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Double Expert Methodology of NPP Power Equipment Inspection to Increase the Exploitation Lifetime

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Abstract. The problem of the lifetime extension of NPP power equipment is actual at present time. In our previous research, we were applying fuzzy sets and fuzzy algorithm methods that yielded positive results for solving this problem. The practice has shown that a forecast tool, based on stochastic theory, cannot be fully acceptable.

The stopping of equipment after some operational time, to carry out maintenance, has sometimes revealed that equipment did not receive significant damage as well as there are no factors, which would testify the approach to failure. Probably, it was due to overly conservative estimation of resource. Therefore, a more accurate forecast of the time interval to failure is needed.

Fuzzy sets, mathematics, linguistic sets and fuzzy algorithms have become an integral part of applied cybernetics. This class of methods, sometimes used to assess equipment reliability, is characterized by high uncertainty of results. Therefore, the choice of the method of two-stage assessment of the resource life of the equipment, precisely in the conditions of insufficient information about the reliability of the equipment, is reasonable.

Significant correction of forecast results can be reached when applying such an operation of fuzzy evaluation like contrasting. It can be noticed that fuzzy contrasting can serve as a tool to clarify significantly the inspection results. The presented results demonstrate the updated concept of peer review of power nuclear power plants, which is focused on increasing the accuracy of the forecast of its safe operation. Therefore, it is possible to gain a significant resource extension of valuable equipment. Furthermore, application of this methodology makes it possible to save all types of costs during repairs significantly.

Keywords: operational time, damage, forecast, resource extension

1 Introduction

The problem of the lifetime extension of NPP power equipment is actual at present time. In our previous research of the problem to increase service life of power equipment [1,2] we were applying fuzzy sets and fuzzy algorithm methods [3–6], which yielded positive results for solving this problem. The practice has shown that a forecast tool, based on stochastic theory, cannot be fully acceptable.

As it is known, the first method to disclose uncertainty was a possibility theory method. Using the definition of running equipment's failure as a background that started its operation from the time point $t_1 = 0$ as fully operational and after certain period of time came to the condition of "failure" or non-operational at the point $t_2 = T$, we can apply such a definition like "*time of operation before failure*". This extremely important value of equipment reliability exists on the scale of astronomical time and utilizes hours, years as a unit of measurement and is denoted by the letter T. Thus, the longer equipment operates without failures and breakdowns the more reliable is. However, on the practice there is such a complicated value of equipment's quality as *reliability*. By the definition, reliability is an ability of technical system to maintain all of its characteristics and parameters over time that is necessary to perform all required functions by the system. The following values are components of reliability: *failure free operation, reparability, duration of use, duration of storage*.

Duration of use and *duration of storage* are the same as the time of operation before fail are viewed through the astronomical time scale. *Failure free operation* and *reparability* are more complex characteristics.

The above mentioned stochastic method for determination of reliability of power equipment has shown that when making the decision only those reliability parameters of the element can be used, that have numeric characteristics. As for qualitative characteristics, such as failure free operation, reliability, duration of use, etc. – classic method doesn't provide solutions at the moment. That is why we try to apply modern theory of fuzzy pluralities or so called "fuzzy logic theory" to resolve present issues. This theory is convenient to solve fuzzy tasks.

Taking advantages of fuzzy logic opportunities, one can introduce for the consideration the following components of reliability:

- *Reparability*. Which requirements a repairable system should meet? First, it consists of the elements that have high reliability, are so widespread that can be kept in the storehouses or purchased to make it easy the replacement of the same elements that failed.
- *Presence of scheme structural combinations* to provide reservation (back up) of insufficiently reliable items.

- *Reliability of the elements connection* between each other, element and joint fixation using brazing or welding, reliability of medium's separation means (gaskets, seals, etc.)
- *Signs of wear (deterioration)*, presence of gaps, vibrations, etc.

It is obviously, that there can be many more components of reliability.

