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TECHNICAL OBJECT ENVIRONMENT SIGNALS AND ITS ELIMINATION FROM DIAGNOSTIC MODEL

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Abstract

Diagnostics of many common technical objects (compressor blades, oil pipelines) has been noticed to be realized mostly on the basis of measured diagnostic signals resulting from object operation without sufficient consideration given to usually difficult to measure signals of its environment. Such approach is inconsistent with basic rule of diagnostics that strictly orders research and analysis of technical condition in environment (PN-90/N-04002). Hence many works occurred concerning diagnostics of technical objects (e.g. compressor blades – in motion and in repose), characterized by the fact, that environment signals are taken into consideration without necessity of measuring them [2-7]. A necessity exists to elaborate new object diagnostic methods in repose and in operation including environment but without need (if possible) of using frequently unavailable or difficult to measure environment signals. This problem is solved by diagnostic methods based on diagnostic models allowing, through special operations, for elimination of real environment. Elimination of environment from model is possible as an effect of proper conduct of diagnostic research that in base form should include measurement of environment and diagnostic signals. In models A^2_{T12T01} *and* φ_{T12T01} *dependence on environment does not occur. Hence each change of model must be interpreted only as change of object technical condition. Such models might be applied for various objects operating in complex environments (eg. oil pipelines, bearings, etc.).*

Keywords: *diagnostic, models, environment, compressor blades, oil pipelines*

1. Introduction

Most of currently applied diagnostic methods is only based only on processing signals resulting from object operation (diagnostic) [9], without giving proper consideration to signals (of significant power) of its varying, difficult to measure environment. Therefore basic rule of technical diagnostics described in PN-90/N-04002 ordering research and analysis of technical object in its environment is not realized, thus making these methods inadequate. Hence the matter of including environment into diagnostic process of technical objects is still present and developed.

Therefore a necessity exists to elaborate new object diagnostic methods in repose and in operation including environment but without need (if possible) of using frequently unavailable or difficult to measure environment signals. This problem is solved by diagnostic methods based on diagnostic models allowing, through special operations, for elimination of real environment (examples of such models are: A^2_{P1P2} i A^2_{T12T01}, φ_{T12T01}, A^2_{M1M2}) [2-7].

2. Theoretical basis of diagnostic models with environment elimination

Elimination of environment from model is possible as an effect of proper conduct of diagnostic research that in base form should include measurement of environment signals *x(t)* and diagnostic signals *y(t)*. Elimination of *x* signals from model might be realized through:

- proper development of research in space {*P*} (two points of measurement P_1 and P_2) [3],
- proper development of research in time {*T*} (two periods of observation T_{01} and T_{12}) [2, 4-6],
- simultaneous application of research with various {*M*} (two methods of research M_1 and M_2 - functional M_1 and vibroacoustic M_2).

2.1. Elimination of environment from A^2_{P1P2} model [3]

Analyzed object, e.g. compressor blade (Fig. 1), is a space object. In this space diagnostic research is conducted and two different points P_1 and P_2 are chosen. Subsequently, in these points object is induced to oscillation with identical signal x^{P1} and x^{P2} what grants signals y^{P1} and y^{P2}.

