DECISION MAKING ABOUT AIRCRAFT ENGINE BLADES CONDITION BY USING NEURAL NETWORK AT THE STEADY-STATE AND NON-STEADY-STATE MODES

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Summary

The work is devoted to problem solution of the gas-turbine engines (GTE) blades condition monitoring and diagnosis of the crack-like damages at the steady-state and non-steady-state modes of GTE. It is based on the development of theoretical basis of the vibroacoustical diagnosis methods, the application of the modern signal processing methods and new information technique for decision making. The application of the following signal processing methods: Wavelet-transformation and dimensionless characteristics of the vibroacoustical signals is proved. Neural networks are used for decision making about blades condition by the above mentioned features application. Classification of turbine blade condition was carried out using a two-layer Probability Neural Network (PNN).

Keywords: blade, crack-like damages, vibroacoustical condition monitoring, neural networks.

INTRODUCTION

The problem of prolongation of aircraft turbine engine working life and increasing their reliability is the issue of the day. This problem may be solved using improved existing and new methods and diagnostic instruments. Despite the fact that the progress in development of existing methods and instruments is considerable, the problem of functional diagnostics of fatigue defects in compressor and turbines blades of an aircraft engine is not solved yet. We propose to solve this problem by using the vibration and vibroacoustical diagnostic methods [1]. Since the most fatigue defects of the GTE rotor components directly connect with vibration processes which take place in operating engine. On the other hand, vibration and vibroacoustical methods provide the possibility to diagnose and non-destructively evaluate defects without disassembling the engine. It may be done using advances in computer-based technology and information handling methods for recognition of the rotor component condition in the operating engine. Creation of the monitoring system is based on application and further development of low-frequency vibroacoustical diagnostic methods which use vibrating and acoustical noise as diagnostic information.

1. PROBLEM STATEMENT

Generally monitoring is a continuous process of information gaining about the object vibrating condition, transformation and analysis of it, and making decision about object technical condition. The stages of the mentioned informative process depend on the engine operation modes. These modes define specific character of vibrating and acoustical excitation of the compressor and turbine blades, and consequently, they define the methods and algorithms of signal processing which must be chosen or developed.

Initiation and increase of a fatigue crack in the blade lead the instantaneous change of its stiffness. Usually the change of stiffness is modeled by the piecewise-linear characteristic of the restoring force [1, 2]. Non-linearity leads to variation of oscillation parameters and to occurrence of local non-stationary component in the measured signal.

The dynamic model of gas-turbine engine as an object for fatigue cracks diagnostics in turbine blades and compressors was created. This model is used for simulation and analysis of vibroacoustical processes which occur at the steady-state and non-steady-state modes of GTE at absence and presence of small fatigue cracks in one blade of the turbine stage (the relative rigidity changing at the crack presence is considered ϑ=0,03;0,05). The three modes of GTE are simulated and investigated: m1 - steady-state (constant value of the rotor rotation frequency); m2 - non-steady-state (the fast increase of the rotor rotation frequency); m3 - non-steady-state (the decrease of the rotor rotation frequency).

Simulated signals were processed using Wavelet-transformation and amplitude dimensionless characteristics of the vibroacoustical signals. The preliminary Wavelet decomposition of signals is used for the sensitivity increasing of the amplitude dimensionless characteristics of the vibroacoustical signals as fault features [3]. The following amplitude dimensionless characteristics are used: J_3 - peak factor and J_4 - factor of background. Thus, the fault features are detected and the following feature vectors are formed: $\vec{X}_{mi} = (J_3^{(mi)}; J_4^{(mi)})$, $i = \overline{1,3}$.