2 Description of the Problem

Basic hypothesis can be seen in Figure 1. A combined graph shown on this picture, where a few generally accepted lines of '*equipment reliability evaluation*' are represented. In the coordinates '*operational time – statistical integral function of failures*' – continuous line, and '*operational time – stochastic forecast of reliability degradation line*' – discontinuous line, it is shown in which way majority of modern energy companies are forecasting possible failures of their operating equipment [2, 7]. We also added a horizontal line – '*safety level line below which operation of equipment is prohibited*' shown as $P_{\text{br}}(t)$. The junction of this horizontal line with the degradation curve will create a time gap T that forecasts a guaranteed campaign of safe operation.

The practice has shown that such a forecast tool, based on stochastic theory, cannot be fully acceptable. The stopping of equipment after operational time T to carry out maintenance has often shown that equipment didn't receive significant damage as well as there are no factors that would testify development of failure. It turned to be an extra reinsurance that is excessive in the conditions of intensive operation. Therefore, it can be noticed, that having a more accurate forecast of dangerous situation onset, it is possible to gain a significant resource extension of valuable equipment. Proposed time gain is shown in the same picture with mark T_{corr} – 'corrected time of safe operation'. Usually this time is bigger than the one received from traditional stochastic method, $T_{\text{corr}} > T$. However, cases, where results can be opposite, cannot be excluded.

Value P_{br} in Figure 1 is accepted as a maximum permissible safety level of power equipment. Numerical value P_{br} is considered constant through all operational period. It is described by a straight line, which is parallel to the time axis. Numerical value P_{br} is selected from operational experience analysis of certain equipment. At the same time, pre-failure conditions are taken into account and their reasons are revealed. Own safety levels can be selected for each type of equipment. The junction of P_{br} line with 'equipment reliability degradation' line $P(t)$ shows that the degradation of equipment has reached such a level that its further operation may lead to failure.

Difference between T_{corr} and T determines a time extension of safe operation. A time interval between first and second expertize is selected from the following considerations. Expertize is performed on the running equipment. It is done to determine the degradation level of character-

