ESTIMATION LIKELIHOOD OF SPEED OF CHANGE OF DIAGNOSTIC PARAMETERS OF TRANSFORMERS

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Farhadzadeh E.M., Muradaliyev A.Z., Ismayilova S.M.
Azerbaijan Scientific-Research and Design-Prospecting Institute of Energetic
AZ1012, Ave. H.Zardabi-94
E-mail:fem1939@rambler.ru

ABSTRACT

Methods of classification retrospective data on independent groups of homogeneous data and estimations of reliability the assumption of constant speed of deterioration during normative service life are developed.
Keywords. *The transformer, diagnostics, criteria, speed of the change, the guaranteed estimations*

I. INSTRUCTION

Increase of efficiency of the control of conformity of a technical condition power transformers and autotransformers (further: TR) to shown requirements represents the important and difficult problem. Its importance caused by the high cost TR, expenses increasing in process of ageing TR for diagnostics, restoration of deterioration, and growth of influence of the human factor. Difficulty of the decision this problem connected with an insufficient computerization of process the analysis of retrospective data, including results of measurement diagnostic parameters (DP). Stochastic character of change DP, influence on DP numerous factors, deterministic the approach in methodology of the analysis of the technical condition TR, not considering these features, is a principal cause of observable discrepancy of results the analysis to real process.

Application of modern methods to research of technical condition TR demands automation of calculations. Considering, that number DP TR is estimated in tens, and number of versions of attributes of distinction TR - hundreds, application of computer technologies allows to solve not only challenges, but also extremely bulky.

"Tool" of practical realization of these technologies are the intellectual automated information systems (IAIS) with that difference from known AIS, that alongside with formalization and storage of retrospective data in special "database", ordering and a press of the information necessary for the analysis, they carry out this analysis and represent recommendations on maintenance service and repair TR.

As bright example of such approach, recommendations [1] serve at chromatographic analysis of the dissolved gases in oil TR. The essential contribution to perfection of system of the analysis of results of measurement DP brought with the researches [2] focused on use of expert systems. Authors of clause spend the researches for more severe constraints - when number experts is limited by units, and IAIS provides with their necessary information and the recommendations, allowing to prove made decisions with the set size of risk of the erroneous decision.

At the analysis of data of measurement DP, along with comparison DP with maximum permissible values, the great value has also the analysis of speed of change DP. This parameter calculated under the formula:

$$\vartheta\{\Pi,(t_2-t_1)\}=\vartheta[\Pi,t]=\frac{\Pi(t_2)-\Pi(t_1)}{(t_2-t_1)}; \qquad (1)$$

where: $\Pi(t_2)$ and $\Pi(t_1)$ - accordingly current and preceded values DP (Π) during the moments of time t_2 and t_1. Its local character, which does not allow comparing with speed of change various DP (owing to distinction of dimensions) concerns to, lacks of this parameter.

The lack it is deprived speed of change of the relative values DP, calculated under the formula:

$$\vartheta\{Iz[\Pi,(t_2-t_1)]\}=\vartheta[Iz(\Pi,t)]=\frac{[Iz(\Pi,t_2)-Iz(\Pi,t_1)]}{(t_2-t_1)} \qquad (2)$$

where: $Iz(\Pi,t)$ - relative size DP (Π), a describing degree of deterioration of property of a material of units TR during the moment t. In conformity with the developed practice, the size $Iz(\Pi,t)$ in abbreviated form named by "deterioration" during the moment t and calculated under the formula:

$$Iz(\Pi,t)=\frac{\Pi(t)-\Pi_o}{\Pi_\partial-\Pi_o} \qquad (3)$$

where: Π_∂ and Π_o - accordingly, maximum permissible and initial values DP. Having substituted (3) in (2), we shall receive:

$$\vartheta\{Iz[\Pi,(t_2-t_1)]\}=\vartheta[Iz(\Pi,t)]=\frac{[\Pi(t_2)-\Pi(t_1)]}{(t_2-t_1)(\Pi_\partial-\Pi_o)}=\frac{\vartheta[\Pi,(t_2-t_1)]}{\Pi_\partial-\Pi_o} \quad (4)$$

