urządzeń przedstawiają rysunki nr 3



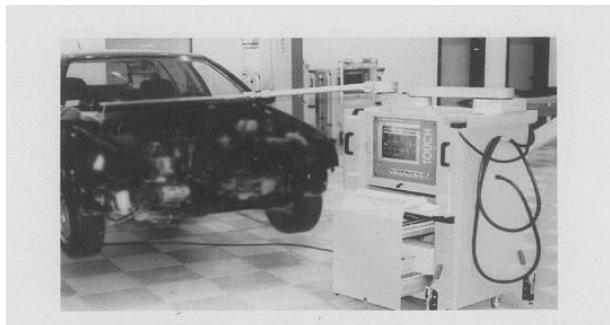
Rys. 3. Rama do powypadkowych napraw nadwozi Car-Bench [2]

Fig. 3. Car-Bench for crash body repair [2]

as damaged and then superficially repaired by a new owner may lack certain equipment elements, such as airbags, pyrotechnic belt tensioners, headlight position switches, energy bumpers or ABS elements. Such vehicles are also granted type approvals, because diagnosticians at the vehicle inspection station often skip the above-mentioned equipment during inspection, checking only suspension, steering, braking systems, and vehicle lighting. Granting type approvals for vehicles with repaired bodies is particularly dangerous, because the diagnostician is not aware of the repair and has no equipment to check body geometry. Meanwhile, the market offers equipment for body geometry repair and check. Such equipment is shown in figures 3 and 4, and measuring range with measurement printout in figures 5 and 6.

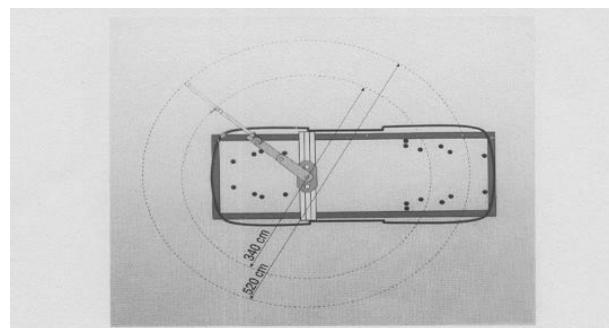
Another problem is a widespread practice of granting type approvals for vehicles which do not meet specific ecological requirements. This applies to correct functioning of a lambda meter or catalyzing system. During the repair not all damaged elements are repaired or the vehicle is not equipped with necessary shields which constitutes a fire hazard. Construction and technological development of vehicles requires appropriate team and equipment to conduct an inspection and technical check of the vehicle. An example can be here an EOBD system or ADR system registering driver's work, vehicles are equipped with, the inspection of which requires appropriate procedures and diagnostic equipment.

Meanwhile, also this year, the number of individual vehicles brought to Poland, which were often involved in road accidents or collisions, was greater than the number of new vehicles registered. Thus, we are faced with road safety and ecological hazards when the national system of accident and collision



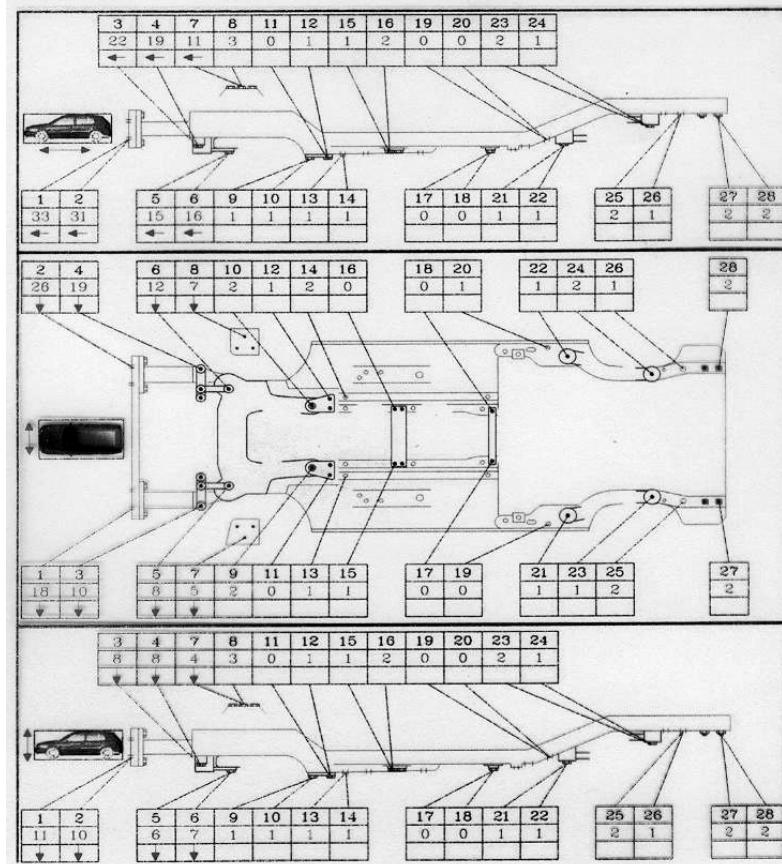
Rys. 4. Urządzenie pomiarowe „TOUCH” firmy Spanesi [2]

Fig. 4. Spanesi TOUCH measuring device [2]



Rys. 5. Zakres pomiarowy urządzenia [2]

Fig. 5. Device measuring range [2]



Rys. 6. Przykładowy wydruk pomiaru systemem pomiarowym TOUCH firmy Sparesi [2]

Fig. 6. Sample measurement printout, using Sparesi TOUCH measuring system [2]

i 4, zaś zakres pomiarowy z wydrukiem pomiarów na rysunkach 5 i 6.

Odrębny problem stanowi powszechnie dopuszczanie do ruchu pojazdów w sytuacji gdy badany egzemplarz pojazdu nie spełnia określonych wymagań ekologicznych. Dotyczy to po prawności działania sondy lambda czy układu katalizującego. W trakcie naprawy pojazdu nie usuwa się wszystkich uszkodzeń lub też nie wyposaża się pojazdu w niezbędne osłony co czyni zagrożenie pożarowe. Rozwój konstrukcyjny i technologiczny pojazdów wymaga odpowiedniego przygotowania kadrowego i aparaturowego w celu przeprowadzenia badań i oceny stanu technicznego pojazdu. Przykładem tego niech będzie wyposażenie pojazdów w system EOBD czy system rejestrujący pracę kierowców ADR, których diagnozowanie wymaga odpowiednich procedur i aparatury diagnostycznej.

Tymczasem do Polski, także w roku bieżącym, sprowadzono więcej pojazdów w systemie indywidualnym niż zarejestrowano pojazdów nowych, które niejednokrotnie uczestniczyły w zdarzeniach drogowych takich jak wypadki bądź kolizje. Istnieje zatem zagrożenie bezpieczeństwa drogowego i ekologicznego w sytuacji gdy krajowy system ewidencji wypadków i kolizji nie współdziała ze stacjami kontroli pojazdów i firmami ubezpieczeniowymi.

Wnioski nasuwają się same, iż konieczne jest uregulowanie prawne i wykonawcze, które określą w Polsce procedury dopuszczające pojazdy do ruchu po przeprowadzonych wcześniej naprawach.

register does not cooperate with vehicle inspection stations and insurance agencies.

The conclusion is clear – we need legal and executive regulations which would determine procedures regarding the repaired vehicle type approval in Poland.

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CFD-FASTRAN – NARZĘDZIE DO NUMERYCZNEJ ANALIZY OPŁYWU OBIEKTÓW PRZEZ STRUMIENЬ POWIETRZA

CFD-FASTRAN – SOFTWARE PACKAGE FOR NUMERICAL ANALYSIS OF FLOW AROUND A BODY BY THE AIR STREAM

W niniejszym artykule przedstawiono sposób wykorzystania specjalizowanego oprogramowania CFD-Fastran do wspomagania procesów projektowania i realizacji prac badawczych obejmujących tematykę związaną z zagadnieniami opływu ciał przez strumień powietrza. Opisano proces rozpoznawania walorów użytkowych przedstawionego programu oraz zilustrowano jego wykorzystanie na przykładach konkretnych obiektów technicznych. Poniższy materiał przedstawia fragmenty prac badawczych prowadzonych przez autorów niniejszego opracowania. Z uwagi na charakter tychże prac prezentowane wyniki nie zawierają szczegółowych danych.

Słowa kluczowe: CFD-Fastran, numeryczna mechanika płynów, proces symulacyjny.

The manner of use special software CFD-Fastran for computer aided design and study of flow around a body has been presented in this paper. Authors described process of CFD-FASTRAN virtues recognition and presented examples of using this program for selected technical objects. Presented material describe fragments of studies carried out by the authors. Taking into consideration subject matter of this studies presented results don't include detailed data.

Keywords: CFD-Fastran, computational fluid dynamics, simulation process.

1. Wstęp

Proces powstawania nowych obiektów składa się z wielu faz, wśród których jedną z najistotniejszych jest faza projektowania obiektu. Poprawna realizacja tego etapu pozwala uniknąć szeregu komplikacji w późniejszych pracach. Dlatego też tak istotną rolę odgrywają obecnie narzędzia wspomagające proces projektowania. Uzyskane na tym etapie wyniki pozwalają niejednokrotnie na obniżenie kosztówtworzenia danego obiektu, ale również mogą posłużyć do określenia stopnia bezpieczeństwa eksploatacji konkretnego obiektu. Obecnie trudno wyobrazić sobie produkcję określonego produktu bez wcześniejszej analizy jego „przyszłości”. Co prawda nie można wszystkiego przewidzieć na etapie projektu, ale wykorzystanie narzędzia służącego do symulacji określonych zagadnień znacznie zwiększa obszar nieprzewidzianych sytuacji, które mogą pojawić się w trakcie eksploatacji.

2. Charakterystyka pakietu cfd-fastran

W ostatnich latach w dużym tempie rozwija się numeryczna mechanika płynów, która daje możliwości szerokiej oceny zjawisk towarzyszących strumieniu przepływu, udokumentowanie ich jeszcze na etapie prac wstępnych i wprowadzeniu poprawek do realizowanego projektu.

