SPIS TREŚCI

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NECHVAL K.N., NECHVAL N.A., BERZINS G., PURGAILIS M.: **Planning inspections in service of fatigue-sensitive aircraft structure components under crack propagation**; EiN 4/2007, s. 3-8.

For important fatigue-sensitive structures of aircraft whose breakdowns cause serious accidents, it is required to keep their reliability extremely high. In this paper, we discuss inspection strategies for such important structures against fatigue failure. The focus is on the case when there are fatigue-cracks unexpectedly detected in a fleet of aircraft within a warranty period (prior to the first inspection). The paper examines this case and proposes stochastic models for prediction of fatigue-crack growth to determine appropriate inspections intervals. We also do not assume known parameters of the underlying distributions, and the estimation of that is incorporated into the analysis and decision-making. Numerical example is provided to illustrate the procedure.

SROKA Z.J.: **Durability of engine components due to alternative fuels**; EiN 4/2007, s. 9-14.

Shortage of crude oil gives the reason to look for alternative engine fuels. Some of them are well known like: gas-fuels - LPG, CNG, LNG, bio-fuels - RME, B10, B20 etc. or very future like hydrogen. There are many problems to solve being sure that they are actual alternative fuels – engine efficiency, ecology, emission. Among of them, the durability of engine due to different fuel is the crucial point of many research discussion. The paper includes info about: durability of technical object, combustion engine as a technical system, engine fuels and their features and example of engine wear performance due to rape methyl ester fuel, natural gas fuel experience, hydrogen thermodynamic effect and small case of prediction of life time.

DENCZEW S.: **Auditing as important element of modern water supply and sewage systems management**; EiN 4/2007, s. 15-19.

The water supply and sewage segment is element of municipal infrastructure, in particular technical infrastructure, and water supply systems, are components of critical infrastructure.

We can say therefore that water supply and sewage segment task is to provide public services with municipal nature (water supply and removal of sewage belonging to water supply and sewage services), strategic importance (mainly water supply in crisis situations), and social nature (water supply for fire fighting or people and assets safety).

CHŁOPEK Z.: **Effects of using CRT particulate matter filters for self ignition engines**; EiN 4/2007, s. 20-23.

Particulate matter emission, next to that of nitrogen oxides, belongs to the most serious ecological threats posed by combustion engines. This is particularly dangerous in great urban agglomerations. One of the most significant sources of particulate matter emission in the urban centres are self ignition engines of lorries and urban buses. Most effective ways of lowering particulate matter emission are particulate matter filters. This paper presents studies results on the influence of using self regenerating CRT filter on their emission, from the bus engine. The tests were conducted in the static and dynamic conditions.

TOMASZEK H., ŻUREK J., JASZTAL M.: **A method of evaluating time of fatigue crack growth to limiting value of some selected structural components – an outline**; EiN 4/2007, s. 24-28.

The paper has been intended to introduce a method of evaluating time of fatigue crack growth to limiting value for some selected structural components during aircraft's operation process. The method, base on stress intensity factor and Paris' formula, which describe physical nature of the process. To describe the dynamics of the crack propagation was used a partial differential equation of the Fokker-Planck type. Having solved this equation enables the density function of the crack length to be found. This function, gave possibility of determination time density function when fatigue crack growth achieves limiting value.

CHALAMOŃSKI M.: **Analysis of thermal centre failuring**; EiN 4/2007, s. 29-32.

Thermal centre failuring is the cause of high costs for the companies administering the centres, its consequences influence heat recipients. Since failuring occurs mostly during the periods of the greatest demand for heat (autumn-winter-spring), and the fact that thermal centres are exploited throughout the whole year, there is a necessity to monitor their technical condition. That is why introducing failure analysis is crucial to identify the effects causing malfunctioning of individual elements of a given thermal centre.

KOMARNICKI P., BIENIEK J., BANASIAK J.: **Operational effectiveness of a sieve-aerodynamic separator under the conditions of the variable load of sieves**; EiN 3/2007, s. 33-35.

It was found on the basis of the testing conducted that the supporting air flow essentially affected the effectiveness of the aerodynamic separation on a laterally inclined sieve. As a result of the choice of the air flow in side fans the zones of increased cleaning effectiveness were determined.

RUSIN A., LIPKA M.: **Systems of supporting the supervision of the operational safety of steam turbines**; EiN 4/2007, s. 36-42.

The possibilities of supervising the operation of thermal turbines enabling the tracking and prevention of events that may lead to serious failures are discussed. The algorithms of the monitoring the thermal stress levels of particular components are presented, together with brittle cracking hazards on the grounds of failure diagrams. The algorithms are based on typical quantities measured and recorded by the measurement systems of power units as well as on the material characteristics obtained from non-destructive tests.

KOWALSKI K.: **The development of the professional education process using statistical techniques analysis of questionnaires**; EiN 4/2007, s. 43-48.

At the beginning, author briefly presents the Polish Armed Forces cadre's professional military education (PME) development system that includes PME development of logistic officers conducted at the Military Academy of Land Forces. A practical method of continuing development of the educational process based on statistical analysis of customer's satisfaction survey data was described. Additionally, using the example, presented appropriate actions taken to improve the PME process.

KUNDLER J.: **Long-term maintenance of aeronautical information system on the base of statistical methods**; EiN 4/2007, s. 49-54.

The AIS service (Aeronautical Information Service) is an operational service for Air Traffic Control and the functionality via availability and data integrity is one of the critical factors for the AIS Centre. Particularly the ATC operation is highly depended from IT-Systems, technical infrastructure and there availability. The analysis shows the relevant standard requirements of availability and long-term maintenance to an AIS-System and their statistical analysis. The goal of statistical analysis is to investigate the observed parameter like availability and robustness of functionality and services. In the paper research of maintenance parameter based on the statistical analysis, and results for further operational use are discussed. The statistical analysis was used for planning process of the product management. The analysis of different incident types and their characteristics based on the collected statistical maintenance data over operational period from 2001 to 2006 was performed. The results of statistical investigation will be used for a more stabile forecasting of operational use of the system and get statistical information for the future trend and migration of a new system platform. The statistical analysis is shown the relevant requirements of ATC maintenance for long-term used IT Systems.

DROŻYNER P., MIKOŁAJCZAK P.: **Maintenance of vehicles, machines and equipment in view of the ISO9001 requirements**; EiN 4/2007, s. 55-58.

The paper describes the ISO 9001;2001 requirements related to machine operation. These are general requirements concerning the process-related approach, infrastructure, staff competence and product execution. Examples of real life approaches to the issue are presented.

PERZ K.: **Operational states of insulation in refrigerated transport of goods;** EiN 4/2007, s. 59-62.

In the paper are presented operational states of thermal insulation occurring during exploitation. The analysis of processes devastating thermo-insulation systems during operation was conducted. Also the criteria of the borderline condition of those insulations were described.

MŁYŃCZAK M.: **Queuing system with variable server number;** EiN 4/2007, s. 63-65.

Description of main characteristics of Mass Maintenance Systems is given. Problems of queuing system effectiveness due to loss of time for both arrivals while waiting for service and for servers waiting for arrivals are discussed. System with changeable number of servers is proposed. Calculations are made in order to find out what is influence of main queuing system parameters on the total operational cost regarding time losses. It is shown that decision about system structure depends mainly on system service index and server initial cost.

KOSMAN W.: **Operation of the multi-fuel cycles under off-design regime**; EiN 4/2007, s. 66-71.

The paper presents an analysis of an multi-fuel power cycle. The cycle includes a gas and steam turbine. The methods and tools are described, which allow to model the operation of the cycle in the off-design regime.

ŻÓŁTOWSKI B.: **Diagnostic system maintenance the ability of machines**; EiN 4/2007, s. 72-76.

This work presents the main descriptors of the diagnostic system machines exploitation. Determine the measure of the technical state, the boundary value and the periodicity of diagnostics. Problems and the tasks of the system of the exploitation of machines with utilization of computer techniques were distinguished on this background.

MÜLLER M.: **Maintenance success control (Key figures and controlling in maintenance)**; EiN 4/2007, s. 77-78.

The importance of maintenance has increased during the last years. Costs for maintenance are seen as valuable investments. Key figures and controlling are important instruments to make transparent both actual services and value of maintenance.

SPÖRK N.: **The way forward to excellence in maintenance**; EiN 4/2007, s. 79-80.

It is common across all industries, that most organisations are attempting to get highest profitability. To successfully manage this, adequate management procedures have to be implemented also in the field of maintenance. Independent from the level of sophistication, any organisation is operating in, there is a need for a stepwise evolution of maintenance, in case the target is excellence in maintenance.

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PLANNING INSPECTIONS IN SERVICE OF FATIGUE-SENSITIVE AIRCRAFT STRUCTURE COMPONENTS UNDER CRACK PROPAGATION

For important fatigue-sensitive structures of aircraft whose breakdowns cause serious accidents, it is required to keep their reliability extremely high. In this paper, we discuss inspection strategies for such important structures against fatigue failure. The focus is on the case when there are fatigue-cracks unexpectedly detected in a fleet of aircraft within a warranty period (prior to the first inspection). The paper examines this case and proposes stochastic models for prediction of fatigue-crack growth to determine appropriate inspections intervals. We also do not assume known parameters of the underlying distributions, and the estimation of that is incorporated into the analysis and decision-making. Numerical example is provided to illustrate the procedure.

***Keywords**: Aircraft, fatigue crack, inspection interval.*

1. Introduction

Fatigue is one of the most important problems of aircraft arising from their nature as multiple-component structures, subjected to random dynamic loads. The analysis of fatigue crack growth is one of the most important tasks in the design and life prediction of aircraft fatigue-sensitive structures (for instance, wing, fuselage) and their components (for instance, aileron or balancing flap as part of the wing panel, stringer, etc.). An example of in-service cracking from B727 aircraft (year of manufacture 1981; flight hours not available; flight cycles 39,523) [2] is given on Fig. 1.

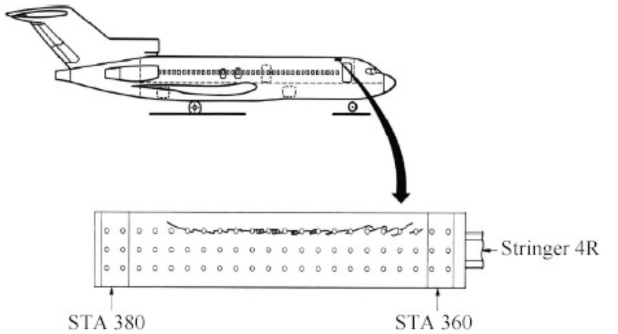

Fig. 1. Example of in-service cracking from B727 aircraft

Several probabilistic or stochastic models have been employed to fit the data from various fatigue crack growth experiments. Among them, the Markov chain model [1], the second-order approximation model [7], and the modified second-order polynomial model [6]. Each of the models may be the most appropriate one to depict a particular set of fatigue growth data but not necessarily the others. All models can be improved to depict very accurately the growth data but, of course, it has to be at the cost of increasing computational complexity. Yang's model [7] and the polynomial model [6] are considered more appropriate than the Markov chain model [1] by some researchers through the introduction of a differential equation which indicates that fatigue crack growth rate is a function of crack size and other parameters. The parameters, however, can only be determined through the observation and measurement of many crack growth samples. If fatigue crack growth samples are observed and measured, descriptive statistics can then be applied directly to the data to find the distributions of the desired random quantities. Thus, these models still lack prediction algorithms. Moreover, they are mathematically too complicated for fatigue researchers as well as design engineers.

A large gap still needs to be bridged between the fatigue experimentalists and researchers who use probabilistic methods to study the fatigue crack growth problems.

2. Problem description

Let us assume that a fatigue-sensitive component has been found cracked on *n* aircraft within a warranty period. The cracking had not yet caused an accident, but the safety experts have told the manager that had this item failed, an accident was possible. It is clear that the part would have to be redesigned and replaced. The manager's dilemma is that redesigning the part, manufacturing the new design, and installing it in the fleet would take, say, at least two years. The manager must decide how to manage risk for the next two years. The alternatives include doing nothing and accepting the risk of continued cracking and the possibility of an accident. An inspection program is usually instigated, which should reduce the risk of failure, but due to uncertainties in aircraft loading histories, provides no direct measurement of the criticality of the detected cracks. Generally, such a program would lead to some aircraft being grounded, eliminating risk for those aircraft and reducing overall risk, but reducing operational capability. This would leave precious few aircraft to spare before the service's ability to accomplish its mission became impaired. In such a scenario, the decision process involves a complex probability problem concerning the likelihood of additional failures and acceptable risk. To compound the difficulty little guidance is provided in aircraft design specifications for this situation. The situation presented is not uncommon.

The purpose of this paper is to present a more accurate stochastic crack growth analysis method, while maintaining the simplicity of the proposed stochastic fatigue models, for the above problem. We discuss the optimal relationship between the inspection time and the prespecified minimum level of reliability. To illustrate the proposed technique, a numerical example is given.

3. Paris-Erdogan law as a starting point

The basis of most of the fatigue models is the Paris-Erdogan law [5] relating the rate of growth of crack size a to N cycles:

$$\frac{da(N)}{dN} = q[a(N)]^b \tag{1}$$

in which q and b are parameters depending on loading spectra, structural/material properties, etc. We fit da/dN vs $a(N)$ with a function that we can integrate between limits (initial crack size, a_0, and any given crack size, a) to get a life prediction.

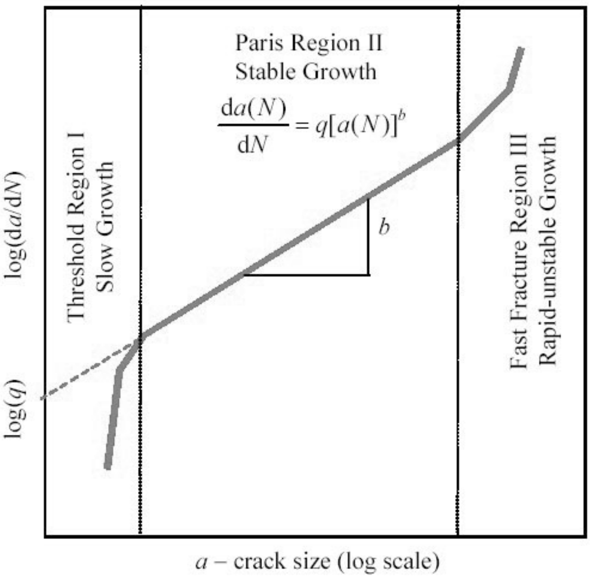

Fig. 2. Crack growth rate versus crack size curve; (I = near-threshold region; II = linear region; III = instability region)

In the linear region (see Fig. 2) we use the Paris-Erdogan Equation (1) as follows. Integrating:

$$\int_{N_0}^{N} dN = \int_{a_0}^{a(N)} \frac{da}{qa^b} \tag{2}$$

we have:

$$N - N_0 = \frac{1}{q(-b+1)}\left[a(N)^{-b+1} - a_0^{-b+1}\right] \tag{3}$$

Thus, the crack growth equation representing the solution of the differential equation for the Paris-Erdogan law is given by

$$N - N_0 = \frac{1}{q(b-1)}\left(\frac{1}{a_0^{b-1}} - \frac{1}{a(N)^{b-1}}\right) \tag{4}$$

3.1. Sensitivity analysis

Consider the solution of the differential equation for the Paris-Erdogan law written in the form of (4) as:

$$N(a) = \frac{1}{q(b-1)}\left(\frac{1}{a_0^{b-1}} - \frac{1}{a^{b-1}}\right) \tag{5}$$

where a_0 is the initial crack size at N_0=0. The derivatives of the number of load cycles with respect to the parameters q and b read:

$$\frac{dN(a)}{dq} = -\frac{N(a)}{q} \tag{6}$$

and

$$\frac{dN(a)}{db} = \frac{1}{b-1}\left[\frac{1}{q}\left(\frac{\ln a}{a^{b-1}} - \frac{\ln a_0}{a_0^{b-1}}\right) - N(a)\right] \tag{7}$$

From this one can see that the number of cycles to reach a certain crack size is very sensitive to changes of the parameter q.

4. Statistical variability of fatigue-crack growth

The traditional analytical method of engineering fracture mechanics (EFM) usually assumes that crack size, stress level, material property and crack growth rate, etc. are all deterministic values which will lead to conservative or very conservative outcomes. However, according to many experimental results and field data, even in well-controlled laboratory conditions, crack growth results usually show a considerable statistical variability (as shown in Fig. 3).

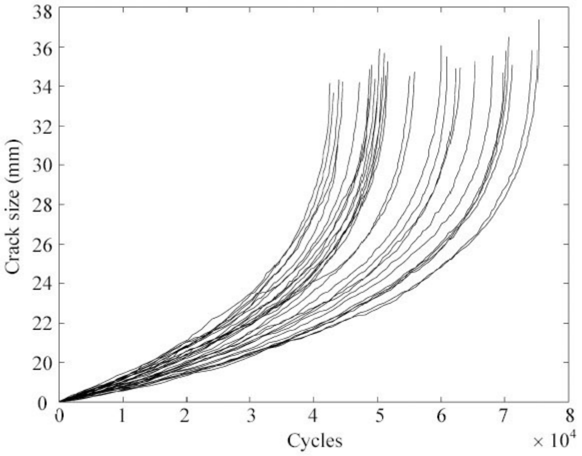

Fig. 3. Constant amplitude loading fatigue test data curves

Yet more considerable statistical variability is the case under variable amplitude loading (as shown in Fig. 4).

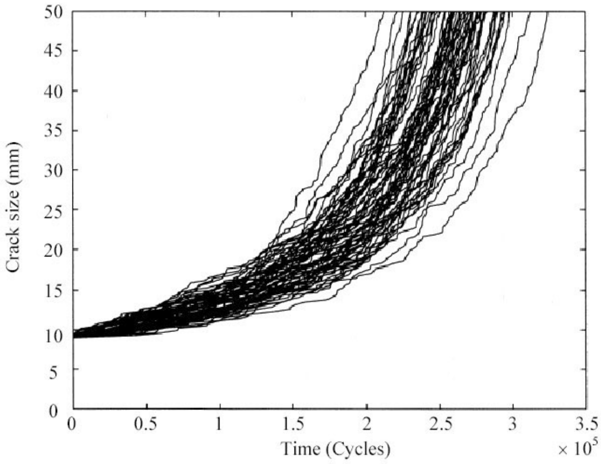

Fig. 4. Variable amplitude loading fatigue test data curves

The basis of most data analyses seems to be to take logarithms in (1) and estimate b and q by least squares in the equation:

$$\ln(da(N)/dN) = \ln q + b \ln a(N) \tag{8}$$

Unfortunately to use this equation estimates of $da(N)/dN$ are required. Estimates of derivatives are notoriously unreliable. If several repetitions of an experiment under the same conditions are made it is not always clear how to combine the results. Moreover, as a regression model the properties of the estimates of the coefficients in (8) are not the same as those of estimates of the coefficients in (4). Thus it is sensible to ask why the estimation does not proceed directly from the data on crack size and cycles through equation (4).

It is interesting to note that if b were known q could be estimated from a straight line:

$$\frac{1}{a_0^{b-1}} - \frac{1}{a^{b-1}} = \left(b-1\right)q(N-N_0) \tag{9}$$

and indeed such a plot for a few values of q is indicative of the nature of the Paris-Erdogan equation in a particular case.

During the service of the components being assessed, there may be uncertainties in the applied loading conditions, extrapolation of the material data to service conditions, component dimensions, and nature, size and location of detected (postulated) defects, etc. These uncertainties/ variations are critical inputs to the crack growth assessment and can be taken into account using probabilistic methodologies. There is now an extensive literature on the subject of the statistical nature of crack growth. Most of the literature is concerned with model building and the agreement between the general features of the model and the observed behaviour of the crack. However, little use has been made of the statistical nature of the models to analyze experimental results.

While most industrial failures involve fatigue, the assessment of the fatigue reliability of industrial components subjected to various dynamic loading situations is one of the most difficult engineering problems that remains. Material degradation processes due to fatigue depend upon material characteristics, component geometry, loading history and environmental conditions. As a result, stochastic models for crack growth have been suggested by many investigators in the last 15 years. These include evolutionary probabilistic models, cumulative jump models and differential equation (DE) models. DE models are the most widely used models for predicting stochastic crack growth accumulation in the reliability and durability analyses of fatigue critical components.

In practical applications of the stochastic crack growth analysis, either one of the following two distribution functions is needed: the distribution of the crack size at any service time or the distribution of the service time to reach any given crack size. Unfortunately, when the crack growth rate is modelled as a random process, these two distribution functions are not amenable to analytical solutions. As a result, numerical simulation procedures have been used to obtain accurate results. The simulation approach is a very powerful tool; in particular, with modern high-speed computers. However, it is a very time consuming procedure and therefore simple approximate analytical solutions are very useful in engineering.

The purpose of this paper is to present a more useful stochastic fatigue crack growth models by using the solution of the Paris-Erdogan law equation, which result in a simple analytical solution for either the distribution of the service time to reach any given crack size or the distribution of the crack size at any service time.

The probability that crack size $a(N)$ will exceed any given crack size $a^{\bullet}$ in the service interval $(N_0, N^{\bullet})$, $\Pr\{a(N^{\bullet}) > a^{\bullet}\}$, is frequently referred to as crack exceedance probability and can be found based on the stochastic fatigue crack growth model. In addition to this probability distribution of crack size, the probability distribution of cycles (or time) for a crack to grow from size a_0 to $a^{\bullet}$, $\Pr\{N(a^{\bullet}) \le N^{\bullet}\}$, can also be found based on the above model. In fact, the probability that service time $N(a^{\bullet})$ will be within the interval $(N_0, N^{\bullet})$ for crack size to reach $a^{\bullet}$ is identical to $\Pr\{a(N^{\bullet}) > a^{\bullet}\}$. That is $\Pr\{N(a^{\bullet}) \le N^{\bullet}\} = \Pr\{a(N^{\bullet}) > a^{\bullet}\}$. To summarize the concept of the above derivation, the readers can refer to Fig. 5.

5. Stochastic fatigue-crack growth parameter variability models

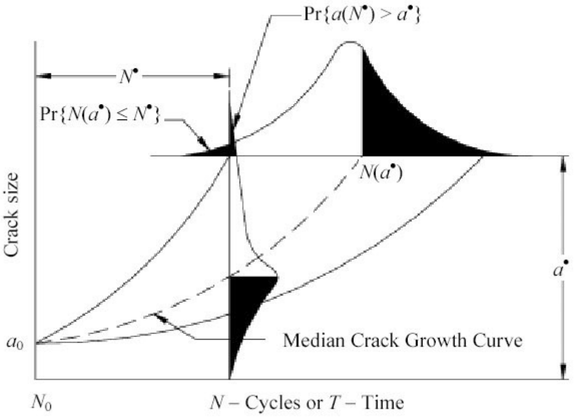

Fig. 5. Schematic diagram of crack size distribution and random time distribution

These models allow one to describe the uncertainties in one or two parameters of the solution (4) of the differential equation (1) for the Paris-Erdogan law via parameters modelled as random variables in order to characterize the random properties, which seem to vary from specimen to specimen (see Fig. 3). In other words, the stochastic fatigue-crack growth parameter variability models (with respect to the parameters b and q modelled as random variables) are given by:

$$N - N_0 = \frac{1}{Q\left(B-1\right)}\left(\frac{1}{a_0^{B-1}} - \frac{1}{a^{B-1}}\right) \tag{10}$$

where $(N{-}N_0)$ is a joint random variable of B and Q. In fact, these models are suited to account for this type of variability. The ones however cannot explain the variability of the crack growth rate during the crack growth process. In particular, crack growth data (crack size versus service time and vice versa) may been analyzed using Eq. (10) by considering, for instance, two different approaches:

(i) B is identical for each specimen and Q varies from specimen to specimen, referred to as Case 1;

(ii) both B and Q vary from specimen to specimen, referred as Case 2.

For Case 1, with B=1, the crack growth data for each specimen are best fitted by equation:

$$N - N_0 = \frac{ln\left[\dfrac{a(N)}{a(N_0)}\right]}{Q} \tag{11}$$

to obtain a sample value of Q, where $a(N) \equiv a$, $a(N_0) \equiv a_0$. For Case 2 equation (10) is used to best fit the crack growth data for each specimen to obtain a set of sample values of B and Q. From the statistical standpoint, B is considered to be a deterministic value and Q to be a statistical (random) variable in Case 1, while both B and Q are considered to be statistical variables in Case 2. It is found that the lognormal or Weibull distribution provides a reasonable fit for B and Q in both cases.

5.1. Weibull crack growth parameter variability model

Consider Case 1. The Weibull probability distribution function, $F(q;\sigma,\delta)$, of Q is expressed as:

$$F(q;\sigma,\delta)=\begin{cases}1-exp[-(q/\sigma)^{\delta}], & q\geq 0,\\ 0, & \text{otherwise},\end{cases} \tag{12}$$

in which $F(q;\sigma,\delta)$ is the probability that Q is smaller than or equal to an arbitrary value q; σ and δ are distribution parameters representing the scale parameter and the shape parameter, respectively.

5.2. Crack exceedance probability

For B=1, the probability that crack size $a(N)$ will exceed any given (say, maximum allowable) crack size $a^{\bullet}$ can be derived and expressed as:

$$Pr\{a(N)>a^{\bullet}\}=Pr\left\{Q>\frac{ln[a^{\bullet}/a(N_0)]}{N-N_0}\right\}=$$

$$=exp\left[-\left(\frac{ln[a^{\bullet}/a(N_0)]}{\sigma(N-N_0)}\right)^{\delta}\right] \tag{13}$$

For B=b≠1 the maximum allowable crack size exceedance probability for a single crack is given by:

$$Pr\{a(N)>a^{\bullet}\}=Pr\left\{Q>\frac{[a(N_0)]^{-(b-1)}-[a^{\bullet}]^{-(b-1)}}{(b-1)(N-N_0)}\right\}=$$

$$=exp\left[-\left(\frac{[a(N_0)]^{-(b-1)}-[a^{\bullet}]^{-(b-1)}}{\sigma(b-1)(N-N_0)}\right)^{\delta}\right] \tag{14}$$

It will be noted that the crack exceedance probability can be used for assigning sequential in-service inspections [4].

6. Stochastic fatigue-crack growth lifetime variability models

These models allow one to characterize the random properties, which seem to vary during crack growth (see Fig. 4), via crack growth equation with a stochastic noise V dependent, in general, on the crack size a:

$$\frac{1}{(b-1)q}\left(\frac{1}{a_0^{b-1}}-\frac{1}{a^{b-1}}\right)=N-N_0+V \tag{15}$$

$$ln\left(\frac{1}{(b-1)q}\left(\frac{1}{a_0^{b-1}}-\frac{1}{a^{b-1}}\right)\right)=ln(N-N_0)+V \tag{16}$$

$$\frac{1}{a_0^{b-1}}-\frac{1}{a^{b-1}}=(b-1)q(N-N_0)+V \tag{17}$$

$$ln\left(\frac{1}{a_0^{b-1}}-\frac{1}{a^{b-1}}\right)=ln[(b-1)q(N-N_0)]+V \tag{18}$$

and so on, where $V\sim N(0,\sigma^2(b,q,N))$, $a_0\equiv a(N_0)$, $a\equiv a(N)$. They are suited to account for this type of variability. The ones however cannot explain the variability of the crack growth rate from specimen to specimen.

6.1. Crack exceedance probability

If $V\sim N(0,\sigma^2)$ in (15), then the probability that crack size $a(N)$ will exceed any given (say, maximum allowable) crack size $a^{\bullet}$ can be derived and expressed as:

$$Pr\{a(N)>a^{\bullet}\}=\Phi\left(\left[N-N_0-\frac{[a_0]^{-(b-1)}-[a^{\bullet}]^{-(b-1)}}{(b-1)q}\right]\Big/\sigma\right) \tag{19}$$

where $\Phi(.)$ is the standard normal distribution function,

$$\Phi(\eta)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\eta}exp(-x^2/2)dx \tag{20}$$

If $V\sim N(0,[(b-1)\sigma(N-N_0)^{1/2}]^2)$ in (17), then the probability that crack size $a(N)$ will exceed any given (say, maximum allowable) crack size $a^{\bullet}$ can be derived and expressed as:

$$Pr\{a(N)>a^{\bullet}\}=\Phi\left(\left[\frac{(b-1)q(N-N_0)-([a_0]^{-(b-1)}-[a^{\bullet}]^{-(b-1)})}{(b-1)\sigma(N-N_0)^{1/2}}\right]\right) \tag{21}$$

In this case, the conditional probability density function of a is given by:

$$f(a;a_0,N_0,N)=\frac{a^{-b}}{\sigma[2\pi(N-N_0)]^{1/2}}\cdot$$

$$\cdot exp\left(-\frac{1}{2}\left[\frac{(a_0^{-(b-1)}-a^{-(b-1)})-(b-1)q(N-N_0)}{(b-1)\sigma(N-N_0)^{1/2}}\right]^2\right) \tag{22}$$

6.2. Data analysis for a single crack

Consider the regression model corresponding to (17). Because the variance is non-constant (17) is a non-standard model; however, on dividing by $(N-N_0)^{1/2}$ the model becomes:

$$\frac{a_0^{1-b}-a^{1-b}}{(N-N_0)^{1/2}}=(b-1)q(N-N_0)^{1/2}+W \tag{23}$$

where W is normally distributed with mean zero and standard deviation $(b-1)\sigma$ independent of N. Thus if b is known the estimator of $(b-1)$q is just the least-squares estimator of the coefficient in Equation (23) and the estimate of $(b-1)\sigma$ is just the estimate of the variance of the regression. It remains to determine what to do about b.

Given the data describing a single crack, say a sequence $\{(a_i,N_i)\}_{i=1}^{n}$, it is easy to construct a log-likelihood using the density given by (22) and estimate the parameters b, q and σ by maximum likelihood. The log-likelihood is:

$$L(b,q,\sigma;\{(a_i,N_i)\}=-b\sum_{i=1}^{n}ln\,a_i-n\,ln\,\sigma-$$

$$-\frac{1}{2}\sum_{i=1}^{n}\left(\frac{a_0^{1-b}-a_i^{1-b}-(b-1)q(N_i-N_0)}{(b-1)\sigma(N_i-N_0)^{1/2}}\right)^2 \tag{24}$$

Inspection shows that this differs from the standard least-squares equation only in the term $-b\sum\ln a$, where the subscript i has been dropped. The likelihood estimators are obtained by solving the equations:

$$dL/db=0;\quad dL/dq=0;\quad dL/d\sigma=0 \tag{25}$$

In this case the equations have no closed solution. However, it is easy to see that the estimators for q and σ given b are the usual least-squares estimators for the coefficients in (23) conditioned on b,

$$\hat{q}(b) = \frac{1}{b-1}\left(n a_0^{1-b} - \sum_{i=1}^{n} a_i^{1-b} \right)\left(\sum_{i=1}^{n} (N_i - N_0) \right)^{-1} \qquad (26)$$

$$\hat{\sigma}^2(b) = \frac{1}{n(b-1)^2} \sum_{i=1}^{n} \frac{[a_0^{1-b} - a_i^{1-b} - \hat{q}(b)(b-1)(N_i - N_0)]^2}{N_i - N_0} \qquad (27)$$

and on substituting these back in the log-likelihood gives a function of b alone,

$$L(b) = -b \sum_{i=1}^{n} ln\, a_i - n\, ln[\hat{\sigma}(b)] - n/2 \qquad (28)$$

Thus the technique is to search for the value of b that maximizes $L(b)$ by estimating q and σ as functions of b and substituting in $L(b)$. In this study a simple golden-section search worked very effectively.

6.3. Pooling data

When several experiments have been performed it is possible to combine the log-likelihoods from each experiment to give estimators of the parameters of interest. Suppose that several experiments have been performed. Each experiment is labelled with j, j runs from 1 to m, and yields n_j observations. The data are then a set of sequences $\{(a_{jk}, Njk)\}$, with $j=1, \ldots, m$, $k=1, \ldots, n_j$. The log-likelihood for the whole set of experiments is simply the sum of the log-likelihoods for the individual cracks; writing $L_j(b_j, q_j, \sigma_j)$ for the log-likelihood for the jth crack gives:

$$L_j(b_j, q_j, \sigma_j; \{(a_{jk}, N_{jk})\}) = -b_j \sum_{k=1}^{n_j} ln\, a_{jk} - n_j\, ln\, \sigma_j - $$

$$- \frac{1}{2} \sum_{k=1}^{n_j} \left(\frac{a_0^{1-b_j} - a_k^{1-b_j} - (b_j - 1) q_j (N_k - N_0)}{(b_j - 1)\sigma_j (N \; - N_0)^{1/2}} \right)^2 \qquad (29)$$

and

$$L = \sum_{j=1}^{m} L_j(b_j, q_j, \sigma_j; \{(a_{jk}, N_{jk})\}) \qquad (30)$$

The global log-likelihood can be used to investigate explicit parametric models for the parameters, or simply as a way to pool data. Estimation by maximum likelihood proceeds exactly as above; the q_j and σ_j are obtained as ordinary least-squares estimators from equations like (26) and (27), one for each crack, and substituted back into the log-likelihood to yield:

$$L(b_1, b_2, \ldots, b_m) = -\sum_{j=1}^{m} b_j \sum_{k=1}^{n_j} ln\, a_{jk} - \sum_{j=1}^{m} n_j\, ln[\hat{\sigma}_j(b_j)] - \frac{1}{2}\sum_{j=1}^{m} n_j \qquad (31)$$

When the cracks are all assumed to be independent with distinct parameters the estimators from the joint log-likelihood are precisely those obtained by estimating from each separately as outlined above.

If a common value of b is used and the q_j and σ_j are assumed to absorb most of the experimental variability, the joint log-likelihood reduces to:

$$L(b) = -b \sum_{j=1}^{m} \sum_{k=1}^{n_j} ln\, a_{jk} - \sum_{j=1}^{m} n_j\, ln[\hat{\sigma}_j(b)] - \frac{1}{2}\sum_{j=1}^{m} n_j \qquad (32)$$

7. Stochastic fatigue-crack growth parameter and lifetime variability models

These models allow one to describe the uncertainties in the fatigue-crack growth of the Paris-Erdogan law via crack growth equation with a stochastic noise dependent, in general, on the crack size, and parameters modelled as random variables in order to characterize the random properties, which seem to vary both from specimen to specimen and during crack growth (see Fig. 4). In other words, the stochastic fatigue-crack growth parameter and propagation lifetime variability model (with respect to the parameters B and Q, modelled as random variables, and the stochastic noise V dependent, in general, on the crack size a) may be given, for example, as:

$$N - N_0 = \frac{1}{(B-1)Q}\left(\frac{1}{a_0^{B-1}} - \frac{1}{a^{B-1}} \right) + V \qquad (33)$$

7.1. Crack exceedance probability

In this case, the probability that crack size $a(N)$ will exceed any given (say, maximum allowable) crack size $a^\bullet$ can be derived and expressed as:

$$Pr\{a(N) > a^\bullet\} = E\left\{ exp\left[-\left(\frac{[a(N_0)]^{-(b-1)} - [a^\bullet]^{-(b-1)}}{\sigma(b-1)(N - N_0 + V)} \right)^{\delta} \right] \right\} \qquad (34)$$

8. Example

Let us assume that a fatigue-sensitive component has been found cracked on $n=10$ aircraft within a warranty period. Here a fleet of ten aircraft have all been inspected.

Tab. 1. Inspection results

Aircraft	*Flight hours (N_i)*	*Crack size (mm) (a_i)*
1	*3000*	*1*
2	*2300*	*0.5*
3	*2200*	*1*
4	*2000*	*2*
5	*1500*	*0.8*
6	*1500*	*1.5*
7	*1300*	*1*
8	*1100*	*1*
9	*1000*	*1*
10	*800*	*1*

It is assumed that cracks start growing from the time the aircraft entered service. For typical aircraft metallic materials, an initial discontinuity size (a_0) found through quantitative fractography is approximately between 0.02 and 0.05 mm. Choosing a typical value for initial discontinuity state (e.g., 0.02 mm) is more conservative than choosing an extreme value (e.g., 0.05 mm). This implies that if the lead cracks can be attributed to unusually large initiating discontinuities then the available life increases.

We test a goodness-of-fit of the data of Table 1 with the Weibull fatigue-crack growth parameter variability model (see Case 1), where:

$$\hat{Q}_i(b) = \frac{a_0^{1-b} - a_i^{1-b}}{(b-1)(N_i - N_0)}, \quad i = 1(1)n \qquad (35)$$

with a common value of b, $a_0=0.02$, and $N_0=0$.

8.1. Goodness-of-Fit Testing

We assess the statistical significance of departures from the Weibull model by performing empirical distribution function goodness-of-fit test. We use the S statistic [3]. For complete datasets, the S statistic is given by:

$$S(b)=\frac{\sum\limits_{i=[n/2]+1}^{n-1}\left(\frac{ln(\hat{Q}_{i+1}(b)/\hat{Q}_i(b))}{M_i}\right)}{\sum\limits_{i=1}^{n-1}\left(\frac{ln(\hat{Q}_{i+1}(b)/\hat{Q}_i(b))}{M_i}\right)}=0.43 \qquad (36)$$

where $[n/2]$ is a largest integer $\le n/2$, $\hat{Q}_i$ is the ith order statistic, the values of M_i are given in Table 13 [7]. The rejection region for the α level of significance is $\{S>S_{n;1-\alpha}\}$. The percentage points for $S_{n;1-\alpha}$ were given in [3]. The value of b is one that minimizes $S(b)$. For this example, $b = 0.87$ and

$$S=0.43 < S_{n=10;\ 1-\alpha=0.95}=0.69 \qquad (37)$$

Thus, there is not evidence to rule out the Weibull model. Using the relationship (4), the inspection results can be extrapolated from the expected initial crack size, a_0, to the time of the next inspection when the maximum allowable crack size is equal to $a^{\bullet}$=10 mm as presented in Table 2.

Table 2: Predicted next inspection results

Aircraft	Maximum allowable crack size $a^{\bullet}$ (mm)	Next inspection time (flight hours)
1	10	5626
2	10	5503
3	10	4126
4	10	3033
5	10	3030
6	10	2477
7	10	2438
8	10	2063
9	10	1875
10	10	1500

9. Conclusions

The authors hope that this work will stimulate further investigation using the approaches on specific applications to see whether obtained results with it are feasible for realistic applications.

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DURABILITY OF ENGINE COMPONENTS DUE TO ALTERNATIVE FUELS

Shortage of crude oil gives the reason to look for alternative engine fuels. Some of them are well known like: gas-fuels - LPG, CNG, LNG, bio-fuels - RME, B10, B20 etc. or very future like hydrogen. There are many problems to solve being sure that they are actual alternative fuels – engine efficiency, ecology, emission. Among of them, the durability of engine due to different fuel is the crucial point of many research discussion. The paper includes info about: durability of technical object, combustion engine as a technical system, engine fuels and their features and example of engine wear performance due to rape methyl ester fuel, natural gas fuel experience, hydrogen thermodynamic effect and small case of prediction of life time.

Keywords*: Combustion engines, durability, alternative fuels.*

1. Introduction

Over 97% of world amount of vehicles are driven by internal combustion engines feeding with fuels made of crude oil. Unfortunately resources of petroleum will run out in the nearly 40 years [8]. Besides, operation of combustion engine gives pollutions, dangerous for human and animal as well as does greenhouse effect. In Europe, road traffic accounts for average 25% of total countries' carbon dioxides emissions. So, it has been necessary to looking for alternative drive system for cars. One of the solution is to use the same combustion engines but running on different fuels. There is well known gas composition propane-butane, called LPG (Liquefied Petroleum Gas), but it is manufactured from crude oil (40% of world production), it means it depends on petroleum. The another gas fuel is natural gas in the form of CNG (Compressed Natural Gas) or LNG (Liquefied Natural Gas). Huge popularity in South America and Asia has got alcohols as engine fuels. The last ten years showed biofuels (fuels made of organic compounds) as alternative to standard fuels. In Poland Rapeseed Methyl Ester has been still discussed. At the end hydrogen – as the cleanest fuel and without problem of resources.

Various fuels need verification of engine design due to mechanical and thermal loads, chemical influences and durability of engine components. In this paper was trying to show problems of durability of engine due to alternative fuels – fig. 1.

2. Durability of technical object

The basic importance to sensible operation of technical object has got the knowledge of its failures. It is forced on designing and manufacturing processes, too. Failure, understood as a limiting state of object can be dangerous for human life or/and does financial losses. The ability to fulfill required function is called dependability [10]. It covers some features of object as follows: availability, reliability, maintainability, safety, service and durability. The durability is an important tie in dependability chain – fig. 2.

Durability is defined as a ability of an entity to remain able to perform a required function under conditions of use and maintenance until a limiting state is reached. Durability of technical object is measured by time factor or quantity of work until failure is reached. Next, measure of work can be wear level or wear intensity of part of object. The durability diagrams wear versus time or mileage are built. For different object or for different systems inside of the same technical object can be found various schemes – fig. 3.

3. Combustion engine as a technical object – structure and function

Internal combustion engine is a heat machine inside of it fuel energy is transformed to mechanical during heat process of combustion. Combustion engine is a complex machinery in which there are constructional and functional sets. It means that there are systems with the individual objectives to realize but subordinate main goal of getting mechanical power. Knowledge of systems' structure and components performance gives the possibility to design, manufacture and operate engine in right way. It can be useful to predict a durability of machinery, too.

Internal combustion engine is divided into some level of constructional structure. Each of them does specific function. Design structure of combustion engine as a technical object is shown on figure 4 [15].

Level n^{o}1 means whole engine as a technical object consists of many subsystems building level n^{o}2. Each of sets from level two can be functioned as separate one and creates next levels of decomposition - fig. 5 [15].

