Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

THE ISSUES OF QUANTUM IN EMPIRICAL RESEARCH ON MACHINES AND OTHER POWER SYSTEMS

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Abstract

The paper provides justification for that the scientific research on empirical systems, particularly machines as well as other power systems, should take into account randomness and unpredictability of events which exist in their operation. The reference is made to achievements of the quantum mechanics, pointing the emerging postulate that the quantities called complementary have an important property consisting in that simultaneous and accurate measurement of their values is impossible. It has been shown herein that from the quantum mechanics it follows that by repeating empirical researches, whether they are observations, experiences or experiments, we cannot expect the same results, but we can expect the same frequency of acquiring the individual results. This indicates that acquirement of a particular research result is a random event. Additionally, the attention is paid that discovery in science, of the principle of ambiguous causality has led to oppugning the former belief of existence of unequivocal determinism (i.e. unequivocal effect from each cause) and adopting the ambiguous determinism that is determinism resulting from the probabilistic laws of the quantum mechanics, which allows (as known) the existence of choice.

Considering the achievements of the quantum mechanics as well as the empirical research results acquired in the phase of operation of machines and other power systems, it has been proposed to take the achievements into account for the empirical research.

Keywords: *decision, diagnostics, probability, reliability, diagnosing system*

1. Introduction

During operation of any machine, as well as any other power system, regardless of the type of the applied measuring system, the information on energy properties is obtained as a result of initiating and sustaining the operating process that leads to the performance of measurement. This process is [2, 5, 6] a two-dimensional stochastic process $\{D(\mathrm{t}, \vartheta)\colon t \geq 0,\ \vartheta \geq 0\}$, which is composed of the process $\{B(t)\colon t \geq 0\}$ of operating the measuring devices and the process $\{C(\vartheta)\colon \vartheta \geq 0\}$ of acquiring information by the devices, which is the result of measurement.

Publications referring to metrology [eg. 18, 19] say that the measurement means an action where it can be stated that at a given time and under defined conditions and by using defined methods and the related measuring devices, a determined measured quantity (w) is a value from the numerical interval $[a, b]$, i.e. that

$$a \le w \le b \tag{1}$$

where

$b - a = 2\varepsilon$, where 2ε - threshold.

The process $\{B(t): t \ge 0\}$ is a process that results from use of measuring devices when a tested machine (or other power system) is under operation performing a specific task, thus, is a process considered in a long time, which may but do not have to involve the following:

- repeated or various momentary measurements leading to obtaining the momentary values (x_i, t_i), $i = 1, 2, \ldots, n$ as well as
- elaborated results of the tests and developed reasoning that results from them.

This process has a significant impact on reliability of the results of empirical studies [7, 8, 9, 17, 23]. However, the process $\{C(\vartheta): \vartheta \ge 0\}$ is a process connected with performing measurements of physical quantities (energy parameters of machines) and with conducting a reasoning (inductive, deductive) at a defined time called a short time, so at operating (working) time of measuring devices, within which the final information (diagnosis) on energy state of the machine is obtained. Thus, the process $\{C(\vartheta): \vartheta \ge 0\}$ is made by the following realizations: diagnostic testing which consists in measuring a physical quantity characterizing the machine and reasoning which leads to development of a diagnosis on energy state of the tested machine (power system). Thus, an output of completion of the process $\{C(\vartheta): \vartheta \ge 0\}$ is a diagnosis, whose the reliability is the greatest when the measuring devices worked reliably during the course of the process, and disturbances resulting from interaction of the environment were of small scale due to resistance of these devices to such disturbances.

However, each inference about energy state of a machine is characterized by uncertainty because some mistakes can (and generally do) happen while making measurements.

