GAS TURBINE FAULT DIAGNOSTIC SYSTEM BASED ON FUZZY LOGIC

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Abstract. *In the article a method of parametric diagnostics of a gas turbine, based on fuzzy logic is proposed. The diagnostic map of interconnection between some parts of turbine and changes of corresponding parameters has been developed. Also we have created model to define the efficiency of the compressor using fuzzy logic algorithms.*

Keywords: gas turbine; fuzzy logic; diagnostic

SYSTEM DIAGNOSTYKI AWARII TURBINY GAZOWEJ OPARTY NA LOGICE ROZMYTEJ

Streszczenie. *W artykule zaproponowano metodę parametrycznej diagnostyki turbiny gazowej w oparciu o logikę rozmytą. Opracowana została diagnostyczna mapa połączeń między niektórymi zespołami turbiny gazowej oraz zmianami odpowiednich parametrów. Ponadto udało nam się stworzyć model do określania wydajności sprężarki przy użyciu algorytmów logiki rozmytej.*

Słowa kluczowe: turbina gazowa, logika rozmyta, diagnostyka

Introduction

One of the major problems of forecasting the gas turbine condition is identification of malfunctions, which is based on the theory of images recognition [5, 8]. Malfunctions of turbine's condition break into a final number of classes and types which contain the failure conditions met most often at operation period and modeled using logic diagnostic model [1,4]. To decide about failure conditions classes based on parameters of work processes the diagnostic features are selected [6, 7, 9].

Based on analysis of turbine operation the author present methods of expert estimations for definition of malfunction character of all important parameters in time and interrelation of measured parameters with various kinds of malfunction of a turbine. The given technique allows tracing changes of a turbine's condition on the basis of changing of key parameters (speed, vibration, exhaust temperature and etc.). Thus the description of processes in system is carried out by means of linguistic rules at which the condition of the unit is estimated by a set of values in a range from 0 to 1.

1. Theory

Using the authentic statistical data on faults of the units obtained as a result of processing of the operational information or modeling of failure conditions, the process of malfunction's definition is based on the statistical theory of hypotheses checking.

In case of difficulties with gathering of the statistical information and high cost of carrying out of natural tests of the unit in a basis of recognition of malfunctions it is expedient to use the determined method related with the turbine's description by logic determined model. Recognition of malfunctions is based on the logic systems using methods of fuzzy logic.

During the operation period the probability of turbine's conditions classes should increase as soon as malfunction occurred. If it is ideal recognition system the probability of the valid class of unit's condition will be equal 1.

However because recognition system error is present some uncertainty of a unit's conditions remains. It can be expressed through posterior probability of condition classes $P_{an}(K_1)$, $P_{an}(K_2)$, ..., $P_{an}(K_i)$ characterizing position of object conditions in the corresponding class if certain results of measurements are obtained. These probabilities can be defined, using Bayesian formula.

In a turbine operating time realization of parameters is obtained as $B_j(y_1,y_2,...,y_a)$. Posterior probabilities of an accessory of realization to each class are defined by the equation (1).

$$P(K_i / B_j) = \frac{P(K_i)P(B_j / K_i)}{\sum_{i=1,j=1}^{D} P(K_i)P(B_j / K_i)}, \tag{1}$$

where $P(K_i)$ is prior probability, K denotes a class; $P(B_j/K_i)$ is the posterior probability of hypotheses that B-realization has a membership of class K_i; $P(K_i/B_j)$ denotes conditional probability that turbine's state is a membership of j class.