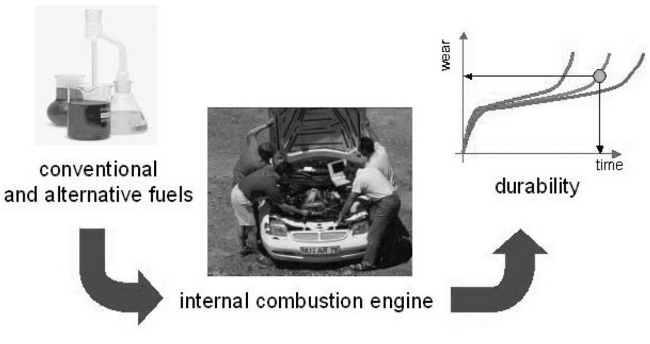

Fig. 1. Durability of engine components due to different fuels – problem outline

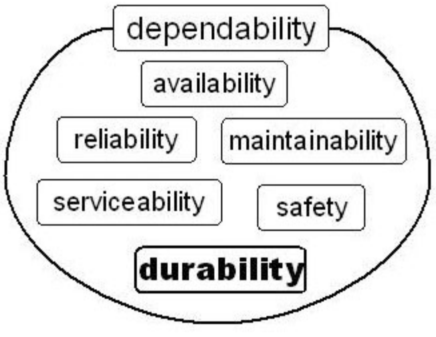

Fig. 2. Durability circumstance

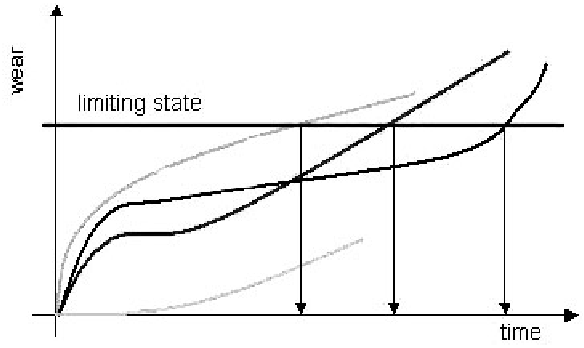

Fig. 3. Examples of durability diagrams

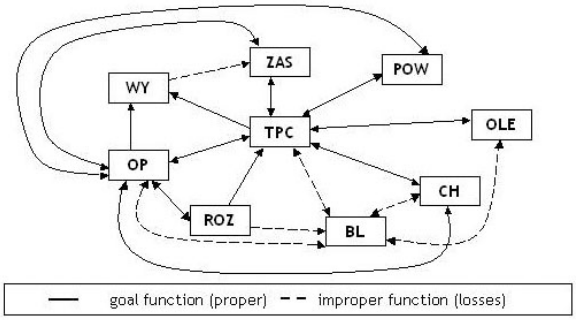

Fig. 6. Structure of functional subsystem for constructional sets of feeding and piston-rings-cylinder

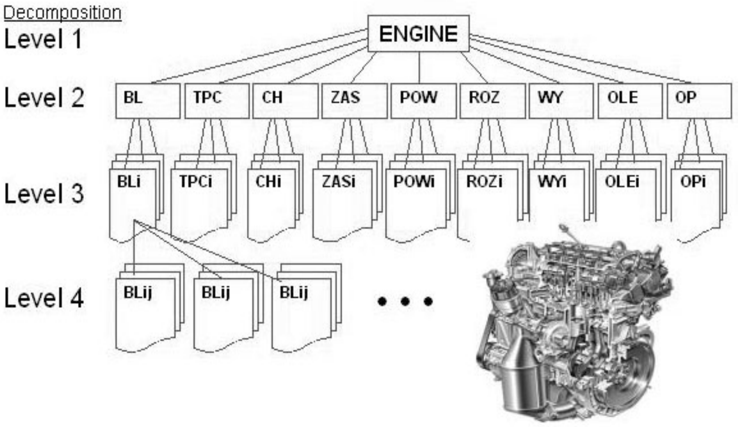

Fig. 4. Lay-out of open constructional system of combustion engine: BL – block of engine, TPC – piston-rings-cylinder, CH – cooling, ZAS – fuelling, POW – air supply, ROZ – valve timing, WY – exhaust, OLE – lubrication, OP – additives and control unit

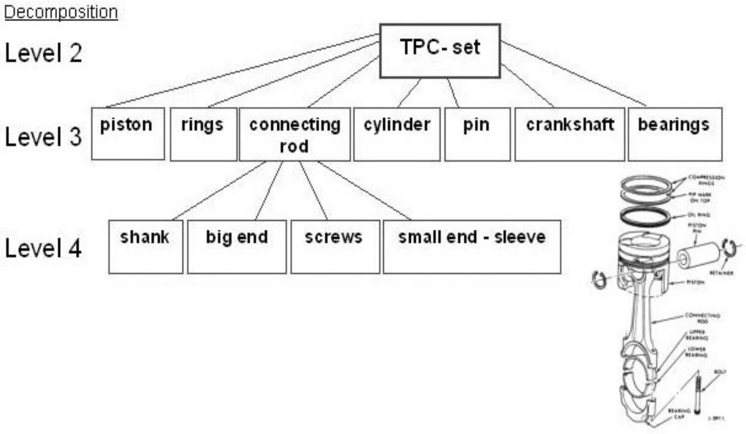

Fig. 5. Structure of open constructional system of piston-rings-cylinder set

The last level of the system structure is an element it means components which is the smallest – separate part (without of any another inside of it). But, the newest scientific achievements treat the smallest part as a system with atomic bonds, where it can be friction, too. Because of this structure like mentioned above are open and to analyze it can be taken only that level which is necessary.

There are functional dependability between constructional structure in engine. It means that functional system also exists. The main goal is to reach mechanical power with as high efficiency as possible. Function can be proper (working process) or improper (losses). Functional structure for feeding system is shown on fig. 6 as an example [15]. The right function is air and fuel feeding to combustion chamber through inlet manifold and fuel set to move piston and crankshaft from subsystem piston-rings-cylinder. Dynamics of combustion process caused vibration in block of engine. Improper functions in this case are vibrations and deflection of block.

4. Fuels for combustion engines

Combustion engines need fuel keeping chemical energy transferred to the useful work. There three typical group of fuels as follows:
- gasoline (petrol),
- diesel oil (petrodiesel),
- alternative fuels.

4.1. Gasoline

Gasoline (petrol) is a complex blend of carbon and hydrogen compounds as a products of crude oil distillation. Ii is used to run spark ignition engines. To improve performance some additives are added, different for different manufacturers. Because of this all gasoline are basically the same, but no two blends are identical. There are two important features of gasoline as follows: volatility and resistance to knock (octane). Volatility is a measurement of how easily the fuel vaporizes. If the gasoline does not vaporize completely, it will not burn properly. Resistance to knock is simply the temperature the gas will burn at. Higher octane required a higher temperature to burn. Following the relation between compression ratio and pressure inside combustion chamber if they increase so does the need for higher octane fuel [4, 7].

4.2. Diesel oil

Diesel fuel, just as gasoline is a complex blend of carbon and hydrogen and is produced from crude oil in a process called frictional distillation. In general, diesel is simpler to refine than gasoline. Since diesel oil vaporizes at a much higher temperature than gasoline, there is no need for a fuel evaporation control system as with gasoline. Diesel fuels are rated with a cetane number, which includes the ease at which the fuel will ignite [4, 19].

4.3. Alternative fuels

Alternative fuels are combustion engines' fuels that are not made of petroleum. There are many kinds of fuels that vehicles can run on as follows [4, 7, 8, 19]:
- alcohols – ethanol and methanol,
- biodiesel – just a diesel but made of plant oil or animal fat,
- LPG – Liquefied Petroleum Gas (called propane) – hydrocarbons gases under low pressure,
- natural gas in the form of CNG (Compressed Natural Gas – under high pressure) and LNG (Liquefied Natural Gas - under deep low temperature),
- hydrogen,
- Liquids made of coal.

Alcohols (methanol and ethanol) have been popular alternative fuels for many years. In fact, first car made in Ford factory was fuelled with alcohol. Both ethanol and methanol are used as transportation fuels especially in South America and Asia. Ethanol is general made of corn (grain) but it can be made of biomass – organic materials, which includes agricultural crops and waste, plant material left from logging and trash including cellulose. Ethanol is in alcoholic beverages, however it is denatured, which means people can not drink it. The second alcohol – methanol, can be made of biomass resources like wood as well as coal. Today methanol is made of natural gas because it is cheaper. Alcohols, as a engine fuels are used in pure stare or as blends e.g. E85 (85% of ethanol and 15% of gasoline). Combustion engine run on alcohols are specially designed to tolerate the corrosive nature of these kind of fuels.

Biodiesel is a lot like diesel oil but made of vegetable oil or animal fat. Biodiesel keep various states as follows: regular vegetable oil (pure oil – not so popular) or ester or blend ester with diesel. Biodiesel is biodegradable though, so it is much less harmful to the environment if spilled. Biodiesel is made in a process called transesterification. Vegetable oil or animal fat are changed to esterified oil. There is RME – Rape Methyl Ester fuel for diesel engine in Poland, for example. Ordinary diesel engine can operate on biodiesel.

LPG – Liquefied Natural Gas is a natural hydrocarbon fuel made of mixture of propane and butane. It has the special property of becoming liquid when under pressure and reverting to gases at atmospheric pressure. This means it can be easily and conveniently stored as a liquid in tank under the not so high pressure (about 1,4 MPa). 250 times denser as a liquid than a gas mix, means that LPG can be stored in relatively small space. About 60% of the world production of LPG comes from separation natural gas but the rest is a by-product from refining of crude oil. Because of this 40% some researchers could not say about LPG – alternative so it need crude oil for production.

CNG – Compressed Natural Gas is a natural gas under high pressure. Like crude oil natural gas comes from underground. It is one of the most environmental friendly fuels and because of this it popularity is growing. Natural gas is mostly made of methane (70-95%) Simple molecular structure of methane (CH_4) makes possible its nearly complete combustion. This gas is stored under high pressure up to 20 MPa.

LNG – Liquefied Natural Gas is a natural gas that is very cold, because it is made by refrigerating (minus 160 Celsius degree) to condense it into a liquefied state. The liquid form is much dense than natural gas which means much more energy for the amount of space it takes up. That means LNG is a popular fuel for large trucks that need to go a long distance before they stop for more fuel. It is popular in North America and Canada.

Hydrogen – for many scientists it is the fuel of the future. It is number one on the periodic chart of element and the lightest of all elements. It is easy to produce through electrolysis from water or from natural gas. Because hydrogen burns nearly pollution-

Tab. 1. Chemical and physical features of engine fuels [3, 17, 19]

Features	Gasoline	Diesel	Biodiesel	Natural Gas	Alcohols	Hydrogen
Molecular weight, kg/kmol	100-110	105-200	110-220	16-18	32-46	2,02
Density, kg/m^3	720-760	820-880	880-920	460-570	788-795	0,09
Calorific value, MJ/kg	42-44	42-46	37-42	45-50	19-27	120
Composition wt. %						
Carbon	85-88	84-87	75-79	75	52	0
Hydrogen	12-15	13-16	11-13	25	13	100
Oxygen	0	0	10-11	0	35	0
Sulfur	0	0,01-0,05	0,001	0	0	0

free it has been looked at as the ultimate clean fuel. Hydrogen burns to the heat and water vapor. Trace of hydrocarbons or/and nitrogen oxides in exhaust gases belongs to the oil lubrication and nitric in air. The main problem of using hydrogen as a fuel is to storage – because of leakage (the smallest element). While only experimental vehicles are operating in this fuel now, the potential for this unique energy source is excellent [17].

Liquids from coal are gasoline and diesel fuels that do not come from petroleum.

Just like oil and natural gas, coal is a non-renewable, fossil fuel fored in the erth from what was once living plants. Being the solid, coal is not easy to use as a transportation fuel. However there are ways to make gasoline, diesel, methanol, and other chemicals from coal. In the table n°1 below, some features of engine fuels are included.

5. Engine performance due to fuel

Theory of combustion engine shows close relation to the fuel, of course. Analyses of thermodynamics of combustion engine as a heat machine and then determinations of thermal and mechanical loads of engine components start from Clapeyron formula (1):

$$pV = Tbn_1MR \tag{1}$$

status: p - pressure of charge (mixture fuel and air), V- volume of combustion space, T- absolute temperature of charge, b - actual factor of charge moles changing, n_1- total number of moles of charge just before compression, MR- universal gas constant.

A number of kilograms of fresh air to burn portion of one kilogram of fuel depends on fuel's composition according to formula (2):

$$M_t = \left(\frac{1}{0,23}\right)\left(\frac{8}{3}C + 8H - O\right) \tag{2}$$

status: C, H, O – mass fractions in the fuel of carbon, hydrogen, oxygen (respectively).

Thermal load of engine can be defined as a heat flux released inside engine under given operating conditions (3) [1, 2]:

$$Q = W_pB_o\xi \tag{3}$$

status: W_p- fuel calorific value, B_0- fuel consumption in time unit, ξ - heat release rate inside combustion chamber.

And the another example of combustion engine theory given by formula of effective efficiency – also depending on fuel (4):

$$\eta_o = \left(\frac{N_e}{G_eW_p}\right) \tag{4}$$

status: η_o – effective efficiency of engine, N_e – effective power, G_e – fuel consumption, W_p – calorific value of fuel.

This short presentation, mentioned above shows a fuel as a one of the basic link to describe mechanical, thermal and chemical loads of engine and to define its durability.

Depends on the type of fuel it can be reach various p-V diagrams and temperature changing – fig. 7.

The results of thermodynamics changing can be changing in mechanical and thermal loads – some example on fig. 8 and 9.

The features of fuel decide on chemical processes like for example corrosive range of effect of sulfur in fuel – fig. 10.

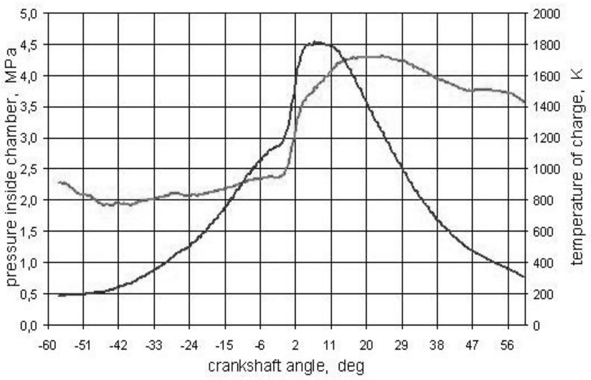

Fig. 7. An example of p-V diagrams and temperature curves

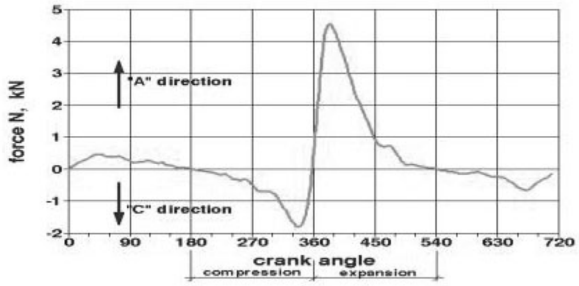

Fig. 8. Changing of normal force in piston-cylinder set

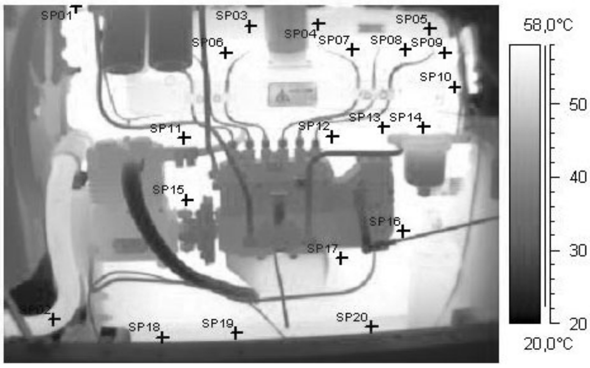

Fig. 9. Thermal load of engine – thermo vision camera view

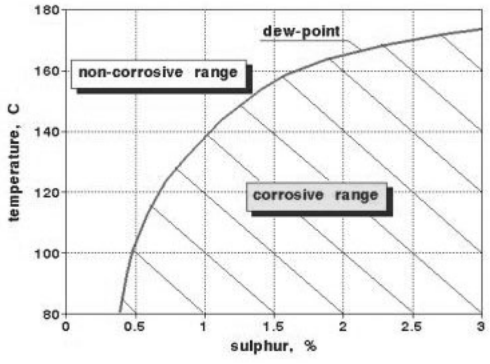

Fig. 10. Corrosive range versus quantity of sulfur in fuel and temperature

6. Durability of engine components due to different fuels – examples

As is written at the beginning of the paper, the measure of durability of engine components can be wear level as a limiting state. There are two typical wear factor as follows: control wear described in lab condition and operational – when actual conditions are used.

Appropriate number of technical objects and time it is necessary to defined operational wear limit. In labs, durability tests are organized in shorter time than road tests. Statistical comparison of data is used to right effect on final results.

Example of lab and road durability tests are presented in this chapter. First case is connected with lab short test of RME fuel – chapter 6.1. The second one was done on road, when engine was fuelling with CNG for mileage of 120,000 km – chapter 6.2. Important role in durability tests belongs to prediction of life time. That case is considered on hydrogen supplied engine in theoretical way – chapter 6.3.

6.1. Control wear factors for RME

Durability test in lab was carried out in Wroclaw University of Technology. The diesel engine SB 3.1 fuelling with standard diesel oil and Rape Methyl Ester was the object of the tests. Investigations were made according to ECE R49.03 standard conditions and using isotopic method with irradiated materials in some engine components. The piston rings, cylinder liner and slide bearings were irradiated by different materials and their pieces going to lubricating oil left signals in probes. Test has 13 measuring points and took 520 minutes. After test the average specific wear factor was calculated following formula 5 [12]:

$$Z_{avg} = \left(\frac{\sum_{i=1}^{13} Z_i U_i}{\sum_{i=1}^{13} N_{ei} U_i} \right) \tag{5}$$

status: Z_i –wear per hour in "i" point of test, N_{ei} – effective power in "i" point of test, U_i – work rate in "i" power of test.

The tests' results are showed on figures 11, 12 and 13.

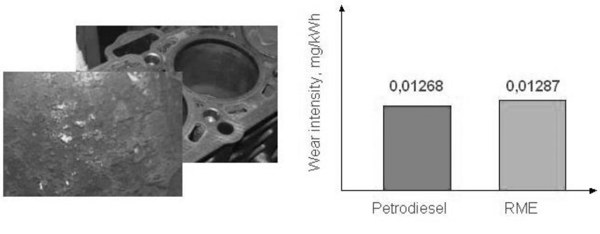

Fig. 11. Wear of cylinder liner of engine fuelling with standard and RME fuels

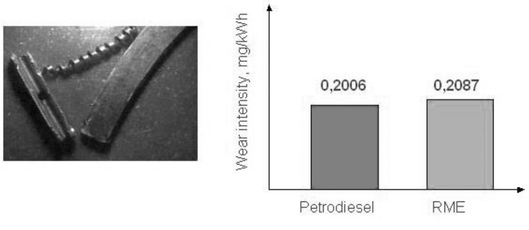

Fig. 12. Wear of piston rings of engine fuelling with standard and RME fuels

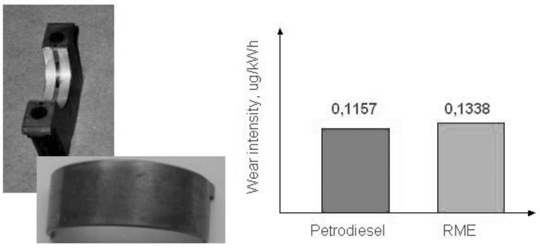

Fig. 13. Wear of slide bearings of engine fuelling with standard and RME fuels

The researches of fuels effect on wear level of piston rings and cylinder liners show differences less than 5% for various fuels. It is inside of error measurement range. So, it can be said there is no statistical effect of using different fuels on tested engine components. For slides bearings the difference in wear intensity is bigger – up to 16% bigger value for RME than diesel oil. It could be explain by less power in engine RME supplying, which decides on force in crankshaft set.

6.2. Operational wear factors for CNG

CNG as an engine fuel was tested on engine 2,0 dm^3 at Renault Laguna car in road conditions. It took total distance 320,000 km but last of 120,000 km was driven on CNG trough Wroclaw city streets as well as it was operated during long trips in Poland. The car and engine were regular checked following the manufacturer schedule of service. Before and after test engine components were measured and geometry or/and weight losses were wear factors of durability. Some example of results of tests are presented on fig. 15-17.

6.3. Durability prediction for hydrogen engine

Durability prediction of engine was done on an example of piston rings from theoretical hydrogen fuelling engine. Based on reference's data, the mathematical model of wear process of

Fig. 14. Renault Laguna supplying with CNG – some views

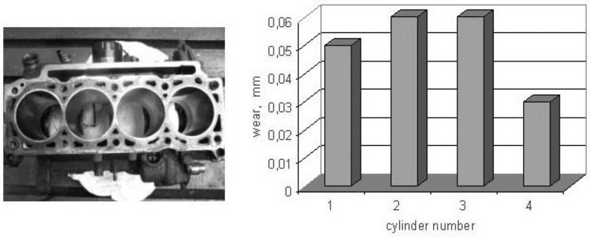

Fig. 15. Wear level of cylinder liner less than limit

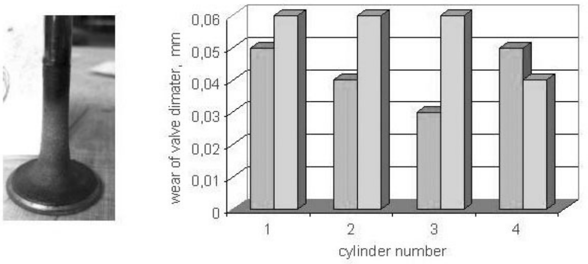

Fig. 16. Wear level of valves diameter less than limiting state (left column – inlet valve, right – exhaust)

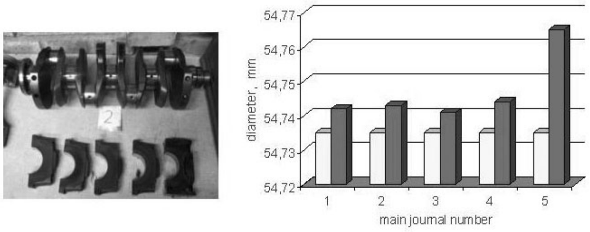

Fig. 17. Diameters of main journals of crankshaft higher than manufacturing limit (left)

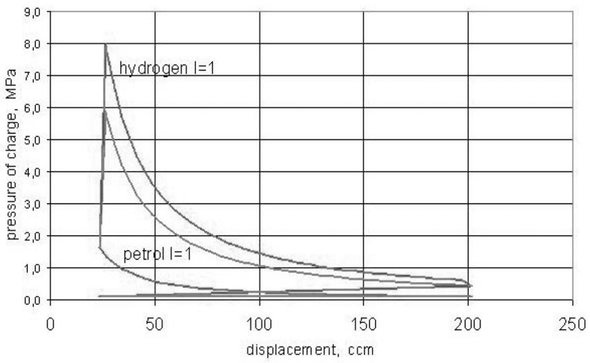

Fig. 18. Theoretical engine work cycles for analyzed cases

piston rings has been created [6, 16]. It is formula considers wear intensity of cast-iron piston rings vs. pressure inside combustion chamber for mitigated solid friction conditions (6):

$$z_p = 0,00002p^3 - 0,0003p^2 + 0,0016p \qquad (6)$$

status: z_P - wear rate of cast-iron piston ring - cm^3/km, p - pressure inside combustion chamber - MPa,

To fulfil this formula, the pressure inside of combustion chamber should be known. Thermodynamic cycle of combustion engine supplying with hydrogen was calculated using standard theory and right formulas. Basic data of engine was taken from Fiat Seicento engine with displacement of $V_c = 899$ cm^3.

Diagrams, mentioned above show different examples of fuelling. Engine work cycles were compared for petrol and hydrogen fuel and for $\lambda = 1,0$. Te results of calculation are done in table 2.

Tab. 2. Thermodynamics parameters of theoretical cycles for Fiat Seicento 900 engine standard and hydrogen fuelling

Parameter	**Petrol**	**Hydrogen**
n, rpm	5300	5300
N_e, kW	10,02/cylinder	12,24/cylinder
g_e, g/kWh	309,9	105,1
η_v	0,81	0,86
p_e, MPa	0,70	1,00
M_t, kg/kg	14,96	34,78
p_{mt}, MPa	5,87	7,99
T_{mt}, K	2458	2575

Status for table 2: n - engine revolution, N_e - power of engine, g_e - specific fuel consumption, η_v - filling ratio, p_e - mean effective pressure, M_t - fresh air need to burn 1 kg of fuel, p_{mt} - maximum pressure of theoretical engine cycle, T_{mt} - maximum theoretical temperature of engine cycle.

When data from table 2 are taken to wear analysis (formula 6), it is occurred more than 19% rise of wear rate for hydrogen supply vs. standard one. (in values z_p=0,0031 cm^3/km for standard, z_p=0,0038 cm^3/km for hydrogen). Equation (6) does not include cyclic work of engine, means cyclic changing of piston ring forcing on cylinder liner. According to tests [9, 18] an impact fatigue of pressure changes inside chamber can make wear 5-10 times more. It means, piston rings and cylinder liner can brake-down much faster.

7. Conclusions

In presented material it is showed different effects of different fuels on durability of engine components. Rape methyl ester, for example does not effect on wear of cylinder liner and piston rings but differences of wear levels are noticed in slide bearings case. Compressed natural gas does not change the durability's limiting state taken for standard petrol. For hydrogen fuelling it can be expected faster wearing of piston rings than for petrol supply. The importance of fuel effect on engine durability belongs to calorific value and elementary composition first of all.

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Sławczo DENCZEW

AUDITING AS IMPORTANT ELEMENT OF MODERN WATER SUPPLY AND SEWAGE SYSTEMS MANAGEMENT

The water supply and sewage segment is element of municipal infrastructure, in particular technical infrastructure, and water supply systems, are components of critical infrastructure.

We can say therefore that water supply and sewage segment task is to provide public services with municipal nature (water supply and removal of sewage belonging to water supply and sewage services), strategic importance (mainly water supply in crisis situations), and social nature (water supply for fire fighting or people and assets safety).

Keywords*: water supply and sewage, operation systems, reference model, integrated model, auditing.*

1. Introduction

Water supply and sewage systems determine and, at the same time, demonstrate economic development on their area. They also demonstrate the country's economic development. Therefore efficient and effective management of such huge assets as water supply and sewage systems requires modern management methods for their operation.

This paper presents auditing concept as modern management method for water supply and sewage systems operation. Generally, auditing is process of checking conformity of active operation system with reference models (e.g. operation system reference model, legal acts, operation standards, etc.). Therefore water supply and sewage system operation auditing is particularly important as it concerns operations related to water supply (strategic nature) and sewage removal (sanitary nature). The role of auditing in developing technical progress in water supply and sewage system operation is very important as – in consequence – it allows to eliminate anomalies and to improve their operation and therefore it allows to reduce operation costs which have high impact on water supply and sewage system development.

2. The purpose and tasks of water supply and sewage system operation

The water supply and sewage operation system constitutes the set of organization, technical, technological, economic, legal, ecological and social activities, fulfilled by teams of people according to sustainable development rule, using scientific methods and good operation practices aimed to utilize water supply and sewage objects and facilities according to their purpose in order to satisfy human needs as concerns water supply and sewage services. Therefore the main goals of water supply and sewage system operation include [1, 2]:

- usage;
- supervision (mainly as concerns goal fulfilling control – water quantity, pressure and quality and sewage flow rate, duct filling and sewage velocity),
- service (consisting in maintaining technical efficiency of water supply and sewage components),
- renovation (intended to restore technical efficiency of water supply and sewage objects and facilities).

Whereas, the main tasks of water supply and sewage operation systems include:

- supply of water in proper quantity, under sufficient pressure and with required quality, as well as removal of sewage and neutralization of sewage deposits,
- effective and rational management of water supply and sewage facilities,
- reduction of operation costs,
- environment protection.

The following drawing presents graphic illustration of water supply and sewage operation systems goals and tasks 1.

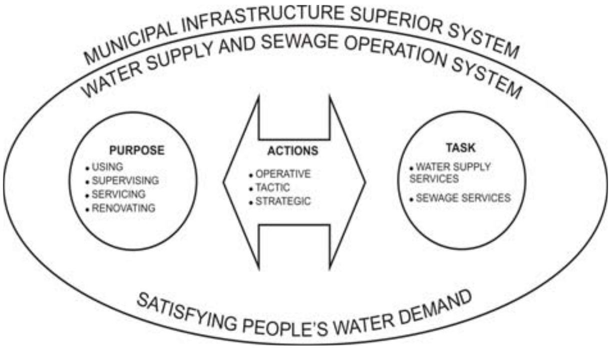

Fig. 1. Graphic illustration of water supply and sewage operation systems goals and tasks

The water supply and sewage operation systems objectives and tasks are fulfilled by organization units which operate in various legal forms (government water supply and sewage enterprises, commercial companies, budgetary agencies, etc.).

3. The common and distinguishing features of water supply and sewage operation systems

The more important common features of water supply and sewage operation systems include such features as complexity, hierarchization, dynamism, inertia, randomness and variety of events occurring in systems, uncertainty, high level of complication of individual processes and high level of automation. It is illustrated by Figure 2.

Whereas, features which differentiate water supply and sewage operation systems include:

- different functions;
- different operation conditions and, consequently, different parameters describing operation condition,

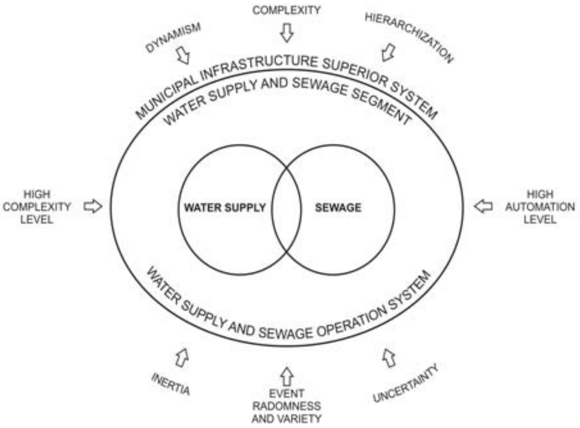

Fig. 2. Diagram of selected features specific for water supply and sewage operation systems

- different physical, chemical and bacteriological properties of conveyed agents (water and sewage);
- different operation process status models.

The last of mentioned above feature, i.e. different models of water supply and sewage operation process conditions, is particularly interesting [3]. It is illustrated by Figure 3.

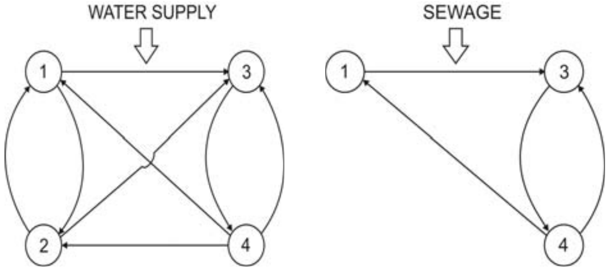

Fig. 3. Diagram of water supply and sewage operation process graphs [3], Designations: 1 – operation, 2 – standstill, 3 – waiting for renovation, 4 – renovation

The difference in models of water supply and sewage operation process conditions results from fulfilled by them functions, that is: continuous water supply with standstill ability and not disrupted sewage removal precluding standstill situation. This results in different ways in designing sewage operation systems where actions aimed to maintain continuous sewage removal shall be provided.

4. The water supply and sewage operation system auditing concept

The essence of water supply and sewage operation systems consists in detailed examination of system operation in relation to adopted models, such as operation system reference model, legal acts in force or defined operation standards [4, 5].

Whereas the main goal of water supply and sewage operation system auditing is verification of conformity of implemented activities with reference models and, in case deviations are found, indicating specific correction actions and their profitability. Figure 4 presents concept for sequence of actions in water supply and sewage operation system auditing.

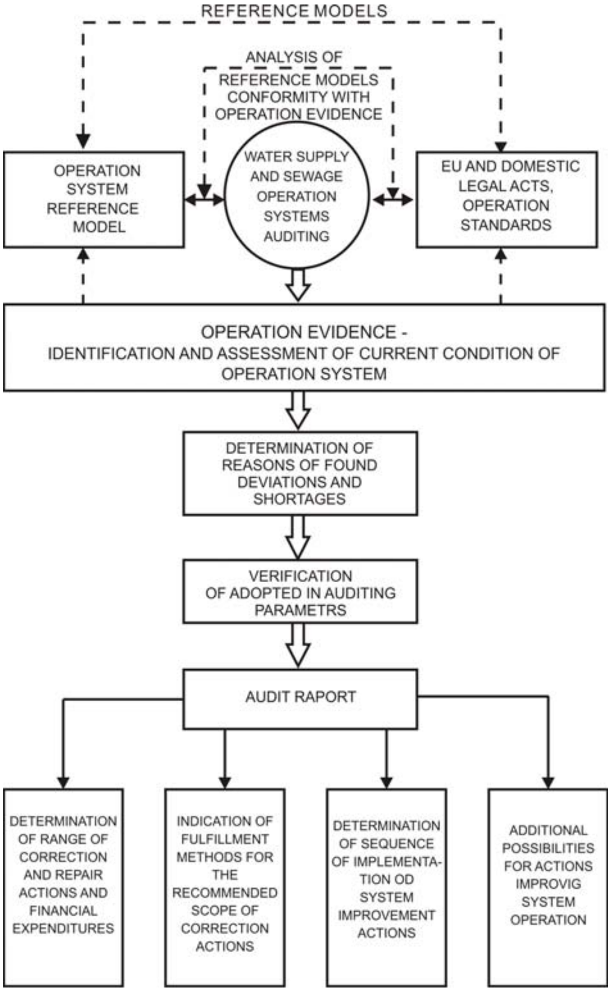

Fig. 4. The concept of water supply and sewage operation system auditing process flow

The application of water supply and sewage operation system auditing provides continuous verification of conformity of the examined system with the adopted reference models. It allows also for elimination of irregularities on the current basis.

The operation system reference model may have modular structure (e.g. organization, technology, controlling, etc. modules) corresponding to size and complexity of the examined system. The discovered and documented facts, gathered during observation, meetings with operation personnel and research in operation process constitute operation records.

The water supply and sewage operation system auditing is not control or evaluation. It is necessary to have attitude for checking correctness and consistence of procedures with the adopted reference models.

5. The proposal of positioning of auditing in water supply and sewage operation system structures

The structure of operation system complex model shall include such elements as: designing, implementing, verifying, operating, which shall be understood as the basic ones. Auditing, controlling, certifying and accrediting belong to the modern elements of operation system development [6-9]. Figure 5 illustrates sequence of construction of complex model of water supply and sewage operation.

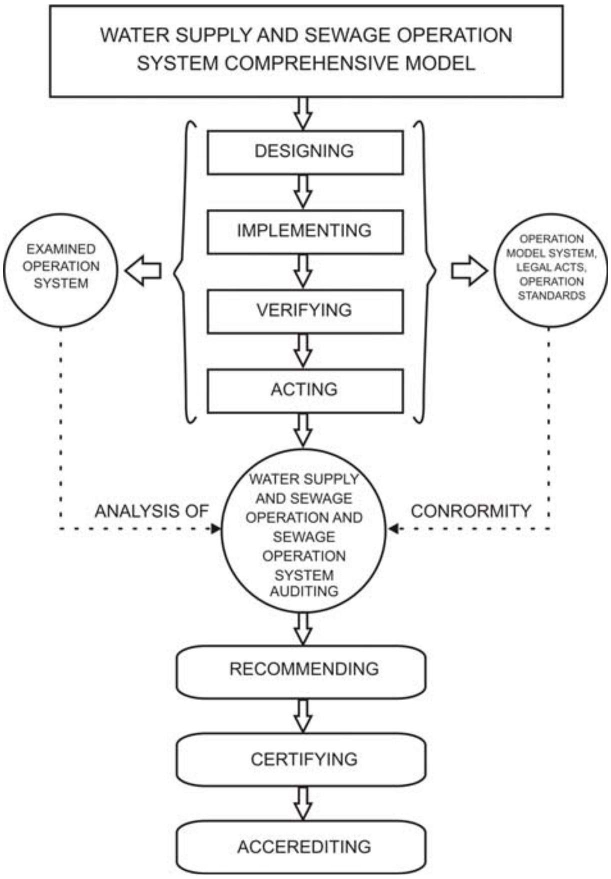

Fig. 5. Diagram of concept of complex model of water supply and sewage operation system

The main purpose for water supply and sewage operation system deigning is satisfying water demand of people by providing water supply and sewage services in long-term, reliable, safe, effective and efficient manner. Figure no 6 presents proposal for algorithm of complex model of water supply and sewage operation system.

The presented algorithm of complex model of water supply and sewage operation system includes all elements of modern management of such huge assets as water supply and sewage facilities.

6. Summary and conclusions

The provided discussion allows to say that efficient, effective and rational management of water supply and sewage operation system, based on modern scientific methods and applying modern techniques, such as auditing, shall secure reliability and safety for provision of water supply and sewage services. It also guarantees the high quality of provided services related to satisfying water demands of people. Even this superficial review of operation problems concerning water supply and sewage demonstrates their importance and conforms their significance for correct functioning of towns and villages and for economic development of country.

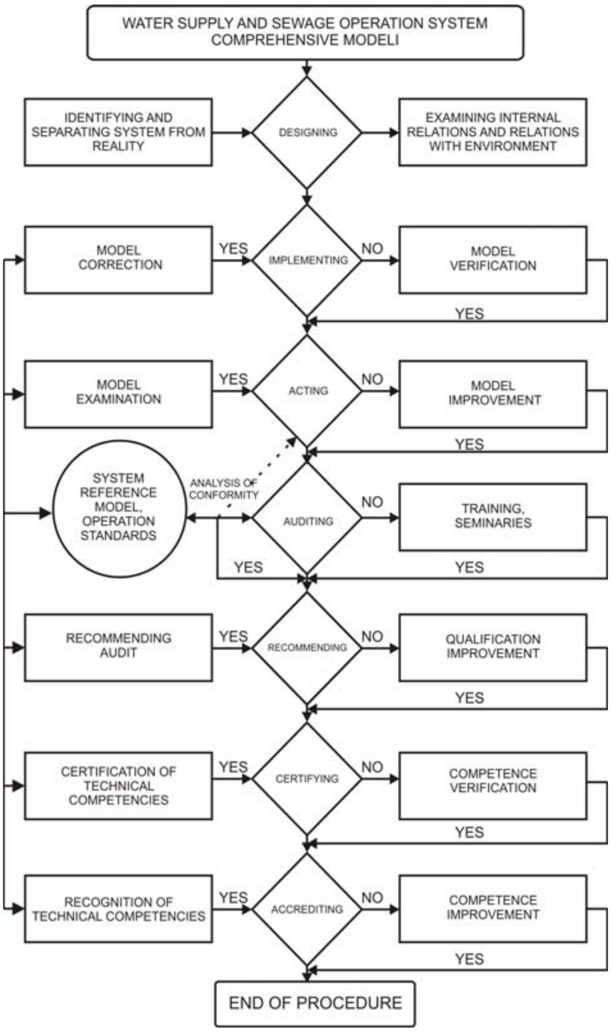

Fig. 6. Diagram of concept of algorithm of complex model of water supply and sewage operation system

The following conclusions are expressed in final summary:

1. The water supply and sewage operation system auditing constitutes the modern method for management of such resources as water supply and sewage facilities.
2. The auditing substance consists in checking conformity of the examined water supply and sewage operation system with the adopted reference models (reference operation model, operation standards, EU and domestic legal acts).
3. The presented auditing concept has cognitive nature with possibility of application in operation practice.

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Zdzisław CHŁOPEK

EFFECTS OF USING CRT PARTICULATE MATTER FILTERS FOR SELF IGNITION ENGINES

Particulate matter emission, next to that of nitrogen oxides, belongs to the most serious ecological threats posed by combustion engines. This is particularly dangerous in great urban agglomerations. One of the most significant sources of particulate matter emission in the urban centres are self ignition engines of lorries and urban buses. Most effective ways of lowering particulate matter emission are particulate matter filters. This paper presents studies results on the influence of using self regenerating CRT filter on their emission, from the bus engine. The tests were conducted in the static and dynamic conditions.

Keywords*: self ignition engines, pollutants emission, particulate matter filters.*

1. Introduction

Particulate matter emission is one of the most serious ecological threats posed by motorism. It is well known that particulate matter – PM10 concentration limits are one of the most frequently exceeded acceptable air pollutants concentration limits in the urban agglomerations [5, 11, 12]. Harmfulness of particulate mater to health is also known [5, 11, 12].

Figure 1 shows photography of particulate matter emitted from the self ignition engine.

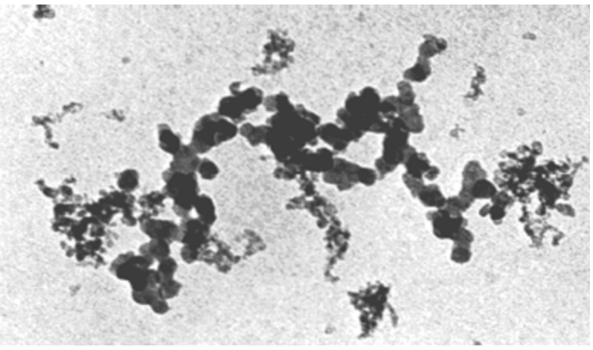

Fig. 1. Particulate matter in agglomerates, emitted from the self ignition engine

Particulate matter consists of soot and various substances deposited on it: organic and non–organic [5] – figure 2.

