The dimension indicator of the vibration signal for diagnosing gas turbine engines support bearings

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Abstract. This paper showcases the results of a study on the correlation dimension of the vibration signal in cases of the destruction of aviation engines support bearings. The relevance of the study is determined by the search for promising solutions to improve the maintenance of aircraft engines. It is established that the correlation dimension of the vibration signal of working and defective bearings are contrast with a significance level of 0.002. The scientific significance of the research lies in the statistical substantiation of the application of the vibration signal dimension in gas turbine engines diagnosis systems.

Key words: destruction of support bearing, correlation dimension, population variance, null hypothesis, contrast of means, significance level, confidence coefficient.

1. Introduction
One of the characteristics of dynamic systems is its dimension, which is determined by the minimum number of independent variables (coordinates, factors) necessary to fully describe the state of the system. The following kinds of dimensions are known and applied: capacity of the set, information dimension, correlation dimension, Lyapunov’s [1]. In practice, the most widely used dimension is the correlation dimension \( D_c \), which is determined by the Grassberger-Procaccio correlation integral and the Takens delay method.

Today, \( D_c \) is used in the study of nonlinear dynamical systems of various natures [2]. There are publications in the field of complex mechanical systems [3], medical diagnostics [4] and geophysical research [5].

Our goal was to study the \( D_c \) of the vibration signal of aircraft gas turbine engines in the event of the destruction of their support bearings. In this case, the dynamic system will be a gas turbine engine, and the observed signal - the signal from the vibration sensor.

2. Methodology
In our research we used a series of 12 flights made by each of 7 engines: 4 flights immediately before the destruction of the support bearing (bearing is defective), 4 flights before them (bearing is damaged) and 4 earlier flights with the same engine (bearing is working).
The data of the last flights in which the bearing was destructed is not considered. Each flight represents 3000...4000 values of the vibration signal from a standard vibration sensor. According to this data the $D_c$ is calculated by a delay method with parameters: delay time - 1/2 to the first minimum of the autocorrelation function of signal and number of embedded coordinates - 10.

Thus, 3 samples of 28 flights each were created, which allows us to compare the $D_c$ of the engines vibration signal with working, damaged and defective support bearings.

The research plan is presented in table 1.

| Table 1. Research plan | State of the support bearing |
|------------------------|------------------------------|
| Input data             | working, damaged, defect.    |
| Vibration signal engine # 1…7 | 7 x 4 = 28 observed value | 7 x 4 = 28 observed value | 7 x 4 = 28 observed value |

Further, the obtained $D_c$ were statistically processed. This consisted of excluding rough data (outliers), calculating sample means and variances, kurtosis and skewness, determining the distribution law of observations and population variance.

Statistical characteristics obtained during the calculus are shown in table 2.

| Table 2. Statistical characteristics of the study | State of the support bearing |
|-------------------------------------------------|------------------------------|
| Name of characteristics | working, damaged, defect.    |
| Means of $D_c$            | 2.77, 2.66, 2.38             |
| Samples variance         | 0.23, 0.25, 0.33             |
| Samples confidence interval (0.95) | ± 0.19, ± 0.20, ± 0.23 |
| Population variance      | ± 0.17                       |

3. Analysis of received data
Statistical processing [6] of three samples of the $D_c$ vibration signal revealed that:

- the observations are homogeneous. According to the ratio of the maximum relative deviations of individual observations and the quantile of the $\tau$-test for a significance level 0.05, they have no outliers from the means values;
- sample values of kurtosis and skewness confirm the hypothesis of a normal distribution of observations;
- according to the Cochran criterion the sample variances belong to one population variance equal to the weighted average variance of all sample variances;
- means of $D_c$ for working, damaged and defective bearings, respectively, are 2.77, 2.66 and 2.38;
- based on the population variance 0.22, the number of observations 28 and the normality of the distribution law, the confidence interval for the mean $D_c$ all samples with confidence coefficient 0.95 are ± 0.17;
- the null hypothesis about indistinguishability of means $D_c$ is rejected with the significance levels given in table 3.
Table 3. Significance levels of contrast between means $D_c$
(confidence coefficient)

| Contrast          | Significance Level |
|-------------------|--------------------|
| working - damaged | 0.4 (60%)          |
| damaged - defect  | 0.03 (97%)         |
| working - defect  | 0.002 (99.8%)      |

4. Conclusions
This study established that the correlation dimension ($D_c$) of the vibration signal depends on the technical condition of the engine support bearings. For working and defective bearings the contrast $D_c$ has a significance level of 0.002 (confidence coefficient 99.8%). For damaged and defective bearings it is 0.03 (97%) and for working and damaged 0.4 (60%).

In our research, we did not use flights in which the amplitude of the vibration signal increased before the moment of failure of the support bearing. Therefore, the method for diagnosing aircraft engines by evaluating the $D_c$ of a vibration signal leads, in comparison with traditional methods, to increase in the time of forecasting from issuing the diagnostic signal to the destruction of the support bearing.

The obtained result allows us to recommend using the dimension of the vibration signal when searching for solutions in the field of dynamic resource management and optimizing the maintenance of aircraft engines for promising passenger aircraft [7], as well as reducing the life cycle cost of sixth generation engines of military aircraft [8].

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