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An application of statistical symptoms in machine condition diagnostics

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ABSTRACT

Analysis of symptom lifetime histories (trends) is widely employed in diagnostics of machines, in particular those designed for long service life. These trends, however, often reveal considerable irregularities, or fluctuations, which cannot be attributed to technical condition evolution. They can render diagnostic reasoning vague and uncertain. This results from the fact that symptom values are influenced not only by object condition parameters, but also by a number of other factors, which sometimes are dominant. More detailed analysis leads to a conclusion that a measure of symptom value fluctuations can itself be used as a diagnostic symptom. This conclusion is supported by the model-based consideration, employing a modification of the Energy Processor (EP) model, developed specifically for this purpose. To illustrate this special feature, several examples are presented and discussed, employing databases obtained for large steam turbines.

1. Introduction

When referring to machines in general, their damage can be defined as a ‘continuous or sudden loss of integrity and/or operational feature’ [7]. At early stages of technical diagnostics development, attention was focused mainly on the ‘sudden losses,’ i.e. random damages [1,19]: the aim was to detect and identify such occurrences, a procedure which can be referred to as the *qualitative* diagnostics. With growing complexity, cost and importance of machines, the question of damage extent, or lifetime consumption, estimation (i.e. *quantitative* diagnosis) became vital. This naturally has led to the remaining life *prognosis* [18,24], at least for machines operated beyond their design life, which is by no means an uncommon practice, especially with both fossil fuel-fired and nuclear power generating units. Attention has thus shifted to the ‘continuous losses,’ alternatively referred to as ‘natural damage,’ resulting from general ageing and/or wear.

Machine technical condition can be described by the condition parameters vector:

$\mathbf{X}(\theta)=\{X_1(\theta), X_2(\theta), \ldots, X_n(\theta)\}$; θ denotes lifetime. When considering ‘natural damage,’ we may assume that $X_i(\theta)$, $i=1, 2, \ldots, n$ are continuous and monotonic functions.[1] It is thus reasonable to assume that measurable diagnostic symptoms,[2] which are related to $X_i(\theta)$ via diagnostic relations, are also continuous and monotonic functions of θ. This

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[1] Stepwise changes are introduced by overhauls or repairs; at this point their influence is neglected.

[2] Symptom is understood here as a ‘condition symptom’ (i.e. a measurable quantity covariant with system condition) rather than a ‘failure symptom’ (i.e. an event). For more details see e.g. [6,21].

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assumption is in fact corroborated by the Energy Processor (EP) model (see e.g. [2–5,20]), wherein values of measurable symptoms increase monotonically with the generalized damage D (see Section 2), identified as a condition parameter.

A prognosis has to be based on an analysis of symptom time histories (trends) [18,24]. In practice these trends are often very irregular. If a fault develops fast and the symptom is very sensitive to relevant condition parameter, this development can dominate the symptom time history, so that reasoning becomes fairly straightforward. This is illustrated by a case of an unbalance caused by permanent rotor bow in a steam turbine (Fig. 1a). The example shown in Fig. 1b is, however, much more typical: a slow monotonic increase is 'damped' by large fluctuations, apparently not related to machine technical condition. This is usually the case when dealing with symptom evolution resulting from lifetime consumption, in the presence of strong interference and with control parameters varying within a wide range.

Symptom trends analysis is a valuable and widely used tool in machine condition monitoring [5,13,14,23,25]. Both the shape of symptom vs. time function and increase rate (slope or time constant) convey information on malfunction type and

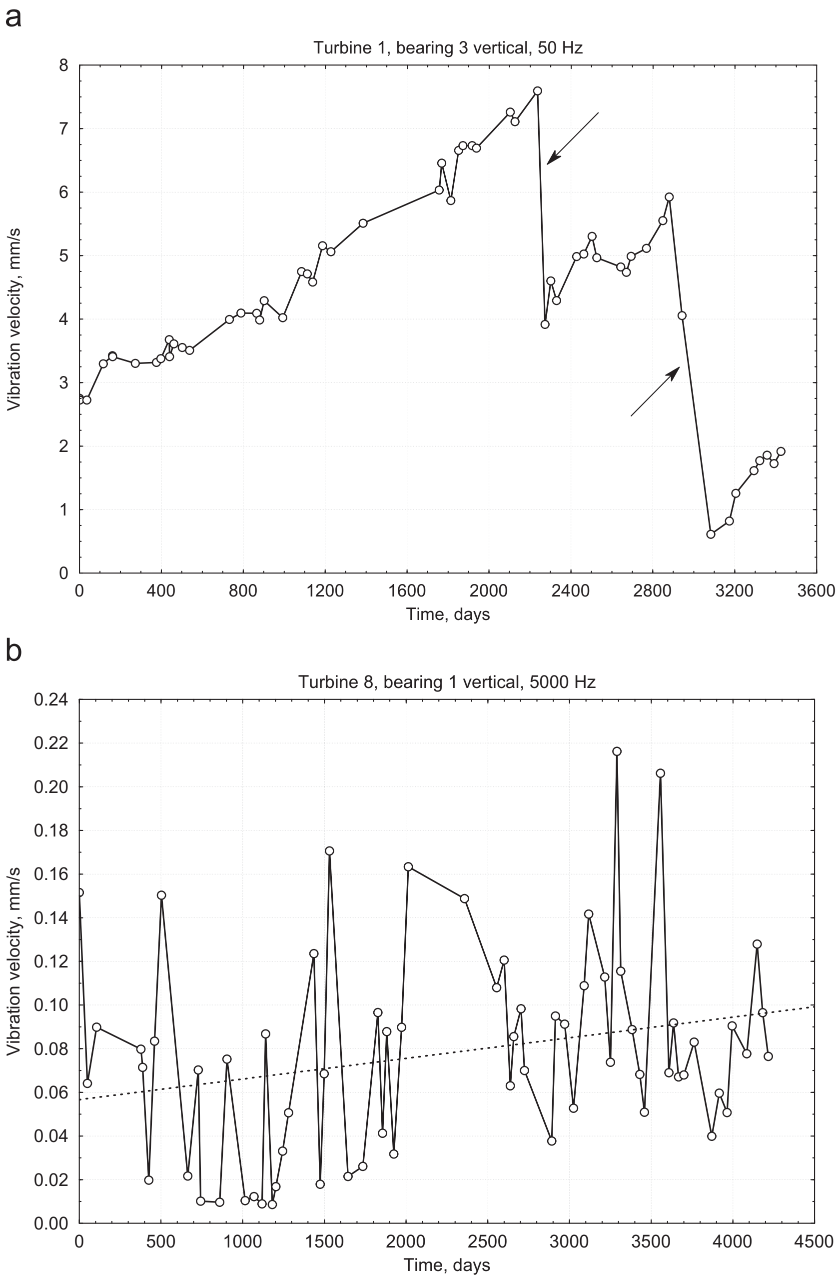

Fig. 1. Examples of symptom time histories: vibration levels in specified frequency bands vs. time: (a) A 230 MW steam turbine, rear intermediate-pressure turbine bearing, vertical direction, 50 Hz band; discontinuities (indicated by arrows) refer to rotor balancing and (b) A 200 MW steam turbine, front bearing, vertical direction, 5000 Hz band. Dashed line represents linear fit.