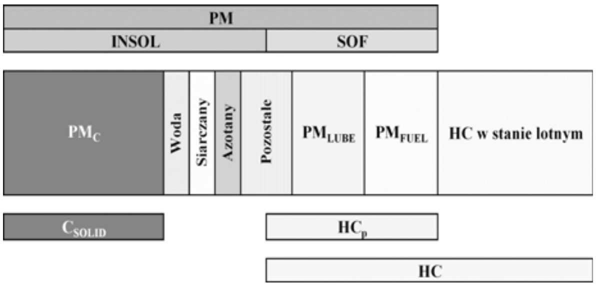

Fig. 2. Particulate matter content diagram: SOF – organic fraction dissolvable in methylene chloride CH_2Cl_2. INSOL – fraction insolvable in methylene chloride CH_2Cl_2 (most often non–organic)

Carbon part – PM_C of particulate matter consists of soot (C_{SOLID}). Non–organic fraction consists of: water, metal salts, (sulfates and nitrates) as well as other none organic substances, like heavy metals. Particulate matter organic fraction consists of hydrocarbons HC_p, from fuel (PM_{FUEL}) and from diesel oil (PM_{LUBE}). Hydrocarbons contained in the particulate matter form part of the hydrocarbons emitted from the engine – their remaining part is in the volatile state. Most dangerous to health particulate matter components are: organic compounds, particularly heavy ones (coming first of all from oil fraction) and heavy metals. Particulate matter acts in a very harmful way on human organisms, mechanically affecting the air passages [11, 12].

The main source of particulate matter emission in the transport sector are self ignition engines. Because of that, the methods of lowering particulate matter emission from self ignition engines are being sought as well as those to replace these engines with other types in the vehicles used in the areas most ecologically endangered. There are several possibilities of lowering particulate matter emission from the vehicle engines. Classic methods being perfecting engine design solutions and developing new generations of diesel oil [5, 7]. Other work on catalytic fuel additives is also being conducted, providing decrease of pollutants emission, including particulate matter [10]. The use of biofuels to supply self ignition engines is an effective solution. Biofuels containing vegetable oil esters enable effective limitation of particulate matter emission [9, 10]. Particularly good effects can be obtained in this field using E95 fuel (of over 90 percent bioethanol content) to supply self ignition engines of special design (Scania DSI9E 01) [6]. Using natural gas as a fuel is also an effective solution [7]. Usually natural gas is used to supply spark ignition engines, which are modified self ignition engines powering heavy duty vehicles [7].

A classic method to decrease the emission of particulate matter is the use of particulate matter filters– DPF (Diesel Particulate Filter) [1 – 5, 7, 13 – 27]. These filters enable even 10 – fold reduction of particulate matter emission. The basic operational problem of these particulate matter filters is the necessity of regenerating them due to pollutants being collected in the filter pack. The solution, which in the recent years revolutionised limiting particulate matter emission, is the use of self regenerating particulate matter filters – CRT (Continuously Regenerating Trap). System CRT consists of two modules: oxidising catalytic converter OXICAT and particulate matter filter DPF [3, 13, 15, 17, 20, 21]. CRT filter diagram and the way it works is shown on the figure 3.

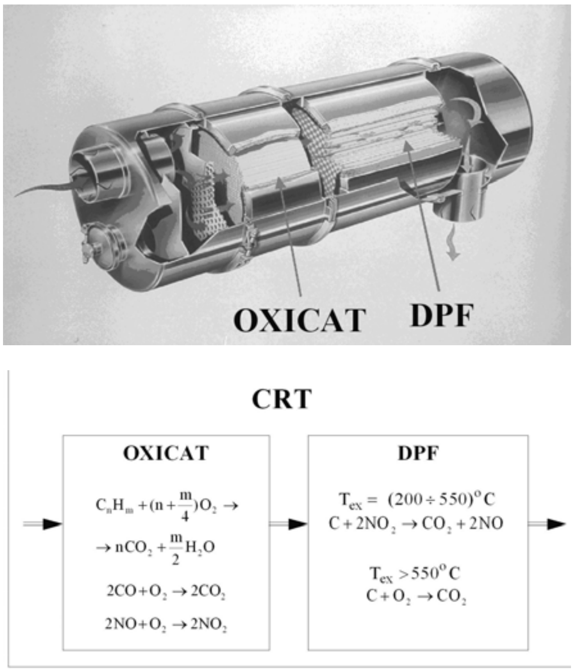

Fig. 3. Particulate matter filter system continuously regenerating during operation – CRT [17]

In the oxidising catalytic converter, oxidisation of the following substances takes place: organic compounds into carbon dioxide and water, carbon monoxide to carbon dioxide and nitrogen oxide to nitrogen dioxide. Thanks to significant affinity of nitrogen dioxide with carbon it is possible to effectively oxidise soot, forming a matrix of particulate matter, already in the temperature just above 200ºC, while oxidising soot by an oxygen contained in the exhaust gasses takes place at sufficiently high speed, only at the temperature above 550ºC [2, 17, 25]. Since, the oxidisation of soot contained in the filter effectively takes place already from 200ºC, the filter constantly undergoes the process of regenerating itself during engine operation [2, 17, 25].

2. Results of CRT filter efficiency studies

CRT filter efficiency studies have been carried out using British system Eminox and self ignition 6CT107 Andoria Mot engine in the following tests [5]:

- static ESC test (European Stationary Cycle) to study pollutants emission – with a start up of a warm engine,
- dynamic ETC test (European Transient Cycle) to study pollutants emission – with a start up of a warm engine
- dynamic HDDTT test (Heavy Duty Diesel Transient Test) to study pollutants emission – with a start up of a cold engine – HDDTT–c with a start up of a warm engine – HDDTT–h,
- dynamic ELR test (European Load Response) to smoke test of the exhaust – with a start up of a warm engine.

They were the first CRT system tests in Poland in the dynamic conditions, also for the first time in Poland, the engine studies were carried out using American HDDTT dynamic test.

The equipment used complied with the type approval procedures requirements. In the dynamic tests, the values measured were being recorded constantly with a 10 Hz frequency.

Figures 4 – 8 show specific brake pollutants emission and specific brake fuel consumption in the research tests– ETC, HDDTT and ESC, while figure 9 – shows light absorption coefficient for the exhaust gasses in the ELR test. For comparison the results shown are for the engine: without the filter and with the filter.

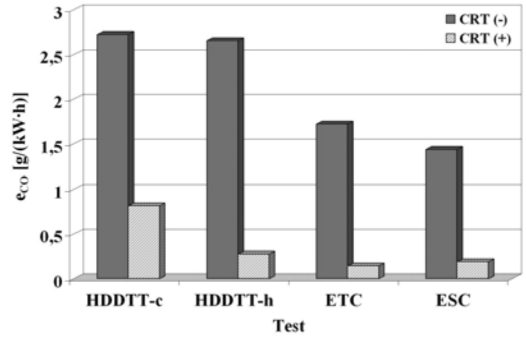

Fig. 4. Specific brake carbon monoxide emission in the research tests without a filter CRT( ) and with a filter CRT(+)

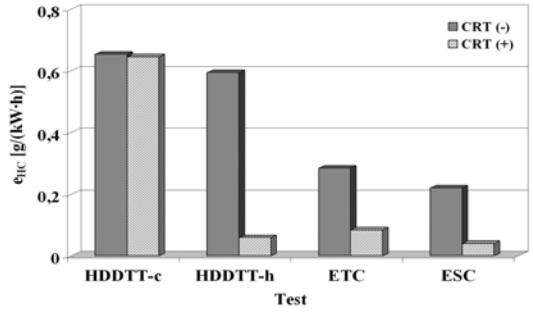

Fig. 5. Specific brake hydrocarbons emission in the research tests without a filter CRT( ) and with a filter CRT(+)

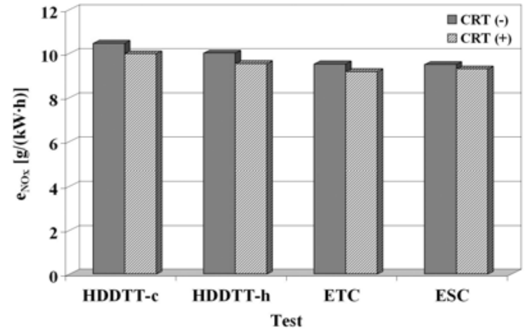

Fig. 6. Specific brake nitrogen oxides emission in the research tests without a filter CRT( ) and with a filter CRT(+)

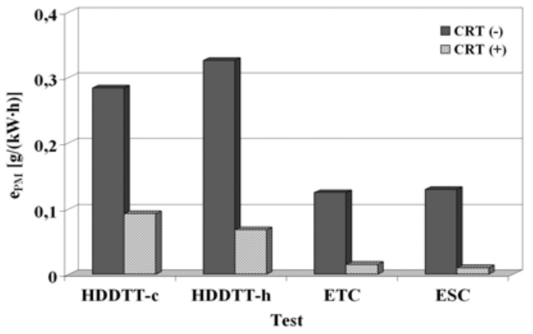

Fig. 7. Specific brake particulate matter emission in the research tests without a filter CRT( ) and with a filter CRT(+)

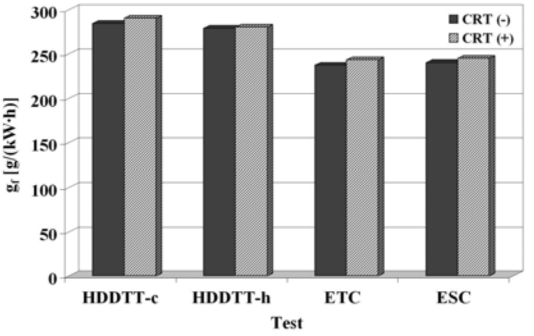

Fig. 8. Specific brake fuel consumption in the research tests without a filter CRT( ) and with a filter CRT(+)

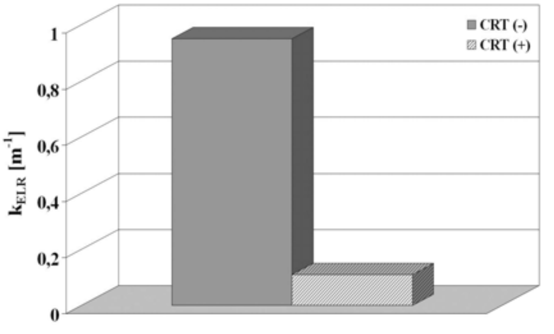

Fig. 9. Light absorption coefficient for the exhaust gasses in the ELR test without a filter CRT( ) and with a filter CRT(+)

As a result of using CRT filter, a significant reduction of particulate matter emission has been obtained in all tests. The greatest efficiency was achieved in the static conditions (ESC) – over 90%, but even in the dynamic test HDDTT with a start up of a cold engine, the efficiency of almost 70–percent should be regarded as very good. The use of CRT filter also caused significant reduction of carbon monoxide and hydrocarbons emission. It is important, that an increase of nitrogen oxides emission did not occur, but instead, even their small reduction took place. Specific brake fuel consumption remained practically at the unchanged level. This confirms effectiveness of the filter self regeneration process during operation. It is worth noting the fact, that an average exhaust counterpressure, due to using CRT filter was small, being about 3 kPa – figure 10.

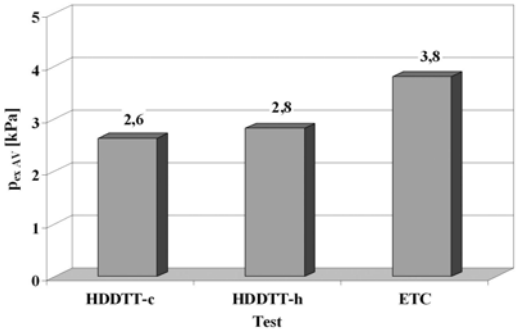

Fig. 10. Average exhaust counterpressure in tests

Slight increase in the exhaust temperature was noted, due to using CRT filter – by an average umpteen degrees centigrade (figure 11).

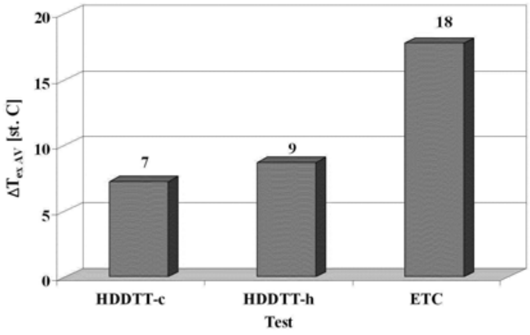

Fig. 11. Average exhaust temperature difference behind the CRT filter (with a filter fitted and without it) in tests

CRT filter tests in the static and dynamic conditions confirmed great effectiveness of this method of reducing particulate matter emission.

3. Final remarks

CRT filter effectiveness tests were conducted in the tests, complying with type approval procedures in Europe and United States. In reality of vehicles operation, particularly urban buses, there are big discrepancies between combustion engines operating conditions and type approval tests conditions. First off all, during normal operation, engine loads are smaller, resulting in lower exhaust temperature. This can cause insufficient effectiveness of the filter regeneration during operation – practice of using CRT filters in urban buses confirms these worries [24, 25]. Therefore it is advisable to conduct operational tests of CRT filter in the urban busses as well as bench tests, simulating bus engine operating condition. Such tests would be expected to reveal sensitive points of the effectiveness of lowering the particulate matter emission and filter self regenerating, in relation to the engine thermal state. Such knowledge could be used to work out indications and guidelines to: on one hand – the conditions of the filter installation, and on the other – optimising engine operating conditions with regards the efficiency of lowering particulate matter emission, under the conditions of small loading of the combustion engine.

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A METHOD OF EVALUATING TIME OF FATIGUE CRACK GROWTH TO LIMITING VALUE OF SOME SELECTED STRUCTURAL COMPONENTS – AN OUTLINE

The paper has been intended to introduce a method of evaluating time of fatigue crack growth to limiting value for some selected structural components during aircraft's operation process. The method, base on stress intensity factor and Paris' formula, which describe physical nature of the process. To describe the dynamics of the crack propagation was used a partial differential equation of the Fokker-Planck type. Having solved this equation enables the density function of the crack length to be found. This function, gave possibility of determination time density function when fatigue crack growth achieves limiting value.

***Keywords**: fatigue crack, stress intensity factor, limiting state.*

1. Introduction

Some selected aircraft's elements are destroyed during operation process as a result of fatigue crack growth. Usually, these elements are included in aircraft's structure and engine. Particularly dangerous damages are fatigue cracks in aircraft's engine. They are caused by fatigue crack of compressor blades, turbine and drive shaft. The damages occur rarely but have very serious effect in the form of aircraft's crash.

The base of prevention this damage is preventive service, worked out with use of prognosis specific symptom's growth. To this end, it's necessary to recognize fatigue crack process connected with flying time. The process of destruction is observed by special diagnostic systems, which are continuously improving.

In this work, authors base on previous publications [1-5]. An attempt has been made in this paper, to present a method of evaluating distribution of time, when fatigue crack growth achieves limiting value, assuming that:

1. Destructive factor is an element's load, taking vibrations into account.
2. Having spectrum of load, one can determine:
   - total number of load's cycle N_c during time of one flight,
   - maximum load in thresholds for given spectrum of load, amount to: $\sigma_1^{max}, \sigma_2^{max}, \ldots, \sigma_L^{max}$ (L – number of thresholds in given spectrum),
   - the number of repetition specific threshold's value during one flight, amount to n_i, where: $N_c = \sum_{i=1}^{L} n_i$.
3. Maximum load values for given thresholds can be defined:
$$\sigma_i^{max} = \frac{\sigma_i^{max} + \sigma_i^{min}}{2} + \sigma_i^a \qquad (1)$$
where: σ_i^{max} - maximum value of cyclic loading within i-th threshold; σ_i^{min} - minimum value of cyclic loading within i-th threshold; σ_i^a - amplitude of cyclic loading within i-th threshold, i=1,2,...,L.
4. Maximum load values: $\sigma_1^{max}, \sigma_2^{max}, \ldots, \sigma_L^{max}$ (for given thresholds), respond to frequency of theirs occurrences:
$\frac{n_1}{N_c} = P_1$, $\frac{n_2}{N_c} = P_2$, ... $\frac{n_L}{N_c} = P_L$.
In above mentioned way, probabilistic description of element's load was determined for every flight or assumed operational cycle of the aircraft.
5. Authors assumed that, within the confines of operational cycle, occurring minor load after major or inversely didn't require additional changes in created model.
6. Crack growth process has been described with the Paris' formula in the following form:
$$\frac{da}{d\ N_z} = C(\Delta K)^m \qquad (2)$$

where: ΔK - range of changes stress intensity factor value; C, m- material constants; a - crack length; N_z - the number of fatigue cycles.

2. Probabilistic model for density function of crack growth determination

Assumptions:

- Device's technical state was being determined by one dominant diagnostic parameter in the form of crack length "a";
- Crack length change can occur only during operating time;
- Paris formula described in the form (2), in this case has following form:
$$\frac{da}{d\ N_z} = C\ \ M_k^m(\sigma_{max})^m\ \ \pi^{\frac{m}{2}}\ \ a^{\frac{m}{2}} \qquad (3)$$

where: M_k - coefficient of the finiteness of the component's dimensions and position of the crack, σ_{max} - maximum value of cyclic loading, described in the form (1).

Relationship (3) can be expressed against time i.e. in more detail – against flying time of the aircraft. Hence, the following assumption is made:

$$N_z = \lambda t \qquad (4)$$

where: λ – intensity of the occurrence of fatigue load's cycles for structural component, t – flying time of the aircraft.

In our case, $\lambda = \frac{1}{\Delta t}$, where Δt - load's cycle duration. Relationship (3) depending on time has following form:

$$\frac{da}{d\ t} = \lambda\ \ C\ \ M_k^m(\sigma_{max})^m\ \ \pi^{\frac{m}{2}}\ \ a^{\frac{m}{2}} \qquad (5)$$

Using notifications made earlier, one can set to describing – in probabilistic terms – the dynamics of crack growth. Thus, authors assumed: probability that for the flying time equal to "t", the crack length is “a” amount to $U_{a,t}$. For this, dynamics of crack growth was described by difference equation:

$$U_{a,\ t+\Delta t} = P_1U_{a-\Delta a_1,\ t} + P_2U_{a-\Delta a_2,\ t} + \ \cdots\ + \ P_LU_{a-\Delta a_L,\ t} \qquad (6)$$

where: P_i – probability of stress σ_i^{max} occurring, described by the form (1), (i = 1, 2,..., L). These probabilities satisfy a condition: $P_1+P_2+...+P_L=1$, Δa_i - crack increment during Δt time for stress σ_i^{max} (i = 1, 2,..., L). These increments can be determined using forms (1) and (5).

Difference equation (6) has following sense: probability that for the flying time equal to “$t + \Delta t$” the crack length is „a”, however for the flying time equal to “t”, the crack length is “$a - \Delta a_{śr}$“ and in the time range (t, $t + \Delta t$) raised by $\Delta a_{śr}$, where $\Delta a_{śr}$ is determined using assumed loading value.

Difference equation (6) in functional notation took the following form:

$$u(a,\ t+\Delta\ t) = \sum_{i=1}^{L} P_i u\ \ (a-\Delta\ a_i,\ t) \qquad (7)$$

where: $u(a,t)$ - density function of crack length depending on flying time.

The following differential equation of the Fokker-Planck type has been obtained from equation (7):

$$\frac{\partial u(a,t)}{\partial t} = -\alpha(t)\frac{\partial u(a,t)}{\partial a} + \frac{1}{2}\ \beta(t)\frac{\partial^2 u(a,t)}{\partial a^2} \qquad (8)$$

Solution of eq (8) is the requested crack length density function:

$$u(a,t) = \frac{1}{\sqrt{2\pi\ \ A(t)}}\ e^{-\frac{(a-B(t))^2}{2A(t)}} \qquad (9)$$

where: $B(t)$ - an average value of crack length for the flying time “t”, $A(t)$ - a variance of crack length for the flying time “t”.

3. Determination of flying time distribution for the period of time when fatigue crack growth achieves limiting state for coefficient m=2

Probability that fatigue crack length achieves limiting value can be determined using density function (9). It required determination of the crack limiting value for assumed flight’s safety. To determine some critical value of the crack length, the stress intensity factor in the following form can be used:

$$K = M_k\ \ \sigma\sqrt{\pi\ \ a} \qquad (10)$$

where: M_k - coefficient of the finiteness of the component’s dimensions and position of the crack. The stress intensity factor, determined with dependence (10), becomes a quantity of a critical value K_c, when the crack length and the stress take critical values a_{kr} and σ_{kr}, respectively. Then it is called “resistance of the material to cracking”:

$$K_c = M_k\ \ \sigma_{kr}\sqrt{\pi\ \ a}_{\ kr} \qquad (11)$$

With eq (11) applied, and for introduced the factor of safety, one can find the admissible value of the crack:

$$a_d = \frac{K_c^2}{kM_k{}^2\sigma_{kr}^2\pi} \qquad (12)$$

where: k - safety factor.

Connection between total flying time and number of the flights has been made by the form:

$$t_N = \sum_{i=1}^{N} t_i \qquad (13)$$

where: N - the number of flights, t_i - time of i-th flight duration.

With eq (13) applied, density function can be described by the form:

$$u(a,t_N) = \frac{1}{\sqrt{2\pi A(t_N)}}\ e^{-\frac{(a-B(t_N))^2}{2A(t_N)}} \qquad (14)$$

Coefficients $B(t_N)$ and $A(t_N)$ for m=2, are solutions of the following integrals:

$$B(t_N) = \int_0^t \alpha\left(t_N\right)dt = a_0(e^{\lambda\bar{C}_2 t_N} - 1) \qquad (15)$$

$$A(t_N) = \int_0^t \beta\left(t_N\right)dt = \frac{1}{2}a_0^2\bar{C}_2\omega\left(e^{2\lambda\bar{C}_2 t_N} - 1\right) \qquad (16)$$

where: $\bar{C}_2 = C_2E[(\sigma^{max})^2\ ]$, $C_2 = CM_k^2\pi$, $\omega = \dfrac{E[(\sigma^{max})^4]}{\left(E[(\sigma^{max})^2]\right)^2}$.

With use the crack length density function (14) and formula (12) one can determine probability that: in range of the flying time (0, t_N), current crack length achieves limiting value:

$$Q(t_N,a_d) = \int_{a_d}^{\infty} u(a,t_N)da \qquad (17)$$

Flying time density function for the period of time when fatigue crack growth achieves limiting value can be defined:

$$f(t) = \frac{\partial}{\partial t}\ Q(t;a_d) \qquad (18)$$

Equation (18) can be also defined by the following form:

$$f(t) = \int_{a_d}^{\infty} \{\frac{\partial}{\partial t}\ u(a,t)\}\ da \qquad (19)$$

In order to calculate integral (19), it’s necessary to:

- determine derivative of $u(a,t)$ function with respect to time;
- find antiderivative of a function (19).

Determination of derivative of function (14) was realized in following way:

$$\frac{\partial}{\partial t}[u(a,t_N)] = \Big(\frac{1}{\sqrt{2\pi[\frac{1}{2}a_0^2\bar{C}_2\omega(e^{2\lambda\bar{C}_2t_N} - 1)]}}\Big)'\ e^{-\frac{(a-a_0(e^{\lambda\bar{C}_2t_N} - 1))^2}{2\frac{1}{2}a_0^2\bar{C}_2\omega(e^{2\lambda\bar{C}_2t_N} - 1)]}} +$$

$$+\frac{1}{\sqrt{2\pi[\frac{1}{2}a_0^2\bar{C}_2\omega(e^{2\lambda\bar{C}_2t_N} - 1)]}}\ \Big(e^{-\frac{(a-a_0(e^{\lambda\bar{C}_2t_N} - 1))^2}{2\frac{1}{2}a_0^2\bar{C}_2\omega(e^{2\lambda\bar{C}_2t_N} - 1)]}}\Big)' =$$

$$= \Big(\frac{2(a-a_0(e^{\lambda\bar{C}_2t_N} - 1)a_0\lambda\ \bar{C}_2\ e^{\lambda\bar{C}_2t_N}}{a_0^2\bar{C}_2\omega(e^{2\lambda\ \bar{C}_2\ t_N} - 1)} +$$

$$+\frac{2(a-a_0(e^{\lambda\ \bar{C}_2\ t_N} - 1))^2\lambda\ \bar{C}_2e^{2\lambda\ \bar{C}_2\ t_N}}{a_0^2\bar{C}_2\omega(e^{2\lambda\bar{C}_2t_N} - 1)^2} -$$

$$-\frac{\bar{C}_2\lambda\ \ e^{2\lambda\ \bar{C}_2t_N}}{(e^{2\lambda\bar{C}_2t_N} - 1)}\ \Big)\ u(a,t) \qquad (20)$$

Determination of antiderivative of function was carried out with use of following expression:

$$w(a,t) = u(a,t)\cdot\theta(a,t) \qquad (21)$$

where: $\theta(a,t)$ is wanted expression.

Derivative of function – $w(a,t)$ with respect to crack length should be equal expression (20). Derivative $w(a,t)$ function with respect to „a” has following form:

$$\frac{\partial w(a,t)}{\partial a} = u'(a,t)\cdot\theta(a,t) + u(a,t)\cdot\theta\ \ '(a,t)$$

Hence, derivative $\frac{du(a,t)}{da}$ determination allow as follows:

$$\frac{\partial w(a,t)}{\partial a}=u(a,t)\left(-\frac{2(a-a_0(e^{\lambda\bar{C}_2t_N}-1))}{a_0^2\ \bar{C}_2\omega(e^{2\lambda\bar{C}_2t_N}-1)}\right)\cdot\underbrace{(?)}_{\theta(a,t)}+u(a,t)\cdot\underbrace{(?)}_{\theta'(a,t)} \qquad (22)$$

Expression (22) should be equal to expression (20), and as a result of the comparison we can receive following form of θ(a,t) function:

$$\theta(a,t)=\left(-a_0\lambda\bar{C}_2\ e^{\lambda\bar{C}_2t_N}-\frac{(a-a_0(e^{\lambda\bar{C}_2t_N}-1))\ \lambda\bar{C}_2\ e^{2\lambda\bar{C}_2t_N}}{(e^{2\lambda\bar{C}_2t_N}-1)}\right) \qquad (23)$$

and derivative of $\theta(a,t)$ function with respect to „*a*”:

Hence, expression describing antiderivative of function (19) has been described in the form:

$$w(a,t)=U(a,t)\cdot\Big[-\Big(a_0\lambda\ \bar{C}_2\ e^{\lambda\bar{C}_2t_N}+ +\frac{(a-a_0(e^{\lambda\bar{C}_2t_N}-1))\ \lambda\ \bar{C}_2\ e^{2\lambda\bar{C}_2t_N}}{(e^{2\lambda\bar{C}_2t_N}-1)}\Big)\Big] \qquad (24)$$

Calculation of integral (19) gave opportunity to determine flying time density function for the period of time when fatigue crack growth achieves limiting value:

$$f(t_N;a_d)=w(a,t)\Big|_{a_d}^{\infty}=u(a_d,t_N)\Big[\Big(a_0\lambda\ \bar{C}_2\ e^{\lambda\bar{C}_2t_N}+ +\frac{(a_d-a_0(e^{\lambda\bar{C}_2t_N}-1))\ \lambda\ \bar{C}_2\ e^{2\lambda\bar{C}_2t_N}}{(e^{2\lambda\bar{C}_2t_N}-1)}\Big)\Big] \qquad (25)$$

where:

$$u(a_d,t_N)=\frac{1}{\sqrt{2\pi(\frac{1}{2}a_0^2\ \bar{C}_2\omega(e^{2\lambda\bar{C}_2t_N}-1)}}\ e^{-\frac{(a_d-a_0(e^{\lambda\bar{C}_2t_N}-1))^2}{a_0^2\ \bar{C}_2\ \omega(e^{2\lambda\bar{C}_2t_N}-1)}}$$

$a_d=\frac{K_c^2}{k\ M_k^{\ 2}\sigma_{kr}^2\pi}$ - crack length limiting value.

4. Determination of flying time distribution for the period of time when fatigue crack growth achieves limiting state for coefficient m≠2

Density function of crack length was given in the following form:

$$u(a,t)=\frac{1}{\sqrt{2\pi\ \ A(t)}}\ e^{-\frac{(a-B(t))^2}{2A(t)}} \qquad (26)$$

where: *a* - crack length, *t* - flying time of the aircraft, *B(t)* - an average value of crack length for *m≠*2, in the form:

$$B(t)=\Big[a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\lambda CM_k^m\ \pi^{\frac{m}{2}}\ E[(\sigma^{max})^m]\ \ t\Big]^{\frac{2}{2-m}}-a_o \qquad (27)$$

A(t)- a variance of crack length for *m≠*2 in the form:

$$A(t)=\frac{2}{2+m}\ CM_k^m\ \pi^{\frac{m}{2}}\frac{E[(\sigma^{max})^{2m}]}{E[(\sigma^{max})^m]}\cdot \cdot\left[(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\lambda CM_k^m\ \pi^{\frac{m}{2}}\ E[(\sigma^{max})^m]\ \ t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}\right] \qquad (28)$$

Notations:

C - material constant;

M_k- coefficient of the finiteness of the component’s dimensions and position of the crack;

$E[(\sigma^{max})^{2m}]=P_1(\sigma_1^{max})^{2m}+P_2(\sigma_2^{max})^{2m}+\ldots+P_L(\sigma_L^{max})^{2m}$;

$E[(\sigma^{max})^m]=P_1(\sigma_1^{max})^m+P_2(\sigma_2^{max})^m+\ldots+P_L(\sigma_L^{max})^m$;

a_o - initial crack length;

λ - intensity of load cycles occurring $(\lambda=\frac{1}{\Delta\ t})$;

Δt - load cycle duration time.

Flying time density function for the period of time when fatigue crack growth achieves limiting value can be defined:

$$f(t)_{a_d}=\frac{\partial}{\partial t}\ Q(t;a_d) \qquad (29)$$

Equation (29) can be also defined by the following form:

$$f_{a_d}(t)=\int_{a_d}^{\infty}\{\frac{\partial}{\partial t}\ u(a,t)\}\ da \qquad (30)$$

Using previously way, in order to calculate integral (30), it’s necessary to:

- determine derivative of u(a,t) function with respect to time;
- find antiderivative of a function (30).

Determination of derivative of function (26) was realized in following way:

$$\frac{\partial}{\partial t}\left[u(a,t)\right]=\underbrace{\left(\frac{1}{\sqrt{2\pi\ \ A(t)}}\right)'}_{D}\ e^{-\frac{(a-B(t))^2}{2A(t)}}+ +\left(\frac{1}{\sqrt{2\pi\ A(t)}}\right)\cdot\underbrace{\left(e^{-\frac{(a-B(t))^2}{2A(t)}}\right)'}_{F} \qquad (31)$$

$$D=\frac{\lambda CM_k^m\ \pi^{\frac{m}{2}}\ E[(\sigma^{max})^m]\ (a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\lambda CM_k^m\ \pi^{\frac{m}{2}}\ E[(\sigma^{max})^m]\ t)^{\frac{2m}{2-m}}}{2\frac{2}{2+m}\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\lambda CM_k^m\ \pi^{\frac{m}{2}}\ E[(\sigma^{max})^m]\ t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}\ ]\ \sqrt{2\pi\ \ A(t)}} \qquad (32)$$

Notation: $\_=CM_k^m\pi^{\frac{m}{2}}E[(\sigma^{max})^m]$ (33)

Hence: $D=-\left(\frac{\lambda\_(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}}{2\frac{2}{2+m}\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}\ ]\ \sqrt{2\pi\ \ A(t)}}\right)$ (34)

Calculation F:

$$F=\left(e^{-\frac{(a-B(t))^2}{2A(t)}}\right)'= =e^{-\frac{(a-B(t))^2}{2A(t)}}\underbrace{\left(-\frac{[(a-B(t))^2]'2A(t)-(a-B(t))^2\cdot 2A(t)'}{4(A(t))^2}\right)}_{G} \qquad (35)$$

Notations:

$$\omega=\frac{E[(\sigma^{max})^{2m}]}{(E[(\sigma^{max})^m])^2} \qquad (36)$$

$$A(t)=\frac{2}{2+m}\_\omega\ \ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}\ ] \qquad (37)$$

$$B(t)=\left\{[a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t]^{\frac{2}{2-m}}-a_o\right\} \tag{38}$$

Calculation G:

$$G=\frac{(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{m}{2-m}}\cdot(a-B(t))\ (\frac{2-m}{2})}{\frac{2}{2+m}\ \omega\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]}+$$

$$+\frac{(a-B(t))^2\ 2\_^2\omega\ \lambda(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}}{2\ \frac{4}{(2+m)^2}\_^2\omega^2\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]^2} \tag{39}$$

Hence, taking equations (34) and (39) into account, equation (31) takes the form:

$$\frac{\partial}{\partial t}[u(a,t)]=-\frac{\lambda\_(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}}{2\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]\ (\frac{2}{2+m})}u(a,t)+$$

$$+\frac{(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{m}{2-m}}\cdot(a-B(t))\ (\frac{2-m}{2})}{\frac{2}{2+m}\ \omega\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]}u(a,t)+$$

$$+\frac{(a-B(t))^2\ \lambda(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}}{2\ \frac{4}{(2+m)^2}\ \omega\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]^2}u(a,t) \tag{40}$$

Antiderivative function in (30) expression, takes the form:

$$w(a,t)=u(a,t)\cdot\theta(a,t) \tag{41}$$

where: *θ(a,t)* is wanted expression.

Derivative of function w(a,t) with respect to crack length should be equal expression (40). Derivative *w(a,t)* function with respect to „*a*" has following form:

$$\frac{\partial w(a,t)}{\partial a}=u'(a,t)\ \theta(a,t)+u(a,t)\ \theta'(a,t) \tag{42}$$

Derivative of *u(a,t)* function:

$$\frac{\partial u(a,t)}{\partial a}=u(a,t)\ \left(-\ \frac{(a-B(t))}{A(t)}\right) \tag{43}$$

Taking (43) into account eq (42) takes the form:

$$\frac{\partial w(a,t)}{\partial a}=u(a,t)\left(-\frac{(a-B(t))}{A(t)}\right)\underbrace{(?)}_{\theta(a,\,t)}+u(a,t)\cdot\ \underbrace{(?)}_{\theta'(a,\,t)} \tag{44}$$

Equation (44) was compared to (40):

$$\left\{\frac{(a-B(t))(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{m}{2-m}}(\frac{2-m}{2})\_}{\frac{2}{2+m}\ \omega\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]\_}+\right.$$

$$+\frac{(a-B(t))^2\ \lambda(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}\ \omega\_^2}{2\ \frac{4}{(2+m)^2}\ \omega\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]^2\omega\_^2}-$$

$$\left.-\frac{\lambda\_(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}\_\omega}{2\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]\ \_\omega\ (\frac{2}{2+m})}\right\}u(a,t)=$$

$$=u(a,t)\left(-\frac{(a-B(t))}{A(t)}\right)\underbrace{(?)}_{\theta(a,\,t)}+u(a,t)\theta'(a,t) \tag{45}$$

Using equation (45), following equation was obtained:

$$u(a,t)\left\{\frac{(a-B(t))(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{m}{2-m}}(\frac{2-m}{2})\_}{\frac{2}{2+m}\ \omega\_[(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]}+\right.$$

$$\left.\frac{(a-B(t))^2\ \lambda\omega\ \_^2(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}}{2\ \frac{4}{(2+m)^2}\ \omega^2\_^2\ [(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]^2}\right\}=$$

$$=u(a,t)\left(-\ \left(\frac{(a-B(t))}{A(t)}\right)\right)\ \underbrace{(?)}_{\theta(a,\,t)} \tag{46}$$

$$u(a,t)\left\{-\frac{\lambda\_^2\ \omega\ (a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}}{2(\frac{2}{2+m}\ )\_\omega[(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2+m}{2-m}}-a_o^{\frac{2+m}{2}}]}\right\}=$$

$$=u(a,t)\ \theta'(a,t) \tag{47}$$

Using equation (46), *θ(a,t)* function was determined:

$$\theta(a,t)\left[-(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{m}{2-m}}(\frac{2-m}{2}\ )\_-\right.$$

$$\left.-\ \frac{(a-B(t))\lambda\omega\_^2(a_o^{\frac{2-m}{2}}+\frac{2-m}{2}\_\lambda\ t)^{\frac{2m}{2-m}}}{2A(t)}\right] \tag{48}$$

Derivative of (48) function with respect to „*a*" takes the form:

$$\frac{\partial\theta(a,t)}{\partial a} = -\frac{\lambda\omega\_^{2}\left(a_o^{\frac{2-m}{2}} + \frac{2-m}{2}\_\lambda\ t\right)^{\frac{2m}{2-m}}}{2A(t)} \qquad (49)$$

Received derivative gave the proof of equation (47) correctness.

Equations (46), (47), (48) i (49) have following notations: *B(t)* - given by equation (38), *A(t)* - given by equation (37), *ω* - given by equation (36), Ĉ- given by equation (33).

Hence, expression described antiderivative of function (30) has following form:

$$w(a,t) = u(a,t)\left[-\left(a_o^{\frac{2-m}{2}} + \frac{2-m}{2}\_\lambda\ t\right)^{\frac{m}{2-m}}\left(\frac{2-m}{2}\right)\_ - \frac{(a-B(t))\lambda\omega\_^{2}\left(a_o^{\frac{2-m}{2}} + \frac{2-m}{2}\_\lambda\ t\right)^{\frac{2m}{2-m}}}{2A(t)}\right) \right] \qquad (50)$$

Calculation of the integral (30) gave opportunity to determine flying time density function for the period of time when fatigue crack growth achieves limiting value:

$$f(t;a_d) = w(a,t)\Big|_{a_d}^{\infty} =$$

$$= u(a_d,t)\left[\left(a_o^{\frac{2-m}{2}} + \frac{2-m}{2}\_\lambda\ t\right)^{\frac{m}{2-m}}\left(\frac{2-m}{2}\right)\_ + \right.$$

$$\left. + \frac{(a+B(t))\lambda\omega\ \_^{2}\left(a_o^{\frac{2-m}{2}} + \frac{2-m}{2}\_\lambda\ t\right)^{\frac{2m}{2-m}}}{2(A(t))} \right] \qquad (51)$$

where: $u(a_d,t) = \frac{1}{\sqrt{2\pi\ A(t)}}\, e^{-\frac{(a_d-B(t))^2}{2A(t)}}$

Equation (51) determines fatigue life of selected structural elements in using condition at a given spectrum of load and for Paris formula with coefficient m≠2.

5. Conclusion

Determined, in this paper, flying time density function for the period of time when fatigue crack growth achieves limiting value is very important for aircraft's structure durability research. Presented in second item equation can be expressed as a dependent on calendar time and combined with number of aircraft's flights.

The main advantage of the method is fact that takes into consideration random value of aircraft's structure loading. Using of this method can contribute to decrease of durability calculation time. Value of used constants and others required values can be estimate with aid of maintenance data and using method of moment or reliability function.

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ANALYSIS OF THERMAL CENTRE FAILURING

Thermal centre failuring is the cause of high costs for the companies administering the centres, its consequences influence heat recipients. Since failuring occurs mostly during the periods of the greatest demand for heat (autumn-winter-spring), and the fact that thermal centres are exploited throughout the whole year, there is a necessity to monitor their technical condition. That is why introducing failure analysis is crucial to identify the effects causing malfunctioning of individual elements of a given thermal centre.

***Keywords**: thermal centre, failuring, analysis.*

1. Introduction

A thermal centre is a complex technical system, which is to convey heat of precisely defined parameters and amount from the heat distribution network to recipients. Thermal centres are a part of heat distribution systems (a subsystem) and at the same time they constitute an administrative border between the heat distribution network user (a heat producer), and the inner system user inside a heated building (a heat recipient). Figure 1 presents a block diagram of a heat distribution system.

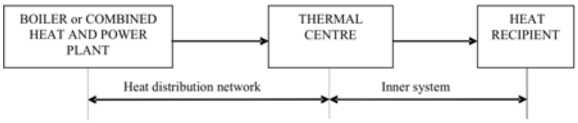

Fig. 1. Block diagram of a heat distribution system

Considering the importance of thermal centres, it is crucial for them to be highly reliable since the costs of heat supply intervals are incurred by both the thermal centres users as well as the recipients.

The only way to increase the reliability of thermal centres is to analyse the causes of their failuring, which will make it possible to identify and eliminate the factors causing failures in the future.

Thermal centres are classified according to various criteria, which very often, thanks to their complexity, do not render their individual features. Figures 2 and 3 present demonstration diagrams of a thermal centre.

1.1. Thermal centre components

- pipelines:
- automatic regulation sets comprising of :
  - regulators:
    - with a discontinuous output signal (double, triple, and impulse),
    - with a continuous output signal (pneumatic, hydraulic and electric);
- measuring systems:
  Physical quantities, whose measures are taken are as follows: temperature, pressure (differential pressure) and the flux or the heating factor volume;
- actuator:
  - regulation valves,
  - servo-motors valves;
- protective elements (safety valves);
- elements replenishing water depletion within an installation;

Replenishing water depletion within an installation powered by a thermal centre takes place from the heat distribution network (from the primary pipe). Crucial elements of each replenishing system are cut-off valves and a water-meter for measuring water to be replenished;

- stabilising elements:
  - diaphragmatic expansion tank for boiler,
  - pressure stabilisers.

Stabilisers constitute of : a pump, a tank and automatic pressure regulators, which include a pressure sensor, a regulator and an electro-magnetic valve.

- heat exchangers;
- pumps.

2. Analysis of thermal centre failuring

Decomposing a thermal centre makes it possible to analyse its structure. Figure 4 shows a sub-division of a given thermal centre to be analysed as well as its basic components.

