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## Spis treści / Contents

# USAGE FACTOR CURVE AS THE TOOL FOR AN ASSESSMENT OF A REST LIFETIME OVER 40 YEARS DESIGN LIMIT FOR COMPONENTS OF NUCLEAR POWER PLANTS (NPP)

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Summary

In introduction the short overview on the actual importance of the Nuclear Power Plants (NPPs) Ageing-Plant Life Extension (PLEX) problem is presented. The proposed forecast for the rest of life span of a pressurized NPP-component based on the calculated Usage Factor Curve can provide less conservative results than the normally used standard usage factor calculations. The main task of the presented Usage Factor Curve approach is the statistical interpretation of the recorded reactor transients and evaluation of load condition of the component resulting from these transients. Such analytical procedure applied during exploitation of NPPs is showing more realistic status of facility and can diagnose existing reserve in lifetime of pressurized NPP-components.

Keywords: Nuclear Power Plants, lifetime extension prediction, usage factor.

KRZYWA WSPÓŁCZYNNIKA ZUŻYCIA, JAKO NARZĘDZIE OCENY POZOSTAŁEGO CZASU EKSPLOATACJI ELEKTROWNI JĄDROWYCH (EJ) PONAD 40 LETNI OKRES PROJEKTOWY

Streszczenie

Na wstępie krótko przedstawiono aktualne znaczenie problematyki przedłużenia projektowego okresu eksploatacji Elektrowni Jądrowych (EJ). Znormowane ustalenie przewidywanego projektowego okresu eksploatacji EJ, opierające się na obliczaniu tzw. współczynnika zużycia dla ciśnieniowych elementów konstrukcyjnych, może prowadzić do niedoszacowania dozwolonego okresu pracy EJ. Zaproponowana w artykule metodologia Krzywej Współczynnika Zużycia może wykazać lepszą ocenę pozostałego czasu eksploatacji. Zasadniczym elementem przedstawionej procedury ustalania Krzywej Współczynnika Zużycia w czasie eksploatacji EJ jest wykorzystywanie statystycznie zbieranych danych o rzeczywistej historii obciążeń elementów konstrukcyjnych i cząstkowe okresowe obliczanie przebiegu współczynnika zużycia. Zastosowanie takiego analitycznego narzędzia pozwala na diagnozę stanu zużycia i realniejszą prognozę pozostałego dozwolonego czasu eksploatacji elementów konstrukcyjnych EJ.

Słowa kluczowe: Elektrownie Jądrowe, ocena pozostałego czasu eksploatacji, współczynnik zużycia.

## 1. INTRODUCTION

The European know-how and experience in life assessment and life extension of nuclear power plants (NPPs) components is recognized world-wide, and is in great demand. These topics have become increasingly important during the last few years, because of economical as well as political reasons and incoming prolongations of operating licence over old 40 years standard's design limits are going to presently used 60 years design licence limits and in some postulated cases from USA even higher to 80 years. In the USA, as has been pointed out above, some licenses for life extension have already been granted. Life extension (from 40 to 60 years) could be an attractive option for the operators of up to 80 % of US NPPs if it can be performed without major replacements. In France, life extension is being studied with increasing emphasis. 'Hidden' life extension has already taken place, 40 years is today as nominal plant lifetime, in contrast to the span of about 20 to 30 years usually given earlier [1]. In Switzerland the Swiss Nuclear Society [2] has created scopes for the permanent collecting and analysing the Ageing-Plant Life Extension (PLEX) experience of Swiss NPPs operating companies and actual information from this internet source could be interesting for readers.

In the following we would like to refresh the idea from [3] and show a simple method which promises to obtain less conservative assessment of the rest of life of pressurized NPP components, by slightly increased calculating effort. Of course it has to be seen as a part of extensive multi-disciplinary survey for long term operation of pressurized NPP components.

The various sources of degradation of life of NPPs components can be divided into six groups from Table 1 e.g. according [4]. Generally, NPPs Ageing-Plant Life Extension (PLEX) problems are permanently present in publications and are in focus of interest of scientific societies (e.g. International Association of Structural Mechanics in Reactor Technology IA-SMIRT) and regulatory and experts organisations (e.g. International Atomic Energy Agency IAEA in Vienna). The PLEX primarily concern passive components, i.e. components without moving parts. Regarding active components like pumps and valves, deterioration usually manifests itself in a more obvious manner, and exchange of components can often be performed during regular maintenance work. Nevertheless, ageing of active components cannot be completely neglected as a risk factor. There is no generally recognised procedure to determine the admissible lifetime of a nuclear power plant. Decisions are usually based on economic reasons as well as on general engineering practice. Various individual ageing-related problems have been studied in some detail in the past. A number of mechanisms are known; nevertheless, they are not completely understood. For example, the so-called dose rate effect in steel irradiation embrittlement has been known for years; but it still cannot describe reliably and quantitatively today, giving rise to an increased risk of pressure vessel failure in older NPPs. Another problem not fully understood is the propagation of fatigue cracks in austenitic steel pipes. All in all, it is clear that the global risk of a reactor accident grows significantly with the number of nuclear power plants which are in operation longer than about 20 years. The knowledge on PLEX is well summarized in many IAEA publications, on this place we would mentioned the positions [5] and [6] listed in **REFERENCES**. The summary of identified research and developments needs connected with PLEX is recently giving in the paper [7] of the SMIRT 20 Conference.

Of these six destructive mechanisms from Table 1, the fatigue and creep have the most important influence on the long term strength of materials pressurized component.

For the NPPs owners it is of the upmost importance to obtain as much information as possible about the fatigue usage factor of essential components, as a basis for decisions regarding in service inspections, replacements or manner of operation of the plant.

Table 1. Sources of Ageing Degradation

| NO | DEGRADATION MECHANISM | INFLUENCED COMPONENTS AND SYSTEMS | CAUSED BY |
|---|---|---|---|
| 1 | IRRADIATION AND EMBRITTLEMENT | REACTOR PRESSURE VESSEL (RPV) INTERNALS OF RPV | DESIGN, MATERIAL, IMPURITIES IN STEEL (COPPER, PHOSPHOR) |
| 2 | FATIGUE CORROSION, CREEP | PIPING AND ITS FITTINGS AND SUPPORTS. NOZZLES, VALVES, MIXING REGIONS OF FLUIDS WITH DIFFEREI\1T TEMPERATURES | RESULTING LOCAL STRESSES, OPERATIONAL LOADING, SYSTEMS ENGINEERING |
| 3 | GENERAL CORROSION, PITTING, WASTAGE | SYSTEMS WITH LOW VELOCITIES OF FLUIDS, CONDENSATE IN STEAM LINES, SERVICE WATER SYSTEMS. SAFETY INJECTION SYSTEMS INTERNALS OF PUMPS AND V AL VES | SYSTEM ENGINEERING, OPERATIONAL INFLUENCES SERVICES (DESIGN), MATERIALS |
| 4 | STRESS CORROSION CRACKING | WELD VINCINITY IN COMPONENTS; (STAINLESS STEELS), STRAIN INDUCED FERRITIC PIPING (HIGH TEMPERATURE AND OXIGENCONTENT OF FLUID) | MATERIAL, OPERATIONAL CONDITIONS, CHEMICAL CONDITIONS, INSULATION AND GASKET MATERIAL |
| 5 | WELD RELATED CRACKING, HYDROGEN EMBRITTLEMENT | ALL KIND OF WELDS, INTERFACE BETWEEN STAINLESS STEEL CLADDING AND VESSEL'S MATERIAL | STEEL-COMPOSITION AND MANUFACTURING PROCESS |
| 6 | EROSSION-CORROSION | STEAM AND FEED-WATER PIPING, STEAM SEPARATORS, HEAT EXCHANGES, TURBINE BLADES | CHEMICAL CONDITIONS (PH-VALUE), MATERIALS, SYSTEMS ENGINEERING |

## 2. DAMAGE ASSESSMENT BY ANALYSIS

Analytical methods of determining the usage factor are set forth in the following accepted worldwide codes: from USA in ASME Section III, Subsection NH and NB, and from Germany in KTA 3201.2.

Fig. 1 shows schematically the flow of damage assessment by analysis. As shown in this picture, the stress analysis is the central point of the calculation method. The geometry and the load cases of the components are mostly so complex, that an accurate analysis can only be performed by Finite Elements Method (FEM) computer programs. These programs are used for calculations the six components of stress in selected sections. For assessing the rest of life in accordance with as fore mentioned codes, the stresses must be classified into $P_m$, $P_b$, etc.

A postprocessor program suitable for such calculations can be used, e.g. CASAFE [8] , was developed by consulting firm Colenco AG (former well known as part of Motor-Columbus Ing.) from Baden, Switzerland, in cooperation with Firma FIDES Informatik AG years ago. For the both wide used NPPs type of reactors: Boiling-Water Reactor (BWR) and Pressurized-Water Reactor (PWR) according ASME Section III-NB for design temperature below 350°C only fatigue usage factor has to be take into account.

The post processing program CASAFE is capable to calculate fatigue for usage factor, as well as other stress requirements in accordance with ASME Section III. The CASAFE has a standard link with FEM-Programs ANSYS and NASTRAN; other interfaces could be implemented on request. The results output of CASAFE are in the form of tables and/or graphics. One of the most interesting applications of CASAFE (Version ABSI) was for the Project SNR-300, where the design temperature was 450°C and additionally to fatigue the creep has been considered for the usage factor [9].

The experiences of ca. 40 year long lifetime of Swiss NPPs, won during periodical inspections, have shown, that the wall thickness degradation by e.g. erosion occurred; especially for critical components as e.g. elbows or valves made from carbon steel. With other words the periodically measurements of wall thicknesses of critical components by e.g. ultrasonic techniques have to be done and archived. In the cases of such wall thickness degradation it has to be considered the performing of new stress analysis with smaller geometrical dimensions of components. The new stresses will be used for post processing calculations of usage factor. For the components from austenitic steels or using cladding the degradation will be probably smaller, but the measurements of the wall thickness of critical components as well as looking for the cracking have to be performed during each periodical inspection of NPPs.

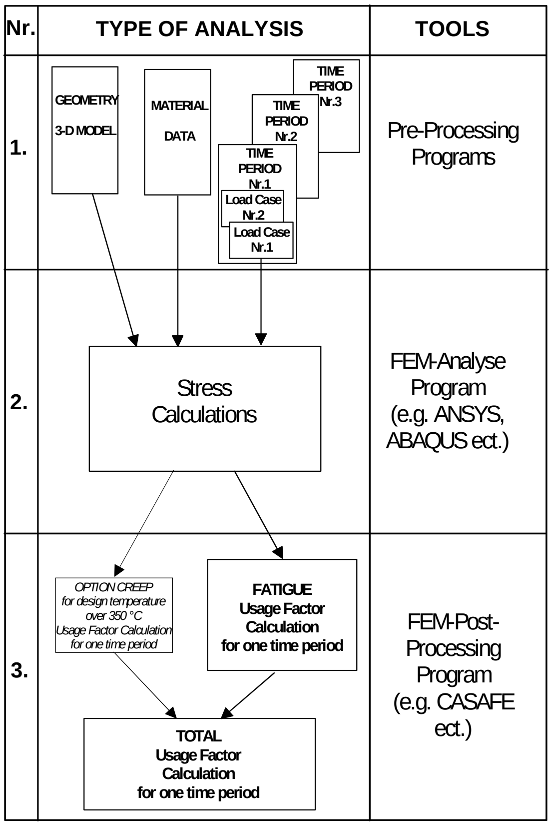


*Fig.1. Three steps of analysis for usage factor calculation with examples of analytical tools*

## 3. DEFINITION OF USAGE FACTOR CURVE

As mentioned previously in Pt.1 INTRODUCTION, the usage factors are required to assess the rest of life of NPP components. For this purpose the history of load should be known. Since sophisticated and costly Life Time Monitoring (LTM) Systems are relatively new and still partially in the proving stage, we are looking for an alternative approach to solve this task.

Usually the design calculations of usage factor are based on a hypothetically assumed manner of operation of NPP over its life span of 40 years.

In the Fig. 2, straight line "A" represents design calculation with the usage factor, of 85% at 40 years. Straight line "B" represents the calculation of the usage factor after 20 years of operation, by the same method as for the design calculations, but in calculated the known history of load (e.g. usage factor of 35% at 20 years of operation).

The known history of load of the component allows us to reconstruct the dynamics of time development of usage factor.

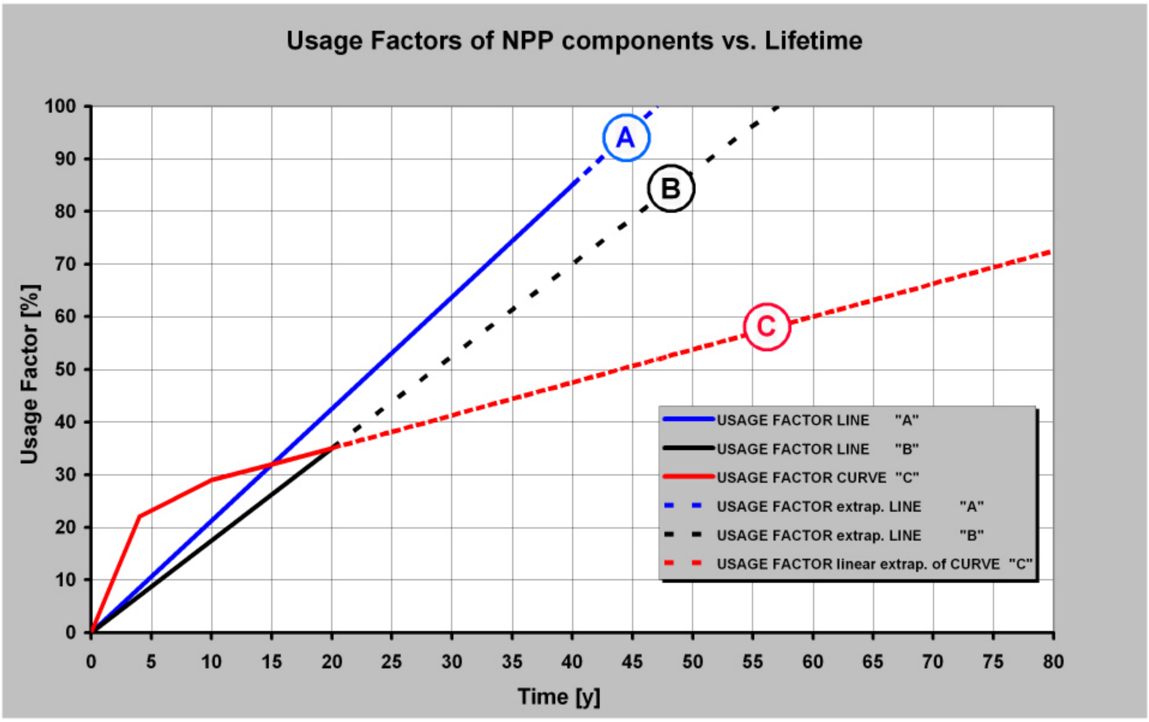


*Fig.2. An example of usage factors calculation for the same NPP facility: A-design calculation, B-after 20 years of operation in one time-step calculation, C-after 20 years of operation more detailed calculated in few time-steps. Concluded; taking into account the known 20 years load history in cases B and C, the analytical diagnosis of a longer lifetime tendency can be shown*

By dividing the known history of load into a few shorter time periods, for example 2, 4, 10, 15 and 20 years, and calculating the respective usage factor values, we can show the non-linear character of this time development. For example this non-linear reserve has been extensively study in work [10].

The curved line "C" represents this function. As can be seen in Fig. 2 the extrapolations of lines "B" and "C" will forecast different rest of life values. For example at a usage factor of 50% we obtain approximately 28 respectively 44 years of life expectancy, assuming a similar way of operation.

The main task in calculating the usage factor during a specific time period from the past is that actual life history of component has to be reconstructed on the basis of recorded reactor transients.

Firstly a system specialist has to analyse the mentioned records to recognise the load cases as well as their frequencies.

Secondly it is necessary to recognise the physical connection between the known load cases and stress history of the respective component. We have two possibilities to do this: experimentally and theoretically.

The first possibility is based on experimental tests using mobile instrumentation for measuring and recording the load parameters, similar to that done by LTM Systems.

The second possibility consists of thermo- and fluid dynamic calculations based on real main transient (temperature, pressure) recorded during the operation time of reactor.

On the grounds of these physical connections it is possible to determine the boundary conditions of loading for individual load cases, and the number of occurrences for the respective component.

Finally the entire known operating time is to be broken down into a few time periods for which the individual load cases and their frequencies are to be determined and the usage factor calculated. This procedure is to be repeated for each time period.

It is to be noted, that for the same load cases occurring in different time periods only one FEM Analysis has to be performed (till component's wall thickness stay the same). This means, that for subsequent time periods, usage factors values can be obtained from post-processing program only e.g. CASAFE.

The Usage Factor Curve obtained by these calculations is the basis for an assessment of rest of life of the component. The lineal, (tangential to the last measured and analysed period) extrapolation of this Usage Factor Curve, as shown in Fig. 2, can be used for the lifetime diagnosis of NPP components.

## 4. CONCLUSION

The forecast diagnosis for the rest of life span of a pressurized NPP-component based on the calculated Usage Factor Curve can provide less conservative results (i.e. longer lifetime) than the normally used standard calculations.

The main task of the proposed approach is the statistical interpretation of the recorded reactor transients and evaluation of load condition of the component resulting from these transients.

## 5. REFERENCES


[1] P. Kovacs, "*Impacts of nuclear power plant life management and long-term operation*", Nuclear Energy Agency, Facts and opinions, NEA News Vol.24, 2006 -, No.2, p. 7 – 9

[2] Swiss Nuclear Society SNS, (Schweizerische Gesellschaft der Kernfachleute SGK) www.kernfachleute.ch

[3] J.A. Patorski, P. H. Hirt, N. Jaussi, "*Usage Factor Curve as Rest of Life Assessment for Pressurized NPP-Components*", Transactions of the International Conference on Availability Improvements in Nuclear Power Plants, Madrid, Spain, Apri110-14, 1989, Copyright© 1989 by the Sociedad Nuclear Espanola.

[4] H. Eisele, "*Limitations in the operational use of components and systems in nuclear power plants*", Kerntechnik 52 No. 3

[5] IAEA-TECDOC-1305, "SAFE AND EFFECTIVE NUCLEAR POWER PLANT LIFE CYCLE MANAGEMENT TOWARDS DECOMMISSIONING", IAEA, VIENNA, 2002, ISBN 92–0–113002–3, ISSN1011–4289,© IAEA, 2002

[6] IAEA-TECDOC-1503, "NUCLEAR POWER PLANT LIFE MANAGEMENT PROCESSES: GUIDELINES AND PRACTICES FOR HEAVY WATER REACTORS", IAEA, VIENNA, 2006,ISBN 92–0–106206–0, ISSN 1011–4289, © IAEA, 2006

[7] W. Richins, S. Novascone, CH. O'Brien, *"Summary of SMIRT 20 Preconference Topical Workshop- Identifying Structural Issues in Advanced Reactors*", Proceeding of 20th International Conferences SMIRT, Div. X, Paper 2504, Espoo, Finland, August 9-14, 2009

[8] *CASAFE Components Analysis Stress and Fatigue Evaluation, Nachprozessor zur graphischen Resultatauswertung und Spannungsabsicherung von Finite Element Berechnungen*, Motor-Columbus & Fides Informatik, Zurich 1985.

[9] A. Huber, N. Jaussi, N. J. van Waveren, "*Nonlinear Thermal Analysis and Code Verification of SNR-300 Heat Exchanger Nozzle and Suspension Structure*", Proceeding of 8th International Conferences SMIRT vol. E 1/5, Brussels 1985.

[10] A. Kovacs, "*Calculation of predicted lifetime of nuclear power plant vessels by deterministic and probabilistic methods*", J. Technology, Law and Insurance, ISSN: 1359-9372, Vol. 4, Issue 3 & 4 Sept. 1999, p. 201 – 206.


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**Niklaus JAUSSI** has received the M.Sc. in Mechanical Engineering in 1964. He began his professional career in 1976 by Escher-Wyss Zürich in the department of closed cycle Helium gas turbines on the position of design engineer. In 1966 he has change and start the international part of his professional at General Atomic in San Diego, Cal., cooperating in the development of a Helium gas cooled high temperature reactor (HTGR). After 6 years of USA proffessionell expirience his coming back to Switzerland in 1972 and starting the job for General Eletric (Getsco) in the group for structure mechanics analysis. He is the author and the peer – reviewer of the stress reports of the mechanical components mostly for the Swiss NPP Leibstadt. In 1977 he has change to Motor Columbus MC Ing. Ltd. Consulting Engineer Inc./Colenco AG in Baden Switzerland with duties for the section of mechanical components. An important example of his consulting activity by MC Ing. was the designing of the additional emergency cooling system for the NPP Würgassen in Germany. From 1987 Niclaus Jaussi has concluded his proffesional career at the Swiss Nuclear Safety Inspectorate (HSK / ENSI), in the section of mechanical components. Since his retirement in 2002 is working in his own consulting firm "Outsource GmbH (Lmtd.) externe dienste" in Basel and serving with his wide know-how for the nuclear industry.

# GEAR FAULT DIAGNOSIS AND INDUSTRIAL APPLICATIONS

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Summary

This paper introduces the concept of a gear profile, which is the polar representation of the time synchronous averaged vibration signal computed on the rotation period of a pinion. A gear profile provides an attractive visual representation of the meshing efforts on the individual teeth for each of the gears present in a gearbox. It is mostly useful for the detection of local tooth faults (cracks, pitting) or shaft eccentricity faults. Its computation however presents some pitfalls as some parameters need to be selected with care: choice of the mesh harmonic to demodulate, filter bandwidth, signal duration for the time averaging. We propose some practical rules on how to select them. The amplitude and frequency modulation functions of the profile can then be computed, and the amount of the modulation may be quantified by some parameters. We also present a case where the electrical currant measurement can be very helpful for gear fault diagnosis. The technique is illustrated on a few industrial cases.

Key words: gear profile, time synchronous averaging, local tooth faults.

## INTRODUCTION

Time Synchronous Averaging (TSA) is a well adopted signal processing technique which enables periodic waveforms to be extracted from noisy signals [1]. It is particularly suited for the vibration analysis of mechanical systems such as gearboxes, as it enables the vibration of a single gear to be separated from the vibration of the complete system. This technique usually requires the measurement of a trigger signal, typically delivered by a one pulse per revolution tachometer. In case that a speed measurement is not available a technique has been proposed in order to perform angular resampling without the need of a speed sensor, when the machine is submitted to limited speed fluctuations [2, 3]. This technique is based on the speed estimation from one mesh harmonic.

TSA is mostly useful for the detection of local faults (tooth cracks, pitting) or distributed faults (eccentricity). This technique however requires the adjustment of a few parameters: choice of the mesh harmonic to demodulate, filter bandwidth, signal duration for the time averaging . In section I we present the methodology and propose some practical rules on how to select the parameters. In section II the technique is illustrated on a few industrial cases for gear diagnosis.

## 1. METHODOLOGY

The TSA signal of the vibration signal x(t), assumed to be zero-mean, is defined as

$$TSA(t) = E[\, x(t)\, ] \qquad (1)$$

It is estimated by angular resampling and averaging of the vibration signal over the rotation period of the gear of interest. The number of averaging should be high enough in order to ensure convergence of the TSA; however speed fluctuations should remain relatively limited for the speed estimation method used in [3]. The signal duration is here automatically adjusted, and the TSA convergence is assessed by observing the decrease of the energy of the TSA vs. the number of averaging. The good convergence can also be quantified by Stewart's method [4]. If the energy does not converge to a stable value then the number of averaging is either too low or the signal principal part is not deterministic but rather random periodic, i.e. *cyclostationary*. This may then be highlighted by 2nd order tools such as the instantaneous variance or Time Synchronous Variance (TSV) [5]:

$$TSV(t) = E[\, |x(t) - TSA(t)|^2\, ] \qquad (2)$$

where x(t) - TSA(t) is also called the residual signal. The TSV is more appealing when the underlying cyclic phenomena are not exactly periodic but exhibit some jitter, due for instance to random slips as it is the case for bearings [5]. Gear signal however are assumed to be rather periodic, but the TSV may still be useful to analyze in case of incipient tooth faults (pitting) which will at first excite the higher frequencies.

It is also possible to compute some indicators of cyclostationarity at 1st and 2nd order, corresponding respectively to the TSA and the TSV, which may be valuable in order to quantify and trend the observed phenomena [6]:

$$ICS1 = \frac{\sigma^2[TSA]}{\sigma^2[x]} \quad \text{and}$$

$$ICS2 = \frac{\sigma^2[TSV]}{DC[TSV]^2} \quad (3)$$

where σ stands for the standard deviation and DC[.] for the mean value.

The estimated TSA in (1) can then be bandpass filtered around the mesh fundamental frequency or one of its harmonic, and then Hilbert transformed in order to compute the modulation functions. Since the TSA signal is deterministic we propose to select the mesh harmonic with the highest amplitude, which may not always be the fundamental component depending on the measurement transmission path. The filter bandwidth, i.e. the number of sidebands *Ns* to include in the bandpass filter must be high enough so as to keep a good resolution but must not to include some spurious components related to nearby mesh harmonics. We choose a number of *Ns=10* sidebands. This is practically sufficient, however *Ns* must not exceed half the mesh order, i.e. half the number of teeth of the gear.

The filtered TSA signal can then be represented in a polar way over the rotation period of the gear. This so-called *gear profile* provides a visualization of the variation of the meshing pressure on the individual teeth of the gear, useful for the diagnosis. The Amplitude and Frequency Modulation Functions (AMF, FMF) can also be represented in a polar way.

Lastly, the modulation of the AMF can be quantified by the following modulation rates:

$$TMAeff = \frac{AMFeff \times \sqrt{2}}{DC[AMF]} \quad \text{and}$$

$$TMApp = \frac{AMFpp/2}{DC[AMF]} \quad (4)$$

representing the RMS and peak-to-peak amplitude modulation rates respectively. Definitions are equivalent for the FMF.

## 2. APPLICATIONS

### 2.1 Kaplan Hydraulik Turbine

This first application deals with a Kaplan hydraulic turbine equipped with a multiplication gearbox with ratio 180/24=7,5. The GCD (Geatest Common Divisor) between tooth numbers is 12 here. The turbine is operating at full load (1,6MW). TSA was performed on the vibration signal measured at bearing 3 in vertical direction (Fig. 1). Fig. 2 shows a good convergence of the TSA energy after about 100 period averaging. The TSA of the 24 tooth gear, represented on Fig. 3, exhibits a few peaks, which can also be seen on the FMA & FMF profiles of the mesh fundamental component (Fig. 4). On Fig. 3 is also represented the instantaneous standard deviation, i.e. the squared root of the TSV. The indicators of cyclostationarity (3) are also computed. Note a relatively low value of the ICS2, indicating that the cyclic phenomena are mainly periodic deterministic.

Note also the rather high values of the modulation rates (*TMAeff* =54%, *TMFeff*=13%). This seems to indicate a relatively poor condition of the gears. Indeed after visual inspection the client observed some "*surface wear on the teeth due to relatively deep pitting*". Measurements performed the following year showed a little evolution (*TMAeff* =59%, *TMFeff*=33%) which needs to be observed.

Note that the TSA seems to be composed of two identical patterns on Fig. 3, which actually corresponds to the common sub-period of the gears, due to the GCD=12. This is due to the presence of 1/12 sub-harmonics of the mesh frequency in the signal spectrum, indicating the presence of tooth wear families. The computation of the gear profiles was not really necessary for the diagnosis here but allowed to confirm visually the relatively poor condition of the gears.

### 2.2. Unrolling machine

This second application deals with an unrolling machine used in the aluminum industry. The rolls are driven trough a reduction gearbox with ratio 30/48 (GCD=6). For measurement in March 2010, the TSA of the 30 tooth pinion was computed (Fig. 5) as well as the corresponding gear profiles for second mesh harmonic, since this component appears to have much higher level than fundamental in this case. The AMF profile on Fig. 6 shows high eccentricity (*TMAeff*=93%), which indicates a meshing pressure concentrated on one part of the gear pinion only. Machine inspection revealed some relatively high degree of bearing clearance and a misalignment with the driving motor, however no fault on the gears. Another measurement was then performed in October after maintenance actions. The new profiles (Fig. 7-8) show drastic changes (*TMAeff*=37%). Also observe the changes in the indicators ICS1 & ICS2 (Fig. 5 & 7).

