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# USE OF MATHEMATICAL SKILLS FOR TECHNICAL CONDITION ASSESSMENT OF POWER AUTOTRANSFORMERS

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## СОДЕРЖАНИЕ

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# USE OF MATHEMATICAL SKILLS FOR TECHNICAL CONDITION ASSESSMENT OF POWER AUTOTRANSFORMERS

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***Abstract:*** *In this paper, we review innovative approaches to assess the technical condition of autotransformers using mathematical methods. The main purpose of these methods is to increase the efficiency of diagnostics and prevent possible failures in power systems. The developed mathematical expression is based on complex data analysis, application of statistical methods and machine learning technologies.*

*This makes it possible to achieve more accurate and earlier detection of potential problems. As a result of these innovative approaches, the possibilities for early detection and prevention of faults are significantly increased. This is important for ensuring the smooth operation of power systems and preventing potential accidents. Thus, the use of mathematical methods in the assessment of the technical condition of autotransformers is an effective and promising direction of development. It allows to increase reliability and safety of power systems operation, as well as to reduce the risks of unforeseen failures.*

***Keywords:*** *power autotransformer, diagnostic methods, analysis, HARG, approach, fuzzy logic, mathematical expression.*

***Annotasiya:*** *Ushbu hujjatda biz matematik usullardan foydalangan holda avtotransformatorlarning texnik holatini baholashning innovatsion yondashuvlarini ko‘rib chiqamiz. Ushbu usullarning asosiy maqsadi diagnostika samaradorligini oshirish va energiya tizimlarida yuzaga kelishi mumkin bo‘lgan nosozliklarning oldini olishdir. Ishlab chiqilgan matematik ifoda ma’lumotlarni kompleks tahlil qilish, statistik usullar va mashinani o‘rganish texnologiyalarini qo‘llashga asoslangan. Bu mumkin bo‘lgan muammolarni aniqroq va oldinroq aniqlashga imkon beradi. Ushbu innovatsion yondashuvlar natijasida nosozliklarni erta aniqlash va oldini olish imkoniyatlari sezilarli darajada oshmoqda. Bu energiya tizimlarining uzluksiz ishlashini ta’minlash va yuzaga kelishi mumkin bo‘lgan baxtsiz hodisalarning oldini olish uchun muhimdir. Shunday qilib, avtotransformatorlarning texnik holatini baholashda matematik usullardan foydalanish rivojlanishning samarali va istiqbolli yo‘nalishi hisoblanadi. Bu energiya tizimlarining ishlashining ishonchliligi va xavfsizligini oshirishga, shuningdek, kutilmagan nosozliklar xavfini kamaytirishga imkon beradi.*

***Kalit so‘zlar:*** *quvvat avtotransformatori, diagnostika usullari, tahlil, HARG, yondashuv, loyqa mantiq, matematik ifoda.*

***Аннотация:*** *В данной статье мы рассмотрим новаторские подходы к оценке технического состояния автотрансформаторов с использованием математических методов. Главная цель этих методов заключается в повышении эффективности диагностики и предотвращении возможных сбоев в энергосистемах. Разработанное математическое выражение основано на комплексном анализе данных, применении статистических методов и технологиях машинного обучения. Это позволяет достичь более точной и ранней детекции потенциальных проблем. В результате применения этих инновационных подходов, возможности по раннему выявлению и предотвращению неисправностей значительно увеличиваются. Это важно для обеспечения бесперебойной работы энергосистем и предотвращения возможных аварий. Таким образом, использование математических методов в оценке технического состояния автотрансформаторов является эффективным и перспективным направлением развития. Это позволяет повысить надежность и безопасность работы энергосистем, а также снизить риски возникновения непредвиденных сбоев.*

***Ключевые слова****: силовой автотрансформатор, методы диагностики, анализ, ХАРГ, подход, нечеткая логика, математическое выражение.*

## Introduction

In the conditions of continuous development of the power industry, ensuring the reliability of power transformers becomes the most important aspect of

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power systems. In this paper, new approaches to the assessment of the technical condition of autotransformers will be considered, which are aimed at improving the efficiency of diagnostics and preventing possible failures. Autotransformers play a key role in power transmission and distribution. Effective detection and prevention of faults in their operation is of strategic importance for maintaining the normal operation of power systems. This paper proposes a mathematical expression to evaluate the technical condition of autotransformers based on novel analysis methods.