Owocem rozwoju tej dziedziny nauki jest między innymi oprogramowanie którego nazwa wyróżnia się charakterystycznym przedrostkiem CFD (CFD - Computational Fluid Dynamics). Jednym z tego typu narzędzi jest program CFD-Fastran. Oprogramowanie to umożliwia modelowanie zjawisk opływu ciał przez strumień przepływu.

1. Introduction

The process of construction new objects is made up of many phase, among which the most important is phase of design. Correct execution this stage allows to avoid many complications in the future. That is why, new tools for computer-aided design fulfil so significant role. Received results in this stage allow to fall cost of produce given object. Furthermore they are useful to characterize degree of safety of operation. At present it is difficult to imagine production given object without prior analysis its “future”. It is a known fact that it is impossible to predict all situation in stage of design however using tools for advanced simulation considerably narrow down area unforeseen situation within using.

2 Characteristic of cfd-fastran software package

In recent years, development of numerical fluid dynamics is very fast. It give possibility of broad evaluation phenomena of fluid flow around an elements and substantiate its on preliminary stage of project as well as bring correction into effect.

Effect of development this science discipline is among other things software with prefix CFD (CFD – Computational Fluid Dynamics). One of this kind of software is CFD-Fastran. This software make possible modeling flow around a body phenomena, and theirs analysis.

2.1. Pakiet programowy CFD-Fastran

CFD-Fastran jest pakietem programowym służącym do badania zagadnień dotyczących opływu ciała strumieniem przepływu o właściwościach ściśliwych. Kompozycja programu ma charakter modułowy. Wyszczególnić możemy w nim trzy podprogramy [2]:

- CFD-Geom – preprocesor – w środowisku którego następuje przygotowanie siatki obliczeniowej modelu badań;
- CFD-Fastran – procesor – zapewniający możliwość ustalenia warunków początkowych realizowanych symulacji, oraz realizujący proces obliczeniowy;
- CFD-View – postprocesor – służący do wizualizacji otrzymanych wyników.

Cały pakiet można traktować jako wirtualny tunel aerodynamiczny w którym to obiekt badań obudowany jest przez określona liczbę elementarnych komórek. Komórki te mogą być reprezentowane przez czworoboki bądź też trójkąty (dla rozpatrywanego zagadnienia przepływu płaskiego – 2D) lub przez prostopadłościany, ostrosłupy i pryzmaty (dla zagadnień przestrzennych – 3D).

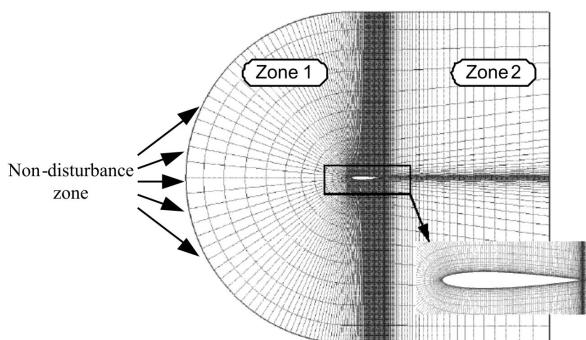
2.2. Testy porównawcze

Jako jeden z pierwszych zadań badawczych, realizowanych przy wykorzystaniu wyżej opisanego oprogramowania, było określenie jego walorów użytkowych. W tym celu przeprowadzono [2]:

- testy porównawcze zalecane przez producenta oprogramowania, oraz;
- testy porównawcze dostępne w różnych niezależnych źródłach.

W przypadku rozpatrywania zagadnień aerodynamicznych jako standardowy test, najczęściej spotykany w literaturze, stosuje się badanie opływu profilu NACA 0012 o cięciwie aerodynamicznej $b=1\text{m}$. Przed przystąpieniem do realizacji procesu obliczeniowego przygotowano siatkę obliczeniową modelu, w której geometria modelu, tj. profil NACA 0012, obudowana została płaszczyzną w kształcie litery C (rys. 1). Przyjęcie takiego kształtu siatki uwarunkowane było walorami geometrycznymi badanego obiektu.

Proces symulacyjny zrealizowano dla trzech przypadków, w których dokonywano zmian kąta natarcia α profilu oraz wartości ciśnienia P_∞ i temperatury T_∞ strumienia w strefie niezaburzonej, określonej w nomenklaturze programu „strefą dalekiego pola”. Wartości parametrów wejściowych przepływu dla poszczególnych przypadków przedstawiono w tabeli 1.



Rys. 1. Widok siatki pomiarowej dla profilu NACA 0012

Fig. 1. View of calculation grid for NACA 0012

2.1. CFD-Fastran software

CFD-Fastran a software package is designed for flow around a body with compressible stream. Moreover, this software has modular structure. We can distinguish three modules [2]:

- CFD-Geom – preprocessor - designed for mesh model preparation,
- CFD-Fastran – processor – enable to determine initial condition for simulation and realization of computation process,
- CFD-View – designed for visualization received results.

The software, we can treat as a virtual wind tunnel in which object is encased in elementary calculation cells. The cells have varied shapes, for example: quadrilateral, triangle (for two-dimensional problems) as well as cubicoid, pyramid and prism (for three dimensional problems).

2.2. Comparative tests

As a first work task, authors decided to reconnoiter CFD-Fastran utilitarian virtues. To this end, carried out [2]:

- comparative tests announced by producer, and;
- comparative tests available in different independent sources.

As a standard test for aerodynamic problem, is used NACA 0012 aerofoil profile test with aerodynamic chord 1m. Before starting computational process it was necessary to create model's grid. Geometry of model i.e. NACA 0012 aerofoil profile was builded around by C-shaped figure (fig. 1). Adoption this shape of grid was dictated by specific geometry conditions the object.

Simulation process was carried out for three case (three values of angle of attack α for profile and three values of pressure P_∞ and temperature T_∞ for undisturbed zone called "distant field zone"). Values of initial parameters of the flow for particular case are showed in the table 1.

Tab. 1. Dane wejściowe do obliczeń profilu NACA0012

Tab. 1. Initial parameters for calculation NACA 0012 aerofoil profile

Przypadek 1 Case 1	Przypadek 2 Case 2	Przypadek 3 Case 3
$U_\infty = 243,1 \text{ [m/s]}$ $\alpha = 1,49^\circ$; $T_\infty = 300 \text{ [K]}$; $P_\infty = 58560 \text{ [Pa]}$;	$U_\infty = 190,96 \text{ [m/s]}$; $\alpha = 8,34^\circ$; $T_\infty = 300 \text{ [K]}$; $P_\infty = 74525 \text{ [Pa]}$;	$U_\infty = 277,4 \text{ [m/s]}$; $\alpha = 2,26^\circ$; $T_\infty = 300 \text{ [K]}$; $P_\infty = 51300 \text{ [Pa]}$;

Do badań przyjęto przepływ turbulentny opisany za pomocą równań Naviera-Stokesa. Dla każdego z powyższych przypadków, jako model obliczeniowy, przyjęto model Roe's. Natomiast jako wzorzec do analizy porównawczej przyjęto współczynnik ciśnienia C_p , definicję którego podaje poniższa zależność:

$$C_p = \frac{P - P_\infty}{\frac{1}{2} \rho V^2} \quad (1)$$

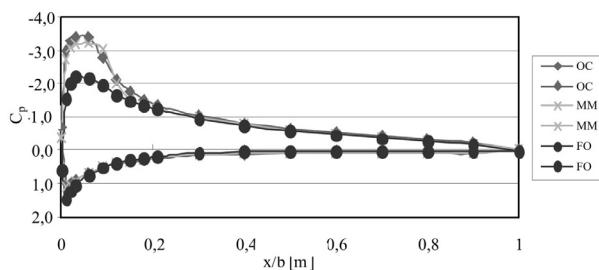
gdzie: P - wartość ciśnienia w danym punkcie na powierzchni profilu; P_∞ - wartość ciśnienia strumienia przepływu w strefie niezaburzonej; ρ - gęstość strumienia przepływu w strefie niezaburzonej; V - prędkość strumienia przepływu.

Przykładowe wyniki przeprowadzonych badań przedstawiono na rysunku 2.

Dokonując porównania otrzymanych wyników z danymi otrzymanymi na drodze eksperymentalnej, zamieszczonymi przez producenta oprogramowania, można stwierdzić, iż wartości otrzymane w wyniku symulacji komputerowej pokrywają się z wartościami otrzymanymi w trakcie realizacji eksperymentu. Niemniej jednak widoczne są pewne różnice pomiędzy poszczególnymi „ogranicznikami” przyjmowanymi do rozwiązania wybranej metody obliczeniowej. Ich dobór ściśle związany jest z jakością wygenerowanej siatki oraz stopniem złożoności modelu symulacyjnego i charakterem badanego przepływu.

Zagadnienie oplwu profilu było dosyć prostym zadaniem dlatego też w kolejnym kroku przystąpiono do budowy modelu skrzydła prostego o profilu NACA0012 o rozpiętości $l=2,4$ [m] i cięciwie $b=1$ [m] (rys. 3).

O ile dysponowano wytycznymi co do jakości siatki dla profilu NACA0012, to dla pozostałych przykładów zamieszczonych w niniejszym opracowaniu nie posiadało żadnych danych. Dlatego też postanowiono przeprowadzić doświadczenie umożliwiające wyznaczenie charakteru wpływu siatki obliczeniowej na wartości otrzymanych wyników. Do rozwiązania tego zagadnienia zbudowano trzy modele. W przypadku pierwszego modelu zastosowano siatkę obliczeniową o bardzo rzadkim zagęszczeniu komórek. Niewielkie zagęszczenie wygenerowane zostało tylko w okolicach noska profilu i na krawędzi spływy skrzydła. Liczba wszystkich komórek tworzących siatkę obliczeniową wyniosła $n=123\,424$. Dla drugiego modelu siatka obliczeniowa została zagęszczona tylko i wyłącznie na jego obwodzie. Dla tego modelu liczba wszystkich objętości wynosiła $n=476\,444$. Natomiast model z numerem trzy „oklejony” został siatką która została zagęszczona zarówno na obwodzie skrzydła jak i w przestrzeni go otaczającej. W tym przypadku liczba komórek stanowiących siatkę obliczeniową wynosiła $n=634\,018$.



