A METHOD OF RELIABILITY CHARACTERISTICS ESTIMATION ON THE BASIS OF ADJUSTMENT AND DIAGNOSTIC INFORMATION

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Abstract: The paper presents innovative method of reliability characteristics estimation on the basis of symptoms of parametric and temporary defects (prior to occurrence of catastrophic defects). The method is based on evident relations between adjustment, diagnostics and reliability, which are observed in an organised system of utilisation of each complex technical object.

1. INTRODUCTION

During operation of expensive and complex technical objects (aircraft, aircraft engines) grows importance of their maintenance comprehended as optimum actions within the frames of their adjustment, diagnostics and reliability examination (Bobrowski, 1985; Boliński and Stelmaszczyk, 1981; Borgoń et al., 1998; Lindstedt 2002; 2009; Żurek, 2001).

In operational practice observed is frequently following chain of events:

– adjustment actions are caused by wear of components of a technical object, or in other words by change of technical condition, thus the adjustment is combined in natural way with diagnostics;
– wear of elements of the object leads to occurrence of various defects in various time periods, which form the base for determination of reliability indexes, thus the reliability is directly combined with diagnostics.

In the maintenance of technical objects important is preservation of proper relations between adjustment, diagnostics and reliability with consideration of the fact that the adjustment and the diagnostics are based on determined functions and the reliability – on probabilistic functions.

The reliability examinations can be carried out individually for each technical object in its environment on the basis of information about all maintenance actions carried out on the object. The possibility of determination of individual reliability characteristics on the basis of functional and diagnostic information can be particularly important for cases, when the set of objects is small and their environment very diversified.

2. DEFECTS AS A BASE OF RELIABILITY CHARACTERISTICS

In the course of reliability examinations great role play comprehensive examinations of occurrence of various accidental defects. The defect changes the reliability state, which is quantitatively described by reliability indexes.

In the process of determination of reliability of a technical object considered are various types of defects: catastrophic (total), parametric (ageing, partial), and temporary (Bobrowski, 1985; Borgoń et al., 1998; Sotskow, 1973; Zamojski, 1981).

These defects have various forms and various mechanism of formation, therefore during reliability examinations defects identification is the substantial problem.

Catastrophic (total) defects are sudden events leading to the catastrophe or total inoperability of the technical object. These defects are unambiguous and evident, therefore easy to identification and must be considered arbitrarily in the process of calculation of reliability indexes.

The parametric defect (partial, ageing, degradation) is an event, which gradually leads to the inoperability state of the object. In given moment of operation this defect does not cause inoperability of the object and is only a premise to occurrence of the state of inoperability in the future. The identification of a parametric damage is difficult and requires special measurement systems applied for assessment of the system operation and for diagnostic examinations (Borgoń et al., 1998; Lewitowicz and Kustroń, 2002; Lindstedt et al., 2003). These defects should be considered in calculation of reliability indexes.

The temporary defect is an event, which appears randomly and after a certain period disappears automatically without leaving unambiguous evidence of its occurrence. Identification of temporary defects is very difficult and requires diagnostic examinations. These defects should be used for calculation of reliability indexes.

During calculation of reliability indexes determination of probability of operability R(t) is necessary. These calculations should consider three basic types of defects (catastrophic, parametric and temporary). In analysis of reliability we assume that occurring defects are independent events (Sotskow, 1973) and in this case:

$$R(t) = f\left(R_a(t), R_b(t), R_c(t)\right) \tag{1}$$

where: $R_a(t)$ – probability of correct operation in view to catastrophic defect, $R_b(t)$ – probability of correct operation in view to parametric defect, $R_c(t)$ - probability of correct operation in view to temporary defect.

