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E.V. Dereng

THE MATHEMATICAL MODELS OF TRENDS OF COMPLEX TECHNICAL OBJECTS STATES CHANGES IN THE LONG-TERM OPERATION

Abstract. *In this paper we propose an approach to joint trend monitoring and analysis of time series, formed by registration parameters of complex technical objects states in their long-term operation. The proposed approach is based on the formation of diagnostic model in the form of polynomial approximation of measured output variables interdependencies in steady-states and selection of deviations from this model. For obtained multidimensional arrays of deviations the methods of their two-dimensional analysis are considered and the problem on eigenvalues and eigenvectors of corresponding correlation arrays is solved. That allows the using of well-known methods of singular spectral analysis and trend monitoring. The software for the proposed approach is developed.*

Key words: *diagnostics, time series, trend monitoring and analysis*

Introduction

An important problem of extending the life cycle of complex technical objects (CTO) is a reliable estimation of the technical state according to the registration data of the states coordinates and the output coordinates during the operation.

The transition to more advanced strategies of CTO resource management requires a number of scientific and applied problems solution, the most important of which are the problems of adequate diagnostic modeling and developing the methods for estimation of the CTO parameters deviations in their operations from the rated state.

The most important problem is the reliability improvement of statistical conclusions about the technical states of diagnosed objects on the basis of use and development of methods of trend monitoring and analysis of time series, formed by registration parameters (measured state variables and output variables).

The main part

The process of a multidimensional set of states coordinates and CTO output coordinates changes in long-term operation are the research object.

The mathematical models of trends of CTO states changes and methods of their determining, dependencies researching and forecasting are the subject of this research [1,2,3].

The change of CTO state is determined by its output variables, some of which (the available power, running torque, etc.) are the indirectly measured or are unavailable for direct measurements in operational conditions. Estimation of these variables can be obtained only by methods of mathematical modeling, for realization of which in modern technical means of state monitoring and diagnostics the appropriate mathematical models (MM) are required [4,5,6].

The known theoretical mathematical models, which are based on non-linear conservation and balance equations, allow to obtain the required estimates at providing the given accuracy, but the computational complexity of the numerical realization of these models limits their use in the diagnosis technical systems. Famous phenomenological mathematical models, based on the linearization of nonlinear equations, allow to obtain the required estimates, however, for the considered class of objects the modeling errors at the numerical implementation of these models greatly exceed the permissible ones.

The known mathematical models do not allow to resolve the taking place contradiction between the necessary and achievable (based on them) estimation accuracy of output variables measured indirectly and inaccessible for direct measurement, ensuring realization of perspective methods of monitoring and diagnosing of CTO technical state, as well as the contradiction between the computational complexity of MM and the possibility of their realization in the diagnosis technical means.

On the basis of aforesaid the research topic has great scientific and practical importance, because it is directed on actual scientific and applied problem solving. The essence of this problem is to resolve the mentioned contradiction by creating the set of

mathematical models of CTO states estimation in the long-term operation, that intended for computer realization in means of CTO monitoring and diagnosis to obtain the trends estimations of output variables, including indirect measurements and inaccessible to direct measurements ones.

The purpose of this research is justification of the approach to trend analysis of multidimensional set of CTO state coordinates and output coordinates in long-term operation, to complex application of methods of trend analysis and technical states monitoring by the consecutive realization of steps of the trend component determination of multivariate time series, formed by a set of registration parameters deviations of diagnosis objects from their statistical models (SM), and the application of the proposed methods of multivariate trend analysis and monitoring with the statistical significance level estimation (Fig. 1).

The central idea (hypothesis) of research is the assumption that during the complex power objects operation inevitably a long-term trend of parameters is present, but this trend is a consequence of a gradual and natural degradation of their characteristics (interdependencies of state variables) in view of developing a resource [6]. Therefore, the only deviation from such multidimensional interdependencies provides information about the object technical state. The proposed approach can be defined as a generalization of methods of trend analysis and monitoring on multidimensional time series of deviations from the SM. Mathematical models of CTO state monitoring in long operation are considered as statistical models of data generation.

