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Review

# Periodically correlated random processes: Application in early diagnostics of mechanical systems

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ABSTRACT

The covariance and spectral characteristics of periodically correlated random processes (PCRP) are used to describe the state of rotary mechanical systems and in their fault detection. The methods for estimation of mean function, covariance function, instantaneous spectral density and their Fourier coefficients for a given class of non-stationary random processes on the basis of experimental data, namely: the synchronous averaging, component, least squares method and linear filtration methods are considered. The first and second order periodicity detection methods are used for vibration signals analysis. A method for mechanical system fault identification and classification based on a harmonic series representation is developed. Examples of fault detection in rolling/sliding bearings and gearboxes are given.



**Contents**



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## 1. Introduction

The necessity for a transition from the control of a mechanism functionality to detection of incipient defects leads to a search for new diagnostic features that can react to a small deviation of technical state parameters from the standard ones. Detection of faults that have not yet caused accidents, as well as estimation of the degree and features of faults is possible only when the vibration signals fine structure and their connection with the kinetics and dynamics of mechanisms are studied. The description of such a structure is possible on the basis of suitable mathematical models of vibration signals which represent the features needed to estimate the state of the mechanical system. The features of vibration signals are: recurrence and stochasticity. Recurrence is caused by a cyclic principle of mechanism operation and stochasticity can be generated by fluctuations of the oil thickness and viscosity, friction, spontaneous and uncontrolled changes of loading, turbulence etc. Recurrence and stochasticity in vibrations are mostly represented in their interaction. It is exactly in the character of such interaction that those properties of oscillations appear which in a majority of cases can be determinant for estimation of the mechanical system state. Periodically and almost periodically non-stationary random processes (within the second order theory – periodically and almost periodically correlated random processes) are suitable models for the description and analysis of this interaction [1–3]. These random processes are also called cyclostationary [4–6]. The approach based on such models was verified by us for the first time for the analysis of vibration signals generated by HPP turbo-aggregates sliding bearings [7] and its efficiency was demonstrated in further investigations. Rotary mechanism faults are shown in vibration signals as the appearance of new harmonic components and as modulation of harmonics. The probabilistic characteristics of periodically correlated random processes (PCRP) and their generalizations provide information about such changes and may be used either for diagnosis directly or as a basis for the formation of new diagnostic features, and these features can be used to detect faults at the early stages of their initiation. Many examples of using PCRP methods for vibration signals analysis are described in the literature [8–15]. In [15] the concept, grounded on vibration signals analysis using PCRP methods and their generalizations, and the use of its results to estimate the mechanical system state was called revolutionary by Antoni. In this tutorial paper, the author analyzed papers published in English on the estimation of the mechanical system state based on cyclic non-stationarity characteristics. The results of investigations carried out in Ukraine are mainly represented in the papers published in Ukrainian beginning from 1995 [7]. We do not give these publications in the references because it is difficult for journal readers to reach them. Since the results obtained in these papers have some specific content that may be of interest to Mechanical System and Signal Processing readers, we have decided to present them briefly in this paper. Note that the investigations performed are based on original results obtained by the authors in the field of the theory and statistics of periodically and almost periodically correlated random processes when the period of non-stationarity is a priori known or unknown [1,2,16–25].

Synopsis: the paper consists of Introduction, three Sections divided into subsections and Section 5. The basic properties of both the first and the second order moment functions of PCRP – mathematical models of vibration signals, their physical and diagnostic interpretations – are given in Section 2.1. Attention is paid to harmonic series representation of a given class of non-stationary processes, which allows us to find a connection between the probabilistic characteristics of signals as well as the statistical characteristics of the processes that modulate their main harmonics. This connection is very important for substantiation of the stochastic recurrence structure, and the detection and identification of defects. Diagnostic indicators that can be used for the estimation of a mechanism's observed vibration state are given Section 2.2. Methods of estimating the whole complex of covariance and spectral characteristics, namely: synchronous averaging, component method, least squares method and linear filtration methods, including band filtration for modulating processes separation, are considered Section 3.1. The methods developed by the authors for the estimation of non-stationarity periods and the detection of hidden periodicities of both the first and second orders on this basis are described Section 3.2. The main peculiarities of the PCRP-analysis used in the paper are considered Section 3.3. In Section 4 the examples of the vibrations PCRP-analysis for the detection of the rotary machineries faults are considered. This section is divided into three subsections and each of them is dedicated to a separate analysis of vibration generated by rolling bearing, sliding bearing and also by gear box. When estimating the state of observed mechanisms the stages of investigations are separated, namely: correlation and spectral analysis of stationary approximation, separation and analysis of the vibration deterministic part, searching for the hidden periodicities of the second order, correlation and spectral analysis of the PCRP-structure of the vibration stochastic part, separation and analysis of correlation and spectral characteristics of the stationary modulating processes.

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