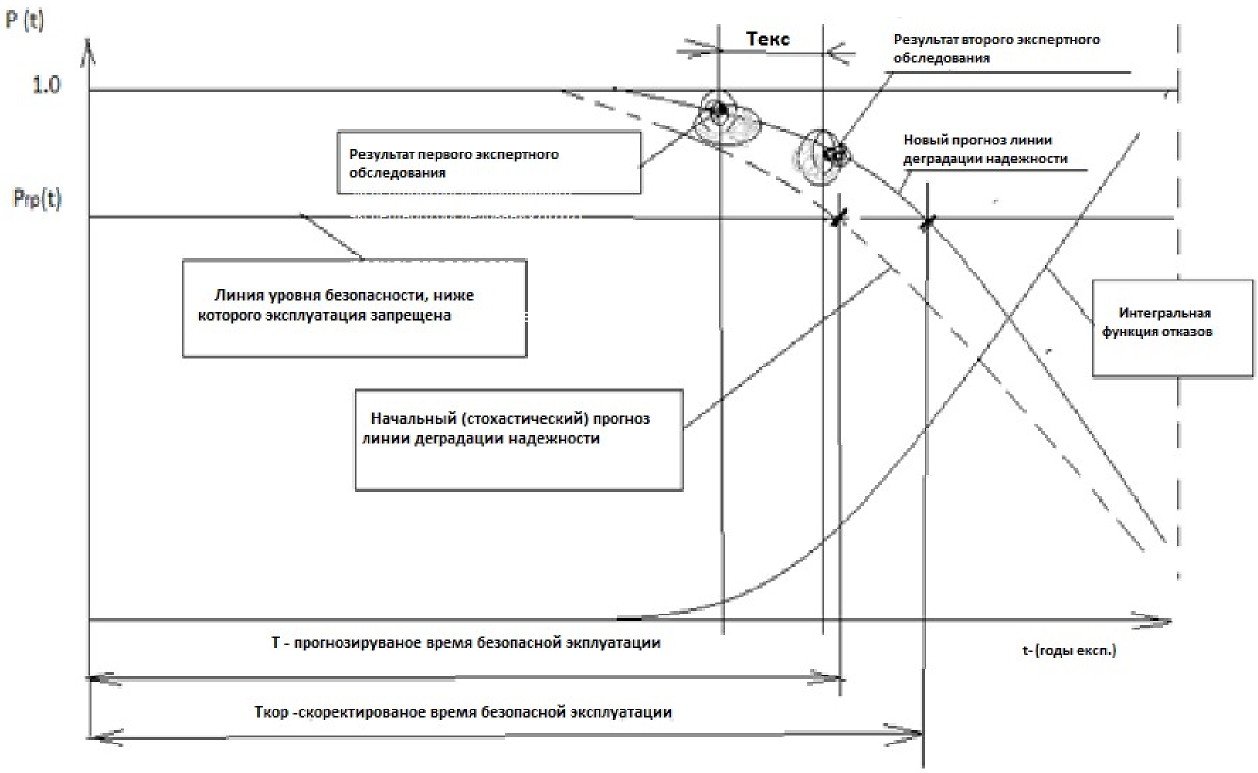

Figure 1. Double expert strategy of the power equipment inspection. $F(t)$ – integral function of failures (continuous line in coordinates). $P(t)$ – equipment's reliability degradation line (discontinuous line in coordinates). $P_{\text{br}}(t)$ – determines such a safety level, below which operation is not acceptable (Horizontal line). T_{ex} – time interval between first and second inspection of reliability. T_{corr} – restored forecast of degradation line position, which allows corrected timing of safe operation.

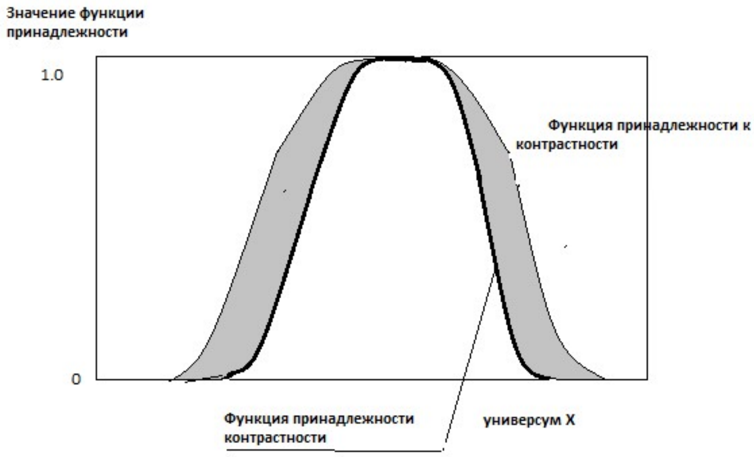

Figure 2. Graphic illustration of the contrast operation functions of affiliation Gauss type.

istics of equipment defining its reliability (such as values of vibration, friction, etc.). First expert evaluation is recommended to be carried out when first visible changes in operation of equipment and parts appear. The second expertize carry out at 0.05 of time before the guaranteed resource has been reached. Value of $P(t)$ obtained by formula

$$P(t) = 1 - F(t) = 1 - \frac{1}{\sigma\sqrt{2\pi}} \int\limits_{0}^{\infty} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt,$$

where: t – independent variable (astronomical time), years; μ – evaluation of average operational time before failure, years; σ – evaluation of standard deviation of failure time from average (mode), years.

3 Research Method

To obtain the result, let's appeal to the theory of possibilities, based on the modern theories of L. Zadex, B. Kosko, E. Mamdani and others [3, 8–10]. As known, the fuzzy sets mathematics, linguistic sets, fuzzy relations, fuzzy algorithms, etc. became an integral part of applied cybernetics. However this class of methods, primarily, comes from that the task of reliability evaluation is significantly unidentified. Considering this, let's consider that a method selection in this condition is rational. Significant correction of forecast results can be reached when applying such an operation of fuzzy evaluation like statement. It can be noticed that fuzzy contrasting can serve as a tool to contrast expert information, namely a tool to clarify significantly the inspection results.

This solution has been shown earlier in Figure 2 during formation of a working hypothesis. An affect that is gained during double inspection of equipment is shown on Fig. 3. Additional inspection must be carried out after certain period, defined on chronological scale. During this period, equipment that is in service will accumulate additional signs of degradation. Drawing an approximation line between both inspection results, it is possible to determine the junction point of the 'prohibited operation line' with a general curve of degradation more precisely.