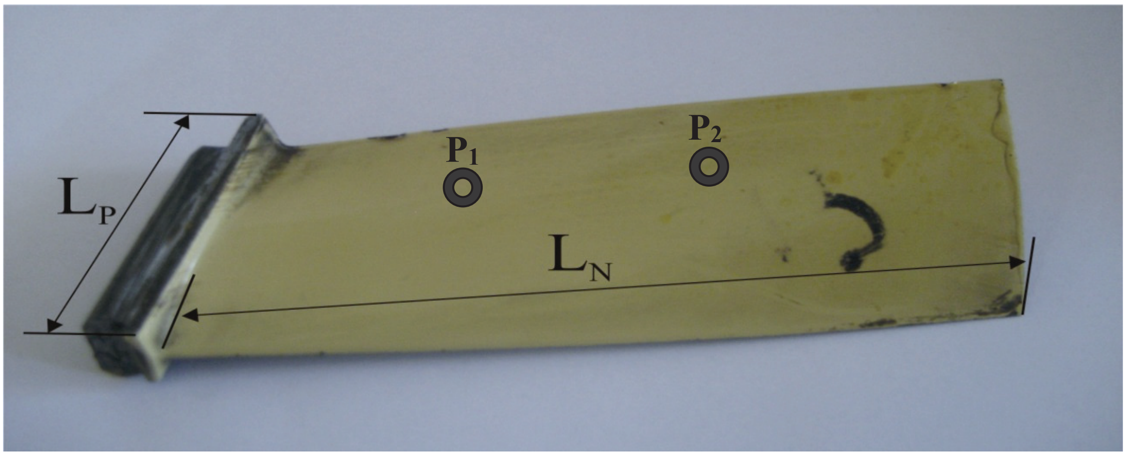

Fig. 1. First grade blade of axial compressor of aircraft engine SO-3 L_N=113 mm, L_p=40 mm with indicated points of oscillation inductor

As should be noted, environment signals x^{P1} and x^{P2} are difficult to measure which hinders determination of proper diagnostic model. Subsequently correlation functions R_{yy}^{P1} and R_{yy}^{P2} are determined and assumption is made that correlation functions R_{xx}^{P1} and R_{xx}^{P2} were determined (this operation is virtual) and, furtherly, power densities of these signals S_{yy}^{P1}, S_{yy}^{P2}, S_{xx}^{P1} and S_{xx}^{P2}. Finally signal amplification *Y(jω)* to *X(jω)* is determined for P_1 and P_2. Then, following is obtained:

$$A^2_{P1} = \frac{S^{P1}_{yy}}{S^{P1}_{xx}}, \quad A^2_{P2} = \frac{S^{P2}_{yy}}{S^{P2}_{xx}}. \tag{1}$$

where:

A^2_{P1} – amplification of *X* and *Y* signals from blade induction in *P1*;
A^2_{P2} – amplification of *X* and *Y* signals from blade induction in *P2*;

Diagnostic model, from which environment signals power was eliminated might be determined as quotient of A^2_{P2} and A^2_{P1}:

$$A^2_{P1P2} = \frac{A^2_{P2}}{A^2_{P1}} = \frac{\dfrac{S^{P2}_{yy}}{\cancel{S^{P2}_{xx}}}}{\dfrac{S^{P1}_{yy}}{\cancel{S^{P1}_{xx}}}} \xrightarrow{S^{P2}_{xx} \cong S^{P1}_{xx}} \frac{S^{P2}_{yy}}{S^{P1}_{yy}}. \tag{2}$$

Assumption that $S_{xx}^{P1} \equiv S_{xx}^{P2}$ valid as the diagnostic research realized in space $\{P\}$ for $P1$ and P_2 were conducted in the same time, with the same tool and using the same and identically adjusted measurement devices [3].

Characteristic of this model is that environment is included, but its measurement is not necessary.

2.2. Elimination of environment from A^2_{T01T12} model (amplification square) [7]

Analyzed object, e.g. compressor blade of operating rotor machine (Fig. 1), is an object observed by contactless sensor in time T_{02}. Initial selection of signal is introduced to separate such fragment of signal, so that full transition of blade below the sensor is projected (from moment T_0 to T_2). This time is divided onto two subperiods of blade approaching sensor T_{01} and blade receding from sensor T_{12} (T_1 being moment when blade is directly below the sensor – Fig. 2).