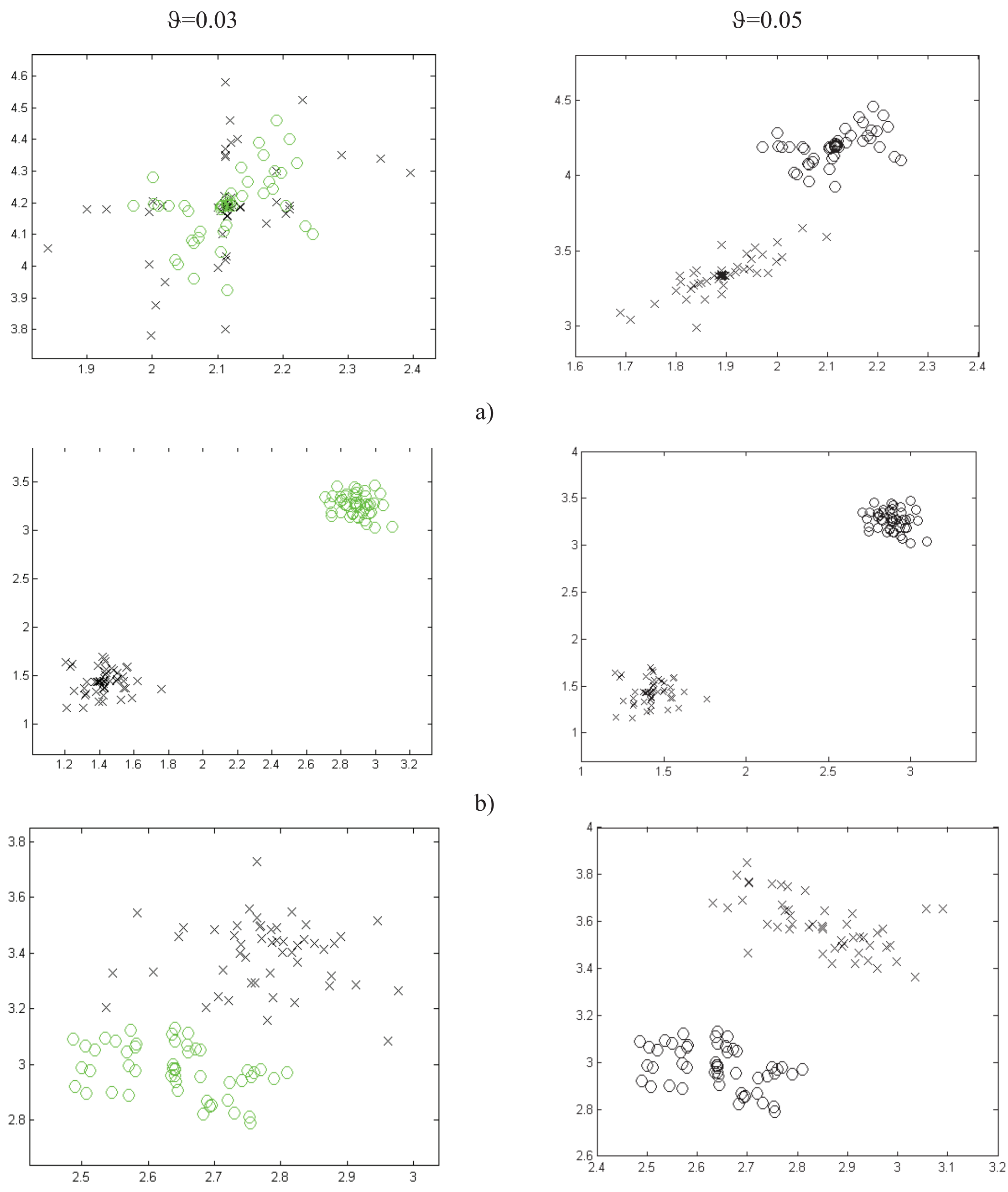


Fig. 1. The learning sets of the feature vectors for the three modes of GTE: a) m1, b) m2 and c) m3 (o – without damage S_0, x – with damage S_1).

The mentioned vectors are used for the decision making about blades condition: the absence (S_0) or the presence (S_1) crack-like damage.

By using the feature vectors the learning and test sets are received for the above mentioned three modes of GTE: m1, m2 and m3. The learning sets are shown in Fig. 1 for the relative rigidity changing at the crack presence ϑ=0.03 and ϑ=0.05. Axes indicate the peak factor and factor of background.

As it can be seen from a given plot, the linear division into blades conditions S_0 and S_1 occurs for the learning sets only at the m2 mode for both cases ϑ=0.03 and ϑ=0.05, but at the m1and m3 – only for ϑ=0.05.

The aim of this work is efficiency analysis recognition of aircraft engine blades condition at the steady-state and non-steady-state modes of GTE by using neural networks.