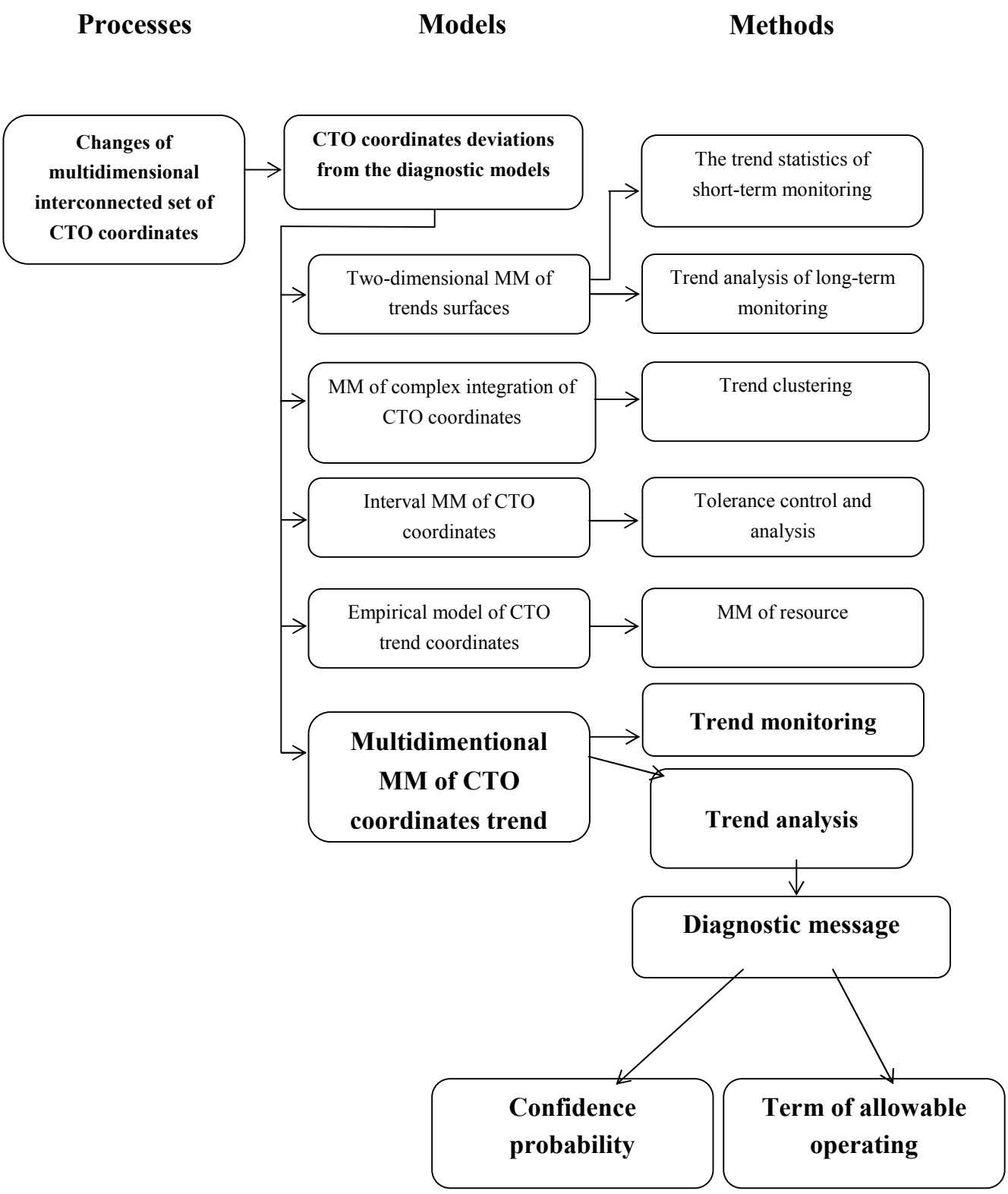

Fig. 1. Approach to investigation of multidimensional time series of CTO operation data