Red-marked elements are the ones which were notified broken in the data base. Thermal centre decomposition was conducted up to level 2 which indicates that the composition of individual elements was of minor importance, and consequently the causes of failuring were not estimated every time it was malfunctioning

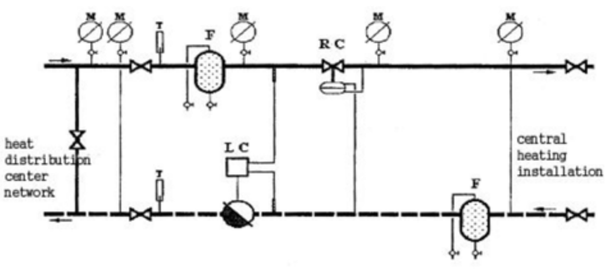

Fig. 2. Thermal centre diagram of direct connection without parameter transformation [2]: RC – differential pressure regulator, LC – heat meter, F – sludger filter

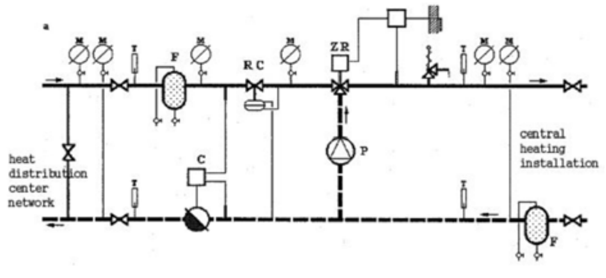

Fig. 3. Pump mixing node diagram with a pump in the mixing circuit [2]: RC – differential pressure regulator, P – mixing pump, C – heat meter, F – sludger filter, ZR – control valve

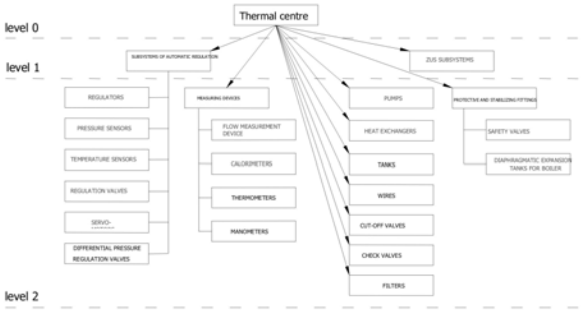

Fig. 4. Thermal centre decomposition

(in the data base provided by Toruńska Energetyka Cergia SA only few devices were provided with the exact cause of their failure).

Failure of a given device leads to entire thermal centre breakdown (even though in some cases the centre could still complete some of its functions) and consequently it is vital to take actions in order to make it fully efficient. There are 2 kinds of actions: repairing or replacing a broken device with a new one of the same or better parameters. When it comes to pressure stabilisers only repairing is possible since this system is viewed to be complete and connected (there haven't been a single case of simultaneous replacement of all the elements at once).

For the purpose of this analysis failuring rates have been enumerated - w_u. This rate stands for the quotient of the number of failures of a given device throughout the whole year and the general number of failures noted during the year.

Table 1 presents the number of thermal centres maintained by the Toruńska Energetyka Cergia SA at the time of research.

2.1. Failures of pressure stabilisers (ZUS)

There were 343 failures during the time of research. The greatest number of them occurred in 2004, namely 67 failures (19%), the smallest – 8 failures (2%) – in 1997. As presented in Table 6 up till 1999 the number of failures was minute, approximately 12 occurrences a year, whereas between 2000-2005 the average number of failures rose up to 47. The year 2000 constitutes a distinct boundary separating those two periods, this is when the number of failures rose noticeably (from 13 in 1999 up to 64 in the year 2000).

In the case of pressure stabilisers actions to be taken to make them efficient and operational comprise only of repairs which also included replacing some parts with brand new ones, such as a pump or a regulator. Not a single case of replacing the entire pressure stabiliser with a new one was identified. The failuring rate w_u is presented in Tab. 2.

2.2. Calorimeter failures

Within the research period there were 2366 calorimeter failures. Most of them were noted in the year 2002 – 908 (38%), the smallest number in 1995 – 41 (1,7%). Throughout the whole research period the number of failures in the following years increases or decreases against previous years, however no noticeable deviations could be observed (the greatest variation is to be depicted between 1996 and 1997, when the number of failures increases by 125, which accounts for 5,2% of the general number of events). The year 2002 is exceptional, as the number of failures increases dramatically (in comparison to 2001 the number of failures rises by 744 which accounts for 31,45% of all events of that kind during the researched period). It is closely connected with the fact that in the year 2002 there was a change in the Law on Measures thus some calorimeters installed between 1994-99 could no longer be viewed reliable and lost their measuring properties (the law defined the correct properties of a calorimeter, whereas in Poland before that time there were various solutions applicable connected with storing data, display format, etc.). Some calorimeters needed to be legalised. Having operated for 5 years calorimeters with a blade circulation transducer have to be taken for a major overhaul, whose costs come to 80% of the price of a new one – therefore, in the result of a tender, the calorimeters which did not meet the criteria of the new law were replaced.

Actions to be taken in order to bring the devices back to their original shape were: replacements with new ones 43% (1028 cases) and repairs 57% (1338 cases).

Calorimeter failuring rate w_u is presented in Table 3.

2.3. Pump failures

Between 1995-2005 there were 146 pump failures, with the greatest number – 48 (33%) in the year 2005, and the smallest – 2 (1,36%) – noted in 1996, 2002 and 2003.

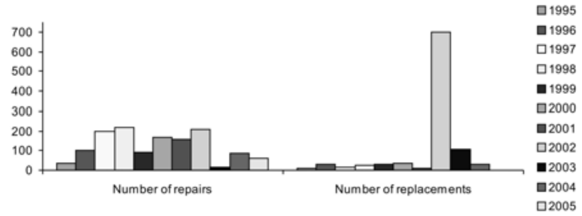

Fig. 5. Calorimeter failures

Tab.1. The number of thermal centres.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Number of centres	1209	1225	1229	1249	1269	1294	1333	1349	1340	1358	1385

Tab. 2. Failuring rate for pressure stabilisers

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
w_u	0,0500	0,0349	0,0112	0,0218	0,0269	0,0856	0,0602	0,0249	0,0927	0,1115	0,0657

Tab. 3. Calorimeter failuring rate:

	1995r	1996r	1997r	1998r	1999r	2000r	2001r	2002r	2003r	2004r	2005r
w_u	0,1708	0,3267	0,3570	0,3769	0,2479	0,2375	0,3527	0,5795	0,2520	0,1947	0,1073

In the years 2004 and 2005 there was a dramatic increase in the number of replacements in accordance with the company's invest plans. UPE pumps were purchased and fitted to suit central heating purposes and UPS pumps for hot useful water. Pumps used before that time had gland sealing between the engine and the pump connected with the atmosphere. 80% repairs of the above mentioned pumps dealt with replacing that sealing and the bearings, which were flooded resulting from the sealing damage. UPE pumps are constructed in such a way that the connection of the engine and the pump is inside it and it is flooded with water all the time.

Actions taken to bring pumps back to their original shape were 58% repairs (85 cases) and 42% replacing with new ones (61 cases).

Pump failuring rate w_u is presented in Table 4.

2.4. Pressure transducers failures

Within the research time pressure transducers were out of order 31 times. Most failures – 12 (39%) were noted in 2005, whereas in 1995-1997, 1999, 2001-2003 no damages were reported.

Actions taken in order to bring pressure transducers back to their original shape were 71% (22 cases) repairs and 29% (9 cases) replacing with new ones.

Failuring rate w_u for pressure transducers is presented in Table 5.

3. Analysis of thermal centre failuring

Within the research period there were 6933 thermal centre failures. The greatest number of them - 1567 (22%) occurred in 2002, whereas the smallest in 1995 – 240 (4%). During that time there were 4740 repairs and 2193 replacements with new ones which respectively stands for 68% and 32% of all the actions taken in order to restore the thermal centres' usability. The greatest number of repairs and replacements with new ones was noted in 2002 - 566 and 1001 respectively. Table 6 presents the quantification of thermal centre failures.

According to the data presented in Table 6, apart from the year 2002, the number of all failures per one centre was smaller than 1. The year 2002 is exceptional since in that time a great number of calorimeters and devices measuring the flow had to be replaced. The year 1995 is the most efficient since the rate is 0,20.

In 2002, 65% of centres failed, whereas in 1995, only 170 centres failed which constitutes 14% of all the centres.

4. Analysis according to maximal and minimal criteria of w_u rate

Table 7 presents the figures of failuring rate of all the elements analysed during the researched period. Table 8 presents the greatest failuring rates throughout the years. According to Table 7 between 1995-2005 calorimeters and servo-motors were most prone to failure. During six (1996, 1997, 1998, 2000, 2001, 2002) out of 11 years of the researched period it is calorimeters that have the greatest failuring rate. In 2002 it is extremely high - 0,5795 and its rate is the greatest from amongst all the maximum failuring rates noted at the time of the research. During the remaining 5 years (1995, 1999, 2003, 2004, 2005) is it servo-meters that have the highest failuring rate.

5. Summary

According to the results of the research the greatest part in the failuring structure during the researched period belongs to failures of calorimeters and servo-motors. Their failures constitute respectively for 34,13% and 20,64% of all the causes of thermal centre failuring. The smallest part belongs to failures of exchangers and safety valves - respectively 0,10% and 0,12% of all the failures. For calorimeters and servo-motors, whose failures constitute for over 50% of all the thermal centre failures

Tab. 4. Pump failuring rate

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
w_u	0,0167	0,0050	0,0139	0,0140	0,0310	0,0238	0,0151	0,0013	0,0040	0,0449	0,0830

Tab. 5. Failuring rate w_u for pressure transducers

	1995r	1996r	1997r	1998r	1999r	2000r	2001r	2002r	2003r	2004r	2005r
w_u	0,0000	0,0000	0,0000	0,0031	0,0000	0,0107	0,0000	0,0000	0,0000	0,0133	0,0208

Tab. 6. Quantification of thermal centres' failures

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Number of failures	240	401	717	642	484	748	465	1567	496	595	578
Number of failed centres	170	251	389	395	321	451	294	882	345	358	324
Complete number of all the centres	1209	1225	1229	1249	1269	1294	1333	1349	1340	1358	1385
Number of failures per one centre	0,20	0,33	0,58	0,51	0,38	0,58	0,35	1,16	0,37	0,44	0,42
% of failed centres	14,06	20,49	31,65	31,63	25,30	34,85	22,06	65,38	25,75	26,36	23,39

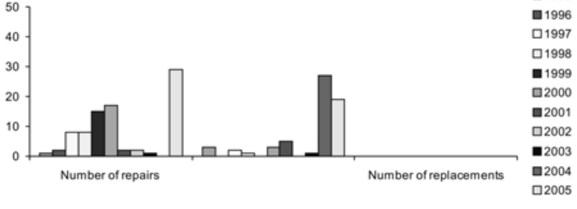

Fig. 6. Pump damages

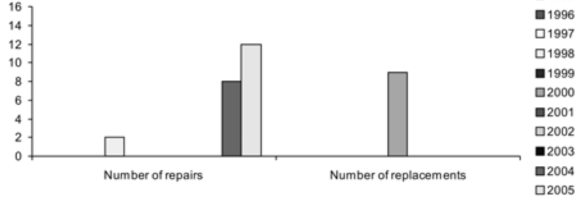

Fig 7. Pressure transducers failures

Tab. 7. Figures of failuring rate w_u noted during the researched period

		w_u										
Lp.	Device	1995r	1996r	1997r	1998r	1999r	2000r	2001r	2002r	2003r	2004r	2005r
1	ZUS	0,0500	0,0349	0,0112	0,0218	0,0269	0,0856	0,0602	0,0249	0,0927	0,1115	0,0657
2	Servo-motor	0,3083	0,2095	0,1478	0,1978	0,2541	0,1698	0,1914	0,1078	0,3327	0,2962	0,3270
3	Calorimeters	0,1708	0,3267	0,3570	0,3769	0,2479	0,2674	0,3527	0,5795	0,2520	0,1947	0,1073
4	Flow measuring devices	0,1708	0,1446	0,1353	0,1044	0,1653	0,1524	0,1355	0,2017	0,0786	0,0682	0,0640
5	Pumps	0,0167	0,0050	0,0139	0,0140	0,0310	0,0267	0,0151	0,0013	0,0040	0,0449	0,0830
6	Regulators	0,1292	0,1072	0,2120	0,1651	0,1901	0,2019	0,1570	0,0562	0,1512	0,1664	0,2163
7	Regulation valves	0,0375	0,0499	0,0265	0,0421	0,0269	0,0160	0,0151	0,0038	0,0282	0,0266	0,0277
8	Pressure sensors	0,0125	0,0050	0,0070	0,0093	0,0227	0,0040	0,0129	0,0006	0,0000	0,0000	0,0000
9	Temperature sensors	0,1042	0,1172	0,0893	0,0654	0,0351	0,0642	0,0602	0,0243	0,0605	0,0549	0,0761
10	Pressure transducers	0,0000	0,0000	0,0000	0,0031	0,0000	0,0120	0,0000	0,0000	0,0000	0,0133	0,0208
11	Safety valves	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0067	0,0069
12	Exchangers	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0067	0,0052

Tab. 8. Maximal w_u rates noted during the researched period.

	1995r	1996r	1997r	1998r	1999r	2000r	2001r	2002r	2003r	2004r	2005r
name	Servo-motors	Calorimeters	Calorimeters	Calorimeters	Servo-motors	Calorimeters	Calorimeters	Calorimeters	Servo-meters	Servo-meters	Servo-meters
w_u	0,3083	0,3267	0,3570	0,3769	0,2541	0,2674	0,3527	0,5795	0,3327	0,2962	0,3270

an exception to the rule was made at the stage of formulating preliminary assumptions for the analysis. Therefore, decomposition of the thermal centre was expanded up to the level 3. It is crucial, however, to remember that the causes of calorimeters and servo-motors failuring were defined on the basis of partial data analysis – the one providing precise and unequivocal descriptions of failuring of the above mentioned devices.

Failures connected with batteries going dead were filed only if the battery went dead before its nominal time (provided by the producer).

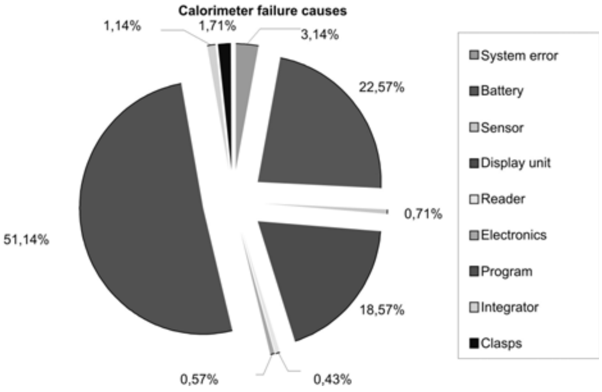

Fig. 8. Causes of calorimeter failures

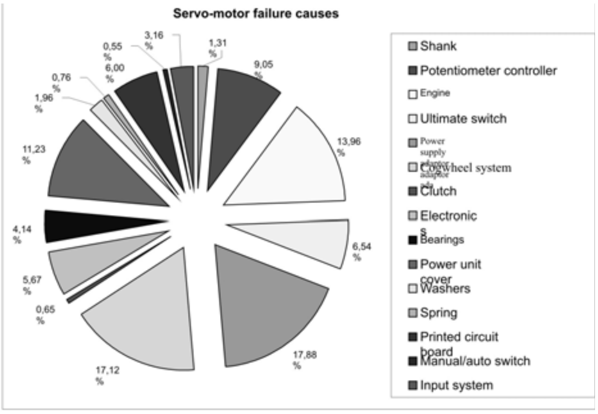

Fig. 9. Causes of servo-motor failures

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OPERATIONAL EFFECTIVENESS OF A SIEVE-AERODYNAMIC SEPARATOR UNDER THE CONDITIONS OF THE VARIABLE LOAD OF SIEVES

It was found on the basis of the testing conducted that the supporting air flow essentially affected the effectiveness of the aerodynamic separation on a laterally inclined sieve. As a result of the choice of the air flow in side fans the zones of increased cleaning effectiveness were determined.

***Keywords**: cleaning unit, fan output, shutter sieve, grain purity, grain losses.*

1. Introduction and objective of the testing

The sieve-aerodynamic separation process in cereals combine-harvesters operating in mountainous areas is subject to a disadvantageous impact of the area inclination [3, 6]. On slopes of an inclination above 10° the operational quality of combine-harvesters provided with flat shutter sieves worsened considerably [1, 2, 4]. The decrease in the separation effectiveness under those conditions is due to the gravitational displacement of the threshing mass separated from the straw (grain, minor straw fractions, chaff, etc.) onto the lower-located side of the sieves of the cleaning unit and its local overload. In order to eliminate the negative effects of the operation of the inclined cleaning unit the model of a sieve-aerodynamic separator was made at the Agricultural Engineering Institute of the Wrocław University of Environmental and Life Sciences in which, in addition, a lateral system of nozzles that directs the regulated air flow under the top shutter sieve was implemented to the conventional central blowing system [5]. The operational parameters of the sieve-aerodynamic separator should be optimized taking into account two criteria: the level of air purity obtained and the size of generated losses. Tending towards the optimization of those indexes, variations of the cleaning air flow rate and variations of the air flow direction were assumed.

Considering the foregoing, the aim of this paper is to present the impact of the multidirectional air flow rate at the operation of the sieve-aerodynamic separator under the conditions of an inclination.

2. Testing methodology

A test bench designed and made at the Agricultural Engineering Institute of the Wrocław University of Environmental and Life Sciences was used to perform the testing (Fig. 1).

The basis constituted a sieve separator maintaining the geometrical and kinematical parameters of the sieve that is generally used on Bizon combine-harvesters. The test bench was provided with a system of lateral nozzles that allow obtaining the proper size of the aerodynamic flow directed locally under the top cleaning sieve. A screen was mounted on the test object the goal of which was to catch the mass of well-aimed wheat grains leaving the area limits of the sieve basket.

The first stage of the testing comprised the measurements of the impact of the side air flow on the grain purity under the sieve surface at various outputs of the air flow-generating fans.

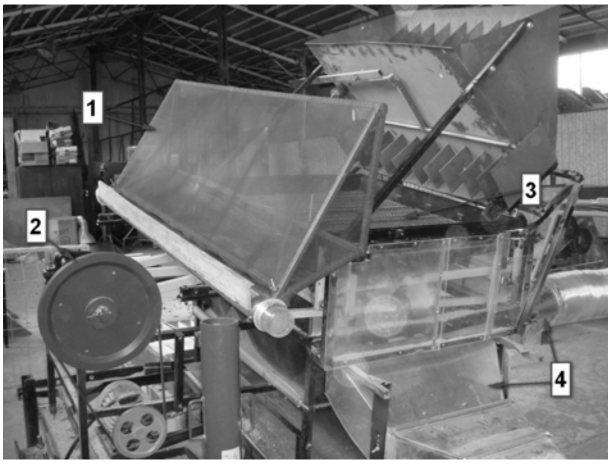

Fig. 1. View of the test bench provided with the air multi-flow unit and the grain catching screen: 1-shield, 2-power transmission system, 3-sieve, 4-nozzles

Upon starting the test bench the grain mass subject to the interference of the air flow was falling to fifty measurement containers disposed under the sieve basket (Fig. 2). Afterwards the contents of the containers were weighed by separating the mass of impurities.

The measurements of the separator losses consisted in catching, using the screen, the grain leaving the area limits of the sieve basket. The following conditions were maintained during the performance of the testing of grain purity and losses: the working sieve slot h=7mm (data for the top sieve of the Bison combine-harvester - wheat), the side inclination of the sieve basket was α=10°, the longitudinal inclination of the sieve basket

Fig. 2. Disposition of the measurement containers under the sieve being tested

was β=-5°, the supply of the sieve with the grain flow was 3,5 kg·s^{-1}.

The testing was performed at the following outputs of the fans:

- main fan WGŁ only switched on with the outputs (Q_I, Q_{II}, Q_{III}, Q_{IV}, Q_V),
- main fan WGŁ (Q_{II}) and side fan WB switched on (Q_1, Q_2, Q_3, Q_4, Q_5),
- main fan WGŁ (Q_{III}) and side fan WB switched on (Q_1, Q_2, Q_3, Q_4, Q_5).

where:

$$\boxed{\text{WGŁ}} \begin{cases} Q_I=0{,}66\ \mathrm{m^3 \cdot s^{-1}} \\ Q_{II}=0{,}95\ \mathrm{m^3 \cdot s^{-1}} \\ Q_{III}=1{,}22\ \mathrm{m^3 \cdot s^{-1}} \\ Q_{IV}=1{,}58\ \mathrm{m^3 \cdot s^{-1}} \\ Q_V=1{,}90\ \mathrm{m^3 \cdot s^{-1}} \end{cases} \qquad \boxed{\text{WB}} \begin{cases} Q_1=1{,}01\ \mathrm{m^3 \cdot s^{-1}} \\ Q_2=1{,}28\ \mathrm{m^3 \cdot s^{-1}} \\ Q_3=1{,}50\ \mathrm{m^3 \cdot s^{-1}} \\ Q_4=1{,}73\ \mathrm{m^3 \cdot s^{-1}} \\ Q_5=1{,}95\ \mathrm{m^3 \cdot s^{-1}} \end{cases}$$

3. Test results

In the first testing stage the impact and the effectiveness of the cleaning air flow on the grain purity and losses was assessed. Figure 3 presents the variability of the purity indexes for the screened-out cereal mass. The generated air flow QII from the main fan WGŁ allows obtaining the purity deemed sufficient at ca. 97% in the zone (A) only. As the screened-out mass displaces towards the sieve outlet the indexes decrease, reaching 94,21%. The results obtained indicate clearly that the transverse inclination of the sieve basket at the angle α=10° significantly worsened the cleaning operation on the shutter sieve when supplied with the main fan WGŁ only.

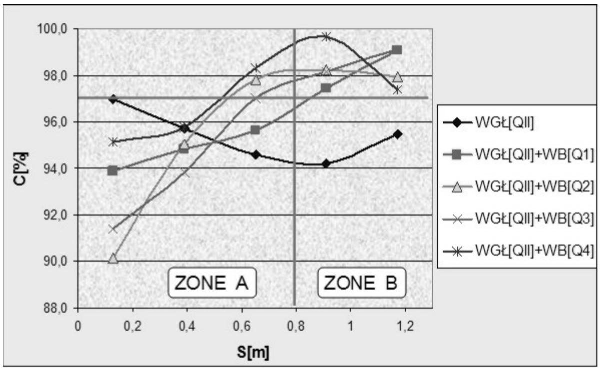

Fig. 3. Runs of the grain purity indexes C[%] of the screened-out cereal mass in relation to the working width S[m] of the sieve separator

When studying the function curve runs presented on the diagram it can be stated that the use of an additional – side air flow (side fan WB switched on) considerably affected the run of the purity indexes, first of all in zone B. Upon supplementing the air flow from the main fan WGŁ with the air flow from the side fan WB with a gradually increasing output there follows a considerable rise in the purity indexes obtained. The highest value of the purity index exceeding 99,0% is observed for the system WGŁ(Q_{II})+WB(Q_4).

A second component of the testing conducted was to determine the impact of the air flow of a various output on grain losses.

The variability of the parameter of average grain losses depending on the air flow rate Q in the air flow from the main fan WGŁ is presented in Figure 4. The analysis of the diagram showed that the one-directional air flow generated by the main fan WGŁ shaped the level of the grain loss index at the acceptable level up to 2,5%. At the air flow rate of 1,90 m3 ·s^{-1} the level of average losses did not exceed 0,54%.

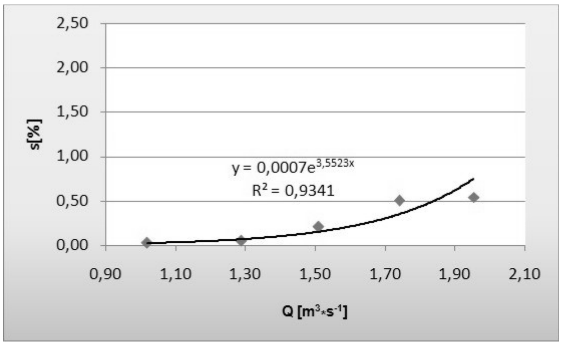

Fig. 4. Impact of the air flow Q[m^{3}s^{-1}] on the level of average losses s[%] in the system with the main fan WGŁ generating a longitudinal air flow

The diagrams of the grain loss variability in function of the air flow rate from the side fan Q_B are shown in Figure 5. The obtained diagrams of average losses were measured at two constant settings of the main fan output Q_{II}=0,95 m^3 ·s^{-1} and Q_{III}=1,22 m^3 ·s^{-1}. Thus the determined levels of average grain losses are the result of the summary interference by the main and side fans. It can be seen that the level of average grain losses grows jointly with the rise in the „summary" air flow rate. The diagram of that relationship has the nature of a growing exponential function. The size of the determination factors R^2 shows a good matching of the runs of the tendency curve lines to the variability of the determined average magnitudes. Both in the group of lower flow rates Q_{II} and in that of higher flow rates Q_{III} there follows the excess of permissible losses by -2,5%.

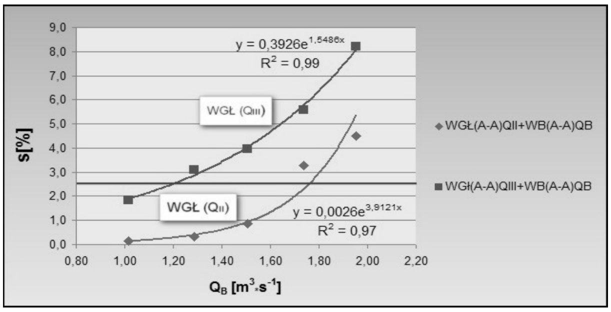

Fig. 5. Impact of the air flow rate QB[m^{3}s^{-1}]on the level of average grain losses s[%]

With the assumed constant values of the main fan outputs Q_{II} and Q_{III} the outputs of the side fans WB were changing within the range of Q_B = 1,01-1,95 m^3 ·s^{-1}.

The highest level of losses for the main fan and side fan system (WGŁ+WB) was observed for the main fan output at the level Q_{III} equal to 1,22 m^3 ·s^{-1}. The excess of the level of permissible losses followed at the output Q_B already above the value of 1,29 m^3 ·s^{-1}.

4. Conclusions

1. The use of a longitudinal air flow from the fan with standard parameters for the Bizon combine-harvester results, at the side inclination of the sieve, in the lowering of purity indexes down to ca. 94% while maintaining relatively low grain losses at the level of 0,54%.
2. Both in the system of the one-flow air supply and multi-flow air supply the rise in the air flow rate results in a rise of grain purity indexes with a simultaneous level of grain losses.
3. The analysis of tendency curves has showed that the limit level of the air flow rate in the multi-flow system should not exceed the value of $Q_B = 1{,}20\ m^3 \cdot s^{-1}$ at the set constant output of the main fan Q_{III}, and the value $Q_B = 1{,}7\ m^3 \cdot s^{-1}$ for the constant output of the main fan Q_{II}.
4. The results obtained show a need for a multi-flow supply of the sieve with air relatively to its surface load and the use of the Monte-Carlo optimization procedure for the determination of both the air flow rates from the main fan WG and the side fan WB.

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SYSTEMS OF SUPPORTING THE SUPERVISION OF THE OPERATIONAL SAFETY OF STEAM TURBINES

The possibilities of supervising the operation of thermal turbines enabling the tracking and prevention of events that may lead to serious failures are discussed. The algorithms of the monitoring the thermal stress levels of particular components are presented, together with brittle cracking hazards on the grounds of failure diagrams. The algorithms are based on typical quantities measured and recorded by the measurement systems of power units as well as on the material characteristics obtained from non-destructive tests.

***Keywords**: steam turbine, operation, supervision, safety.*

1. Introduction

The operational safety of any machine or equipment is a crucial issue that must be addressed in each phase of their life, especially if they pose big potential hazards to people and the environment. Such is the case of power machines and equipment used in Polish power plants. An additional factor that compels more intensified monitoring procedures is their long operational life.

Most basic power units with the capacity of 120 MW, 200 MW, 360 MW and 500 MW, installed in Polish power plants have already been operated for over 200 thousand hours. This means that the material state of their main components, i.e. boilers and turbines, may show the signs of substantial wear. The aging processes, such as fatigue, creep, erosion, corrosion, have lead to considerable decrements in their durability. This problem is particularly important in the case of turbines, the failure of which may cause serious consequences. Hence, on-line monitoring of the operation of power systems is a very important issue that secures their safety. The algorithms of tracking the state of stresses and cracking hazards of turbine rotors discussed in the paper can contribute to the improvement of their operational safety.

2. Methods of modeling the strength states

Modern techniques of measuring the thermal stresses in power machine components are faced with many application difficulties, especially as far as rotors of steam turbines are concerned, where direct measurements are impossible. In the engineering practice, two methods of temperature indirect measurements, are used:

- the characteristic temperatures difference (ΔT) in a stationary component,
- the temperature derivative (dT/dt) at selected points of the internal or external surface of the stationary component.

In the characteristic differences measurement method the differences between the mean temperature of the cylinder wall thickness or valve and the internal surface temperature are measured. The latter measurement is taken at a certain distance from the internal surface of the component. Also, dynamical changes in the temperature of the working medium bear additional measurement errors, as, in such case, the temperature measured in the middle of the component wall is not a mean value. Another disadvantage of such solution are disturbances of the temperature field in the component wall evoked by massive shields of the thermocouples. It may be proved that the measurement of the differences in temperature enables its comprehensive correlation with the thermal stresses in a given component only in the steady state.

The method based on the measurements of the heating up rate may be used in the case of the quasi-stationary state in the component wall [1], which is reached after long-lasting heating up of the component at constant speed. Accordingly, the method is unsuitable for the supervision of transient states, which pose the greatest hazards in the course of the power unit operation.

Turbine Stress Controller (TSC) is one of the most popular systems used for current control of stresses [2]. The system is based on the measurements of the temperature differences treated as measures of the thermal stresses of the material in the turbine components and the subsequent comparison with the limit values. The temperature measurements are taken at the most critical points of the turbine casing. The temperature distribution in the turbine rotor is electronically simulated, assuming one measurement of the casing internal surface. This enables, although with certain approximation, the designation of the temperature of the casing surface, constituting the basis for further calculations of the total mean temperature of the rotor.

STREMO [3] is another system of calculating thermal stresses which uses the mathematical models that describe the non-stationary temperature distribution in critical components. The thermal stresses are calculated from the measurement of the difference between the mean wall temperature T_m (measured in the middle of the wall) and the temperature taken from the internal wall surface T_w. Such system, cooperating with MARCO, makes it possible to determine current limit loads and prevents unwelcome stresses in the thick-walled components, shortening the duration of the start-up phase and reducing thermal losses during the most dynamical unsteady states.

TENSOMAX [4] is yet another system enabling the monitoring of thermal stresses in steam turbine components. It is especially useful when there is no access to the temperature measurements from the most important machine components, or when such measurements are impossible. Three basic parameters, usually available under operational conditions, are measured within the framework of this system: steam pressure measured in the vicinity of the critical components of the turbine rotor, and the pressure and temperature of the outlet steam taken within the outlet area. The corresponding heat transfer coefficients α are calculated on the grounds of the mathematical models of the system. The models are based on the results of experimental tests on thermal conduction of a geometrically similar turbine rotor model, in the vicinity of the critical zone.

2.1. Analysis of the representation of the temperature field in the rotor

To check the possibility and accuracy of the representation of the temperature distribution in the rotor, by means of the measurements taken in the casing wall, calculations were made on a simplified geometrical model of the rotor and casing in the zone of the turbine control chamber (Fig. 1.). The diameters and wall thicknesses correspond to real components. The initial thermal state of the model of the rotor and casing was assumed to be on the same level. The changes in the steam temperature surrounding the external surface of the rotor and the inner surface of the casing, as well as the graphs of convective heat-transfer coefficients on these surfaces at start-up are shown in Fig. 2. The measurement points corresponding to the location of the thermocouples were assumed as diameters: ϕ1343, ϕ1210, ϕ1076. Such diameters represent shallow measurements (point K_1), measurements taken in the middle of the wall thickness (point K_2), and deep measurements (point K_3) in the casing. Points W_1, W_2 and W_3 designated in the rotor constitute a reference base to the simulation of the temperature distribution corresponding to the thermal states of the casing. Accordingly, it is possible to designate two values of the temperature differences in the casing (ΔTk_1 and ΔTk_2) and two values of the temperature differences in the rotor, that is: ΔTw_1 and ΔTw_2.

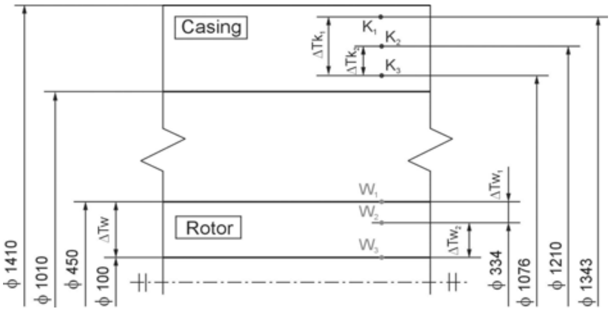

Fig. 1. Geometrical model of the control chamber in the HP part of the turbine, with designated measurement points

The analysis of the changes in the distribution of the temperature fields in the course of simulated start-up, while describing the temperature differences in the assumed points of the casing and the rotor, also enable the determination of the corresponding differences ΔTk and ΔTw. The changes in the increase of temperature ΔTk_1 and the corresponding ΔTw_1 were shown in Fig. 3. A big scatter of the values is clearly noticeable. Such picture is far from the expected linear nature of the changes. The differences between the approximation line and the measured values are too big to assume the credibility of the measurements that should reflect the thermal state of the rotor by means of representing the temperature distribution in the casing. Hence, the stresses calculated on the grounds of such measurement do not show the exact state of the rotor stresses. Hence, another method is needed to represent the exact state of stresses in the rotor, for example, the method based on Duhamel's integral presented below [5-8].

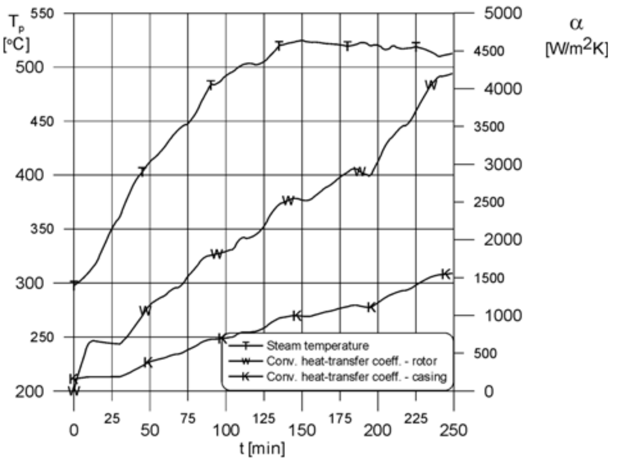

Fig. 2. Graphs of steam temperature and convective heat-transfer coefficients for a model of the control chamber in the HP part of the turbine

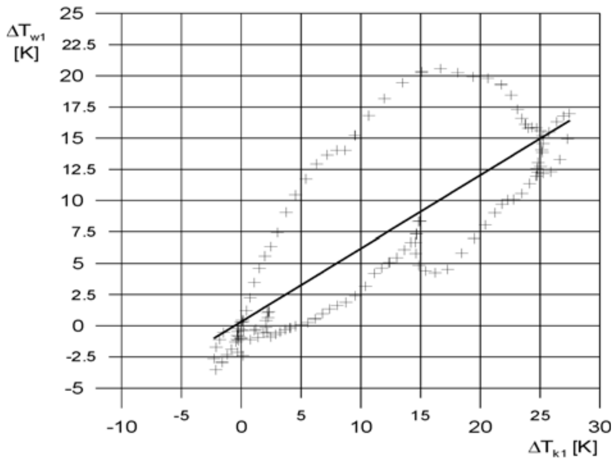

Fig. 3. Dependence between temperature increases in the rotor and the casing $\Delta Tw_1 = f(\Delta Tk_1)$

3. Duhamel's integral method

The algorithms calculating elastic thermal stresses on the grounds of Duhamel's integral take advantage of the principle of superposition and of the so called influence functions in the form of Green's function. Such dependence refers the values of thermal stresses to temperature excitations.

Thus, the thermal stresses in any time t may be calculated as:

$$\sigma^T = \int_o^t \frac{dT(\tau)}{d\tau} f(t-\tau)d\tau \tag{1}$$

The influence functions f(t) depict the stress response of the component material to unitary excitation step, i.e. the flux of the heat of the working medium (surrounding a given component) with known temperature and convective heat transfer coefficient α. The functions may be designated by means of the finite elements method (FEM), upon strict determination of the geometrical and material properties of the component, and, in particular, of the boundary conditions of heat exchange. They are determined for different cross-sections of the components and different stress state [7].

Exemplary graphs of the influence functions determined by means of FEM for the point located in the bore of the rotor in the HP part of a high-power turbine are shown in Fig. 4.

The components of mass stresses (in the case of rotating elements) should be added to the thermal stresses calculated from equation (1) at any time t, and, in the case of pressure elements – the stresses evoked by surface loads [9]. Thus, the calculated stresses enable current tracking of the state of effective stresses in the components.

In the next part of the paper, the applications of the algorithm to the analysis of cracking hazards are discussed.

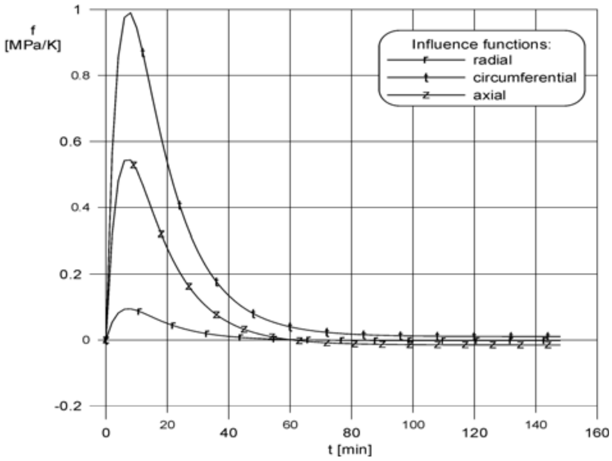

Fig. 4. Influence functions for the point in the bore of the active rotor in the HP part of the turbine

4. Cracking criteria

The method of supervising the cracking of turbine components based on the failure diagrams is often labeled as the double criteria approach – as it combines two different cracking criteria: stress intensity factor K_I and limit loads criterion [10,11].

4.1. Failure diagrams

The failure diagrams define safe and unsafe zones in terms of coordinates K_r-S_r, which are defined as follows:

$$K_r = \frac{K_I}{K_{max}} \qquad S_r = \frac{\sigma_{max}}{\sigma_f} \tag{2}$$

where: $K_I = M\sigma_{max}\sqrt{a}$ – stress intensity factor, M – constant, dependent on the location of the defect in the component, σ_{max} – maximal tensile stress within the defect, K_{max} – limit value of K_I usually assumed as K_{IC}, σ_f – limit value of stress – for a given material – often assumed as $\sigma_f = 0,5\left(R_e + R_m\right)$, R_e – yield stress, R_m – ultimate strength.

In simplified terms, the boundary of the safety zone is a rectangle defined by the following dependence:

$$K_r \le 1 \quad S_r \le 1 \tag{3}$$

In the failure diagrams (Fig. 5) the safety zone is marked by boundary straight lines demarked as a. In consideration of the safety reserve, the above limitation shall take the following form (straight lines marked as *b*):

$$S_r \le 0,8 \tag{4}$$

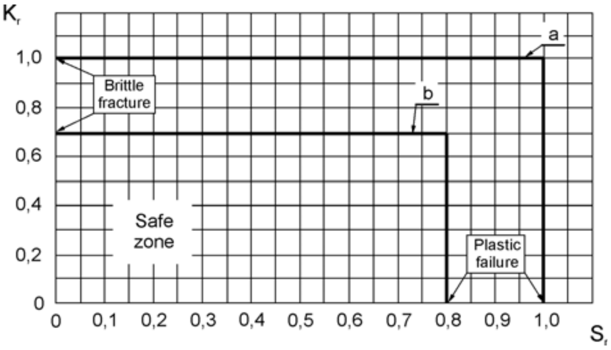

Fig. 5. Simple failure diagrams

More complex models include the cracking enlargement by plasticity zones. This leads to the reduction of the strength of a given material to cracking. The recommended equations may take the following form [11, 12]:

$$K_r = \frac{1}{\sqrt{1 + 0,5\ S_r^2}} \tag{5}$$

$$K_r = \frac{1}{\sqrt{1 + \dfrac{0,5\ S_r^2}{1 - 0,5\ S_r^2}}} \tag{6}$$

$$K_r = \frac{S_r}{\sqrt{\dfrac{8}{\pi^2} ln\,sec\left(\dfrac{\pi}{2} S_r\right)}} \tag{7}$$

The failure graph corresponding to equation (7) is designated in Fig. 6 by curve *c*.

If the graph of the tensile curve *σ-ε* is known for a given operational temperature and a given material, the safety zone may be described by the following equation [11, 12]:

$$K_r = \frac{1}{\sqrt{\dfrac{E \cdot ln\left(1+\varepsilon\right)}{\sigma\left(1+\varepsilon\right)} + \dfrac{\sigma^3\left(1+\varepsilon\right)^3}{2R_e^2 E \cdot ln\left(1+\varepsilon\right)}}} \tag{8}$$

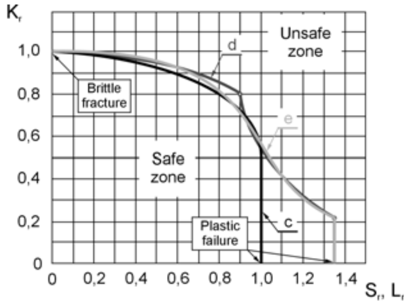

Fig. 6. Failure diagrams for the second and third step of the quality of assessing defects

Sometimes, parameter S_r is replaced by parameter L_r, defined in the following way:

$$L_r = \frac{\sigma_{max}}{R_e} = S_r \cdot 0,5\left(1 + \frac{R_m}{R_e}\right) \tag{9}$$

In such case, the safety zone (for soft steel with definite yield stress) is marked by curve *d* in Fig. 6.