2. RECOGNITION OF BLADES CONDITION

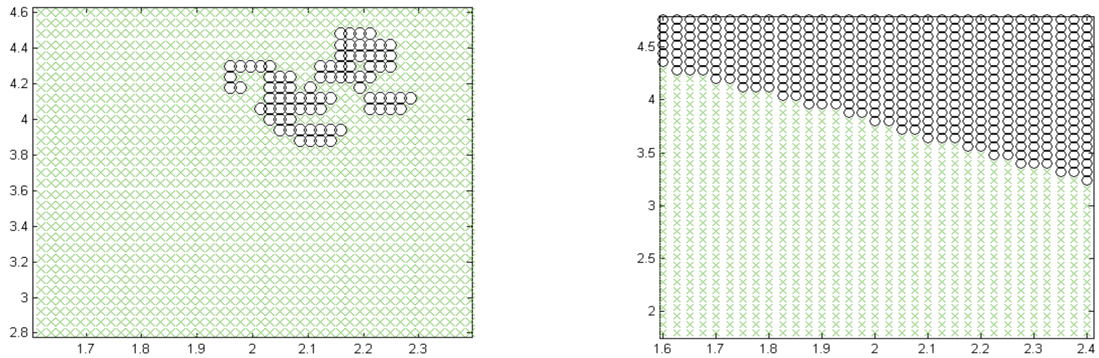
Classification of turbine blade condition was carried out using a two-layer Probability Neural Network (PNN) [4]. The first layer consists of 100 neurons. As a second layer it is used the so called competitive layer from 2 neurons. These neurons determine correct solution probability - the input vector belongs to a faulty type or not. Such classification is based on Bayes methods and needs probability density estimate for a condition type. For that, set of learning vectors are used. Every vector is described by Gauss function with a center in the point corresponding to this vector. The sum of named functions according to the whole available set of learning vectors is equal to probability density of input vectors for each condition types. The value of the Gauss function mean-square deviation σ specifies the width of the neurons activation function and defines their influence on a probability density estimate sum. This implies that the parameter σ influences on the classification result, therefore its value is determined mostly experimentally.

The results of classification are shown in Fig. 2 for the relative rigidity changing at the crack presence ϑ=0,03 and ϑ=0,05.

The effectiveness of turbine blades condition classification by PNN was judged by the coefficient K (this coefficient is a value of correct classification probability). Relationships between the coefficient K and the influence parameter σ for test sets of the feature vectors is shown in Fig. 3. As it can be seen from a given plots, PNN recognizes the blades condition with the following minimum values of the correct classification probability:

- m1 (steady-state mode) – K=0.93 for ϑ=0.05 at the σ=0.1 (recognition for ϑ=0.03 is not correct – K=0.3);

ϑ=0.03 ϑ=0.05



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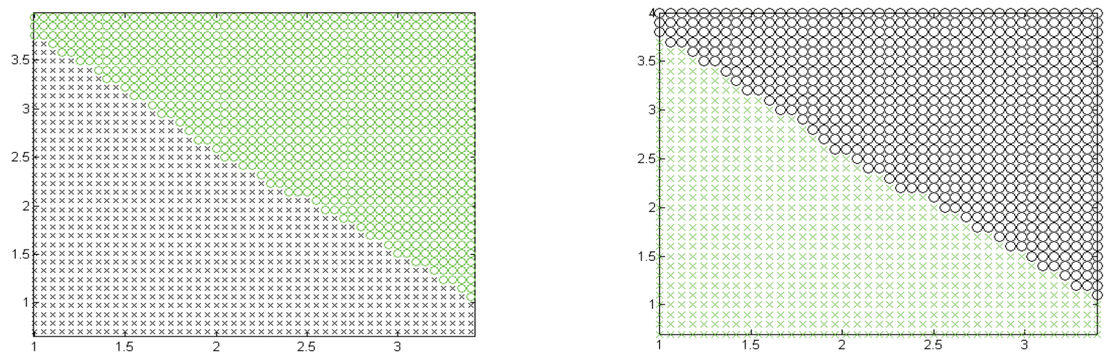