Each measurement is performed with a defined accuracy which depends on the applied measuring methods and measuring devices (means), and testing conditions and qualifications of the staff doing the measurements. Thus, it arises a problem of existing inaccuracy in each measurement. This inaccuracy results from both: errors of the applied methods and measuring devices as well as changes in properties (characteristics) of the tested machine, proceeding while making the measurements. The cause of the inaccuracy is mainly a limited resolution of the measuring devices (which results from their threshold, randomness of the studied phenomena) and such errors as: quantization error, aperture error and sampling time error in case of using a digital signal for measuring [18]. Thus, the empirical studies of each machine or other power system involve measurement uncertainty which should be explained at least to the extend to be able to determine the main cause, i.e. whether the inaccuracy is mainly the result of [18, 19]:

- errors of measuring methods and measuring devices which, as known, depend largely on accuracy, sensitivity of measuring transducers or sensors, inaccuracy of the devices, which is defined by the inaccuracy class, as well as on stability and reliability of measuring devices – or
- changes in the characteristics of the machine while making measurements.

A correct explanation for the reasons of these inaccuracies in measurements is necessary to be able to estimate rightly the inaccuracies of the machine properties (power systems) and to make the right choice of proportion between the inaccuracy in measuring devices and the current inaccuracy in the properties of a machine as well as other power systems. The difficulty in determining the measurement uncertainty connected with the properties of the measuring methods and measuring devices, and the properties of diagnosed machines (and other power systems) is the quantum nature of their changes that causes randomness and unpredictability of events in empirical research. Therefore, it is necessary to consider this issue.

2. Randomness and unpredictability of events in empirical research

The measurement technique is dominated by a deterministic approach to identification of energy state of machines, however, more and more often the probabilistic aspects of empirical studies are noticed [6, 13, 16, 22, 23]. This is due to the traditional perception of the changes in energy state of machines and other power systems, which assumes that randomness and unpredictability in empirical research when making the measurements can be, in general, omitted. For this reason, an analysis of results is limited to the use of the classic account of errors and sometimes this account of errors is omitted without thorough justification of its uselessness for empirical research. One of the important reasons for this approach in diagnostics of machines was the fact that from the early years of the twentieth century, in science, there was in force a deterministic theory for describing phenomena, events and processes, finally developed by marquis Pierre Simon de Laplace. In the theory, P.S. de Laplace made an assumption that there were similar laws in both the macro- and micro-world, according to which all the changes proceed. In compliance with these laws every phenomenon occurs, lasts and disappears, all events (facts) proceed and any processes are realized. Following this theory, the entire universe is completely determined in both macro-and micro-scales. This vision of changes proceeding in space and time, was the basis for development of the science of those days, also the basic methodological assumption of physicists, until the early twentieth century. This view has led to development of the mechanics known today as classical (i.e. non-quantum, before quantum). Also it caused an emergence of belief that the laws of motion and any other changes can be expressed in the form of differential equations that have unequivocal solutions. This determinism is expressed in

- the principles formulated by Isaac Newton, describing the laws of nature,
- partial differential equation proposed by Erwin Schrödinger (1926), whose the solution is the wave function determining the quantum state of a micro-particle at any time in deterministic aspect,
- Albert Einstein's equation regarding the photoelectric effect as well as in the equation which describes, also in the deterministic aspect, the relationship between energy, mass and its velocity.