Equation (8) may be simplified for the types of steel without a definite yield stress in the following way:

$$K_r = \left(1 - 0,14 \cdot L_r^2\right)\left[0,3 + 0,7 \cdot exp\left(-0,65 \cdot L_r^6\right)\right] \tag{10}$$

Thus, curve K_r-L_r has the form of curve *e*.

4.2. Propagation of fatigue cracks

The cracking of materials in the course of the processes of fatigue is evoked by nucleation and crack increase. On the grounds of basic knowledge of the rate of fatigue cracking in the range from conventionally assumed initial crack, or other type of defect, to the final failure of the element, it is possible to predict its life under the conditions of allowable propagation of cracks. Accordingly, repairs or replacements of the components may be planned.

The cracking rate *da/dN* expressed as an increase of cracking length da during one operational cycle [mm/cycle, m/cycle] may be described in a general manner by means of the following equations [10, 13]:

$$\frac{da}{dN} = f\left(\sigma, a, C, Y, R, \chi\right) \tag{11}$$

where: σ – stress, expressed as the stress amplitude σ_a or $2\sigma_a = \Delta\sigma$, a – actual cracking length, C – material constants, Y – geometrical parameters of the component, $R = \sigma_{min}/\sigma_{max}$ – coefficient of the asymmetry of the cycle, χ – function representing the record of the load.

In the engineering practice, *Paris – Erdogan* equation is commonly used in the following form:

$$\frac{da}{dN} = c\left(\Delta K\right)^m \tag{12}$$

where: c, m – quantities regarded as material constants that should be designated in the experimental tests; $m \in <2, 7>$, $\Delta K = K_{max} - K_{min}$.

The above equation makes it possible to calculate the increase of potential cracking in turbine rotors caused by the cyclical nature of their operation.

5. Modeling of cracking hazard for rotors in high-power steam turbines

The rotor in the IP part of a high-power turbine during cold start-up was analyzed. The results of modeling cracking hazards were presented in the failure diagram. To describe the rate of potential defects propagation, Paris – Erdogan equation was applied (12).

On the grounds of available data, the minimal value of material toughness K_{IC} assumed in the calculations equaled 30 MPa $\cdot m^{1/2}$ for the temperature of metal below or equal to 100°C. Such option covers the worst possible case. Next, a linear increase of K_{IC} together with the rise of temperature was assumed, up to the value of 60 MPa $\cdot m^{''}$ at the temperature of 400°C, above which K_{IC} remains constant. The yield stress for the rotor material was assumed as a function of metal temperature.

In the modeling of the cracking hazards of the analyzed start-up, the stress component of the highest values was considered, i.e. the stresses that lead to the tear of potential defects.

The potential value of the defect dimensions was designated as a_0, depending, among other factors, on the sensitivity of the measuring equipment, number of operational cycles that the machine has already worked. For a newly manufactured machine the length of the potential defect was assumed as $a_0 = 2{,}5$ mm, i.e. on the level of the sensitivity of the measuring equipment. Higher values of a_0 are assumed for machine elements after N operational cycles, during which diagnostic tests were not performed. Thus, the value of a_0 is derived from Paris – Erdogan equation.

In the modeling of the cracking hazards for rotors it was also considered that there are zones where dangerous tensile stresses occur. The changes of the critical values of the defects dimensions in the zone of the resistance part of the blade groove were analyzed. The grid of the element and further details concerning the supervised zone were demarked as *A* – see Fig. 7 and 8.

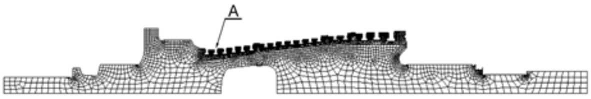

Fig. 7. Axially-symmetrical calculation model of the rotor in the IP part of the turbine

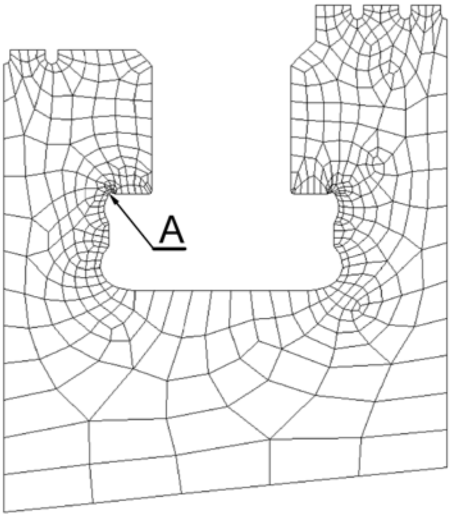

Fig. 8. Detailed location of point A in the rotor in the IP part of the turbine

In the course of the calculations of the critical dimensions of the crack within zone A, the axial stresses component was considered in its highest positive values. The greatest hazard of the failure of elements shall be associated with the defects located along the resistance surface of the groove (on its circumference), i.e. in the plane perpendicular to the rotor axes.

The nature of the changes in the start-up parameters, i.e. temperature and pressure, measured in front of part IP of the turbine and the increases of the rotational speed were shown in Fig. 9. The simulation of the start-up was conducted from the initial cold condition of the rotor, characterized by leveled of temperature of 250ºC.

The changes in the stresses at point A in the groove of the blade were illustrated in Fig. 10. The highest level of stresses in the course of the simulated MES start-up was recorded in 110th minute from the initiation of the start-up, when the effective stresses reached the value of 395 MPa. The axial stresses reached the highest value in the 107th minute and remained on the level of 240 MPa. For 107 min. of start-up, the distribution of the axial stresses in the vicinity of point *A*, were shown in Fig. 12.

For the discussed start-up, on the grounds of Duhamel's integral (1), the tearing stress component within the defect, which is the axial stresses component (curve A in Fig. 10) was modeled. Next, the values of K_r and L_r were calculated and the graph of the changes $K_r = f(L_r)$ designated for a new rotor, or for a rotor

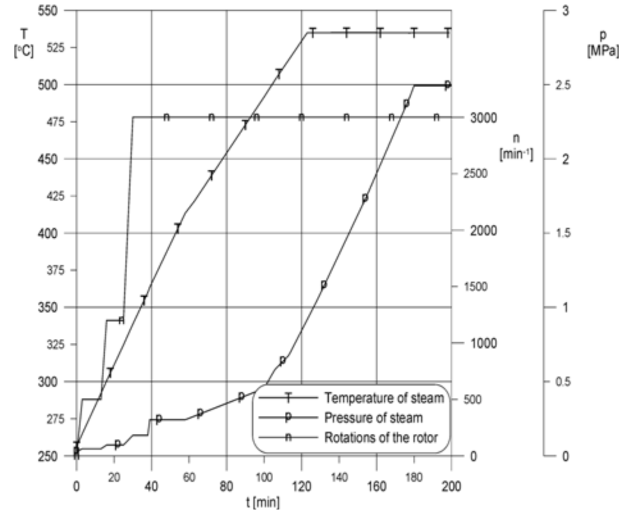

Fig. 9. Graphs of steam temperature, pressure and rotational speed of the rotor in the IP part of the turbine

in which no cracks were detected. The changes $K_r = f(L_r)$ were illustrated on the failure diagram (Fig. 11). Points 1, 2, and 3 correspond to the 30th, 80th and 125th minute of the start-up.

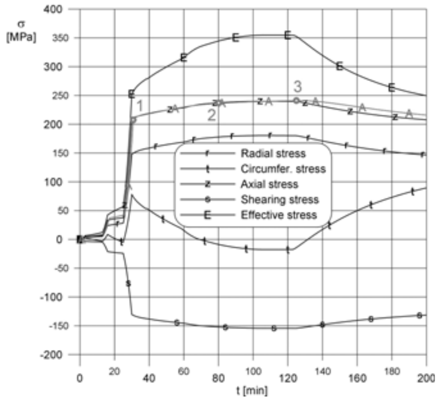

Fig. 10. Graph of the stresses components at point A in the blade groove of the IP rotor during the start-up from the cold condition

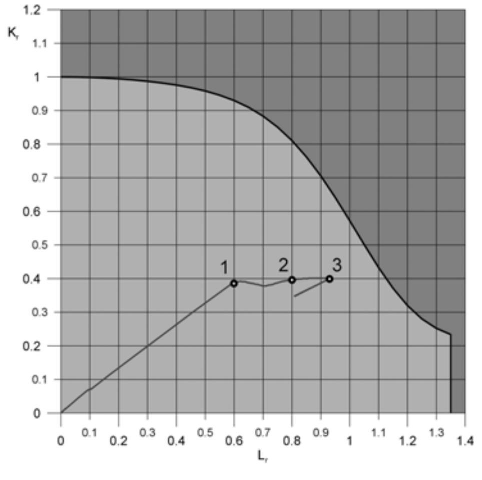

Fig. 11. Failure diagram for point A of the rotor in the IP part of the turbine

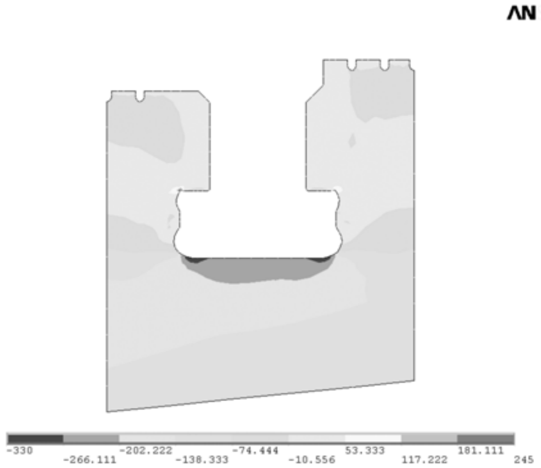

Fig.12. Distribution of the axial stresses at point A in the blade groove in the 107th minute of the start-up from the cold condition

The start-up was conducted in such a manner that during its whole duration the safety boundary was not exceeded (Fig. 11). Higher values of K_r on the level of 0,39 ÷ 0,4 were recorded, after the rotor reached the 3000 rpm rotational speed. A significant impact on the entire state of material stresses at the supervised point, and, consequently, on the value of K_r, was exerted by the stresses associated with the centrifugal forces of the turbine blades. When the temperature of the steam stabilized, on the level of 535ºC (after 127th minute) a decrease of the value of K_r and L_r was recorded („withdrawal" of the curve within the safety boundary).

Also, the assessment of the possibility of potential defect propagation was conducted, the graph of which has a similar course to the graph in Fig. 9, with similar stress state within zone A. On the grounds of Paris' law it was estimated that after the 640th start-up of the turbine, the length of the defect that may potentially occur at point A in the groove rises to the value of a_0 = 4,92 mm (Fig. 13).

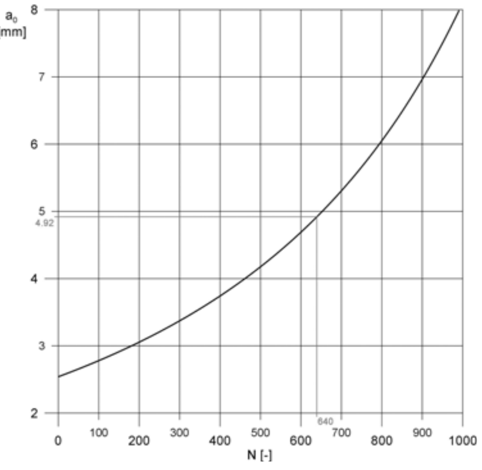

Fig. 13. The propagation of crack during the start-ups of the IP rotor from the cold condition – according to Paris' law

The failure graph plotted for N= 640 cycles (Fig. 14) indicates that in the course of further operation of the turbine the values of

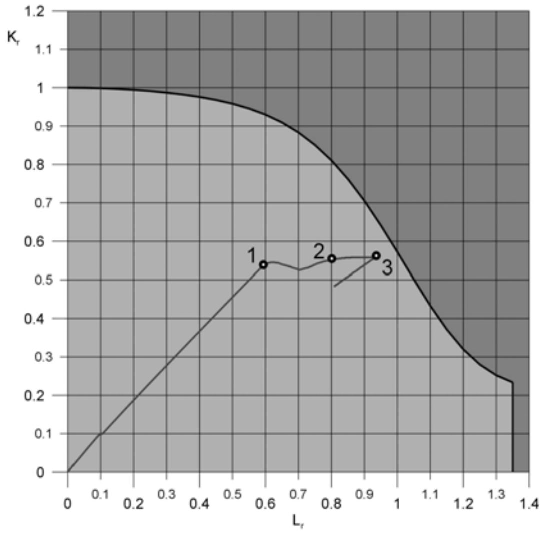

Fig. 14. The failure diagram for point A of the rotor in the IP part of the turbine from the cold condition after 64th start-ups

the relation between the stress intensity factor and K_{IC} increased up to 0,56 for the monitored point, whereas the value of L_r rose up to 0,93. The curve visible in the diagram is still within the boundary of the safety zone, but point 3 moved to the unsafe zone boundary. Thus, to continue the operation of the machine, diagnostic tests are required to confirm or exclude the probability of damage at the supervised point of the rotor groove.

In addition, the analysis of the behavior of potential defects was conducted in the course of the tests of the increase of the rotor rotations. The rotor rotations were raised up to 3300 min^{-1} in the range from the 102nd minute to 111th minute of the start-up, when the maximal values of the stresses were recorded. The graph of the steam parameters in the course of the process (recorded before IP part) and the changes in the rotational speed were presented in Fig. 15.

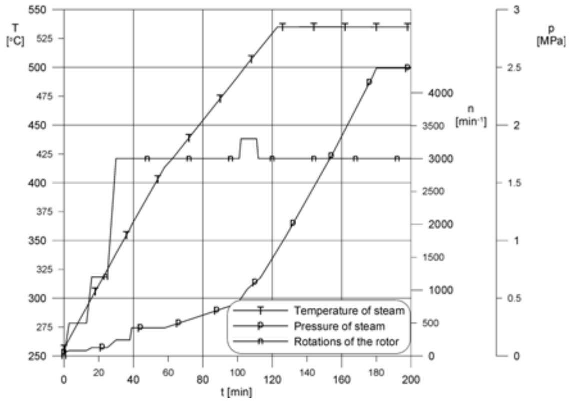

Fig. 15. Steam parameters and the rotational speed during the start-up from the cold condition in the IP part of a high-power turbine, together with the test on increasing the rotational speed

The changes in the stresses for the analyzed start-up (calculated by means of the finite elements method) occur at point A in the rotor, as shown in Fig.16. It was assumed that the material stress reaches the highest value in the 110th minute and then levels off at 365 MPa (effective stresses). The highest values of the axial stresses were detected in the 107th minute of the start-up, when they reached 244 MPa. The distribution of the axial stresses within the blade groove, together with its maximal values, is shown in Fig. 18.

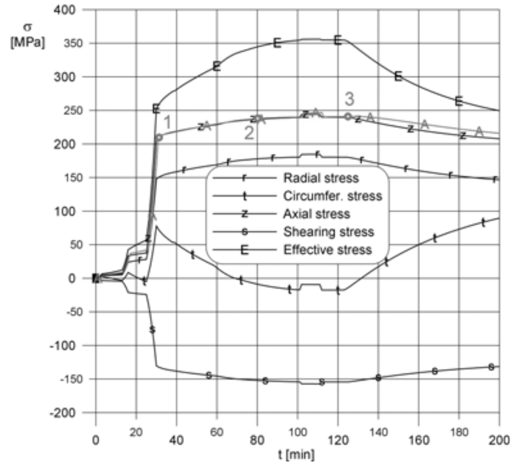

Fig. 16. Graph of the stresses components at point A in the IP rotor during the start-up from the cold condition, accompanied by the tests on increasing the rotational speed

The axial stresses (curve *A* in Fig. 16) – within the zone of the defect – was modeled on the grounds of Duhamel's integral, whereas the course of the start-up was illustrated in the failure diagram (Fig.17).

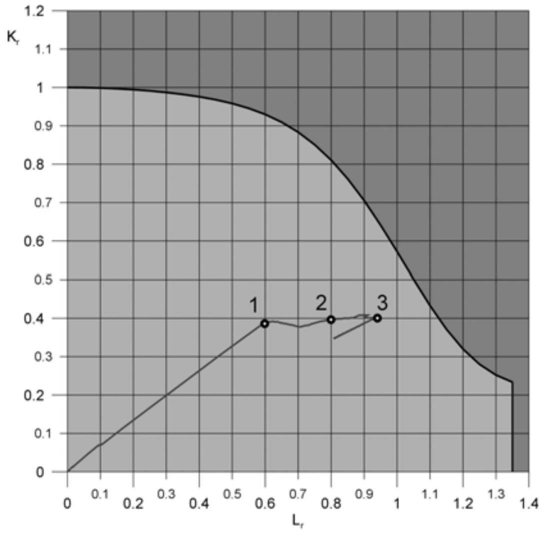

Fig. 17. Failure diagram for point A in the rotor in the IP part of the turbine from the cold condition accompanied by the tests on increasing the rotational speed

The course of the changes indicated in Fig. 17, is similar to those indicated during the start-up, from the cold condition without temporary increase of the rotations. A noticeable difference occurs from the 102nd to the 111th minute of the start-up, i.e. when the rotations were increased. Thus, due to increased stresses from the mass forces in the entire stress condition, the stress tearing up potential defects also increased. The value of K_r rose to 0,41.

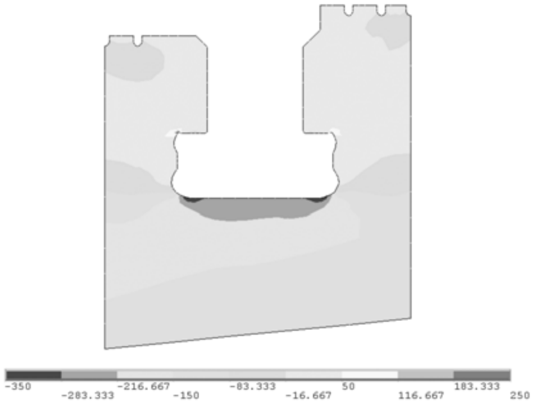

Fig. 18. Distribution of the axial stresses at point A in the blade groove in the 107th minute of the start-up from the cold condition accompanied by the test on increasing the rotational speed

6. Conclusion

The presented method of operational supervision over the rotors of steam turbines makes it possible to track potential brittle cracking hazards. The calculations of the stresses at the critical points in the rotor in the on-line mode have been based on the algorithms drawn from Duhamel's integral. The comparison between the values of the stresses derived from the calculations and the finite elements method indicate fine accuracy of the simplified method. The proposed monitoring of the cracking hazards by means of the failure diagram are derived from the values of K_{IC}. The algorithms consider the variability of K_{IC} together with the temperature of the rotor metal. For the rotors with extended operational time, where non-destructive tests were not conducted, up to date adjustment of the potential defects that might occur in the rotor was proposed, on the grounds of Paris' equation. The discussed algorithms may constitute the basis for support systems of operational supervision, including recent versions of Thermal Limit Blocks of Turbines.

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Kazimierz KOWALSKI

THE DEVELOPMENT OF THE PROFESSIONAL EDUCATION PROCESS USING STATISTICAL TECHNIQUES ANALYSIS OF QUESTIONNAIRES

At the beginning, author briefly presents the Polish Armed Forces cadre's professional military education (PME) development system that includes PME development of logistic officers conducted at the Military Academy of Land Forces. A practical method of continuing development of the educational process based on statistical analysis of customer's satisfaction survey data was described. Additionally, using the example, presented appropriate actions taken to improve the PME process.

***Keywords**: lifelong learning, logistic branch officers' training, on-going development of education process, quality management.*

1. Introduction

Current and potential challenges, which officers of the combat service support will face in the near future, can predict new refined requirements in the broad aspect of readiness to achieve objectives.

A reorganization of the logistical support is being continued in Western Armies (in the field of combat service support) aimed at creating new organizational structures in the management system as well as personnel readiness.

The newest project, by the Headquarters Department of the U.S. Army, titled: „Commissioned Officer Professional Development and Career Management", is an outstanding example of personel management. It describes how the scope of new principles of personnel development and management were worked out [1].

Similar action was also taken in the Polish Armed Forces, where the new system of professional personnel development has been in place since (the 1st of July 2004) [7]. The fundamental assumptions of this pamphlet are resulting from minimum qualifying requirements established in art. 36 of the pragmatic law as it pertains to the appointing of individual official posts. [8]

The detailed course of study and curriculum was established in decision No. 276/MON (14 of September 2004) regarding the system of professional personnel development in the Polish Armed Forces (Log Official MON, 2004, No. 12, item 130). It details the minimum qualifying requirements ranging from official postappointments to individual full-time steps and preparation for performing official duties in specific official posts, to main canons of improving the system.

All forms of professional personnel development will be conducted in military education units (for officers in military academies and higher officers' schools, and for non-commissioned officers in the active army in non-commissioned officers training centres). The specialist courses, before assuming official posts in an area, will be organized outside the system of military education.

The complements of this system are study and specialist courses conducted in-country, consistent with the equivalent forms of national education and training.

This system of professional development should enable active-duty soldiers in the course of their military service to meet all qualifications predicted in post description cards, based on models from individuals' military education.

Postgraduate study and specialist courses also fit into the system of professional development. Postgraduate study - authenticated by a diploma from the appropriate college: Operating-Tactical Study from the National Defence Academy (NDA) and the Academy of the Navy (AON), Operating-Strategic Study at NDA, and the Defensive Politics Study at NDA.

According to the above decision, the Military Academy of Land Forces (MALF) was tasked to provide over 50 specialist courses designed for officers. The list of courses, targets and training tasks, organizational assumptions, thematic scope of the training courses (syllabus) and the course schedule are published in the programme-organizational guidelines of courses organized at MALF [9].

A few specialist courses are planned at MALF for officers of the logistical personal branch at the captain and lieutenant level.

The cornerstones of syllabus assumptions, in the above-mentioned specialist courses, were required qualifications and duties reflected in post description cards (PDC) to which attendees can be appointed after successful completion. It is necessary to understand that candidates trained, e.g. for a company commander, can serve in various logistical companies: in the general logistical personal group - maintenance, supplies, training, command and control, logistical courses; in the material personal group - of keeping, storing, supplying petrol, oil and lubricants (POL), and long-range pipelines; the transport and troop movement personnel groups; the adjustment of the move and finally, the technical personnel group and the maintenance and recovery company.

Of course, it isn't so that the number of PDC is the same as the number of posts of commanders of the above-mentioned companies. For instance, the post of commander of the maintenance and recovery company (mrcoy), or the supply company (scoy), incorporate at least a dozen different PDCs. Their diversity comes from setting the specificity role of the sub-units in upper structures e.g.: of the armoured cavalry brigade, the mechanized brigade (MB), of the assault-storm brigade, the artillery brigade or the logistical brigade. Attendees' qualifications and duties were based on the PDC of commanders mrcoy and mcoy of MB.

In the Combat Logistics Support Department (CLSD) of the Command and Control Institute MALF (substantially responsible for the implementation of the above courses) undertook the research project with the purpose of improving the quality of the logistics training course.

General assumptions and the current state of the research will follow.

2. General assumptions of research

The mission of the CLSD as described in the MALF's charter embraces the accomplishment of educational tasks, training and research in a range of command skills, logistics control and signal sub-units, combat service support and in organizing armament and military equipment maintenance, all under modern battlefield conditions.

In accordance with its mission, the CLSD undertakes to implement the MALF development program priorities within the scope of its areas of responsibility with special emphasis on: permanent improvement in the quality of the didactics and increasing its role in the educational process; the constant development of scientific activity; continuous development and increasing the participation of computerization in the process of training and CLSD's operations.

The college's graduates demonstrate the quality of the didactics. The students, their practical skills, their creativity, their knowledge and their opinion of the college are creating the college's image; not only in the academic environment but in its surroundings too. Because of that, word of mouth should be taken into consideration in processes relating to the college.

The above statement is the underlying reason for a permanent educational development project carried out by the CLSD. One should note that the aim of the project is not introducing the management system for quality training consistant with the ISO 9001 norm [6] and getting accreditation, but to put into practice procedures ensuring the lasting improvement in quality training accomplished in the CLSD.

Established operations targeting the permanent improvement in training quality accomplished in the CLSD include:

- analysis and assessment of the current situation concerning the quality of training in order to identify the most important educational areas for further improvement in quality,
- identification of objectives for improving the quality of training,
- seeking available solutions to achieve these goals,
- evaluating these solutions and making the most effective choices,
- putting those solutions into practice,
- assessin, verifying, analysing and evaluating the results of implementing those solutions,
- formalizing the indicated changes.

According to the quality of education the following goals were established in CLSD:

- ensuring the high level of classes and how they are perceived, by students and future employers,
- scientific development – lasting increase in individuals' qualifications, improvement in management of work and undertaking new tasks resulting from educational needs and the demand of future employers, i.e., army units,
- initiating, supporting and co-organizing internal efforts (in the college) and external projects (outside the college), to broaden attendees' knowledge within the scope of broadly understood innovations in the skills needed to command logistical sub-units and signals of contemporary battlefield conditions, combat service support and managing armament and military equipment maintenance,
- the implementation, monitoring, correction and improving the politics of quality,
- completion of tasks assuring training effectiveness resulting from the Bolognese Process.

The realization of the above-mentioned will be achieved through:

- maintaining lasting improvement of the training effectiveness system in CLSD,
- full involvement of CLSD's chief and subordinate department managers in maintaining and improving CLSD's ongoing training effectiveness system,
- conducting the permanent monitoring, measurement and analysis in accordance with the scope of ways and methods of improving the training quality assurance system, both among CLSD staff as well as attendees,
- regular review of current teaching aids in the form of "e-learning" materials and classroom instruction and established school curricula revision,
- cooperation with the college staff, command institutions of the Republic of Poland's Armed Forces, military units, research- and-development and industrial centers.

Effective improvement of educational services is closely related to the customers' comprehensive understanding of the ISO 9001 norm requirements. In the case of a military university we can rate among its customers: studios and course candidates, studios and course auditors, the college staff, graduates, army units, Department of Science and the Cadre Department of Military Education.

Clearly combining requirements and concerns of all interested parties is not simple. Therefore, narrowing the circle of customers to attendees of officer specialty courses for logistical branch personnel to the level of lieutenant and captain was essential for the purposes of this plan. The corrective limitation is appropriate if we consider that our action is focused on first the assessment, and then the on-going improvement of the training process. This goal is similar in different colleges [5]. It is necessary to precisely evaluate its present state if we want to improve the quality of the training process. An appropriately developed questionnaire form is a crucial tool for getting the right feedback information from customers.

Two kinds of questionnaire forms were used in order to get feedback information (appropriate to courses): an introductory questionnaire form (utilized in the first days of the course the connection with) and a closing questionnaire form (utilized after graduation and containing attendees' opinions, their impressions and their training service).

In terms of imposing requirements more often, every now and then they would extend the traditional technical competence of army unit commanders of an their basic capability. These capablities include: individual initiative, leadership abilities, problem-solving skills, communication skills, teamwork skills, creativity and innovation as well as setting and accomplishing priorities (appropriate questions concerning this issue were also posed in the questionnaire form) [2].

The above-mentioned skills and characteristics of specialty course attendees from the personnel logistics branch exert an essential influence on the personal ranking of officers as well as affecting the quality of subsequent assignments based on the PDCs and from the job skills description.

The preliminary phase of the project included analysis of:

- documents standardizing the lifelong training course in the EU, Poland and the Republic of Poland Armed Forces,

- post description cards – PDCs (job skills descriptions) from representative posts of company commanders of the personnel branch (maintenance, recovery and supply company),
- programs of specialty training courses in the personnel logistics branch in MAGF.

The following received questionnaire surveys:

- attendees of specialty course No. 1025001 (of general-logistical company commanders) and attendees of specialty course No. 2030027 (lieutenants of the personnel logistics branch) - 2006 and 2007 r,
- a representative group of officers of the Army personnel logistics branch (the so-called “experts”) the majority of which were representatives of rungs of Army logistics organizational structures (military rank ranging from captain to colonel, with tenure in the service from 12 to 36 years).

3. Results of the implementation of the project

Carefully designed questionnaire forms are a crucial tool for permanently improving the training process in the CLSD. These forms ensure the acquisition of appropriate feedback information from customers, in this case from attendees of specialty courses of the personnel logistics branch taught in MALF and of the logistics managerial personnel “employers” of the Army,

While developing the questionnaire forms, special attention was given to ensuring that the basic purpose for administering questionnaire forms of this type, that is, measuring the degree to which the training service provided by the CLSD is fulfilling customers’ expectations, was met. The group developing the questionnaires was expanded to include not only CLSD staff, but also specialists from the Training Technology Department of MALF as well.

The reliability of results of the completed survey and the credibility of respondents’ answers were ensured by designing questions for the questionnaire form used to measure customer satisfaction according to the following principles [4]:

a) the questions were short and concise – thereby increasing the probability that they will be read completely and with sufficient attention,
b) questions were formulated clearly and precisely, and in each:
    - the most important concepts were defined,
    - specialized jargon was avoided,
    - pronouns were avoided where it might not be clear to what they referred,
    - double negatives were avoided,
    - confusing adverbial structure was avoided,
c) the fact that questions concerning possible aims might not translate into actual future behaviours at was taken into consideration,
d) wording such as “depending on” that is commonly used to reply to hypothetical questions, thereby making it difficult for respondents to answer, was limited,
e) only questions directed to actual persons were asked,
f) only questions concerning one problem were being asked, they avoided hook questions that ask about several issues at a time,
g) in closed questions replies were formulated individually,
h) a complete list of replies providing for all possible situations were to be included in the list of possible replies,
i) loaded questions that would steer respondents into being sympathetic or disapproving towards the question’s subject were not included in the questionnaire form,
j) also taken into consideration was the fact that although something imight make sense when designing the questionnaire form that does not mean that it would make sense to the one being polled.

3.1. Research recapitulating courses

Research recapitulating courses was carried out with attendees of specialty course No. 1025001 (for general-logistics company commanders) and with auditing participants of specialty course No. 2030027 (for lieutenants of the personnel logistics branch) - of edition 2007. Getting feedback on their opinions and their impressions is the fundamental reason for performing a questionnaire survey among participants who have completed training service courses. This feedback is essential input information for the on-going improvement of the continuing education process. An essential element dealing with the thematic assessment of the questionnaire form for a delivered educational service was introduced in fig.1.

Results of questionnaire forms are subjected to a statistical analysis. Assessments of the course were rated among popular indicators on the basis of a long-standing training practice: the degree of the topicality of the subject matter introduced, the scope of knowledge of a given subject matter, format of classes. Rates allowing an assessment of customer satisfaction were also found to be essential to analysis access to the Internet, and the adaptability or willingness to participate in professional development “at a distance”. Action modifying the course syllabus will apply to the next editions of the course , depending on analysis results.

The main emphasis was put on singling out those subjects which are not useful, in the opinion of the course participants, to their professional practice. Such topics (subjects) are removed from the educational courses offered and replaced by those resulting from the needs and expectations of a given group of customers.

In the literature of the field, the assessment based on an analysis of the usefulness of the subject is known as the “statistical control of the process”. The rationale of this method consists in establishing borders to the natural changeability of the process, then identifying measurements whose value remains outside these borders. When these measurements are upset, we say that the process is unreliable. We are referring to subjects which were judged into the way running away, in using results of polls to the assessment then from stayed, and the program of the training course needs revising. Such action is required and acceptible around item 8 ISO 9001 norms - Measurements, analysis and improvement. Using statistical methods should, consistant with this norm, aid the organization in demonstrating the ability of processes to achieve planned results [3].

Practical application of a statistical analysis algorithm to the results of the poll was introduced as an example of analysis of the questionnaire forms from attendees who took part in course No. 2030027. 32. 22 subjects participated in the assessment. A five-point scale was applied to individual subjects. An overall comparison of poll results was outlined in table No. 1, where columns from 1 to 22 introduced a number of points which received the given theme from the participant of a course (1-32).

1. To what extent did training fulfill your expectation?[1]

1	2	3	4	5
0 %	25 %	50 %	75 %	100 %

2. How do you assess individual topics of the training course?

		☹		😐		☺
No	Topics/subjects	**1**	**2**	**3**	**4**	**5**
		0 %	**25 %**	**50 %**	**75 %**	**100 %**
1.	**3.1.ZLDT** T1. CSS of the mechanized sub-unit (of tanks) in tactical activity					
2.	T2. Food supply					
3.	T3. PLO supply					
4.	T4. Road transport of hazardous materials					
5.	T5. Logistical support of sub-unit realizing peace tasks (stabilization) in the multinational arrangement					
6.	T6. Host Nation Support (HNS)					
7.	T7. Problems of the environmental protection in the realization of objectives of logistical support of tactical activity					
8.	**3.2. LZM** T1. Material supply logistics					
9.	T2. Military economy elements					
10.	T3. Storage economy elements					
11.	**3.3. EUiSW** T1. Chosen problems of the construction of the tank-vehicle appliance					
12.	T2. Chosen problems of the technical maintenance					
13.	T3. Principles of the maintenance of AaME					
14.	T4. The organization and functioning of the Logis-E computer system					
15.	T5. The repair system of AaME					
16.	T6. Principles of conservation and storage of AaME					
17.	T7. Maintenance of AaME and environment protection					
18.	T8. Prophylactic activity in the scope of preventing accidents with the eapon and with the ammunition and in the road traffic with the participation of military vehicles					
19.	**3.4. ZT** T1. Motor transport					
20.	T2. Trans-shipment In motor transport					
21.	T3. Rail way transport					
22.	T4. Health and Safety during transport duties					

[1] Choose the reply through of putting the sign "X" on the chosen variant

Fig. 1. The summary questionnaire extract of 2030027 course

Tab. 1. The list of results of the summary questionnaire of 2030027 course

	No of the topic, item. fig.1								
	1	2	......	14	....	19	20	21	22
No of the participant	Number of points received by participant								
1	4	4		3		5	4	5	5
2	4	5		3		4	5	5	5
3	4	4		3		4	5	5	5
4	5	5		2		5	5	5	5
....									
28	4	5		3		4	4	4	4
29	4	4		3		5	5	5	5
30	3	3		2		2	2	2	2
31	4	5		3		3	3	2	4
32	4	4		2		4	4	4	4
Average, $X_{śr}$	3,75	4,34		2,56		4,10	3,97	4,16	4,03
Stand. deviat., S	0,88	0,75		0,91		0,79	0,82	0,85	0,78
Average value from $X_{śr}$, Ψ					3,998				
Average value from S, $S_{śr}$					0,807				

Four last rows contain averages outlined for the of allotted points from the table of right subjects ($X_{śr}$), value of standard deviation (S), mean value for the course (Ψ), mean value of standard deviation ($S_{śr}$). Above value was outlined taking standard relations.

Testing lines were outlined in the aim of more distant analysis of results of the poll for $X_{śr}$, the bottom testing line - *DLKxśr,* the upper testing line - *GLKxśr* and the average line - *ŚLKxśr* from relations:

$$DLKx_{śr} = \Psi - 1{,}5 \cdot S_{śr},$$

$ŚLKx\text{śr} = \Psi$,
$GLKx_{\text{śr}} = 5$,

and testing line for S, bottom testing line – DLK_S, the upper testing line – GLK_S from relations:

$DLK_S = 0$,
$GLK_S = 1{,}5 \cdot S_{\text{śr}}$.

Individual subjects of the course are judged in two stages. First whether the average number of points ($X_{\text{śr}}$) calculated for the given subject is smaller than border worth outlined for points (*DLKxśr*) is tested. Then the standard deviation value of points is tested (S). The following decisions accepted depending on the results of analysis:

- to leave the subject: $DLKx_{\text{śr}} < X_{\text{śr}} \le GLKx_{\text{śr}} \wedge DLK_S \le S < GLK_S$,
- remove the subject: $X_{\text{śr}} \le DLKx_{\text{śr}} \wedge DLK_S \le S < GLK_S$,
- corection of the subject: $X_{\text{śr}} \le DLKx_{\text{śr}} \wedge GLK_S < S$.

Of course one possibility is still left - replacing the subject - but it is resulting from analysis of the clause 4 of the questionnaire form concerning offered changes in the future edition of the course.

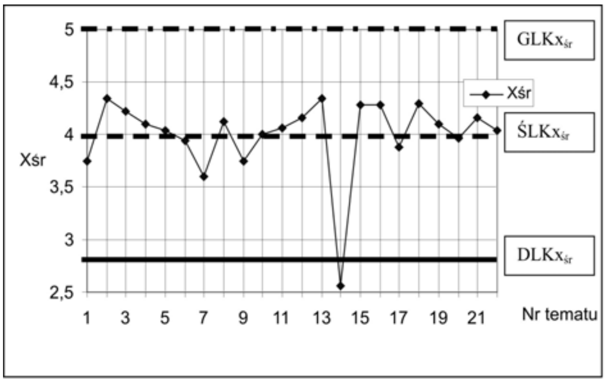


Fig. 2. Curve of average points ($X_{\text{śr}}$) for particular themes

Figure No. 2 shows a course of the average value of points ($X_{\text{śr}}$) outlined for individual subjects. Only subject item 14 (fig. 1) received the average number of points which is found lower down the outlined *DLKxśr*. In comparison with the remaining subjects, averages of points are located between *GLKxśr* and *DLKxśr*. As a result of more distant analysis, based on the graph of standard deviations, fig. 3, it was decided to remove the subject item 14 (the topic "Maintenance of Armour and Military Equipment", subject 4 - the Organization and functioning of the Logis-E computer system) from the syllabus. As shown in the graphic illustration, introduced in fig.3, the value of standard deviation for the subject item 14 (fig. 1) results in an irregularity: $DLK_S \le S < GLK_S$, extracted the above decision.

3.2. Desired features and abilities of logistics personnel

The employers (unit commanders) frequently expect levels of technical competence beyond the standard definitions of their subordinate personnel. It was decided to identify the most essential features and skills, which characterize the logistical personnel should be characterized in order to improve their abilities through training. In the "preliminary", questionnaire form directed to attendees of logistics courses as well as to logistics managerial personnel "experts" included this question, among others:

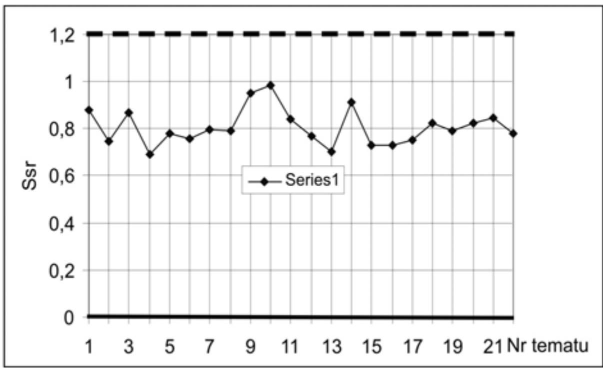


Fig. 3. Curve of standard deviation points'(S) for particular themes

What skills of a course participant should determine when somebody should be singled out to attend the logistics course?

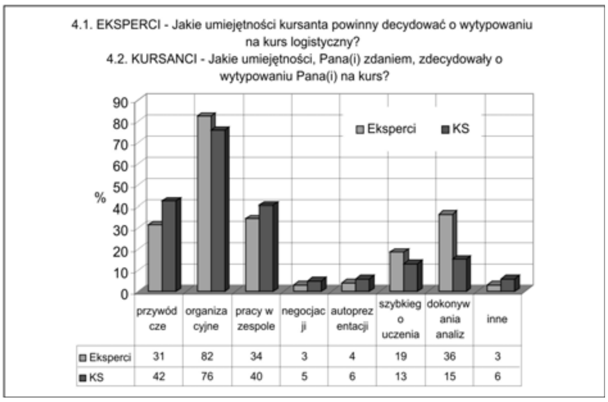
The following skills were suggested: leadership, organizational, teamwork, negotiating, self-presentation, self instruction, analytical, and various others.

Moreover, the question was asked: what characteristics of the participant should determine when somebody should be singled out to attend the logistics course?

The following features were suggested: creativity, ease of communication, responsibility, efficiency, regularity, dynamism, adaptability to new situations, assertiveness, and various others.

The results of the desired skills assessment according to a weighted scale were depicted in fig. 4. The "experts" as well as "participants in a course" put organizational abilities first (82% - "experts" and 76% - "participants in a course"). In the next places are: leadership skills, teamwork and analytical. The "Experts" put analytical skills in second place (36%). Teamwork ability took third place with only a slightly smaller score of (34%) and fourth place is occupied by leadership skills (31%). In the assessment of "participants in a course" second and third place, include: leadership skills with the score (42%) and teamwork (40%).

However, among the most desirable features, responsibility, efficiency (appropriately: "experts" - the 65% and the 39%, "participants in a course" - the 58% and the 41%) were marked out.



	przywód cze	organiza cyjne	pracy w zespole	negocjac ji	autoprez entacji	szybkieg o uczenia	dokonyw ania analiz	inne
▨ Eksperci	31	82	34	3	4	19	36	3
■ KS	42	76	40	5	6	13	15	6

Fig. 4. Desired capabilities of logistics officers

4. Summary

In dynamically changing conditions of the logistics officers service, the fact of the possibility of improving their professional skills appropriate to the needs and requirements of the service is one of the most important interests of the service. That being so, continuously improving training programs through suppliers of educational services, also by the CLSD, allows for fulfilling attendees' and employers' requirements and results in a good image for the contractor.