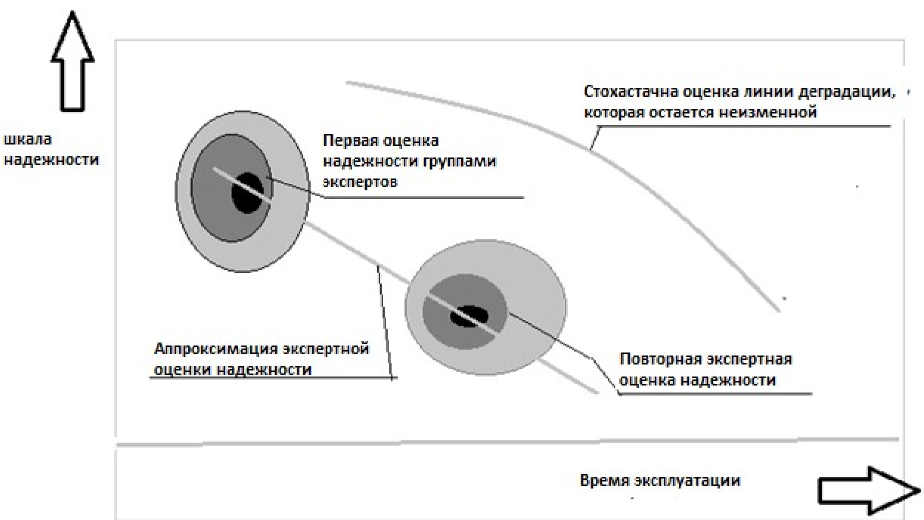

Figure 3. Explanation of expert groups action strategy to determine reliability resources of the equipment by the application of double inspection.

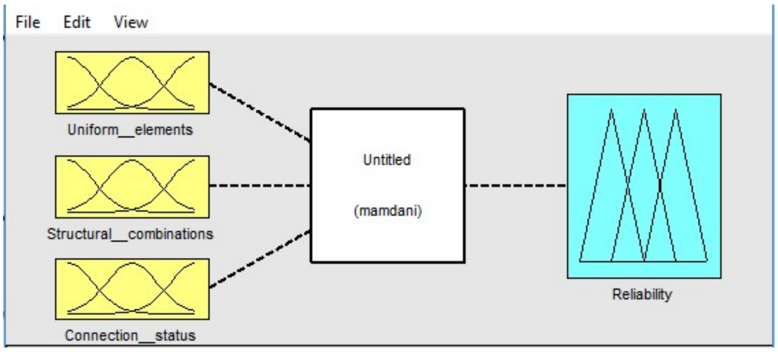

Figure 4. Construction scheme of a fuzzy expert system that recommended to process results of inspection of critical equipment for reliability.

The procedure of expertize results processing, called '*contrasting*' in the article, implies obtaining of reliability evaluation value of studied equipment. Evaluation is generated by coagulation of big amount of fuzzy data determined by experts. In this case 'contrasting' means a reduction of intervals occupied by lingual variables terms on the accepted universums. This case is shown in Figure 3. by the reduction of ellipsoid conditional diameter. In our case, a small diameter ellipsoid can be considered as 'characteristic point'.

Detection and contrasting of two separate evaluations will give an opportunity to approximate a new forecasted line of reliability degradation. A question which line has to be used for extrapolation of causal relationship link between two conditions of process requires many data for its solution. In the first approximation, it can be assumed that equipment continues operation in the preset operational limits. That is why an approximation of main parameter changes with a section of straight line is possible to consider acceptable.

'Data coagulation technique' that experts collect during inspection of equipment described in Figure 4.

In this case, an input of a system has 4 linguistic variables (LV), output – one linguistic variable – 'coagulated reliability evaluation'. More detailed description of a fuzzy conclusion according to E. Mamdani algorithm was presented in our previous materials [1, 2].

4 Conclusions

1. Forecast tool for the reliability assessment of NPP power equipment, based on possibility theory, cannot be fully acceptable.
2. Double expert strategy of the power equipment inspection, based on fuzzy logic theory, give an opportunity to increased service period of its safe operation.
3. This methodology makes it possible to achieve substantial savings of all kinds of resources.

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