These equations are not only deterministic, but also reversible over time [14, 20]. It turned out, however, that despite the efforts of many mathematicians, they did not succeed to prove the existence of uniqueness of the solutions to differential equations. This situation caused an eagerness to seek a probabilistic concept for interpretation of the reality. An example for this can be a probabilistic interpretation of the wave function obtained from the said Schrödinger's wave equation, which was proposed by Max Born (in 1926), who could not accept the fact that this function represented the "real" electron wave, even though other physicists accepted this equation as a tool for solving the problems of the quantum mechanics. In this interpretation the wave function (Ψ) is such a product with values which are complex numbers [4, 11], that $|\Psi|^2$ is a measure of the probability of finding a micro-particle in a given space area (point). That means that you cannot be sure where such a micro-particle as an electron is located, but you can calculate the probability that it finds itself in a given point in space, if the aforementioned wave function is known. This corresponded to Niels Bohr's believes, who accepted the partial and wave theoretical models of existence of micro-particles. Also he believed that it was impossible to predict a specific outcome of empirical studies, and it was only possible to calculate the probability that the outcome of e.g. the given experiment would be such this and no other. But the final blow to the deterministic theory of P.S. de Laplace was done by Werner Heinsenberg's uncertainty principle (1926), which together with the Max Planck's quantum hypothesis (1900), explaining the essence of the radiation of hot bodies, became one of the fundamental elements (achievements) of the quantum mechanics. This theory is nowadays the basis of the modern science and technology. It was established in the twenties of the last century by Werner Heinsenberg, Erwin Schrödinger, Paul Dirac, and also Wolfgang Pauli, Niels Bohr. Albert Einstein and Richard Feynman (creator of nanotechnology, considered by physicists as a genius No. 2 after A. Einstein) made their contributions to this theory, too. Its rules explain functioning of e.g. transistors and integrated circuits, thus one of the most important components of electronic devices, without which there are no modern measuring instruments. These rules apply to modern chemistry (quantum chemistry), cryophysics (quantum liquid) and biology. Among the physical sciences only the theory of gravitation and cosmology are not yet fully agreed with the quantum mechanics [12]. However, it should be expected that one day this will happen. The general theory of relativity describes well the observations because in ordinary conditions there exist weak gravitational fields. However, from the singularity theorems it follows that the gravitational field is very strong in at least two situations: in the area of black holes and during the Big Bang, as well as just afterwards [12]. In the fields of this kind, the quantum effects cannot be omitted [12, 20]. Therefore, it can be expected that the classical theory of relativity should fall due to the mentioned space-time singularities. Currently, the efforts are focused on developing a quantum theory of gravity. The classical (non-quantum) mechanics fell down because it assumed that the atoms should be brought to the state of infinite density. According to the assumptions of the theory, a hot body should radiate electromagnetic waves with the same intensity at all wave frequencies. This would mean that the inference that the total energy emitted by the body is infinite, is true. This inference is, however, wrong and that is why Max Planck formulated the hypothesis saying that electromagnetic waves cannot be emitted at any free rate, but only in specific portions which he called the quanta (hence the name of quantum hypothesis).

Moreover, from the quantum mechanics it follows that such physical quantities as energy, angular momentum (rotational momentum) can change only in steps. It also results that the quantities called complementary have an important property which consists in that impossible is simultaneous and accurate measurement of their values. For instance, the more accurate measurement of the micro-particle position we get**,** the less precisely its momentum, and thus - its velocity, is determined. This proceeds in compliance with the mentioned Heinsenberg's uncertainty principle which determines the degree of inaccuracy in the measurements of the basic physical quantities (position and momentum of a particle, and also energy and time) and this has nothing in common with the accuracy of the measuring methods nor the accuracy of the measuring devices (instruments) [4, 11, 12]. From this it follows that in the micro-world it is not possible to predict accurately the future position of the particle being smaller than the atom, which is important for example for controlling the electron beam in a cathode ray tube. Thus, it is justifiable that the models of the atom, first by Joseph John Thompson, then by Lord Ernest Rutherford and N. Bohr (though the Bohr’s model explained quite well the structure of the simplest atom, a hydrogen atom) have been replaced by a model of the atom based on the quantum mechanics. In this model, the electrons in atoms do not move on any specific orbits, but in so-called the orbitals considered as the areas of space around the nucleus, where the probability of existence of (finding) an electron at a given time has a strictly defined value. As proposed by Richard Feynman it is assumed that a particle does not move on one track, but on all the possible trajectories (available orbits) [1, 12]. The available orbits called the orbitals of the electrons in atoms, are understood as the areas of space around the nucleus where an electron can appear at a defined time, with a determined probability [1].