**Methodology**

1. The first stage of the methodology consists in careful collection of information about the operation of the autotransformer. Important data are temperatures, currents, voltages, and other indicators that must be considered when evaluating the condition of the device.

2. Next, there is the formation of characteristics that reflect various aspects of the transformer operation. This process includes basic parameters and calculated indicators, which will help to more fully describe the features of the functioning of the device.

3. The third stage of the methodology is based on the analysis of statistical data. Statistical methods are used to identify significant patterns, which may include determining correlations, identifying trends and anomalies. This allows a more accurate assessment of the current state of the autotransformer.

4. In the last step, a mathematical expression is developed based on the identified patterns and characteristics. This expression allows real-time assessment of the technical condition of the autotransformer. This approach provides more accurate and reliable assessment results.

The condition of the equipment is evaluated by analyzing the gas content, concentration, and growth rate. If hydrogen ($H_2$) is detected in the fluid being tested, it may indicate an electrical problem. Excess ethane ($C_2H_6$) may indicate thermal problems such as heating and fire at temperatures between +300 and +400 °C. The presence of methane ($CH_4$) in the coolant may indicate higher temperatures, up to +600 °C. If ethylene ($C_2H_4$) is detected in the transformer oil, this may indicate overheating exceeding +600 °C. The presence of dissolved acetylene ($C_2H_2$) may indicate regular sparks and arc slippage. If CO or $CO_2$ is detected in the tested fluid, it may indicate rapid aging or moistening of the solid electrical insulation [1].

One of the most common methods of continuous monitoring is the analysis of gas content in transformer oil using a chromatographic method. This analysis is carried out online, i.e. without interruption of work and without personnel involvement in sampling [2].

The advantages of online chromatographic analysis of various gases in the laboratory can be listed as follows:

1) Unlike laboratory dissolved gas analysis (DGA), which is performed on a one-time or biennial basis according to regulations, the online system runs continuously without interruption.

2) Most failures occur suddenly and over a short period of time, often with no preliminary signs. Online analysis can detect both gradual and abrupt changes in the condition of power ATs.

For a more complete expert assessment of the state and changes in gas composition, it is proposed to use the fuzzy logic method, which includes the following steps:

1. Input data standardization and normalization is the process of data preprocessing.

2. Fuzzification of input data is the translation of specific measured parameters into linguistic terminology, e.g. "low", "medium", "high". This is accomplished through the application of membership functions.

3. Application of fuzzy rules is the use of phasified values according to expert fuzzy rules of the "if, then" kind.

4. The application of fuzzy rules allows to transform the results and provide information about the state of power ATs in the form of evaluation and recommendations for subsequent actions. [3]. The use of fuzzy logic apparatus allows to estimate more accurately the state and transformation of gas state on the basis of gas content analysis

This comprehensive processing of diagnostic parameters, based on our many years of experience in the field of fuzzy rules, has the ability to provide more detailed information about the current state of the power autotransformer and provide valuable recommendations for follow-up actions. This approach optimizes the process of monitoring and maintenance of the CAT, increasing its reliability and service life. By analyzing the data obtained, potential problems can be identified and possible malfunctions prevented, which significantly reduces risks and economic losses. In addition, this method allows you to more accurately determine the optimal time for preventive measures and repairs, which contributes to the efficient use of resources and cost reduction. As a result, the use of this approach can achieve more efficient operation of power transformers and ensure continuous power supply. This is an important aspect to consider when planning and managing the power supply system. [4]. At the same time, it should be noted that each case requires an individual approach and adaptation of the methodology to specific conditions and requirements. It is important to take into account all factors that may affect the operation of the power autotransformer and take appropriate measures to ensure its reliability and efficiency. Only in this way can the best results and confidence in the stable operation of the power supply system be achieved.

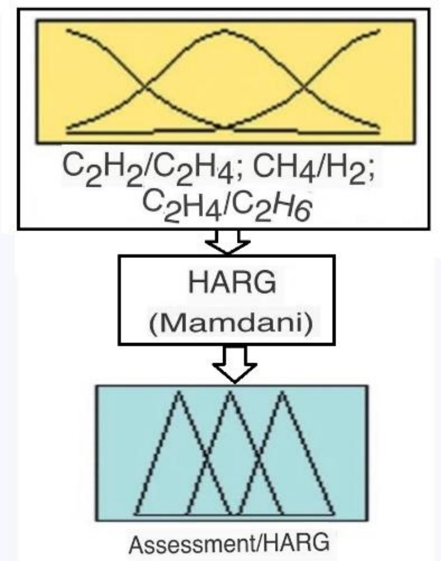


**Fig.1. Scheme of the fuzzy model of diagnostics condition of power autotransformer by analysis of dissolved gases in transformer oil**