It seems that one of the most widespread ways of examining the customer's satisfaction, that is, conducting a survey, can serve very well to continuously improve the instructional service, as achieved in CLSD with very good results. Sine qua non is using the right methodology for obtaining results and systematically building one's own knowledge bases based on questionnaire surveys. The fact that this method is characterized by relatively low costs for the realization should be underlined and as well as the fact that it is very susceptible to computer analysis.

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Jörg KUNDLER

LONG-TERM MAINTENANCE OF AERONAUTICAL INFORMATION SYSTEM ON THE BASE OF STATISTICAL METHODS

The AIS service (Aeronautical Information Service) is an operational service for Air Traffic Control and the functionality via availability and data integrity is one of the critical factors for the AIS Centre. Particularly the ATC operation is highly depended from IT-Systems, technical infrastructure and there availability. The analysis shows the relevant standard requirements of availability and long-term maintenance to an AIS-System and their statistical analysis. The goal of statistical analysis is to investigate the observed parameter like availability and robustness of functionality and services. In the paper research of maintenance parameter based on the statistical analysis, and results for further operational use are discussed. The statistical analysis was used for planning process of the product management. The analysis of different incident types and their characteristics based on the collected statistical maintenance data over operational period from 2001 to 2006 was performed. The results of statistical investigation will be used for a more stabile forecasting of operational use of the system and get statistical information for the future trend and migration of a new system platform. The statistical analysis is shown the relevant requirements of ATC maintenance for long-term used IT Systems.

***Keywords**: Long-term Life Cycle, Maintenance and Reliability of ATC Systems, Research of Incident Characteristics, Descriptive Statistics.*

1. Tasks and goals of Investigation

The Integrated AIS-System is in operational use since year 2000 in a computer centre on Airport. This computer centre will be closed in next time. The complete system with main, redundant systems shall be move to a central IT-infra structure and will be integrated into a central computer centre. The planed life cycle of this system should be finish until end of 2009. But due to different reasons the life cycle of operation shall to extent until year 2011. The UNIX based AIS application on turbo channel technology is out of maintenance. Especially the hardware is out of industrial maintenance and support.

The goal of statistical analysis is to investigate the observed parameter like availability and robustness of functionality and services. Based on given input data base it shall be analyze with help of statistical methods to get information from the known random sample to complete population of service availability and number of incidents and their different types. The results of statistical investigation will be used for a more stabile forecasting of operational use of the system until 2009 and use statistical information as input data for future trend and migration of a new system platform. For the statistical investigation was used the program Statistica Release 6 StatSoft Inc 1984-2001 [4].

2. Introduction of the Integrated Aeronautical Information System (AIS)

The Integrated AIS System is responsible for the technical provision of all related actual information for flight planning and aeronautical information process of all pilots and users of Flight Information Regions. This system includes a world-wide data base with all necessary technical and organizational information for flight in the world. The main requirements are to assure a high availability of function and complete data integrity of data base. The system is an ATC operational system and has direct impact to ATC safety.

The main functionality of the AIS System is:

- NOTAM Data Base,
- Static Data,
- Briefing System,
- FPL Component,
- AFTN Functionality.

The NOTAM Data Base is responsible for the world wide coverage of flight information, distribution of NOTAM, the redistribution of validated NOTAM, automated NOTAM processing and checklist processing. The Static Data Base contains the complete world wide air space structure. This data base is necessary for NOTAM processes and FPL handling. The Integrated AIS-System is a system with a central server and client structure. The main technical infrastructure is located in a main computer centre. AIS are located on all international airports and aerodromes in Germany, the AIS are a legal briefing system for all pilots which will be started from Germany. The AIS centre and NOTAM office is centralized at Langen. The DFS integrated AIS System differs from other standard AIS System because DIAS also includes an integrated Flight Plan Module. The main functionality and tasks are summarized in Figure 1.

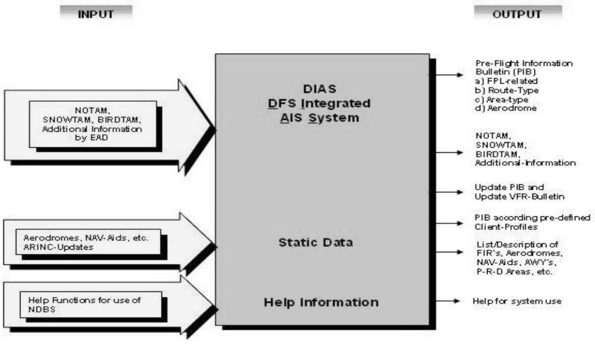

Fig. 1. Overview of task for Integrated AIS System

For communication with the customer the AIS-System includes the following communication lines.

- ➢ Communication via Internet Aeronautical briefing (goal is to handle 80% of briefing via internet),
- ➢ Communication via Fax on demand by customer,

- Communication via direct lines to large airlines,
- Communication via telephone,
- Communication via self briefing stations which are installed on each aerodrome and airport in Germany, especially customer for general aviation.

3. Description and Analysis of Input Data

The statistical input data base contains all technical failures during the operational time period from January 2001 until April 2006. The data base contains the following information:

- Date and time of failure,
- Time period of failure,
- Related failure system / part of system,
- Short description of failure reason,
- Failure categories: random failure, currently coordinated interruption, long term coordinated interruption.

The system is in operational use since January 2000 and in 24 hour 365 days operation. The required operational availability $A_{OPS\text{-}Service}$ (1) based on agreed Service Level Agreement (*SLA*) and is 99.6 % per year.

The statistical quality of operation at *ATC* will be described by the following parameter.

- Operational Availability: $A_{OPS\text{-}Service}$ in % per year
- Mean Time between Failure: *MTBF*
- Mean Time to Repair: *MTTR*
- Maximal Time of Failure: $t_{max\ failure}$
- Operational Robustness: Number of failures per month

Calculation of observed operational Time Period from January 2001 to April 2006

- Number of months: $n_{Month} = 64$
- Hours of operation: $t_{operation}$=1946 days

$t_{operation}$= 46704 hour

Definition of operational availability:

$$A_{OPS-service} = 100 - \left(\frac{t_{not-operational}(h)}{t_{operation}(h)} \right) * 100\% \qquad (1)$$

Where: $A_{OPS\text{-}Service}$ - the operational Availability, $t_{not\text{-}operation}$ - the time of not operation, $t_{operation}$ - the time of operation.

Operational availability $A_{OPS\text{-}Service}$ (1) contains all time periods of failures and planned out of services periods. These periods including all maintenance and service activities which currently or long term coordinated with the operational users of ATC flight information services. Definition of error free availability:

$$A_{error-free} = 100 - \left(\frac{t_{failure-periods}(h)}{t_{operation}(h)} \right) * 100\% \qquad (2)$$

Where: $A_{error\text{-}free}$ - the Availability without errors, $t_{failure\ period}$ - the time of failure period, $t_{operation}$ - the time of operation.

The table 1 describes the different operational service level over the complete period of exploitation and gives also an overview of time distrubution of service time in general, service time without incidents, out of serive time and failure period in percent. Based on these parameters the table 1 describes the operational availability in percent.

3. Definition and Classification of Incidents

3.1. Definition of Incident Types and their classification

The goal is to find the right classes and classification of incidents during the operational use of flight plan and information system. To find the right classification and numbers of classes is the result of theoretical and operational analysis, to define the incident classes from the operational customer point of view. The statistical input data can be divided into the following types of incident classes:

- Randomly failures with operational impact.
  The operational impact is a given definition from operational ATC. The criteria are time oriented, because after a time period of 20 minutes the incident will have direct impact to the flight plan memory.
- Randomly failures without operational impact.
  These are incidents in case of randomly failures shorter then 20 minutes and the functionality of AIS system is given.
- Maintenance incidents which a short-term coordination. This class of incidents is very important in detection of failure and to implement workarounds or failure solutions via hot load procedures into the system. The short-term coordination with operational user shall be less then 30 minutes. Only with approval of operational manager this maintenance activity can be performed.
- Maintenance incidents with long-term coordination. It is the same maintenance activity only the coordination time slot is more then 30 minutes.

The table 2 describes the number of observed incidents based on the quantity point of view. The monitoring of the technical system shall be performed automatically and permanent.

In to a next step the distribution of incidents over the different operational years is presented in table 3. The figure 2 points out the splitting and distribution of different incident numbers and types.

3.2. Analysis of Statistical Characteristics and Splitting Model of Incidents

In the table 4 is given a summary of the main descriptive statistical parameters. The distribution of different incident numbers over operational years is graphical presented in figure 3. The general numbers of Incidents over the operational years is nearly

Tab. 1. Overview about the operational time periods

	Operational service time period	Operational service time without incidents	Operational out of service time period	Failure time period	Coordinated maintenance time period
Hours	46704:00:00	46601:09:31	102:50:29	45:24:54	57:25:35
% part	100	99,78	0,21	0,9	0,12
Operational Availability %	100	99,78	99,78	99,90	99,87

Tab. 2. Overview of incident classes

	Number of Incidents	Number of failures	Number of currently coordinated maintenance activities	Number of long-term coordinated maintenance activities
Number	1256	590	581	85
% part	100	46,97	46,25	6,76

Tab. 3. Distribution of Incident types during observed operational period

Year of Observation	Number of Incidents	Failure $t < 20$ min	Failure $t > 20$ min	Maintenance $t_{coord} < 30$ min	Maintenance $t_{coord} >= 30$ min
2001	221	83	9	111	18
2002	205	58	1	137	9
2003	266	110	1	131	24
2004	214	119	13	68	14
2005	237	117	1	106	13
Until May 2006	54	19	2	30	3

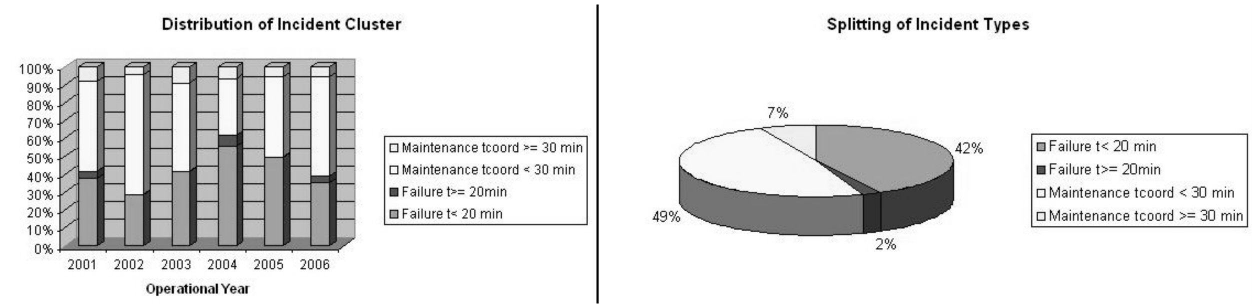

Fig. 2. Distribution and splitting of incidents

Tab. 4. Calculation of basic descriptive statistical characteristics by Statistica6

Variable	Valid N	Mean	Median	Sum	Minimum	Maximum	Std. Dev.	Standard Error
Incidents 2001	221	00:18:29	00:02:00	20:04:19	00:00:01	06:24:01	01:03:14	00:04:15
Incidents 2002	204	12:08:48	00:01:32	05:54:12	00:00:27	02:48:02	01:41:54	11:52:53
Incidents 2003	331	00:06:33	00:01:07	12:06:50	00:00:01	02:35:22	00:18:01	00:00:59
Incidents 2004	214	00:06:09	00:01:40	21:57:43	00:00:18	02:25:02	00:14:25	00:00:59
Incidents 2005	237	00:04:04	00:01:43	16:04:55	00:00:14	01:36:31	00:10:46	00:00:42
Incidents 2006 (until May)	54	00:03:36	00:01:01	03:14:39	00:00:11	00:54:32	00:09:18	00:01:16

similar. For year 2006 are only incidents until May are available, so it is necessary to perform a scaling of values.

- 5 operational months = 54 Incidents,
- 12 operational months = (54 / 5) * 12 = 129.6 = 130 Incidents for year 2006.

General Parameter:

- Number ~ 210 - 230 incidents per year,
- Mean ~ 3- 6 minutes excluded year 2002 18 minutes,
- Median ~ 1-2 minutes, value of mean and median are nearly equal,
- St Deviation~ 10 -18 minutes excluded 2001,
- St Error ~ 1 minute.

The standard deviation and error are very small and significant values.

With respect to figure 3 the reasons of decreased incident number in year 2006 are that the number of updates and functional changes decreased to a minimum. Only necessary functional and security changes were realized and integrated.

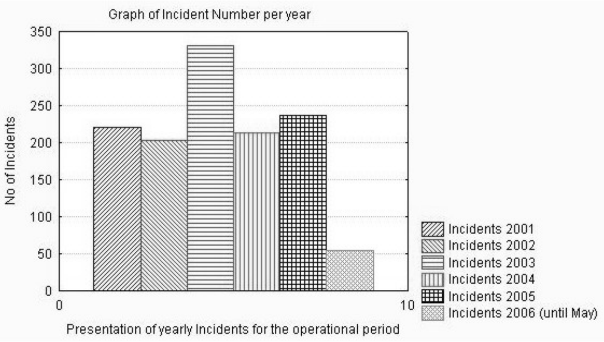

Fig. 3. Distribution of incidents

Excluding values for the years 2001 and 2002 the mean value of incidents are between 00:04:00 and 00:06:00 minutes, the mean is nearly equal around 00:02:00 minutes, the sum is around 00:16.00 to 00:20:00 minutes per year.

The reason of outliner for year 2001 and 2004 in figure 3 are the development and implementation of a major system change.

Due to this fact the first year of operation was attend by defects and their correction. In year 2004 was finished a complete reorganization of operational AIS and was centralized in one AIS-Centre with new AIS function and communication interfaces via internet. This reorganization required a different number of additional and new technical functions. Also a new organization had direct impact and interfaces to the AIS System.

Over the complete operational period the random failures t<20 minutes and maintenance incidents $t_{coordination}$ < 30 minutes are the major incidents, but the numbers are relative similar. Only minor deviations can be observed. The reasons and impact of deviations are the different number of updates, release and changes by hot load procedures. The system and functionality changes are depending from the operational requirement management. The basic and descriptive statistical parameters are described in table 5.

The incident type "Maintenance $t_{coordination}$>= 30 minutes is the most homogeneously sample of observation because the mean and median have the same value. In addition the standard deviation and standard error is relative small. For the incident type "Maintenance $t_{\text{coordination}}$>= 30 minutes the calculated variation coefficient V = 53% (3) and is relative high.

$$V = \frac{StandardDeviation}{arithmeticalMean} * 100\% \qquad (3)$$

Where: V - the variation coefficient.

The parameter "Number of incidents" is the most inhomogeneous sample, due to the large standard error and standard deviation. The variation coefficient V=37% (3).

The analysis findings of the statistical distribution of incident number in figure 5 are the following.

- The distribution of random sample is in-homogenously.
- The reason for high values of standard deviation (St.Deviation) and standard error (St. Error) reflects that the incident clustering is not performed by a scientific statistical method like cluster analysis and is not calculated by different similarity or distance coefficients like Minowski distance or Euclidian distance [1-3,5].
- The clustering of different types of incidents is given from the practical reason and operational business need. Due to this fact the calculated parameter by the program Statistica [4] can be differ from the scientific border.
- Over the operational period it shall be expected around 200 incidents per year, but only 2% of them have operational impact of the AIS functionality.
- The availability of the service is higher then required. But over the operational time period it is not visible that the system will reach more robustness and stability.
- The distribution of different kind of incidents is shown by Box & Whisker Plot in figure 4. We can see the correlation between the different types of incidents. In general the types failures t<20 minutes and maintenance t >= 30 minutes are very similar, also the other two kinds of incidents are similar from the descriptive statistical parameters.

The mean value for incidents with operational impact is 00:51: 09 minutes. The median value is 00:53:48 minutes. The mean and median values are very similar. Mentionable is that 95% confidence interval is 00:32:10 / 01:10:08. With respect to the long operational period the most part of problems were solved by changes or workaround inside of 01:10:08 minutes. Long term down time period is not detected.

With respect to the distributed incidents t<20 minutes it is visible that the time span is in relation much higher. The time period of minimum to maximum is by 14 seconds to 17 minutes, the value of standard deviation is really small, but it is necessary

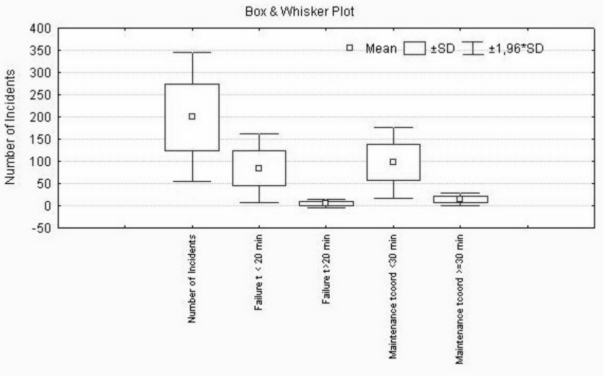

Fig. 4. Box & Whisker Plot of Incident Types

Tab. 5. Descriptive statistical characteristics for the different types of incidents

Variable	Mean	Confidence -95%	Confidence +95%	Median	Sum	Min	Max	Lower Quartile	Upper Quartile	Std. Dev.	Std. Error
No Incidents	199,5	121,38	277,61	217,5	1197	54	266	205	237	74,43	30,38
Failure t<20 min	84,33	42,64	126,02	96,5	506	19	119	58	117	39,72	16,21
Failure t>20min	4,5	-0,96	9,96	1,5	27	1	13	1	9	5,20	2,12
Maintenance t_{coord}<30min	97,16	54,24	140,08	108,5	583	30	137	68	131	40,89	16,69
Maintenance t_{coord}<=30min	13,5	5,9	21,08	13,5	81	3	24	9	18	7,23	2,95

Tab. 6. Statistical characteristics of incidents per operational month

Variable	Mean	Confidence -95%	Confidence +95%	Median	Sum	Min	Max	Variance	Std. Dev.	Std. Error	Skewness	Kurtosis
No Incidents	19,69	16,39	22,98	15,50	1260	5,00	85,00	173,81	13,81	1,65	2,22	8,37
Failure t<20 min	8,81	7,21	10,42	7,00	564	0,00	37,00	41,27	6,42	0,80	2,07	6,50
Failure t>20min	0,42	0,12	0,72	0,00	27	0,00	8,00	1,42	1,19	0,15	4,74	26,91
Maintenance t_{coord}<30min	9,11	7,14	11,08	7,00	583	0,00	42,00	62,16	7,88	0,99	1,59	3,80
Maintenance t_{coord}<=30min	1,34	0,64	2,05	0,00	86	0,00	15,00	8,01	2,83	0,35	2,67	8,29

to notice that the time span is delimited by maximum 20 minutes. The arithmetic mean is by 00:02:13 but the median is by 00:01:40 and differ by around 25 %. The most number of incident plots by 95% confidence interval is related between 00:01:51 and 00:02:34. With respect to these results the distribution of incident plots are not so homogenously like the incidents of category t>20 minutes, but also the most number of plots are related into a small time.

3.3 Statistical Analysis of incident number per month

Due to the high number of information in a first step the monthly number of different incident types where calculated for each operational month over the complete operation period. Based on the program Statistica Release [4] it was calculated the statistical characteristics of incidents per operational month which is described in table 6.

The mean is around 20 incidents per month, the main parts are the types of failures t<20 minutes and maintenance actions *t*<30 minutes. These types of incidents have no impact to the operational use of AIS-system. The numbers of other kind of incidents with operational impact are smaller. Over the complete operational period from 2001 to April 2006 we had only 27 incidents with a really operational impact. The deviation from minimum and maximum for number of monthly incidents are really high, N_{min}=5 and N_{max}=85. This deviation confirms the inhomogeneous and asymmetrical characteristic of distribution. The graphical presentation of times series number of incidents over the researched time period is presented in figure 5.

With reference to the figure 5 we can detect the following pattern:

- After start of operational use after a period of 7-8 month the number of incidents decreases in a strong way. For detail analysis it will be recommended to analyze in detail the reason of incidents from the failure point of view or to check the requirement situation during this time period.
- The next operational year of AIS-system was performed on the similar level of incident number until April 2005.
- The number of incidents in April 2005 is extremely escalated, because during this period the AIS System is updated and changed by a high number of changes requests.
- After realization of these large system changes the use of system shall established in more robustness and more stabile, because on the figure 5 is visible that the number of incidents in general decreased.
- Based on a 6-7 years used hardware platform the number of incidents is not increased. The hardware works very stabile and reliable. From the technical point of view the operational system processes in correlation to basic applications like data base and the specific AIS-application are the main reason of incidents and failures.

This figure 6 shows the overview plot of all defined types of incidents. The plot in figure 6 contains two different scales on right and left side form the mentioned incident types. All kind of plots are flatter and not homogenously, all types contain a different level of extremes. In the plot of figure 6 is visible that the failures of incident category t>20 minutes which have direct impact to the operation are only singular and have a similar homogenously distribution over the complete operational period.

In Figure 6 shows also different extremely outliers of high number of maintenance incidents *t*>30 minutes during August and September of year 2003. Also during this time period we can observe a high number failures *t*<20 minutes and maintenance incident *t*<30 minutes. This is a strong indication of instable system operation and strong impact of changes to the system availability and robustness. The same pattern can observed during the time period on April 2005. It will to suggest performing a detail analysis of changes and problem reports for these periods. Since May June 2005 we can detect that the numbers of all incident types are decrease extremely to a low number and this low level consists until end of observed operational period.

4. Conclusions

The statistical analysis gives the scientific approval of following findings and conclusions:

- Based on the actual system the availability of *AIS* service and functionality is fulfill and meets the requirements.
- From investigation point of view the required *SLA* parameter „Availability" is not sufficient and not complains for a complete description of service quality and statistical analysis.
- In addition it will be necessary to define new parameter like stability and robustness. From the *SLA* point of view it shall be agreed also a max time period out of service in depended from failure or maintenance category, because from the

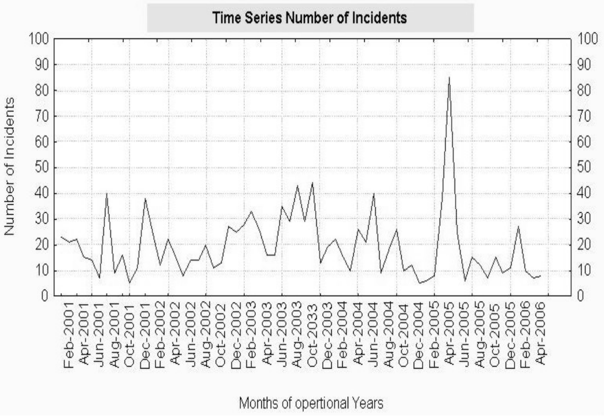

Fig. 5. Time Series Number of Incidents per operational month

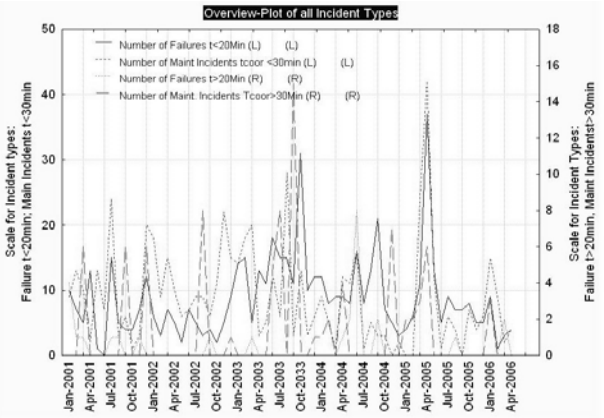

Fig. 6. Overview of all kinds of incidents types to the operation period

customer point of view only the functionality of service is important. The reasons of activities are in responsibility of service provider.

- Additionally also a maximal number of incidents per year or per month shall be defined.
- From statistical point of view it is visible that the number of incidents over operational years is stabile.
- It is not recognizable that by the long operational use of the systems and in particular the hardware platform an increase of incidents is visible.
- It is also not evident that the system and service is vulnerable by regular bringing in of new functionality, updates, patches and the system design is vulnerable to changes.
- With respect to the system migration in 2009 on a new system platform is very important to perform a migration to a more stabile and robust operational system.
- For increasing operational cost and to have an in depended system platform is making sense to work out a new design. To design the system in that way, that exist a in depended IT system platform wit an in depended operational system, preferable a open source operational system like LINUX and to have an in depended hardware platform. In addition the AIS application can to bring into a virtualized system platform.

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MAINTENANCE OF VEHICLES, MACHINES AND EQUIPMENT IN VIEW OF THE ISO9001 REQUIREMENTS.

The paper describes the ISO 9001;2001 requirements related to machine operation. These are general requirements concerning the process-related approach, infrastructure, staff competence and product execution. Examples of real life approaches to the issue are presented.

***Keywords**: maintenance of vehicles, process approach, ISO 9001.*

1. Introduction

The number of companies managed according to the ISO 9001 requirements is growing. A significant portion of them are those whose activities are closely linked to operating machines, devices and vehicles. When implementing, and then maintaining, a Quality Management System (QMS), they face a dilemma: should they treat the use of technical objects as a process which should be monitored, analyzed and improved, or should it be reduced to a procedure which describes the principles of handling technical objects (which usually means conducting planned maintenance, replacements, greasing, etc.). A question arises whether it is acceptable from the point of view of a certified QSM to apply other common operation strategies, like use of a machine until it breaks down.

2. Strategies of vehicle and machine

There have been numerous reports in the literature of systems and strategies of machine operation and maintenance [1, 2, 3, 6], starting with the simplest ones (operation until a machine breaks down, routine and preventive maintenance) through strategies based on the technical condition, reliability, amount of work performed, etc.

An informed choice of strategy is made mainly by large companies, having at their disposal sufficient human, financial and technical resources. In small and medium businesses (SMB), the choice is frequently without realization and is usually reduced to adopting one or several of the following models [4]:

- production-oriented strategy (operation until a machine breaks down);
- according to the operation manual, technical documentation and legal requirements;
- outsourcing of services related to machine maintenance;
- philosophical approach strategies (5S, Kazein, TPM, etc. in modern, not necessarily big companies);
- strategies stemming from ISO procedures.

2.1. Production-oriented strategy (operation until a machine breaks down)

The choice of this kind of strategy is usually equal to the lack of any strategy of machine operation. Machines and devices are operated until failure or its first symptoms appear; after that, they are repaired and used further.

This strategy is used in two cases. If it was an informed choice of this manner of machine operation, the choice was preceded by an economic analysis (possibly including safety and health issues), which showed its profitability. Any investments in surveys or diagnostics are unprofitable in view of the achieved benefits, such as reduced failure frequency, stoppage planning, etc. Machines operated according to this strategy are doubled and easy to repair; any failure of such machines and resulting stoppages are not critical to the company activities. In the other, not as frequent, case adopting this strategy is a result of a short-sighted, wasteful production policy of the company.

2.2. According to the instruction manual, technical documentation and legal requirements

Many companies adopt a machine maintenance strategy which conforms to the instruction manual and technical documentation supplied with machines. These documents contain information about the required replacement (oil, belts, bearings) and surveys (e.g. warranty survey, after 10 000 km, after 500 months). The strategy is therefore planned and preventive in character and in the case of some machines (e.g. cranes and pressure containers) certain regulations issued by the Office of Technical Supervision apply, concerning the necessity to perform surveys (inspections) mainly related to the safety issues.

The Office of Technical Supervision is a legal entity which performs tasks related to technical supervision within the scope laid down in the law of technical supervision and executive regulations to it [7].

2.3. Outsourcing of services related to machine maintenance

Outsourcing is a management strategy which consists in performing tasks, unrelated directly to the main scope of the company activity, by an external partner. This enables the company to focus its resources on the areas crucial to its basic activities, in which it achieves a competitive edge. The company outsources the operation of such processes which are considered auxiliary, e.g. IT (Information Technology), transport, accountancy or machine maintenance.

The companies which opt for such a model of machine maintenance should consider the following issues:

- the contracts should be long-term, enabling an assessment of the service performance,
- the service provider should be regarded as a competitive entity for the internal machine maintenance service – if the service provider is not competitive, outsourcing is not a good solution;
- a contract should focus on achieving results and not on delivering services. Apart from the price, the following should be taken into account: evaluation of the proposed principles

of machine maintenance, processes to be implemented, how the results will be assessed, how the decisions concerning prevention and prediction will be taken, etc.

2.3. Philosophical approach strategies (Total Productive Maintenance)

The TPM program is an approach to machine maintenance management of Japanese origin. Maintenance management based on the TPM approach consists mainly in preventing quality defects, preventing machine failures and their regulation. It is a program of permanent improvement based on the cooperation of the maintenance and production workers. This model is more and more frequently adopted by Polish companies, mainly by large, international ones; it can also be found in efficiently-managed SMBs. One of the system features is that a machine operator performs daily maintenance-related tasks, which results in elimination of failures caused by the lack of daily maintenance, and service specialists can devote their time to other activities. Thus, a conflict of operation system managers is avoided; a machine operator and its service team act together and account for their actions together.

3. A strategy which stems from the adopted ISO9001 procedures

Growing competition and customer requirements are forcing companies to implement and maintain quality management systems (QMS). Such systems are usually certified based on the ISO9001 standard. It is very important that the standard does not specify the requirements concerning the product (or service) provided by a company, but refers to the organization of all business processes (from marketing to invoicing) which are vital to its production. The standard is adequate to each type of production (service) being the outcome of each business activity, regardless of the geographical or cultural location of a company. It sets down the principles of planning, execution and supervision of particular activities [5].

3.1. Identification of the standard's requirements

In terms of the machine and device operation in the company, the following points of the standard directly apply to this issue: 4.1 – General requirements, 6.2 – Human resources, 6.3 – Infrastructure, and 7. – Product manufacture. Obviously, other standard requirements concerning corrective or preventive actions, or data analysis, may also apply, or do apply to operation; however, if they do not apply directly, they will not be discussed in this paper.

3.1.1. Identification of the standard requirements "4.1 General requirements"

Organizations are obliged to apply a so-called "process approach" in quality management, which means the necessity to identify the processes necessary in QMS, determine their sequence and interrelations, determine the criteria of effectiveness, monitor, measure and analyze. A process is understood to denote each action which transforms input (input data) to output (output data) with the use of resources. A definition of a process is contained in the ISO 9000:2000, point 3.4.1.

The process approach required by the standard causes the companies, which identify processes within themselves and present them as a so-called "process map", to define – apart from the main processes (e.g. production) leading to the final product – the processes of machine operation in the overall scope of activities leading to the final product. An example of a process map with an identified process of machine maintenance (understood as their operation) in an example SMB is shown in Fig. 1.

An important consequence of adopting machine and device operation as process is the necessity to identify it according to the standard requirements. The identification includes the process objectives, its owner, input and output data, criteria of effectiveness as well as ways of monitoring; in practice it is usually found in the Process Charter, whose example is shown in Table 1.

Another requirement of the standard (4.1 f) makes it necessary to improve processes. For machine and device operation it means that the process owner (usually the chief mechanic, the chief of the machine maintenance department) is required to monitor the process and measure it with adopted indicators and measures and to take corrective actions if the limiting values are exceeded.

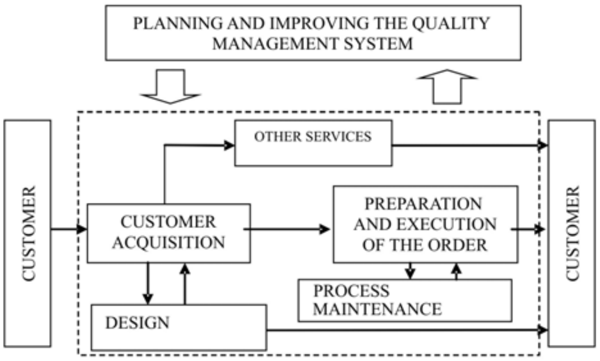

Fig. 1. A process map in an SMB with an identified process maintenance

Tab. 1. An example Process Charter "Process maintenance" in a water supply and sewage removal company

1. Process objective:	*Achieving the optimum state of readiness of the equipment that the company has at its disposal to perform its tasks and to ensure the continuity of the order execution process*
2. Process owner:	*company owner*
3. Process input:	*service requirements (based on the technical documentation), current requirements (based on the current technical condition), employees' skills and authorizations to performs certain tasks, safety and health requirements, plan and scope of surveys and repairs, reported failures, new machine/device*
4.Process output:	*machines and devices in working order, list of machines and devices, records of failure repair, needs in terms of repair/survey planning, needs in terms of new machines and devices, invoices for a service,*
5. Process participants:	*company employees – mechanics as well as machine and device operators*
6. Manner of monitoring	*analysis of a machine operation card, analysis of fuel consumption, analysis of failure cost*
7.Effectiveness indicator	*the number of hours of stoppage resulting from failure of machines/devices, not greater than 5% of the work time*

3.1.2. Identification of the standard requirements "6.2 Human resources"

This item of the standard imposes the obligation to ensure competent personnel. The company should identify the needs in terms of personnel responsible for machine maintenance; the term "competence" is understood to denote the necessary education, experience, training, etc. If the competence is insufficient (e.g. lack of appropriate education), the company is obliged to satisfy the needs (e.g. be providing the necessary training) and, additionally, assess the effectiveness of the actions taken.

3.1.3. Identification of the standard requirements "6.3 Infrastructure"

The standard requirements in terms of infrastructure include such resources as the company buildings, working space, tools, machines, devices, information techniques, communication, etc. If machine operation is not identified as a process, the principles of supervision over machines and devices should be set forth so as to ensure the conformity of the product with the requirements, i.e. meeting the obligations, both in terms of deadlines and quality, towards the customer. Note that in this case there are no direct requirements concerning the measurement of effectiveness of machine operation, and the approach is purely procedure-related.

3.1.4. Identification of the standard requirements "7. Product execution"

Product execution, i.e. its manufacture (or delivering a service) is the basic goal of a company existence. Except in the cases when machine and device operation is part of the direct execution of the goal (e.g. transport companies), the standard requirements related to the machine operation concern the following items:

a) 7.2.2 Review of the requirements concerning the product in sub-item c) the company is able to meet the relevant requirements,
b) 7.5.1 Supervising the manufacture and service delivery in sub-item c) applying the appropriate equipment,
c) 7.5.2 Validation of the production processes and service delivery in sub-item b) approval of the equipment and qualifying the staff.

3.2. ISO9001 requirements and the strategy of machine and device operation

The standard unambiguously indicates the necessity to apply the appropriate equipment in product execution, which is to be understood as the equipment which must be properly operated. However, the manner in which the requirement is to be met is the operator's choice; this is shown in Fig. Achieving the objective is possible in two ways:

1 – application of the process approach, i.e. identifying machine operation as a process, which is usually auxiliary, yet independent, in character, with the obligation to monitor, analyze and improve, stemming from the approach,
2 – qualifying machines and devices as infrastructure and defining the supervision principles in a procedural manner.

4. Examples of operation tasks

In the example presented here, activities of machine maintenance in process-related and infrastructure-related approaches are compared. Table 2 lists the activities broken down into specific operation tasks. The example does not include consideration of the identification of particular legal requirements and training, as in each case they have to be taken into account.

If the process-related approach is adopted, the relationship should be identified between various activities (production, machine maintenance, servicing customers, etc.). Among the good sides of this approach there is the ensuring of the supervision over particular elements in the whole system of processes, as well as over their combination and interrelation. However, it seems that without the appropriate information processing system, such an approach cannot be effectively executed. The problem can be solved by introducing a system of the CMMS class (Computerized Maintenance Management) - (repair management, maintenance, investment, service), in which operation events are registered and reports are generated with the assessment indexes of the operation system [4].

Tab. 2. An example of operation tasks in infrastructure-related and process-related approach

Operational tasks	***Determination of the supervising tasks for the infrastructure***	***Determination of the tasks in the process-related approach***
Periodical technical surveys and routine repair.	*Determination of the time and scope of the technical surveys and routine repair.*	*The same as on the left and: reporting the performed technical surveys and routine repairs, planning (frequently with the use of mathematical, prognostic and econometric models) and registering the actual amount of labour needed, consumption of the operational materials and costs. Assessment of the prognosis errors and promptness.*
Damage repair	*Establishing the principles of notifying failures. Sometimes reporting the performed damage repairs, taking into account the time, scope, cost and reasons of the damage.*	*Determination of the detailed principles of notifying failures, registering the time of failure stoppages, duration of damage repairs, cost, registering the repaired systems or parts, analyzing the causes of damage, earmarking the work time fund of the machine maintenance department – frequently with the use of statistical analysis.* *Assessment of the damage repair acceptability, e.g. by analysis: damage reaction time, time of machine restoration to the operational condition, financial loss.*
Diagnostics	*Frequently organoleptic, within its basic scope during operation, sometimes routine, with making comparisons of the measured values of diagnostic signals with the limiting values (warning and failure-indicating).*	*Routine diagnostics or condition monitoring. Registering the measured values of diagnostic signals, comparing with the limiting values (warning and failure-indicating).* *Forecasting the changes in technical condition.*

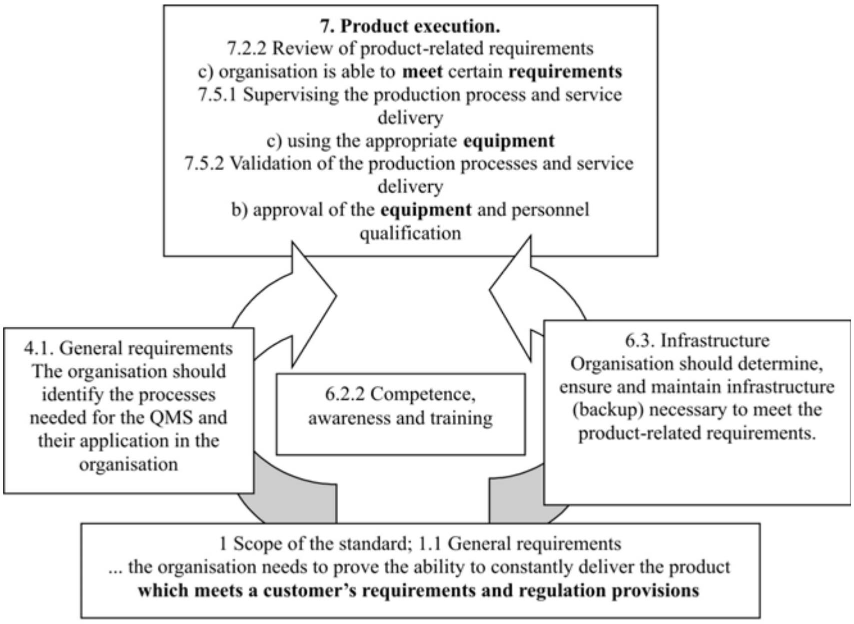

Fig. 2. Possible approaches to meeting the requirements of the ISO9901;2000 standard for a product execution in terms of machine and device operation

5. Summary

ISO9001:2000 is the most popular standard implemented in companies; it determines a model of planning, execution and supervision over particular business models in order to achieve complete customer satisfaction (including the so-called "internal customer"). From the point of view of machine operation, it is important to ensure the application of the appropriate equipment for the production processes execution. This is understood to denote the application of appropriate machines and ensuring their proper technical condition, which affects the meeting of requirements in terms of production, quality and deadlines.

The ISO9001 standard, being a QMS, details only the requirements to be met, without imposing upon the company what methods it would choose to achieve it. For machine operation, meeting the requirements concerning the application of the appropriate equipment is possible in two ways:

1 – by adopting the process approach together with the measurements and analyses of the process;
2 – by adopting the procedural approach, defining more or less general principles of conducting surveys, maintenance, repairs, etc.

In each of these cases, the actions must be effective, i.e. they must ensure the meeting of a customer's demands; however, adopting the process approach ensures the improvement of the process effectiveness. Note that the necessary competence of the maintenance personnel has to be ensured and the relevant legal regulations have to be taken into account, e.g. related to routine repairs, technical documentation or European Directives.

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Karolina PERZ

OPERATIONAL STATES OF INSULATION IN REFRIGERATED TRANSPORT OF GOODS

In the paper are presented operational states of thermal insulation occurring during exploitation. The analysis of processes devastating thermo-insulation systems during operation was conducted. Also the criteria of the borderline condition of those insulations were described.

***Keywords**: insulation board, refrigerating bodywork, borderline condition of insulation boards, criteria of the borderline condition of insulation boards.*

1. Introduction

Exploitation of refrigerated means of transport for transporting foodstuff is an essential issue in the system of transport. The technical conditions of the system decide about the ability to fulfill ordered tasks. Failure to meet the assumed technical requirements by particular vehicle results in various negative consequences such as e.g. damage of forwarded goods can cause high financial losses, as well as ecological threat forcing the carriers and recipients to troublesome and usually expensive procedures associated with elimination of not suitable for eating foodstuff. The problem is even bigger if it concerns food products for which conditions, such as temperature, humidity and often also atmospheric composition, are precisely specified. Another limitation while transporting foodstuff is usually short expiration date of those articles, which is associated with the tendency of cutting off the amount of chemical substances for food conservation, so the time of transporting goods from manufacturer to customer is also considerable limited.

In this paper an attempt was made to present issues considering maintaining refrigerated of transport in operational state; that is operational, nonoperational and intermediate states are described. It was also attempted to determine criteria of reaching the borderline state by a vehicle, which causes temporary or even permanent exclusion of the particular vehicle from operation.

2. Scope of research

The object of research of this paper is cooling means of transport used for transporting foodstuff. Described means of transport consists of:

- thermal bodywork,
- devices responsible for shaping microclimate in the loading chamber,
- measuring devices controlling values of characteristic parameters.

In the paper are considered just borderline states of part of the vehicle – of the thermal cover. Its task is to limit the heat exchange between the interior of the loading chamber and the environment. Moreover, the bodywork should guarantee: [1]:

- protecting the load from humidity and light,
- sanitary transport conditions,
- protecting the load against theft,
- proper location and protection of the load against undesirable movements during transporting.