In the process of operation the maintenance crew tries to prevent appearance of catastrophic defects ($R_a(t) = 1$), then:

$$R(t) = f\left(R_b(t), R_c(t)\right) \quad (2)$$

It is observed that during operation and maintenance (adjustment and diagnostics) it is possible to determine symptoms of parametric (b) and momentary (c) defects, what enables determination of estimators of reliability characteristics $R_b^*(t_i)$ and $R_c^*(t_i)$. Then we have:

$$R(t) = f\left(R_b^*(t), R_c^*(t)\right) \quad (3)$$

From the physical description of parametric defects results that they are relevant to the technical condition of the object and, temporary defects are relevant to the state of adjustment of the object.

Hence changes of technical condition (technical potential) exceeding assumed threshold can be considered as symptoms of parametric defects, and changes of state of adjustment (adjustment potential) exceeding assumed threshold – as symptoms of temporary defects.

3. ADJUSTMENT AND TECHNICAL POTENTIALS OF AN OBJECT

An object must be correctly adjusted. Required is proper relation between utility (functional) signals U_O and signals D_K resulting from the technical condition of the machine. This relation can be described with state equation (Lindstedt et al., 2005; Lindstedt, 2009; Söderström and Stoica, 1997):

$$\frac{dU_O}{d\Theta} = a_{R_C} U_O + b_K D_K \quad (4)$$

where: U_O – complex signal of operational adjustment (environment); D_K – complex diagnostic signal; a_{Rc} – parameter of state of adjustment (adjustment potential); b_K – parameter of intensity of effect of technical condition on possibility of adjustment.

Complex signals resulting from functioning of the object in the environment U_O and complex signals resulting from changes of technical condition D_K in the environment U_O can be determined from the following relations (Lindstedt et al., 2003; 2005; Lindstedt and Magier, 2004; Lindstedt, 2009):

$$U_O = \sqrt{N_{U1}^2 + N_{U2}^2 + N_{U3}^2 + \dots} \;; \qquad D_K = \sqrt{N_{D1}^2 + N_{D2}^2 + N_{D3}^2 + \dots} \quad (5)$$

Where N_U with relevant index refers to number of operational thresholds exceeding for all signals of environment, and N_D with relevant index refers to number of exceeding of operability thresholds for all diagnostic signals. The method of reduction of the course of any signals to numbers of exceeding of relevant thresholds is shown in Lindstedt et al. (2003; 2005); Lindstedt and Magier (2004); Lindstedt (2009):

Current value of state of adjustment a_{Rc} can be determined from following relation resulting from the state equation (4):

$$a_{Rc} = \frac{\Delta U_0}{\Delta\Theta\left(U_0 + \hat{a}_{Rc} D_K\right)} \quad \textit{where} \quad \hat{a}_{Rc} = -\frac{b_K}{a_{Rc}} = \frac{\sum U_{Oi} D_{Ki}}{\sum D_K^{\,2}} \quad (6)$$

Changes of the parameter a_R can be considered as symptoms of temporary defects.

The object must be in proper technical condition. Required is proper relation between diagnostic signals D_K resulting from the technical condition of the object and environment signals U_O. We can formulate following state equation (Lindsted et al., 2005; Lindstedt, 2009; Söderström and Stoica, 1997):

$$\frac{dD_K}{d\Theta} = a_{Rb} D_K + b_U U_O \quad (7)$$

where: a_{Rb} – parameter of technical condition (technical potential); b_U – parameter of intensity of effect of operation on technical condition.

Current value of technical condition can be determined using the relation resulting from the state equation (7):

$$a_{Rb} = \frac{\Delta D_K}{\Delta\Theta\left(D_K + \hat{a}_{Rb} U_O\right)} \quad \text{where} \quad \hat{a}_{Rb} = -\frac{b_U}{a_{Rb}} = \frac{\sum D_{Ki} U_{Oi}}{\sum U_{Oi}^{\,2}} \quad (8)$$

It is assumed that:

- exceeding by the parameter of technical potential a_{Rb} its standard deviation by 1/2σ can be considered as occurrence of a symptom of parametric defect, which allows determination of estimators of parametric defects $R_b^*(t_i)$.
- exceeding by the parameter of adjustment potential a_{Rc} its standard deviation by 1/2σ can be considered as occurrence of a symptom of temporary defect, which allows determination of estimators of temporary defects $R_c^*(t_i)$;

Above assumptions are basis for reliability characteristics estimation:

$$R_b^*(t_i) = \frac{n_b - m_b(t_i)}{n_b} \quad (9)$$

where: $m_b(t_i)$ – number of parametric defects in time interval [0, t_i]; n_b – number of parametric defects in object life-time.

$$R_c^*(t_i) = \frac{n_c - m_c(t_i)}{n_c} \quad (10)$$

where: $m_c(t)$ – number of temporary defects in time interval [0, t_i]; n_c – number of temporary defects in object life-time.