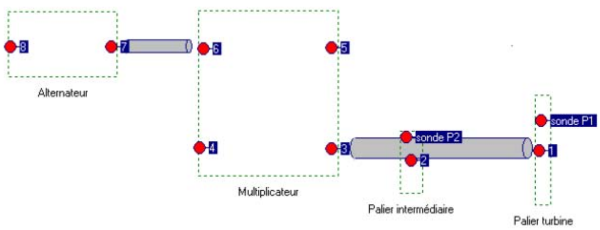


*Fig. 1. Schematic of the hydraulic turbine; multiplication ratio is 180/24*

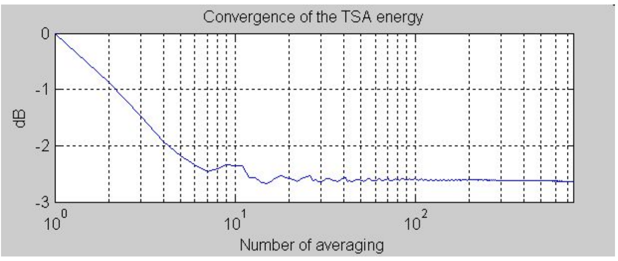


*Fig. 2. Convergence of the TSA energy versus the number of averaging for the 24 tooth pinion*

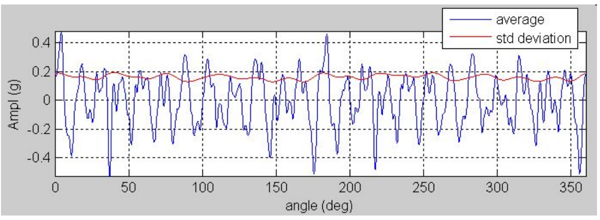


*Fig. 3. TSA of the 24 tooth pinion (ICS1=54%, ICS2=4%)*

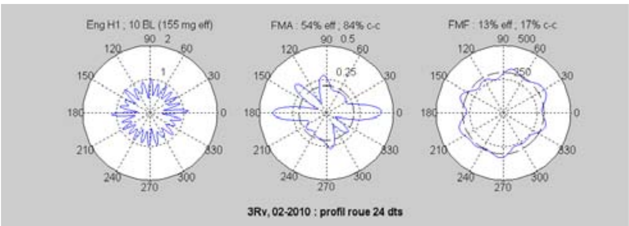


*Fig. 4. Gear profile and modulation functions of the mesh first component*

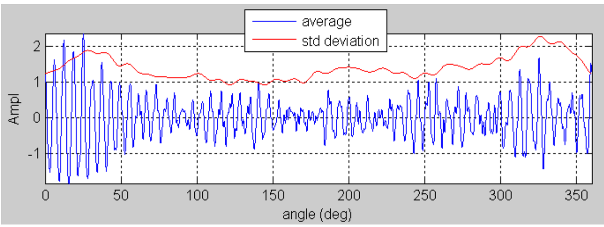


*Fig. 5. TSA of the 30 tooth pinion (ICS1=16%, ICS2=24%)*

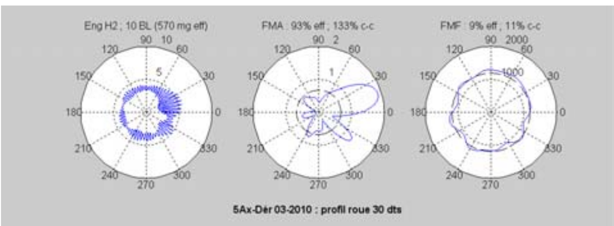


*Fig. 6. Gear profile and modulation functions of the mesh $2^{nd}$ harmonic*

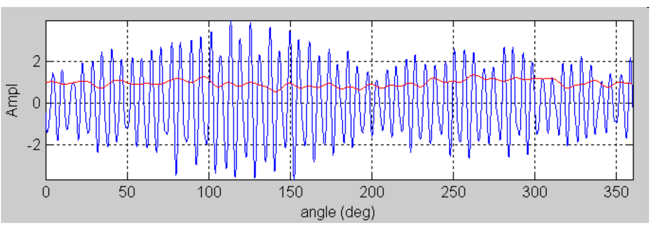


*Fig. 7. TSA of the 30 tooth pinion after maintenance (ICS1=72%, ICS2=10%)*

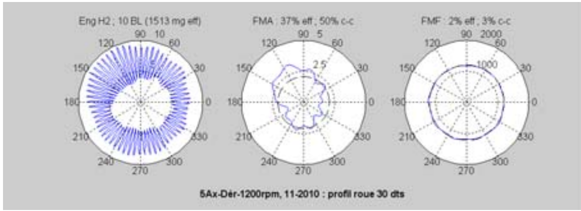


*Fig. 8. New gear profile and modulation functions of the mesh $2^{nd}$ harmonic*

## 2.2. Gear tooth fault diagnosis of drying rolls

This last application deals with the diagnosis of local gear faults of drying rolls in a paper making machine, by means of the electrical current. Currant analysis is a very useful tool for the diagnosis of faults inducing torque or speed fluctuations [7]. It ideally compliments vibration analysis without being intrusive. In this case the operator observed abnormal variations of the current absorbed by the AC motor driving a drying roll section. The variations were apparently random, as it appears in the measurement signal (Fig. 9). The AMF of the current fundamental component was computed and averaged synchronously with the rotation period of the rolls (about 1.6sec). The AMF profile shows 4 main peaks (Fig. 10), which may indicate local tooth faults on the main geared roll. Indeed when dismantling the gear the operator literally observed '*several falling teeth*'.

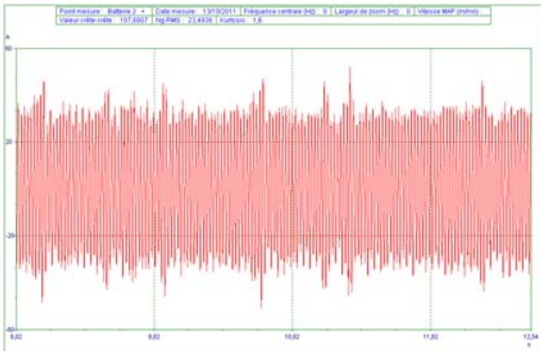

*Fig. 9. Electrical current signal of the driving motor*

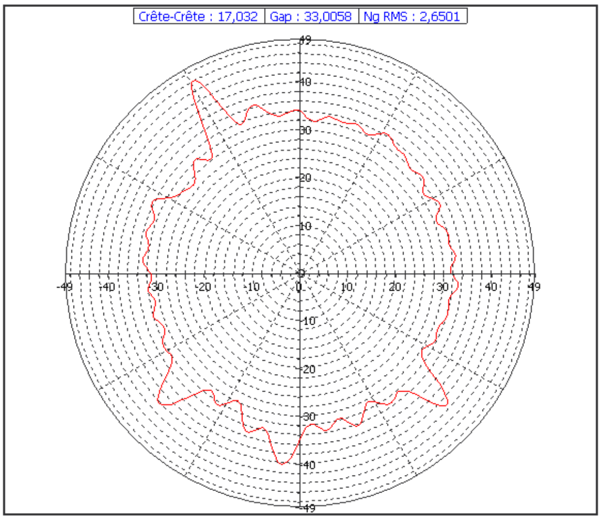


*Fig. 10. AMF profile averaged over the rotation period of the geared roll (TMAeff=11%, TMApp=26%)*

## 3. CONCLUSIONS

In this paper, we have shown on a few examples that gear profiles obtained from the classical TSA can bring an interesting added value for gear diagnosis. Care must be taken however as they do not provide the full diagnosis but must come in addition to traditional spectrum analysis (relative amplitudes of mesh harmonic, presence of sub-harmonics, coincidence frequency, level of sidebands…). Gear profiles can be useful in order to visualize the fault (local tooth faults, eccentricity) when a problem is first suspected. More research and experience is needed in order to interpret the different parameters (modulation rates, indicators of cyclostationarity) and to relate them to the severity of the fault.

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## REFERENCES

[1] S. Braun, *The extraction of periodic waveforms by time domain averaging*, Acoustica 32 (1975) 69–77.
[2] F. Bonnardot, M. El Badaoui, R. B. Randall, J. Danière, F. Guillet, *Use of the acceleration signal of a gearbox in order to perform angular resampling (with limited speed fluctuation),* Mechanical Systems and Signal Processing 19 (2005) 766–785.
[3] F. Combet, L. Gelman, *An automated methodology for performing time synchronous Averaging of a gearbox signal without speed sensor*, Mechanical Systems and Signal Processing 21 (2007) 2590–2606.
[4] R. M. Stewart, *Some useful data analysis techniques for gearbox diagnostics*, University of Southampton Report MHM/R/10/77, July 1977.
[5] J. Antoni, F. Bonnardot, A. Raad, M. El Badaoui, *Cyclostationary modelling of rotating machine vibration signals*, Mechanical Systems and Signal Processing 18 (2004) 1285–1314.
[6] A. Raad, J. Antoni and M. Sidahmed, Indicators of Cyclostationarity: *Theory and Application to Gear Fault Monitoring*, Mechanical Systems and Signal Processing, 22(3), pp.574-587, 2008.
[7] C. Pachaud, *L'analyse de l'intensité du courant statorique : outil de surveillance et de diagnostic*, Journal sur l'enseignement des sciences et technologies de l'information et des systèmes, Vol. 4, 12 (2005).

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# CHALLENGES IN MAINTENANCE OF VIBRATION MONITORING SYSTEMS DEDICATED TO UNDERGROUND MINING MACHINERY

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Summary

The paper presents practical considerations connected with implementation of vibration monitoring systems for the underground mining machinery. Technical aspects together with system scheme and functionality are presented. Factors influencing on maintenance and monitoring of the diagnostic system itself are discussed in relation to some examples of troubleshooting strategies. Mining industry specific aspects of monitoring systems including varying operating conditions of machinery and the requirement of ATEX compliance are presented. Certain factors influencing the vibration data connected with monitoring system maintenance as well as the methods of validation of vibration samples are examined. For example, an industrial system FAMAC VIBRO is presented as an implemented complex solution for vibration monitoring of mining machines.

Keywords: condition monitoring system, coal mining machines monitoring, vibration based diagnostics.

## IMPLEMENTACJA I OBSŁUGA SYSTEMÓW MONITORINGU DRGAŃ DEDYKOWANYCH DO MASZYN GÓRNICTWA PODZIEMNEGO

Streszczenie

Artykuł prezentuje praktyczne zagadnienia związane z implementacją systemów monitoringu drgań dedykowanych dla maszyn górnictwa podziemnego. Zaprezentowane są aspekty techniczne związane z budową i funkcjonalnością wraz z czynnikami związanymi z eksploatacją i monitoringiem stanu samego systemu. Przedstawiono przykłady często występujących problemów wraz z propozycjami ich rozwiązywania. Omówiono również wymagania stawiane systemom monitoringu przez przemysł górniczy z uwzględnieniem zgodności ze standardem ATEX oraz ciężkimi warunkami eksploatacji jego komponentów. Przedstawiono walidację sygnałów drganiowych jako jeden ze sposobów weryfikacji poprawnego działania systemu. Omówione zagadnienia zilustrowano na przykładzie systemu FAMAC VIBRO – kompletnego rozwiązania do monitoringu drgań maszyn górnictwa podziemnego.

Słowa kluczowe: system monitorowania drgań, monitoring maszyn górnictwa podziemnego, diagnostyka drganiowa.

## INTRODUCTION

Recent progress in automation, integrated electronic and IT solutions for underground mining industry has contributed to significant improvements in terms of productivity and economic operation of mines. One of the steps leading to enhancement of the machine availability and productive usage is implementation of reliable and trustable vibration based monitoring system and such trend is seen in areas connected with mining industry [8]. As the mining sector is very specific in terms of the machine operating conditions and the requirements for the applied hardware it is crucial to tune the condition monitoring systems to meet that criteria. Proper solutions for problems like the data transfer between consecutive levels of the system, signal validation, ATEX compliance of the electronic components are crucial when adapting such systems to work in mining environment.

## 1. CHALLENGES IN DEPLOYMENT

Implementation of successful vibration monitoring system in underground mining is not a trivial task. One of the factors contributing to that fact is that condition monitoring system most often has to be properly integrated with the infrastructure functioning on particular mine. This involves power supply, data transmission possibilities and topology of the mine. It is also common practice to integrate the condition monitoring system with the higher level mine monitoring and managing system [4] – like it is done with FAMAC VIBRO and e-mine® discussed in one of the following chapters.

Mining machinery - including conveyors, demands high amount of mechanical power to be transmitted with high gearbox ratios. Gearboxes often consist of multiple stages including the planetary gears. This contributes to the complicated kinematics of monitored drives and from the vibration monitoring perspective results in high amount of estimates to be calculated and traced simultaneously.

One of the limitations is always the number of the mounted sensors. From the diagnostic point of view more signals from particular machine is better. From the client point of view multiplying the sensor locations increases the costs and requirements regarding the data transfer throughput. As a result of compromise between those two criteria it is common practice to mount two sensors for conveyor drives – one dedicated to monitor input gear stages and another one on the output stage.

After selection of the sensors mounting points on the gearbox it is often important to design additional shielding components protecting them from accidental mechanical shocks.

To ensure the reliable path of the signal to the consecutive acquisition modules it is important to use a proper cable and protect it against corrosion and mechanical failure. A special attention has to be paid to selection of proper hermetic connectors. Also proper placement of the connections should be planned in such manner to enable dismounting and servicing of separate modules without cutting the cables.

Besides mechanical damage of the wires the influence of adjacent electrical equipment should be taken into consideration. Applying proper screening on signal cables is crucial in protection against electromagnetic interference.

## 2. CHALLENGES IN MAINTENANCE

Monitoring systems designed to improve maintenance of the machines should be treated with proper maintenance strategy itself. As the complexity of the condition monitoring increases the probability of possible malfunctions rises. These may lead to the conclusion that it is proper to introduce the concept of condition monitoring of condition monitoring systems. Such approach is especially needed for vibration based condition monitoring systems applied in mining industry. Maintenance of such systems should be planned at the design stage with consideration of the underground mining specific aspects. Planning of the maintenance of the vibration monitoring systems includes:

- managing the changes in the system structure in the way that not interrupts the current functioning of the system,
- ensuring the proper way to set the system parameters (for example: sample length, sampling frequency, measuring range and sensitivity) without corrupting the integrity of the collected data,
- organizing the system structure in the way that enables robust identification of the components that are not functioning properly.

One of the challenges in vibration condition monitoring of the mining conveyors is integration of the vibration data with information about the machine operating conditions and changes applied to whole asset. For example – mining conveyors drives location changes as the wall system progresses which may influence on the vibration signal. Shortening the conveyor influences the load present in the drive. When abovementioned information is included it builds certain context that should be considered during the decisions about the failure preventive actions.

## 3. ENSURING QUALITY OF VIBRATION DATA

All concepts and algorithms used in vibration based condition monitoring assume that vibration samples are valid and not corrupted by means of sampling, value range, sensor condition etc. It is natural to assume such conditions in research and well supervised deployment stage of implementation of the system, but experiences show, that approach taken when using system for long time should be different.

To ensure the good diagnosis regarding the machine state in changing operating conditions and limited possibilities of visual inspection of the system by qualified personnel - which is often the case in underground mining industry, it is crucial to deploy consistent and robust signal validation policy.

Target of validation is to extract the correct signals from samples collected by monitoring system. Correct signal is considered as signal that truly represents the machine behaviour. It is presented by acceleration, velocity and displacement waveforms and those waveforms should contain the expected frequency contents. For small datasets it is common to perform validation by using experience of the qualified engineer who can assess the signal validity visually. When it comes to large amount of data produced by complex industrial monitoring systems such approach is inefficient. This generates demand for automation and development of algorithms that are capable of detection of certain aspects of signal invalidity. Those algorithms called rules may be divided in certain groups. Those involve amplitude validation rules where examples of the most robust are [6,7]:

- **Minimum energy rule** – which states that recorded signal should contain minimum level of energy to be considered as valid. This rule can be expressed by RMS value as follows:

$$E_{RMS} = \sqrt{\frac{1}{N}\sum_{1}^{N} x^2[n]} > T_{MinE\_RMS} \quad (1)$$

Use of RMS value instead of energy normalizes the estimator taking into account signal length.

- Perseval's theory based **Energy Conservation Rule.** This rule defines constraints on the difference between signal energy calculated in time and frequency domain. Because of effects specific for digital signals such difference may occur. This rule may be expressed also with use of RMS value:

$$Abs\left(1 - \frac{timedomainERMS}{frequencydomainERMS}\right) = abs\left(1 - \frac{\sqrt{\frac{1}{N}\sum_{i=0}^{N-1} x[i]^2}}{\sqrt{\frac{1}{2}\sum_{k=0}^{N/2}\left(\frac{2}{N}X[k]\right)^2}}\right) < Thres\_P \quad (2)$$

- **N-point rule** – the result of this algorithm is the maximum number of consecutive samples having the same value
- **U-point rule** – indicator of the number of unique values in the signal
- **Z-point rule** – maximum number of consecutive samples having the same sign

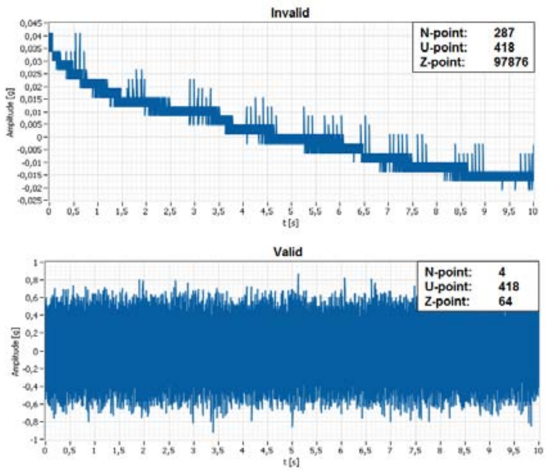


*Fig. 1. Examples of invalid and valid signal and results of validation algorithm performed on the samples. Signal recorded by real system deployed in underground mine*

As an example of use of these methods to distinguish valid and invalid signals comparison is provided on Fig. 1. It can be clearly seen that invalid sample contains no useful information about monitored machine. The cause of the signal shape may probably be some electrical interferences present during the acquisition. Overall low level of the signal indicates that monitored machine was on idle state. As the comparison of results of validation rules show, it is possible to discard invalid sample by proper setting the limits of the rules output values.

## 4. ADVANCED SIGNAL ANALYSIS

Most of the progress in vibration signal analysis for machine diagnostics was made in the area of stationary conditions of machinery operation. In mining machines fluctuation of load causes changes in rotational speed and such behaviour of these two parameters makes the process of diagnostic reasoning more difficult. As Fig. 2 shows, conventional vibration estimates values are sensitive to load and speed. Fig. 3. presents additionally that not only is the value of rotational speed important, but in some cases also its direction. Such relation may be specific to particular gear and depend on its geometrical properties and assembly factors.

According to abovementioned facts there is a need of development of advanced signal processing methods allowing to diagnose machine state with consideration of the variability of operational parameters.

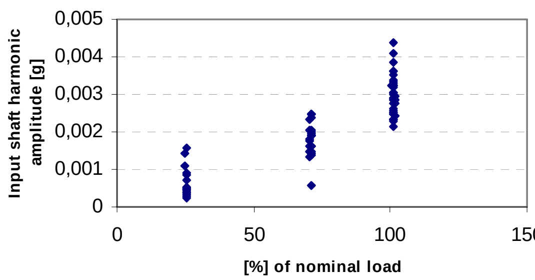


*Fig. 2. Correlation between input shaft harmonic amplitude and load obtained for high power gearbox dedicated for conveyor drives*

To deal with the rotational speed fluctuations order tracking is introduced. In many cases where there is no possibility of installing a tachometer probe the tacho signal needed for order tracking has to be extracted from vibration data. Methods of speed reconstruction can be based for example on time-frequency analysis or phase demodulation techniques [2, 9].

Besides methods for rotating speed information extraction certain progress was done in the area of the reconstruction of load level information present in vibration signal. Some algorithms use amplitude demodulation of meshing components to obtain the load profile and then perform normalization of the signal [11]. As the load causes speed fluctuation, the amplitude of components used for demodulation can also change due to the shape of system frequency response function. To overcome this, another method was developed introducing the IP (Instantaneous Power) which reflects the global amplitude modulation effects caused by load [5].

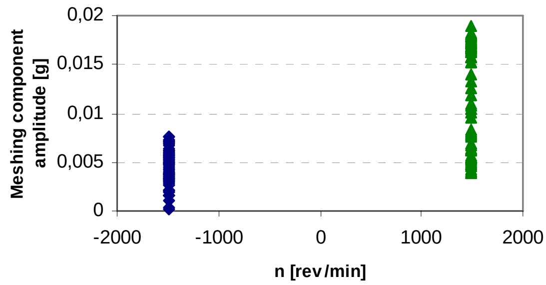


*Fig. 3. Differences between meshing component amplitudes for different speed direction*

Besides efforts of normalisation there are methods based on grouping the vibration data into clusters containing the same operational state of machine. Those methods can be based on data mining algorithms [3]. After clustering one can assure that vibration estimates are trended within one operational state of machine.

## 5. DESCRIPTION OF EXEMPLARY SYSTEM

As an example of the vibration based condition monitoring system dedicated to mining machinery FAMAC VIBRO system (Fig. 2.) will be discussed both with its general hardware and software aspects.

FAMAC VIBRO is a part of the supervisory system managing the coal extraction process called e-mine® and it is component responsible for monitoring of gearboxes, conveyor drums and shearer loaders [5]. System consists of three levels:

- Underground visualization,
- Surface visualization,
- Service provided by FAMUR's Diagnostic Center.

Core component of the e-mine® system is the Green Diamond – underground server designed to coordinate processes assigned to the local station – FAMAC LS. Such approach results in architecture allowing to monitor machines located in big distances like it is in the sequence of conveyors. Besides the Green Diamond other parts of the system are [5]:

- LS FAMAC VIBRO – underground local server dedicated to collecting, processing and presenting the data. Its main function in to transfer data to the Green Diamond and also to the other supervisory systems to ensure the adequate response when warning or alarm is present,
- LB FAMAC VIBRO – this is the component used in extended systems for collecting data and transferring it to local station,
- RS/OPTO converter - is the component providing signal conversion to fiber optic.
- Intrinsically safe data hub,
- Accelerometers compliant with the explosive atmosphere requirement,
- Temperature sensors.

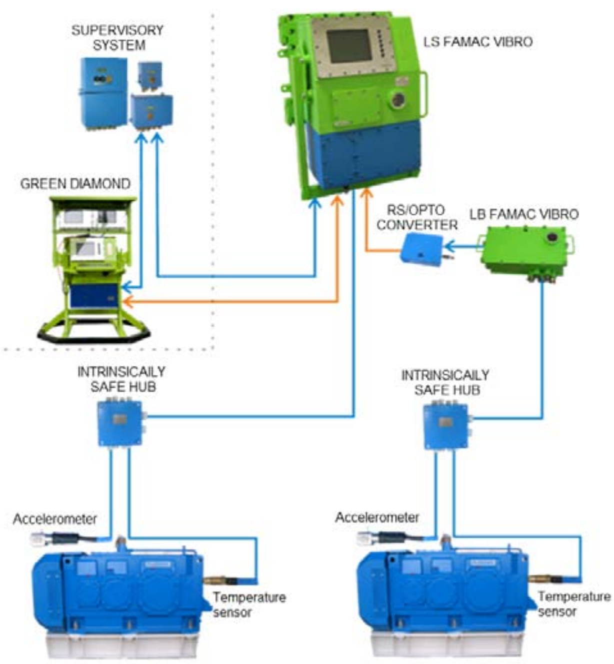


*Fig. 4. Architecture of the system*

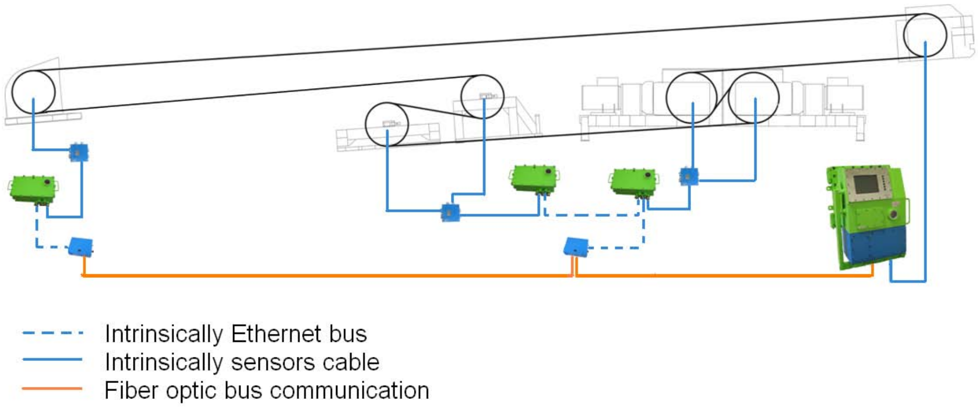


*Fig. 5. System scheme for belt conveyors*

Signals collected from the machines including vibration and temperature are transferred to the local station. Optical fiber is used at that stage to ensure ATEX compliance. Such approach also provides high data transfer rate which is crucial in sending raw vibration samples collected by the system [8]. Besides raw vibration data certain estimates are calculated by dedicated software module basing on the machine kinematics and are written to the database. Integration with the e-mine® system enables to correlate the vibration data with the state of certain assets.

Analyses performed on the signals are separated in two levels. First – standard level is implemented on software included with systems itself. It contains robust and basic analysis including RMS and Peak-to-Peak values giving the information about general condition of machine. Second level of analysis is provided by Diagnostic Center.

Precise vibration based diagnostics of mining machines requires more advanced methods. Recent developments in that area showed importance of aspects as signal preprocessing for local damage detection [10] or optimum methods for demodulation band selection [1].

Analysis and research on that areas and are conducted by Famur's Group Diagnostic Center.

## 6. CONCLUSIONS

Deploying and maintaining a vibration based condition monitoring system on underground mining machinery is complex task. The advantages of preventive maintenance including the reduction of the production downtime and protecting the machines against catastrophic failure cause, that number of mines implementing such systems on their assets increases.

One of the examples of successful implementation of vibration based condition monitoring system in underground mine is FAMAC VIBRO system deployed in KWK Wieczorek. System has over two years of service. Many issues connected with hardware design of the system and standard online vibration analysis have been solved so far.

Increasing interest of potential clients contributes to development of new generation of solutions. However there is still a lot of uncovered ground in the area of optimal diagnostic methods selection especially when taking into account influence of variable operating conditions.

## REFERENCES

[1] Barszcz T., Jabłoński A.: *A novel method for the optimal band selection for vibration signal demodulation and comparison with the Kurtogram*, Mechanical Systems and Signal Processing 25, 2011, p. 431-451

[2] Bonnardot F., El Badaoui M., Randall R. B., Danierea J., Guilleta F.: *Use of the acceleration signal of a gearbox in order to perform angular resampling (with limited speed fluctuation),* Mechanical Systems and Signal Processing 4(19), 2005, p. 766-785

[3] Gibiec M., Barszcz T., Bielecka M.: *Selection of clustering methods for wind turbines operational data*, DIAGNOSTYKA'4(56), 2012, p. 37-42

[4] Gustafson A., Galar D.: *Fusion of production, operation and maintenance data for underground mobile mining equipment*, The Ninth International Conference on Condition Monitoring and Machinery Failure Prevention Technologies 2012

[5] Heyns P. S., Stander C. J., Heyns T., Wang K., Ngwangwa H. M.: *Vibration based condition monitoring under fluctuating load and speed conditions*, 18th World Conference on Nondestructive testing, 2012

[6] Jablonski A., Barszcz T., Bielecka M.: *Automatic validation of vibration signals in wind farm distributed systems*, Measurement 44(10), 2011, p. 1954-1967

[7] Jablonski A., Barszcz T.: *Validation of vibration signals for heavy duty machinery*

*diagnostics*, Mechanical Systems and Signal Processing Special Issue, submission No. MSSP11-665
[8] Kępski P., Barszcz T.: *Application of Vibration Monitoring for Mining Machinery in Varying Operational Conditions*, Condition Monitoring of Machinery in Non-Stationary Operations 2012, Part 4, p. 461-469
[9] Urbanek J., Zimroz R., Barszcz T., Antoni J.: *Reconstruction of rotational speed from vibration signal – comparison of methods*, The Ninth International Conference on Condition Monitoring and Machinery Failure Prevention Technologies 2012
[10] Zimroz R.: *Role of signal preprocessing in local damage detection in mining machines*, DIAGNOSTYKA'2(46), 2008, p. 33-36
[11] Zimroz R., Combet F.: *Time Varying Outer Load And Speed Estimation By Vibration Analysis – Application To Planetary Gearbox* Diagnosis In A Mining Bucket Wheel Excavator, DiIAGNOSTYKA'4(40), 2006, p. 7-14
[12] http://www.famur.com.pl/page/index/59

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# DIAGNOSTICS OF CORROSION DEGRATATION OF LIGHT MARINE STRUCTURES

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Summary

Applying diagnostics consisting in evaluation of deformation based on corrosion potential measurements it is possible to extend life time of technical structures and make them safe for people and environment. Development of anticorrosion techniques and staff training is a fundamental requirement for safe exploitation of technical structures made of new 7020M aluminum alloy. Corrosive marine environment enforces engineers and technicians to implement advanced anticorrosion methods to make life on ship much safer. The paper presents results of investigations of ship aluminum alloys subjected to strain test fatigue test and new method diagnostic corrosion.

New aluminum alloy 7020M for selected heat treatment is better than the alloy 7020 utilized so far. Lack of zinc in 5xxx series alloys results in enhanced corrosion resistance as compared to 7xxx series but simultaneously their stress properties are significantly lower. A method of corrosion diagnostic has been proposed aimed at increasing the exploitation safety

Keywords: diagnostic, degradation aluminum alloys, stress corrosion cracking, fatigue corrosion.

DIAGNOSTYKA DEGRADACJI KOROZYJNEJ LEKKICH KONSTRUKCJI OKRĘTOWYCH

Streszczenie

Przez stosowanie diagnostyki oceniającej stan odkształcenia poprzez pomiar potencjału korozyjnego konstrukcji możemy nie tylko przedłużać żywotność obiektów technicznych ale czynić je bezpiecznymi dla ludzi i środowiska. Metoda pomiaru wartości potencjału korozyjnego odniesiona do wzorca laboratoryjnego możliwa szybką ocenę stanu odkształcenia analizowanego obszaru konstrukcji. Rozwój technik antykorozyjnych i szkolenie specjalistów to podstawowy wymóg dla bezpiecznej eksploatacji obiektów technicznych wykonywanych z coraz to nowszych materiałów inżynierskich. Środowisko morskie o szczególnie agresywnie korozyjnych właściwościach, nakazuje i wymaga od inżynierów i technologów okrętowych wdrażania coraz to zaawansowanych zabezpieczeń przeciwkorozyjnych, które mogą uczynić pracę na morzu znacznie bezpieczniejszą.

W artykule przedstawiono wyniki badań wytrzymałościowych i zmęczeniowych okrętowych stopów aluminium i nowy sposób diagnostyki korozyjnej. Nowy stop 7020M dla określonej obróbki cieplnej jest lepszy od dotychczas stosowanego stopu 7020. Brak Zn w stopach serii 5xxx powoduje że wykazują lepszą odporność korozyjną niż stopy serii 7xxx ale mają znacznie mniejszą właściwości wytrzymałościowe. Przedstawiono sposób diagnozowania procesów korozyjnych mających na celu zwiększenie bezpieczeństwa eksploatacyjnego

Słowa kluczowe: diagnostyka, degradacja stopów aluminium, korozja naprężeniowa, zmęczenie korozje.

## INTRODUCTION

The corrosion is inseparable natural process of environmental devastation of the material surface caused by spontaneous chemical and electrochemical processes. The corrosion in sea water and atmosphere is an electrochemical one which is connected with the flow of current and its density influences the intensity (pace) of corrosion. Corrosion problems are related to considerable part of engineer materials applied to the technology. Those materials are usually alloys of at least two chemical elements of large susceptibility to oxygenation. The contact of those materials with air or other corrosive factors causes degradation of their strength properties in result of material decrease.

The anticorrosive system is designed, to assured definite construction durability, to fulfill time of its function, called construction "vitality". Unfortunately, the longer time is, the larger costs are. Data from "Corrosion Costs and Preventive Strategies in the United States Report" verified in 2005 year and published on website www.corrosioncost.com ; www.corrosioncost.com shows, that direct expenditures on corrosion in USA at present carry out 276 billion $ annually (6% national product brutto). Expenditures on corrosion for shipping industry [1] are 1% this sum. It was estimated , that in Poland these expenditures can reach even more than 10% [2].