Rys. 2. Wykres $C_p=f(x/b)$ dla $2z/b=0.9$; Ograniczniki obliczeniowe: OC - Osher-C, MM - Mim-Mod, FO – First Order

Fig. 2. Graph $C_p=f(x/b)$ for $2z/b=0.9$: OC - Osher-C, MM - Mim-Mod, FO – First Order

Research, based on turbulent flow, was described by Navier-Stokes equations. Simulations for above mentioned cases used Roe's calculation model. As a reference standard authors assumed pressure coefficient C_p defined as:

$$C_p = \frac{P - P_\infty}{\frac{1}{2} \rho V^2} \quad (1)$$

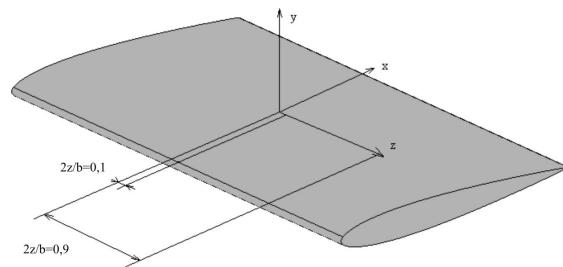
where: P - pressure in a given point of aerofoil profile; P_∞ - pressure of fluid flux in undisturbed zone; ρ - density of fluid flux in undisturbed zone; V - velocity of fluid flux.

Examples of the results of calculation are presented in figure 2.

Comparing results carried out by experiment and simulation process, reveals that values received from wind tunnel experiment are consistent with values received with aid of computational simulation. Any discrepancies are connected with quality of generated grid and complexity simulation's model and nature of the flow.

Problem of flow around profile is rather simply so, therefore in next step authors built model of wing NACA 0012 (span $l=2.4$ m and chord $b=1$ m, fig. 3).

Authors had data concern mesh quality for NACA0012 but for others examples placed in this paper they didn't have the data. For this reason authors decided carry out experiment consist in calculate aerodynamic characteristic for different mesh. To do experiment they built three models. For first model they built very thin mesh with not large concentration in the vicinity of aerofoil profile nose and trailing edge. Number of cells in mesh amounted to $n=123\,424$. For second model they built mesh with concentration only on wing's periphery, and number of cells in mesh amounted to $n=476\,444$. For third model they built mesh with concentration on wing's periphery as well as on surround space. Number of cells in the third model amounted to $n=634\,018$. Manner of mesh concentration are presented in figure 4.



Rys. 3. Widok skrzydła prostego z umiejscowionymi płaszczyznami pomiarowymi

Fig. 3. View of wing with measurement's plane

Sposób zagęszczenia siatki dla poszczególnych modeli przedstawia rysunek 4.

Pomiar wartości parametru C_p przeprowadzono w dwóch płaszczyznach. Pierwsza z nich umiejscowiona została w pobliżu osi symetrii skrzydła równej $2z/b=0,1$, druga natomiast w pobliżu końcówki skrzydła równej $2z/b=0,9$ (rys. 3). Obliczenia realizowano dla następujących danych wejściowych:

kąt natarcia skrzydła	$\alpha=6^\circ$
wektor prędkości	$U_\infty=190,96 \text{ [m/s]}$
ciśnienie	$P_\infty=101325 \text{ [Pa]}$
temperatura	$T_\infty=293 \text{ [K]}$

Przykładowy wyniki przeprowadzonych badań przedstawiono na rysunku 5. Z przeprowadzonych testów w sposób jednoznaczny wynika, iż jakość siatki obliczeniowej ma istotny wpływ na wartości otrzymywanych wyników. Tak więc, od ilości komórek stanowiących siatkę obliczeniową i sposobu ich rozmieszczenia zależy wynik obliczeń.

Nie poprzestając na tych dwóch numerycznych doświadczeniach przeprowadzono kolejny test, tym razem dla skrzydła skośnego. Również i w tym przypadku profil użyty do konstrukcji geometrii skrzydła oparty został na profilu NACA0012. Wartość cięciwy skrzydła w jego osi symetrii wynosi $b_1=2 \text{ [m]}$, natomiast na krawędzi skrzydła $b_2=1 \text{ [m]}$. Rozpiętość skrzydła wynosiła $l=7,2 \text{ [m]}$. Tym razem nie przeprowadzano doświadczeń mających na celu ustalenie własności siatki obliczeniowej. Bazując na wynikach dotychczasowych doświadczeń wygenerowano siatkę zawierającą 2 079 266 komórek, które umieszczone w 18 obszarach. Zagęszczenie komórek zdefiniowane w pobliżu skrzydła (tak zbudowana siatka dawała pewność poprawnego uwarunkowania zadania). Również i w tym przypadku jako wielkość porównawczą wybrano wartości współczynnika ciśnienia C_p .

Na rysunku 6 przedstawiono przykładowy wynik przeprowadzonych badań.

Ponieważ otrzymane wyniki w określonych obszarach odiegły od danych przyjętych za wzorzec, postanowiono zmodyfikować siatkę dokonując zagęszczenia komórek na końcówce skrzydła z automatycznym rozrzedzeniem w jej części środkowej. Wyniki otrzymane dla tego przypadku przedstawia rysunek 7.

Przeprowadzona modyfikacja siatki obliczeniowej uwiadoczyła możliwość „zepsucia” rozwiązania zadania. Okazało się, że właściwy dobor liczby i sposobu rozmieszczenia ko-

Measurement of essential quantities for calculate C_p carried out in two planes. First plane was situated nearby axis of symmetry of wing which amounted $2z/b=0,1$. Second plane was situated nearby end of wing which amounted $2z/b=0,9$ (fig. 1).

1). Research was carried out for following input data:

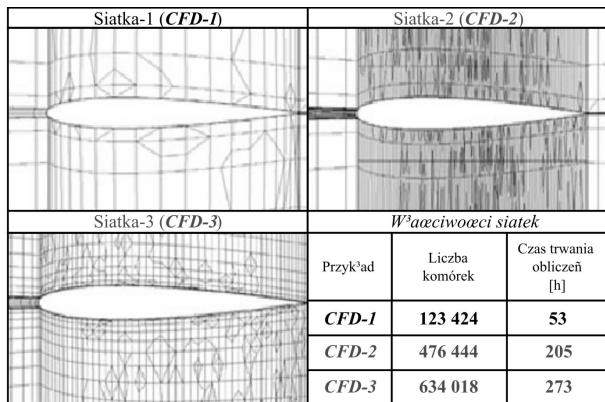
angle of attack	$\alpha=6^\circ$
velocity vector	$U_\infty=190,96 \text{ m/s}$
pressure	$P_\infty=101325 \text{ Pa}$
temperature	$T_\infty=293 \text{ K}$

Examples of the results of calculations are presented in figure 5. Carried out tests gave the proof that quality of grid have an influence on result's values. Hence, the number of grid cells and manner of their lay-out affect results of simulation.

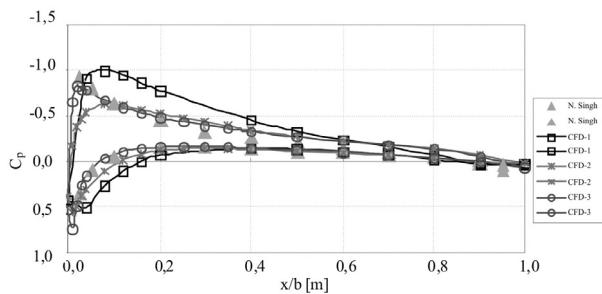
Authors didn't stop at that the research, and they performed the tests for swept wing and aerofoil profile NACA0012. Chord of the wing at axis of symmetry amounted to $b_1=2 \text{ [m]}$ and on edge of wing amounted to $b_2=1 \text{ [m]}$. Wingspan amounted to $l=7,2 \text{ [m]}$, with use results of previous tests authors built mesh with concentration at periphery of wing. In this case, authors didn't test quality of grid. On the basis on results, received in previous test for straight wing, was generated grid included 2 079 266 cells which are located in 18 areas. Near by the wing, grid was thickened (as for straight wing). As a comparative value was chosen value of pressure coefficient C_p . On figure 6 was presented example of the received results.

Received results differ from assumed standard, hence authors affirmed that grid should be concentrated at the end of the wing with rarefaction in central part. Received results show figure 7.

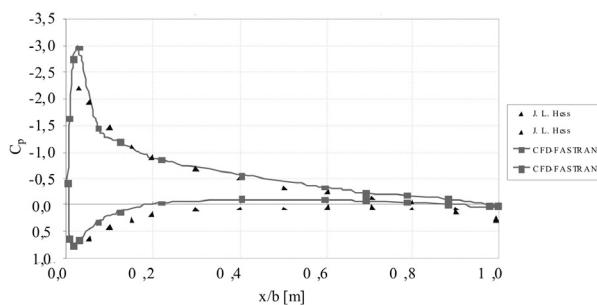
Modification of the grid demonstrate possibility of results “deterioration”. This research reveals problem of properly selection of cells number and theirs locations in all volume of the grid. Authors draw a conclusion that: lack of experience in grid generation can be the cause of receiving incorrect results.



Rys. 4. Widok sposobu zagęszczenia siatek dla poszczególnych modeli
Fig. 4. View of maner grid concentration for individual model



Rys. 5. Wykres $C_p=f(x/b)$ dla skrzydła prostokątnego dla $2z/b=0,9$
Fig. 5. Graph $C_p=f(x/b)$ for $2z/b=0,9$



Rys. 6. Wykres $C_p = f(x/b)$ dla skrzydła skośnego dla $2z/b=0,9$

Fig. 6. Graph $C_p = f(x/b)$ for $2z/b=0,9$

mórek w całej objętości siatki obliczeniowej jest bardzo istotny. A zatem z powyższego materiału wynika, że brak doświadczenia w sposobie generowania siatki obliczeniowej może być przyczyną otrzymania błędnych wyników.