Transferring these findings into the field of macro scale research, it can be assumed that from W. Heinsenberg's uncertainty principle it results that by repeating empirical research, regardless of whether they are observations, experiences or experiments, you cannot expect the same results. Thus, the question arises: how different can the results be expected? The answer is as follows: this depends on the taken testing method, accuracy of the used measuring instruments, conditions of the tests, and possibility of their repeatability, experience of the person conducting the tests, the number of performed measurements, duration of the tests, etc. This means that by repeating the empirical tests, especially experiments, under given conditions, we should always expect different results. This indicates that acquirement of a specific test result is a random event. Thus, the measured values must be considered as random variables. Of course, if the variability of results is small, it can be omitted, but in any such case the reasonability for such proceeding must be justified. The most important phases of empirical research include performance of measurements [3, 6, 13, 16, 22, 23]. Each measurement has got a feature that the acquired measurement results (values of physical quantities) involve the said uncertainty and errors arising from the existence of different disturbances. It must, therefore, be assumed that the randomness of each measurement result is its integral attribute.

Thus, the quantum mechanics based on W. Heinserberg's uncertainty principle, introduces the unavoidable randomness and unpredictability into the science and practice.

More general uncertainty than the said uncertainty principle is introduced by a phenomenon known as deterministic chaos [21]. This phenomenon can be observed if the studied model is a system of differential equations, especially nonlinear equations of the second, third and fourth order. It is known that the solution to a deterministic system of differential equations takes the form of very complicated oscillations, of which the cause is not a large number of degrees of freedom or local disturbances, but the increasing instability dependent on the precision in determining the initial state which depends on the initial conditions connected with time and also on the coefficients of the time-dependent equations. The deterministic chaos is closely related to occurrence of so-called attractors that are usually non-periodic trajectories attracting other trajectories from their environment [1, 21]. Detection of the attractors enables better prediction of appearing random events. Thus, making an allegation that the empirical system develops chaotically may simplify the study of its evolution. This means that chaos is not always a negative phenomenon. Adding the noise with random properties to the non-disturbed empirical system, can lead to statistical stabilization or periodicity in the evolution of the system. This requires a new approach to the relationships existing among deterministic and statistical and probabilistic methods for empirical studies on machines and other power systems.

Another source of chaos may be inaccuracy in defining the parameters in the model. This fact is connected with the phenomenon of bifurcation (splitting into real test results acquired when testing the empirical systems and the expected (supposed) ones).

Discovery of the principle of ambiguous causality in science has led to oppugning the old belief of unequivocal determinism (i.e., unequivocal effect from a cause) and adopting an ambiguous determinism that is determinism resulting from the probabilistic laws of the quantum mechanics, which allows (as known) the existence of choice.

From the presented considerations it results that by organizing and conducting empirical tests of machines and other power systems, the attention should include the following laws (rules) of:

- ambiguous causality, i.e. existence of randomness of events (including the event which is a diagnose about a machine's state), and therefore, it is necessary to recognize at least the ambiguous determinism,
- uncertainty formulated by W. Heinsenberg,

and also such facts as:

- existence of general randomness of nature as its indispensable feature, resulting from its infinite complexity,
- existence of deterministic chaos resulting from the so-called sensitivity of models of empirical systems, especially machines, to their initial state,
- limited (always) accuracy of measuring methods and measuring devices, thus also of the measurements performed with these devices,
- inaccuracy of the machine being an empirical system,

- unreliability of the measuring systems (instruments) adopted to perform the measurements and thus to identify the energy state of the machines.

The measurements refer to specific test procedures during which when implemented there can be made many mistakes as a consequence of:

- performance of empirical tests in highly disturbing conditions,
- improper performance of measurements and calculation of errors (e.g. not taking into account the quantization error and aperture error, and time sampling error), because of using the measuring devices with insufficient (inadequate) accuracy and/or omitting some measurements,
- wrong recording the results of measurements being properly performed and signaled by measuring devices,
- incorrect interpretation of measurement results at the stage of their acquisition and subsequent inferences about the state (energy, technical) of the machine due to inaccurate (incorrect) readings of indications by gauges (measuring devices) and adoption of inaccurate data processing algorithms,
- improper identification of machine's energy state, even though proper performance of measurements and disposal of the correct results from empirical tests.