Corrosion problems of exploiting technical and sea objects appear where the corrosive factor is found. The increase of tension in construction elements results in the bearing section changes which are caused by corrosive decrease. Those processes appear as a threat to the work safety. The corrosion intensity depends on many factors, mainly on the chemical constitution of the material as well as on the type of the corrosive factor (gaseous or liquid). The final effect of uncontrolled process of corrosion are: failures, the environmental contamination and danger for the human's life and health. The natural sea environment is especially dangerous in respect of corrosion. That is why the type of the sea construction determines the level of safety threat. Devices and elements of supporting structure which proper functioning affects the work safety should be mentioned here. For instance, the corrosive defects of supporting structure elements of drilling platforms, machines, containers, pipe lines ect., may cause the degradation of sea environment. Similar danger is evoked by the corrosion of metal packages which contains hazardous materials such as mustard gas or pearlite. Materials which are mostly used in sea structure constructing are: hull steel, austenitic steel and aluminum alloys. Aluminum alloys are more often used in building enormous dimensions sea constructions due to their relative strength modulus, a magnetism and weldability. In spite of these advantages, aluminum alloys undergo the corrosion processes because of simultaneous influence of exploiting tensions and sea environment. While uncontrolled, this effect may cause failures. This is the reason why in this article specific sea aluminum alloys are characterized in respect of decrease of mechanical properties under the influence of the corrosion and danger of such processes.

## THE SEA ENVIRONMENT AND ALUMINUM ALLOYS

Technical objects which are exploited in the sea environment are constantly affected by corrosive impact and sea atmosphere. Thanks to a large contents of dissolved salts and gases the sea water is characterized by huge corrosion activity. In open seas the salinity is usually about 3,3-3,7%. In inland seas such as Baltic Sea the salinity is changeable and ranges between 0,5-3% [3]. More then 80% of salt contents exist as chlorides. The oxygenated sea water as well as the impact of microorganisms in connection with the stress which occurs during "the normal work" of the construction are the main factors deciding about corrosive degradation of sea construction materials.

The basic way to protect the engineering materials from the corrosion in the sea condition is the active and passive protection as well as the combination of them. The type of used anti-corrosion method depends on the type of sea construction. On the vessel the combination method is used for the hull that is the connection of the cathode (active) method, protection method and the set of protective paints (passive). For superstructures the sets of protective paints are used (passive protection) and inhibitors are used in closed installations of e.g. the ship cooling.

In the shipbuilding industry 7xxx aluminum alloys series are more often used. They displace commonly used 5xxx alloys series. High-resistant and weldable 7xxx alloys have the best resistance properties among all aluminum alloys used in the shipbuilding. Unfortunately, they are characterized by tendency to stress corrosion in the sea water [4]. Alloys of 5xxx such as 5019(PA20), 5083(PA13) and 5754(PA11) are commonly used in hulls and superstructures building as well as in the equipment of light and fast vessels building. The 5xxx alloys (AlMg6Mn, 7020) as well as 5083 and 7020M (PA47M) are used for stiffening and plating of highly loaded hulls and superstructures which are joined also by welding. It applies especially to fast semi-planing crafts (e.g. motor torpedo boat), hydrofoil boats (e.g.'Zryw'), catamarans (e.g. tourist crafts Bumerang) and to elements of liquefied gas containers – naturally occurring LNG (Liq.Natural Gas) and as crude oil refining products LPG (Liquefied Petroleum Gas).

For instance, in order to built 3 upper decks, stacks, superstructures, masts and the equipment of the longest, so far, transatlantic ship 'France' (V=66.347 BRT) 1.600 tones of aluminum and its alloys were used. Aluminum alloys are exploited also in various reinforced composites, means of military transport (also bullet-proof means) as well as recreation and rescue equipment, ect. [5]

Despite many advantages aluminum alloys need control and corrosive monitoring connected with the susceptibility on stress and fatigue corrosion in the sea water and atmosphere [6]. In the table 1 mechanical properties of particular ship aluminum alloys are depicted and their resistance to concrete types of corrosion are determined by:

a) average percentage decrease of mechanical $K_{Rm}$ and plastic $K_{A5}$ properties under the influence of sea atmosphere.
b) $R_m$', $A_5$' mechanical properties after corrosive exploiting under constant stretching stress in the sea water
c) $Z_{gok}$ fatigue-corrosive durability for N= fatigue cycles in the sea water

As a safety parameter, the ship construction engineer assumes the strength and probability of changes of exploiting properties in a result of heat treatment. It determines the usage of 7xxx alloys and corrosive susceptibility is minimalized by the use of protective paints.

## ON-SHIP CORROSION DIAGNOSTICS SYSTEM

Utilizing the knowledge on electrochemical corrosion, we can reduce the current loss due to corrosion, without additional investment, by up to 40%. Applying the knowledge of electrochemistry, we can monitor the progress of corrosion processes and response much earlier to accelerated wear by eliminating the damage origin and subsequent degradation of construction material or by using the methods of corrosion protection at right time [7, 8].

Table 1. Mechanical properties and corrosion resistance of particular ship aluminum alloys in heat treatment which are the most resistant to corrosion in the sea environment

| Alloys in the state | Static mechanical properties for $10^{-3}s^{-1}$ | | | Corrosion resistance | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **in the sea atmosph- -ere** | | **in the sea water** | | | | | | |
| | | | | corrosion in the salt spray chaber | | stress corrosion for t=1500h and stretching stress $\sigma_o$=0,8 R $_{0,2}$ | | | rotary-flexural fatigue corrosion for f=50Hz and N fatigue cycles | | | |
| | $R_m$ | $R_{0,2}$ | $A_5$ | $K_{Rm}$ | $K_{A5}$ | $R_m$' | $R_{0,2}$' | $A_5$' | Powietrze N=$10^5$ | N=$10^6$ | 3%NaCl N=$10^5$ | N=$10^6$ |
| | MPa | MPa | % | % | % | MPa | MPa | % | $Z_{go}$ MPa | $Z_{go}$ MPa | $Z_{gok}$ MPa | $Z_{gok}$ MPa |
| **7020M** $T_{622}$*1 | 443 | 397 | 9,8 | 4,7 | 36 | 426 | 377 | 2,9 | 236 | 175 | 224 | 134 |
| **7020** $T_{622}$*1 | 372 | 317 | 16 | 4,4 | 30 | 339 | 305 | 8 | 233 | 180 | 226 | 160 |
| **5086** H111 | 358 | 180 | 23 | 3,5 | 23 | 340 | 196 | 15 | 167 | 140 | 155 | 90 |
| **5083** 0 | 295 | 151 | 20 | 3 | 10 | 285 | 146 | 13 | 185 | 155 | 152 | 118 |

*1 heat treatment of 7xxx alloys - $T_{622}$ – super saturation and time - 450°C/1.5h (430°C/45') , cooling in the heat water 80°C and ageing type: 20°C/6 days + artificial ageing: 95°C/15h+150°C/10h [7].
*2 heat treatment of 5xxx alloys 0(H111- annealing recristallize 350 ° C with speed heating and cooling 50°C/h [8]

The results of corrosion researches given in the table 1 show that the corrosive resistance of aluminum alloys of 5xxx set (hydronalium) is higher than the resistance of 7xxx alloys . However, strength properties of 7xxx are better than strength properties of hydronalium.

The development of techniques for monitoring and combating corrosion can only minimize the effects of its degradation character and contribute to the improvement of the service. This is achieved through learning of the mechanisms of corrosion. Corrosion protection is prevention of natural destruction process resulting in the extension of life cycle i.e. from creation to destruction of the material. Such is the perception of the problems of corrosion and corrosion protection [8 9].

OCDS – On-ship Corrosion Diagnostics System applies to the recording, collection and signaling of corrosion risk of structural elements. Based on the registration of the stationary potential, electrochemical ($E_{st}$) of the selected area of structure, not only marine one, one can give a close approximation, using the monograms (tabulated results of laboratory mechanical and electrochemical tests based on electrochemical impedance spectroscopy and its dynamic mode) of the initiation of corrosion processes and the state of deformation (strain) of structures for a given material. Fig.1a. shows the $E_{st}$ registration system in selected areas of ship superstructure shown in Fig.1b.

This system is developed for metallic materials, which have a natural (or artificial) tendency to form on its surface, dense, well adherent, passive oxide film. For aluminum alloys, bi-layer film of oxide is amorphous boehmite and porous hydrargilite This layer is formed as a result of the alloy surface contact with oxygen from air or water. Corrosion of materials in the marine environment is electrochemical corrosion, which is accompanied by a current, which value depends mainly on the value of $E_{st}$ potential, dependent on the level of stress. This insulating layer of oxide must have the appropriate mechanical and physical properties.

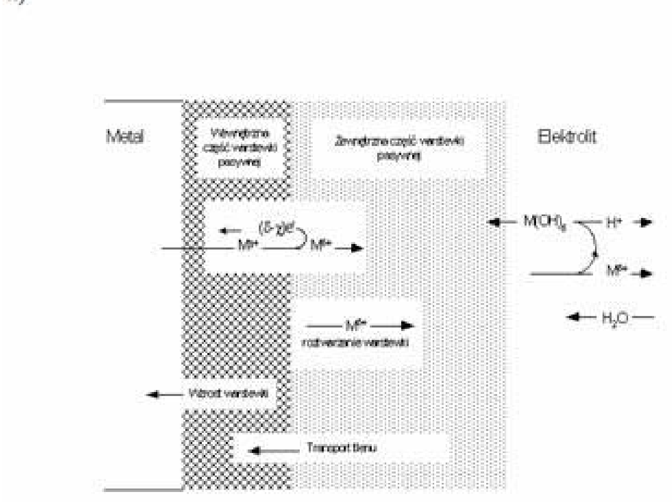
a)

b)

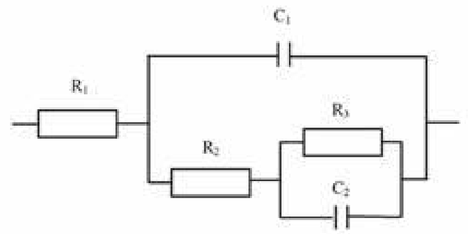
*Fig.1. OCDS installed in selected areas (cracked) of aluminum (alloy 7020) superstructure of the design ship 620: a) 40-foot 3-Deck superstructure being a test object tested with the b) following set-up: Data Logger (voltage record with its own memory and power supply ), separator and the mini electrochemical cell with electrolyte, which was attached to the crack of the base metal and welded joints [Patent no. P.394421 of 2011]*

Passive state, protection (meaning there are no corrosion processes) ensures the continuity and integrity of amorphous boehmite adhesion to the substrate alloy. Insulating properties of the brittle layer prevent the flow of corrosion current (state 0) at fixed values of $E_{st}$ according to the diagram shown in Fig.2a. Properties of the passive layer and of porous hydrargilite giving information on the risks of corrosion in the laboratory conditions are determined by EIS, and are described by the electrochemical parameters of the oxide layer determined based on the equivalent circuit shown in Fig.2b.

a)




b)




Equivalent circuit for aluminum passive layer:
$R_1$ – electrolyte resistance,
$C_1$ – capacitance of the passive layer,
$R_2$ – coupled resistance of the passive layer and the charge transfer reaction,
$R_3$ – adsorption resistance,
$C_2$ – negative capacitance.

*Fig.2. Electrochemical parameters of passive oxide film naturally or artificially (polarization in acid) formed on the surface of the alloy determined by EIS or DEIS: a) schematic diagram of the flow of corrosion current b) equivalent circuit of passive oxide layer*

Intact (without load) passive oxide film as the dielectric isolates the aluminum substrate from oxygen and the flow of corrosion current (transition of metal cation Me + to the electrolyte - which is sea water or the atmosphere - Cl-anion to the metal surface) and its further oxidation

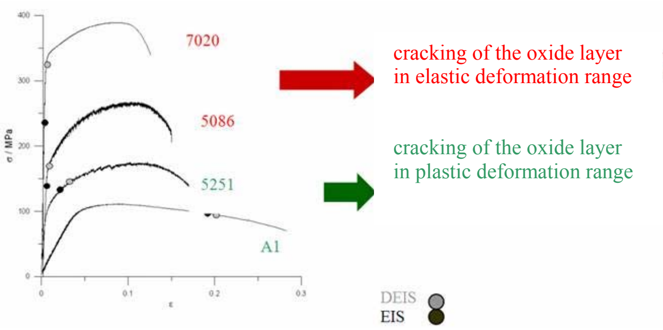



*Fig.3. Mechanical properties of ships aluminum alloys, inclusive of their level of stress cracking of the oxide layer as determined by the DEIS and EIS (owner of DEIS method is Gdansk University of Technology, Chemical Faculty) compared to the properties of pure aluminum [9,10]*

Fig.3. shows the results of electrochemical studies of slow strain rate test of ship aluminum alloys. Stress level at which the oxide film rupture occurs and the process of corrosion initiates were determined.

If the rupture takes place in the elastic range (operating range), the "lifetime" of the structure is shorter. As it can be seen the problem concerns high-strength alloys (7020), which means that the aforementioned superstructure should be monitored in terms of stress level and additionally protected with coating systems.

## CONCLUSIONS

1. Modification with Cr and Zn of the alloy 7020 for Zn+Mg>7% (7020M) resulted in an increase in stress properties and comparable corrosion resistance.
2. Better corrosion resistance is revealed by 5xxx series alloys as compared to 7xxx alloys, but they possess inferior stress properties.
3. Corrosion resistance of 7xxx series alloy can be improved using selected heat treatment T622 (artificially aged after saturation), in which cooling after saturation was accomplished in hot water (80°C).
4. For investigated alloys the additional anticorrosion protection measures have to be applied.

## SUMMARY

It is possible not only to increase the life of technical object but also to keep humans and environment safe throughout proper corrosion protection and monitoring corrosion processes. The development of anti-corrosion techniques and training of specialists are the basic requirements in safe exploiting of technical objects made of latest engineering materials. The sea environment has particularly aggressive corrosion properties. The sea imposes and requires implementing modern anti-corrosion protection from engineers and ship technologists which may make the work on a sea much safer.

**REFERENCES**

[1] http://www.corrosioncost.com
[2] Sokólski W.: *Współczesne problemy ochrony przeciwkorozyjnej konstrukcji*. Materiały szkoleniowe. Gdańsk 2005
[3] Schlichter D.: *The importance of dissolved organic compounds in sea water for the nutrition of Anemonia sulcata (Pennant)*, Proc. 9th Europ. Mar. Biol. Symp. 395 , 1975
[4] Jurczak W., Arutunow A: *Long-term researches of stress corrosion cracking of Al-Zn-Mg alloys Surface Engineering 2A'* Vol. I s. 127-134, 2005
[5] Cudny K., Puchaczewski N.: *Stale i stopy aluminium w budownictwie okrętowym*. PWN 1995
[6] Jurczak W.: *Wpływ składu chemicznego i obróbki cieplnej na własności mechaniczne i odporność korozyjną stopów układu Al-Zn-Mg przeznaczonych na spawane konstrukcje okrętowe*". PG, Wydział Oceanotechniki i Okrętownictwa, Gdańsk, 1997
[7] Davis J. R.: *Aluminum and aluminum alloys*. Ohio 2004
[8] Kyzioł L.: *Wpływ obróbki cieplnej i składu chemicznego na odporność na korozje naprężeniową i zmęczeniowo korozyjną stopów AlMg6 i AlZn5Mg2CrZr*. AMW 1995
[9] Jurczak W.: *Maritime methods of anticorrosive protection with use of aluminum and its alloys*. Polish Journal of Environmental Studies, vol.16 no.3C, pp.34-43, 2005
[10] K. Darowicki, J. Orlikowski, A. Arutunow, W. Jurczak.: *The comparative electrochemical analysis of the passive layer cracking process on aluminium alloys performed by means of dc and ac techniques*. Journal of Electrochemical Society, 2006
[11] K. Darowicki, J. Orlikowski, A. Arutunow, W. Jurczak.: *The effect of tensile stresses on aluminum passive layer durability*. Electrochimica Acta, 2007

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# MEASUREMENT AND EVALUATION OF MECHANICAL VIBRATION OF RECIPROCATING MACHINES

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Summary

Mechanical vibration is used in condition monitoring and diagnostics of machines. Measurement and evaluation of vibration depends on machine type and machine part. ISO standards describe evaluation of machine vibration by measurements on non-rotating parts and on rotating shafts of non-reciprocating machines. For condition monitoring and diagnostic purposes measurements and evaluation of rotating shafts vibration of reciprocating machines have to be carried out. This paper describes: types of rotating shaft vibration of reciprocating machine; longitudinal vibration and torsional vibration of crankshaft as diagnostic signal; measurement of displacement axial (longitudinal) vibration of crankshaft free end; measurement of acceleration axial vibration of crankshaft free end; measurement of acceleration torsional vibration (angular acceleration) of crankshaft free end; evaluation of torsional and axial vibration of crankshaft free end. Courses of angular accelerations, axial displacement and axial acceleration of crankshaft free end will be presented and discussed.

Key words: reciprocating machines, rotating shafts vibration, longitudinal vibration, torsional vibration.

POMIARY I OCENA DRGAŃ MECHANICZNYCH MASZYN TŁOKOWYCH

Streszczenie

Drgania mechaniczne elementów są wykorzystywane w dozorowaniu i diagnozowaniu maszyn. Pomiary i ocena drgań zależą od typu maszyny i części maszyny. Normy ISO opisują ocenę drgań mierzonych na niewirujących elementach maszyn i drgań mierzonych na wirujących wałach maszyn nie będących maszynami tłokowymi. Celem rozwoju dozorowania i diagnozowania maszyn tłokowych dokonano pomiarów i oceny drgań wirującego wału korbowego maszyny tłokowej. W artykule przedstawiono: rodzaje drgań wirujących wałów maszyn tłokowych; drgania wzdłużne i skrętne wału korbowego jako sygnały diagnostyczne; pomiary drogi drgań wzdłużnych wolnego końca wału korbowego; pomiary przyspieszenia drgań wzdłużnych wolnego końca wału; pomiary przyspieszenia drgań skrętnych (przyspieszenia kątowego) wolnego końca wału; ocenę drgań skrętnych i wzdłużnych wolnego końca wału. Zaprezentowano i przeanalizowano przebiegi drgań wzdłużnych i skrętnych wolnego końca wału.

Słowa kluczowe: maszyny tłokowe, drgania wirującego wału, drgania wzdłużne, drgania skrętne.

## INTRODUCTION

Compared to rotor machines, reciprocating machines are of more complex construction, as they have gear changing the reciprocating motion into the rotating motion of the crankshaft. A fault of one element of the piston-crank unit makes the whole machine faulty. Such faults often result in machine failure.

Machine failures and component faults are prevented by condition monitoring and diagnosing of machines, where vibration signals are important signals appropriately utilized. The methodology of condition monitoring and diagnostics is subject to standardization – international ISO standards have been and are being developed, and on their basis national ISO-compliant standards are established.

This article analyzes published international standards in view of their use in condition monitoring and diagnostics of reciprocating machines. Possibilities of developing methods for diagnosing these machines are indicated.

## 1. CONDITION MONITORING AND DIAGNOSING OF MACHINES IN THE LIGHT OF ISO STANDARDS

In [22] Kolerus overviews the up-to-date standards relating to vibration diagnostics of machines. The relevant standards are divided into those related to condition monitoring during machine operation and standards oriented towards diagnosing. It follows from the grouped standards that monitoring-directed standards are those object-oriented.

There are separate standards for reciprocating and non-reciprocating machines as objects of diagnostics. For the two types of machines standards are specified for measurements of mechanical vibration on non-rotating parts and on rotating shafts. Due to the reference point, measured vibration is divided into vibration measured without a fixed reference point (absolute vibration) and vibration measured in relation to a specific reference point (relative vibration).

The standard ISO 10816 Part 1–7 refers to the evaluation of vibration measured on reciprocating and non-reciprocating machines. The evaluation of vibration measured on non-rotating parts depends on the machine type, use, dimensions and operating conditions [2, 3, 4, 5, 6, 7, 8, 19, 20]. Evaluation refers to absolute vibration values measured in places specified by the relevant standard. The RMS value of vibration is measured in this case.

Standards ISO 7919 Part 1–5 refer to the evaluation of vibration measured on rotating parts of non-reciprocating machines [11, 12, 13, 16, 18]. Shaft lateral vibration is evaluated by measurements in defined points: at bearings or in their direct vicinity. The standard determines the method of measurement of absolute and relative vibration.

The standard ISO 22266-1 refers to the evaluation of vibration measured on rotating parts of some turbines operating in specified conditions. Torsional vibration is evaluated [12].

## 2. VIBRATION OF ROTORS

Rotating elements are termed "rotors" [11, 21]. Rotors are modeled by replacing masses and elasticity of the rotor with masses in the form of disks with equivalent masses connected by massless springs or massless shafts with equivalent rigidity. Such models have vibration nodes and arrows. The number of nodes is related to the frequency of rotor free vibration. In vibration nodes the material stresses reach maximum values and vibration amplitudes of a given form equal zero. In the arrows vibration amplitudes reach maximum values and the stress equals zero. Rotors can have lateral, torsional and longitudinal vibration. Stresses caused by vibration add up with working stresses and may lead to material damage of the rotor shaft. In many machines rotor vibration has to be monitored.

The standard ISO 7919 describes measurement of lateral vibration. Longitudinal vibration can be measured, similarly to lateral vibration, by non-contact eddy current sensors. In the case of non-reciprocating machines longitudinal vibration is negligibly small. Torsional vibration of rotors in operation observed outside vibration nodes causes changes in rotor angular velocity in a given plane of observation. Measures of torsional vibration can be as follows: stresses at the nodes, deformation of a shaft section, changes in angular velocity of the shaft. The results depend on the position of the measurement plane / section on the rotor shaft axis.

"In general torsional vibration is more difficult to measure than lateral vibration. Torsional response – both strains and motions – can be measured at intermediate points in a system. Strain gauges are available in a variety of sizes and sensitivities and can be placed almost anywhere on a shaft. They can be calibrated to indicate instantaneous torque by using static torque loads on drive shafts. If calibration is not possible, stresses and torques can be calculated from strength of materials theory. Strain gauges are usually mounted at 45° angles so that shaft bending does not influence torque measurements. The signal must be processed by a bridge-amplifier unit that can be arranged to compensate for temperature. Because strain gauge signals are difficult to take from a rotating shaft, such techniques are not common diagnostic tools. Slip rings can be used to obtain a vibration signal from a shaft. Wireless telemetry is also available. A small transmitter mounted on the rotating shaft at a convenient location broadcasts a signal to a nearby receiver. Commercial torque transducers are available for torsional measurement. However, they must be inserted in the drive line and thus may change the dynamic characteristics of the system. If the natural frequency of the system is changed, the vibration response will not accurately reflect the properties of the system" [3].

"The general method of determining the rotational speed is to use some form of tachometer or shaft encoder. Common ways to measure torsional vibration angular velocity oscillations are by means of toothed wheels or gears and magnetic pickups (a fixed sensor). "The signal generated by the teeth of the wheel passing the fixed sensor has a frequency equal to the number of teeth multiplied by shaft speed. If the shaft is undergoing torsional vibration, the carrier frequency will exhibit frequency modulation (change in frequency) because the time required for each tooth to pass the fixed pickup varies. This is a very rugged and reliable measurement approach and is suitable for long-term monitoring of turbomachinery when required. Other approaches involve optical methods using grids or stripes on the shaft as the target. Sometimes the stripes or grid patterns are etched on a tape that is stuck to the shaft. In such cases care must be exercised to ensure that there is no large optical discontinuity where the ends of the tape butt together. Optical methods involving lasers and the Doppler principle are sometimes used as well" [3].

## 3. VIBRATION OF RECIPROCATING MACHINE ROTORS

Rotors of most reciprocating machines consist of pistons, connecting rods and a crankshaft. Crankshafts are capable of producing significantly large lateral, torsional and longitudinal vibration.

Evaluation of that vibration has not been standardized. The difficulties lie in a multitude of types and models of reciprocating machines and inter-relations between various types of vibration. Some authors indicate coupled torsional and longitudinal vibration of the crankshaft.

Rotors of reciprocating machines are modeled similarly to those of rotating machines. Contrary to rotor machines, mass moments of inertia of the model disks are not constant, but depend on the rotation angle of the crankshaft. Angular velocity as a function of rotation angle is not constant – in other words the machine does not run uniformly. A major difficulty is that the journal axes during vibration do not remain parallel to the axes of the supporting sleeves.

The place and method for measurements of rotor vibration in reciprocating machines depend on the purpose of the tests. It follows from [2] that the crankshaft free end is a convenient location of measurement, and that lateral and longitudinal vibration is useful for diagnostic purposes.

At the crankshaft free end the most significant forms of all types of vibration achieve maximum values. While a crankshaft rotates, the centre of the free end journal does not overlap with the rotating axis. The free end journal centre moves along a roughly elliptical trajectory. The free end normally does not stand out of the bearing supporting the last main journal, but it can be prolonged and brought outside the machine.

Measurements of axial vibration of the crankshaft free end, like lateral vibration [13], can be performed as contact (absolute vibration) or non-contact (relative vibration) measurements. In both cases the sensor axis should be co-axial with the shaft journal axis, the front plane of the journal cannot have shape errors and must be perpendicular to the axis. In non-contact measurements, e.g. by eddy current sensors aligned with the shaft journal, the effect of non-perpendicularity of the shaft end front can be negligibly small. Deflection of a crankshaft, typical of operating reciprocating machines, causes the position of journal axis to change. For this reason sensors of longitudinal vibration of reciprocating machines have to set themselves co-axially in relation to the shaft or compensate for the existing misalignment. The first scenario is realistic for contact sensors, that touch the journal front through a slide plate. Then the problem to be solved is to properly press the sensor to the journal and provide for appropriate conditions for the plate to slide on the shaft front end. The effect of this method may be additional casual vibration. The other scenario is real for non-contact measurements by using a pair of sensors set so that shape and position errors will produce signals of the same values and opposite signs in each sensor.

Practically, the only accessible place on a crankshaft suitable for measurements of torsional vibration (without disturbing the machine integrity) is its free end. Torsional vibration measurements in this place started as long ago as 1912 when the Sulzer company introduced a torsiograph, later named Geiger torsiograph after Dr Josef Geiger. A detailed description of torsiograph can be found in J. Geiger's: *Der Torsiograph, ein neues Instrument zur Untersuchung von Wellen. ZVDI 60 (1916) 40 und 42* [22]. The Geiger torsiograph works according to the principle of seismic mass (like contact transducers of absolute vibration velocity and accelerations). The characteristic feature of this type of torsiograph is that inside a drum directly mounted on the free end or a drum driven by a belt transmission there is a mass with high moment of inertia elastically coupled with the drum. The drum generates vibration similar to that of the free end, while the mass, due to the large mass moment of inertia, rotates inside the drum at a constant angular velocity. The relative motion between the drum and mass is measured: the angle of torsional vibration. Torsiographs mounted directly on the shaft free end require an expanded system of signal transmission to peripheral devices.

The transducer that could perform non-contact measurements of torsional vibration accelerations seems to be the one working on the Ferrari principle [1]. In this case, however, the problem lies in undesired relative motions occurring in the machine between the measuring disk mounted on the shaft and the transducer mounted on the machine body. These motions generate measurement errors and can even lead to transducer damage, due to a little width of measuring gap.

## 4. TESTING OF ROTOR VIBRATION OF RECIPROCATING MACHINES

Tests were made to examine how axial run-out of the measuring disk mounted on a dual mass rotor influences transducer angular accelerations. The transducer and the run-out sensor were mounted on the rotor machine body. Tests were carried out for a constant rotating speed, far from the resonance speed of rotor vibration. The values of measuring disk deviations and the corresponding angular accelerations are shown in Fig. 1.

Torsional and longitudinal vibration of a single-crank, three cylinder air compressor were evaluated at its small load. The compressor only discharged air through a pipeline fitted with an oil separator, cooler, filter and silencer. Torsional vibration was tested by means of a non-contact angular acceleration transducer, while longitudinal vibration by means of a non-contact distance sensor and a contact linear acceleration transducer.

The angular acceleration transducer was mounted on the shaft in relation to the compressor body in such a way that the transducer could follow all motions of the shaft except rotation. The measuring disk run-out against the transducer was measured as well as the run-out of the free end against the compressor body. The axial run-out of the measuring disk (close to the disk edge) relative to the transducer was 0.12 mm. The radial run-out of the shaft free end relative to the compressor body was: vertically – 0.92 mm, horizontally – 0.38 mm.

immovable in relation to the compressor body. A synchronically averaged course of longitudinal vibration distance is shown in Fig. 3.

A piezoelectric linear vibration acceleration transducer was aligned with the shaft free end axis

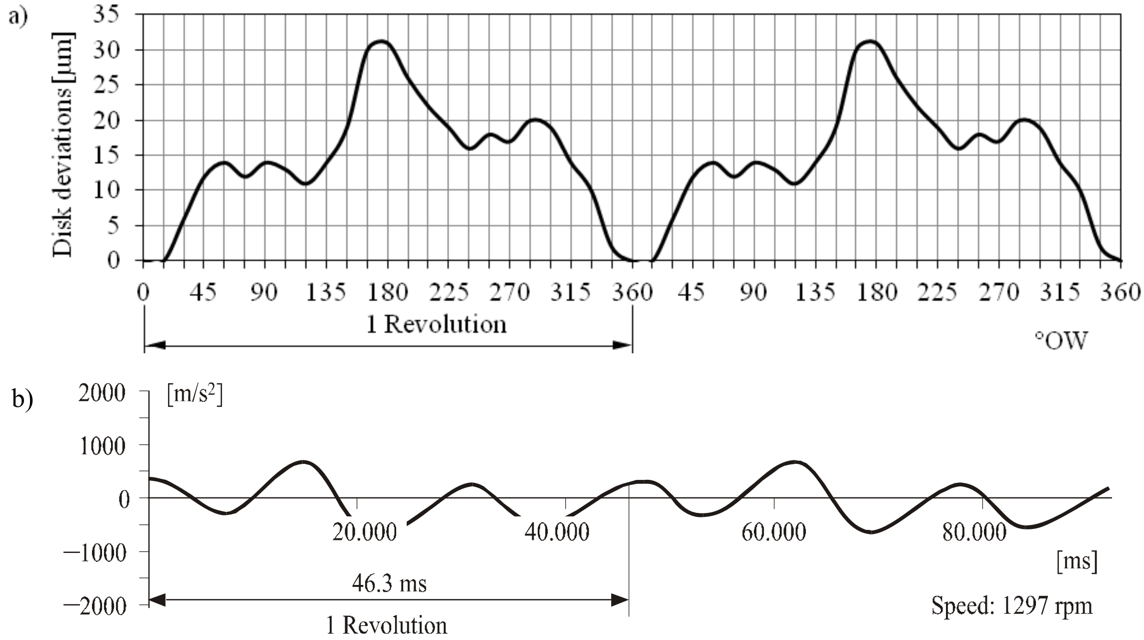


*Fig. 1. Values of measuring disk deviations (a) and the corresponding angular accelerations (b)*

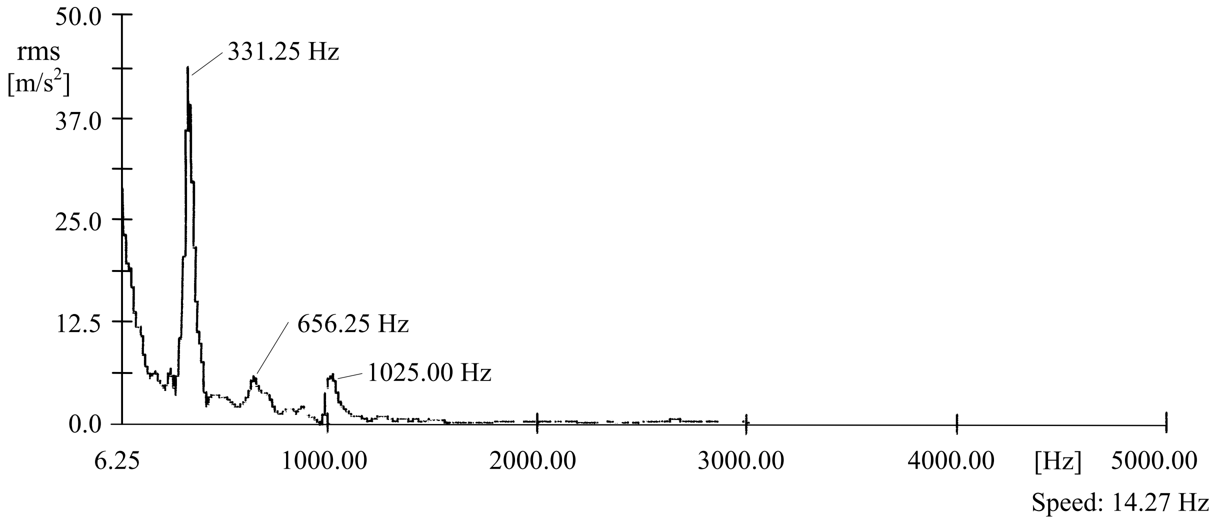


*Fig. 2. Spectra of torsional vibration: 0–5000 Hz and 0–100 Hz*

It can be assumed that there were two causes of shaft run-out: free end journal shape deviations and shaft deformations (deflection) caused by the weight of the compressor flywheel and the tension force of compressor drive vee-belts. In the torsional vibration measurements the data were synchronically averaged in the time and frequency domains. Spectra of torsional vibration are shown in Fig. 2. The timing of vibration and the course of position marker for cylinder No. 2 with the piston in the top dead centre are given in Fig. 3.