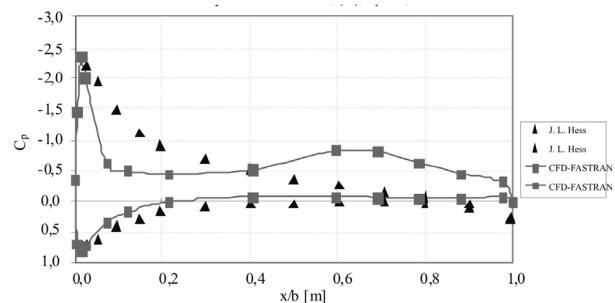
3. Numeryczna analiza zjawiska opływu strumieniem przepływu wybranych obiektów

Przeprowadzone testy porównawcze pozwoliły stwierdzić, że scharakteryzowane we wstępnie niniejszej pracy oprogramowanie, może z powodzeniem być wykorzystane do analizy zjawiska opływu dowolnego obiektu przez strumień przepływu. Zatem, postanowiono zamodelować geometrię bomby lotniczej i przeprowadzić badania mające na celu określenie wpływu przyjętej wzajemnej konfiguracji geometrycznej części czołowej, środkowej i tylnej na własności aerodynamiczne badanego obiektu.

W tym celu zamodelowano geometrię bomby w jej podstawowej konfiguracji geometrycznej (zgodnej z dokumentacją techniczną – rysunek 8).

Wyznaczono dla tego wariantu podstawowe parametry aerodynamiczne takie jak współczynniki: siły oporu i siły nośnej. Ponadto, wykorzystując możliwości programu CFD-View dokonano analizy rozkładu wartości ciśnienia na powierzchni bomby (rys. 9) jak i w przestrzeni ją otaczającej.

W kolejnym kroku dokonano wspomnianej już modyfikacji konfiguracji geometrycznej bomby budując 9 kolejnych wariantów (rys. 10). Badania i analizę przeprowadzono dla dwóch grup obiektów W1-W5 i W6-W10, związanych z kształ-



Rys. 7. Wykres $C_p = f(x/b)$ dla skrzydła skośnego dla $2z/b=0,9$ dla modelu z zagęszczoną siatką na końcu skrzydła

Fig. 7. Graph $C_p = f(x/b)$ for $2z/b=0,9$ for grid concentrated at the end of the wing

3. Numerical analysis of the flow around selected objects

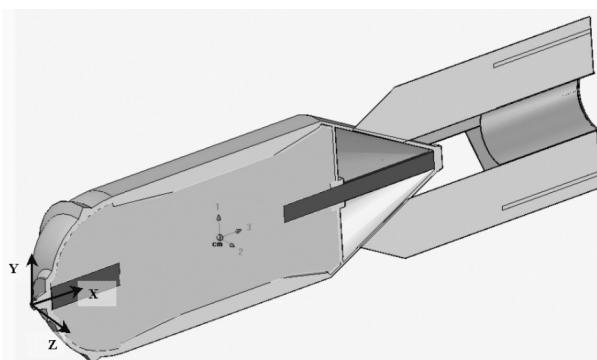
Realized comparative tests allow to affirm that described software can be used for analysis of flow around aircraft's elements. Therefore, authors desided to model aircraft's bomb geometry and to perform simulation for evaluation of front, centre and rear geometry influence on aerodynamic's characteristic the object. To this end, bomb geometry for basis configuration was built (according to technical documentation – fig. 8).

For assumed variant, aerodynamic characteristic such as aerodynamic drag and aerodynamic lift has been calculated. Furthermore, the software gave possibility to analyze pressure distribution on bomb's surface and surrounding space.

Next simulation was carried out for eight modified geometry version (fig. 10.). Research and analysis was realized for the following objects W1-W5 and W6-W10 connected with bomb's front geometry. Examples of results are present on figure 11.

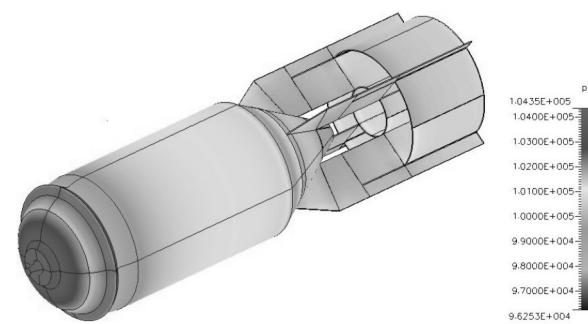
Carried out results gave possibility of selection best geometry configuration with optimal parameters C_x , C_y of the bomb (C_x , C_y - coefficients of aerodynamic drag and lift)

Ejection seat applied on aircraft TS-11 ISKRA was another object of research. The ejection seat has a specific geom-



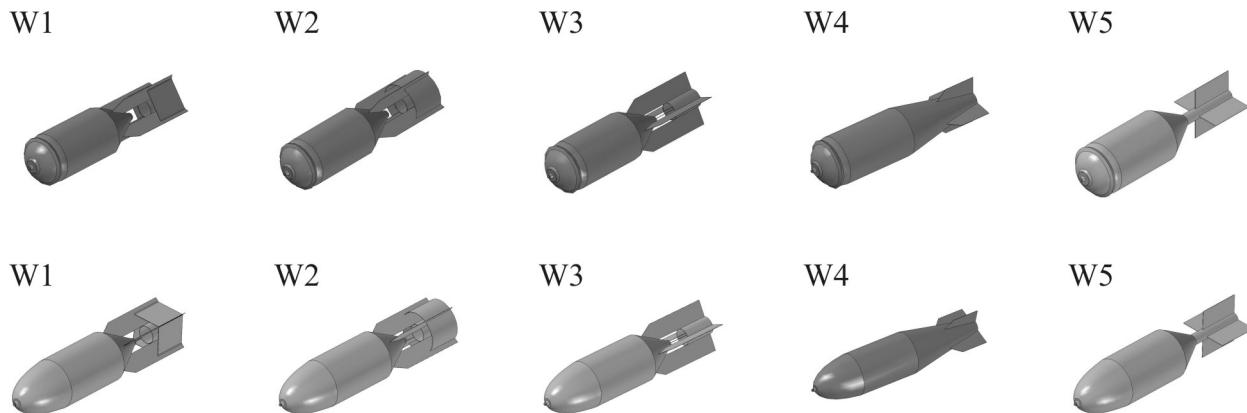
Rys. 8. Przekrój bomby lotniczej w konfiguracji podstawowej

Fig. 8. Section of aircraft's bomb for basis configuration



Rys. 9. Rozkład wartości ciśnienia na powierzchni bomby

Fig. 9. Pressure distribution on bomb's surface



Rys. 10. Warianty konfiguracyjne obiektu badań

Fig. 10. Variants of model geometry

tem części czołowej bomby. Przykładowe wyniki dla pierwszej grupy przedstawiono na rysunku 11.

Przeprowadzone badania pozwoliły na wybór konfiguracji geometrycznej pozwalającej na uzyskanie jak najlepszych wartości parametrów C_x i C_y bomby (C_x , C_y - współczynniki aerodynamiczne siły oporu i siły nośnej)

Kolejnym obiektem badań był fotel katapultowy stosowany na samolotach szkolno-bojowych TS-11 Iskra. Specyfika budowy siatki obliczeniowej dla tej klasy obiektów związana jest z przyjęciem właściwej topologii obiektu, stanowiącej podstawę do wyznaczenia obszarów obliczeniowych siatki. Nieregularność kształtu wymuszało przyjęcie określonych uproszczeń w budowie geometrii obiektu, które nie wnoszą dodatkowych błędów do wartości otrzymanych wyników (rys. 12) [4].

Istota badań tego typu obiektów związana jest z analizą bezpieczeństwa załogi wojskowych statków powietrznych w sytuacjach awaryjnych. Znajomość charakterystyk aerodynamicznych układu fotel-pilot jest jednym z elementów pozwalających na realizację numerycznej symulacji procesu katapultowania w przyjętych warunkach lotu. Analiza uzyskanych w ten sposób wyników może posłużyć do określenia warunków bezpiecznego użycia fotela katapultowego lub też badania wypadków/katastrof lotniczych z udziałem wojskowych statków powietrznych.

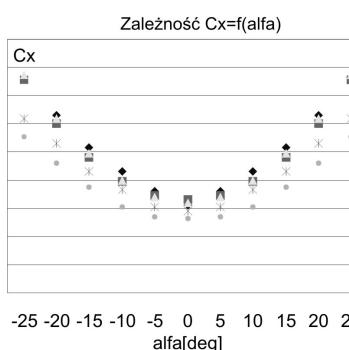
Jednym z kolejnych obiektów badań był samolot MiG-29 [3]. Złożoność poruszanej problemu przejawiała się w spo-

try which cause necessity of shape simplification and creation proper grid topology (fig. 12) [4].

Essence of the study this type of objects is connected with aircraft's crew safety analysis during emergency situations. Knowledge about aerodynamic's characteristics is one of the elements which give possibility to prepare numerical simulation of emergency escape process for assumed flight conditions. Analysis of carried out results can be used for specification of ejection seat safety using. Furthermore it can be used for study about accidents or catastrophes analysis of the military aircrafts.

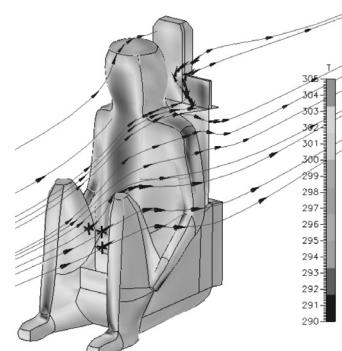
One of the following object of studies was aircraft MiG-29 [3]. Complication of raising the problem showed in grid generation and selection initial parameter of computation. In this case, it was necessary to built proper grid topology and area of calculation grid. Number of the area came to 93. Grid generation process is the most time – consuming from among all. Participation of this stage in whole research process achieve 80% of time, which in presented case came to 5 months. Figure 13 present calculation grid division on aircraft's surface.