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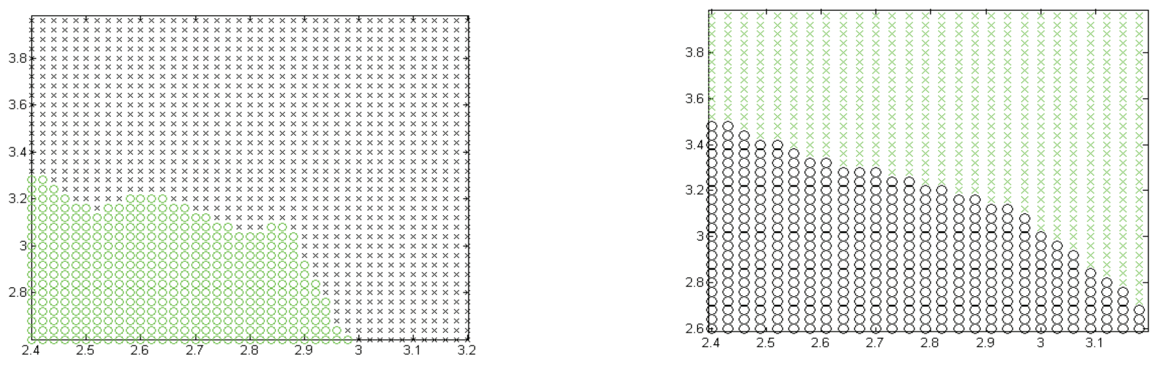
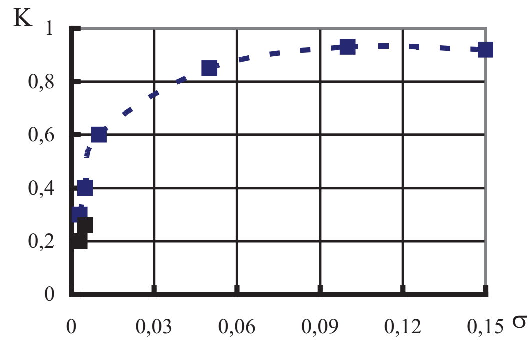


c)

Fig. 2. The results of classification for three modes of GTE: a) m1, b) m2 and c) m3
(o – without damage S_0, x – with damage S_1).

- m2 (non-steady-state mode) – K=0.96 for both cases ϑ=0.03 and ϑ=0.05 at the σ=0.1,…0.12;
- m3 (non-steady-state mode) – K=0.94 for both cases ϑ=0.03 and ϑ=0.05 at the σ=0.1.



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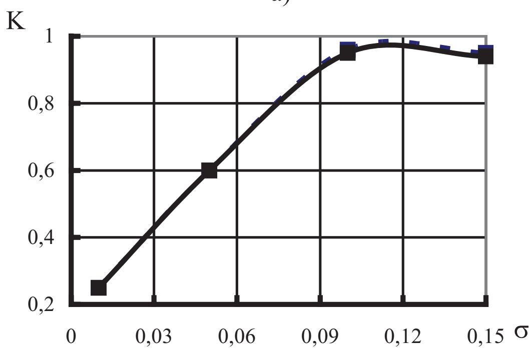

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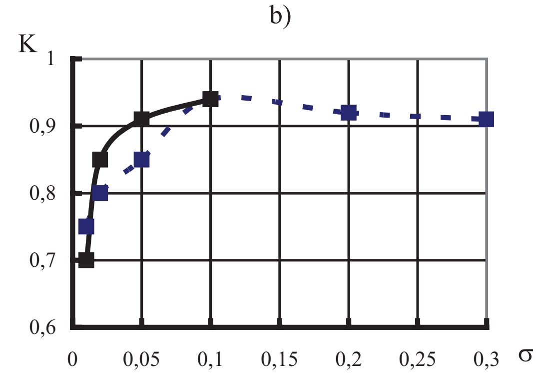

c)

Fig. 3. Dependencies of correct recognition probability on the influence parameter σ of a neural network for three modes of GTE: a) m1, b) m2 and c) m3 (continuous lines – ϑ=0.05, dotted lines – ϑ=0.03).

So, in spite of diagnostic features irregularity and little changes at turbine blade condition changing from defectless to faulty one, PNN provides classification of diagnostic object condition with the high values of the correct classification probability at the steady-state and non-steady-state modes of GTE.

CONCLUSION

1. Simulation and analysis of vibroacoustical signals radiated at steady-state and non-steady-state modes by an engine rotor with defectless and cracked blades allow to form the learning and test sets of the feature vectors.
2. Application of a Probability Neural Network provides turbine blades condition classification using the peak factor and factor of background of the results of Wavelet Decomposition of vibroacoustical signals with the high values of the correct classification probability at the steady-state and non-steady-state modes of GTE.
3. Received results are new and justify efficiency of turbine blades condition recognition at the presence of small crack-like damages. These results can be used to create a vibroacoustical monitoring system for aircraft engine rotor components.

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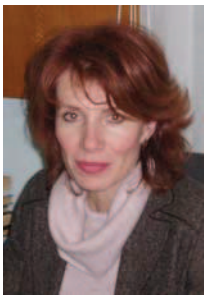

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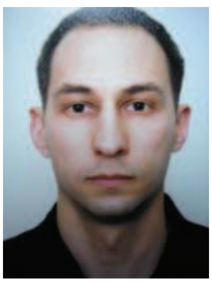

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