An eddy current sensor of longitudinal vibration distance was placed on the free end journal axis, and pressed through a carbon plate to the shaft front. The transducer handle, flexibly pressing the transducer to the shaft front, was rigidly attached to the compressor body. A synchronically averaged course of longitudinal vibration accelerations is shown in Fig. 3.

A significant influence of vibration from other sources on the measured vibration, torsional vibration in particular, was observed during the tests. Besides, it was noticed that the way the acceleration transducer is pressed to the shaft front is also important.

## 5. SUMMARY

There are no standards for the evaluation of rotor vibration of reciprocating machines. The establishment of such standards may significantly assist in condition monitoring and diagnostics of reciprocating machines.

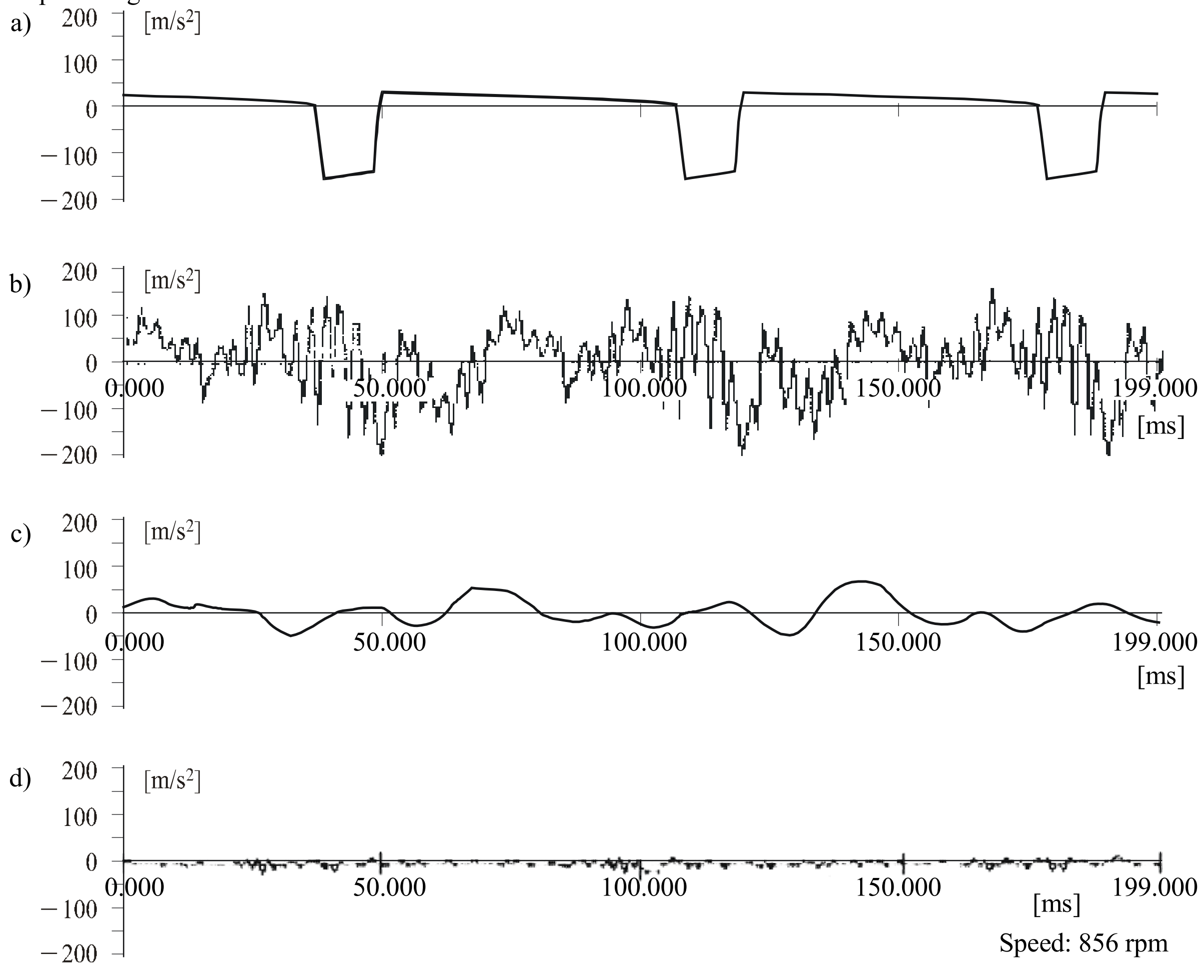


*Fig. 3. The timing of vibration: a) the course of position marker for cylinder No. 2 with the piston the top dead centre, b) a synchronically averaged course of torsional vibration accelerations, c) a synchronically averaged course of longitudinal vibration distance, d) a synchronically averaged course of longitudinal vibration accelerations*

Acceleration transducers working on the Ferrari principle are also sensitive to the motion transverse to the principal rotating motion of the measuring disk. Transverse motion may be caused by lateral and longitudinal vibration and by deviations of shape and position of the measuring disk and rotor shaft. One can see from Fig. 1 that the impact of measuring disk axial run-out on angular accelerations is unique and measurable.

It is possible to measure torsional vibration accelerations of reciprocating machines using a non-contact acceleration transducer. The torsional vibration spectrum from Fig. 2 is a spectrum typical of reciprocating machines. It consists of two parts:

– high frequency range dependent on the frequency value of rotor free vibration and the number of torsional vibration forms,
– low frequency range connected with non-uniform run (varying rpm) for this type of machines.

The timings of torsional vibration are correlated with those of longitudinal vibration, Fig. 3.

There are no difficulties to perform non-contact measurement of longitudinal vibration distance of the shaft free end. The course of this distance, presented in Fig. 3, satisfies the expectations, although it contains components resulting from the shaft front axial run-out and shaft lateral vibration. The measurement method has to be properly modified.

Contact measurement of longitudinal vibration accelerations of reciprocating machine rotors is difficult due to the shaft free end run-out and rotor lateral vibration. An additional problem to be solved is accurate transmission of vibration from the shaft onto the transducer via a slide plate. It follows from Fig. 3 that despite a high level of disturbances, the acceleration signal appears at places typical of these machines and after an improvement of the measuring method it can be useful in condition monitoring and diagnostics.

**REFERENCES**

[1] Bielawski P.: *Diagnozowanie mechanizmów tłokowo-korbowych agregatów: sygnały i problemy pomiarowe*. Pomiary Automatyka Kontrola, 2005, No. 9 bis, pp. 236-238.
[2] Bielawski P.: *Elementy diagnostyki mechanizmów tłokowo-korbowych maszyn okrętowych*. Studia No. 39, WSM, Szczecin, 2002.
[3] Eshleman R.L.: *Machinery vibration analysis II*. Vibration Institute, 1996.
[4] ISO 10816-1:1995 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 1: General guidelines.*
[5] ISO 10816-2:2009 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 rpm, 1800 rpm, 3000 rpm and 3600 rpm.*
[6] ISO 10816-3:2009 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 rpm and 15 000 rpm when measured in situ.*
[7] ISO 10816-4:2009 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 4: Gas turbine sets with fluid-film bearings.*
[8] ISO 10816-5:2000 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 5: Machine sets in hydraulic power generating and pumping plants.*
[9] ISO 10816-6:1995 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 6: Reciprocating machines with power ratings above 100 kW.*
[10] ISO 10816-7:2009 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 7: Rotodynamic pumps for industrial applications, including measurements on rotating shafts*.
[11] ISO 1940-1:2003 *Mechanical vibration. Balance quality requirements for rotors un a constant (rigid) state. Part 1: Specification and verification of balance tolerances*.
[12] ISO 22266-1:2009 *Mechanical vibration. Torsional vibration of rotating machinery. Part 1: Land-based steam and gas turbine generator sets in excess of 50 MW.*
[13] ISO 7919-1:1996 *Mechanical vibration of non-reciprocating machines. Measurements on rotating shafts and evaluation criteria. Part 1: General guidelines*.
[14] ISO 7919-2:2009 *Mechanical vibration. Evaluation of machine vibration by measurements on rotating shafts. Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 rpm, 1800 rpm, 3000 rpm and 3600 rpm.*
[15] ISO 7919-3:2009 *Mechanical vibration. Evaluation of machine vibration by measurements on rotating shafts. Part 3: Coupled industrial machines*.
[16] ISO 7919-4:2009 *Mechanical vibration. Evaluation of machine vibration by measurements on rotating shafts. Part 4: Gas turbine sets with fluid-film bearings.*
[17] ISO 7919-5:2005 *Mechanical vibration. Evaluation of machine vibration by measurements on rotating shafts. Part 5: Machine sets in hydraulic power generating and pumping plants.*
[18] ISO 8528-9:1995 *Reciprocating internal combustion engine driven alternating current generating sets. Part 9: Measurement and evaluation of mechanical vibrations*.
[19] ISO/CD 10816-8 *Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Part 8: Reciprocating compressor systems*.
[20] Kolerus J.: *Aktueller Stand und Tendenzen der nationalen und internationalen Normung für die Schwingungsüberwachung von Kraftwerksturbosätzen*. Symposium zur schwingungsdiagnostischen Überwachung von Kraftwerksturbosätzen, Potsdam, 22–24 März 2006.
[21] PN-93/N-01359 *Drgania mechaniczne. Wyważanie wirników sztywnych. Wyznaczanie dopuszczalnego niewyważenia resztkowego.*
[22] Zima S.: *Kurbeltriebe*. Vieweg Verlag, Wiesbaden, 1999.

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# THE ESTIMATION OF THE CAUSE OF THE MACHINES DAMAGES

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Summary

In this paper we introduce problem of determining algorithms for state genesis which is the basis for rules creating of machine state estimation in the past.

Keywords: machine state genesis, procedure algorithmization, conclusion rules.

SZACOWANIE PRZYCZYNY USZKODZENIA MASZYN

Streszczenie

W artykule przedstawiono problemy związane z określeniem algorytmów genezowania stanu, które są podstawą do wyznaczania reguł wnioskowania dla oszacowania stanu maszyny w przeszłości.

Słowa kluczowe: genezowanie stanu maszyn, algorytmizacja procedur, reguły wnioskowania.

## 1. PROBLEM CHARACTERISTICS

Usage in exploitation process of machine condition genesis methods, being the basis of state recognition process automatization, requires among others the optimization of diagnostic parameters set and genesis methods. The solution of these problems depends on many factors connected with the level of machine complexity, using multi-symptom observations, the quality of exploitation process, and wear process.

Machine state genesis is a process which enable to foreseeing the machine's state in the past, basis on an incomplete history of diagnostic researches results. It enables to estimate the machine's state in the past or to determine the cause of machine's disability determined at the moment of examination. In the state genesis process, very important problem is to choice:

a) diagnostic parameters set in relation to the machine's working time, value of time step, and the size of an optimal set of diagnostic parameters;
b) genesis method in relation to the genesis horizon, minimum number of elements of the time row indispensable for running the genesis, and the machine's working time.

The problem of examining the above problems in the process of machines condition genesis, examining dynamics of their constructions, high requirements set by users, as well as effective legal acts concerning users' safety and environmental protection, are an impulse for searching new diagnosis methods and determining new measures and tools describing their current diagnostic states in the process of their exploitation, which are presented below as proper procedures and algorithms of condition genesis, and stemming from them conclusion rules.

## 2. OPTIMIZATION PROCEDURE FOR DIAGNOSTIC PARAMETERS SET

Set of diagnostic parameters is distinguished from the set of output parameters. Basis on researches results,, aiming at confirming some suggestions included in works concerning diagnostic information reduction in prognosis process, it is considered that the determination of diagnostic parameters set in prognosis process should include:

a) ability to reflect the machine state changes in exploitation time;
b) quantity of information on the machine's state;
c) relevant changeability of diagnostic parameters values in the time of machine's exploitation.

The postulates above can be presented as methods. These are: the correlation method of diagnostic parameters values with the machines state, and the method of informational capacity of a diagnostic parameter. An advantage of these methods is that they allow to choose single-element and multi-element sets of diagnostic parameters from the set of output parameters. A single-element set refers case, when the machine is decomposed into units and it is necessary to choose one diagnostic parameter. A multi-element set is obtained when in presented procedures less strict limitation is used consisting in qualifying into the diagnostic parameters set those parameters whose indicator values are higher (lower) than accepted, respectively for the method, small (large) positive numbers.

The estimation methodology algorithm of the optimal machines diagnostic parameters set consists stages:

1. Data acquisition:
   a) the set of diagnostic parameters in the function of machine exploitation time $\{y_j(\Theta_k)\}$, obtained in the time of passive-active experiment performance, where $\Theta_k \in (\Theta_1, \Theta_b)$;
   b) the set of diagnostic parameters values: $\{y_j(\Theta_1)\}$ – nominal values, $\{y_{jg}\}$ – boundary values, j=1, …, m;
   c) the set of machine states $\{\Theta_k: \{s_i\}, k=1, …, K; i=1,…, I\}$ obtained during the realization of the passive-active experiment, where $\Theta_k \in (\Theta_1, \Theta_b)$;
2. Optimization of diagnostic parameters set values (only in case of a large size of the set Y, e.g. m>10). The set of diagnostic parameters is estimated with the help of:
   a) correlation method of machine's state diagnostic parameters (exploitation time, $r_j = r(W, y_j)$, ($r_j = r((\Theta, y_j)$);
   b) method of machine's state diagnostic parameters information quantity $h_j$.

As the result of output parameters set optimization, in order to choose a diagnostic parameters set, the weight values are obtained:
   a) calculation weights $w_{1j}$;
   b) as the criterion for choosing a diagnostic parameter (diagnostic parameters), the maximization of weight values $w_{1j}$ was accepted, and choosing diagnostic parameters according to the above criterion.
   c) in order to consider the user's preferences, it is possible for him/her to insert weights $w_2$ (standardized values) from the range (0,1), and choosing diagnostic parameters according to the above criterion.

## 3. THE PROCEDURE OF MACHINE STATE GENESIS

Problems appearing during the machine's technical state genesis process come down to:

1. The analysis of being the subject machine genesis, i.e. the process of its technical state deterioration, the determination of dynamics tendencies of state parameters changes, the selection of states in which the machine could be, the machine's decomposition into units and systems, the criteria of state selection and the probability of their occurrence, the selection of "the best" diagnostic parameters describing the machine's state change.
2. The selection of "the best" method of state genesis determination.
3. The use of information $I_G$, acquired from the state genesis for the analysis of the present state cause of the machine at the moment of machine examination.

The machine's technical state genesis should consist in the determination (with complete and incomplete data) of diagnostic parameters trend of values changes, characterizing the process of the machine's technical state deterioration in the past, comparing instantaneous values of diagnostic parameters to boundary values and on this basis estimating the time of reliable work of the machine's systems and units in interesting for the user past time of the machine's exploitation, or the analysis of the cause of the located at the moment of examining damage.

The solution of the presented postulate can be presented by the following algorithm:

1. Let the phenomenon of technical state deterioration be presented by the time row $y_t = <y_1, y_2, ..., y_b>$, then it is the set of discrete observations $\{y_\Theta = \zeta(\Theta);\ \Theta = \Theta_1, \Theta_2,..., \Theta_b\}$ of a certain non-stationary stochastic process $\zeta(t)$.
2. With the assumption that the mechanism of stochastic process values changes in time $\Theta \in (\Theta_1, \Theta_b)$ is determined by the trend $\mu(\Theta)$ interfered by random reactions $\eta(\Theta)$

$$y_\Theta = \mu(\Theta) + \eta(\Theta)\,, \qquad (1)$$

where:

$\mu(\Theta)$ – characterizes a determined component of the time row $y_\Theta$, it describes the development tendency of the observed diagnostic parameter $y(\Theta)$,

$\eta(\Theta)$ – characterizes the aberrations from the trend and expresses the effect of random factors (terrain conditions, climate conditions, operation quality).

Such estimation $\{\mu_p(\Theta)\}$ is constructed for an unknown form of the trend $\mu(\Theta)$ which would assure proper accuracy of the genesis $y_G(\Theta)$ with the interpolation (or approximation) $\mu_G(\Theta)$ on a period of the machine's work $(\Theta_b, \Theta_G)$, $\Theta_G = \Theta_b - \tau_2$.

3. Estimating $\mu_G(\Theta)$ also determines values of the observed diagnostic parameters at the moment $\Theta_G$, and thus enables the genesis of the machine's technical state $W(\Theta_G)$.
4. As the acceptable machine's exploitation state $W_{dop}$ in the time range $(\Theta_b, \Theta_G)$ the value of time is accepted, for which the boundaries of the mistake range for separate geneses $\sigma(y_t, y_G, G(y_\Theta,\tau))$ determined on the subset $\Omega^y \in \Omega$ of available realizations of the observed parameters $\{y_j(\Theta)\}$ and their geneses $\{y_{j,G}\}$ according to the accepted genesis method $G(y_\Theta,\tau)$ did not exceed with the radius of the mistake range $r_G$ the boundary values $\{y_{j,g}\}$.

$$r_G = q\sigma_{G,} \qquad (2)$$

where:

$q_{\gamma,K}$ - the constant parameter estimated from the Student decomposition table for the required trust level $\gamma$ and $K$-2 of the number of degrees of freedom,

$\sigma_G$ - standard aberration of the random component of genesis mistake $e_G$

5. In case when system operation dependent on the technical state, the required form of the machine's state genesis is the information about the time ($\Theta_1$, $\Theta_b$) the technical state was in accepted state $W_{dop}$ (on this basis the machine's state in the past can be estimated). It is also proposed that the additional values of GST (machine's state genesis) are the radius of genesis mistake range $r_G$ (Fig. 1):

$$GST = < W_{dop}, r_G > \tag{3}$$

The time range ($\Theta_1$, $\Theta_b$) is then the estimation period of the genesis mistake expected value $e_G$ and the radius of the genesis mistake range $r_{\sigma G}$, and the time period $\Theta_b$ - $\tau_2$ will be the period of the active genesis, i.e. the estimation of:

a) the genesis value of the diagnostic parameter for the genesis horizon time $\tau_2$, $y_{jG}(\Theta_b-\tau_2)$;
b) the estimation of the range radius of the genesis mistake $r_G(\Theta_b - \tau_2)$;
c) the estimation of potential times $\{\Theta_{Gi}\}$ of the machine's entering the disability state.

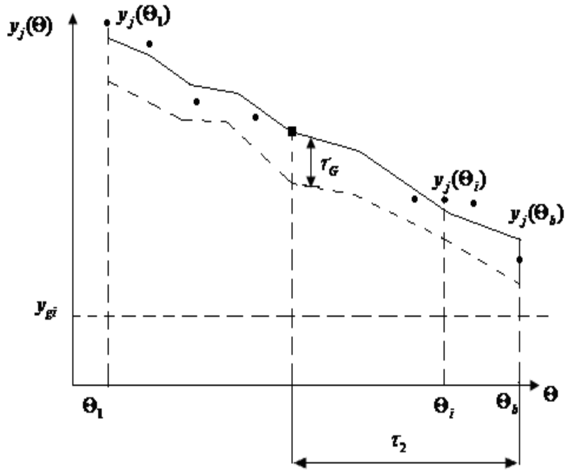


*Fig. 1. Scheme of estimating the genesis diagnostic parameter value*

Taking up considerations of machine state genesis [1,2,3,4,5,6,7,8,11,12], it is impossible to indicate the advantage of some genesis methods enabling the genesis of diagnostic parameters values and the estimation of machine technical state $S(\Theta_1,\Theta_b)$. It is, however, possible to apply some criteria concerning the requirement connected with:

a) genesis form (genesis value of a diagnostic parameter, estimated machine's state in the past, the value of the work done by it in the past, or another form of machine state genesis);
b) the changes influence on machine's exploitation and maintenance actions conditions over the machine's exploitation characteristics, which should be considered while choosing the genesis method;
c) possible to use genesis methods (e.g. quality methods, modified exploitation methods of trend, and modified adaptation methods).

Among the small number of methods enabling machine state genesis, two groups can be distinguished: quality methods (*situational genesis*, basis on the registered symptoms; *expert genesis* basis on the information collected from the environment) and analytical methods (approximation and interpolation methods) [2,3,4,6,7,8].

**Situational genesis**

In case of situational genesis, the cause of the disability is estimated basis on the visual inspection of the machine performed directly after the state's occurrence. Collected information's (situational data) are used to compare with situational data being the result of modeling of some damages. Then, data correspondent to the input situational data are searched. During modeling of a certain event, the cause is known for which the machine's disability occurred, and at the moment of damage, created in his way situational data is collected in order to create a base correspondent to some, often typical, damages. This procedure can be used at the estimation of the occurred machine's disability state through the comparison of the collected data with the situational data respective to specific events (also with the use of the user's knowledge), which enables the determination of a probable cause of the damage occurrence.

**Genesis basis on the information acquired from the environment**

The method consists in determining the causes of the occurred machine state basis on the information collected from witnesses relations of a certain event. For example, in car accident, it is possible to determine the cause of the accident basis on the of witnesses' relations. Another case can be the information given by the machine's operator who can provide very important data on the machine's behavior before the event. In industry, industrial cameras are often used, which can help in determining the cause of the occurred disability.

**Genesis basis on the registered values of diagnostic parameters**

Assuming the possibility of registering diagnostic parameters values and the machine's states in the time of its exploitation (e.g. in the time of passive–active experiment), a data base is obtained in the form of information matrix: diagnostic parameters values – machine state – exploitation time. At the moment of the machine's ability loss, there will probably be the possibility to determine, on the basis of the collected information and visual inspection of the machine, what could be the cause of the disability state occurrence.

The above presented machine state genesis methods, their synergy and the user's experience, ought to allow the creation of appropriate procedures whose realization ought to enable the machine's state genesis.The presented methods analysis of diagnostic parameters estimation genesis value, and correspondent to them genesis mistakes, allows to state that in order to estimate the diagnostic parameters genesis value on the basis of their uncertain and incomplete values from the time range $(\Theta_1, \Theta_b)$, it is necessary to use:

1. Within the range of approximation methods:
   a) multinomial point mean-square approximation with the radius of genesis mistake range $r_{ja}$:
   $$r_{ja} = e_{Gj} = \max_{k=1,K} B = \left| y_{j,a}(\Theta_k) - y_j(\Theta_k) \right| \quad (4)$$
   b) trigonometric approximation with the radius of genesis mistake range $r_{ja}$ :
   $$r_{ja} = e_{Gj} = \max_{k=1,K} B = \left| y_{j,a}(\Theta_k) - y_j(\Theta_k) \right| \quad (5)$$
2. Within the range of interpolation methods:
   a) interpolation with the use of combined functions type 1, 2 and 3 for the time range $(\Theta_1, \Theta_b)$ of the size $r_1$ with the radius of genesis mistake range $r_{j,int}$ [7,9]:
   $$r_{j,int} = e_{Gj} = \max_{k=1,r2} B = \left| y_{j,int}(\Theta_k) - y_j(\Theta_k) \right| \quad (6)$$

The estimation of diagnostic parameters value, with use of above presented genesis methods, allows to determine their genesis values $\{y_{j,int}(\Theta)\}$, which then allows to formulate the below presented algorithm of machine's state genesis.

The algorithm of machine state genesis according to the scheme of estimating diagnostic parameters values includes:

1. The genesis of the diagnostic parameters value set $\{y_j^*\}$:
   a) with use of approximation method of diagnostic parameter value $y_j^*$ in time range $(\Theta_1,\Theta_b)$ with the radius of approximation mistake of the "mistake channel" $r_a$ with methods (mean-square method, trigonometric method);
   b) with use of diagnostic parameter value interpolation $y_j^*$ in the time range $(\Theta_1,\Theta_b)$ with the radius of interpolation mistake of the "mistake channel" $r_{j,int}$ with methods (combined functions type 1, 2 and 3 method);
   c) method selection according to the minimal and maximal value of the radius of the approximation or interpolation mistake (matching mistake $e_G$).
2. The analysis of state occurrence cause $s_i(T_{LU})$:
   a) the presentation of the set $\{s_i(\Theta_k),\ i=1,\ldots, 1;\ k=1, \ldots, K\}$.
   b) the estimation of the common point of the "mistake channel" appointed by the mistake radius $r^*_j = \max(r_{ja}, r_{ji})$ and the boundary value of the diagnostic parameter $y_j^*$ at the moment $\Theta_S \in (\Theta_1,\Theta_b)$, which means that the cause of the located state $s_i$ was a "momentary occurrence" of the state at the time $(\Theta_1,\Theta_b)$;
   c) the estimation of a bigger number of common points of the "mistake channel" appointed by the mistake radius $r_j = \max(r_{j,a}, r_{j,int})$ and the boundary value of the diagnostic parameter $y_j^*$ at the moments $\Theta_s \in (\Theta_1,\Theta_b)$ means that the cause of the located state $s_i$ was the "increasing development" of the state $s_i$ at the time $(\Theta_1,\Theta_b)$
   d) in case of common points lack, the estimation of the minimal distance of the "mistake channel" from the boundary value at the moment $\Theta_S \in (\Theta_1,\Theta_b)$, which means that the probable cause of the located state $s_i$ was a "momentary incomplete appearance" of this state at the time $(\Theta_1,\Theta_b)$;
   e) the analysis of the identity of state sets $\{s_i(\Theta_k),\ k=1, \ldots, K\}$and located by $T_{LU}$ state $s_i$ in order to determine the cause of its occurrence in the context of the obtained potential "common points" or the minimal distance of "approximations".

The presentation of different possibilities to determine the machines' state genesis allows to formulate the following conclusions:

1. All the algorithms allow to estimate the optimal, as far as the accepted criterion is concerned, diagnostic parameters genesis values in the time range $(\Theta_1,\Theta_b)$, whilst for further research it is proposed to:
   a) use approximation methods of the diagnostic parameter value $y_j^*$ (mean-square method, trigonometric method), with the radius of approximation mistake of the "mistake channel" $r_{j,a}$;
   b) use interpolation methods of the diagnostic parameter value $y_j^*$ (combined functions of different types method) with the radius of interpolation mistake of the "mistake channel" $r_{j,int}$;
   c) select the method according to the minimal and maximal value of the radius of the approximation or interpolation mistake (matching mistake).
2. Analysis methods of the state occurrence cause $s_i(T_{LU})$:
   a) the estimation of the common point of the "mistake channel" appointed by the mistake radius $r^*_j = \max(r_{ja}, r_{ji})$ and the boundary value of the diagnostic parameter $y_j^*$ at the moment $\Theta_S \in (\Theta_1,\Theta_b)$, which means that the cause of the located state $s_i$ was a "momentary occurrence" of the state at the time $(\Theta_1,\Theta_b)$;
   b) the estimation of a bigger number of common points of the "mistake channel" appointed by the mistake radius $r^*_j = \max(r_{ja}, r_{ji})$ and the boundary value of the diagnostic parameter $y_j^*$ at the moments $\Theta_s \in (\Theta_1,\Theta_b)$ means that the cause of the located state $s_i$

was the "increasing development" of the state $s_i$ at the time $(\Theta_1,\Theta_b)$;

c) in case of common points lack, the estimation of the minimal distance of the "mistake channel" from the boundary value at the moment $\Theta_S \in (\Theta_1,\Theta_b)$, which means that the probable cause of the located state $s_i$ was a "momentary incomplete appearance" of this state at the time $(\Theta_1,\Theta_b)$;

d) the analysis of the identity of state sets $\{s_i(\Theta_k)$, k=1, …, K$\}$ and located by $T_{LU}$ state $s_i$ in order to determine the cause of its occurrence in the context of the obtained potential "common points" or the minimal distance of "approximations".

## 4. THE PROCEDURE OF MACHINE STATE GENESIS EXAMINATION

Examining the procedures includes:

a) examining the diagnostic parameters set in the aspect of estimating an optimal set of diagnostic parameters for diagnostic parameters values genesis according to the algorithm (point 2);

b) estimating genesis methods of diagnostic parameters values according to the algorithm (point 3);

c) examining the genesis value of diagnostic parameters with the genesis mistake, and the manner of estimating the cause of the machine's disability state depending on the following parameters:
- genesis method of diagnostic parameters values,
- the size of diagnostic parameters set,
- genesis horizon.

In order to obtain measurement data for procedure researches, the set of diagnostic parameters $Y_1$ was used from exploitation researches of the combustion engine of the car Star 11422 [7] in the form of time rows whose elements are the values of diagnostic parameters of fumes analysis: CO – carbon oxide [ppm], $CO_2$ – carbon dioxide [ppm], NO – nitro oxide [ppm], $NO_2$ – nitro dioxide [ppm], NOx – nitro oxides [ppm], CxHx - hydrocarbons [ppm], K - smoking [1/m]. xamining the procedure of estimating an optimal set of diagnostic parameters for the prognosis of diagnostic parameters values consisted in estimating an optimal set of diagnostic parameters according to the algorithm (point 2).