The classification of means of transport is given, among other things, also ATP Agreement (Agreement on international transportation of quickly decaying foodstuff, on special means of transport for transporting such goods). The basic criterion classifying a vehicle to particular group is the value of overall heat-transfer coefficient 'k', which describes the intensity of heat exchange between interior of the chamber and the environment. According to ATP agreement, the vehicles can be divided into the one with:

- normal insulation – $k \leq 0{,}7$ W/(m^{2}K),
- strengthened insulation – $k \leq 0{,}4$ W/(m^{2}K).

For constructing cooling bodyworks are used laminated boards. They consist of two layers (metal or plastic), which guarantee appropriate rigidity of the boards, and of the core (usually made of polyurethane foam), which protects the interior of the bodywork from penetration of the heat from the environment.

Such boards can be made in two ways – either in the process of gluing particular layers composing the board, or by foaming the polyurethane foam between the two layers.

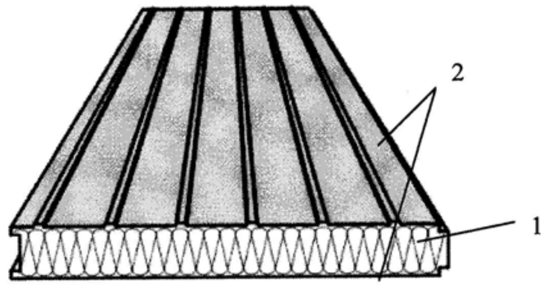

Fig.1 Laminated board (1 – core insulation, 2 – material of the layers)

In the core of thermo-insulation board, used for constructing cooling bodyworks, have to be placed elements of construction for mounting e.g. hinges, locks and reinforcements under the refrigerating unit. In such places occur so-called heat leakage bridges that are places of actual reduction of thickness of the insulation. One of the tasks of the bodyworks' designers is to reduce the number of those bridges.

Cooling bodywork during exploitation is exposed to deterioration of its insulation parameters e.g. change of the overall heat–transfer coefficient due to impact of operational parameters. So it is essential to monitor the technical condition of the vehicle continuously in order to ensure the best conditions of transportation, so that any changes of the parameters will not influence negatively the quality of transported goods.

3. Operational states of insulation systems

Faults resulting in deterioration of reliability of cold insulations may come into being on three stages of existence of the cooling unit: during designing, production and while operation. Unserviceabilities formed on the designing stage generate structural defects, and faults on the production stage – cause technological defects. Faults occurring while operation are called damages. Structural and technological defects do not eliminate particular unit from operation, just cause the deterioration of its quality understood as the level of satisfying the needs of the user. They can occur as visible defects or hidden ones, which reveal after some time of operation or in particular operational conditions.

Deterioration of technical unit reliability can cause a change of its physical condition. Notion standard, quoted earlier in this document, presents following definitions essential for the discussed issue:

- Operational state – state of reliability in which the unit can perform its task in comply with the requirements,
- Nonoperational state – state of reliability, in which the unit cannot perform its task in comply with the requirements,
- Damage – event consisting in transition of the unit from operational to nonoperational state,
- Criteria of damage – requirements concerning a feature or group of features, on the basis of which the fact of occurring damage is established.

Another notion necessary to define for further proper consideration of the issue is 'condition'. It can be presented as a set of particular values of physical quantities accepted for describing material unit or phenomena, occurring simultaneously and inseparably.

Examples of routing diagrams illustrating different cases of technical unit transition from operational to nonoperational states are presented in Fig. 2.

The above definitions present a situation, in which particular unit can be just in two extreme states. It can exist just as 'operational' on 'nonoperational'. Transition between those states is radical and is called 'damage'. Such situations occurring in reality are considered breakdowns or catastrophes. In practice it is possible to generate a sequence of intermediate states between operational and completely nonoperational state. Those states can be named in following way:

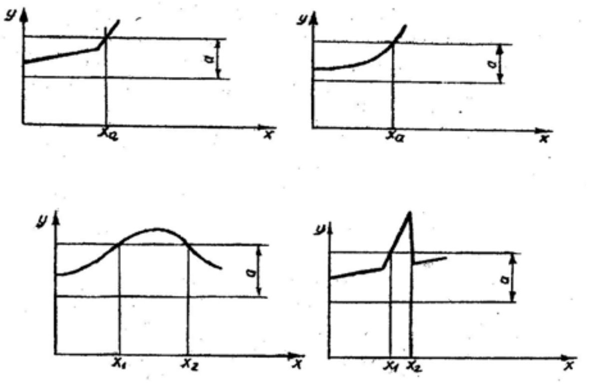

Fig 2. Examples of routing diagrams of transition of the unit from operational to nonoperational state; x – operational parameter, y – value of measured feature, a – tolerance region for operational state, a) irreversible changes – stepping process, gradual process, b) reversible changes - stepping process, gradual process

- Operational state – desired state of ideal unit. The insulation board already produced, as long as it meets the quality requirements, is in the fully operational state and can be used for exploitation.
- A sequence of consecutive accepted states – a sequence of states, in which the basic insulation functions carried out are in comply with assumed criteria, e.g. damage of lacquer layer covering the layers of cold insulation does not influence the task realised, it can just influence the esthetical requirements for the insulation.
- A sequence of consecutive tolerated states – a sequence of states in which the basic unit functions are disturbed, but because of different reasons such a situation must be tolerated. During transporting foodstuff on short distances such little damages of insulation influence the overall heat-transfer coefficient, but do not cause the deterioration of the quality of food transported. Such state can be called a tolerated state.
- State of menace – a state, in which the unit carrying out its function can pose a menace of deterioration of the quality of protected goods, ecological risk, increase the energy- and time-consumption of the functions realised. Such state, when identified, can be treated as tolerated one in some operational conditions despite of deeply disturbed some of the functions of the unit, or as an inadmissible state for further unit exploitation. Such a situation can be often observed for cooling vehicles. During food transportation, the vehicle is exposed to frequent damages of the external body panelling due to external factors or of the internal panelling – due to securing the goods improperly. Particular vehicle has to get to the delivery point, so despite of the threat of goods' quality deterioration posed by the damage, it must be treated as a tolerated state.
- Nonoperational state – a state, in which the unit is eliminated from exploitation because of impossibility to carry out the imposed functions. Such a state can be reversible if the unit is reparable, or irreversible, if the repair is impossible. Reparability is dependent of the technical potential (in terms of repairing technologies) and costs (the repair can be cost-effective or not). If the impossibility of carrying out the imposed functions is of physical character, the reason of this can be called damage; in other cases nonoperational states, as well as other states, have decisive character (that is, it does not ensue just from technical condition of the unit). An example of such nonoperational cold insulation is disturbance of the insulation core of the board. Damaged panelling causes intensive propagation of moisture inside the board, increasing the overall heat-transfer coefficient. Such insulation does not meet the imposed criteria, so it has to be excluded from operation.

Depending on the decisive criteria selected, it is possible to qualify the unit to the proper state.

4. Analysis of damaging processes of thermo-insulation systems of refrigeration bodyworks

During the 'life cycle' of the refrigeration bodyworks occur many situations, in result of which the unit can achieve nonoperational state by not fulfilling the assumed operational parameters. The specification of operational conditions of the bodywork is the reason for wide variety of working conditions. This is the reason for wide diversity of damaging processes. On figure 3 is presented classification of processes damaging insulation boards, describing the reason, consequence and symptoms of particular damage.

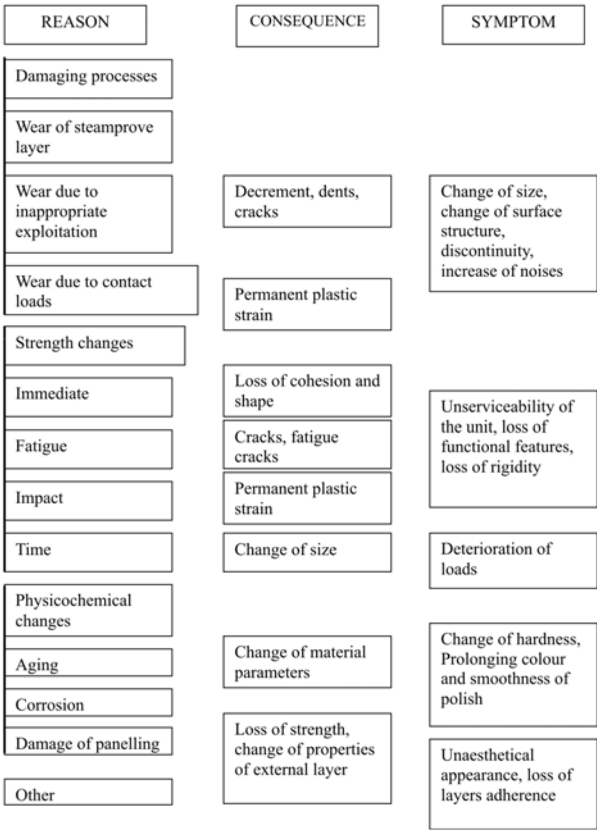

Fig. 3 Classification of processes damaging insulation boards

Assumptions influencing deterioration of quality of discussed thermo-insulation systems can occur, as previously mentioned, on different stages of existence of the unit.

On the designing stage, deterioration of the assumed durability can ensue from mistakes of constructors – designers. It can be the result of personal lack of knowledge or purposeful decision of resigning from the optimal parameters of design, ensuing from reasons other than technical.

Both on the designing and production stage, defects can appear on two levels:

- during production of laminated board,
- during mounting the laminated boards composing particular technical unit.

Proper quality of thermal insulation can be achieved by appropriate realisation of particular technological processes during production of boards, especially during preparing adequate proportions of particular components of foam, mixing them and during pouring the combined components into the form. On the stage of mounting the boards it is recommended to pay attention to proper tightness of joints, as accurate insulation of joints is the basic factor influencing reliability of the produced unit.

Exploitation stage is the most essential in existence of every technical object. During this time the cooling bodywork fulfils functions for which it was designed, produced and prepared for use that is transporting goods in appropriate climatic conditions. On this stage appear most of the dangers causing loss of values of parameters deciding about its usability for exploitation.

Damages to the cooling bodywork are caused by impact of forcing factors, which can be divided into two groups:

- factors ensuing form functions carried out by given unit, in this case – by cooling chamber (working media),
- factors characteristic of the environment in which particular chamber functions (external factors).

Working media stop operating the moment, when the unit stops fulfilling its function, that is transporting and storing foodstuff, while external factors influence the unit whether it is exploited or not.

The cooling bodywork during operation usually suffers damages caused by improper exploitation. The damages are most often caused by external factors and occur accidentally e.g. influenced by the force causing plastic strains. Another example of damages is scratches. Both examples are usually the result of insufficient qualifications of the drivers servicing particular vehicle or lack of caution while operating the vehicle. Many of the damages of the boards are cracks of the layer of varnish of the insulation panelling. Such type of damage has little influence on overall heat-transfer coefficient, as it does not disturb the insulation layer (the core) of the board, but ignoring it might cause corrosion of the panelling and the moisture penetrating the core can cause increase of this coefficient.

Damages of the bodyworks can also be caused by influence of environmental factors, such as intense solar radiation causing cracking of the varnish layers of the panelling, acid rains speeding up processes of corrosion of metal panelling and introducing moisture into the core through crevices, high temperature speeding up, among other things, also corrosion processes. Essential influence on the insulation condition has also atmosphere pollution and microorganisms (fungi, mildew, algae). Damages of the car bodyworks usually embrace the external or internal panelling of the insulation (depending on which part of the chamber they were initiated) and possibly the area of insulation core adherent directly to the panelling.

5. Criteria of the borderline of thermal insulation

Technical objects, including thermal insulations, can be in two states: operational and nonoperational. As previously mentioned, transition between those two states is racidal and called ‘damage’. For the need of this paper it was accepted that operational state is not only lack of damages and limitations in the quality of operation, but also such state of the unit, in which all the functions are realised in the best way from the point of view of all criteria that can be specified for estimating the quality of this realisation. Those criteria can be divided into three groups:

- Technical and structural criteria – most important here are criteria of functionality associated with operation of the unit.
- Economic criteria – used to determine the borderline state in case, when due to technical changes of the element the efficiency of using it drops.
- Environmental criteria – used to estimate the influence of the device on natural environment.

Among technical and structural criteria can be established the physical parameter – certain physical quantity – the value of which will determine usability of given insulation in the process of exploitation. Such a parameter is the heat transfer coefficient already mentioned above. Any exceeding of a specific level of this quantity implies that the operation of the facility should be discontinued.

The very important group are technical criteria, ensuing form the structural characteristic of insulation boards. As the insulation during exploitation in different of conditions is exposed to various loads, it can be damaged, or at least the mechanical or compression strength can deteriorate. While exploiting the unit there is steady deterioration of the properties of the boards. It is caused e.g. by aging, corrosion or fatigue. Despite the fact that materials for insulation boards, in the moment of introducing them into operation, have some determined mechanical strength or resistance to development of microorganisms, low hygroscopicity and absorbability, of course, during exploitation those parameters deteriorate. Exceeding the determined limitations can cause withdrawal of the unit form further use.

Economic criteria – used to establish the borderline conditions of the insulation board in case when there is a change of its technical condition, which causes lowering the effectiveness of using it. The example here might be increase of overall heat-transfer coefficient due to mechanical damage of the board. With the increase of the coefficient increases also the amount of energy supplied to refrigerating unit. On the basis of economic calculation should be determined the borderline for wear or degree of damage of the insulation boards working in particular operational conditions. While settling the economic criteria for thermal insulation, the technical requirements and economic efficiency of exploiting it should be taken into account. When further exploitation, due to change of the values of condition parameters, requires higher investments than those settled, and prime-costs are higher than planned, it is pointless.

Because of growing environmental pollution, the importance of environmental criteria in estimating the borderline conditions of cold insulation is growing. Their aim is to protect both natural and influenced by people environment. Those criteria include also legal standards, market laws, trends and aesthetics. Legal standards regulate acceptable amount of pollution and noise both during exploitation and production. They also include hints for further use of materials composing insulation boards (recycling of wastes). Every departure from the legal standard is a measure of insulation failure.

In case of estimating the borderline conditions of insulation board (on the basis of the above criteria), the decision about reaching the borderline condition depends on a person responsible for withdrawing the board from exploitation. Often it occurs that temporary loss of usability of the board does not have to result in withdrawing it from operation, as it is not equivalent to reaching the borderline condition. An example here might be increase of costs of energy required to ensure proper conditions during exploitation of the refrigerator, when the external temperature is higher due to hot weather. Taking into account longer period of time, then costs of maintaining the refrigerator made of boards in exploitation will not exceed the determined economic criteria.

6. Conclusions

Determination of operational and nonoperational states of thermal boards composing thermo insulation system is an essential issue during exploitation. To estimate the borderline condition of insulation boards the importance of every factor for determining the condition should be taken into account. While estimating state of boarders working in different conditions might occur little deviations of particular parameters. The rule is that in every case analysis of the issue of borderline condition estimation is effective, which takes into account the rule of priority of the functional criteria – influence of the physical factors, then economic factors and finally – environmental factors. Next, other criteria might be considered.

Because of the structure of the unit, the technical control of the bodywork might be difficult during operation, so every carrier should have the system of stationary diagnostics implemented and operating in the transport base. The system should determine the type of diagnosed damages, methods of diagnosing them and time intervals between the inspections.

Technical condition of the cooling bodywork determines safety of goods transported, so fulfilling all the criteria should by the priority task of every carrier.

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Marek MŁYŃCZAK

QUEUING SYSTEM WITH VARIABLE SERVER NUMBER

Description of main characteristics of Mass Maintenance Systems is given. Problems of queuing system effectiveness due to loss of time for both arrivals while waiting for service and for servers waiting for arrivals are discussed. System with changeable number of servers is proposed. Calculations are made in order to find out what is influence of main queuing system parameters on the total operational cost regarding time losses. It is shown that decision about system structure depends mainly on system service index and server initial cost.

***Keywords**: mass maintenance syetem, system structure, operational cost.*

1. Introduction

A model of transportation systems applies usually Queuing Models (also: Waiting Lines, Mass Maintenance System) as a tool to modeling, improving and quality assessment. These models take into account various undesired events disturbing correctly designed process. Queues in real operation process arise as an effect of event randomness and shortage of dynamic adaptation due to external demands. Process is defined as a function assigning to operation states set of operation times and creates a set of random time intervals corresponded to states separated by events. Transportation processes are described as a set of states of transportation process which superior function is to perform randomly arising transportation services. Key elements of the Mass Maintenance Systems (MMS) are: customers (service demands) and service places (servers). Depending on necessities, availability or opportunities, one may permit in the system for creating queuing for service or resource releasing. Working of the system consists on: accepting a customer for free service place or position it in the queue, if it is possible, perform the proper service and remove it from the system. System works properly if customers are not rejected, do not wait too long or if servers are not idle (do not wait for customers). From the customer point of view, quality of the maintenance system is high if on demand at least one server is free. From the system management point of view, server effectiveness is the best if it is busy continuously, even independently if customers queue for service. Adaptation of the system to such variations of demands is difficult as well technically as organizationally but minimizing of waiting intervals both customers and servers may in longer period decrease operational loses [1,5,7].

2. Queuing systems characteristic

Maintenance system has to accept the customer, get him service and release it [1,3,5]. If necessary in the system may be crested queue and than the system contains (Fig. 1):

- arriving in time service requests (arrivals- failed vehicle with repair demand, customer for shopping, airplane collecting passengers, ship coming for cargo),
- service stands offering action (servers- vehicle diagnostic place, fuel distributor, salesman, loading place),
- queue to place customers waiting for service.

Classification of MMS's takes into account several criterions: the way of arrivals (batch, singly), time distribution between arrivals, number of servers, distribution of service time, possible queue, its regulation and capacity.

According to known notations (Kendall, Lee) [1], system is described by the set of symbols: A/B/C/D/E/F, where: A, B describe arrivals stream and distribution of service time, C is a number of servers, D is a queue regulation (way of entering the service system from the queue), E is a total number of customers staying in the system (total number of servers and queue capacity).

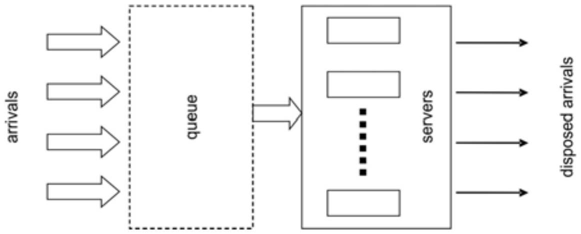

Fig. 1. Elements of mass maintenance system

The main modeling objective is a possibility of analyzing and assessing of system performance, where the most important assessment characteristics are the probability of acceptance refusal, expected number of busy servers or queue length. Analysis and assessment of system parameters is possible analytically by the way of Markov Chains. It is necessary anyway accepting strong limitations and assumptions regarding arrival stream and distribution of service time. Arrival stream is required to be Poisson and service time distribution should be exponential. In that case system assessment is possible analytically. In other situation (time distribution of interarrivals and service not exponential) more effective are simulation methods, though there are some approximate methods giving analytical solution by a little less strong assumptions (semi Markov method) [1,4,6].

Queuing systems are classified according to parameters (arrival stream, service time) and their structure. There are single and multiserver systems, open and closed, and series and parallel. There are very few examples of the systems having changeable number of servers, i.e. systems having possibility of opening and closing servers depending on queue parameters [6,7]. In system with losses (queues not allowed) one may observe number of lost arrivals in given period.

3. System with changeable number of servers

In M/M/m/∞ system arrival stream is Poisson and service time is exponentially distributed. Arrival intensity λ, service intensity μ and number of servers m are the parameters of that system. System allows queuing. Mean size of the queue is given as:

$$\bar{v} = \frac{\dfrac{\rho^{m+1}}{(m-\rho)^2(m-1)!}}{\sum_{i=0}^{m-1}\dfrac{\rho^i}{i!}+\dfrac{\rho^m}{(m-1)!(m-\rho)}};\rho=\frac{\lambda}{\mu};\frac{\rho}{m}<1 \qquad (1)$$

and average number of busy servers is $\overline{m_{nz}} = 1-\rho$, and probability of idle state P_0 is probability that there is no arrivals in the system: $P_0 = \dfrac{1}{\sum_{i=0}^{m-1}\dfrac{\rho^i}{i!}+\dfrac{\rho^m}{(m-1)!(m-\rho)}}$

Especially, considering single server system (m=1, M/M/1/∞), the above formulas are simplified and in steady state are: $\bar{v} = \dfrac{\lambda^2}{\mu(\mu-\lambda)}$ and $P_0 = 1-\dfrac{\lambda}{\mu}$.

System with the ability of adaptation to changeable conditions may work in this way that depending on given criterion (queue length, idle time) system open or close server that criterion is maintained on required level. Time of server awaking after idleness (tuning time) may also be taken into account but this special case has limited application [2]. The problem of changeable server number is significant regarding three important operational costs: cost due to waiting time for service, cost of lost time while server is idle, initial cost due to construction/opening next server.

It is shown in Fig. 2 comparison for various parameters of arrival intensity (λ=0,2-0,9), service intensity (μ=1) and idle state probability.

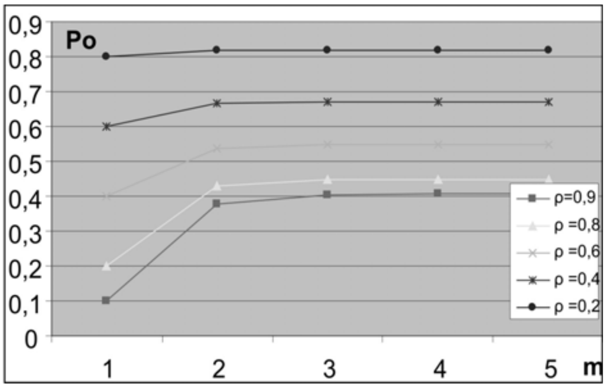

Fig. 2. Server idleness probability due to server number and index of relative service intensity of the system

4. Operational cost analysis for multi server system

The largest change in the probability of server idleness is seen in the range between one and two servers. Hence in systems M/M/m where inter arrival periods and service times are highly variable (variation index in exponential distribution is equal to 1), by relative service intensity of the system approaching 1, probability of meeting zero arrivals in system approaches 0. Actuation of second and following servers raises probability of free server and on the other hand elongates server idle time. In that case, according to instantaneous or periodic arrival intensity or queue length, if many arrivals wait then the system puts working a new server, while there is no arrival waiting, system gets back to previous state (decreases number of servers).

Introducing cost as a quality criterion for the system operation, the target function is described as:

$$Kc(m) = tk(m) * Ko + tb(m) * Kb + Kp \qquad (2)$$

where: $Kc(m)$ – total system operating cost, Ko – unit cost of arrival waiting, Kb – unit cost of server idleness,
$tk(m)$- average arrival waiting time:

$$tk(m) = \frac{\bar{v}}{\lambda} = \frac{\dfrac{\rho^{m+1}}{(m-\rho)^2(m-1)!}}{\lambda\left(\sum_{i=0}^{m-1}\dfrac{\rho^i}{i!}+\dfrac{\rho^m}{(m-1)!(m-\rho)}\right)}$$

$tb(m)$- average server idleness time:

$$tb(m) = \frac{P_o}{\lambda} = \frac{1}{\lambda\left(\sum_{i=0}^{m-1}\dfrac{\rho^i}{i!}+\dfrac{\rho^m}{(m-1)!(m-\rho)}\right)}$$

Kp – initial server cost.

Analytical determination of the minimum cost function is complex because of existence in above formulas of sum dependent on m, therefore in the range of largest variability, the shape of cost function was obtained numerically for single and double server system (Fig. 3). In calculation, unit cost for waiting and idleness are equal.

Analysis of the above diagrams (Fig. 3a) says that if initial cost is neglected, double server system is in the whole range of system service index ρ=0,1 - 0,9 “cheaper” in operation. Single server cost function has minimum at ρ=0,5, and for two

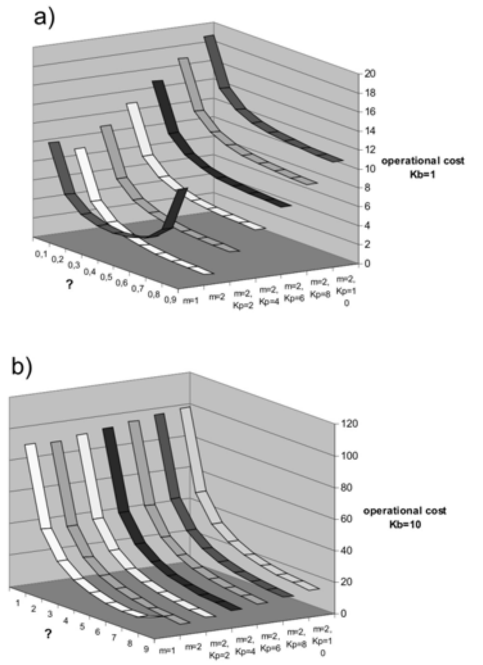

Fig. 3. Operational cost at one and two servers, regarding initial cost in the range of 2 to 10 units and for idleness cost Kb=1: (a) and Kb=10: (b)

servers is monotonically decreasing. Taking into account initial cost one gets that single server system is cheaper if initial cost does not exceed 2 cost units. For more expensive servers (*Kp* >10), single server system has lower cost in the whole range of ρ variability.

Next stage of the analysis is the determination of influence of the ratio of idleness cost to arrival waiting cost (Fig. 3b). It may be reasonably assumed, that idleness cost of the server (it serves for many arrivals for long time) should be higher than waiting time of the single arrival. In the numerical example idleness server cost is assumed 10 times the cost of waiting time of the arrival. Obtained results show that total operation cost raises only a little due to initial cost of the server Kp and even for single server system total cost is on the same level like for many servers.

5. Summary

Markov chains applied to queuing systems introduce to model of the real system strong assumptions about exponential service time which make this model not very realistic. Analytical outcomes for M/M/m systems let us only in insignificant level for its optimization due to complicated form of equations. Numerical analysis shows that the most effective organizational actions in multiserver system are valid in the range between one and two servers (total operational cost is the most sensitive for changes in server number 1 to 2).

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OPERATION OF THE MULTI-FUEL CYCLES UNDER OFF-DESIGN REGIME

The paper presents an analysis of an multi-fuel power cycle. The cycle includes a gas and steam turbine. The methods and tools are described, which allow to model the operation of the cycle in the off-design regime.

***Keywords**: multi-fuel cycles, off-design.*

1. Introduction

The multi-fuel power cycle become an essential alternative for conventional and combined heat and power plants [1,3,4,7]. The main advantage of such cycles is the possibility of their better adjustment to the user demands and in consequence the decrease of the operation costs [2,4]. The selection of the basic parameters such as the power output or the amount of the generated heat is strictly connected to the conditions under which a specified cycle is to operate.

Such strictly limited selection results in a very good efficiency of the operation in the design regime. However the range of the off-design regime in which the operation is profitable may be very small. Therefore even the initial choice of the cycle components requires also an analysis of the off-design operation.

This paper presents the tools and results for such an analysis. The cycle under investigation is a multi-fuel power plant with a gas and steam turbines. The article describes a model applied to the simulation of the operation under various regimes. The following issues are analyzed:

- the adjustment of the gas turbine in order to satisfy the power demands,
- the efficiency of the combined gas and steam cycles for a changing ambient temperature,
- the division of the load between the gas and steam sub-cycles.

The research regards especially the effectiveness criterion as it has a direct influence on the costs of operation.

2. The analyzed cycle

The cycle under the investigation consists of a gas turbine, a heat recovery steam generator (HRSG) and a condensing turbine. The configuration of the cycle is shown in fig. 1 together with notation of the cycle nodes. The flue gas from the gas turbine feeds the HRSG and allows to generate a part of the livesteam for the steam turbine. A parallel coal boiler produces the rest of the livesteam. Such arrangement allows better flexibility in terms of the fuel.

The gas turbine has an open cycle with one compressor, combustor and expander. The expander has an internal cooling. The cooling air is extracted from the last stage of the compressor and delivered to the first stage of the expander. Since the exhaust gas has quite high temperature at the expander outlet it is further to feed the HRSG. This temperature may even be increased in the afterburner. Such necessity arises in the off-design operation when the stream of the exhaust gas is smaller.

The steam cycle consists of two expanders: a single-flow HP part and double-flow LP part. The cycle includes also exchangers for heat recovery. They are fed by the steam extracted from expander bleedings in both parts of the steam turbine.

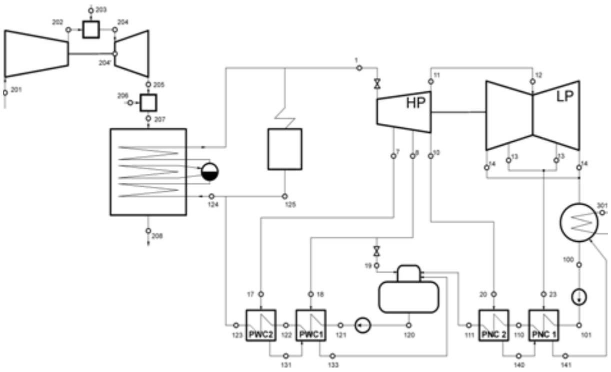

Fig. 1. Thermal arrangement of the analyzed cycle

The design power output for the gas turbine is 66.6 MW and for the steam turbine 48 MW. Several design values are gathered in table 1.

Tab. 1. Design values for the chosen parameters of the cycle

Quantity	*Point*	*Unit*	*Value*
Gas turbine			
ambient air pressure	*201*	*kPa*	*101*
ambient air temperature	*201*	*°C*	*15*
ambient air humidity	*201*	*%*	*60*
inlet guide vane angle	*201*	*-*	*1*
compressor outlet pressure	*202*	*kPa*	*1800*
fuel mass flow	*203*	*kg/s*	*10.3*
combustor outlet temperature	*204*	*°C*	*1150*
turbine inlet temperature	*204'*	*°C*	*1100*
power output	*-*	*MW*	*66.63*
Steam cycle			
livesteam pressure	*1*	*MPa*	*5.7*
livesteam temperature	*1*	*°C*	*480*
livestem mass flow rate	*1*	*t/h*	*200*
condenser pressure	*14*	*kPa*	*6*
feed water flow rate at the HRSG inlet	*124*	*t/h*	*100*
poer output	*-*	*MW*	*47.86*

Both turbines are selected in such a manner that for design regime the afterburner does not operate and most of the heat from the exhaust gas is regenerated in the HRSG. The exhaust gas temperature at the HRSG outlet (point 208 in fig. 1) is 200 °C.

3. The modeling of the off-design operation

The analysis of the operation under off-design regime requires appropriate tools for the simulation of the operation of the cycle. A simulation module was designed for this purpose [6].

The module consists of several components, which simulate the operation of the chosen machines of a thermal cycle, such as the compressor, combustor, gas expander, steam expander, heat exchangers and so on. This allows to analyze various arrangements of combined multi-fuel cycles.

The simulation module for off-design operation must take into account the influence of the user as well as the atmospheric (ambient) conditions on the operation of the machines. Therefore the input data for the analysis consist of a set of parameters, which are either set directly by a user or derive from the atmospheric conditions. For the analyzed cycle the set of the input data includes:

- ambient air pressure, temperature and humidity,
- compressor inlet guide vane angle (IGVA),
- gas fuel flow rate to the combustor,
- gas fuel flow rate to the afterburner,
- livesteam pressure, temperature and flow rate,
- cooling water temperature at the condenser inlet,
- feed water flow rate at the HRSG inlet.

The simulation allows to determine the parameters of the flowing media (air, exhaust gas, steam and water) in chosen nodes of the cycle, that is at the inlets and outlets of each of the machines. In addition the simulation module calculates the total power output, amount of fuel supplied to the steam boiler and the efficiency of electric power generation.

The efficiency of the gas turbine in terms of the electric power generation for the cycle shown in fig. 1 is calculated as:

$$\eta_{GT} = \frac{N_{GT}}{m_{203} \ LHV_{gas}} \tag{1}$$

and for the steam cycle:

$$\eta_{ST} = \frac{N_{ST}}{m_1 \left(i_1 - i_{123} \right)} \tag{2}$$

The total efficiency of the electric power generation for the whole cycle is calculated for the total actual amount of the fuel supplied to the system:

$$\eta = \frac{N_{GT} + N_{ST}}{\left(m_{203} + m_{206} \right) LHV_{gas} + m_{125} \left(i_1 - i_{125} \right) \dfrac{1}{\eta_{SB}}} \tag{3}$$

The symbols applied in the above equations are: m, i - mass flow rate and specific enthalpy, N_{GT}, N_{ST}- electric power output of the gas and steam turbine, η_{SB} - steam boiler efficiency, LHV_{gas} - lower heating value of the gas fuel.

Numbers refer to the cycle nodes according to the fig. 1.

In the design conditions the electric efficiency is 34.50% for the gas turbine and 33.48% for the steam cycle. The total electric efficiency is 42.46%.

4. Matching of the cycle sections in the off-design operation

The machines in the thermal cycle cooperate with each other. This cooperation is especially important when modeling the off-design operation since the alteration of one of the input parameters usually influences and changes other parameters in several nodes of the cycle [5,6]. These changes derive from the altered equilibrium state of the machines. The simulation module determines the equilibrium states for the machines, which match the equilibrium states of other machines in the cycle. This approach allows to calculate the values of thermal parameters in all nodes of the cycle.

The matching of three main sections is especially important in the analysis of the off-design operation for a gas turbine. These sections are: the compressor, combustor and expander. There are several parameters, which describe the operation of these sections but may also be treated as constrains, which force the sections to cooperate. The parameters are:

- Rotational speed. The expander drives the compressor through either one shaft or a transmission gear.
- Air flow. The amount of the exhaust gas depends on the amount of the inlet air to the compressor. The mass balance includes also the amount of the fuel gas, cooling air and flows through the seals.
- Pressures and temperatures. The expander inlet pressure depends on the compressor delivery pressure. The temperature of the air delivered to the combustor depends on the compressor isentropic efficiency and the turbine inlet temperature derives from the combustion process.

As the equilibrium states for the main sections are compared a single matching point may be determined, which uniquely identifies the off-design equilibrium. This point is usually plotted in the compressor characteristic. The equilibrium states for the main gas turbine sections derive from:

- The line of the compressor inlet guide vane angle. The compressor characteristic shows a dependency between the amount of the inlet air and the outlet pressure for various values of the IGVA.
- Mass and energy balance for the combustor. The compressor delivery pressure and its isentropic effectiveness determine the compressor outlet temperature. The mass and energy balance for the combustor determines the amount of air of this temperature, which is required to obtain the desired turbine inlet temperature for a given amount of the fuel.
- Absorption capacity for the expander. There is a strict relation between the pressures at the expander inlet and outlet and the amount of gas which is expanded.

As for the steam cycle, the off-design simulation matches the turbine sections with the regeneration system. The amount of steam extracted from turbine bleedings to feed the heat exchangers depends on the heat exchange conditions in the exchangers. These in turn depends on the pressure of the extracted steam.

5. Gas turbine adjustment to satisfy actual power demands

There are two basic method for an adjustment of a gas turbine, that is for fitting the current power output to the desired demand. The first one is to change the amount of fuel delivered to the combustor. It derives from the mass and energy balance that decreased amount of fuel results in lower turbine inlet temperature. Then the enthalpy drop in the expander is smaller and the output power decreases. Figure 2 presents such a power drop for the analyzed cycle.

The efficiency of the gas turbine drops as the amount of the fuel is decreased. This derives from the thermodynamics of the open gas cycles. This adjustment does not affect much the amount of compressor inlet air and delivery pressure.

The second method to adjust a gas turbine is the change of the compressor inlet guide vane angle (IGVA). The design applied to modern gas turbines allows a flexible change of the IGVA.

Figure 3 shows the matching points of the whole gas turbine plotted in the compressor characteristics. This characteristic relates the compressor pressure ratio and its flow factor for the inlet air. In addition this two parameters are shown as relative to the design values.

The characteristic shows the matching points for four distinct values of the IGVA including the design matching point. The decrease of the IGVA results in smaller amount of the inlet air and lower pressure ratio (see also fig. 5). On the other hand the

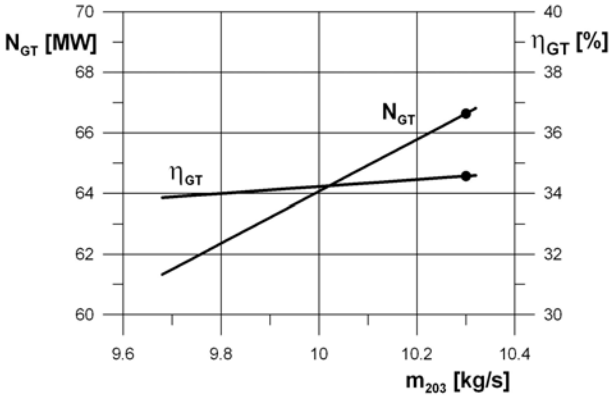

Fig. 2. Gas turbine efficiency and power output for the fuel adjustment

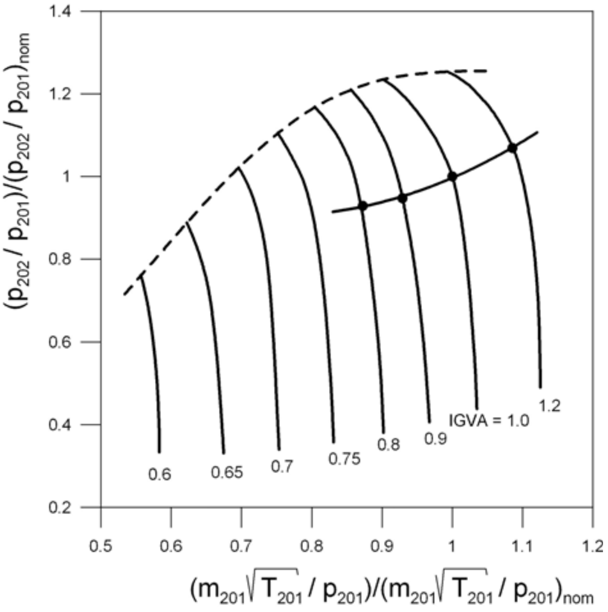

Fig. 3. Gas turbine matching points for various IGVAs

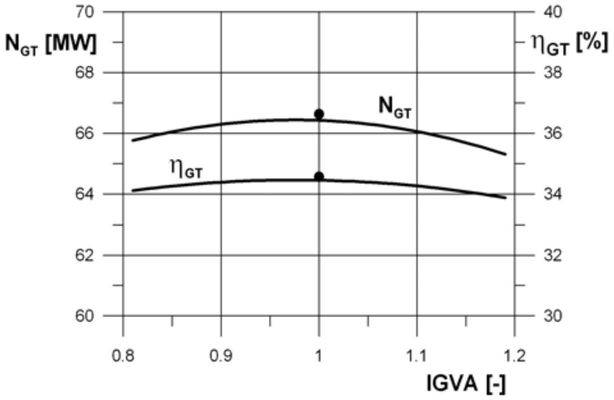

Fig. 4. Gas turbine efficiency and power output for the IGVA adjustment

increase of the IGVA results in a larger amount of the inlet air but since the amount of the fuel remains unchanged the turbine inlet temperature significantly drops. As an effect the power output becomes smaller.

The alteration of the power output for the IGVA adjustment is shown in fig. 4. This figure presents also the change of the gas turbine electric efficiency.

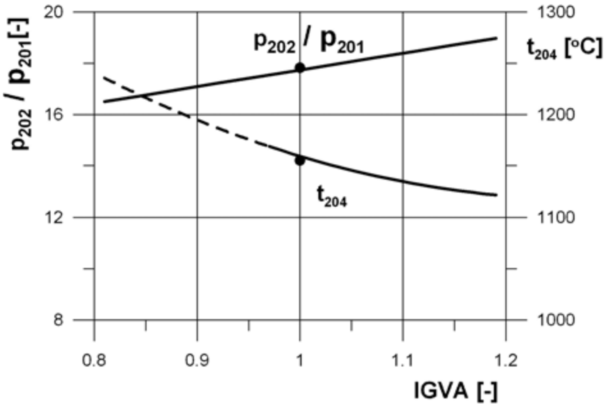

Fig. 5. Compressor pressure ratio and combustor outlet temperature for the IGVA adjustment

If the amount of the inlet air is reduced due to small value of the IGVA but the fuel flow remains unchanged than the temperature of the exhaust gas from the combustion process significantly increases as shown in fig. 5. This may lead to a situation when the combustor outlet temperature exceeds its limiting value, which is extremely dangerous for the expander components in the first stage (blades and rotor). The limiting value is usually slightly higher than the design exhaust temperature. Therefore the IGVA adjustment should always be accompanied by a fuel adjustment. Only such simultaneous adjustment protects the expander against high inlet temperature.

The power output of the gas turbine changes also with the fuel lower heating value (LHV) when the amount of the fuel remains the same. However this method for the alteration of the power output cannot be treated as an adjustment for a standard operation.

6. The efficiency of the combined cycle for a varying ambient temperature

The ambient conditions have an essential influence on the regime of the operation. The gas turbine power output and efficiency depend on the ambient air temperature. Lower temperature results in higher power and better efficiency, which is shown for the analyzed cycle in fig. 6. The change of the temperature affects also the compressor pressure ratio and combustor outlet temperature (fig. 7) - even though the IGVA and the amount of the fuel remain both unchanged.

In case of the steam cycle the ambient conditions affect mainly the condenser pressure. Lower temperature of the cooling water allows to achieve lower pressure and therefore better efficiency and higher power output of the steam turbine as seen in fig. 6.

When the ambient air temperature drops down the total efficiency of the whole cycle rises at first but then starts to fall down. This happens because lower ambient temperature results in lower exhaust temperature at the gas turbine outlet. At some point it is necessary to turn on the afterburner in order to maintain the required exhaust temperature. However afterburner utilizes additional fuel, which counts against the efficiency.