After completing computation process, module CFD-View was used for analysis of pressure distribution on model's surface and surrounding space (fig. 14). Moreover authors calculated aerodynamic characteristics such as coefficients of aerodyn-



Rys. 11. Wykres zależności $C_x=f(\alpha)$ dla wariantów W1-W5

Fig. 11. Graph $C_x=f(\alpha)$ for variants W1-W5

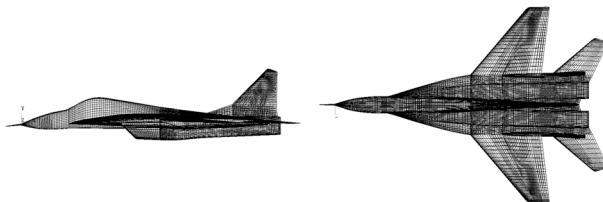


Rys. 12. Widok fotela katapultowego opływanego przez przykładowe strumienie przepływu

Fig. 12. View of ejection seat simulation model with flow stream visualisation

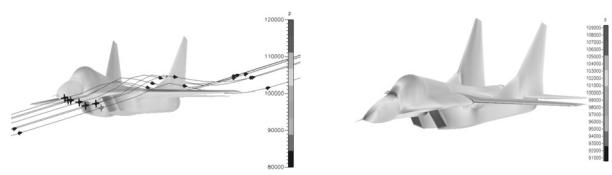
sobie generacji siatki obliczeniowej i doborze parametrów początkowych obliczeń. Nie jest to już prosty model skrzydła gdzie wystarczyło stworzyć osiemnaście obszarów zawierających elementarne objętości. W przypadku obiektu technicznego jakim jest samolot należało w sposób poprawny zbudować topografię obiektu, która posłużyła do wygenerowania obszarów siatki obliczeniowej. Liczba tych obszarów wynosiła 93. Proces budowania siatki obliczeniowej jest najbardziej czasochłonnym etapem pracy. Jego udział w całym procesie badawczym niejednokrotnie sięga osiemdziesięciu procent czasu, co w przypadku geometrii samolotu MiG-29 i jego siatki obliczeniowej wyniosło 5 miesięcy. Na rysunku 13 przedstawiono poziom siatki obliczeniowej na powierzchni samolotu.

Po zakończeniu procesu obliczeniowego, wykorzystując moduł CFD-View, przeanalizowano rozkład wartości ciśnienia dookoła badanego modelu jak i na jego powierzchni (rys. 14). Korzystając z informacji zawartej w plikach tekstowych wyznaczono charakterystyki aerodynamiczne, tj. współczynniki sił i momentów aerodynamicznych. Otrzymane wyniki porównano z wartościami otrzymanymi z badań modelu samolotu w tunelu aerodynamicznym. Z przeprowadzonego porównania wynika, że wraz ze wzrostem kąta natarcia strumienia przepływu rozbieżność pomiędzy uzyskanymi wynikami rosną i dla kąta natarcia 20° wynoszą 15%.

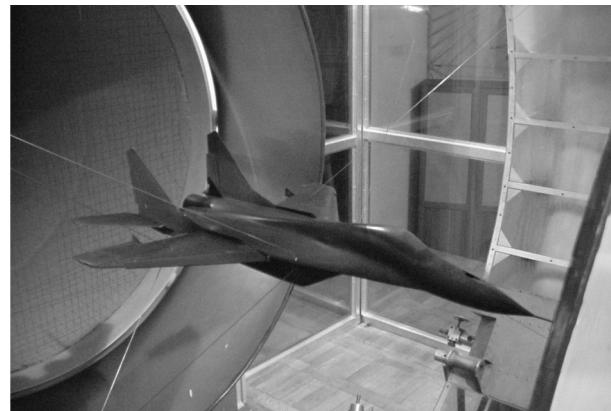


Rys. 13. Widok siatki powierzchniowej
Fig. 13. View of surface grid

mic forces and moment. Received results was compare with data from wind tunnel. This comparison give an conclusion that according to growth flow stream angle of attack follow growth of divergence between simulation and wind tunnel results and for angle of attack 20° amount to 15%.



Rys. 14. Rozkładu ciśnienia na powierzchni samolotu MiG-29
Fig. 14. Pressure distribution on aircraft MiG-29 surface



Rys. 15. Widok modelu samolotu MiG-29 zawieszony w przestrzeni pomiarowej tunelu aerodynamicznego
Fig. 15. View of aircraft MiG-29 situated in measurement space of wind tunnel

4. Wnioski

Z przedstawionych w niniejszym opracowaniu analiz wynika, że wyniki otrzymane dla poszczególnych testów z dużą dokładnością pokrywają się z przyjętymi wzorcami. Wyniki uzyskane dla zbudowanych modeli obliczeniowych różnią się w granicach 10÷20% w stosunku do danych uzyskanych na drodze przeprowadzonych eksperymentów w tunelu aerodyna-

4. Conclusions

Presented in this paper analysis and tests reveals that results of simulation process agree with established standards with great accuracy. Received simulation's results are differed from wind tunnel's results by 10-20% (taking into consideration subject matter of this studies presented results don't include detailed data). Values of received results divergence are

micznym (z uwagi na ich charakter nie zamieszczono wartości konkretnych parametrów w niniejszym opracowaniu). Uzyskane rozbieżności wynikają w głównej mierze z faktu silnej korelacji jakości zbudowanej siatki obliczeniowej z uzyskany mi wynikami obliczeń. Ponadto istotne znaczenie na wartość otrzymanych wyników ma również dobór modelu turbulencji oraz sposobu rozwiązania zadania (wyboru metody obliczeniowej).

Przedstawione w niniejszym artykule przykłady wykorzystania narzędzia programowego z rodziny CFD służą do wyznaczenia i analizy właściwości aerodynamicznych badanych obiektów. Uzyskana w ten sposób informacja jest podstawą do podjęcia prac mających na celu określenie walorów lotnych badanych obiektów oraz analizy bezpieczeństwa ich użycia, co z uwagi na charakter warunków w jakich następuje ich użytkowanie jest niezwykle istotne. Znajomość tych walorów pozwala określić np. zachowanie się układu fotel-pilot w sytuacji awaryjnego opuszczania wojskowego statku powietrznego, czy też wyznaczenie toru lotu zrzuconej bomby lotniczej w celu zbadania czy nie wystąpi kolizja wymienionych obiektów z samolotem-nosicielem. Z uwagi na powyższe, przedstawione oprogramowanie (CFD-Fastran) może w sposób istotny wspomóc proces projektowania określonych obiektów technicznych oraz weryfikowania określonych charakterystyk obiektów już eksploatowanych.

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closely correlate with calculation's grid quality. Furthermore, important influence on values of received results has selection of turbulence model and selection of calculation method.

Presented in this article examples of using software package CFD type, gave possibility to evaluation aerodynamic characteristics of selected object's. Carried out data is a base for further research in order to evaluation aerodynamic virtues and safety using of tested objects. Knowledge about this aerodynamic characteristics for ejection seat – pilot object give possibility to evaluate object's trajectory and allow to avoid collision with aircraft. Similary, simulation of aircraft's bomb airdrop allow to avoid collision with aircraft. On the basis of the study, software package CFD-Fastran can essentially aid technical object's design process and characteristics varyfication of existing objects.

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APPLICATIONS OF NRTC CYCLE TO DETERMINE A DIFFERENT FUEL CONSUMPTION AND HARMFUL EMISSIONS CAUSED BY CHANGES OF ENGINE'S TECHNICAL CONDITIONS

The main topic of the paper is to determine different fuel consumption and harmful emissions caused by engine's changes of technical conditions. The change of technical condition of combustion engine at any working point of engine proves different change of fuel consumption and production of harmful emissions. Therefore it is necessary to compare two technical conditions to determine the same engine load. For this purpose the special simulation programme of engine load in Non-Road Transient Cycle (NRTC) was created.

Keywords: internal combustion engine, fuel consumption, harmful emissions.

1. Introduction

The flawless, reliable, ecological and economical operation is required from vehicles's engines and their equipment. These requirements are not possible to guarantee by quality of design and production only but it is necessary to maintain the engine by regular controls.

During technical life the growth of specific fuel consumption (as increase of carbon dioxide emissions) accompanied with other harmful emissions is caused by engine's impacts of progressive detriments. Application modern diagnostic methods are possible to reach rectification and decrease the production of harmful emissions on to standard level app. by 90 % of cases. From the point of economy and ecology of operation the specific fuel consumption is one of the most important parameters of combustion engines. The lesser is engine's specific fuel consumption the better is environment protection. But the specific fuel consumption is too complex diagnostic signal because almost any engine failures are shown in its increase.

2. Methods

For experiment of different engine consumption and harmful emissions in dependence on change the engine's technical condition was used in Non-Road Transient Cycle (NRTC) [1,2]. This cycle is accepted by European Union directives to represent the typical tractor's engine load during work under outdoor conditions (terrain).

The tested engine was Zetor 7701. Parameters of this engine are below in the Tab. I. The fuel consumption and the production of harmful emissions depend on different adjusted engine's speed and torque. Measurement was carried out under good technical conditions of engine and subsequently under the worse technical conditions of engine. The worse technical condition has been simulated by a modification of the pre-injection angle (changed onto 18 %). Discreet measuring values were processed onto continuous surface of fuel consumption and harmful emissions depending on engine speed and torque. The fuel consumption and harmful emissions at every working points of NRTC cycle was obtained from the continuous surface by the help of PC program.

Tab. 1. Parameters of the engine Zetor 7701

engine type	Z 7701
<i>fuel</i>	diesel
<i>maximum power output</i>	55 kW
<i>maximum torque</i>	280 Nm
<i>cylinder number</i>	4
<i>piston bore</i>	102 mm
<i>piston stroke</i>	120 mm
<i>compression ratio</i>	17
<i>nominal rpm</i>	2200 ot/min
<i>pre-injection</i>	25° in front HU
<i>injection pressure</i>	18,7 ± 0,1 MPa
<i>injection pump</i>	PP 4 M 3137 S 0164
<i>efficiency regulator</i>	RV M 900 1100 3300
<i>injector-nozzle</i>	DOP 160 S 430 - 1436

2.1. The characteristic of fuel consumption in good technical condition

The continuous surfaces are created from values engine consumption and harmful emissions in dependence on engine speed and engine torque measured in two technical engine conditions. These created surfaces subsequently limited by maximal moment and losing engine moment. Thereby we delimit the working engine area.