If it's ideal system, it will show us that the turbine condition is a membership of j-class. In that case:

$$\begin{aligned} P(B_j / K_i) &= 1, i = j, \\ P(B_j / K_i) &= 0, i \neq j. \end{aligned} \tag{2}$$

Consequently, the denominator of formula (1) becomes:

$$\sum_{i=1}^{N} P(K_i)P(B_j / K_i) = P(K_i)P(B_j / K_i) \tag{3}$$

Therefore

$$P(K_i / B_j) = \frac{P(K_i)P(B_j / K_i)}{P(K_i)P(B_j / K_i)} = 1 \tag{4}$$

In this way using the ideal recognition system the reliability of supposition that turbine condition is a membership of K_i – class increases in comparison with the aprioristic data by value:

$$\frac{P(K_i / B_j)}{P(K_i)} = \frac{1}{P(K_i)} \tag{5}$$

The real recognition system has some errors, therefore:

$$\begin{aligned} P(B_j / K_i) &< 1, i = j, \\ P(B_j / K_i) &> 0, i \neq j. \end{aligned} \tag{6}$$

Consequently, $P(K_i / B_j) < 1$ means that we have not fully reliability of aprioristic data in prediction of turbine condition.

For example, we have N-classes representing all groups of turbine conditions. As a result the area of parameters of an unknown class of emergency conditions is obtained $B_j(y_1, y_2,..., y_m)$. It is needed to define posterior probability of hypotheses: H_1 – B_1 is a membership of class K_1; H_2 – B_2 is a membership of class K_1 and etc., up to K_{N-1}; B_j is a membership of class K_1 .

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Table 1. Identification table of turbine condition type of "GTK-10-4"

Malfunction	R1T2	R2π2	R3T3	R4T8	R5Mg	R6T5	R7p3	R8ε	R9p1	R10p8	R11T1	R12G	R13eн	R14mп	R15Tн	R16V1	R17V4	Rules
Erosive tear of turbine blades		Δ1		Δ2	Δ1	Δ1	Δ3	Δ2	Δ1	Δ1	Δ2						Δ1	R2R4R5R6R7R8R9R10R11R17
Turbine blades damages		Δ3		Δ1	Δ2	Δ1	Δ3	Δ2			Δ3	Δ2				Δ1	Δ2	R2R4R5R6R7R8R11R12R16R17
Dirtying of Axial compressor		Δ1			Δ2							Δ2				Δ3		R2R5R12R16
The efficiency of combustion chamber is decrease					Δ3		Δ2				Δ1							R5R7R11
Degradation of the HPT flowing duct				Δ1		Δ2			Δ1	Δ3	Δ2					Δ3		R4R6R9R10R11R16
Depressurizing of HPT section			Δ2	Δ3	Δ3	Δ1	Δ2				Δ3							R3R4R5R6R7R11
Changing the resistance of HPT gas-air flow duct	Δ1	Δ3	Δ2	Δ2	Δ1	3Δ	Δ2									Δ1		R1R2R3R4R5R6R7R16
Axial compressor blades damages	Δ2	Δ1	Δ2	Δ1	Δ3	Δ3	Δ1					Δ2				Δ2		R1R2R3R4R5R6R7R12R16
Erosive tear of axial compressor blades	Δ2											Δ1						R1R12
Changing the resistance of LPT gas-air flow duct						Δ1				Δ2								R10
Deterioration of the state of Axial compressor flowing													Δ1	Δ3	Δ2		Δ1	R13R14R15R17
Deterioration of compressor bearings condition	Δ2	Δ2										Δ3				Δ1		R1R2R12R16
Degradation of LPT bearings										Δ1			Δ2	Δ1			Δ3	R10R13R14R17

In that case posterior probability of hypotheses is defined as below:

$$H(H_i / B_j) = \frac{P(K_i) f\left[\frac{B_j}{y_1^{K_i}, y_2^{K_i}, \ldots, y_i^{K_i}}\right]}{\sum_{i=1,j=1}^{D} P(K_i) P(B_j / K_i)}, \tag{7}$$

where $P(H_i)$ is the prior probability of hypotheses;

$f\left[\frac{B_j}{y_1^{K_i}, y_2^{K_i}, \ldots, y_i^{K_i}}\right]$ - multidimensional function of credibility;

$y_1^{K_i}, y_2^{K_i}, \ldots, y_i^{K_i}$ is the pattern of K_i - *class*, expressed by set of signs. Using (7), it is possible defined, to which class *Ki* from *N* belongs B_j - realization.