This all makes that in empirical research where measuring methods and measuring devices are applied, there exists a problem of measurement uncertainty that results from changes in properties of the machine being an object of empirical studies, which takes place when performing the measurements, as well as from errors of the measuring methods and measuring means [12, 13] . Consequently, uncertainty arises which has to be explained in the research. The explanation should include at least a formulation of the main cause for this uncertainty, mainly whether it is the result of:

- changes in properties of the machine being an object of empirical research, which proceed at the time of measurements, or
- errors of the measuring methods and measuring devices (instruments, means).

Therefore, for this type of studies, it is important [19]:

1) to estimate the value of uncertainty for the object of empirical studies which is the machine,
2) to estimate the value of uncertainty for the measuring technique (measuring methods and measuring devices),
3) to select appropriate proportion between the uncertainty of measuring technique and the existing uncertainty of the studied object (machine).

In this situation, elaboration of a specific information (diagnosis) on the energy state of the machine or any other power system, requires application of the mathematical statistics, calculus of probability and stochastic processes.

3. Indications for quantum aspects of empirical studies on machines and other power systems

During empirical studies of machines and other power systems there exists a research situation that causes randomness and unpredictability of the recorded events. Therefore, [5, 7, 9, 10, 13, 16, 18, 19, 22, 23]:

- for empirical studies of machines and other power systems there is a degree of uncertainty in the test results, connected with all the examined phenomena and events involving wear, damage, generation of energy signals, etc.),
- it is not possible to predict precisely the changes in technical and energy characteristics of machines and other power systems under operation,

- there are changes in state of machines and other power systems (being the objects of empirical studies) when making measurements, as well as errors of the applied measuring methods and measuring devices,
- negligible variability can be determined as a result of application of the calculus of errors that does not lead to defining a real value,
- significant variability requires an application of the statistical estimation,
- real value (correct value) is an abstract term,
- it is necessary to assume that the value of the arithmetic mean, obtained from the measurements, is different than the real value of the measured physical quantity,
- one cannot expect the same results, but can expect the same frequency of obtaining the given result.

The considerations demonstrate that in empirical studies of machines and other power systems an uncertainty arises in the results acquired during performance of measurements. Therefore, a necessity occurs to identify the reasons of the uncertainty in the results. The most important reasons for the uncertainty in the results include among others [4, 8, 9, 10]:

- quantum changes in the properties of machines and other power systems (their energy and wear), that lead to quantum dissipation of their energy

$$E_{max} = E_1 \to E_2 \to \dots \to E_{n-2} \to E_{n-1} \to E_n = E_{min} \qquad (2)$$

$$\searrow e \quad \searrow e \qquad \searrow e \quad \searrow e$$

where:

E_i (i = 1, 2,..., n□) – energies determined due to recording by the measuring system the subsequent drops in energy (E) of the machine (mechanism) in a form of portions (quanta) e; E_{max} – maximum energy that can be generated by a machine (mechanism) at the time of correct operation, possible to be recorded by the measuring system, E_{min} – minimal energy that can be generated by a machine (mechanism) at the time of failure (recording this energy by the measuring system does not have to be possible),

- quantum symptom of changes in physical quantities which characterize: the flow of heat or electricity, energy radiation in the form of a stream of particles or electromagnetic waves, radioactive decay, etc.,
- in metrology, the term of "quantum of time" was implemented instead of the term of "time",
- digital signal is a quantized and sampled quantity involving errors of quantization and aperture and the error of the sampling time,
- a set of tensions generated by the analog-to-digital transducer is discrete, the successive voltage values differ by the quantum "q",
- there are programs used for generating the reference voltage (U_w), named „quantum by quantum programs", which in the successive „i" steps generate the voltage $U_w = i \cdot q$, q – value of the voltage quantum,
- frequency is quantized by nature over time,
- essence of the measurement $a \le w \le b \quad \to \quad b - a = 2\varepsilon$ is quantized,
- measured values are random variables,
- conditions that cause variability of measures are variable,
- there is uncertainty of the applied measuring methods and measuring instruments,
- time of measuring is different due to the need of repeating the measurements,
- there are different experiences of the persons performing the measurements,

- there is uncertainty of the properties in the power systems being the objects of studies,
- recording the momentary values is a stochastic process,
- ambiguous causality implies ambiguous determinism, that is determinism resulting from the probabilistic laws of the quantum mechanics,

The considerations present that changes in energy state of machines and other power systems will have a quantum nature. These changes considered during operation of the systems will be realizations that can be regarded as continuous-time discrete-state stochastic processes. An exemplary realization of such a process depicting changes in dissipated (dissipation) energy of any marine power system is shown in Fig. 1.