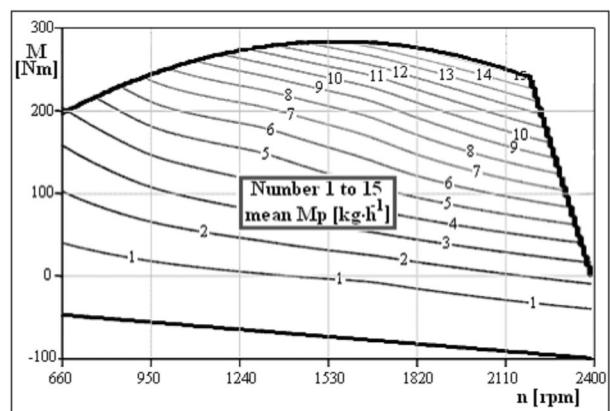


Fig. 2.1. The hourly fuel consumption in dependence of engine speed and engine torque

Tab. 2.1. The example of fuel consumption in selected working engine points

$fit(660,28) = 0.819$	$fit(1500,100) = 4.139$	$fit(2000,280) = 16.834$
$fit(1000,0) = 0.709$	$fit(1500,180) = 6.692$	$fit(2200,100) = 6.397$

2.2. The characteristic of fuel consumption in worse technical condition

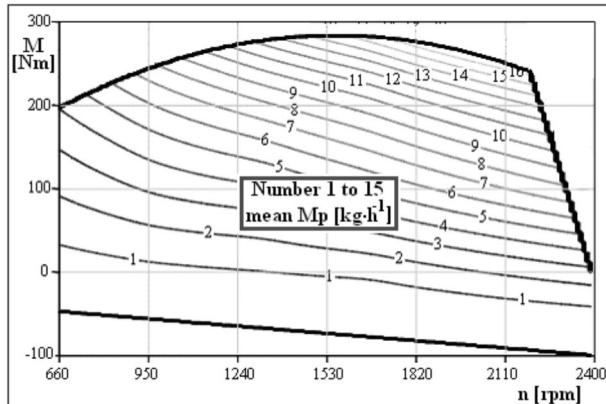


Fig. 2.2. Hourly fuel consumption in dependence of engine speed and engine torque

Tab. 2.2. The example of fuel consumption in selected working engine points

$fit(660,28) = 0.913$	$fit(1500,100) = 4.485$	$fit(2000,280) = 18.77$
$fit(1000,0) = 0.782$	$fit(1500,180) = 7.642$	$fit(2200,100) = 7.294$

2.3. The course of engine speed and torque

The engine speed and torque is given percentage in cycle. The first necessary step which is needed for other processing is lead over this percentage setting on engine speed [rpm] and engine torque [Nm].

Specified percentage rpm are transferred into the rpm depending on the time, this way:

There will determine referential rpm, which forms a base (100 %) for calculation of actual motor rpm. This is close to the nominal rpm:

$$n_{ref} = n_{lo} + 0.95(n_{hi} - n_{lo}) \quad (2.1)$$

Where: n_{ref} is referential engine speed [rpm]; n_{lo} is low engine speed [rpm], determined by calculating 50% of the declared maximum net power; and n_{hi} is engine speed [rpm] determined by calculating 70% of the declared maximum net power (so rpm higher than nominal).

The actual engine speed:

$$n(s) := \frac{(n_{ref} - n_{idle}) \cdot n_{\%_s}}{100} + n_{idle} \quad (2.2)$$

where: $n(s)$ are actual engine speed in NRTC cycle [rpm], idle engine speed 660 [rpm], n_{ref} are reference engine speed 2294 [rpm] and $n_{\%_s}$ are set percentage engine speed.

Specified percentage engine torque will transform on the torque [Nm] depending on the cycle time, this way:

The actual engine torque:

$$M_c(s) := M_{max}(s) \cdot 0.01 \cdot M_{\%_s} \quad (2.3)$$

Where: $M_c(s)$ is course of engine torque [Nm], $M_{max}(s)$ is maximal moment by given engine speed cycle and $M_{\%_s}$ is set engine torque in cycle.

3. Result

If we know the mode of engine speed and engine load in given cycle (fig. 2.4), we would have to assign to single points (engine speed x engine load) from surface of hourly engine consumption given by immediate fuel consumption. The model of NRTC cycle is founded on presumption that every measured point continuance in its course for a period 1 second. By this period is every points assigned fuel consumptions which is corresponding by given engine speed and engine load.

Influence of engine failure the fuel consumption increased in cycle from 1,779 kg to 2,002 kg and average specific fuel consumption increased from 275,755 [g·kWh⁻¹] to 306,784 [g·kWh⁻¹].

In the same way as the fuel consumption, the different production of pollutant emission can be expressed.

The engine produced in good technical condition during cycle 5,411 kg emission carbon dioxide, 165,373 g emission carbon monoxide, 1,025 g emission hydrocarbon and 42,71 g emission nitrogen oxides.

The engine produced in worse technical condition 5,77 kg emission carbon dioxide, 254,058 g emission carbon monoxide, 1,157 g emission hydrocarbon and 30,6 g emission nitrogen oxides.

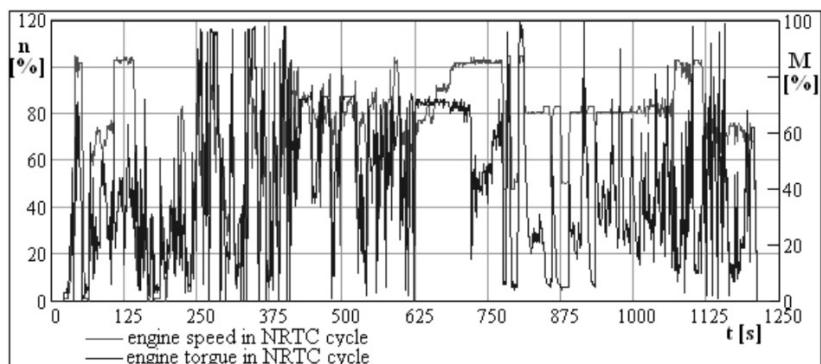


Fig. 2.3. The course of percentage engine speed and engine torque in NRTC cycle

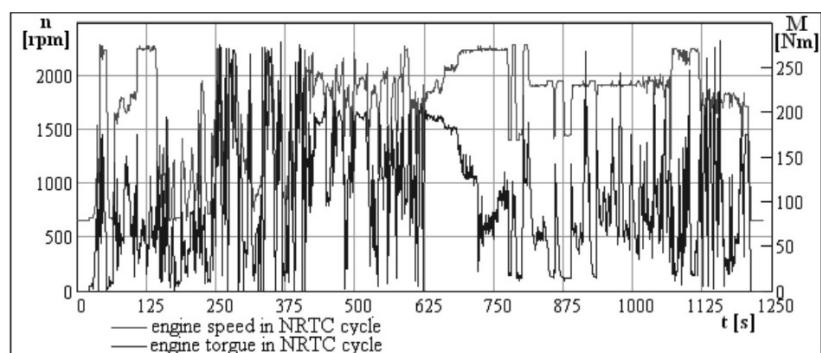


Fig. 2.4. The course of engine speed and engine torque in NRTC cycle

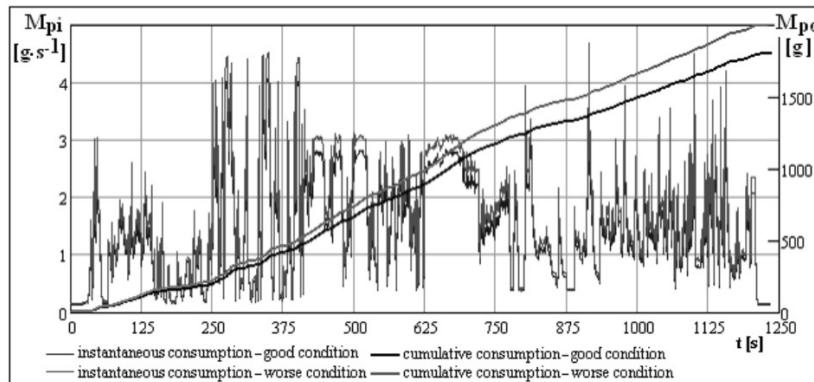


Fig. 2.5. The course of immediate and cumulative fuel consumption in NRTC cycle

4. Discussion

The technical condition has undoubtedly impact on fuel consumption and production of harmful emissions. The evaluation impacts on change of engine's technical condition by mere comparison with fuel consumptions and harmful emissions production in a few points of working characteristic has only minimal testify ability about harmfulness vehicles.

Because during of operation happen to ingravescence of technical engine condition and thereby too increase emissions

production, is controlled the emissions production from motor vehicles in regular interval. At present is provided this measure in Vehicle Technical Station and is technical and economical compromise by which is evaluated only combustion's quality in two working points the motor's characteristic. Like this provided control has only little predicable ability about its harmfulness.

Into the future will be suitable to lead new inspection maintenance, which will be objective in adjudication given vehicle.

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TRIBOLOGICZNE WŁAŚCIWOŚCI CERAMICZNO-WĘGLOWYCH WARSTW POWIERZCHNIOWYCH OTRZYMYWANYCH W ELEKTROLITACH O RÓŻNEJ ZAWARTOŚCI GRAFITU

TRIBOLOGICAL PROPERTIES OF CERAMIC-CARBON SURFACE LAYERS OBTAINED IN ELECTROLYTES WITH A DIFFERENT GRAPHITE CONTENT

W pracy przedstawiono tribologiczne właściwości kompozytowych warstw powierzchniowych tlenek glinu-grafit. Warstwy otrzymano metodą elektrolityczną, w elektrolitach o różnym stężeniu grafitu. Wytworzono warstwy skojarzone z tworzywem PEEK/BG w ruchu posuwisto-zwrotnym, w warunkach tarcia bezsmarowego. Przedstawiono rezultaty badań współczynnika tarcia pary ślizgowej i zużycia masowego tworzywa. Celem określenia mikrogeometrii powierzchni warstw tlenku glinu oraz warstw tlenek glinu-grafit przeprowadzono badania struktury geometrycznej powierzchni za pomocą profilografometru stykowego, przed i po teście tribologicznym. Zaprezentowano również obrazy struktury i morfologii powierzchni warstw tlenek glinu-grafit oraz tworzywa PEEK/BG wykonane przy zastosowaniu elektronowej mikroskopii skaningowej.