In case the determined model of the turbine is used, the problem of recognition of a malfunction classes becomes simpler. The determined system uses set of the signs definitely characterizing a condition of the unit, and is constructed on the logic systems of recognition using fuzzy logic algorithms.

Logic signs of malfunctions are considered as elementary statements. Logic signs can be qualitative, defining presence or absence of some properties or processes, and also, quantitative, defining sign hit in a certain interval, corresponding to value "is serviceable" / "is faulty", which are limited with set points.

On the basis of the analysis of diagnostic signs it is possible to make the identification table (Table 1) which is based on predicted functional parameters. Identification rules of malfunction classes are based on principles of fuzzy logic.

The estimation of presence of diagnostic signs doesn't demand categorical answers "Yes" or "Not", but it is carried out using the linguistic rules. So, the temperature of exhaust gases of the turbine (T1) can be described with following conditions: "high" – more 480°C (D3), "normal" – a range 400°C to 475°C (D2), "low" – less 400°C (D1). At the insufficient information on functional parameters of the turbine, in case of impossibility to establish malfunction type it agree the presented tables, the importance of an expert estimation which in the subsequent should be used for specification of the information on parameter and degree of its influence on a technical condition of the turbine in rules of indistinct logic increases.

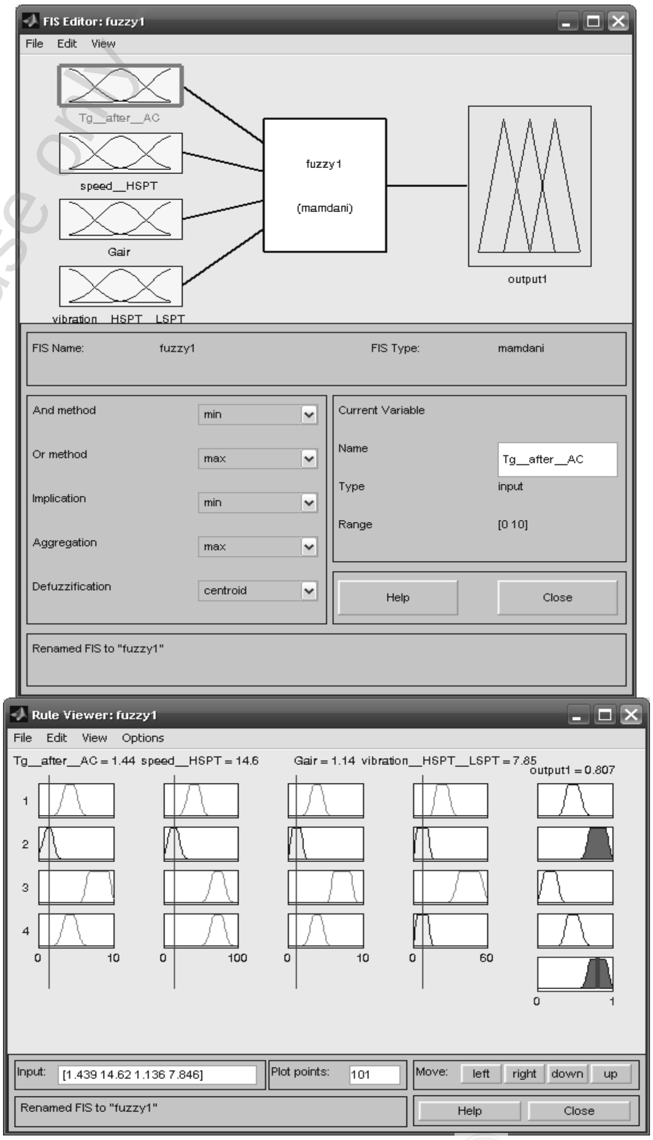

Fig. 1. Modeling of axial compressor condition

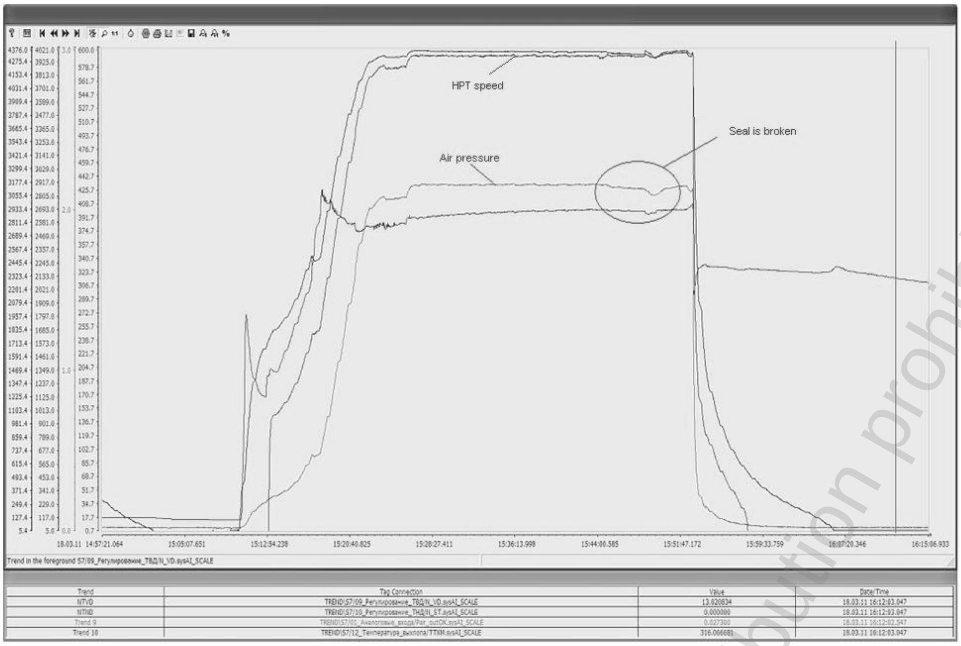

Fig. 2. Destruction of Axial compressor seals

2. Practice