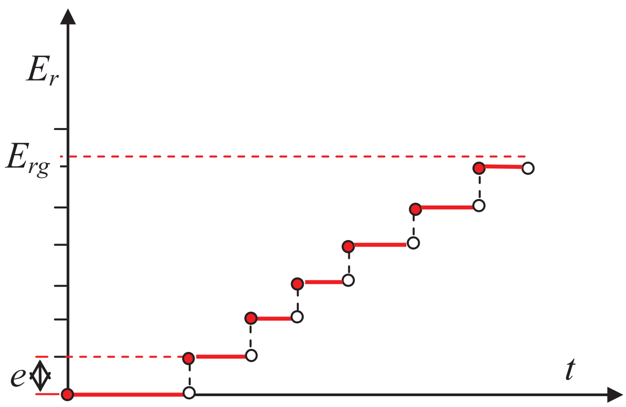

Fig. 1. Interpretation of the process of accumulating dissipated energy E_r for a machine (power system): e – portion of energy (quantum), by which the energy E_r decreases,
E_{rg} – boundary dissipation energy

The presented research situation shows that the empirical studies on machines and other power systems have to include uncertainty of test results. This is necessary, because it means that such studies require determining the consequences of the uncertainty. Thus, while performing empirical tests of machines and other power systems it is worth to keep in mind the achievements of the quantum mechanics.

The general premises that induce to take advantage of the achievements of the quantum mechanics for empirical studies on mechanisms in a machine and other power systems can include the following [3, 4, 11, 15]:

1) the quantum theory is considered to be one of the most perfect theories being applied for various domains of physics,
2) no incompatibility has been noted between the quantum theory and the results of empirical studies in the areas of knowledge wherever used,
3) the quantum mechanics tends to describe the relationships among macroscopic phenomena, events and processes, that have been initiated by micro-objects,
4) a knowledge of surveying, which like the quantum mechanics uses quanta for the measured values, is applied for empirical studies,
5) properties of the power systems are expressed by physical quantities of a random nature.

Therefore, due to the existing randomness and unpredictability of events, including acquiring the same momentary values of different physical quantities, the test results obtained from empirical studies of machines and other power systems must be considered in the probabilistic approach by using the calculus of probability theory, mathematical statistics and the theory of stochastic processes. A deterministic approach can be applied for analysis of the test results for the mentioned empirical systems only in cases justified by the assumed purpose of the studies. However, this approach have to be precisely argued by providing adequate explanation for its validity by employing the methods of inductive reasoning, deductive reasoning and reasoning by analogy.

4. Summary – remarks and conclusions

The empirical studies of machines and other power systems have to take into account the randomness and unpredictability of events which exist in their operation. The operating practice of the machines and other systems as well as the quantum mechanics show that by repeating empirical tests, regardless of whether they are observations, experiences, or experiments, we cannot expect the same results, but can expect the same frequency of acquiring the particular results. It means that that acquirement of a specific test result (measurement result) is a random event. This shows the need of regarding in this type of research the calculus of probability, mathematical statistics and the theory of the stochastic processes.

The principle of ambiguous causality has to be considered in the empirical studies of machines and other systems, which means the need of assuming the ambiguous determinism, so determinism resulting from probabilistic laws of the quantum mechanics, allowing (as known) existence of choice.