Słowa kluczowe: właściwości tribologiczne, warstwa kompozytowa, mikroskopia skaningowa, tworzywo sztuczne, mikrogeometria powierzchni.

The paper presents the tribological properties of composite aluminium oxide-graphite surface layers. The layers were obtained by the electrolytic method, in electrolytes with a different graphite concentration. The produced layers were coupled with a PEEK/BG material in reciprocating motion, under lubricant-free friction conditions. The results of research regarding the coefficient of a friction couple wear and mass wear of the material are presented. In order to determine the microgeometry of the aluminium oxide layers' surface and of aluminium oxide-graphite layers, investigation was conducted of the geometrical structure of the surface using a contact profilographometer before and after a tribological test. Images are also presented in the paper showing the structure and surface morphology of aluminium oxide-graphite layers and the PEEK/BG material, taken using scanning electron microscopy.

Keywords: tribological properties, composite layer, scanning microscopy, plastic material, surface microgeometry.

1. Introduction

The oxide ceramic layers Al_2O_3 , produced via hard anodizing belong to a group of materials with a strongly developed surface. They are frequently used for lubricant-free sliding couples with polymers, in the production of servo-motors, compressors or shock absorbers.

Under technically dry friction conditions, the essence of a polymer/aluminium oxide layer, the latter being hard and resistant to wear, is the formation of a polymer sliding film. The film has an ability to significantly reduce resistance to motion in a further friction process causing, however, an increase in mass wear of the material in the initial phase of the couple's interaction [1, 2]. Preventing such undesirable effects has been realized so far through the creation of polymer compositions being a mixture of a basic material with fillers. In the case of PTFE based compositions, fillers in the form of powders, flakes or fibres are used. The most important materials used as fillers in the production process of composite materials with a PTFE matrix include powdered graphite, carbon, molybdenum disulfide, glassy carbon and powders of the following metals: bronze, brass, antimony, nickel, and oxides of some metals. Owing to a laminar structure of the crystal lattice and anisotropic properties of cohesion forces of the fillers, i.e. graphite or molybdenum disulfide, a partial replacement of external friction with internal

friction of a low value takes place between the interacting surfaces, which leads to a reduction of the friction forces [3].

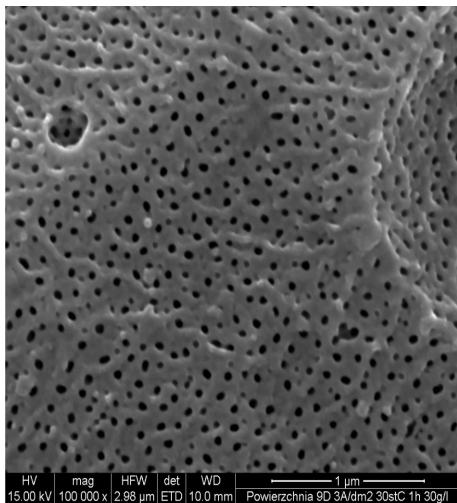
A similar effect of a reduction in resistance to motion during technically dry friction, without excessive mass wear of the material in the initial phase of the couple's interaction, could be achieved by incorporating the graphite into the oxide structure.

2. Ceramic-carbon surface layer

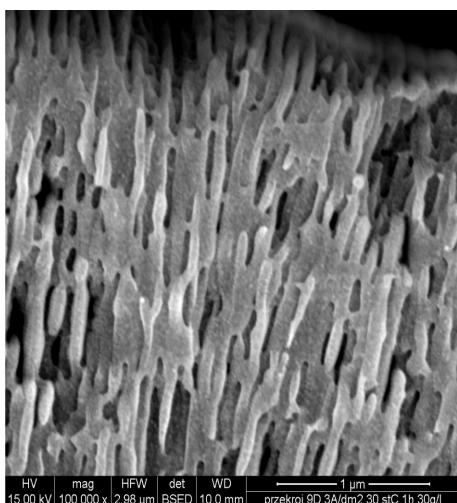
The object of the tribological tests were ceramic-carbon layers of aluminium oxide/graphite, produced on a substrate of aluminium alloy EN AW-AlMg2, of dimensions: 1.8×6 cm. The process of surface layers production was preceded by cleaning the aluminium alloy surface through etching in a 5% KOH solution and a 10% HNO_3 solution, followed by rinsing in distilled water.

The layers were obtained in an electrochemical oxidation process by the direct-current method, in electrolytes with organic acids' and graphite's additions. Four electrolytes were used, differing with the graphite content from 0 to 30 g/litre of electrolyte. The oxidation process was conducted for an electric charge of 180 Amin for all the surfaces. Current density amounted to $2 - 4 \text{ A}/\text{dm}^2$ with oxidation time of 40 - 90 minutes. The bath temperature was 293 and 303 K.

The image of the aluminium oxide-graphite layer's morphology, taken using scanning electron microscopy (Fig. 1), presents, characteristic for aluminium oxides, surface porosity of a cylindrically structured. The porosity is an effect of the columnar architecture of the structure (Fig. 2), oriented against the electric field [4].



Rys. 1. Morfologia powierzchni warstwy tlenek glinu-grafit
Fig. 1. Surface morphology of aluminium oxide-graphite layer



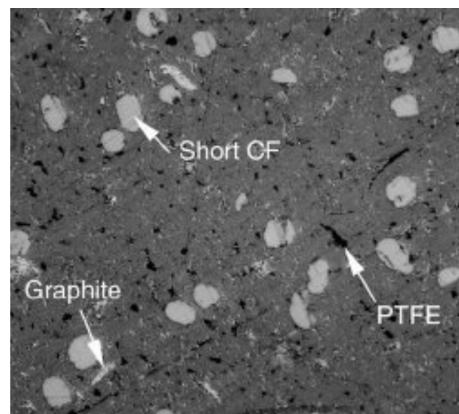
Rys. 2. Struktura warstwy tlenek glinu-grafit
Fig. 2. Structure of aluminium oxide-graphite layer

3. The PEEK/BG material

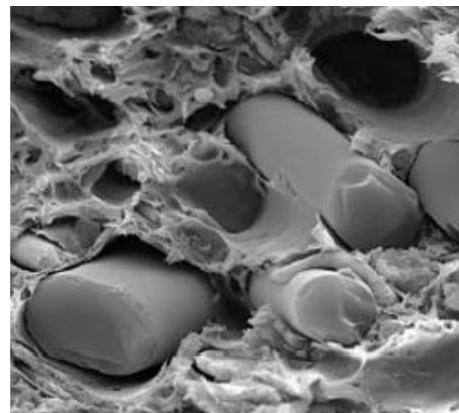
The material interacting with the aluminium oxide/graphite layers was a high-quality polymer composite based on polyetheretherketone. PEEK is a partly crystalline thermoplastic material with very good mechanical properties. It is characterized by a high temperature of continual work, amounting to 523 K, and perfect chemical and radio-resistance. Good sliding properties and low absorbability, ensuring high dimensional stability, complement the properties of this high-parameter material, making it a universal material for a number of applications.

An addition of PTFE, graphite and carbon fibres to the PEEK material (Fig. 3) yields a material with enhanced mechanical strength, a reduced friction coefficient and improved abrasion re-

sistance. Its optimal tribological properties make the PEEK/BG particularly suitable for applications in friction couples consisting of bearings. Photographs of the material (Figs. 3, 4) have disclosed a unidirectional arrangement of carbon fibres in the structure of PEEK/BG [5-8]. For the tribological tests, a surface of the material was used, in relation to which the fibres were arranged perpendicularly. A PEEK/BG sample prepared for the tests was cube-shaped, with a side of 10 mm.



Rys. 3. Morfologia powierzchni PEEK + 10% PTFE + 10% grafitu + 10% włókien węglowych [6]
Fig. 3. Surface morphology of PEEK + 10% PTFE + 10% graphite + 10% carbon fibres [6]



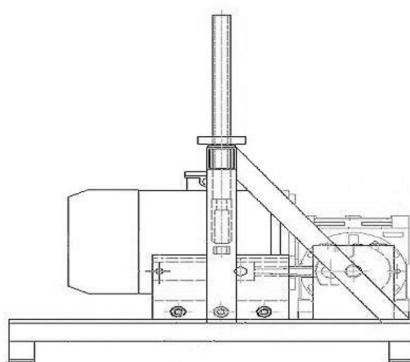
Rys. 4. Przelom PEEK + 10% PTFE + 10% grafitu + 10% włókien węglowych [6]
Fig. 4. Fracture PEEK + 10% PTFE + 10% graphite + 10% carbon fibres [6]

4. Research methodology

Tribological tests were conducted on an RS 2007 testing machine, dedicated for testing materials which interact as a sliding couple in reciprocating motion (Fig. 5).

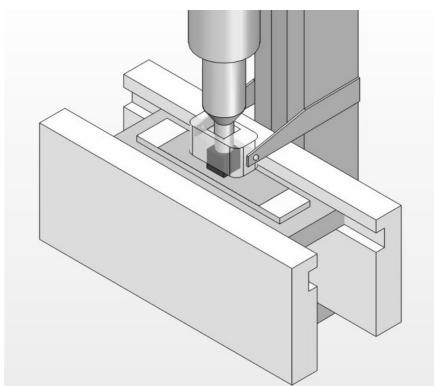
The friction couple in RS 2007 (Fig. 6) reproduces the work of components of a piston-cylinder couple. The specimen used in the test is a sector of a piston gasket ring and the counter-specimen is a sector of a cylinder sleeve. Counter-specimens are fixed in a guide moving with a reciprocating motion, through a crankshaft driven by a motor. The specimens fixed in extensometer transducers are pressed against counter-specimens using bobs.

The tribological tests were carried out in dry friction condi-



Rys. 5. Schemat testera RS 2007

Fig. 5. RS 2007 tester diagram



Rys. 6. Węzeł tarcia testera RS 2007

Fig. 6. RS 2007 tester friction couple

tions, at a constant ambient temperature and constant relative humidity of the air. The tests were carried out for a constant friction distance of 25 km + 10 km, under unit pressure of 30 N and at an average sliding speed of 0.3 m/s.