For approbation of the offered methods of forecasting of development of malfunctions of units the emergency stops which have occurred at compressor station "Dzhangala" (Uralsk, Kazakhstan) are considered. As an example the analysis of operational parameters of the Gas turbine unit type of GTK-10-4 refused on a cause of defect of axial compressor air seals is resulted.

In the given model for diagnostics of axial compressor condition following parameters according to Table 1 are chosen:

- temperature of air after the Axial Compressor, (Tg_after_AC), [0…100],°C;
- high pressure turbine (HPT) speed, (speed_HSPT), [0…100], rpm;
- high pressure turbine vibration, (vibration_HSPT), [0…60], mm;
- air pressure after axial compressor, (Gair), [0…10], kg/cm^2.

For each measured parameter the "gauss2mf" function has been chosen as a membership function (Figure 1). As a result, we can see that the fuzzy output value of the axial compressor condition is equal 0.807.

In this unit appreciable falling of turns of both shafts HPT and LPT (parameter R14 in Table 1), reduction of compression ratio (parameter R13) was observed. Also on the trends we can see, that the vibration on HPT shaft (R15) was 2,15 mm/sec which is higher than normal value.

Hence, the solving rule of malfunction identification will become: d = R13R14R15R17;

According to the Table 1 the given rule means presence of malfunction classified as malfunction of a flowing part of the axial compressor, with its possible destruction.

3. Conclusions

On the basis of the executed researches following results are obtained:

- The analysis of methods of technical diagnostics is made and also the basic principles of an assessment of a technical condition of the gas turbine are developed;
- Principles are proved and methods of the qualitative and quantitative analysis of the working capacity, allowing describing a technical condition of gas turbines are offered;
- Decisions for creation of the approached analytical models of recognition damages of gas turbines on the basis of algorithms of fuzzy logic are obtained.

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