4. ESTIMATION OF RELIABILITY CHARACTERISTICS OF RR ALLISON 250 TURBO-SHAFT ENGINE BEARING UNIT (AN EXAMPLE)

The bearing unit (Fig. 1) consists of eight bearings installed in engine supports and one bearing installed inside the wheel driving the reduction gear (Lindstedt et al., 2003).

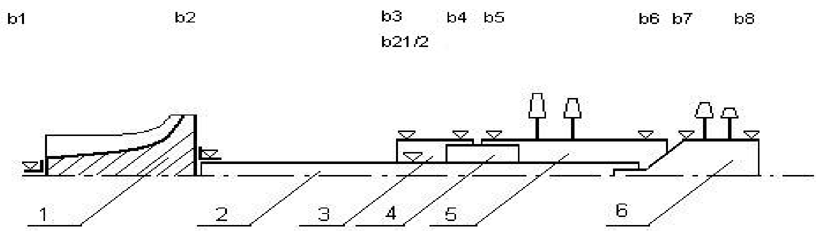

Fig. 1. Bearing unit of the RR Allison 250 turbo-shaft engine (1 – compressor, 2, 3, 4 – shaft, 5 – low pressure turbine, 6 – high pressure turbine, b1 – b8 – bearings)

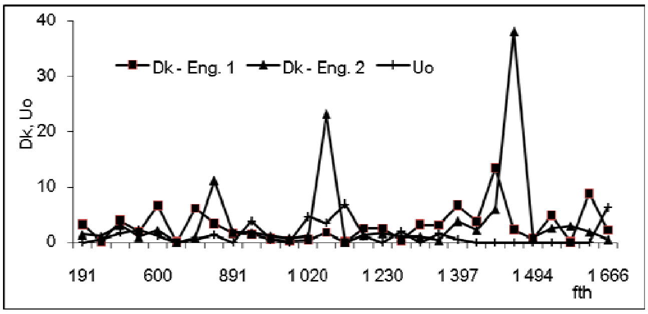

Fig. 2. Complex diagnostics of bearing unit of the Allison 250C20B engines No. 1 and 2 on the basis of normalised numbers of exceeding of threshold values of diagnostic signals

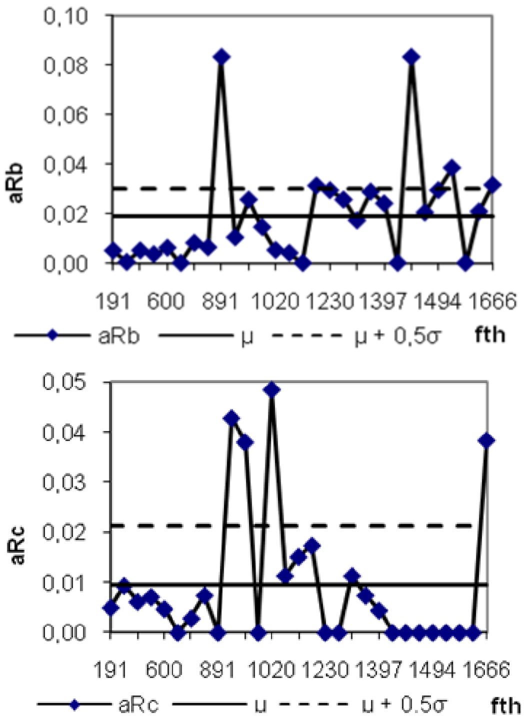

Fig. 3. Changes of parameters a_{Rb} and a_{Rc} vs. flight time – engine No. 1

The bearing unit operates in unfriendly environment of other engine subassemblies, which are represented by the complex signal U_O. Its technical condition changes continuously, generating partial diagnostic signals reduced to the complex diagnostic signal D_K.

