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Using adaptive algorithms based of fuzzy logic in vibration diagnostic systems

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Abstract

The paper dwells upon the possibility of using adaptive algorithms based on fuzzy logic in vibration diagnostic systems. An urgent task of improving diagnostic systems by increasing diagnostic reliability with minimal costs for their testing is given in the paper. The authors prove fuzzy logic rules to be necessary for diagnostic tasks. There are functions of vibration acceleration values at various shaft rotation frequencies. An example of vibration diagnostic and monitoring system operation using fuzzy logic is given. The authors prove that using fuzzy logic-based algorithms allows moving forward to the next stage in vibration diagnostic system development.

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Keywords: diagnostics, fuzzy logic, rules, condition

1. Introduction

An integral part of providing reliable and uninterrupted operation of the most critical units and facilities is a usage of technical diagnostic means at all the stages of their operation. An efficient in-place diagnostics allows moving forward to condition-based repair and maintenance of the facilities. Since bearing assemblies are liable to high dynamic loads, operation of facilities depends on their condition. That is why there is an urgent task of improving diagnostic systems by increasing diagnostic reliability with minimal costs for their testing [1].

From the beginning, an in-place diagnostics of rotating parts of machinery was made manually or aurally, so the testing results were in strong dependency from the experience of the diagnostic expert.

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The next step of vibration diagnostics was connected with scientific advancement and the advent of computing machines. In the last decades lots of new diagnostic systems have appeared, measuring vibration parameters (vibration features) and comparing then to the critical values, and, as a result, determining condition of the unit.

The next step in diagnostic systems development is considered their evolving due to the increasing automation level. Such systems require more progressive and productive mathematical tools and models. Since, full mathematic model of the diagnosed unit operation is really hard to create due to large number of interconnections, the development of adaptive properties of diagnostic systems is possible only using fuzzy logic algorithms.

The paper is aimed at determining the possibility of using fuzzy logic tools for diagnostic purposes.

Fuzzy logic is a system combining classic bivalent logic in a context of uncertainty. It allows describing qualitative inexact concepts and our knowledge about the world around, and to operate the knowledge in order to obtain new information. The main idea of the control systems using fuzzy logic is integrating an “expert experience” into the system controlling the dynamic process. In control systems with fuzzy logic complicated relations between the input and output of the dynamic processes are described with the rules of fuzzy logic using linguistic variables instead of a sophisticated model. Using linguistic variables, rules and lows of fuzzy logic, and approximate reasoning, allows integrating an expert experience into the developed control scheme [2, 3].

Fuzzy logic has the following advantages:

Fuzzy logic supports development of a fast prototype of a device with further complication of its functionality;

Fuzzy logic model is much easier for comprehension than similar mathematic model based on differential and difference equations;

Fuzzy logic models are much simpler for hardware realization in comparison to the classic control algorithms;

Fuzzy logic uses such laws as “if X than Y.

As it was stated in papers [4-7], when there is a defect – the growth of vibration signal amplitude with a rotation frequency increase will be higher for a defected bearing. It is also known that non-faulty assemblies have lower vibration level than faulty ones. However, one cannot determine an unambiguous divide for the values of the vibration diagnostic features which separates non-faulty and faulty condition due to intercrossing distributions of diagnostic feature values of non-faulty and faulty facilities. In other words, the 1st and 2nd-type diagnostic errors cannot be avoided but may be decreased in amount using rules of fuzzy logic.

Since the condition identification at increased shaft rotation frequency N2 is higher than at the basic N1 frequency, let us assume the reliability of diagnostics with N2 frequency acceptable for separating the diagnostic feature with a critical value into non-faulty and faulty conditions. However, high-frequency testings are often connected with extra costs (energy, time, resources, etc.) as well as the reduction of safety level during the diagnostics. That is where the question of the selection between different speed modes arises.

2. Experimental

Let us consider the fuzzy logic system work principle. As input variables we shall adopt the vibration acceleration of the diagnosed bearing assembly and frequency of shaft rotation, the output value will be the diagnostic result.

Let us introduce linguistic terms “low” “medium” and “high” using an expert approach. Thus, we connect the vibration acceleration values to a particular term.

Vibration acceleration values membership functions for the assembly diagnosed on the basic shaft rotation frequency are presented as a diagram on figure 1 and as formulas (1-6) below:

«low»

$$y=1 \qquad 0\ m/s^2 \le x \le 3\ m/s^2 \tag{1}$$

$$y=4-x \qquad 3\ m/s^2 \le x \le 4\ m/s^2 \tag{2}$$

«medium»

$$y=x-3 \qquad 3\ m/s^2 \le x \le 4\ m/s^2 \tag{3}$$

$$y=5-x \qquad 4\ m/s^2 \le x \le 5\ m/s^2 \tag{4}$$

«high»