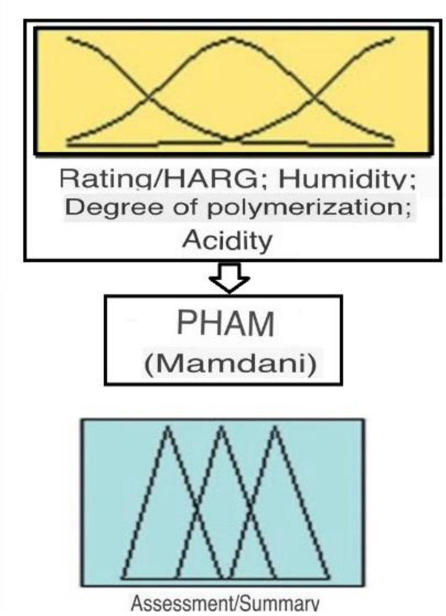


**Fig.2. Scheme of fuzzy model of diagnostics of power AT state estimation by physical and chemical indicators of oil and state estimation by results of HARG analysis of dissolved gases**

It is proposed to consider a fuzzy inference model that can evaluate the transformer condition at low values of gas concentration in the oil. Figure 2 shows the schematic of the fuzzy model for transformer condition diagnosis based on chromatographic analysis. In this model, three linguistic variables are used as input parameters of the fuzzy inference system in the first stage of diagnosis:

1) The ratio of acetylene to ethylene concentrations;

2) The ratio of methane to hydrogen concentrations;

3) The ratio of concentrations of ethylene to ethane.

For each of these input linguistic variables, the following term sets are established:

- The value of the ratio of acetylene to ethylene concentrations can be "small", "medium" or "high".
- The value of the ratio of methane to hydrogen concentrations can be "small", "medium" or "high".
- The value of the ratio of ethylene to ethane concentrations can be "small", "medium" or "high".

Thus, this model allows to take into account different variants of values of the mentioned parameters and to carry out more accurate diagnostics of transformer condition at low values of gas concentration in oil.

The algorithm uses a model that outputs a linguistic variable "State Assessment/HARG". This variable can be described as "unsatisfactory", "questionable" or "satisfactory". To create membership functions that reflect the different gradations of this variable, a survey of experts in the electric utility industry was conducted. The experts rated the elements of the State Assessment/HARG variable on a scale of one to five. The results obtained were used to construct the corresponding membership functions, which can be seen in Figure 2.

Next, the algorithm uses a fuzzy inference model to determine the final state of the transformer based on the physical and chemical parameters of the transformer oil and the preliminary state assessment obtained from the results of chromatographic analysis of dissolved gases in the oil.

In the fuzzy inference process, four main indicators are considered which have the following values:

1) Condition assessment / HARG: "unsatisfactory", “doubtful", "satisfactory";

2) Moisture level: "high", "medium", "low";

3) Polymerization degree: "high", "medium", "low";

4) Acid number: "high", "medium", "low".

Note that the state score/HARG, which is an output parameter in the previous fuzzy model, is also an input parameter in this model.

The same term-multiplicities and membership functions are used in the variable "Condition Assessment/TOTAL" of the fuzzy transformer model as in the variable "Condition Assessment/HARG". Figure 4 shows the transformer condition diagnosis scheme based on the physical and chemical parameters of oil and chromatographic analysis results.

It is important to note that the developed fuzzy models based on the proposed diagnostic algorithm are applied only if at least one of the gases dissolved in the oil exceeds the limit concentration (boundary concentration criterion). If the results of the chromatographic analysis show that the concentrations of each gas are within acceptable limits, the diagnosis model is changed and the value of "Condition Assessment/HARG", which is an input parameter in this model, becomes "satisfactory" without a specific numerical value of the assessment. Therefore, the linguistic variable "State Assessment/HARG" is not explicitly involved in the latter model, but the value "satisfactory" is considered in the model rules for this case. Software implementation of fuzzy diagnostic models.

Nowadays, there are a great number of different models available to represent knowledge in different domains. Of all these models several main types can be distinguished.