The object state monitoring is to identify such changes of the set of its state variables, and changes in interconnections of these variables, that can cause damage of the object operability state. Recorded by the on-board and ground-based equipment of monitoring and diagnosis systems the multidimensional arrays characterize changes of the controlled variables in transition and in steady-state modes. The main information component, that used in the monitoring and diagnosis systems (MDS), is the data about steady-state modes, on the basis of which the diagnostic conclusions are formed, in particular, about the resource and about the probable operating time. So long as the CTO parameters in steady-state modes are functionally connected by set of static characteristics (SC), then it is changes processes of such characteristics can characterize the changes of its technical states. The main creation stage of proposed model of state monitoring consists in the construction a statistical model of data generation in the form of deviations of measured variables in steady-state modes from the such variables values defined by its individual MM

$$\Delta\vec{y}_{pr} = \vec{y}_{pr} - \vec{y}_{mpr}, \tag{1}$$

where $\Delta\vec{y}_{pr}$ – the deviations vector, $\vec{y}_{pr}$ – values of analyzed variables, measured and reduced to test standard conditions, $\vec{y}_{mpr}$ – modeled values of the variables.

According to (1) the space conversion of variables, measured and reduced to test standard conditions, to the space of deviations from the static model is performed. As so as the measured data form a time series, then SM of data generation is proposed in the next form

$$\Delta\vec{y}_{pr}(t_n) = trend\left[\vec{y}_{pr}(t_n) - \vec{y}_{mpr}(t_n)\right] + \vec{\xi}(t_n), \tag{2}$$

where $\vec{\xi}(t_n)$ – values sample of the random process of measurements errors, $trend(\cdot)$ – non-random component in the time series variations.

Static model are proposed to obtain by known methods of nonlinear regression analysis of the operating data. From SM (2) two problems follow: the trend monitoring and trend analysis. The problem of trend monitoring consists in the fact determining of trend presence in the sample of deviations from the static model on a given level of

significance. The trend analysis problem consists in separation of the deviations sample from the static model to the components (trend and noise):

$$\Delta\vec{y} = \Delta\vec{y}_{tr} + \Delta\vec{y}_{noise}.$$

The investigated multidimensional time series of deviations from the SM (Fig. 2) are grouped in a matrix of recorded parameters (state variables and output variables) [6,7,8]. The central idea of the analysis of multidimensional set of signes is formation on their basis of multi-dimensional data array – a multidimensional parallelepiped.

The 2-D analysis methods of complex-valued generation of samples and trend surfaces [9,10,11] and 3-D analysis method in the form of singular decomposition of the generated parallelepiped are proposed for the trend analysis problems solving.

Conclusion

Statistically justified level of CTO state monitoring in the long operation is provided by the analysis of measure of the static characteristics degradation in the form of trend deviations from the initial characteristics. On this basis there is proposed and justified approach to the construction of mathematical models of the technical state monitoring, which provides consecutive of steps forming of polynomial regression mathematical models of static and multidimensional trend models of operational dynamics to estimate the changes of CTO parameters deviations from the given regression ones, that allows to detect changes of the technical state in life cycle. The new methods of 2-D trend analysis are proposed and improving the known methods of trend analysis of time series of data registration of CTO technical state, based on the formation multi-dimensional arrays of trajectory matrices and their singular decomposition, allowing to separate samples at a given level of significance, is fulfilled.

Perspective views of future researches consist in development of forecasting methods of trends temporal progress on the basis of the analysis of multidimensional time series.