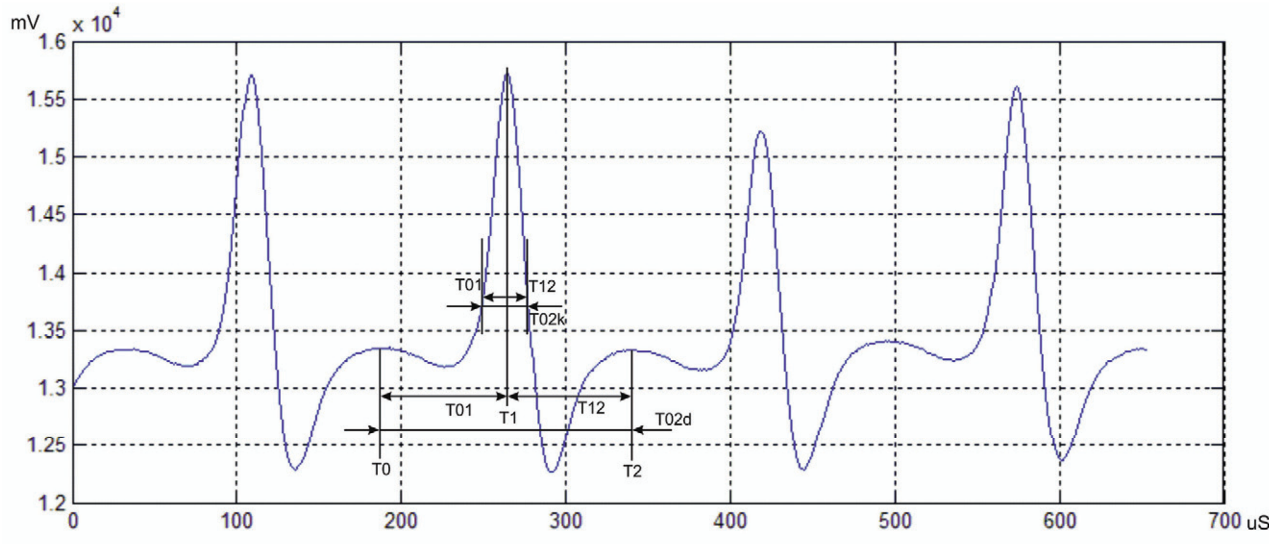

Fig. 2. Signal from induction sensor

Subsequently autocorrelation functions of measured signals are determined in subperiods T_{12} and T_{01}: R_{yy}^{T12} and R_{yy}^{T01}. Furtherly assumption is made that environment correlation functions R_{xx}^{T12} i R_{xx}^{T01} were determined (this operational is virtual) as well as power densities of these signals S_{yy}^{T12} , S_{yy}^{T01}, S_{xx}^{T12} and S_{xx}^{T01}. Then amplification of signal $Y(j\omega)$ is determined in relation to $X(j\omega)$ for T_{12} and T_{01}. Thus the following is obtained:

$$A^2_{T01} = \frac{S_{yy}^{T01}}{S_{xx}^{T01}} \quad A^2_{T12} = \frac{S_{yy}^{T12}}{S_{xx}^{T12}}, \tag{3}$$

where:

$A^2{}_{T01}$ – amplification of X and Y signals during blade approach to the sensor,

$A^2{}_{T12}$ – amplification of X and Y signals during blade recession from the sensor.

Diagnostic model from which environment signals power was eliminated might be determined in form of quotient of $A^2{}_{T12}$ *and* $A^2{}_{T01}$:

$$A^2_{T12T01} = \frac{A^2_{T12}}{A^2_{T01}} = \frac{\dfrac{S_{yy}^{T12}}{\cancel{S_{xx}^{T12}}}}{\dfrac{S_{yy}^{T01}}{\cancel{S_{xx}^{T01}}}} \xrightarrow{S_{xx}^{T12} \cong S_{xx}^{T01}} \frac{S_{yy}^{T12}}{S_{yy}^{T01}}. \tag{4}$$

Assumption that $S_{xx}^{T12} \equiv S_{xx}^{T01}$ is valid as the diagnostic research was conducted in close observation subperiods T_{01} and T_{12} and environment did not change (is constant).

Characteristic of model A^2_{T12T01} is fact that diagnostic signals *y(t)* are bound with environment signals *x(t)* (thus being a diagnostic model) and model itself is determined only basing on measurable signal y(t) in close observation periods T_{01} and T_{12} without necessity of measuring its environment *x(t)*.

2.3. Elimination of environment from φ_{T01T12} model (phase shift difference) [2, 5-7]

Model in from of phase shift difference φ_{T01T12} is determined in very similar fashion as amplification square model A^2_{T01T12}. A separated signal from contactless induction sensor is divided onto two observation subperiods of blade approaching the sensor T_{01} and receding from the sensor T_{12} (Fig.2.). Subsequently cross-correlation functions R_{xy}^{T12} and R_{xy}^{T01}, autocorrelation functions R_{xx}^{T12} and R_{xx}^{T01} are determined as well as their power densities S_{yy}^{T12}, S_{yy}^{T01}, S_{xx}^{T12} and S_{xx}^{T01}. Then phase shift of *y* to *x* might be determined for T_{01} and T_{12}.
The following is obtained:

$$\varphi_{T01} = \mathrm{Arg}\frac{S_{xy}^{T01}}{S_{xx}^{T01}},\ \varphi_{T12} = \mathrm{Arg}\frac{S_{xy}^{T12}}{S_{xx}^{T12}}, \tag{5}$$

where:
φ_{T01} – phase shift of signals *X* and *Y* during blade approach to the sensor T_{01},
φ_{T12} – phase shift of signals *X* and *Y* during blade recession from the sensor T_{12},
Arg – main argument of spectral transmittance.