$$y=1 \qquad 5\ m/s^2 \le x \le 10\ m/s^2 \tag{5}$$

$$y=x-4 \qquad 4\ m/s^2 \le x \le 5\ m/s^2 \tag{6}$$

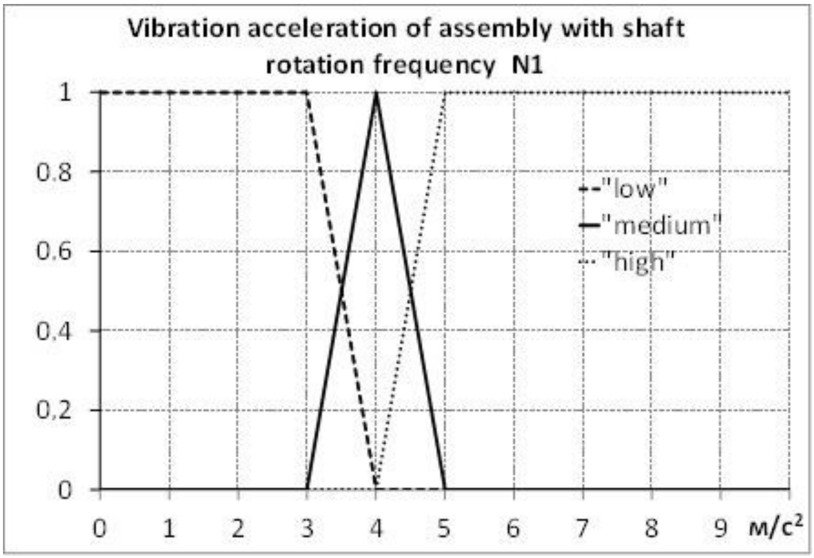

Fig. 1. Vibration acceleration membership functions for the basic shaft rotation frequency (N1) diagnostics.

Vibration acceleration values membership functions for the assembly diagnosed on the increased shaft rotation frequency are presented as a diagram on figure 2, and as formulas below (7-10):
«low»

$$y=1 \qquad 0\ m/s^2 \le x \le 7\ m/s^2 \tag{7}$$

$$y=8-x \qquad 7\ m/s^2 \le x \le 8\ m/s^2 \tag{8}$$

«high»

$$y=1 \qquad 8\ m/s^2 \le x \le 15\ m/s^2 \tag{9}$$

$$y=x-7 \qquad 7\ m/s^2 \le x \le 8\ m/s^2 \tag{10}$$

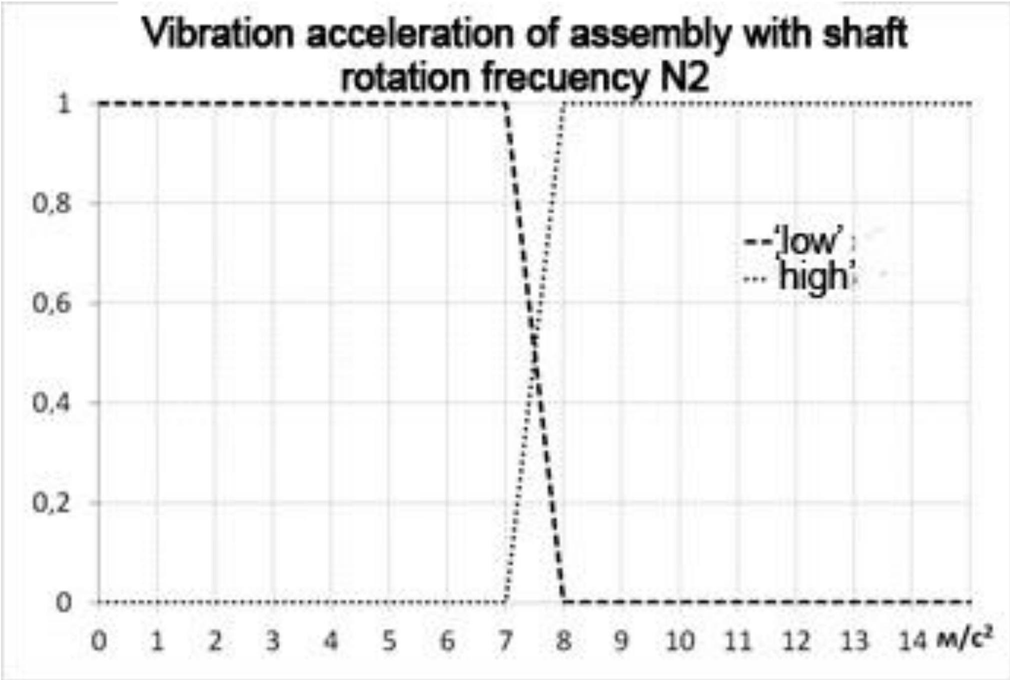

Fig. 2. Vibration acceleration membership functions for the increased shaft rotation frequency (N2) diagnostics.

Vibration acceleration membership functions for the increased shaft rotation frequency as formulas:

On the basis of the obtained linguistic terms for input variables we shall determine the following fuzzy rules:

Rule №1. If vibration acceleration value on the basic rotation frequency is "low", the diagnosed facility is non-faulty.

Rule №2. If vibration acceleration value on the basic rotation frequency is "high", the diagnosed facility is faulty.

Rule №3. If vibration acceleration value on the basic rotation frequency is "medium", an additional diagnostics using increased rotation frequency is required.

Rule №4. If vibration acceleration value on the increased rotation frequency is "low", the diagnosed facility is non-faulty

Rule №5. If vibration acceleration value on the increased rotation frequency is "high", the diagnosed facility is faulty.

Let us consider an example of the rules listed. Let us assume that in testing on a basic shaft rotation frequency the vibration acceleration value 3.8 m/s^2 was obtained. In that case we have:

For the rule №1 Input value correlates to the membership function y=4-3.8=0.2.

For the rule №2 Input value correlates to the membership function y=3.8-3=0.8.

For the rule №3 Input value does not correlate to the membership function.

Consequently, the membership function value for a "medium" term is higher than for a "low" term, so an additional diagnostic test on an increase rotation frequency is required.

In an additional diagnostic test on an increase shaft rotation frequency the vibration acceleration value 6.8 m/s^2 was obtained. In that case we have:

For the rule №4 Input value correlates to the membership function y=1.

For the rule №5 Input value does not correlate to the membership function.

Initial values corresponds to the Rule №4, consequently, an output value will be a non-faulty diagnosed facility.

3. Conclusion

On the basis of the above material we can conclude that application of fuzzy logic algorithms allows moving forward to the next stage in vibration diagnostic systems development.

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