The first type is product models. They represent expert knowledge in the form of "if A, then B" rules. This approach allows to achieve a high degree of homogeneity in the description of rules. Product models are easily scalable and allow for easy addition, modification and deletion of knowledge. In addition, there are special tools for creating expert systems based on product rules, such as GURU (MDBS), ECO (ArguSoft), CLIPS, G2 (Gensym) and others.

The second type is semantic networks. They represent knowledge in the form of a graph, where nodes represent concepts and links between them represent relationships between concepts. Semantic networks make it easy to visualize and analyze knowledge, as well as to perform various operations on it.

The third type is frames. They describe knowledge in the form of structures consisting of slots and values. Slots represent attributes and values represent specific data. Frames allow describing complex knowledge structures and performing operations on them.

Finally, the fourth type is formal logic models. They use formal logical languages to represent knowledge and infer new information based on existing rules. Formal logic models provide a strict formalization of knowledge and allow logical reasoning.

All these models have their own advantages and are used in different fields. The choice of a particular model depends on the problem to be solved and the peculiarities of the subject area. It is important to be able to competently apply these models for effective representation and utilization of knowledge.

With the use of fuzzy logic methods it is possible to effectively handle uncertain knowledge, which makes them particularly useful in models related to production. Expert systems based on fuzzy models are the most common and have many advantages. More than 80% of expert systems use such models, so it is reasonable to apply a software implementation of fuzzy models for power automotive drivetrain diagnostics using a productization approach.

Today, one of the most popular software tools using the production approach and interpretation of fuzzy productions is the FuzzyCLIPS expert system. It is a comprehensive system developed in the C programming language that combines the capabilities of production and logical inference. FuzzyCLIPS offers a wide range of features including fact processing, dynamic rule addition, and customizable contradiction resolution strategies.

In addition, FuzzyCLIPS can be integrated into other programs and includes an object-oriented COOL programming language that is integrated with the logic inference engine. This allows FuzzyCLIPS to be used in various applications and extends its functionality. Thus, the application of fuzzy logic and expert systems such as FuzzyCLIPS opens up a wide range of possibilities for handling uncertain knowledge and improving the efficiency of production models.

At the beginning of the process, the system asks the user for the concentration values of the five gases obtained from the chromatographic analysis. Once these values are entered, the system performs the analysis using the concentration limit criterion.

At the beginning of the process, the system prompts the user for the concentrations of the five gases resulting from the chromatographic analysis. After entering these values, the system performs the analysis using the boundary concentration criterion.

However, it should be noted that the proposed mathematical expression has been successfully tested on real data obtained during the operation of autotransformers. The study revealed that this expression has high accuracy and sensitivity to changes in the state of this device.

Summarizing the results, it is safe to say that the developed mathematical expression represents an innovative approach to assessing the technical condition of autotransformers. The application of this expression allows detecting possible faults at an earlier stage, which contributes to improving the reliability of power systems in general. Thus, this method can become an important tool for power system operators, ensuring continuous and efficient power transmission.