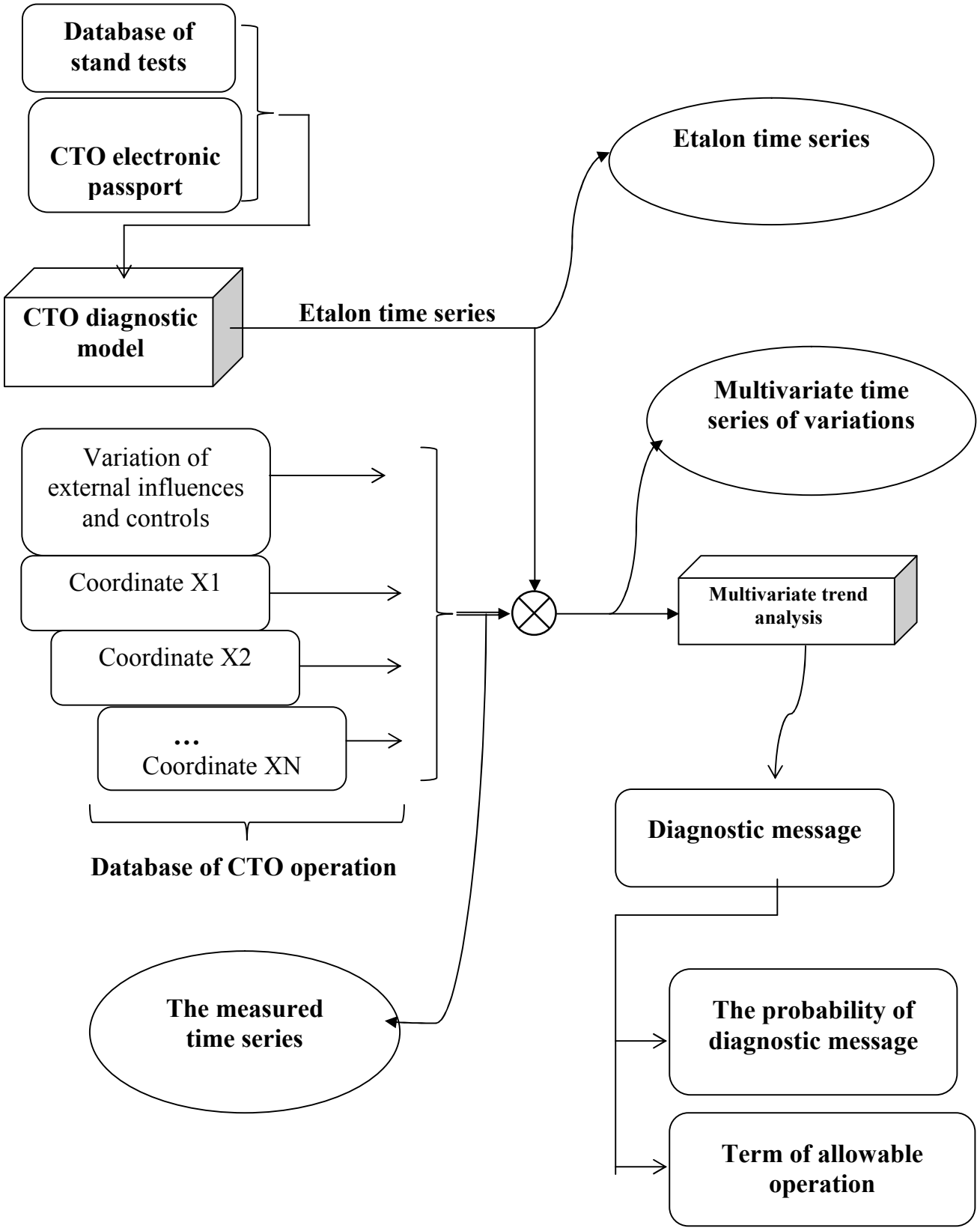

Fig. 2. Mathematical model of deviations from the diagnostic models

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