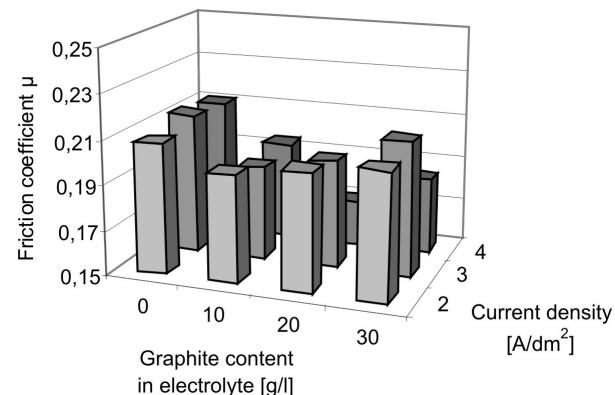
The friction force was recorded by means of a multichannel analog-to-digital converter, *Spider 8*, using the *Catman 4.5* software. Mass wear of the PEEK/BG material was determined by means of an electronic analytical balance *WA-35* of 0.1 mg accuracy. To determine the influence of the interacting surfaces' microgeometry on the tribological test results, measurement of roughness of the oxide layers was made using a contact profilographometer *Form Talysurf*, with applying the 2D method.

5. Reserach results

Based on data obtained from the tribological test carried out for couples of ceramic-carbon surface layers with the PEEK/BG material, the influence was determined of oxide layers' formation conditions (current density, graphite content in electrolyte, bath temperature) on the friction coefficient value and mass wear of the material. The results are presented in a form of charts for particular temperatures of electrolyte.

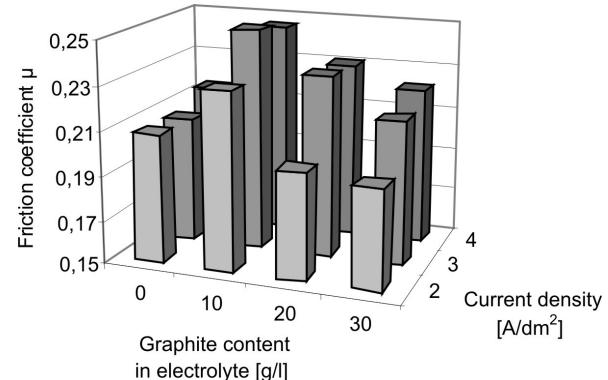
An analysis of the friction coefficient for layers produced at a temperature of 293 K (Fig. 7) suggests that a graphite addition to electrolyte results in decreasing the value of friction coefficient. An increase in current conditions during the electrolysis process results in a decrease of the friction coefficient value for layers produced in the electrolyte with graphite.

In the case of layers formed at a temperature of 303 K (Fig. 8), one can observe an inverse nature of changes of the friction coefficient as a function of current conditions and electrolyte composition. For the layers formed in electrolyte with graphite, while the current density value decreases, the friction coefficient decreases as well. An increase of graphite content in the bath results in a decrease of the friction coefficient value. A layer produced at current density of 4 A/dm² in electrolyte of a temperature of 293 K and graphite content of 20 g/l achieved the lowest friction coefficient value, i.e. 0.17, among the layers produced in electrolytes containing graphite. The friction coefficient for the layer formed in the same current conditions, in electrolyte of the same temperature but without graphite, amounted to 0.21.



Rys. 7. Zależność współczynnika tarcia od gęstości prądowej i rodzaju elektrolitu dla skojarzenia tworzywo PEEK/BG - tlenek glinu-grafit wytwarzanego w temperaturze 293 K

Fig. 7. Dependence of friction coefficient on current density and electrolyte type for the couple: PEEK/BG -aluminium oxide -graphite, formed at a temperature of 293 K

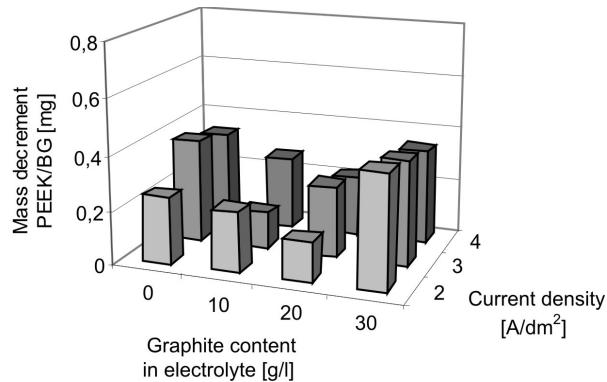


Rys. 8. Zależność współczynnika tarcia od gęstości prądowej i rodzaju elektrolitu dla skojarzenia tworzywo PEEK/BG - tlenek glinu-grafit wytwarzanego w temperaturze 303 K

Fig. 8. Dependence of friction coefficient on current density and electrolyte type for the couple: PEEK/BG -aluminium oxide -graphite, formed at a temperature of 303 K

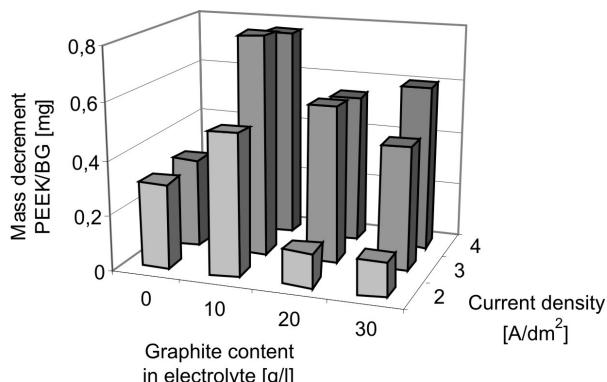
The nature of the PEEK/BG material wear as a function of current conditions and electrolyte composition for layers produced at 303 K (Fig. 9) is identical to the nature of changes in the friction coefficient (Fig. 7). The lowest PEEK/BG mass decrement, i.e. 0.12 mg, was recorded for a specimen

interacting with the layers produced at current density of 4 A/dm^2 in electrolyte at a temperature of 303 K with graphite content of 20 and 30 g/l. The mass decrement of a specimen interacting with the layer formed in the same current conditions, in electrolyte of the same temperature but without graphite, amounted to 0.33 mg.



Rys. 9. Zależność zużycia tworzywa PEEK/BG od gęstości prądowej i rodzaju elektrolitu po teście tribologicznym z ceramiczno-węglowymi warstwami wytwarzanymi w temperaturze 293 K

Fig. 9. Dependence of PEEK/BG wear on current density and electrolyte type after tribological test with ceramic-carbon layers produced at a temperature of 293 K

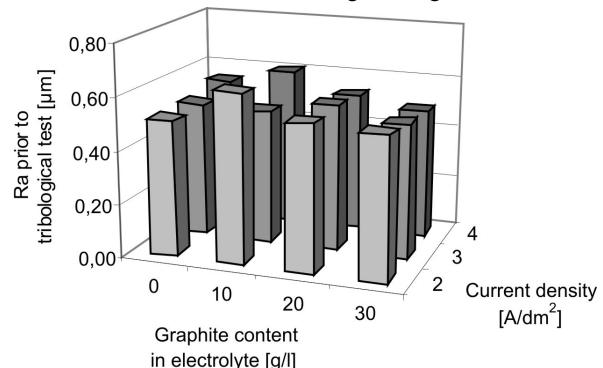


Rys. 10. Zależność zużycia tworzywa PEEK/BG od gęstości prądowej i rodzaju elektrolitu po teście tribologicznym z ceramiczno-węglowymi warstwami wytwarzanymi w temperaturze 303 K

Fig. 10. Dependence of PEEK/BG wear on current density and electrolyte type after tribological test with ceramic-carbon layers produced at a temperature of 303 K

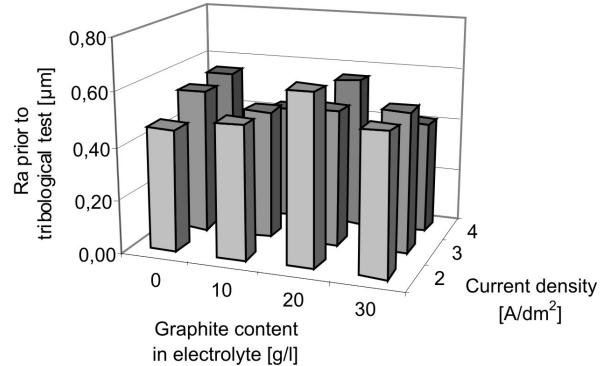
By determining the influence of the microgeometry of ceramic-carbon surface layers on the friction coefficient value and wear of the PEEK/BG material, the basic parameters of the profile were analyzed. Figures 11 and 12 present the measurement of mean arithmetical deviation of the layers' roughness profile before friction. A comparison of parameter Ra of all the oxide layers (0.42-0.64) shows insignificant differences in roughness. The results of the profilographometric ex-

mination corroborate that the geometric structure of the layers' surface has no influence on changes of the friction coefficient or wear of the PEEK/BG material during tribological interaction.



Rys. 11. Średnie arytmetyczne odchylenie profilu chropowatości Ra, ceramiczno-węglowych warstw wytwarzanych w temperaturze 293 K

Fig. 11. Mean arithmetic deviation of roughness profile Ra, of ceramic-carbon layers produced at a temperature of 293 K



Rys. 12. Średnie arytmetyczne odchylenie profilu chropowatości Ra, ceramiczno-węglowych warstw wytwarzanych w temperaturze 303 K

Fig. 12. Mean arithmetic deviation of roughness profile Ra, of ceramic-carbon layers produced at a temperature of 303 K

6. Conclusions

Based on the conducted studies and analysis of test results it has been concluded that as a result of a lubricant-free tribological test for a couple consisting of ceramic-carbon surface layers with PEEK/BG, the polymer material is transferred onto the oxide surface. Incorporation of graphite into the structure of oxide layers formed at a temperature of 293 K at high current density values decreases the friction forces in tribological couples with the PEEK/BG material, whereas incorporation of graphite into the structure of oxide layers produced at a temperature of 303 K at low current density values, reduces the wear of the material.

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