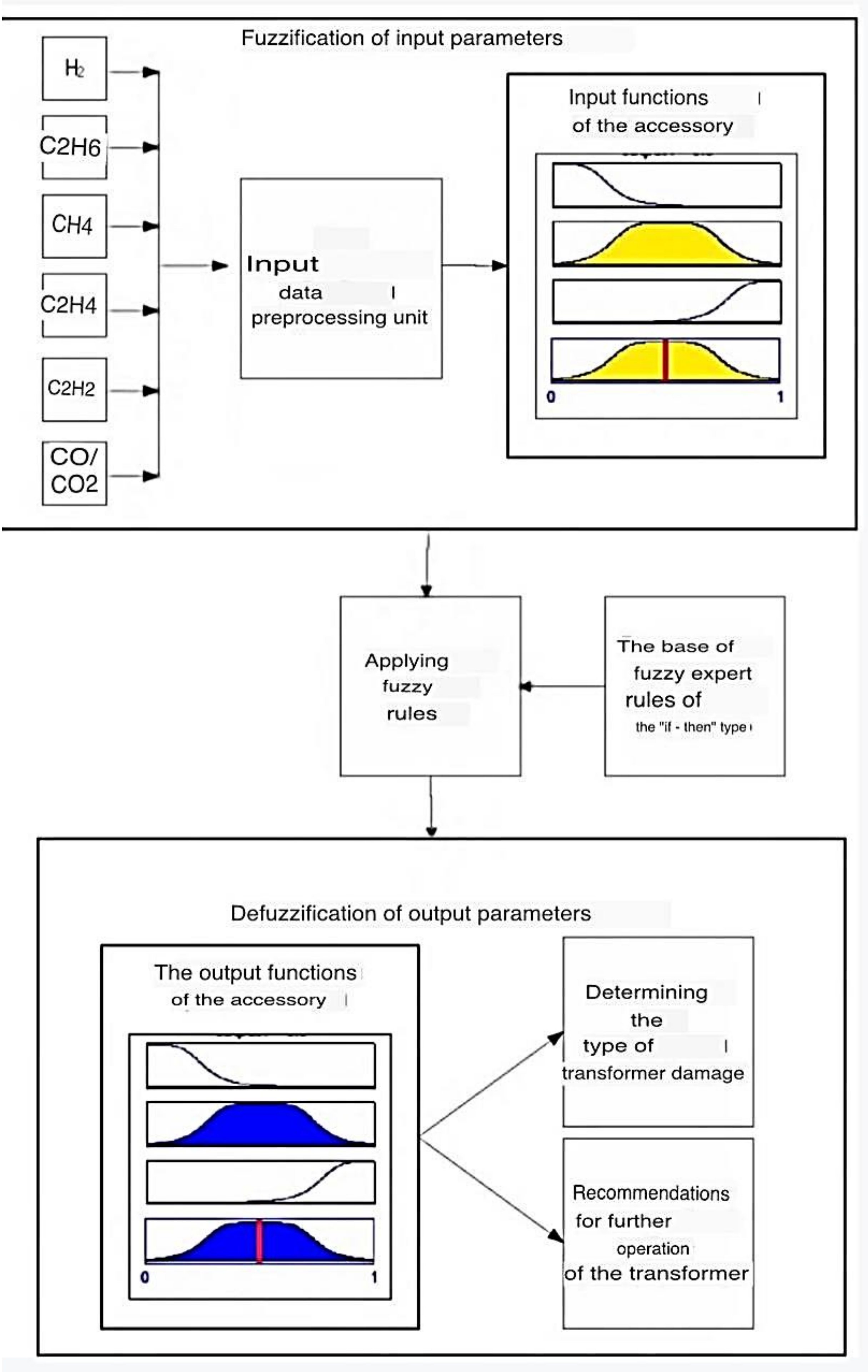


**Fig.3. Block diagram of fuzzy online system of online diagnostics of transformer oil of power AT**

## References

1. Shirokov, O.G.; Zalizny, D.I.; Los, D.M. Parametric identification of the mathematical model of the thermal processes of the power transformer (in Russian) // Vestnik. P.O. Sukhoi State Technical University. - 2005. - № 1. - C. 35-42.

2. Problems of power transformers diagnostics / G. M. Mikheev [et al.]//Problems and prospects of development of power engineering, electrical engineering and energy efficiency: Proceedings of the III Intern. scientific-technical conf. Cheboksary: Izdvo Chuvashunct., 2019. C. 445 -451.

3. A.A. Dimitriev, G. Mikheev. M., Power transformer diagnostics on the basis of fuzzy logic methods. Elektrooborudovanie: exploitation and repair No. 32022.

4. A.A. Dimitriev, G. Mikheev. M., Power transformer diagnostics on the basis of fuzzy logic methods. Electrical Equipment: Operation and Repair No. 32022.

5. Alekseev, B.A. Estimation of a condition of power transformers. Interpretation of the results of the gas-chromatographic oil analysis // Elektro. - 2002. - №2. - C. 10-15.

6. L.G. Sidelnikov, A. M. Sedunin, A. Y. Sykulev, TestService LLC Vibrodiagnostics and Partial Discharge Measurement in Power Transformer.

7. Bashirov, Z.A.; Voloshanovsky, A.Yu.; Naumov, A.A. A. Sensor arrangement methods for the scalar vibration field estimation in the vibrodiagnostics tasks (in Russian) // Problems of Power Engineering. 2000. № 7-8. C. 86-90.

8. Barkov A.V., Barkova N.A., Azovtsev A.Yu. Monitoring and diagnostics of rotor machines by vibration. Recommendations for users of diagnostic systems. Publishing house of SPbSMTU, St. Petersburg, 2000.

9. Petrishchev L.S., Saltanov V.M., Osotov V.N. et al. Investigation of possibility of diagnostics of transformer winding pressing force by their vibration characteristics. - Electrical Stations 1995, N 8, p. 32-37.