Tab. 1. Set of Diagnostic Parameters for the Object S11422_1

**Diagnostic Parameters Matrix for S11422_1**

| PAR | NAME | RJ | DJI | W1J |
|---|---|---|---|---|
| $NO_2$ | Nitro dioxide | 0,75 | 0,01 | 0,922 |
| K | Fume smoking | 0,64 | 0,30 | 0,030 |
| CxHx | Nitrocarbons | 0,48 | 0,67 | 0,013 |
| NOx | Nitro oxides | 0,32 | 0,99 | 0,009 |
| CO | Carbon oxide | 0,28 | 1,05 | 0,008 |
| $CO_2$ | Carbon dioxide | 0,22 | 1,14 | 0,008 |
| NO | Nitro oxide | 0,11 | 1,29 | 0,007 |

For the set of output parameters $Y_{1,}$ the set of diagnostic parameters with appropriate weight values was obtained (Table 1).
Result analysis for the object S11422_1 showed that the highest weight values $w_{j1}$ are possessed by the diagnostic parameters ($NO_2$, K, CxHx), and the lowest weight values $w_{j1}$ by the diagnostic parameters ($CO_2$, NOx). In order to optimize the diagnostic parameters set for the object S11422 (parameters number, the value of the weight $w_{1j}$), it is advised to accept diagnostic parameters of weight values $w_{1j} \geq 0{,}01$ (a 3-element set is obtained).

In case for a rest objects of the Star11422 group, the highest and lowest values of the weight $w_{j1}$ are possessed by different diagnostic parameters: the highest: CxHx, K, CO, NOx, (it is advised to accept diagnostic parameters of weight values $w_{1j} \geq 0{,}02$ – 2-, 3- and 4-element sets are obtained), the lowest: $CO_2$, NO with weight values $w_{1j} \leq 0{,}01$;
Summing up the performed researches of diagnostic parameters optimization procedures for engines of cars Star11422, it is stated that:

a) in genesis procedures researches of machine state, it is suggested to accept diagnostic parameters of weight values $w_{1j} \geq 0{,}07$ and corresponding to it size of the set;

b) it is also suggested to consider a single-element set of diagnostic parameters for which the weight $w_{1j}$ takes maximum value;

c) the accepted optimization criteria unambiguously identify the sets of parameter values having the largest quantity of information on the technical state and the variables in exploitation time of the cars Star 11422 combustion engines.

Examining the genesis procedure of the state for the engines of cars Star11422 in the aspect of determining the genesis method of diagnostic parameter value according to the genesis mistake function, examining the influence of the size of the diagnostic parameters set on the genesis mistake, as well as examining the manner of determining the cause of the disability state on the basis of the genesis value of the diagnostic parameter realized on the basis of:

1. Estimating the genesis methods of diagnostic parameters values, and the manner of determining the cause of the appearance of the disability state at the moment of machine's examination according to

the algorithm (point 3). For the set of diagnostic parameters, obtained was a visualization of values changes of chosen diagnostic parameters of the highest weight values in the function of the accepted working time for the analyzed methods of approximation and interpolation. Example visualizations for the object S11422 and the parameter $NO_2$ are shown in the Fig. 2. Example data enabling the analysis of values of the analyzed parameters In order to estimate the machine state – diagnostic parameters function value correlation for the genesis method of diagnostic parameters values of the lowest genesis mistake value.

The analysis of results showed that:

a) for S11422_1 different best (according to the minimum value of the genesis mistake) genesis methods for diagnostic parameters are obtained:
   - for $NO_2$ – interpolation method of 1 degree (genesis mistake = 10,9%),
   - for K – interpolation method of 1 degree (genesis mistake = 8,7%),
   - for CxHx – approximation method of 2 degree (genesis mistake = 27,7%);

b) in the other objects of Star11422, different best (according to the minimum value of the genesis mistake) genesis methods for diagnostic parameters are obtained (CxHx, K, CO, NOx). Respectively obtained are: for CxHx – interpolation method of 1 degree (genesis mistake = 7,4%), for K – approximation method of 2 degree (genesis mistake = 6,6%), for CO – interpolation method of 1 degree (genesis mistake = 2,9%), for NOx – interpolation method of 1 degree (genesis mistake = 5,1%);

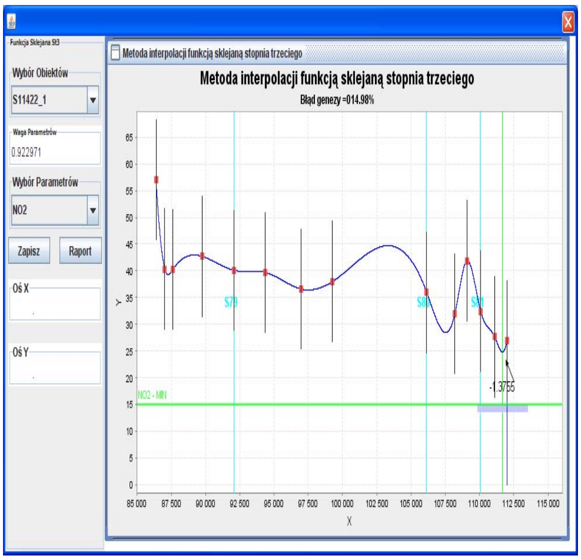


*Fig. 2. Estimating the genesis value of the parameter $NO_2$ (weight $w_1$=0,9229) for the interpolation with the combined function, type 3*

c) in order to determine the cause of the machine's disability basis on the distance of the genesis value of diagnostic parameters with genesis mistake from the diagnostic parameter boundary value for the group objects: Star266, Star11422, the algorithm (point 3) was used: diagnostic parameters analysis according to the maximum weight value, the analysis of genesis methods of diagnostic parameter value according to the minimum genesis mistake, estimating the minimum distance from the boundary value; for S11422 interpolation method of 1 degree is obtained, K parameter (distance = 1,9);

d) an alternative solution can be analyzed of genesis methods only for parameters of the highest weight values, which causes changes in the area of genesis method, diagnostic parameter, and the distance from the value.

Summing up the performed researches of the machine state genesis procedure, it is stated that:

a) as the result of machine state genesis procedures researches, it was concluded that it is necessary to accept diagnostic parameters (algorithm – point 2) and genesis methods according to the algorithm (point 3) as shown above;

a) the accepted optimization criteria and the presented algorithm unambiguously identify diagnostic parameter enabling the determination of the cause of the disability state, which confirms the propriety of the formulated procedure and ought to enable the formulation of appropriate diagnostic conclusion rules in the range

The analysis of machine state prognosis methodology research results allows to formulate dedicated conclusion rules of type "IF – THEN" or "IF – THEN – ELSE" in the area of:

a) diagnostic parameters optimization;
b) state genesis.

In case of the combustion engines of cars Star11422, the generated conclusion rules have form:

a) for the diagnostic parameters optimization set of $Y^o$:
   - if $w_{1j} \geq 0{,}07$ then $y_j \in Y^o$,
   - or if $w_{1j} = w_{1jmax}$ then $y_j \in Y^o$;

b) for state genesis:
   - if there is a combustion engine probable damages set Star11422 cars, the determination of the set of its disability states according to the level of probability of appearing damages according to the rule: if $p(s_i) \geq 0{,}5$ then $s_i \in S$,
   - if there is not a combustion engine probable damages set Star11422 cars, the determination of the set of its disability states according to the value of

exploitation measurement: if $\Theta_i \geq \Theta_l$ then $s_i(\Theta_l) \in S$,

- if the genesis mistake of the approximation method type 2 for the set $Y^o \leq$ genesis mistake of the interpolation method type 1 for the set $Y^o$, then the genesis method of the value of the set $Y^o$ is the interpolation method type 1, otherwise the genesis method of the value of the set $Y^o$ is the approximation method type 2,
- if the distance of the genesis value of the diagnostic parameter $y_j \in Y^o$ with the genesis mistake from the parameter boundary value $y_{jg}$: d($y_{jg}$ – value ($y_{jG}$ + $r_G$) for $y_{jG} > y_{jG}$), d(value ($y_{jg}$ – ($y_{jG}$ – $r_G$) for $y_{jG} < y_{jG}$) then the minimum value d(•) is the minimum distance $d_{min}$,
- if $d_{min} = 0$, then there is one common point with the boundary value (size [$d_{min}$] = 1), if $d_{min} < 0$, then there are more than one common points with the boundary value (size [$d_{min}$] > 1), if $d_{min} > 0$, then there are no common points with the boundary value,
- if $d_{min} = d_{min}$ ($\Theta$ ($s_i$)), then the minimum value $d^s_{min} = d_{min}$ appears at the state in the time $\Theta_S \in (\Theta_1,\Theta_b)$, chich means that the cause of the located state $s_i$ In the time of realization of the test $T_{LU}$ was a "momentary appearance" of his state in the time ($\Theta_1,\Theta_b$)), otherwise $d_{min}$ # $d_{min}$ ($\Theta$ ($s_i$)), which means it is impossible to determine the cause of the state $s_i$ estimated during the realization of the test $T_{LU}$,
- if the size [$d^s_{min}$] > 1, it means that the cause of the located state $s_i$ was an "increasing development" in the time $\Theta_S \in$ ($\Theta_1,\Theta_b$) of the conditions of the state appearance $s_i$ (estimated during the realization of the test $T_{LU}$),
- if $d_{min} > 0$ and there is no common point with the boundary value, then it means that the probable cause of the located state $s_i$ (estimated during the realization of the test $T_{LU}$) was a "momentary incomplete appearance" of the state in the time ($\Theta_1,\Theta_b$);

The presented conclusion rules in the range of machine state genesis, after performing appropriate verification researches, could be basis for dedicated software of a machine state recognition system in an on–line mode (for an on-board system) and off–line (for a stationary system).

## 5. CONCLUSION

This paper shows machine state genesis procedures that allows to formulate the following conclusions:

1. The presented procedures allow to determine optimal, as far as the accepted criterion is concerned:
   a) diagnostic parameters set;
   b) diagnostic parameters values genesis and the estimation of the cause of the machine's disability state.
2. In order to determine the set of diagnostic parameters and state genesis, the above presented procedures can be the basis for estimating conclusion rules in the range of:
   a) determining an optimal set of diagnostic parameters;
   b) estimating the values of diagnostic parameters in the past, and estimating the cause of the disability state located during the machine examination.

## REFERENCES

[1] Będkowski L., *Elements of technical diagnostics* (in Polish), WAT, Warszawa 1991.
[2] Bowerman B. L., O`Connel R.T., *Forecasting and Time Series*, Doxbury Press (USA), 1979.
[3] Box G., Jenkins G., *Time series analysis, forecasting and control*, London 1970.
[4] Cholewa W., Kaźmierczak J., *Data processing and reasoning in technical diagnostcs*, WNT, Warszawa 1995.
[4] Niziński S., *Technical objects exploitation* (in Polish), ITE, Radom 2002.
[5] Lewitowicz J., *Exploitation events genesis*, Conference materials (in Polish), XXXV Zimowa Szkoła Niezawodności, Szczyrk 2007.
[6] Tylicki T., *Machine state evolution researches* (in Polish), Diagnostyka, vol. 25, Warszawa 2001.
[7] Tylicki H., *Report on the researches of optimization methodology of machine state recognition*, Unpublished materials (in Polish), UTP, Bydgoszcz 2007.
[8] Tylicki H., *Optimization methods in machine symptom reliability*, Conference materials (in Polish), XXXV Zimowa Szkoła Niezawodności, Szczyrk 2007.
[9] Zienkiewicz O. C., Zhu J. U., *A simple error estimation and adaptive procedure for practical engineering analysis*, International Journal for Numerical Methods in Engineering, vol. 24 (1987), pp. 337-357.
[10] Żółtowski B., *Condittions of states clasification in machines diagnostics method of determination of terms of mechanical vehicles units operations*, Scientific Notebooks Problems of Operation, no. 5/97, ITE Radom 1997, (p.37-57).

[11] Żółtowski B., *The basics of machines diagnostics*, University Publishers of University of Technology and Agriculture, Bydgoszcz 1996.

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# DEMONSTRATION OF FIRST-PRINCIPLE MODEL ADJUSTMENT APPROACH WITH THE USE OF A SIMPLIFIED HEATER MODEL

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Summary

The paper discusses a process of formulation and identification of a first-principle data-driven heater model. The model is formulated using a system of continuous ordinary differential equations capturing usually nonlinear relations among variables of the model. The considering model applies three categories of parameters: geometrical, physical and phenomenological. Geometrical and physical parameters are deduced from construction or operational documentation. The phenomenological parameters are the adjustable ones. First-principle models are frequently adjusted by trial-and-error, which can lead to non-optimal results. In order to avoid deficiencies of the trial-and-error approach, a formalized mathematical method using optimization techniques to minimize the error criterion, and find optimal values of adjustable model parameters, was proposed and demonstrated in this work.

Keywords: first principle model, data driven model, grey-box methods.

DEMONSTRACJA PODEJŚCIA DO STROJENIA MODELU OPARTEGO NA PRAWACH FIZYKI NA PODSTAWIE UPROSZCZONEGO MODELU PODGRZEWACZA

Streszczenie

Artykuł omawia proces modelowania podgrzewacza regeneracyjnego pracującego w systemie bloku energetycznego z wykorzystaniem strojonych równań fizycznych. Model jest formułowany z użyciem układu zwyczajnych równań różniczkowych obejmujących wzajemne nieliniowe relacje pomiędzy zmiennymi modelu. Rozważany model stosuje trzy kategorie parametrów: geometryczne, fizyczne, oraz fenomenologiczne. Parametry geometryczne oraz fizyczne są ustalane na podstawie dokumentacji konstrukcyjnej oraz operacyjnej. Parametrami strojonym są parametry fenomenologiczne. Modele wyprowadzane na podstawie praw fizycznych są często strojone metodą prób i błędów, co może prowadzić do nieoptymalnych wyników. Dla ominięcia wad metody została zastosowana metoda najmniejszych kwadratów do strojenia parametrów fenomenologicznych modelu podgrzewacza tj. współczynników wymiany ciepła.

Słowa kluczowe: model oparty na prawach fizyki, model danych, metody grey-box.

## NOMENCLATURE

$\dot{m}$ - mass flux [kg/s]
$\dot{Q}$ - energy flux [J/s]
h - enthalpy [J/kg]
H - internal energy [J]
$\rho$ - density [kg/m$^3$]
p - pressure [Pa]
T - temperature [K]
V - chamber volume [m$^3$]
k - heat transfer coefficient [W·m$^{-2}$·K$^{-1}$]
F - heat exchange area [m$^2$]
$c_p$ - specific isobaric heat [J·kg$^{-1}$·K$^{-1}$]
x - state variable
A, B, C, D - linear state-space model representation

## 1. INTRODUCTION

The initial phase in modelling of a technical system is collecting and systematic treatment of available knowledge. The a priori knowledge about a given phenomenon comes from the analysis, comprising of finding all possible connections to other phenomena and physical laws, preceding the modelling. The a priori knowledge is of key importance in modelling although its availability is always limited by the complexity of the physical system.. Even if the governing physical principia are known, it is usually difficult to formulate the specific relationships and obtain particular values of the parameters. Availability of the a priori knowledge and the modelling purpose determine the following: (i) the final type of the model, (ii) the accuracy requirements, (iii) the type of specific modeling procedure, (iv) the complexity of the model and lastly, (v) the method and the cost of its realization. According to the degree to which the a priori knowledge is available, then either a first-principle or a data-driven model, or a combination of both, can be applied (cf. Fig 1). First-principle (FP) models use understanding of the system underlying physics to derive its mathematical representation. FP models are expensive in development since expertise in the area of knowledge at the advanced level is required to derive equations from physical laws, while data-driven (DD) models use system test data to derive its mathematical representation. The advantage of the former approach is the depth of the insight into the behavior of the system and thus ability to predict the performance, while the advantage of the latter is the speed in which an accurate model can be constructed and confidence gained thanks to the use of the data obtained from the actual system. The difficulty of the former approach lies in the determination of the phenomenological parameters like the friction or the heat transfer coefficient. First-principle models are frequently adjusted by trial-and-error, which can lead to non-optimal results. On the other hand, the disadvantage of DD models is the need to handle multiple data sets in order to cover the range of system operation.

## 2. HIGH PRESSURE FEEDWATER HEATER INSTALLATION

A feasibility study presented in this paper is focused on numerical studies on fault detection in application to thermal systems. Heaters installations are typically affected by fouling and corrosion phenomena which may have effect on heat transfer and fluid transportation process [4, 5]. Feedwater heaters are typically designed as three-zone heat exchangers with a condensing section, desuperheater and integrated subcooler (Fig. 1).

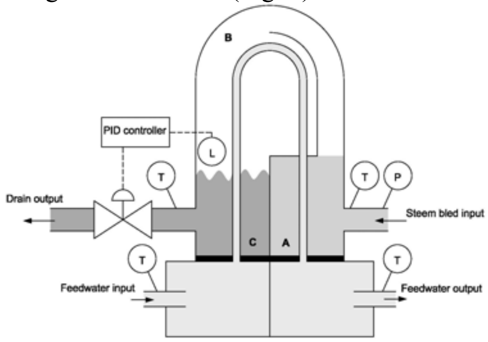


*Fig. 1. Schem of a feedwater heater [5] (A: desuperheating area; B: condensing area; C: subcooling area; T: temperature sensor; L: level sensor; P: Pressure sensor)*

The drainage system of the feedwater heater consists of a drain removal path from each heater. The normal drain flow path is cascaded to the next lower stage heater, and the alternate path is diverted to the condenser. When the turbine is loaded at a given rate, steam is allowed to enter the bank of heaters through extraction outlets [4, 5].

Reliability of feedwater heaters is strongly influenced by their design, applied materials and operating conditions [5]. Most common faults of heaters concern piping systems. Fouling is an accumulation of undesirable material (deposits) on heat exchanger surfaces resulting in deterioration in thermal performance and increase of pressure drop. Evaluation of heater performance can be approached by continuous monitoring of parameters responsible for intensity of heat transfer process. Under normal operating conditions the heat transfer coefficient is constant or slowly decreasing due to a layer of settled material building up on the heat transfer surface. It may happen that large pieces of the settled material can break away from the surface. When the settled material breaks off, the heat transfer coefficient may change the value. Tube bursting makes the feedwater flow into the external jacket of the heater, and consequently feedwater gets mixed with condensate. The leakages have several causes: (i) electrochemical corrosion, (ii) erosion caused by water or steam, and (iii) fatigue – due to mechanical vibrations. Details of each cause of fault, common places of occurrence and discussion on materials for heater's construction are provided in [5]. Moreover, operation of the heater may be influenced by faults of auxiliary devices, such as three-way servovalves regulating flow of fluids through the heater. There occur also malfunctions of control system elements, e.g. sensors measuring operational parameters of the heater and giving information to the controller. Consequences of consecutive malfunctions for the whole power unit are described in [3, 4].

## 3. THE NONLINEAR AND LINEARIZED FEEWATER HEATER MODELS

A continuous-time heat exchanger model was formulated using ordinary differential equations (ODEs). The model was implemented in Matlab as the 'idnlgrey' model structure with the use of first-order differential equations (1) and as the 'idgrey' model structure with the use of linearized state-space equations (2). The third implementation was a block-diagram model in Simulink. System Identification Toolbox commands were used to perform linear and nonlinear grey-box modeling using heater model implemented in m-file, while Simulink Parameter Estimation tool was used to identify the heater model implemented in Simulink. System Identification Toolbox grey-box models require to specify the structure of the ODE model in an m-file. A linear model system is modeled with use both, i.e. the 'idgrey' and the 'idnlgrey 'objects. However, only nonlinear dynamics can be handled using the 'idnlgrey' model object. The 'idgrey' object requires that an m-file to describe the linear dynamics in the state-space form, such that this m-file returns the state-space matrices as a function of the parameters. The 'idnlgrey' object requires to write an m-file or MEX-file to describe the dynamics as a set of first-order differential equations, such that this file returns the output and state derivatives as a function of time, input, state, and parameter values. Simulink models require defining inputs-outputs of a model, specifying the free parameters, and choosing the optimization method. A nonlinear simplified heater model is described with the following equations:

$$\begin{aligned}
&\frac{dT_{12}}{dt} = f_{12}(T_{12}, T_{34}, \dot{m}_1, \dot{m}_2, T_1, T_2) = \\
&= \frac{\dot{m}_1}{\rho_{12}V_{12}}(T_1 - T_2) + \frac{k_{12-34}F(T_{12} - T_{34})}{V_{12}\rho_{12}c_{p12}} \\
&\frac{dT_{34}}{dt} = f_{34}(T_{12}, T_{34}, \dot{m}_3, \dot{m}_4, T_3, T_4) = \\
&= \frac{\dot{m}_3}{\rho_{34}V_{34}}(T_3 - T_4) + \frac{k_{12-34}F(T_{12} - T_{34})}{V_{34}\rho_{34}c_{p34}}
\end{aligned} \tag{1}$$

where ρ, V, $c_p$ are function of pressure, temperature, and enthalpy. The model is schematically presented in figure 2.

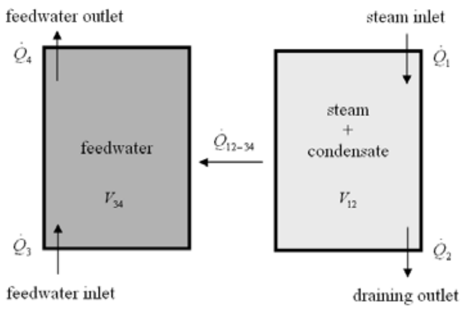


*Fig. 2. Scheme of the simplified heater model*

A linearized model has the form as follows:

$$\begin{aligned} Ax &= Bu + C \\ y &= Cx \end{aligned} \tag{2}$$

where the state, input, and output vectors are, in deviation form as folows:

$$x = \begin{bmatrix} T_{12} - T_{012} \\ T_{34} - T_{034} \end{bmatrix} \tag{3}$$

$$u = \begin{bmatrix} \dot{m}_1 - \dot{m}_{01} \\ \dot{m}_3 - \dot{m}_{03} \\ T_3 - T_{03} \\ T_1 - T_{01} \end{bmatrix} \tag{4}$$

$$y = \begin{bmatrix} T_{12} - T_{012} \\ T_{34} - T_{034} \end{bmatrix} \tag{5}$$

The elements of the state-space A matrix are found by:

$$\begin{aligned} A_{11} &= \frac{\partial f_{34}}{\partial (T_{12} - T_{012})} = \frac{\partial f_{12}}{\partial T_{12}} = \\ &= -\frac{\dot{m}_1}{\rho_{12}V_{12}} - \frac{k_{12-34}F}{V_{12}\rho_{12}c_{p12}} \end{aligned} \tag{6}$$

$$\begin{aligned} A_{12} &= \frac{\partial f_{12}}{\partial (T_{34} - T_{034})} = \frac{\partial f_{12}}{\partial T_{34}} = \\ &= \frac{k_{12-34}F}{V_{12}\rho_{12}c_{p12}} \end{aligned} \tag{7}$$

$$\begin{aligned} A_{21} &= \frac{\partial f_{34}}{\partial (T_{12} - T_{012})} = \frac{\partial f_{34}}{\partial T_{12}} = \\ &= \frac{k_{12-34}F}{V_{34}\rho_{34}c_{p34}} \end{aligned} \tag{8}$$

$$\begin{aligned} A_{22} &= \frac{\partial f_{34}}{\partial (T_{34} - T_{034})} = \frac{\partial f_{34}}{\partial T_{34}} = \\ &= \frac{\dot{m}_3}{\rho_{34}V_{34}} - \frac{k_{12-34}F}{V_{34}\rho_{34}c_{p34}} \end{aligned} \tag{9}$$

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \tag{10}$$

The elements of the state-space B matrix are found by:

$$B_{11} = \frac{\partial f_{12}}{\partial (\dot{m}_3 - \dot{m}_{03})} = \frac{\partial f_{12}}{\partial \dot{m}_3} = 0 \tag{11}$$

$$B_{12} = \frac{\partial f_{12}}{\partial(\dot{m}_1 - \dot{m}_{01})} = \frac{\partial f_{12}}{\partial \dot{m}_1} = \frac{T_1 - T_2}{\rho_{12} V_{12}} \quad (12)$$

$$B_{13} = \frac{\partial f_{12}}{\partial(T_1 - T_{01})} = \frac{\partial f_{12}}{\partial T_1} = \frac{\dot{m}_1}{\rho_{12} V_{12}} \quad (13)$$

$$B_{14} = \frac{\partial f_{12}}{\partial(T_3 - T_{03})} = \frac{\partial f_{12}}{\partial T_3} = 0 \quad (14)$$

$$B_{21} = \frac{\partial f_{34}}{\partial(\dot{m}_3 - \dot{m}_{03})} = \frac{\partial f_{34}}{\partial \dot{m}_3} = \frac{T_3 - T_4}{\rho_{34} V_{34}} \quad (15)$$

$$B_{22} = \frac{\partial f_{34}}{\partial(\dot{m}_1 - \dot{m}_{01})} = \frac{\partial f_{34}}{\partial \dot{m}_1} = 0 \quad (16)$$

$$B_{23} = \frac{\partial f_{34}}{\partial(T_1 - T_{01})} = \frac{\partial f_{34}}{\partial T_1} = 0 \quad (17)$$

$$B_{24} = \frac{\partial f_{34}}{\partial(T_3 - T_{03})} = \frac{\partial f_{34}}{\partial T_3} = \frac{\dot{m}_3}{\rho_{34} V_{34}} \quad (18)$$

$$B = \begin{bmatrix} 0 & B_{12} & B_{22} & 0 \\ B_{21} & 0 & 0 & B_{24} \end{bmatrix} \quad (19)$$

The C matrix is the identity matrix given as:

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad (20)$$

The parameters considered in a simulation are given in table 1.

Table 1. Heaters' parameters

| Nominal parameters | Symbol | Unit | Value |
|---|---|---|---|
| Heat exchange area | $F$ | $m^2$ | 500 |
| Inlet steam mass flow | $\dot{m}_1$ | kg/s | 23 ±1σ |
| Outlet steam mass flow | $\dot{m}_2$ | kg/s | NA |
| Inlet feedwater mass flow | $\dot{m}_3$ | kg/s | 596 ±1σ |
| Outlet feedwater mass flow | $\dot{m}_4$ | kg/s | NA |
| Steam+condensate density | $\rho_{12}$ | $[kg/m^3]$ | 1.2 |
| Feedwater density | $\rho_{34}$ | $[kg/m^3]$ | 952 |
| specific isobaric heat (steam + condensate) | $c_{p12}$ | $[J\cdot kg^{-1}\cdot K^{-1}]$ | 2e+003 |
| specific isobaric heat (feedwater) | $c_{p34}$ | $[J\cdot kg^{-1}\cdot K^{-1}]$ | 4.2e+003 |
| Steam+condensate temperature | $T_{12} = T_2$ | [deg] | NA |
| Feedwater temperature | $T_{34} = T_4$ | [deg] | NA |
| Inlet steam temperature | $T_1$ | [deg] | 269 |
| Inlet feedwater temperature | $T_3$ | [deg] | 108 |
| Steam+condensate volume | $V_{12}$ | $[m^3]$ | 2.9 |
| Feedwater volume | $V_{34}$ | $[m^3]$ | 4 |
| Heat transfer coefficient | $k_{12=34}$ | $[W\cdot m^{-2}\cdot K^{-1}]$ | 1150 |

The aim of the numerical benchmarking exercise is to estimate values of free parameters using three different methods, i.e. the 'idgrey', 'idnlgrey' from System identification Toolbox, and Simulink Parameter Estimation. The system identification was performed as two cases, i.e. A and B. Case A assumes a heat transfer coefficient as a free parameter (Table 2) while the Case B assumes two free parameters (Table 3), i.e. heat transfer coefficient and steam volume. The input data was disturbed by noise of zero mean and variance 1. On the other hand, the output data was additionally disturbed by zero-mean white noise of variance equal 5.

The "True value" parameter defines the target value of the parameter assumed in the simulation, while "Initial guess" means the initial value assumed in the optimization process. The "Error" field evaluates the percentage difference between the "True value" and the "Estimated value" of the parameter. Example of model parameters' trajectories during estimation process in Case B is presented in figure 3.

Table 2. Estimated free parameters (Case A)

| | **Linear Grey-Box Model** | **Nonlinear Grey-Box Model** | **Simulink Estimation** |
|---|---|---|---|
| | k | k | k |
| **Model** | Linear (linearized) | Nonlinear | Nonlinear |
| **'True' value** | 1150 | 1150 | 1150 |
| **Initial guess** | 45 | 45 | 45 |
| **Estimated value** | 1150 | 1150 | 1150 |
| **Error [%]** | 0.1% | 0.05% | 0.1% |
| **Computation time [s]** | 15s | 120s | 70s |

Table 3. Estimated free parameters (Case B)

| | **Linear Grey-Box Model** | | **Nonlinear Grey-Box Model** | | **Simulink Estimation** | |
|---|---|---|---|---|---|---|
| | k | V12 | k | V12 | k | V12 |
| **Model** | Linear (linearized) | | Nonlinear | | Nonlinear | |
| **'True' value** | 1150 | 4 | 1150 | 4 | 1150 | 4 |
| **Initial guess** | 45 | 1 | 45 | 1 | 45 | 1 |
| **Estimated value** | 1150 | 4 | 1150 | 4 | 1150 | 4 |
| **Error** | 0.15% | 0.13% | 0.1% | 0.09% | 0.08% | 0.13% |
| **Computation time [s]** | 25s | | 210s | | 160s | |

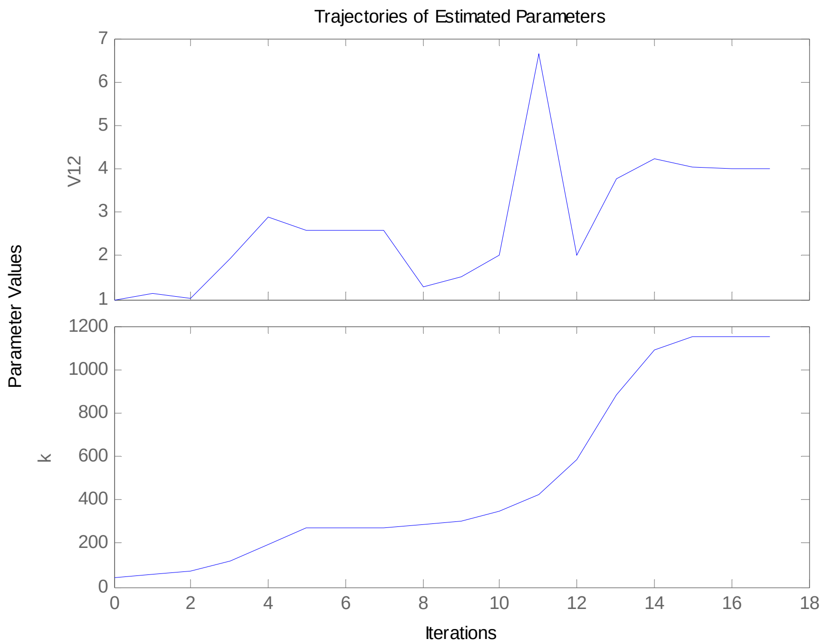


*Fig. 3. Trajectories of adjusted model parameters (Case B)*

## 4. SUMMARY AND CONCLUSIONS

The paper demonstrates a first-principle data-driven approach towards modeling of a feewater heater. The model offers physical insight and sufficient numerical performance to be applicable in understanding underlying physical phenomena, designing control systems, and optimizing processes after supplemented with additional physical equations [1, 3]. FPDD models can be used in many areas where physical understanding is critical, e.g. design of new products or early warning diagnostics of large industrial installations. The model is represented by nonlinear state-space equations having geometrical and physical parameters deduced from available documentation, and adjustable phenomenological parameters (i.e. heat exchange or leakage coefficients) that are estimated from measurement data.