In order to determine signals S_{xy}^{T01} and S_{xy}^{T12}, any distribution in form of *δ(t, τ)* function representing environment signals *x(t)* should be used.

Similarly as in A^2_{T01T12} model, assumption is made that periods T_{01} and T_{12} of signal *y(t)* observation are so close to each other, that environment *x(t)* for these periods might be considered identical and that this environment might be described by any distribution *δ(t, τ)*, as quotient of power cross-density S_{xy}^{T12} and S_{xy}^{T01} does not depend on assumed distribution [2].

Phase shift difference diagnostic model might be determined in the following form:

$$\varphi_{T12T01} = \varphi_{T12} - \varphi_{T01} = Arg\frac{\dfrac{S_{xy}^{T12}}{S_{xx}^{T12}}}{\dfrac{S_{xy}^{T01}}{S_{xx}^{T01}}} \xrightarrow{S_{xx}^{T12} \cong S_{xx}^{T01}} Arg\frac{A_{12}e^{-j\varphi_{T12}}}{A_{01}e^{-j\varphi_{T01}}} = ArgA_{T12T01}e^{-j(\varphi_{T12}-\varphi_{T01})} = Arg\frac{S_{xy}^{T12}}{S_{xy}^{T01}}. \tag{6}$$

Quotient of signal *y(t)* power cross-density and distribution *δ(t, τ)* of blade during recession from the sensor and signal *y(t)* power density and distribution *δ(t, τ)* of blade during approach to the sensor gives operational function with difference of phase shifts of signal *y* during blade recession from the sensor and signal *y* during blade approach to the sensor as an argument. Parameters of this operational function are directly connected with change of blade technical condition.

Characteristic of φ_{T01T12} model is fact that no environment measurement is required, although environment itself is included through specially conducted diagnostic research (two observation periods, diagnostic model determined as quotient of diagnostic models binding diagnostic and environment signals with technical condition parameters).

Another characteristic of φ_{T01T12} model is that diagnostic signals *y(t)* are bound with environment signals *x(t)* (hence being a diagnostic model) and the model itself is determined only basing on measurable signal *y(t)* in close observation periods T_{01} and T_{12} without necessity of measuring its environment *x(t),* represented by distribution *δ(t, τ)*.

2.4. Elimination of environment from A^2_{M1M2} model (amplification square of signal measurement by various methods) [4]

Object is analysed in the same moment (simultaneously) with various methods. Various signals are measured (e.g. electric – functional and vibroacoustic). Example of object to which such comprehensive diagnostics was applied is aircraft propulsion. Electric signals y_{M1} and vibroacoustic signals y_{M2} were correlated. For these signals an identical, immeasurable environment exists. By determining power density of signals S_{yy}^{M1} and S_{yy}^{M2} and environment signal (this operation is virtual) S_{xx}^{M1} and S_{xx}^{M2}, the following model might be assumed:

$$A^2_{M2M1} = \frac{A^2_{M2}}{A^2_{M1}} = \frac{\dfrac{S_{yy}^{M2}}{\cancel{S_{xx}^{M2}}}}{\dfrac{S_{yy}^{M1}}{\cancel{S_{xx}^{M1}}}} \xrightarrow{S_{xx}^{M2} \cong S_{xx}^{M1}} \frac{S_{yy}^{M2}}{S_{yy}^{M1}}. \tag{7}$$

In this case definitely exists only one environment x that generates two various signals: y_{M1} and y_{M2}.

This model does not depend on varying immeasurable environment, hence every change of model parameters is connected only with change of technical condition (of aircraft propulsion).

3. Summary

In models A^2_{P1P2}, A^2_{T01T12}, φ_{T12T01} and A^2_{M2M1} no dependence on environment exists, although it is indirectly included by the specially organized diagnostic tests (two measuring points, two measuring periods, identification of diagnostic model as the quotient of diagnostic models connected environment and diagnostic signals with the technical condition parameters). Hence every change of the model must be interpreted only as change of object technical condition. In these models, the basic diagnostic principle that diagnostic tests and analysis of the technical condition must be carried out in the environment (PN-90/N-04002)). Such models might be applied to various object operating in complex environment (eg oil pipelines, bearings, blades, etc..).

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