References

1. Aczel A.D.: *Prawdopodobieństwo* = 1. Zysk i S-ka Wydawnictwo s.c., Poznań 1997. Tytuł oryginału: Probability 1. Why There Must Be Intelligent Life in The Universe.
2. Benjamin J. R., Cornell C. A.: *Probability, Statistics, and Decision for Civil Engineers*. Copyright 1970 by McGraw-Hill, Inc. Wyd. polskie: *Rachunek prawdopodobieństwa, statystyka matematyczna i teoria decyzji dla inżynierów*. WNT, Warszawa 1977.
3. Będkowski L.: *Elementy diagnostyki technicznej*. Wydanie 2, WAT, Warszawa 1992.
4. Birula I., Cieplak M., Kamiński J.: *Teoria kwantów. Mechanika falowa*. Wydawnictwo Nukowe PWN, Warszawa 2001.
5. Girtler J.: *Sterowanie procesem eksploatacji okrętowych silników spalinowych na podstawie diagnostycznego modelu decyzyjnego*. Monografia. Zeszyty naukowe AMW, Gdynia 1989 nr 100A.
6. Girtler J.: *Diagnostyka jako warunek sterowania eksploatacją okrętowych silników spalinowych*. Studia Nr 28. WSM, Szczecin 1997.
7. Girtler J.: *Probabilistic measures of a diagnosis' likelihood about the technical state of transport means*. Archives of Transport. Polish Academy of Sciences. Committee of Transport. Quartelly. Vol. 11, iss. 3-4, Warsaw 1999, p.33-42.
8. Girtler J.: *Zastosowanie wiarygodności diagnozy do podejmowania decyzji w procesie eksploatacji urządzeń*. Materiały V Krajowej Konferencji DIAG'2003 nt. „Diagnostyka techniczna urządzeń i systemów". Wydział Elektroniki Wojskowej Akademii Technicznej, Warszawa – Ustroń, s.100-109.
9. Girtler J.: *Probabilistyczne miary wiarygodności diagnozy o stanie technicznym maszyn i innych urządzeń*. Materiały XXXI Ogólnopolskiego Sympozjum DIAGNOSTYKA MASZYN, s. 24 (streszczenie), referat na CD-R.
10. . Girtler J.: *Conception of valuation of combustion engine operation*. Journal of KONES. Powertrain and Transport. Editorial Office Institute of Aeronautics BK, Warsaw 2008, pp. 89-96.
11. Gribbin J.: *W poszukiwaniu kota Schrödingera*. Zysk i S-ka Wydawnictwo s.c., Poznań 1997. Tytuł oryginału: In Search of Schrödinger's Cat. Quantum Physics Reality.

12. Hawking S.W.: *Krótka historia czasu. Od wielkiego wybuchu do czarnych dziur*. Wydawnictwa ALFA, Warszawa 1990. Tytuł oryginału: A Brief History of Time: From the Bing Bang to Black Holes.
13. Michalski R.: *Diagnostyka Maszyn Roboczych*. Wyd. ITE, Radom 2004.
14. Moskowitsa M.: *Czy nauka jest dobra*. Wydawnictwo CiS, Warszawa 1997. Tytuł oryginału: Science and Society. The John C. Polanyi Nobel Laureates Lectures.
15. Nalewajski R.F.: *Podstawy i metody chemii kwantowej*. Wydawnictwo Naukowe PWN, Warszawa.
16. Niziński S.: *Elementy diagnostyki obiektów technicznych*. Wyd. UW-M, Olsztyn 2001.
17. Pabis S.: *Metodologia i metody nauk empirycznych*. PWN, Warszawa 1985.
18. Piotrowski J.: *Podstawy miernictwa*. WNT, Warszawa 2002.
19. Polański Z.: *Planowanie doświadczeń w technice*. PWN, Warszawa 1984.
20. Schutz B.F.: *Wstęp do ogólnej teorii względności*. Wydawnictwo Naukowe PWN, Warszawa 2002.
21. Tempczyk M.: *Teoria chaosu dla odważnych*. Wydawnictwo Naukowe PWN, Warszawa 2002.
22. Żółtowski B.: *Podstawy diagnostyki maszyn*. Wyd. ATR, Bydgoszcz 1996.
23. *Inżynieria diagnostyki Maszyn*. Praca zbiorowa po redakcją B. Żółtowskiego i C. Cempla. PTDT. Wyd. ITE, Warszawa, Bydgoszcz, Radom 2004.