The paper compares three implementation approaches (idgrey, idnlgrey, and Simulink), or based on the simplified heat exchange model, i.e. linear and nonlinear. The preferable environment for modeling of complex power plant installations is Simulink providing the causal block diagram GUI. Block diagram model representation is more suitable since it allows to incrementally expand the model of new components, e.g. equations, look-up-tables with experimental characteristics. Hence, the advantage of Simulink Estimation Tool is flexibility that any Simulink model including soft and hard nonlinearities can be identified and calibrated from experimental data. In case of System Identification toolbox from the Matlab package the model has to be formulated as a set of first order differential equations into m-file using 'idgrey' or 'idnlgrey' model structures. This operation increases lead-time of the model development. On the other hand, the benchmarking study shows (Table 1-2) lower performance of the System Identification toolbox compared to Simulink.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] T. Barszcz, P. Czop, *Estimation of feedwater heater parameters based on a grey–box approach*, Int. J. Appl. Math. Comput. Sci., 2011, Vol. 21, No. 4.
[2] T. Barszcz, P. Czop, *A Feedwater Heater Model Intended for Model-Based Diagnostics of Power Plant Installations*, Applied Thermal Engineering, Vol. 31, No. 8-9, June 2011, Pages 1357-1367.
[3] T. Barszcz, P. Czop. *Methodologies and Applications of Virtual Power Plant*: New Environment for Power Plant Elements Modeling, Institute of Sustainable Technologies, Radom 2007
[4] [D. Flynn (eds.), *Thermal Power Plants - Simulation and Control*, The Institution of Electrical Engineers, London 2000.
[5] E. Zbroińska-Szczechura, J. Dobosiewicz. *Uszkodzenia i diagnostyka wymienników ciepła w elektrociepłowniach*, Energetyka, grudzień 2004.

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# HYDRAULIC MODEL BASED METHOD FOR LEAKS LOCATION IN URBAN WATER DISTRIBUTION NETWORK

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Abstract

The paper describes the use one of the methods for locating leaks based on an accurate model of the network. The paper presents the results of this approach for the active experiment which was carried out on the water supply. The experiment consisted of releasing water with the varying intensity of the fire hydrants located on the test area. Based on the readings of flow meters located in the district, the aim was to identify pre-defined areas in which the simulated leaks occurred. The results are summarized in conclusions.

Keywords: urban water distribution network, epanet model, similarity measure, hydraulic model.

## Introduction

Water supply systems supplying water to our homes, workplaces and other institutions are very complex systems of interconnected pipes, valves and all other hydraulic fittings. Their purpose is to ensure continuous access not only to water but also to provide the water to the correct pressure. Due to their complex nature and the distribution below the surface, appear to uncontrolled leaks are a major problem for operating these networks. The cause of these leaks is the most common condition of the pipeline, which as a result of the natural process of usage leads to a weakening of the structure of the pipe, the other to such differences in temperature for different times of the year. External leaks are usually easy to spot, and if they occur in residential areas relevant services are usually quickly informed about the event. In the case of leakage, the external symptoms do not appear or appear only after a long time of occurrence. It is difficult to determine the intensity and location of which leads to a financial loss of water supply companies. Therefore, to reduce these losses have been studies conducted jointly by teams from the Silesian University of Technology and PWiK Rybnik in the project for the construction of the diagnostic system for the detection and location of leaks in water distribution networks [2,3,4]. As part of these activities has developed a number of methods for the detection and location of leaks.

## Hydraulic model based method for leaks location

The developed methodology was based on the many stages of the construction and applications developed network models [2, 3]. The role of the basic model meets here the exact model of the network environment EPANET2 developed in [5]. This model has been prepared on the basis of GIS data used at PWiK Rybnik, which allowed the recording of the network structure and on the basis of accounting data partitions (water consumption by users). Accounting data also served to prepare the averaged profile of water consumption zones concerned. The resulting model was then calibrated based on data obtained from pre-positioned flowmeters. Model then was used to carry out simulations of the network for different states (simulated leaks of varying degrees of intensity and a different location). During the study assumes that the location of leaks will be conducted with an accuracy of the areas identified in the study area. Number of areas and their size and shape depend on the complexity of the network. Areas identified based on the knowledge of experts, taking into account the interest of some distinction PWiK of them due to the various aspects of usage. A limitation was the number of flowmeters installed on the network because of the investment costs. Depending on the number and distribution we have varied quality of leaks location in various areas. As part of the study was also carried out to optimize flowmeters distribution in predefined locations on the network. Optimization was performed with the use of evolutionary algorithms. Was considered a limited number of locations that can be installed flowmeters because of the possibility of their physical location and because of the legal nature of the network location.

One of the methods used for leaks location was hydraulic model based method [1]. This method is based on the flow data obtained from the model for the localized virtual leaks in particular areas of the zone. For each leakage flow values are obtained on the model nodes where flowmeters are physically located on the network. Size-generated leakage is determined on the basis of the model by comparing the flow values of the inputs to the state without leakage (simulated using the model) with the value measured on the real flowmeter input. Comparing the value flow from the model with the values of the actual flowmeters using simple Euclidean distance measure designating (1) between the values, obtained similarity value (2) of the actual situation to situation simulated for the leak location. The higher the similarity obtained for the area in which the simulated leak then was greater certainty that in this area it really occurs.

$$\Delta p_j = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left[\left(Pr_{ij} - Pm_{ij}\right)^2\right]} \qquad (1)$$

$$\prod p_j = \frac{1}{1 + \Delta p_j} \qquad (2)$$

where:
$\Delta p$ - the average distance of the data model and the actual data.
$\prod p$ - the value of the similarity between the model and actual flows.
$P_r$ - the value of the actual flowmeter.
$P_m$ - the value of the virtual flowmeter.
$i$ - an index that describes the number of flowmeters.
$j$ - index describing the number of areas.
$n$ – number of flowmeters are located.

This method assumed that the leak is simulated at one node of the area. Thus, the number of emitters is equal to the number of control areas. If the areas are well isolated (there are well distinguishable even for small leaks) is this assumption is correct, because all the places in the area are equally representative and in the same way revealed the appearance of leaks anywhere in the area flowmeters installed. This method is characterized by a very fast operation. This approach allows the location of individual leaks on the water supply network.

**Example of the application**

The example concerns the location real leaks on the network, which was obtained by the experiment active on the network (water drop the hydrant by varying the flow rate for the duration of the 10 min flow rate). The experiment was conducted in the district Popielów - Rybnik PWiK operations area, one of the zones where the run is to implement the developed system. This zone is characterized by buildings from houses. Table 1 shows the location of the leaks introduced, their size and duration of the experiment. In every place generated by a variety of leak flow rates. Figure 1 shows the location of the leaks entering the network. Figure 2 shows the breakdown zone areas (26 areas).

Table 1 The parameters of the experiment

| Leak time | Leak size [m3/h] | Node number in model |
|---|---|---|
| 09:15 | 1.932 | 4196 |
| 09:30 | 3.198 | 4196 |
| 09:45 | 4.752 | 4196 |
| 10:15 | 2.094 | 6966 |
| 10:30 | 3.486 | 6966 |
| 10:45 | 4.878 | 6966 |
| 11:00 | 1.872 | 7356 |
| 11:15 | 3.132 | 7356 |
| 11:30 | 3.624 | 7356 |
| 11:45 | 4.902 | 7356 |
| 12:30 | 2.052 | 7672 |
| 12:45 | 3.258 | 7672 |
| 13:15 | 2.088 | 693 |
| 13:30 | 3.372 | 693 |
| 13:45 | 5.1 | 693 |

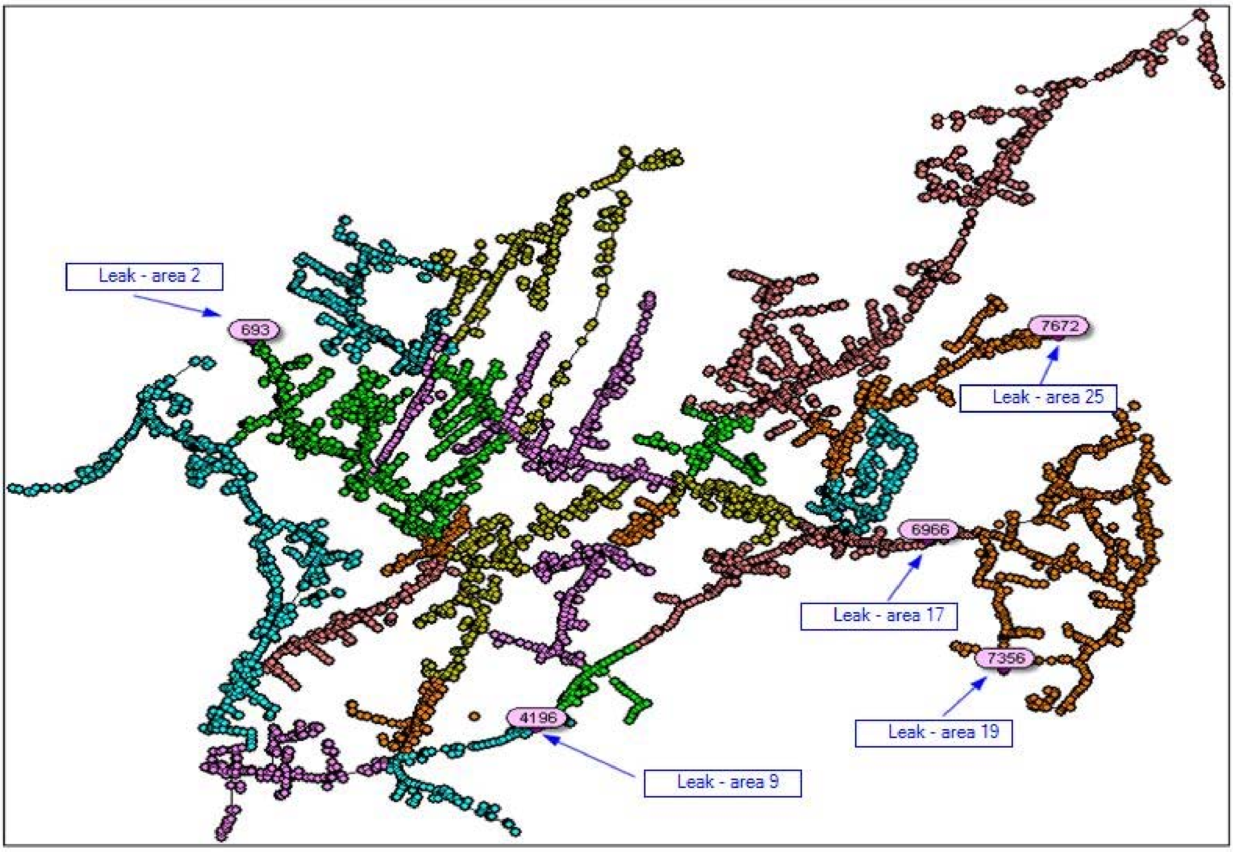


*Fig. 1 Location of leaks*

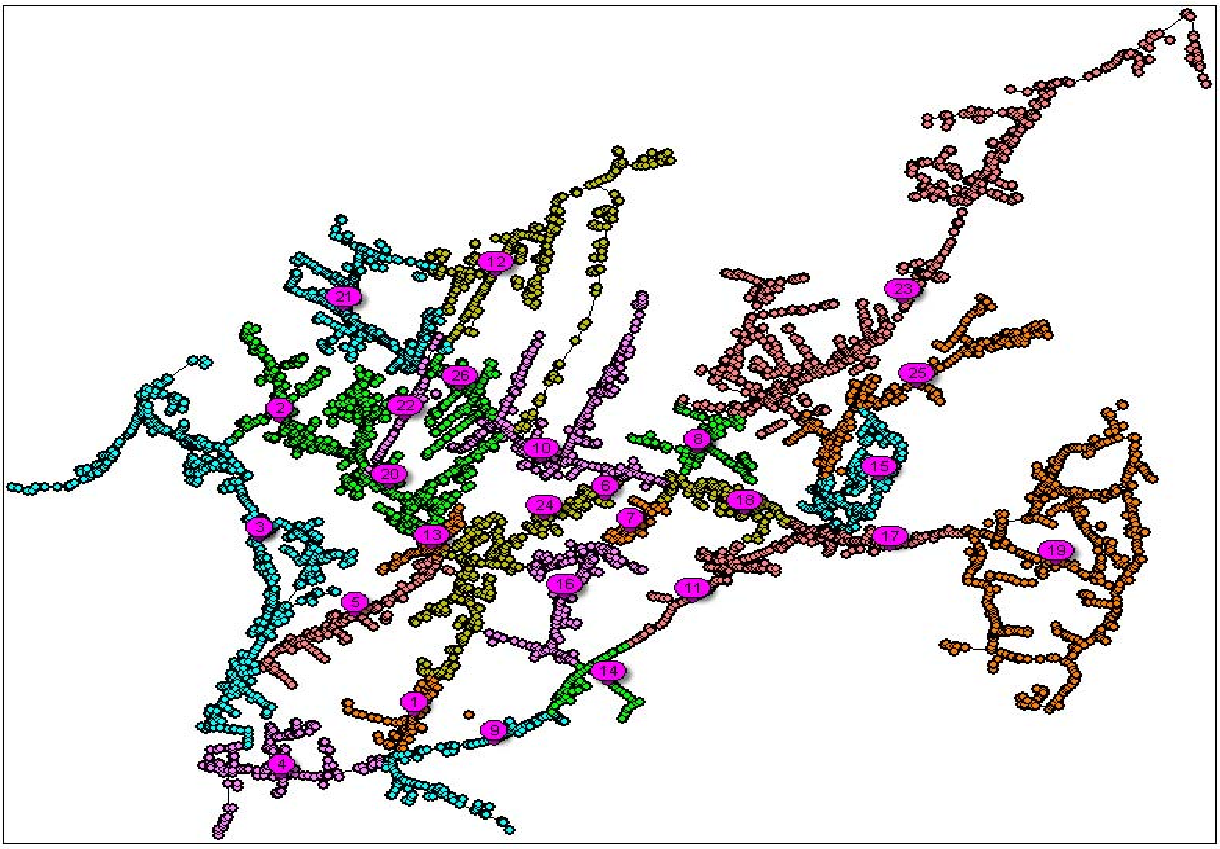


*Fig. 2 The division zone areas*

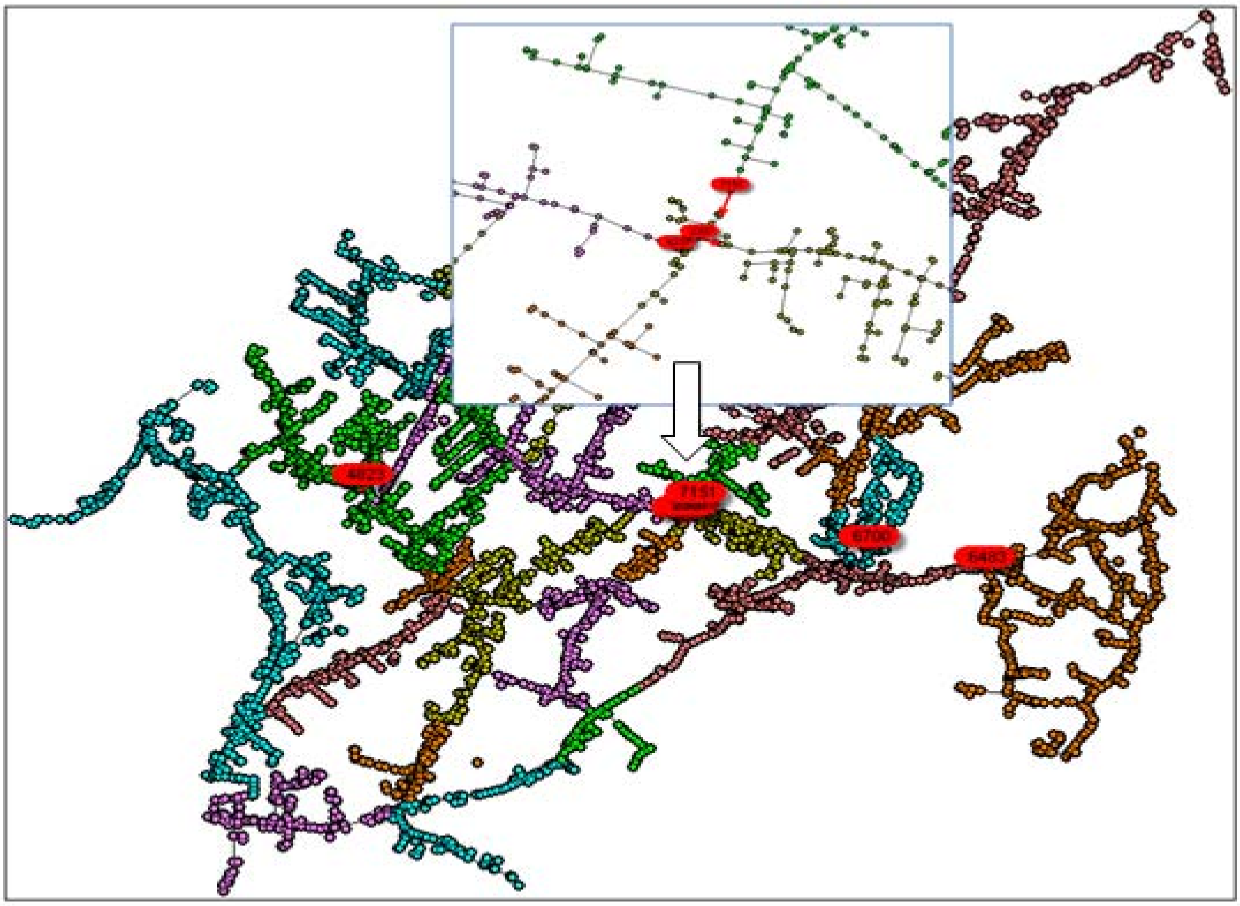

*Fig. 3 Distribution flowmeters*

Figure 3 shows the state of flowmeters distribution on the real network. As of the experiment was installed six flowmeters planned 11th As you can see it is especially poorly metered zone down.

Here are the results for each leaks location using the following method. The collated results include only selected results with the highest similarity.

Table 2. LEAK - AREA 9

| 09:15:00 | | 09:30:00 | | 09:45:00 | |
|---|---|---|---|---|---|
| leak = 1.932 | | leak = 3.198 | | leak = 4.752 | |
| Area | Similarity | Area | Similarity | Area | Similarity |
| 2 | 0,8 | 9 | 0,87 | 3 | 0,83 |
| 3 | 0,78 | 5 | 0,85 | 4 | 0,81 |
| 4 | 0,76 | 1 | 0,82 | 2 | 0,81 |
| 5 | 0,75 | 4 | 0,82 | 5 | 0,78 |
| 9 | 0,74 | 24 | 0,81 | 9 | 0,74 |
| 14 | 0,73 | 16 | 0,81 | 1 | 0,65 |

Table 3. LEAK - AREA 17

| 10:15:00 | | 10:30:00 | | 10:45:00 | |
|---|---|---|---|---|---|
| leak = 2.094 | | leak = 3.486 | | leak = 4.878 | |
| Area | Similarity | Area | Similarity | Area | Similarity |
| 11 | 0,85 | 14 | 0,84 | 17 | 0,88 |
| 18 | 0,83 | 11 | 0,8 | 11 | 0,86 |
| 17 | 0,83 | 17 | 0,78 | 18 | 0,78 |

| | | | | | |
|---|---|---|---|---|---|
| 14 | 0,8 | 18 | 0,77 | 14 | 0,75 |

Table 4. LEAK - AREA 19

| 11:00:00 | | 11:15:00 | | 11:30:00 | | 11:45:00 | |
|---|---|---|---|---|---|---|---|
| leak = 1.872 | | leak = 3.132 | | leak = 3.624 | | leak = 4.902 | |
| Area | Similarity | Area | Similarity | Area | Similarity | Area | Similarity |
| 19 | 0,84 | 19 | 0,8 | 19 | 0,84 | 19 | 0,86 |
| 18 | 0,76 | 11 | 0,68 | 17 | 0,62 | 17 | 0,55 |
| 11 | 0,76 | 17 | 0,68 | 18 | 0,62 | 11 | 0,55 |
| 17 | 0,76 | 18 | 0,67 | 11 | 0,62 | 14 | 0,54 |

Table 5. LEAK - AREA 25

| 12:30:00 | | 12:45:00 | |
|---|---|---|---|
| leak = 2.052 | | leak = 3.258 | |
| Area | Similarity | Area | Similarity |
| 15 | 0,79 | 25 | 0,77 |
| 14 | 0,78 | 15 | 0,76 |
| 25 | 0,78 | 23 | 0,7 |
| 1 | 0,74 | 14 | 0,66 |

Table 6. LEAK - AREA 2

| 13:15:00 | | 13:30:00 | | 13:45:00 | |
|---|---|---|---|---|---|
| leak = 2.088 | | leak = 3.372 | | leak = 5.1 | |
| Area | Similarity | Area | Similarity | Area | Similarity |
| 2 | 0,65 | 2 | 0,68 | 2 | 0,71 |
| 3 | 0,62 | 3 | 0,64 | 3 | 0,65 |
| 4 | 0,6 | 4 | 0,61 | 4 | 0,59 |
| 5 | 0,58 | 5 | 0,58 | 5 | 0,57 |

**Summary**

From the above results it can be concluded that the accuracy of the above leaks location is relatively high. Furthermore, it shows areas are usually close to each other. Despite the incomplete number of flowmeters planned to run on the zone even in case of leakage in area 9 (Table 2) located at a narrow circle of search to a few neighboring areas. In this case, it was known that the value of leakage from a simulation which was performed certainly had a positive effect on the results of the location. It can be seen that the leakage of larger intensities are more localized as clearly manifested in the network and stronger flows affect the value obtained from measuring devices. However, the established threshold of detectability the size of 5m3 / h is maintained. The advantage of the proposed method is the possibility of direct application is independent of the number of currently available flowmeters. There is the necessity to build a new model, only we have to deal with the deterioration of location accuracy. The quality of the results is also affected by location or network numerical model was valid and properly calibrated.

## References

[1] Piotr Tomasik "*The use of accurate models of the network for the detection and location of leaks*," X National Conference on Diagnostics of Processes and Systems, DPS'20011, Zamość 2011

[2] Wojciech Moczulski, Krzysztof Ciupke, Piotr Przystałka, Piotr Tomasik, Dominik Wachla, Rafał Wiglenda, Richard Wyczółkowski, "*Methodology for the construction of a system for monitoring leaks in water distribution networks*", X National Conference on Diagnostics of Processes and Systems, DPS'20011, Zamość 2011

[3] Wojciech Moczulski, Krzysztof Ciupke, Piotr Przystałka, Piotr Tomasik, Dominik Wachla, Rafał Wiglenda, Richard Wyczółkowski, "*Methodology for the construction of a system for monitoring leaks in water distribution networks - example of the application*" X National Conference on Diagnostics of Processes and Systems, DPS'20011, Zamość 2011

[4] Ryszard Wyczółkowski, "*System monitoring and fault detection of water supply*, VIII National Conference on Diagnostics of Processes and Systems, DPS'2007, Słubice

[5] Information on: EPANET2: *Drinking Water Research*, http://www.epa.gov/.../epanet.html,

# THE CONCEPTION OF SIMULATION ENVIRONMENT FOR DEVELOPMENT AND TESTING OF DISTRIBUTED DIAGNOSTIC SYSTEMS[1]

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Summary

Machinery, equipment and system for monitoring and diagnostics are considered. It is assumed that the considered a set of machinery and equipment is distributed territorially and/or functionally (for example, several systems which are part of one machine). Machinery, equipment and system for monitoring and diagnostics that make up a distributed diagnostic system are called nodes of that system.

The article presents the concept of the environment to develop and testing distributed diagnostic systems. Connection with each nodes of distributed diagnostic system is implemented by the agent system and blackboard. Each agent represents the selected node of the distributed diagnostic system. Locally, the agent performs the task of communicating with the node that represents and the tasks of processing and collection of information contained in the received data from that node. Globally, the agent cooperates with other agents by performing tasks transmitting, receiving, processing and storing messages. Blackboard carries out the task of collecting the data common to the entire agent system. Communication with the blackboard is implemented through an agent who represents that.

Keywords: diagnostics of mechanical systems/machines/components, systems modeling and evaluation.

KONCEPCJA ŚRODOWISKA SYMULACYJNEGO DLA POTRZEB TWORZENIA I TESTOWANIA ROZPROSZONYCH SYSTEMÓW DIAGNOSTYCZNYCH

Streszczenie

Rozpatrywane są maszyny i urządzenia wraz z systemami monitoringu i diagnostyki tych maszyn. Zakłada się, że rozpatrywany zbiór diagnozowanych maszyn i urządzeń jest rozproszony terytorialnie i/lub funkcjonalnie (np. kilka układów wchodzących w skład jednej maszyny). Maszyny, urządzenia oraz systemy monitoringu i diagnostyki wchodzące w skład rozproszonego systemu diagnostycznego są nazywane węzłami tego systemu.

W artykule przedstawiono koncepcję budowy środowiska, w którym można tworzyć i testować rozproszone systemy diagnostyczne. Połączenie ze sobą węzłów rozproszonego systemu diagnostycznego realizowane jest przez system agentowy i tablicę ogłoszeń. Każdy agent reprezentuje wybrany węzeł rozproszonego systemu diagnostycznego. Lokalnie, agent realizuje zadanie komunikowania się z reprezentowanym węzłem rozproszonego systemu diagnostycznego oraz zadania przetwarzania i gromadzenia informacji zawartych w otrzymanych od reprezentowanego węzła danych. Globalnie, agent współpracuje z innymi agentami przez realizację zadań nadawania, odbierania, przetwarzania i gromadzenia wiadomości. Tablica ogłoszeń realizuje zadanie gromadzenia danych wspólnych dla całego systemu agentowego. Komunikacja z tablicą ogłoszeń jest realizowana za pośrednictwem reprezentującego ją agenta.

Słowa kluczowe: diagnostyka układów mechanicznych/maszyn/komponentów, modelowanie systemów.

[1] Described herein are selected results of study, supported partly from the budget of Research Task No. 4 implemented under the strategic program of The National Centre for Research and Development in Poland entitled "Advanced technologies of generating energy".

## 1. THE USE OF AGENT TECHNOLOGY

### 1.1. Introduction

According to the dictionary [5] agent (Lat. *agens*, *agentis*, "acting" comes from *agere* "work, do"), this is a person acting on behalf of an institution, company.

As a result of the development of programming methods, there are special programs that, properly configured, act on user behalf, relieving him of certain tasks or searching some information for him [6]. Thus came the term *software agent* [1], where software agent is an autonomous software entity capable of interacting in their environment (especially with other agents).

By connecting several agents are built *multi-agent system*. It is important that under such a system, agents cooperate in order to realize a certain task. Multi-agent systems can create multiple copies of the same agent. As a result of such an operation is performed the parallel processing. Is obtained then higher probability obtain an optimal results.

With a wide range of tools to design and develop multi-agent systems, such as: ZEUS, BOND, or Grasshopper, special attention was paid to the environment called JADE [4]. JADE (*Java Agent DEvelopment Framework*) is a platform that fully complies with the specification developed by FIPA foundation [3].

### 1.2. Examples of application

As part of the work conducted in Institute of Fundamentals of Machinery Design, multi-agent system used in the project DiaDyn [2].

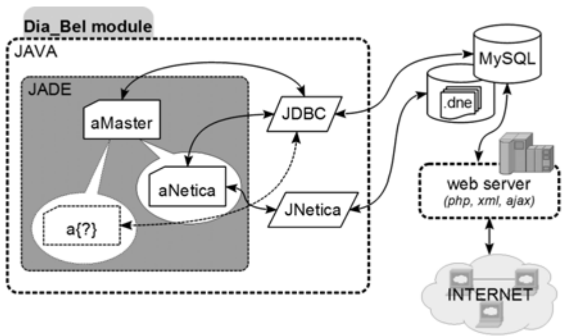


*Fig. 1 The structure of the Dia_Bel module [11]*

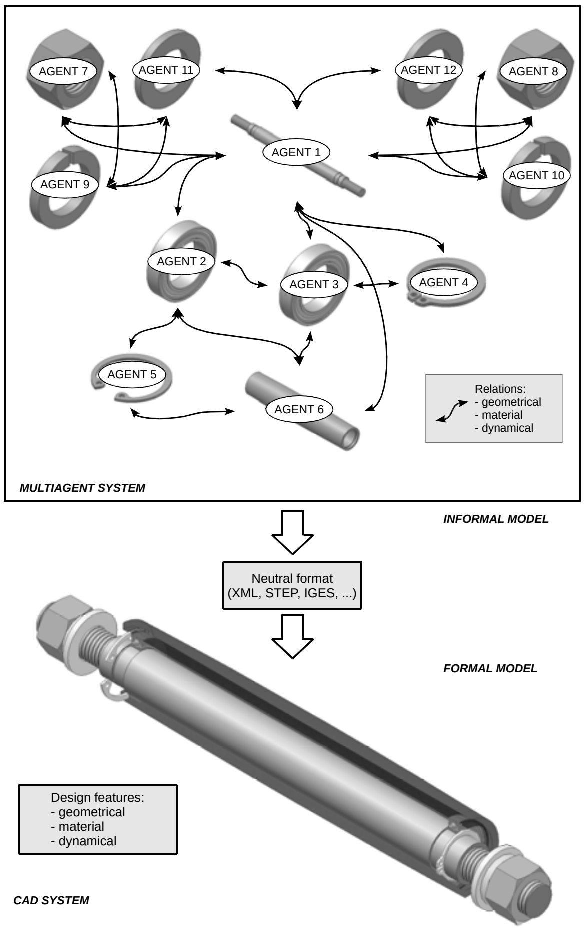


*Fig. 2 Network of agents representing the actual object model as a set of elements. The transition from informal model to formal model [10]*

DiaDyn is an open internet expert system. One of the modules of DiaDyn system is a module called Dia_Bel [11]. This module has been developed for the process of the approximate inference. Dia_Bel module is written in Java [7] and was to carry out various tasks (inference by different methods). For this reason it was decided to use the multi-agent system. It was assumed that each type of task (any method of inference), will be supported by a specialized agent.