Results of operational examination of engines 1 and 2 are presented in Lindstedt et al. (2003, 2005); Lindstedt and Magier (2004). Acquired signals are of various physical nature. They are reduced to universal form, i.e. to number of exceeding of diagnostic thresholds of these signals.

Results of examinations after reduction to numbers of threshold exceeding and complex signals U_O and D_K are shown in Fig. 2.

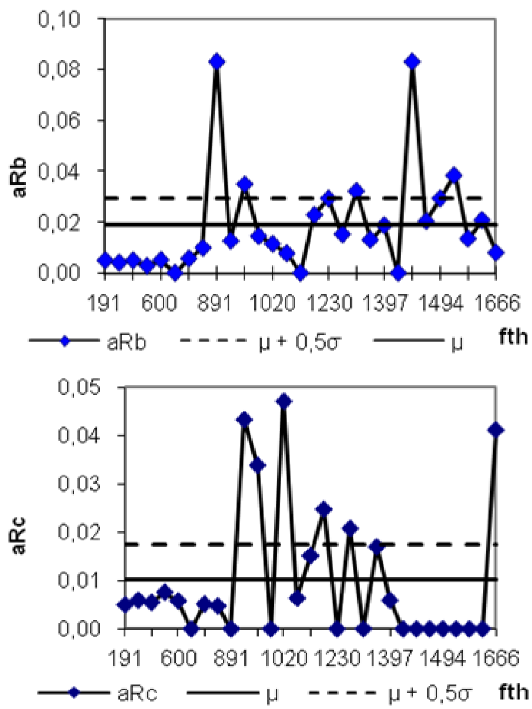

Fig. 4. Changes of parameters a_{Rb} and a_{Rc} vs. flight time – engine No. 2

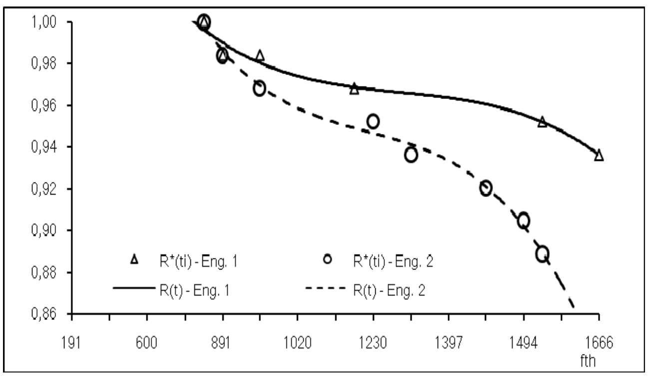

Fig. 5. Reliability characteristics for engines RR Allison 250 No. 1 and No. 2

On the basis of results presented in Fig. 2, and using formulas (6) as well as (8) determined were curves of adjustment potential a_{Rc} and technical potential a_{Rb} of the unit – Fig. 3.

Estimators $R_c^*(t_i)$ i $R_b^*(t_i)$ and corresponding reliability functions $R(t)$ for engines 1 and 2 are shown in Fig. 5.

Fig. 5 shows reliability characteristics for engines 1 and 2. It is easy to see that they differ markedly. Hence expected time of failure-free operation of each engines will be different.

5. SUMMARY

The basis of proper operation of complex technical object is the suitable knowledge about its operational condition (automatics), technical condition (diagnostics) and state of reliability (theory of reliability). It has been found that the observation of changes of parameters of operational condition and technical condition can form the basis for determination of symptoms of parametric and momentary defects, and hence – corresponding reliability estimators, and finally – specific reliability characteristic.

Presented method is characterised with the fact that the reliability characteristic can be determined prior to occurrence of dangerous catastrophic defects for each single object.

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