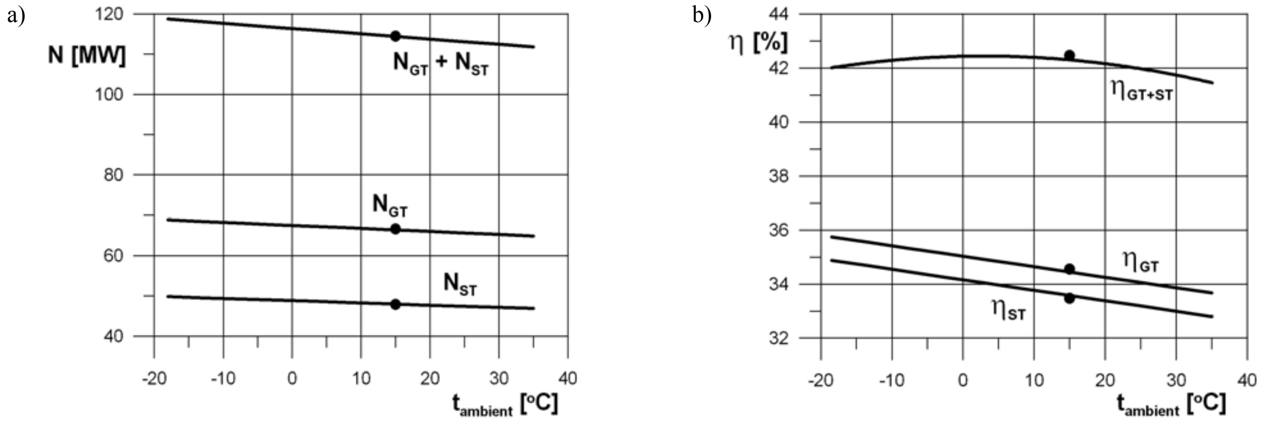

Fig. 6. The power output (a) and efficiency (b) for various ambient temperature

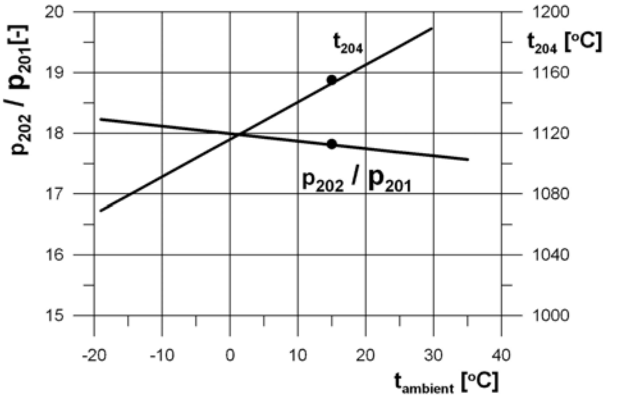

Fig. 7. The compressor pressure ratio and combustor outlet temperature for various ambient air temperature

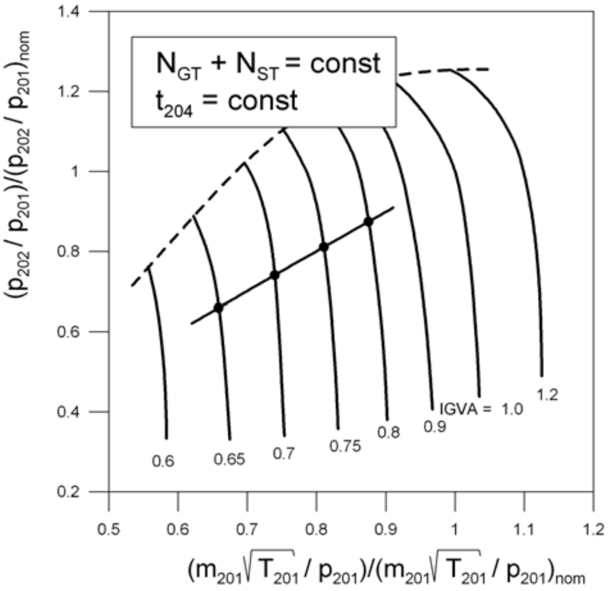

Fig. 8. Gas turbine matching points for a constant combustor outlet temperature

It should also be emphasized that the ambient air temperature may change with quite high frequency but the temperature of the water cooling the condenser does not change as often.

7. The division of the load between the gas and steam sub-cycles

The analyzed system allows to divide the demanded power output between the gas and steam sub-cycle. The division may be completed according to various criteria. In addition the demanded level of the generated power may be achieved through various methods of turbine adjustment.

The following are the results of the sample analysis for a demanded power of 80 MW, which is 69.5 % of the design load. The first method of load division is performed for a constant combustor outlet temperature. First the inlet guide vane angle is set and then the amount of the fuel is adjusted in such a manner that the combustor outlet temperature does not exceed its design value (1150°C, table 1). This is repeated for various IGVAs. The obtained consecutive matching points are plotted in fig. 8.

Additional assumptions are that the steam boiler may operate with the minimum 50% design load and that the HRSG generates as much steam as possible but with respect to the first assumption.

The load division is shown in fig. 9a. The sum of the power generated in the gas and steam turbines equals 80 MW as demanded. Figure 9b presents the efficiencies of both turbines and the whole cycle. The analysis of the efficiency proves that there is an optimal IGVA, which guarantees the highest total efficiency for this method of load division.

The total efficiency drops below the optimal value for smaller IGVAs because the afterburner has to be turned on. This is due to the small amount of the exhaust gas, too small to generate the requested amount of steam in the HRSG while keeping the assumptions of this method correct. Figure 10 shows the dependency between the IGVA and the amount of the fuel supplied to the combustor and afterburner.

The second method to divide the load between both turbines assumes that the afterburner is always turned off. Once again the IGVA is set firstly for the gas turbine. Then the amount of the fuel supplied to the combustor chamber is adjusted in such a manner that the afterburner is not required to operate and the total power output equals 80 MW. Also the assumption is still valid as for the minimum load in the steam boiler and that the HRSG carries as much load as possible.

Figure 11 demonstrates the gas turbine matching points obtained for this method of load division and various IGVAs. The power outputs and efficiencies are shown in fig. 12 for both turbines and the whole cycle.

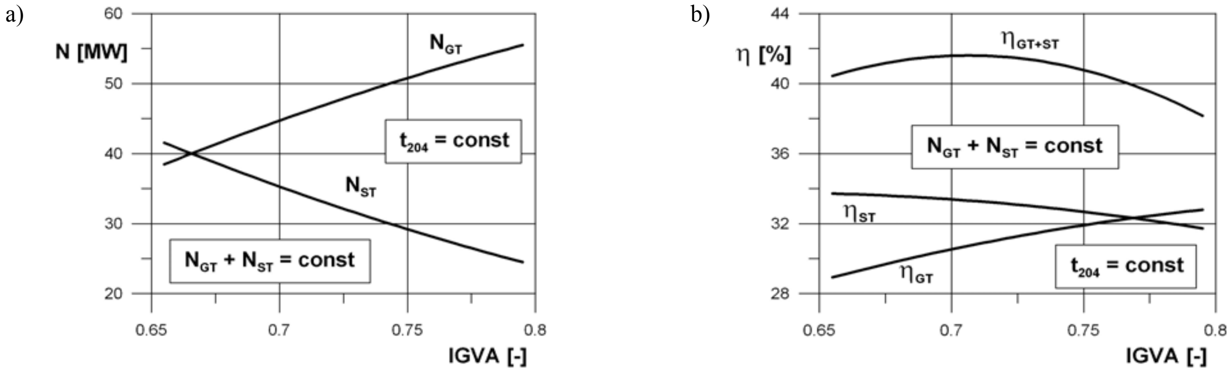

Fig. 9. Power (a) and efficiency (b) for the load division with constant combustor outlet temperature

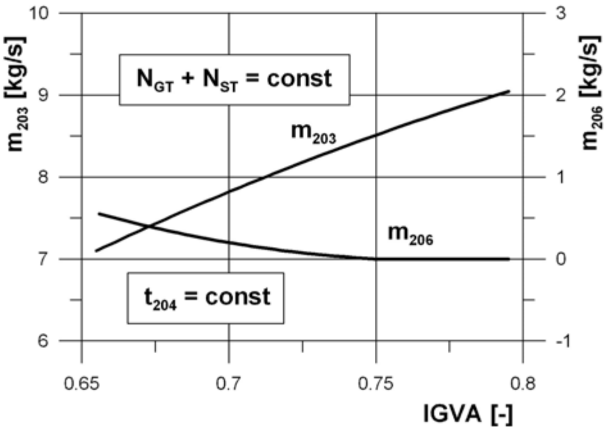

Fig. 10. Amount of the gas fuel for constant combustor outlet temperature (t_{204})

The efficiency of the whole cycle increases for smaller inlet guide vane angles. However there is a constrain - the limiting value of the combustor outlet temperature. Figure 13 presents how the combustor outlet temperature changes for various IGVAs.

The plot in fig 13 clearly suggests that the angles lower than 0.7 of the design IGVA value cause the combustor outlet temperature to rise over the its limiting value. The increased temperature increases the metal temperature in the components of the expander, which are heated by the hot exhaust gas. Therefore the optimization of the load division must consider also the constrain described above.

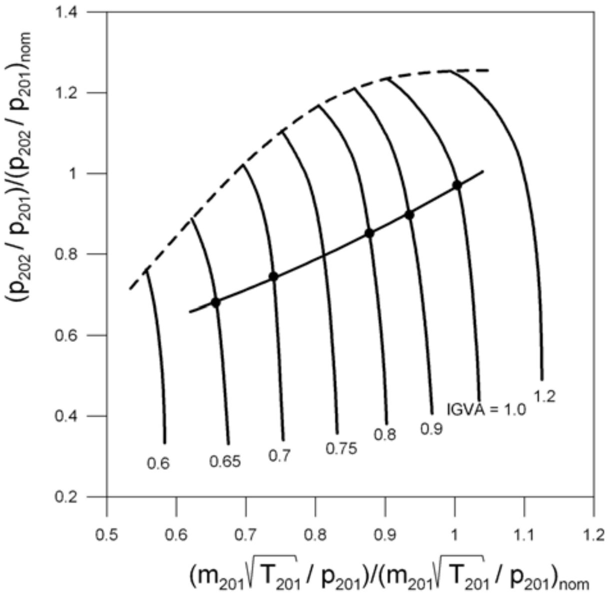

Fig. 11. Gas turbine matching points for the cycle with the afterburner turned off

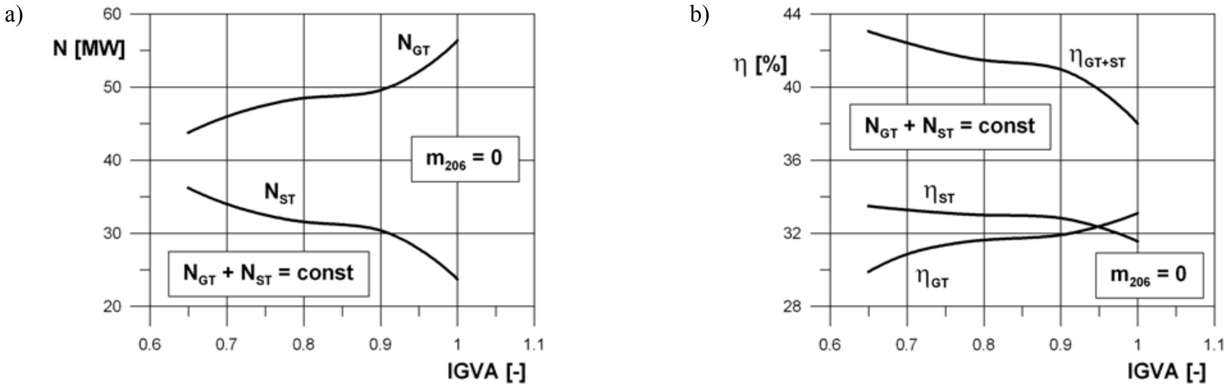

Fig. 12. Power (a) and efficiency (b) for the load division with the afterburner turned off

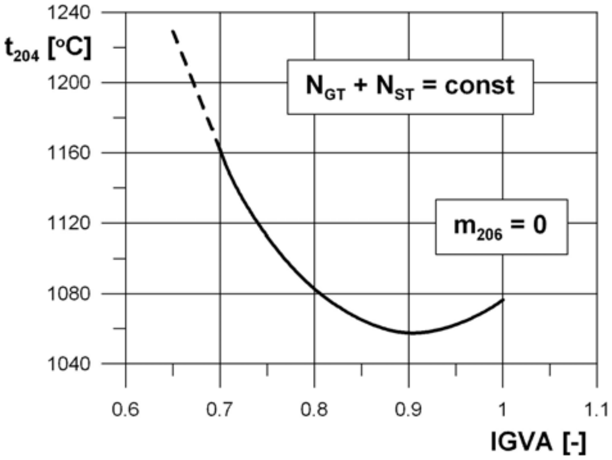

Fig. 13. Combustor outlet temperature for various IGVAs with the afterburner turned off

8. Conclusions

The simulation module for the modeling of the off-design operation presented in this paper allows to assess the influence of various operating regimes on the efficiency of the operation. This assessment determines the optimal method to perform the operation, that is most of all to divide the load between the turbines.

The analysis described here proved that high total efficiency may be achieved despite the decrease of the sub-cycles efficiencies resulting from the operation in the off-design regime. This derives from the fuel savings when gas and steam sub-systems are adjusted and better combined.

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Bogdan ŻÓŁTOWSKI

DIAGNOSTIC SYSTEM MAINTENANCE THE ABILITY OF MACHINES

This work presents the main descriptors of the diagnostic system machines exploitation. Determine the measure of the technical state, the boundary value and the periodicity of diagnostics. Problems and the tasks of the system of the exploitation of machines with utilization of computer techniques were distinguished on this background.

***Keywords**: diagnostics of machines, symptoms of the state, boundary value, periodicity of diagnostic.*

1. Introduction

The command of the technical condition of the machine results from the need of making rational decisions about "quality" and the more far conduct with machine. It can be the decision about the more far use, about the undertaking of preventive interventions or the introduction of changes in construction, technology or the exploitation of machines.

Talk over in these work chosen problems diagnoses the condition of machines, stress the problems of the new strategy of the exploitation of machines, and in this the symptoms of the state, determine the boundary value measure symptoms and the spanking of deadlines the next term of diagnosis.

The initiation of diagnostic systems makes possible the improvement of organization and management of using of machines in industrial institutions with utilization of computer techniques.

2. Main problems in diagnostics of machines

Growing up the level of complexity of machines and criticality of their function from the safety of considerations and constructors and the users of these objects to the acquaintance economic of the technical state and be well-versed in the use prognosis. This is possible, if on stage of constructing integrated were with the object equipment and diagnostic procedures.

Generation of vibration signals in the description of the changes condition the machine

Opinion of the dynamic condition of machines with generate by not he physical processes requires the association of functional parameters the estimated object with the gathering of measures and the opinions of processes howl exit.

While functioning the machines, in the consequence of the existence of the row of external factors (the extortion environment, from different machines) and internal (aging, wastes, the co-operation of elements) in the machine sequence the disorder the states the equilibrium, which propagate oneself in about springy medium - the material of which the machine is built.

The disorder has dynamic character and maintains the conditions of equilibrium among the condition inertia, elasticity, the suppression and extortion.

The disorder propagate oneself from source in the figure of waves in the dependent way from properties physical and the borders configurations, dimensions and the shapes of the machine. This results in the consequence. He existence the causes source and spreading the disorders occurrence of the vibration of the elements of the machine and surround them environment. Processes these are base of the building of the model of the generation of signals, determinate the way of the building, functioning and the changes of the conditions of the object.

One can introduce the sequence of foundations guidance to the model of the generation of signals in the figure, of the cybernetic model, as on fig. 1.

Introduced way of the interpretation of the signal $y(\theta,r)$ there is about the periodical working true in the general case of machines, but not always as simple as on fig. 2.

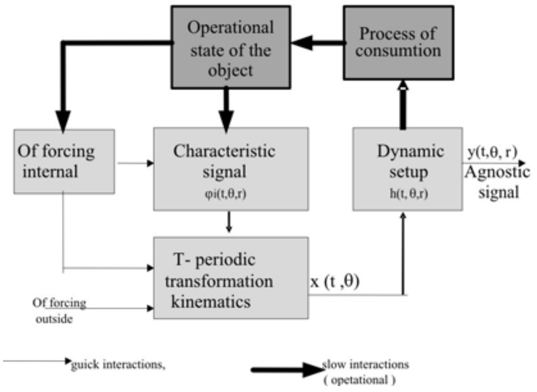

Fig.1. Model of generation the diagnostic

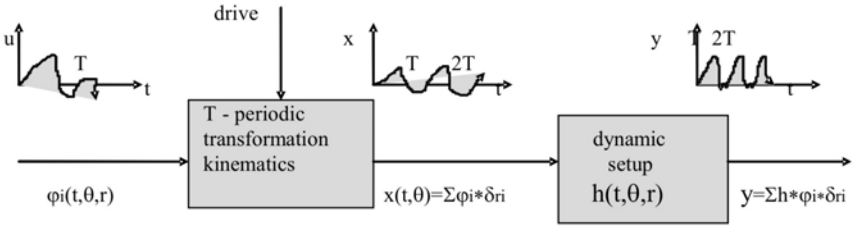

Fig. 2. Transformation of the characteristic signal φ_i and howl in the signal exit as the model of the generation of the signal in machines [2]

The example of such formulation of the question the main transmission of the bridge of the vehicle the whose model of the generation was introduced on fig.3. Howl the received signal exit is important sum of the answer on all events in the any place of the casing of the transmission elementary $U_n(t, \theta, r)$, is present always in this alone sequence in individual arrangements dynamic partial about the pulse function transition $h_n(t, \theta, r)$. These influences after transition by characteristic arrangements dynamic sum oneself and become additional transformation on the trunk of the transmission, near what the change of the place of the receipt of the signal "*r*" tie is also from change transmittance. By $n(t, \theta)$ was the here accidental influence is present marked from the title presence these micro of dynamic phenomena such as the friction, inequality.

Signal initial one can express of the any point the receipt in the approximation the example:

$$y_k(\theta,r) = \sum_{i=1}^{k} a(k) h_i(t,\theta,r) * \left[u_i(t,\theta,r) + n(t,\theta,r)\right] \qquad (1)$$

where: the pulse function transition *h(*)* properties also captures you the trunk, *a(k)* gives the various weights of adding up tie with the place of the receipt "*r*".

Problems the main diagnostics of machines include:

- the logging and processing of diagnostic information;
- the building of models and diagnostic reports;
- the diagnostic inference and boundary value;
- the classification of the conditions of the machine;
- the expectation of the time of next diagnosing;
- the presentation decision information.

Measuring system for the aims of the present diagnostics of machines consists of two basic elements:

- the equipment in which distinguishes oneself modules: subsystem conditioning and processing of signals, the subsystem of processing of the signals of the gauge of phases, the subsystem of the industrial computer, the subsystem of the power supply,
- the software, in whose composition are modules: operating system (VxWorks), the software of the modules of processing and the analysis of signals, software guarantee transport among the layers of the system, software to filings and processing given measuring, software manage work of the system (configuration of the system, testing the system, the initialization of measuring sessions).

The introduced structure of the measuring system uses the newest solution both equipment, how and the program. Applied solution helps easier the extension of the system, and possibility these closure him to any diagnostic systems.

The problems next the practice of applying the methods of diagnosing (fig. 4):

1. The time of forming the diagnostic symptom.
2. The change the boundary symptom - preventive workings (PSOTia).
3. The complex opinion of the state: the measurements of symptoms, the reference to boundary value, prognoses of the state, it is proper the delimitation of the deadline next diagnosing, the geneses of the cause of changes the measure symptom.

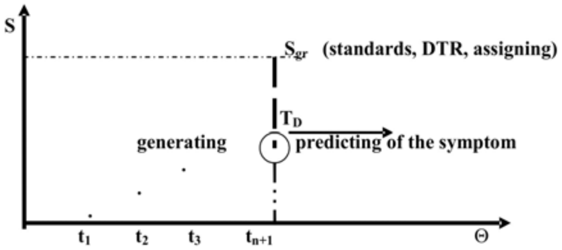

Fig. 4. Modern system diagnostic on exploitation

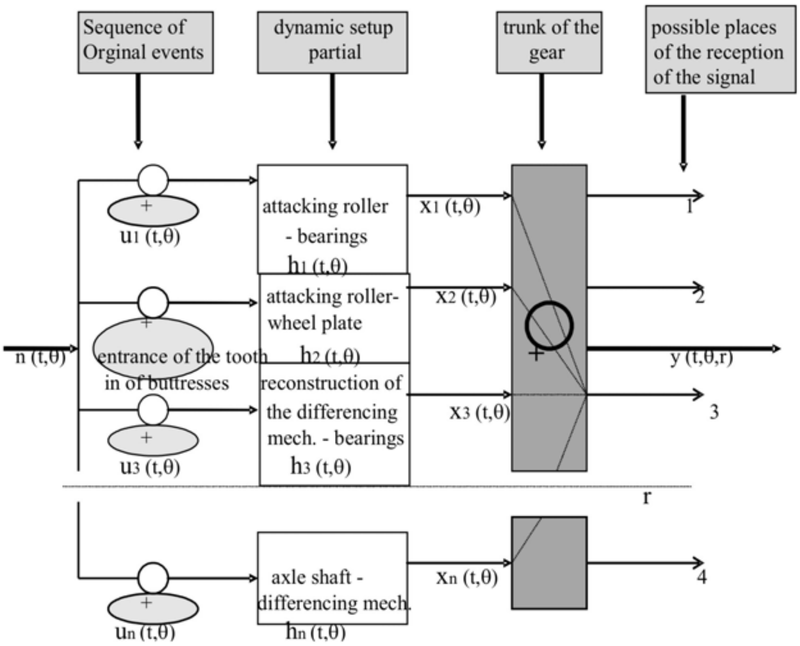

Fig. 3. Model of the generation the diagnostic signal of the toothed transmission

3. Diagnostic system of the exploitation of machines

Present machines determine are such features as: functional, reliability, availability, safety, mobility and flexibility operating. Formation and maintenance of these features is possible the methods of the technical diagnostics which makes possible: diagnostic constructing and production of new machines and maintenance of machines in the condition ability functional.

The use of the machines characteristic:

- gatherings of at random changing times of the correct work;
- at random changing moments of the beginning and changing long the times of duration of the tasks;
- people and machines in at random changing compartment of the time of the use intensive work;
- the influence of at random changing conditions of exploitation;
- the various kinds of tasks executed in the short periods of the time.

Need and the condition of the economy market prove necessity loading the modern authorized strategy of the production and the exploitation of machines. He does not get lost the hitherto existing accomplishments of the newest strategy of exploitation according to the state in the proposal of this strategy, but it is create modernizes. The proposed strategy of exploitation- ASEM - shows on creator and responsible for the product by name. The manufacturer interested as quality and after that the sale responsible for the product from the intention, through construction, production and exploitation, until to utilization after the liquidation of the object. The same manufacturer constructs and he produces his products in the support about the newest achievement technical idea, his product protects the own service during exploitation, and also he provides objects in diagnostic means (the best automatic).

Effectiveness of solution in applying this strategy requires the improvement: the models of diagnostic machines, the methods of diagnosing and prognoses of the conditions of machines, economic, exact and unfailing diagnostic equipment, the principles of the formation of flexibility diagnostic, the algorithms of steering the maintenance of the machines in the condition ability, the methods of the opinion efficiency you diagnostics and the system of the exploitation of machines. Specified questions enclose safely of the problems and unambiguously establish the directions of the development of the technical diagnostics of machines.

The users of machines are interested particularly their ability task, for determine sluggard which belong:

- to mark the symptoms of the condition ability you;
- to determinate the boundary value symptoms of the condition ability,
- to establish the class ability you the object.
- to mark the periodically of diagnosing.

Distinguished tasks diagnostic will be talked over below selectively, near what detailed can their description found in the author works [6, 7].

4. Boundary value symptoms of the condition

Ability task in the formulation symptom is unambiguously it is proper boundary value of the measure symptoms of the state. It is proper the crossing marks you the boundary value of the machine in the state near the quickly of the waste, characteristic oneself the large probability of the sudden breakdown.

Realized often in the industrial practice passive and passive-active experiments diagnostic gives symptoms the state, which compared during infers from it is proper boundary value accessible in many national, foreign, trade norms or with the data from own to experiment. When however lack of such norms from help here push for the studied machine maybe the statistical description of the random process of exploitation for help densely schedule or often the occurrence observed symptom.

It is proper estimation one can realize the border symptom for the safe close of the machine before damaging you for the help of statistical methods.

The formula on delimitation of **Sgr** minimize the probability of the breakdown near set, the admissible probability of the superfluous repair **A** can write down in the figure [1]:

$$Pg\int_{S_{gr}}^{\infty}\left(\frac{S}{X_g}\right)dS = A \qquad (2)$$

where: *Pg* - the probability ability.

According to Birger [1]: $A = k\,(1\text{-}Pg)$, where: *k* - the coefficient of the store (*k* = 1-3 for usual damages, *k* = 3-10 for dangerous damages), *Pg* - availability the machines marked from dependence: $Pg = Nz / Nz + Nn$, where: *Nz* - the number of machines of fit, Nn-number of machines of unfit.

The row of simple transformations leads in the effect to dependence:

$$S_{gr} = s + \sigma_s\sqrt{\frac{P_g}{2A}} \qquad (3)$$

Received the estimation boundary value symptom leaning on it is proper middle value, he creates good bases to simple marking to dispersal and repair politics it is proper ? you the border studied measures of the state in the industrial practice.

5. Periodically diagnoses

Growth intensity he extorts you occurrence of damages in the measure of wearing away the using potential of the machine the need of the optimization periodically diagnosing. From the course intensity he results the damages of the machine that in the period of the growth intensity should enlarge frequency of diagnosing. This helps the lowering of expenditures on the exploitation of the machine (the decrease: intensive to use up you, the waste of the fuel, equipment exchangeable, materials use) and growing up the costs and hard working of diagnosing, the time turn off the machine as also increases from the use.

The optimization periodically of diagnostic does he move you diagnose to the answer on two basic questions: as to lead diagnosing often? to conduct next diagnosing in what range?.

Several possibility determine the delimitation periodically diagnosing (the method of boundary value the symptoms, the method of the smallest sum costs of exploitation), near what for their realization indispensable numerous are given statistical, inconvenient often (in the sense amount and true to gaining over.

In this work the question periodically of diagnostic were considered diagnosing in formulation symptom, use boundary value of the symptom. The of n-measurements chosen in the separate procedure the measure of the signal (symptom) and the delimitation it is proper on their basis boundary value according to dependence you (2), he exists one need determine the sluggard of the deadline of next diagnosing td. The essence of the method introduced in works [6, 7] does he show that one marks the deadline of next diagnosing from dependence these (fig. 5):

$$t_d = \frac{(1-P_r)(S_{gr}-S_m)}{S_m}\theta m \qquad (4)$$

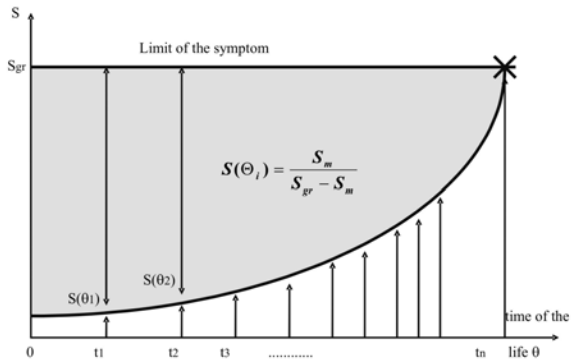

Fig. 5. Periodically of diagnosing in the formulation symptom

6. Manage the system of exploitation

Every of economic organizations has the determined system of management which he is fulfilling for her of requiring of the strategy accepted in the field of the realization. This particularly essential is for these from they, which have essential influence on the course of the productive process (logistics, exploitation, tools and equipment) or control it is proper durable means about essential, from the point of the sight of the firm, value (maintenance the movement, repairs, survey) [4].

Functions subsystem:

- he leads classification and the record of all durable assets,
- proposes basic index technical-economic,
- he supervises exploitation of durable assets ,
- he analyses given from monitoring and makes decisions,
- he infers liquidation of durable assets,
- he plans, supervises and realizes all kinds review , preservation and repairs,
- he establishes basic norms, records and for led works,
- the supply plans in spare parts and necessary materials to repairs,
- he infers and motivates the leasing, infers and motivates outsourcing,
- organizes storing spare parts you exchangeable, their publication and account for,
- he plans investment tasks, organizes and realizes the purchase of machines and equipment,
- he realizes indispensable building and assembly works,
- organizes the receipt of durable assets,
- he prepares the technologies of repairs.

Analysis the range of functions attributed to realize system can determine, what should sail the groups of the data to him, he what given as also generates.

The model manage was built the system of exploitation on basis of analysis of two basic criteria i.e. flow and type given and realized through individual modules functions. Structure manage of the system of exploitation was introduced on fig.6 together with the flow of the data. Make the structure of the system individual modules realize next basic functions:

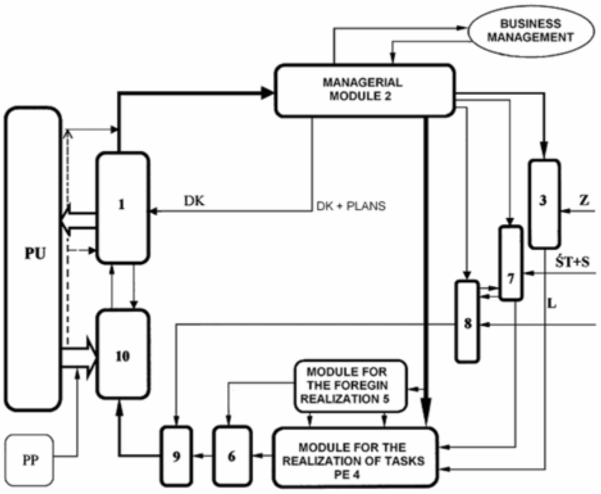

Fig. 6. Model manage the system of exploitation [4]

1. The module of the processing of given responsible too the processing given sent to the system. Just carrier and the media of the broadcast can be considerably diverse.
2. The managerial module, to whose given effect about the various degree of aggregation from the module of the processing of given. One can affirm that he the data is processed according to sets algorithms make the basic gathering for needs manage of SE about 80% these.
3. The logistic module, which delivers indispensable materials, equipment he leads you, the components and standardized machine elements for needs of realized repairs, the stock management and analyses the level of stores, leads the record of given supplies analyses their waste for individual orders, organizes and supervises transportation bought technological equipment, he co-operates from logistics of factory in the range of the economy the scrap-iron.
4. The module of the realization of the tasks which realizes or realization all reviews and lots of supervises of repairs.
5. The module of the strange realization, registration the range of repair works charged the external firm.
6. The module of the control, check quality and range of realized works from the strange realization as also own.
7. The module of the renovation of the technical base, the purchases of machines, renovation and repairs.
8. The module improvement frame, justifications and workers training.
9. The module of accounts, abstract summary compositions as also controls need of the realization of given operations.
10. The module technical realize the functions: planning, constructional, technological, the opinions of the technical state possessed equipment, record and actualization, the emission of records.

PU - the subsystem of the use which exploits machines and equipment.

PP - Remaining subsystem. Reports these subsystem with the system management of using in the smaller degree defined.

The building of the model of the system management of using allows to identify the basic elements of his surroundings, how also modules in the composition subsystem himself.

7. Summary

Accomplishment of the diagnostics of last years, using achieve of many the fields of the science, allow as the tool of formation and opinion of machines, on all stages of their existence. Looking on present trendy developmental machines you should recognize, that present growth their quality is contained you in the sphere their of automating mainly. The guild of measurable becomes automatic accumulating the only objective way it is proper valuation and formation quality of machines.

The range of investigations in the field of the methodology of the diagnostics hugs such questions, how: source of diagnostic information, signals and diagnostic symptoms, the principles of the detailed methods of the diagnostics, modeling in the diagnostics, diagnostic experiments, the aid of the diagnostics modern computer technologies, diagnosing in systems human engineering and social engineering and the organizational and economic aspects of applying the diagnostics. The question these apply in turn to: source of information from the physical side and from the informative side, farther the bases of methods and investigative techniques, simulation and experimenting in the diagnostics and modern inference and visualization of worked out diagnostic-using decisions.

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THE WAY FORWARD TO EXCELLENCE IN MAINTENANCE

It is common across all industries, that most organisations are attempting to get highest profitability. To successfully manage this, adequate management procedures have to be implemented also in the field of maintenance. Independent from the level of sophistication, any organisation is operating in, there is a need for a stepwise evolution of maintenance, in case the target is excellence in maintenance.

***Keywords**: excellence in maintenance, maintenance management, maintenance audit.*

1. Introduction

It is not possible to give a 'standard recipe' for developing a maintenance organisation towards excellence, because too complex, but also too individual the starting positions are in different organisations. But it is possible to explain some common aspects across different types of industries.

The topic presents a model, which can be suitable most of all for such organisations, which are just in the beginning phase of developing their maintenance and which do not find the right sequence of improvements.

2. Target definition

Maintenance targets can be considered according to the Max/Min – principle. Maximizing the maintenance output, which is corresponding to technical equipment efficiency by minimizing all efficiency loss factors. The second portion of maintenance targets is minimizing the input to maintenance, which can be expressed for example in manpower, tools, systems, processes, cost, knowledge etc. The main thing is, that all input factor interact with each other. Relatively small changes in all input factors lead to great results in equipment efficiency.

3. Which concept is the most suitable to start from?

There are many maintenance management concepts and improvement strategies like TPM (total productive maintenance), RCM (reliability centered maintenance, RBI (risk based inspection), CBM (condition based monitoring), LCC (life cycle costing), CMMS (computerized maintenance management software), maintenance management training, spare part optimisation and much more – but which one is the most suitable to start with?

The reality shows, that some organisations tend to use more than one concept simultaneously and if this does not work, new projects get launched in the middle of the projects already defined– so changing horses in the middle of the race. In several cases this leads to dissatisfaction with the results of the projects started. The situation gets even more complex, if one organisation changes the targets of maintenance improvements from increasing equipment reliability to cost reduction and back and forth. It is obvious, that such intends will not be successful.

As an additional fact, it has to be considered, that not all existing concepts are applicable in the same way to all areas, where maintenance occurs. TPM in the automotive industry is state of the art, whereby this is hard to apply to universities. Online condition based monitoring will be necessary in petrochemical plants and other process industries, but does not make much sense in single manufacturing industries like clothes production. For this reason, the existing concepts need to be differentiated and carefully investigated, if and how they can contribute to meet the maintenance targets defined.

4. Maintenance Audit

The so called maintenance audit is a suitable instrument to describe the actual situation of maintenance within a plant and to define the improvement project. Such an audit in general gets conducted with an external, independent auditor. MCE has a high developed method for auditing maintenance departments – the so called 'compact audit'. Such an audit does not take more than 2 days and delivers a good picture about the existing situation, whereby it automatically shows the improvement areas. The investigation covers 12 maintenance management chapters and includes quantitative and qualitative investigations. The results are summarized and presented to the customer and suggestions for improvement steps are given. Customer than can decide to go on with the suggestions alone or together with the partner.

5. Importance of Maintenance Foundation

The audit checks, what basic and enhanced maintenance features are given on site. If the basics – the so called maintenance foundation consisting of basic processes like strategy definition, work order management, spare parts management, qualification management and simple controlling- is not completely existing, it has to be finished, before other steps are defined.

The next step is to check for proper use of maintenance software, or implement it, if not existing. The foundation together with suitable use of maintenance software enables an organisation to look for best practices in maintenance management towards excellence. This is the core of the model suggested. If the basic processes are implemented and enough transparency is given through the use of software to monitor success of further changes, the field will be open for any other approach mentioned in the first section of this abstract.

6. Conclusion

Summarizing all aspects from above means, that maintenance organisations, which do not have the foundation of maintenance implemented, will have problems to reach excellence in maintenance management, because all the basics have to be done first – then the sophisticated concepts will work.

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MCE Industrietechnik, a subsidiary company of MCE AG in Linz, Austria – considers itself as life-cycle partner for the erection and servicing of industrial plants and focuses its activities on the oil and gas sector, chemicals and petrochemicals, fine chemicals and pharmaceuticals, metallurgy, paper and pulp, power generation and distribution, and hydropower. MCE Industrietechnik erects turnkey plants and plant units for industry and infrastructures and is completely independent from manufacturers in its choice of components and thus very flexible in meeting its customers' demands. The services offered – from design and commissioning – also include the full range of maintenance services.

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MAINTENANCE SUCCESS CONTROL
(KEY FIGURES AND CONTROLLING IN MAINTENANCE)

The importance of maintenance has increased during the last years. Costs for maintenance are seen as valuable investments. Key figures and controlling are important instruments to make transparent both actual services and value of maintenance.

***Keywords**: reporting, maintenance controlling, key figures, KPI´s.*

1. Goal

A goal of this article is to show some practical examples for key figures in the area of maintenance. A suitability, as well as preconditions and limits of applicability for maintenance will be discussed.

2. Problem description

Measurability as well as attainability of economical and technical targets - committed in a contract – are essential factors for a successful progress of outsourcing projects in the area of industrial maintenance.

Therefore, effective controlling and reporting systems, supported by key figures, play an important role in every kind of a maintenance contract implementation - either on a base of a frame contract, or as a main contract or as a full service contract.

3. Why and for what key figures in maintenance

Connexions can be shown in a concentrated way by key figures. Due to their choice they are indicators for what is happening in the field of maintenance in an organisation. You can define main areas of maintenance with a determination of a key figure system:

- o Cost control,
- o Evaluation of organisational and operational structures on the side of a service provider,
- o Long-term planning of maintenance activities,
- o Optimisation of maintenance processes.

4. Controlling and reporting systems for maintenance in a refinery

In the following, controlling and reporting systems will be described, which were developed in two levels within the scope of a main contract in a refinery:

- o Current and regular reporting to the client (with periodical analysis of costs, activities and weak points, target values (KPI´s), etc.),
- o Internal controlling with selected maintenance-typical key figures for ongoing evaluation and supervision of service performance.

4.1. Regular reporting to the client

- o Current (client is allowed to look on-line at the CMM system of the service provider or at meetings, if required):
  - Order status,
  - Actual costs of orders,
  - Information regarding problems, bottle necks, deadline shifting.
- o Monthly („Brief report“):
  - Detailed performance and cost controlling (budget, order structure) (also in a graphical way),
  - Costs per service / cost category and single work order,
  - Duration statistics of repairs according to priorities,
  - Middle-term planning / situation with resources and scheduling,
  - Status info about (statutory) periodic inspections („compliance report“),
  - Status of committed KPI´s.
- o Quarterly („Detailed report“, in addition to a “brief report”):
  - Detailed analysis of weak points and failures (safety, quality and cost relevant aspects).
- o Yearly („Management review“, in addition to a quarterly report):
  - Performance / cost controlling (achievement of objectives),
  - Presentation of results concerning a client satisfaction analysis,
  - Agreement on objectives for the subsequent year,
  - Programs for training and qualification measures.

Commitment on key performance indicators (KPI´s) to measure following values:

- Adherence of single and total budgets,
- Availability of (key) plants (mechanical availability),
- Lost time due to accidents,
- Adherence to delivery dates / Throughput time of work orders (duration of repairs according to priorities),
- Quality of workmanship / rate of complaints.

4.2. Key figures as internal controlling instrument

Common key figures of maintenance in practice, which are used for internal evaluation and supervision of service performance:

- o Effectiveness ratios:
  - Urgency / priority (Number of immediate corrective maintenance events / Total number of work orders),
  - Rate of labour utilisation Planned and scheduled man hours / Required operation time for scheduled work orders).
- o Planning ratios:
  - Degree of preparation and planning (Planned and scheduled man hours as a % of total maintenance man hours),

  - Degree of capacity utilisation (Outstanding work orders / available man hour capacity),
  - Assignment of own and external personnel,
  - Portion of overtime,
  - Throughput time of work orders (duration of maintenance events according to priorities),
  - Portion of preventive maintenance (Preventive maintenance man hours as a % of maintenance man hours).
- o Cost ratios:
  - Routine maintenance costs,
  - Specific maintenance costs,
  - Non-affactable maintenance costs,
  - Other service costs,
  - Project costs,
  - Maintenance coefficient (Total maintenance costs / production output).
- o Ratios for a weak point analysis:
  - Maintenance intensity (Total maintenance costs as a % of plant replacement value),
  - Failure rate (maintenance related production down time as a % of available operating time),
  - MTTR (Mean Time To Repair),
  - MTBF (Mean Time Between Failures),
  - (Mechanical) availability.
- o Ratios for material~~s~~ management:
  - Covering spare parts from stores,
  - Material turnover,
  - Number of suppliers (including subcontractors),
  - Proportion of labour costs to material costs.

These data are collected automatically by a CMM system monthly and transferred as a standard report to an excel-sheet.

6. References:

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5. Summary

A value and an output of maintenance can be presented and supervised only by means of a controlling system. Selected key figures should be created for planning, supervision and optimisation of maintenance activities. As a matter of principle, only company- and operation- related key figures should be determined and the effectiveness should be measured on their improvements.

Please note:

- Key figures are instruments for information, controlling and decision-making.
- Key figures will inform you in a concentrated way about technical, organisational and economical connexions.
- If you select key figures, you must be focused to the most important aspects.
- Ratio systems are necessary for transparent presentation of costs and outputs.
- Key figures are the starting point for strategic orientation of objectives.
- Ratio systems will not replace detailed analysis.
- The basic message of key figures depends on a correct interpretation. You will be able to draw the right conclusions only after a critical examination of causes and after implementation of measures for changes.
- Comparisons with key figures of other departments or companies (benchmarking) must be scrutinised because of comparability.

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