The Fig. 1 shows the structure of the Dia_Bel module. *aMaster* agent creates *aNetica* agents and the other agents labeled as *a{?}* which support approximate inference tasks.

JADE multi-agent system was also used in the work related to aided process of the mechanical design [8][9][10]. It is proposed that each software agent is a model of a single part (Fig. 2). In order to obtain assembly of parts are combined agents, usually give a network structure. Such a connections structure should be regarded as a system of mutual design relations between the parts. The aim is to achieve a stable state of equilibrium between different types of design features and their values. The result of multi-agent system is a geometric model of the future product.

### 1.3. General assumptions

Possible situations:

1) At the output of the simulator of the object, data are not standardized. Need to develop a programs that will convert the output data format of the simulator of the object in the input data format of the blackboard. In addition, each program will communicate with the blackboard.
2) At the output of the simulator of the object, data are standardized. Just develop a one program that will communicate with the blackboard.

The best situation is the second situation. Imposition of the output data format of simulator of the object will reduce the number of needed to develop applications. On the other hand, most of the work required to adapt to the imposed format of the output data rests on the authors of the object simulators.

The basic definition of multi-agent system assumes that the some number of agents working together to solve defined problem. In the proposed concept of a simulation environment for development and testing of distributed diagnostic systems, used agent system has to solve the problem of efficient communication between nodes of the distributed system. Therefore, the role of agents is limited to tasks related to the process of communication – as the patterns of interaction between agents, are used mainly cooperation and coordination of communication tasks.

Assumed that the agent's name will consist of a small letter *a* and agent's type designation starting with a capital letter *a{?}* (*{?}* this is the type agent). Agent's type designation is written without spaces, small and capital letters in Latin characters and Arabic numerals.

## 2. THE CONCEPTION OF SIMULATION ENVIRONMENT

### 2.1. Structure of the agent system

On the Fig. 3 shows a diagram of overall structure of the agent system. It is assumed that it will be one host with blackboard application and several hosts with simulators of the objects, which will be write or read calculation results to/from the blackboard – a global database of the distributed system.

On the Fig. 4 shows a diagram of the structure of agent system from the perspective of the connection between the simulator of the object and blackboard. Hosts are connected together via a computer network (LAN or WLAN). In the case of the host with the simulator, next to the application to simulate the behavior of the selected real object, is running agent system that has access to certain directories on local disk.

For a host with blackboards, next to the software performing the functions of data collection, environmental agents are running, which acts as an intermediary between multiple simulators of the objects. Thanks to this access the database from the "outside" is limited.

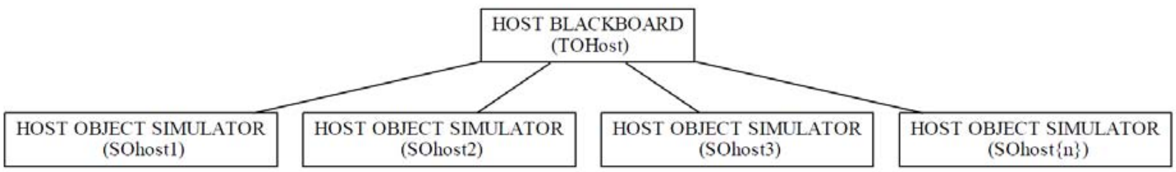


*Fig. 3 Diagram of overall structure of the agent system*

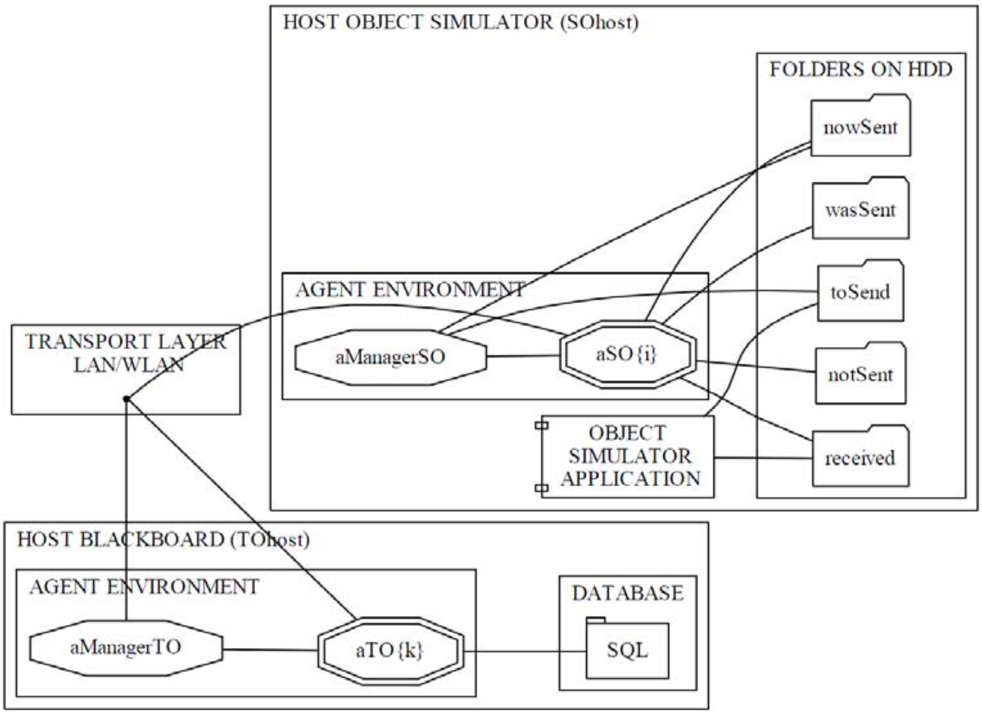


*Fig. 4 Diagram of the structure of agent system*

### 2.2. The list of types of agents

Below is a list of agent's types:

- *aManagerSO* – agent installed on the object simulator host, this agent is primarily responsible for:
  - to check are there any new data generated by the simulator of the object;
  - to verification the formal structure of the XML file;
  - to upgrade the status of the XML file, by modifying the value of the indicated timestamp;
  - to create an agent *aSO{i}*;
  - to delete an agent *aSO{i}*, when it finishes its task.
- *aSO{i}* – agent run by agent *aManagerSO* on object simulator host, *{i}* variable is set to name of the XML file that contains the data generated by the SO, this agent is primarily responsible for:
  - to connect to the agent *aManagerTO* on the side of the blackboard host;
  - to read the XML file and send it to the agent *aTO{k}* on the side of the blackboard host;
  - to upgrade the status of the XML file, by modifying the value of the indicated timestamp;
  - to save in a specified folder on local disk receiving from an agent *aTO{k}* a message that contains the XML structure.
- *aManagerTO* – agent on the side of the blackboard host, this agent is primarily responsible for:
  - to wait for a message from an agent *aSO{i}* on the side of the object simulator host;
  - to create an agent *aTO{k}*;
  - to delete an agent *aTO{k}*, when it finishes its task.
- *aTO{k}* – agent run by agent *aManagerTO* on the blackboard host, *{k}* variable is set to name of the XML file that contains the data generated by the SO, this agent is primarily responsible for:
  - to connect to the agent *aSO{i}* on the side of the object simulator host;
  - to receive a message sent by the agent *aSO{i}*,that contains the XML structure;
  - to process the information contained in the structure of XML and to generate and execute SQL queries;
  - to send SQL query results to the agent *aSO{i}*.

### 2.3. Data format

It is assumed that the data generated by the simulator of the object will be transferred in the form of files stored in XML format. The XML format allows for a unification of all files, regardless of the stored information and allows it to check the formal correctness of the stored content. XML file name must be unique across the distributed system and should be an identification. To generate the file name is proposed to use the MD5 algorithm

(*Message-Digest algorithm 5*). As an input parameter to a MD5 function we can specify a string which is the sum of the following components:

```
XML_FILE_NAME =
file creation time stamp (Unix time)
+ random string of 12 digits
```

A specific XML structure should include information about: XML file, performed simulations, simulated object and also variables and the vectors of values of these variables. Below is shown a general form of a specific XML structure:

```
<?xml version="1.0"
      encoding="ISO-8859-2"?>
<!DOCTYPE objSimData SYSTEM
      "_objSimData.dtd">
<file>
  ...
</file>
<simulation>
  ...
</simulation>
<object>
  ...
</object>
<quantities>
  <quantity>
    ...
  </quantity>
  <quantity>
    ...
  </quantity>
  ...
</quantities>
<vectors>
  <vector>
    ...
  </vector>
  <vector>
    ...
  </vector>
  ...
</vectors>
```

Below describes in detail what information should be included in the presented XML structure.

As information about the XML file must be included:

- version number of the XML structure;
- id of a data file (the same as the XML file name);
- information about who generated the file (e.g. author name);
- description of the data file (additional information about the XML file);
- timestamp (Unix time) to generate the file and save it in *toSend* folder;
- timestamp (Unix time) transfer the file to the *nowSent* folder (start the process to send the file content to the blackboard);
- timestamp (Unix time) transfer the file to the *wasSent* folder or to the *notSent* folder (complete the process of transfer the file to the blackboard – success or failure);
- timestamp (Unix time) queries the database (blackboard);
- timestamp (Unix time) to save in a *received* folder the file that contains data generated by the blackboard;
- status of data file, e.g.: 0 - waiting to send; read data from blackboard, 1 - waiting to send; save the data in blackboard, 2 – busy; sending process is still on, 3 - sent (saved in blackboard), 4 - unsent (unsaved in blackboard), 5 - another error;
- description of the status (additional information about the error, such as error code).

The proposed XML structure is as follows:

```
<file>
  <verXML></verXML>
  <file_id></file_id>
  <file_author></file_author>
  <file_desc></file_desc>
  <timestamp_create>
           </timestamp_create>
  <timestamp_sendstart>
           </timestamp_sendstart>
  <timestamp_sendstop>
           </timestamp_sendstop>
  <timestamp_query>
           </timestamp_query>
  <timestamp_receiv>
           </timestamp_receiv>
  <status></status>
  <ststus_desc></status_desc>
</file>
```

As information about the simulation process should be considered:

- id of the simulation;
- name of the simulation;
- description of the simulation (for more information about the simulation).

The proposed XML structure is as follows:

```
<simulation>
  <sim_id></sim_id>
  <sim_name></sim_name>
  <sim_desc></sim_desc>
</simulation>
```

As information about the simulated object should be considered:

- id of the object;
- name of the object;
- description of the object (for more information about the object);
- the manufacturer's name.

The proposed XML structure is as follows:

```
<object>
  <obj_id></obj_id>
  <obj_name></obj_name>
  <obj_desc></obj_desc>
  <obj_ manufacturer>
      </obj_ manufacturer>
</object>
```

As information about the values of variables should be considered:

- identifier of the variable;
- name of the volume;
- physical unit (if appointed size);
- description of the variable (for additional information about the variable);
- size (single value or a vector of values);
- id of the related variable (e.g. time series requires a two variables, such as time and speed).

The proposed XML structure is as follows:

```
<variables>
  <variable>
    <var_id></var_id>
    <var_name></var_name>
    <var_unit></var_unit>
    <var_desc></var_desc>
    <var_dim></var_dim>
    <var_related_id>
            </var_related_id>
  </variable>
  ...
</variables>
```

As information about the vector of variable values should be considered:

- id of the vector of values;
- identifier of the variable;
- value or values separated by semicolons (values can be either numeric values or the values of quality);
- description of the vector (for more information about the vector values).

The proposed XML structure is as follows:

```
<vectors>
  <vector>
    <vect_id></vect_id>
    <vect_var_id></vect_var_id>
    <vect_value></vect_value>
    <vect_desc></vect_desc>
  </vector>
  ...
</vectors>
```

### 2.4. The message encoding format

The exchange of messages between software agents, JADE uses a special language called *ACL* (*Agent Communication Language*, FIPA-ACL standard). As part of the language defines different types of messages sent, e.g. *inform*, *request*, *query* and *propose* [3][4]. The structure of the sample message is shown below (sign ":" precedes the message parameters).

```
(inform
  :sender agent1
  :receiver agent2
  :content (some information
        content)
  :language English
)
```

This message is a message sent by the sender *agent1* to the recipient *agent2* with the content of *some information content* stored in *English*.

Each message has: id of the sender (*sender*), id of the receiver (*receiver*), message content (*content*), language ID of the message encoding (*language*). The process of transmitting and receiving messages is asynchronous. Each agent, as part of its resources, has its own "mailbox". It was concluded that the use of language ACL facilitate transfer of XML files with data which are generated by the simulator of the object. For this purpose, set the message content as an XML file, and the language defined as XML, as follows:

```
ACLMessage msg =
 new ACLMessage(ACLMessage.INFORM);
msg.addReceiver(<id_recipient >);
msg.setLanguage("XML");
msg.setContent("
  <?xml version="1.0"
      encoding = "ISO-8859-2"?>
  <!DOCTYPE objSimData
      SYSTEM "_objSimData.dtd">
  <file> ... </file>
  <simulation> ... </simulation>
  <object> ... </object>
  <feature> ... </feature>
  <vector> ... </vector>");
send(msg);
```

### 2.5. The communications process

Fig. 5 shows a diagram of process of communication between the three agents: *aSO{i}*, *aManagerTO*, *aTO{k}*. According to previous assumptions, agents to communicate using the ACL language. Computer network (LAN/WLAN) is the medium of transmission between *Object Simulator (SO)* and *Blackboard (TO)*.

Sending XML data generated by the simulator of the object (SOHost) proceeds in five steps:

1) **REQUEST** After creating, the *aSO{i}* agent is ready to send the XML file contents to the blackboard. For this purpose sends to the *aManagerTO* agent request to create a transmission channel.
2) **<<create>> NewAgent()** The task of creating a new *aTO{k}* agent. This task is performed by the *aManagerTO* agent without the use of language ACL and has an indirect, but a key influence on the communication process.
3) **AGREE/NOT-UNDERSTOOD/REFUSE** After creating, *aTO{k}* agent sends to *aSO{i}* agent a response message: permission to establish a transmission channel, the information that the request is unclear or lack of consent to establish transmission.
4) **REQUEST(XML File)** After receiving permission to the transmission of data, the *aSO{i}* agent sends to the *aTO{k}* agent a message containing data stored as XML, otherwise it returns an error to an *aManagerSO* agent and ends the task.
5) **AGREE/REFUSE** An *aTO{k}* agent tries queried database (*Blackboard*). Database query results has an influence on the content of messages sent to an *aSO{i}* agent; possible answers are: `ok` or `error`. In the case when answer is `ok`, *aTO{k}* agent sent to *aSO{i}* agent structure of XML.

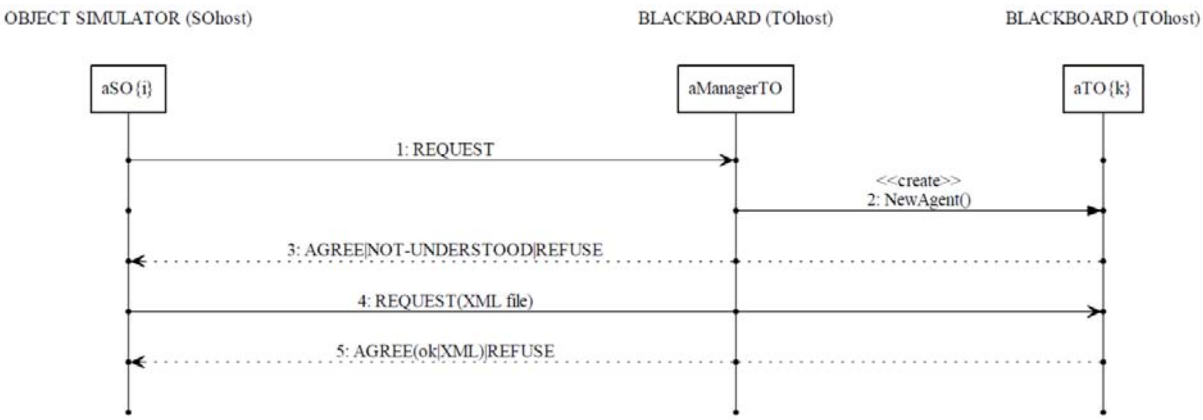


*Fig. 5 Diagram of communication between agents using the ACL language*

## 3. SUMMARY

Ultimately, the described system will be installed on virtual machines (virtualized computing resources). An analysis of the structure of the system shows that the most sensitive element is a blackboard. In order to increase the reliability of this system is planned to use the cloning mechanism for host and database.

The proposed solution allows the combination of simulators of objects developed in different research groups, without having to send the applications. Among the many benefits include: no necessity distribute new versions of the simulator and remote start of the calculation without involving their IT resources. The exchange of messages between hosts is carried out according to fixed rules in a heterogeneous environment.

Using XML allows a simple extension of the proposed structure with new elements, and thus provide additional information.

## REFERENCES

[1] Adamczewski P.: *Słownik informatyczny*, Helion, Gliwice, 2005.
[2] Cholewa W. (Eds.): *Szkieletowy system doradczy DIADYN*, vol. 137 serii Zeszyty, Silesian University of Technology, Department of Fundamentals of Machinery, Gliwice, 2008.
[3] FIPA - The Foundation for Intelligent Physical Agents, http://www.fipa.org
[4] JADE – Java Agent DEvelopment Framework, http://jade.tilab.com
[5] Kamińska-Szmaj I. (Eds.): *Milenijny Słownik Wyrazów Obcych*, Europa, Wrocław, 2002.
[6] Nwana H., Ndumu D.: *A perspective on software agents research*. The Knowledge Engineering Review, 14(0):125–142, 1999.
[7] Oracle Corporation: Java Platform, Standard Edition (Java SE). http://www.oracle.com/technetwork/java/javase/downloads/index.html

[8] Rzydzik S.: *Application of multi-agent system in the design process*, in: M. Wasilczuk: Podstawy Konstrukcji Maszyn – kierunki badań i rozwoju. Tom I. Gdańsk, 2011, s. 163-171.

[9] Rzydzik S., Skarka W.: *Formal model for the purpose of generative modeling based on multi-agent system*. Symposium on Methods of Artificial Intelligence, Gliwice, November 2009.

[10] Rzydzik S., Skarka W.: *Multiagent system for aiding designing process*. New World Situation:New Directions In Concurrent Engeneering, vol. Proceedings of the 17th ISPE International Conference on Councurrent Engeneering, Kraków, 6-10 September 2010, Springer-Verlag, 2010.

[11] Rzydzik S.: *Wnioskowanie w sieci stwierdzeń zorganizowanej jako sieć bayesowska*, in: W. Cholewa (Eds.), Szkieletowy system doradczy DIADYN, vol. 137 serii Zeszyty, Silesian University of Technology, Department of Fundamentals of Machinery, Gliwice, 2008, pp. 67-82.

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# MOBILE DEVICES IN DIAGNOSTIC SYSTEMS

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Summary

The strong growth of mobile technologies with increasing quality and data rates encourage the use of mobile terminals for diagnostic purposes. It concerns the diagnostics of simple objects for everyday use as well as complex objects that often belong to a group of machines called critical objects.

There is no doubt that such solutions will be expected by the operators of machinery and equipment in the near future. Solutions based on mobile technologies require appropriate preparation of diagnostic mobile applications in many aspects. The reasonable implementation of mobile devices forces the application designer to solve at least two difficult tasks. The first task relates to the design of user interface functionality and shape, taking into account a number of existing constraints, such as the screen size of mobile device, performance of the unit, applied data transmission technology and a quality of secure data channel in a mobile network. The second task is associated with the selection of optimal technology used to operate in mobile environment with detailed substantiation of the decision.

The aim of this paper is to describe the basic principles which should guide the implementation of solutions enabling the user wireless access to diagnostic data of a technical object. Also basic requirements for well-designed user interface of the mobile application will be given in the paper.

Keywords: technical diagnostics, condition monitoring, mobile monitoring.

URZĄDZENIA BEZPRZEWODOWE W SYSTEMACH DIAGNOSTYCZNYCH

Streszczenie

Silny rozwój technologii mobilnych, któremu towarzyszy podwyższanie jakości i szybkości przesyłania danych zachęca do korzystania z terminali mobilnych do celów diagnostycznych. Dotyczy to diagnostyki prostych obiektów codziennego użytku, jak również złożonych obiektów, które często należą do grupy maszyn nazywanych obiektami krytycznymi.

Nie ma wątpliwości, że takie rozwiązania będą w najbliższej przyszłości oczekiwane przez operatorów maszyn i urządzeń. Rozwiązania oparte na technologiach mobilnych, wymagają odpowiedniego przygotowania diagnostycznych aplikacji przeznaczonych na urządzenia mobilne z uwzględnieniem wielu aspektów. Wdrożenie urządzeń mobilnych wymusza na projektancie aplikacji rozwiązanie co najmniej dwóch trudnych zadań. Pierwsze zadanie dotyczy projektowania funkcjonalności interfejsu użytkownika i jego postaci, biorąc pod uwagę liczbę istniejących ograniczeń, takich jak rozmiar ekranu urządzenia mobilnego, wydajność urządzenia, stosowaną technologię transmisji danych oraz jakość zabezpieczenia kanału przesyłu danych przez sieć bezprzewodową. Drugie zadanie jest związane z wyborem optymalnej technologii, która będzie użyta na urządzeniu bezprzewodowym.

Celem niniejszego opracowania jest przedstawienie podstawowych zasad, które powinny przyświecać wdrażaniu rozwiązań umożliwiających użytkownikom realizację bezprzewodowej diagnostyki obiektu technicznego. W artykule przedstawione zostaną także podstawowe wymagania dla dobrze zaprojektowanego interfejsu użytkownika aplikacji mobilnej.

Słowa kluczowe: diagnostyka techniczna, monitorowanie stanu, monitorowanie bezprzewodowe.

## 1. INTRODUCTION

Activities in the area of condition monitoring and technical diagnostics of machinery required an appropriate presentation of their results. In the 1980s and 1990s when PC computers became common a large number of software applications for the presentation of such an information on computer monitors. One prevailing type of a system that became fairly common at that time were SCADA (Supervisory Control And Data Acquisition) type systems. These systems have been used for supervising manufacturing processes and they are in common use nowadays too.

The end of the previous century is also the period of time in which mobile devices were revealed for wireless communication and using public mobile networks. As the technology became more and more mature, operators were making to users various services of wireless communication, to name only voice-based services, short messaging systems (SMS) or the internet. Of all users diagnostic systems users have expected a continuous access to object data of their interest. Using mobile devices in order to access these objects through the internet meets their needs. At the same time smartphone devices have provided developers and system architect with vast opportunities. The devices that are now available on the public market are solutions based on a few popular operating systems (Android, iOS, BlackBerry, WindowsPhone…). They provide users with enormous possibilities in using at least one independent communication channels: GSM module for GPRS transmissions, Bluetooth or WiFi.

Over the years the developments of stationary SCADA systems have provided users with general guidelines on the accepted form and the functionality of interfaces of these systems. However, the guidelines require fundamental modifications if mobile terminals are used for presenting the necessary information to users operating monitoring or technical diagnostic systems. At the Chair of Fundamentals of Machine Design, Silesian University of Technology, Gliwice, several projects have addressed the issue of using smartphones as mobile monitoring terminals. The conclusions have allowed us to accumulate and draw general recommendations. Clearly, while designing the above systems one should take into account that any system under the development will be either a part of an existing IT infrastructure or it will be developed from scratch. If the former is the case, the system still should meet data acquisition and storage needs. One key decision is the role that a mobile device must perform within a system. It should be capable operating in one of the following two modes:

- thin client – the mobile device is used only for the presentation of results that are made available by a server. It is not used for computing purposes,
- thick client – the data that are provided by the server to the client device are also processed there, e.g. for trend analysis, etc.

Determining the specific operation mode of a mobile terminal has a significant impact on the choice of a device – it determines base configuration performance parameters.

## 2. LIMITATIONS AND PROBLEMS

Monitoring and diagnostic systems on mobile devices are a convenient solution that, however, possesses some limitations. First of all, users should keep in mind that

- Mobile device screen is much smaller than that of a PC monitor's.
- There are data storage limitations (32 GB limit on most devices due to microSD card capacity).
- Mobile terminal is inferior to a PC computer in terms of performance.
- Mobile networks, Wi-Fi or Bluetooth cannot compete against LAN or industrial networks in terms of capacity/performance.
- Data transmission should be guaranteed regardless the signal strength of mobile networks, Wi-Fi or Bluetooth.
- There are major safety issues concerning data transfer to and from mobile devices.
- One problem that should be taken into account during the design and implementation process is the lack of sufficient knowledge on mobile system based solutions. It can be the source of problems while implementing tasks involving designing and developing mobile device based systems,
- Mobile device are rid of standard keyboards. QWERTY or GSM type keyboards are most often replaced with virtual solutions (in the form of a keyboard projected on screen during data input).
- Mobile devices are not equipped with mouse devices (that are well known in the world of PCs). Some devices feature touch pads that are similar to those used with laptops [5].

The end-user's age is not without significance, neither. It should be taken into account that end-users can be elderly people. Therefore, forcing users to use a small device featuring a diminutive screen and a tiny keyboard (or no keyboard at all) as a terminal device, may limit their efficiency. In such cases even the best performing system may not receive good accessibility reviews (e.g. eye sight problems, touch screen problems, mental health issues, etc.).

## 3. CHOOSING A PLATFORM

First of all, while making a decision on the use of smartphones in a diagnostic system a system platform must be chosen which the system will operate on. The following factors are important:

- Platform performance
- Access to developer kits (SDKs)
- Price
- Safety of the data that are collected on mobile devices
- Safety of the data that are transferred to and from the device
- Platform's popularity – it has major impact on the final application price on a mobile device
- Modification of a mobile solution in terms of interoperability with the user's existing infrastructure (API development).

Also, note that any implemented solution must be supported over the period of a few years at least.

Mobile applications should be developed within that period of time and an access to qualified software developers ensured. Therefore, brand new and unknown platforms should be best avoided for a minimum risk.

## 4. CHOOSING A DEVICE

One fundamental task that is realized while developing a mobile diagnostic system is the choice of an appropriate device or a group of devices that will be used for performing diagnostic and maintenance activities.

As already mentioned, choosing a device is a key element of the design and development process of a mobile system. Attention should pa paid to the following elements:

- screen size – it influences the amount of information and the so-called accessibility
- data input – all data input techniques have their pros and cons. Whether a touch-screen or a conventional keyboard is used, work conditions and the behavior of targeted users should be taken into account.
- mass and comfort – smartphones meet the requirements. Tablets, however, are more problematic due to their screen size (7 to 10 inch.) and size-related transport issues.
- hardware and software updates and upgrades
- user experience.

## 5. INTERFACE DEVELOPMENT FUNDAMENTAL RULES

One of the most important elements of a mobile system that follows the choice of a mobile platform and a device (or a group of devices) is the mobile application user interface. During the design and development process several fundamental rules should be followed in order to have a better chance of developing a good quality, comfortable and intuitive application. The rules are obligatory for both mobile as well as conventional stationary platforms.

When beginning work on the user interface, a screen should be separated into specific zones. Each zone should be used for different activities across the whole application. It should be emphasized that each zone should have distinct borders. The information zones should be set in the order that they are processes by users, from top to bottom and from left to right.

Moreover, while working with the application users should have the ability to verify at which place/location he/she is and what information is presented on the screen. From the standpoint of application users screen captions are also important. Button that can be found on each screen should be well described. With small-size screens where long captions are not possible callouts are recommended, i.e. information appearing while a pointer is hovering over a specific button or they are activated on tapping a button [2].

For aesthetic reasons it is recommended that the amount of presented information should balance its visual appeal. It is essential to avoid using multiple types of fonts within the scope of one application. Fancy fonts should be avoided as well as using them will make the on-screen content much harder to be read. Colors should be paid attention to as well. A color cannot be the only one discriminant of the presented information due to accessibility issues, e.g. daltonism.

Depending on the targeted group of users (expert users, beginners – mobile devices or diagnostic systems) the system should allow an easy learning of the interface. Mobile applications feature very popular interface elements called „menus" (main menu or context menu). It is recommended to develop them in such a way as not to overload users with the context and the number of menu levels. The rule of thumb is that a main menu will incorporate no more than three levels and a context menu no more than two levels. The menu should include no more than a few items at any level [4].

To make one's work with mobile application easier interface solutions on each screen should be consistent. One last rule is minimizing the number of steps (clicks) leading users to the assumed goal. At this point it is possible to apply the rule of 3 taps. According to the rule, the number of taps (or clicks) transferring users to a specified function by buttons or menu elements should not exceed three taps.

## 6. INTERFACE DEVELOPMENT

The above requirements must be fulfilled in the interface development process that includes the following stages:

- Specification of functionality,
- Scenarios of use,
- Interface structure design,
- Interface standard design,
- Interface design prototyping,
- Interface grading.

The development of a scenario is a verbal description of steps that a user must accomplish in order to achieve specific goals. The basis for such scenarios is use case models or sequence diagrams. By a fashion, two or three best scenarios are taken into consideration.

The interface structure determines principal components of the interface and its interoperability in terms of providing a specified functionality to users. For example, the structure can be represented with the Window Navigation Diagram (WND) for modeling of window (screen) layouts and transitions between them.

During the interface design stage a library of elements for interface prototyping and design is developed and set up. Also, this stage involves the nomenclature (element names, their meaning and

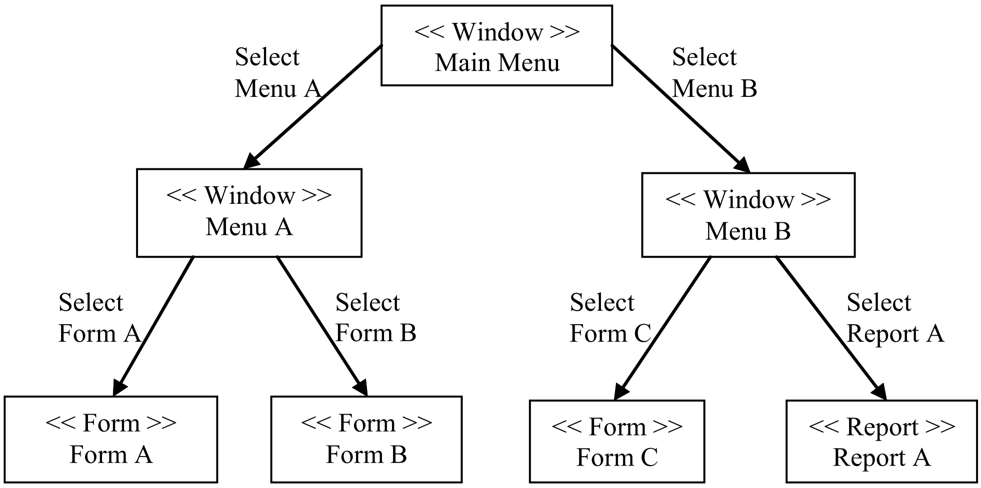


*Fig. 1: An example of Window Navigation Diagram [1]*

form). It is acceptable to define so-called interface metaphors, e.g. shopping cart.

The last stage concerns the so-called interface grading. Briefly, various techniques can be used here to accomplish this task.

One possibility involves checking the interface functionality against requirements by three independent experts. Other methods include the interface review with an end-user or an interactive grading that users perform.

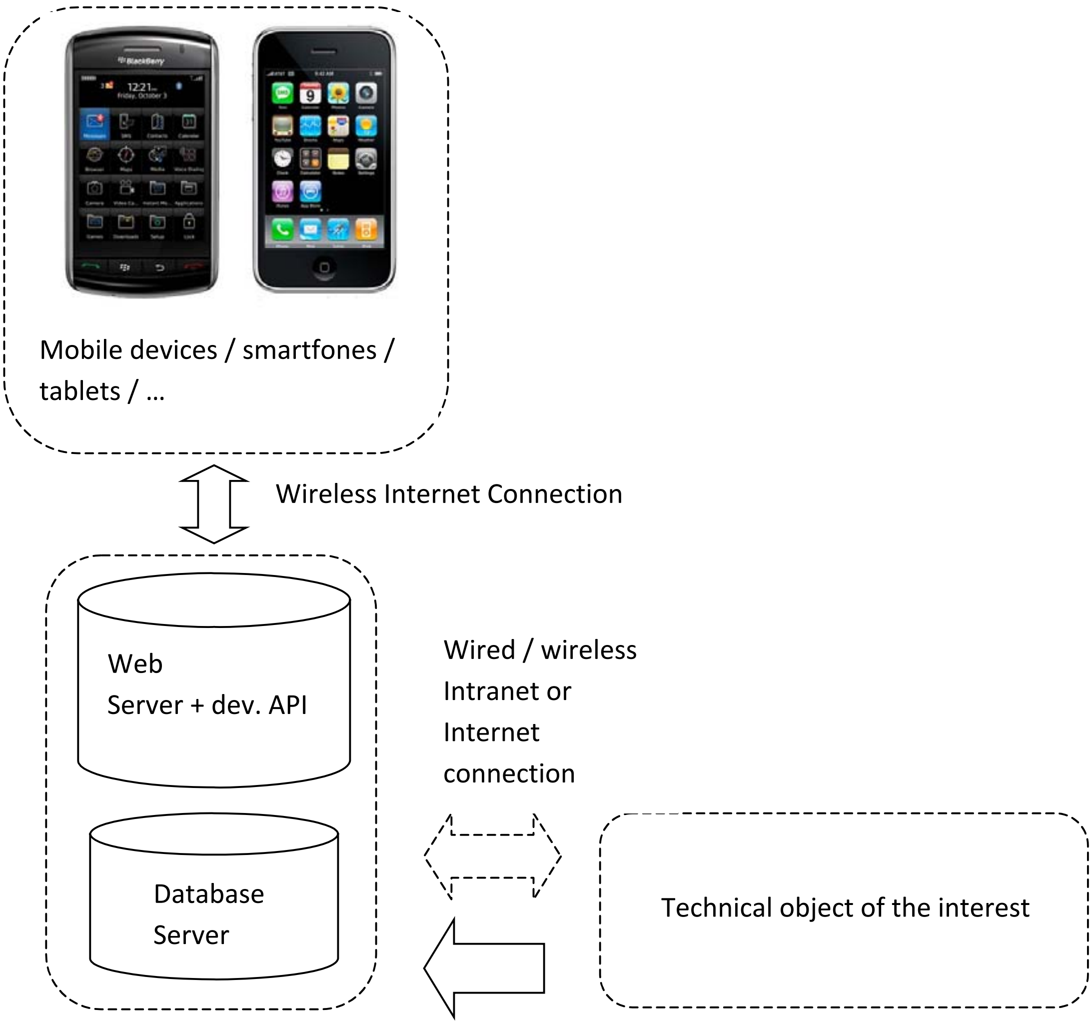


*Fig. 2. Layout of the developed telemetry system*

Regardless the applied method the grading process is completed by on-site testing of the application by users. It is an iterative process that is carried out till positive reviews are obtained.

## 7. EXAMPLES

At Chair of Fundamentals of Machinery Design, Silesian University of Science and Technology, Gliwice, projects that utilize mobile systems for condition monitoring are undergraduate projects as

well as thesis projects and projects by the student research society Mobile Devices in Condition Monitoring and Control.

Examples of well-designed applications are tools developed for BlackBerry PlayBooks (tablets) as well as a BlackBerry 10 Dev Alpha smartphone. One of the applications was developed for the purpose of monitoring of a vehicle participating in the Shell Eco-marathon, Rotterdam [7].

The developed telemetry system incorporates a data concentrator module that is installed on a vehicle. Using GPRS, the module allows for the data transfer via CAN to a main server on a stationary computer. The server stores the data in a SQL database. The server includes an application for transferring of the data from the database to the mobile application.

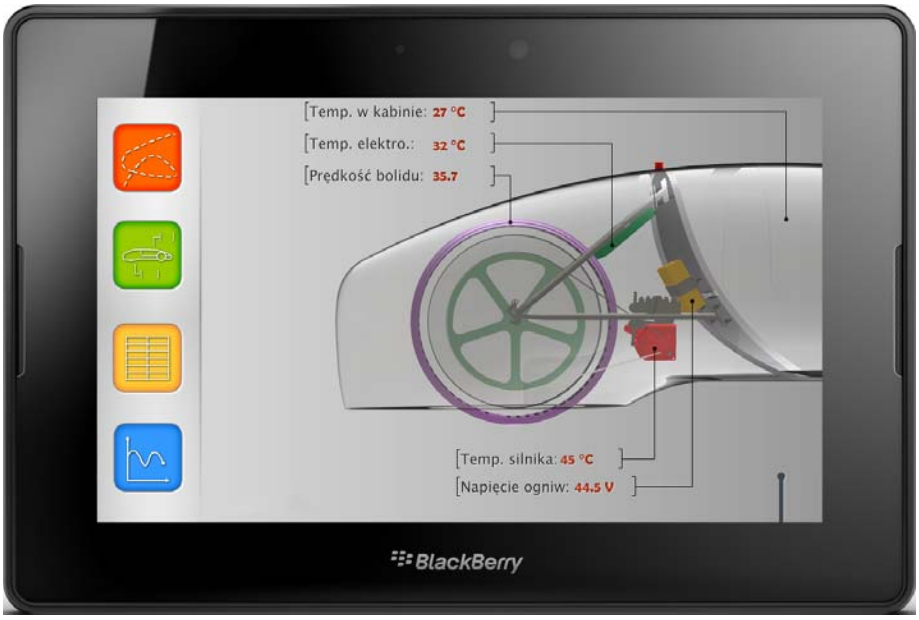


*Fig. 3: Telemetry on BlackBerry PlayBook – additional/extra information [6]*


*Fig. 4: Telemetry on BlackBerry PlayBook – velocity chart [6]*

Data exchange is carried out wirelessly through XML or JSON files. In the described example Wi-Fi was chosen due to limitations of the BlackBerry PlayBook tablet that was rid of a GPRS module.

The BlackBerry PlayBook application was developed using the Adobe AIR technology. It is used for monitoring of parameters of a race car. The interface is easy-to-comprehend even for users not familiar with such applications. The menu zone is located in the left hand-side section of the screen and the communication with end users is by means of icon-based buttons for efficiency. For example, selecting the top icon users will observe the present position of the vehicle on the track illustrated within the screen zone occupying appr. 90% of the screen size. Selecting the second (green) icon will result in the screen presenting all basic information on the vehicle (see Fig. 2).

Tapping on the last icon displays a chart presenting the vehicle's velocity change on a road track (see Fig. 4).

While developing the application, one major criterion was a clear menu on device with a touch-screen. The presented content is readable. The screens are not overloaded with an excessive amount of information.

## 8. SUMMARY

The paper addresses the issue of specific requirements for the development of monitoring and diagnostic system equipped with mobile terminals. The requirements were determined following conclusions acquired throughout the course of IT projects involving attempts to develop such systems. Specifically, research on user interfaces in mobile devices was carried out involving a BlackBerry smartphone based customer feedback system for a major fuel station network. Some interesting examples include undergraduate, and thesis projects and student projects in the society of Mobile Technologies in Condition Monitoring and Control that introduce a new quality into the process of educating future engineers that are familiar with the needs of machinery and technical device operators.

The systems that they have developed have met most quality requirements for mobile interfaces.

## REFERENCES

[1] A. Dennis, B. Wixom, D. Tegarden. *Systems Analysis and Design with UML*. John Wiley & Sons, ISBN 978-0-470-40030-2, 2009.
[2] Majlinda Fetaji, Suzana Loskoska, Bekim Fetaji, Mirlinda Ebibi. *Investigating human computer interaction issues in designing efficient virtual learning environments*. BCI 2007, pages 313–324, 2007.
[3] Rolf Hennicker, Nora Koch. *Modeling the user interface of web applications with UML*. pUML'01, pages 158–172, 2001.
[4] Jarosław Kuchta. *Dokumentacja i jakość oprogramowania. Projektowanie interfejsu użytkownika 1*. 2010, in Polish
[5] Ben Shneiderman, Catherine Plaisant. *Designing the User Interface: Strategies for Effective Human-Computer Interaction* (4th Edition). Addison Wesley, April 2004.
[6] K. Sternal, *Projekt układu telemetrycznego bolidu wyścigowego*, Praca dyplomowa magisterska, Politechnika Śląska w Gliwicach, Katedra Podstaw Konstrukcji Maszyn, Gliwice 2012, in Polish
[7] Information on http://mkm.polsl.pl/

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## Protokół z posiedzenia Zarządu Głównego Polskiego Towarzystwa Diagnostyki Technicznej

Zebranie Zarządu PTDT odbyło się dn. 6.03.2012 w ośrodku Geovita w Wiśle, w którym odbywało się XXIX Sympozjum Diagnostyka Maszyn.

Obecni na posiedzeniu byli:
- prof. dr hab. inż. Walter Bartelmus
- prof. dr hab. inż. Wojciech Batko
- prof. dr hab. inż. Czesław Cempel
- dr inż. Witold Cioch
- prof. nz. dr hab. inż. Andrzej Grządziela, wiceprezes zarządu
- prof. dr hab. inż. Stanisław Radkowski
- prof. dr hab. inż. Tadeusz Uhl, prezes zarządu
- prof. dr hab. inż. Andrzej Wilk
- dr hab. inż. Tomasz Barszcz, sekretarz zarządu

Dodatkowo, jako goście obecni byli:
- prof. nz. dr hab. inż. Janusz Gardulski, przewodniczący komitetu organizacyjnego XXXVIII Sympozjum „Diagnostyka Maszyn"
- dr inż. Sławomir Wierzbicki, sekretarz redakcji czasopisma „Diagnostyka"
- prof. Wiesław Staszewski, nowy redaktor naczelny czasopisma „Diagnostyka"
- prof. Jerzy Motylewski, przewodniczący Komisji Rewizyjnej

Zebranie otworzył Prezes Zarządu PTDT – prof. dr hab. inż. Tadeusz Uhl, witając zebranych.

Sporządzono listę obecności. Obecnych było 9 osób (na 14 członków zarządu), co pozwoliło na podejmowanie decyzji na posiedzeniu. Ustalono, że przedyskutowane zostaną bieżące sprawy, a późniejsze głosowania odbędą się w najbliższym czasie drogą e-mailową. Następnie, T. Uhl przedstawił porządek obrad, który został zaakceptowany.

Prof. Tadeusz Uhl odczytał okolicznościowy adres do prof. Michalskiego z podziękowaniem za wieloletnie prowadzenie czasopisma „Diagnostyka".

Prof. T. Uhl przedstawił nowego redaktora naczelnego „Diagnostyki" – prof. Wiesława Staszewskiego, którego poprosił o zabranie głosu. Prof. W. Staszewski powitał zebranych, a następnie krótko przedstawił przebieg swojej kariery naukowej. Rozpoczął ją u prof. Cz. Cempla, następnie przez 22 lata pracował na uniwersytetach w Wlk. Brytanii. Jednocześnie zdobył stopień doktora habilitowanego (w IMP PAN) i uzyskał tytuł profesora. Nadmienił, że posiada doświadczenie w zakresie czasopism naukowych, jest „assosiated editor" 4 czasopism naukowych. Podziękował za zaufanie i powierzenie funkcji redaktora naczelnego, postara się, żeby środowisko nie było zawiedzione. Ma kilka pomysłów, chciałby je przedstawić i prosi o opinie. „Diagnostyka" jest jednym z najstarszych czasopism naukowych na świecie w dziedzinie diagnostyki maszyn, ale ma niestety zasięg tylko lokalny. Pierwszym globalnym

czasopismem o podobnym profilu był MSSP, ale nie jest skierowane na tematykę diagnostyczną. Po ostatnich zmianach jest jej zresztą coraz mniej.

Pierwsza uwaga to tytuł: „Diagnostyka" w wersji polskiej musi pozostać ze względów formalnych, ale chciałby zmienić tytuł angielski. Odniesieniem powinno być Structural Health Monitoring, publikowany przez Sage, który ma IF 2.2, oraz inne czasopisma związane z poszczególnymi środowiskami, np. budownictwem. Jest też kilka czasopism, które nie posiadają IF. Poza tym prace z zakresu diagnostyki publikowane są w różnorodnych innych czasopismach. Kluczowe w ocenie czasopism są cytowania, dlatego bardzo istotne jest publikowanie w periodykach z USA, które mają największą cyrkulacje.

Angielska wersja tytułu nie ma właściwego odniesienia, słowo „diagnostics" w języku angielskim ma konotacje w medycynie, a nie w inżynierii. Jeżeli chcemy wejść do bazy danych, powinniśmy mieć hasła: SHM (Structural Health Monitoring), HUMS (Health & Usage Monitoring Systems), Condition Monitoring. Dobrze jest wybrać dwa albo trzy elementy, tak, aby tytuł w bazie danych miał dużą cyrkulacje. żadne z istniejących czasopism nie ma takiego spektrum w zakresie tytułów. Takie połączenie byłoby dużą zaletą i poddaje tą sprawę do dyskusji.

Kolejna kwestia to rada naukowa, pojawiło się kilka nazwisk z zagranicy, co jest dobrze widziane. Prof. Staszewski spytał zebranych, czy są sugestie, co do zmiany. Nie jest dobrze widziana zbyt duża liczebność rady programowej, może należy wprowadzić limit? Może należy wprowadzić nowe działy odzwierciedlające nowe zakresy, które planujemy wprowadzić.

W samym czasopiśmie widoczne są drobne problemy językowe, kilka uwag podstawowych w

czasopiśmie i na stronie internetowej, to używanie nie tłumaczeń polskich terminów, ale właściwych zwrotów: editorial board, editor in chief, asssociated editor.

Dobrą wiadomością jest to, że mamy ISSN, stąd do bazy danych jest już niedaleko. Proponuje wejść do bazy Scopus, jest duża i ma dobry zasięg. Należy się tam zarejestrować i starać się o cytowania. Po kilku latach będzie się pojawiać cyrkulacja, cytowania, potem IF. Są metody na właściwe zarządzanie IF, które należy w miarę możliwości zastosować.

Należy przede wszystkim postulować, żeby artykuły z doi były wliczane do dorobku. W obecnej praktyce czasopism artykuły długo są na liście „in-press", kiedy mają tylko indeks doi i gdy artykuł jest publikowany już ma 5-6 cytować. Należy dążyć do publikowania regular papers, Niechętnie publikuje się short communication i technical note. Bardzo dobrze widziane są review article, ponieważ mają bardzo duże cytowania. Takie artykuły powinny się pojawić raz, dwa razy w roku. Warto przejrzeć inne czasopisma i zobaczyć, co nie było w tym zakresie zrobione. Inny pomysł to tutorial articles, które mogą mieć po 100 stron.

Ostatnio pojawiają się np. w MSSP i uzyskują bardzo dobre cytowania. Dodatkowo często robi się special issue na zaproszenie redakcji, co znacznie podnosi cytowania. Niemile widziane są special issues z konferencji, ponieważ to źle wpływa na IF.

Prof. Staszewski zaapelował, żeby nie było artykułów po polsku, ponieważ na autorach z zagranicy robi to złe wrażenie już na początku. Aby powiększyć grono autorów, poprzez swoje osobiste kontakty można przyciągnąć 1-2 zagraniczne artykuły dobrych nazwisk.

Prof. Staszewski wspomniał, że jest propozycja zupełnie nowego czasopisma zgłoszonego do Elsevier'a – International Journal of Condition Monitoring oraz poinformował, że przeprowadzono wstępne rozmowy na temat ewentualnego stworzenia tego czasopisma przy znaczącym wkładzie i na bazie „Diagnostyki". Jest to o tyle dobre, że marka Elsevier jest dużo bardziej znana na świecie niż PTDT. Atutem Diagnostyki jest natomiast ponad 20-letnia historia. Prof. Staszewski nadmienił, że może nawet warto wziąć z grona zainteresowanych powołaniem nowego czasopisma redaktora naczelnego. Dużą zaletą wejścia do Elsevier'a jest to, że taka firma zapewnia profesjonalna obsługę. Elsevier może być nami zainteresowany, bo nie ma swojego czasopisma w tym zakresie. Prof. W. Bartelmus przekazał informacje, że propozycja czasopisma IJCM jeszcze nie jest zgłoszona do Elsevier'a.

Prof. T. Uhl otworzył dyskusje nad propozycjami prof. Staszewskiego.

Prof. Cz. Cempel wspomniał, że „Diagnostyka" zaczynała od 4 stroniczek, następnie ogromną rolę odegrało środowisko olsztyńskie, które wykonało ogromną prace dla korzyści całego środowiska. Ma nadzieję na bardzo dobra kontynuacje przez prof. Staszewskiego. Nad propozycjami trzeba się zastanowić, czasopismo powinno być globalne, ale z zachowaniem naszego wkładu i znaczenia polskiego środowiska.

Dr S. Wierzbicki stwierdził, że nie mogliśmy przejść na tytuł angielski, bo stracilibyśmy ciągłość. Od końca zeszłego roku jest to jednak możliwe i będzie zachowana jego ciągłość pod warunkiem zachowania profilu. Po zmianie nazwy „Diagnostyka" trzeba będzie jednak zmienić numer ISSN. Prof. Uhl stwierdził, że najlepiej zachować tytuł Diagnostyka po polsku, ale zmienić tytuł w jęz. angielskim. Dzięki temu nie zmieni się numer ISSN.

Ponieważ nikt z zebranych nie zgłosił propozycji nowej nazwy, prof. Uhl i Staszewski przedstawili w tej sprawie kilka propozycji. Obecnie jako wstępną propozycję podano:

„Diagnostyka. Applied Structural Health, Usage and Condition Monitoring".

Prof. Uhl przypomniał, że w najlepszym czasopiśmie z dziedziny, Structural Health Monitoring, założonym 10 lat temu jest stanowisko Editor Emeritus, które sprawuje pomysłodawca i pierwszy redaktor naczelny SHM. Jest to dobry pomysł i również chcielibyśmy podkreślić rolę osób szczególnie zasłużonych w założeniu czasopisma. Tytuł taki może być przeznaczony dla prof. Czesława Cempla. Prof. Cempel odparł, że bardzo dziękuje za ten wyraz uznania, ale jednocześnie prosił żeby uwzględnić także dużą rolę prof. Michalskiego.

Prof. Uhl dodał, że chciałby żeby dr S. Wierzbicki pozostał w zespole czasopisma, na co wyraził on zgodę.

Prof. W. Bartelmus przekazał informacje, że pomysł nowego czasopisma IJCM będzie dyskutowany na konferencji w Hammamet i zaprosił do udziału w niej. Dr T. Barszcz powiedział, że został również zaproszony do udziału w tworzeniu tego czasopisma i że może podjąć dyskusję, co do możliwości utworzenia go na bazie „Diagnostyki" na tej konferencji.

Prof. Uhl poprosił o opinie, czy jest zasadne rozmawiać z Elsevier'em? Prof. S. Radkowski, wspomniał inicjatywy Int J of Comadem i czasopismo tworzone przez prof. Gelmana. Tamte propozycje nie przyniosły rezultatu, co robimy teraz? Nasza „Diagnostyka" robi dużo w zakresie środowiska lokalnego, ważne jest żeby te role zachować. Ewentualne przejście do nowej formy organizacyjnej powinno to wymaganie uwzględniać.

Prof. Gardulski zapytał, jaką korzyść będzie miało środowisko i nasze i zagraniczne? Nie powinniśmy dopuścić do sytuacji po prostu „wzięcia tytułu" i historii 22 lat.

Prof. Staszewski odpowiedział, że tu chodzi przede wszystkim o profesjonalnego wydawcę, jakim jest Elsevier, decydująca rolę ma editorial board, a nie publisher, wiec nie jest możliwe zdominowanie czasopisma przez wydawcę. Prof. Uhl dodał, że nasza rada programowa już teraz spełnia standardy światowe, co powinno ułatwić ewentualne rozmowy.

Prof. Gardulski zapytał jak będę prowadzone dalsze uzgodnienia w sprawie tytułu i dyskutowanych na zebraniu spraw. Prof. Uhl odpowiedział, że dziś zebrane zostaną propozycje, potem zostanie rozesłana notatka ze spotkania, potem przewidziane jest zgłaszanie uwag w formie elektronicznej, ponieważ musimy się dostosować do nowych wymagań. Ostateczne decyzje będzie podejmował zarząd w głosowaniu internetowym.

Prof. Cempel wspomniał, że był 2 lata temu na konferencji budownictwa z referatem o diagnostyce. Jest to ważny kierunek naszej współpracy i powinien być on kontynuowany.

Na zakończenie tej części prof. T. Uhl poinformował, że roześlemy notatkę, a następnie prosimy o opinie i głosy.

Prof. Uhl omówił kolejny punkt planu obrad, który zakłada rozdzielanie Rady Programowej od Komitetu Redakcyjnego, według jego informacji nie można być w jednym i drugim. W rozesłanej notatce przedstawione zostaną propozycje zmian w składzie ww. ciał.

Na ręce prof. Uhla wpłynęło pismo z wnioskiem o likwidacje oddziału zachodniego PTDT.

Pismo zostało odczytane i poddane pod dyskusje. Prof. S. Radkowski spytał, jaka jest procedura wg statutu? Prof. Uhl odpowiedział, że przeprowadza się głosowanie, sprawdza to komisja rewizyjna, a ostateczną decyzję w głosowaniu podejmuje zarząd. Prof. Cz. Cempel wyjaśnił powody powstania oddziału i krótko jego losy. Przez ponad 10 lat dobrze spełniał swoją role, ale w zmienionych warunkach nie jest już potrzebny.

Prof. T Uhl zarządził głosowanie, wszyscy obecni głosowali za przyjęciem wniosku.

Prof. A. Grzadziela poinformował, że musi opuścić zebranie, ponieważ otrzymał właśnie wezwanie do Warszawy do Ministerstwa Obrony Narodowej na godz. 19.

Prof. T. Uhl przedstawił sytuację finansową PTDT. Obecnie sytuacja finansowa jest następująca, że żyjemy z certyfikowania kursów. Prof. Uhl bardzo podziękował kolegom, którzy włożyli prace w ocenę materiałów szkoleniowych. W tym roku wystawione certyfikaty przyniosły Towarzystwu 12500 zł wpływu. Prof Uhl bardzo zachęcił do zgłaszania większej liczby kursów do certyfikacji.

Prof. Gardulski dodał, że warto powrócić do wspierania konferencji. Dr T. Barszcz poinformował, że termin składania wniosków o dofinansowanie jest do 31.03 i zajmie się złożeniem wniosku.

Dr T. Barszcz przedstawił wniosek o członkostwo dr M. Figali. Prof. Uhl poddał wniosek pod głosowanie, został przyjęty jednogłośnie.

Dr Barszcz przypomniał o wpłatach składek członkowskich. Prof Gardulski poprosił o wysłanie przypomnień e-mailem z numerem konta i kwota.

Prof. T. Uhl przedstawił stan przygotowań do kongresu MKDT. Przedstawił przygotowane ulotki i adres strony internetowej. Już jest możliwość rejestracji artykułów. Poprosił o rozpropagowanie informacji.

Jako ostatnia sprawę prof. Uhl przedstawił połączenie księgowości i sekretariatu, które zostało ostatnio przegłosowane. Obecnie koszt prowadzenia księgowości to 600 zł, a praca ogranicza się do kilku sprawozdań. Jest propozycja prowadzenia i księgowości i sekretariatu za taka sama kwotę. Wkrótce roześlemy informacje kontaktowe.

Prof. Uhl spytał zebranych, czy są jakieś wolne wnioski.

Prof. Cempel poinformował, że ostatnio są fundusze z kapitału ludzkiego, może warto rozważyć dofinansowanie z tego źródła? Prof. Uhl odpowiedział, że jest to dość niska skuteczność, a przygotowanie wniosków jest bardzo pracochłonne. Wyraził nadzieje, że powstanie sekretariatu pomoże w przygotowywaniu takich wniosków.

Prof. T. Uhl podziękował wszystkim obecnym członkom zarządu i zakończył posiedzenie.

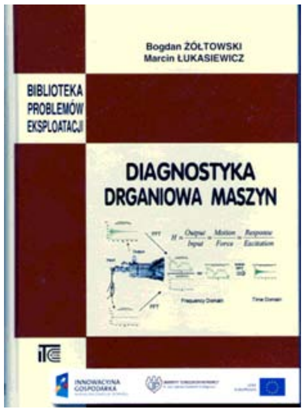
*Protokołował*
*dr hab. inż. Tomasz Barszcz*

***…są książki, których grzbiety i okładki stanowią najlepszą ich część…***

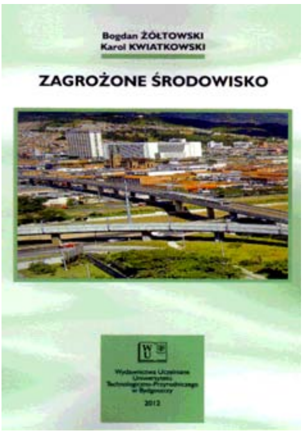
## *BADANIA DEGRADACJI STANU MASZYN W EKSPLOATACJI*

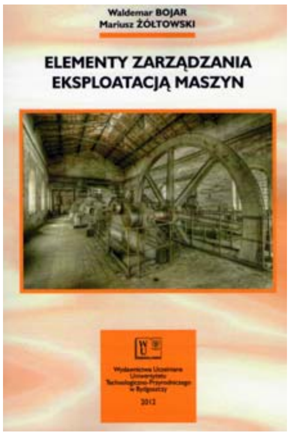
### „ZADUMA NAD WIRUSEM UTRATY ZDATNOŚCI"

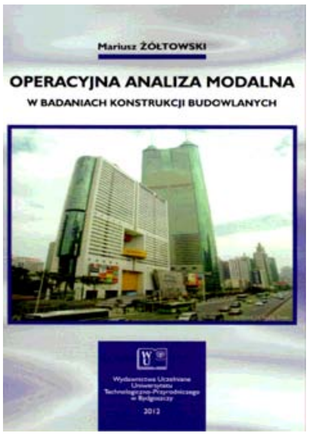
Zespół **prof. Bogdana ŻÓŁTOWSKIEGO**, dziekana Wydziału Inżynierii Mechanicznej UTP w Bydgoszczy przez 3 lata prowadził badania w temacie PO IG. Na zakończenie PROJEKTU zespół przedstawił kilkanaście opracowań książkowych. Oto niektóre z nich… w problematyce …diagnostyki i eksploatacji maszyn w ujęciu stanu zdatności, ryzyka, bezpieczeństwa i ochrony środowiska…

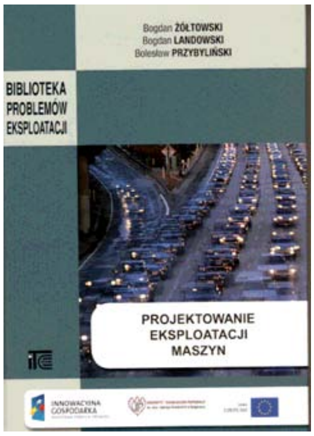



Badania stanu degradacji maszyn środowiskowych wspomagane technikami informatycznymi całościowo ujęto w prezentowanej serii wydawniczej, dostępnej w zespole *„pojazdów i diagnostyki"* WIM UTP.










Członkowie zespołu tych opracowań (Żółtowski B., Tylicki H., Drelichowski L., Bojar W., Przybyliński B., Kałaczyński M., Łukasiewicz M., Żółtowski M., Landowski B., Kwiatkowski K.) stanowią i zaświadczają o nowej i aktualnej wiedzy eksploatacyjnej.

***…pisanie książek i publikacji nie jest dowodem wiedzy, lecz przyzwyczajenia do siedzącego trybu życia…***

***„BŻ"***

Diagnostyka

**APPLIED STRUCTURAL HEALTH, USAGE AND CONDITION MONITORING**

Obszar zainteresowania czasopisma to:
- ogólna teoria diagnostyki technicznej
- eksperymentalne badania diagnostyczne procesów i obiektów technicznych;
- modele analityczne, symptomowe, symulacyjne obiektów technicznych;
- algorytmy, metody i urządzenia diagnozowania, prognozowania i genezowania stanów obiektów technicznych;
- metody detekcji, lokalizacji i identyfikacji uszkodzeń obiektów technicznych;
- sztuczna inteligencja w diagnostyce: sieci neuronowe, systemy rozmyte, algorytmy genetyczne, systemy ekspertowe;
- diagnostyka energetyczna systemów technicznych;
- diagnostyka systemów mechatronicznych i antropotechnicznych;
- diagnostyka procesów przemysłowych;
- diagnostyczne systemy utrzymania ruchu maszyn;
- ekonomiczne aspekty zastosowania diagnostyki technicznej;
- analiza i przetwarzanie sygnałów.

Topics discussed in the journal:
- General theory of the technical diagnostics,
- Experimental diagnostic research of processes, objects and systems,
- Analytical, symptom and simulation models of technical objects,
- Algorithms, methods and devices for diagnosing, prognosis and genesis of condition of technical objects,
- Methods for detection, localization and identification of damages of technical objects,
- Artificial intelligence in diagnostics, neural nets, fuzzy systems, genetic algorithms, expert systems,
- Power energy diagnostics of technical systems,
- Diagnostics of mechatronic and antropotechnic systems,
- Diagnostics of industrial processes,
- Diagnostic systems of machine maintenance,
- Economic aspects of technical diagnostics,
- Analysis and signal processing.

*Wszystkie opublikowane artykuły uzyskały pozytywne recenzje wykonane przez niezależnych recenzentów.*

*All the published papers were reviewed positively by the independent reviewers.*



Kopia wszystkich artykułów opublikowanych w tym numerze dostępna jest na stronie www.diagnostyka.net.pl

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