So that to pass to relative values of speed of change DP, it is necessary to divide absolute value of speed of change DP on $(\Pi_\partial-\Pi_o)$. In some cases, the size Π_o ignored. It is inadmissible, if in process of deterioration size DP decreases. If in process of deterioration size DP increases, the error depends on a paritynd Π_∂. This parity is more the error of calculations is more. The estimation of size $\vartheta[Iz(\Pi,t)]$ is not end in itself. According to [3] $\vartheta[Iz(\Pi,t)]$ it compared to precede value.

So, according to [1] change of speed for concrete DP more, than on 10 % a month testifies to presence of quickly developing defect in TR. In other words:

$$\delta\vartheta(\Pi,t)=\left\{\frac{\vartheta\{\Pi,(t_3-t_2)\}-\vartheta\{\Pi,(t_2-t_1)\}}{\vartheta\{\Pi,(t_2-t_1)\}}\right\}<0{,}1 \quad (5)$$

If $(t_3-t_2)=(t_2-t_1)$ the formula (5) becomes simpler and looks like:

$$\delta\vartheta(\Pi,t)=\left\{\frac{[\Pi(t_3)-\Pi(t_2)]}{[\Pi(t_2)-\Pi(t_1)]}\right\}<1{,}1 \quad (6)$$

On fig.1 law of change DP according to four measurements, accordingly, during the moments t_0, t_1, t_2, t_3 where t_0 - the moment of measurement Π_o is resulted.

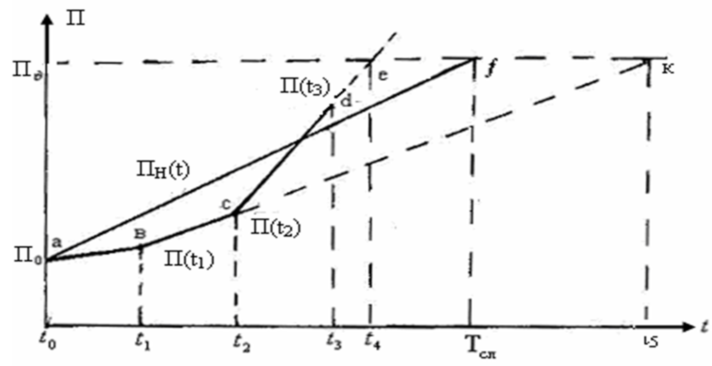

Fig.1. Graphic illustration of change DP before restoration of deterioration

As follows from fig.1, the given measurements during the moment t_3 testify to that that $\Pi(t_3)<\Pi_\partial$. However, speed of change DP does not satisfy to a condition (6). Speed on a site $(t_2\div t_3)$ essentially is more, than on a site $(t_1\div t_2)$, $\delta\vartheta(\Pi,t)>1{,}1$. If to extrapolate line cd, that is to assume, that at $t>t_3$ speed of change DP remains constant it will appear, that $\Pi(t)$ will be equal Π_∂ during the moment of time t_4.

A seeming simplicity of these calculations is deceptive. Process of deterioration TR far not always corresponds a broken curve $abcdke$. The analysis of features of real process of deterioration, the account of these features is an indispensable condition of objectivity of the automated calculations.

If deterioration of the transformer connected with growth DP, in process of increase in service life, TR observed not only natural continuous increase in numerical value DP, but also its discrete reduction at use of those or other forms of restoration of deterioration or discrete increase at influence of operational factors. For example [1], at decontaminations of oil, addition of the decontaminated oil and of some other ways of improvement quality of oil TR, concentration of the gases dissolved in oil decreases. Moreover, at refusal of system of cooling, influence of through currents of short circuit, concentration of the gases dissolved in oil sharply increases and at absence of defects TR during one - two months decreases. Dependence of many DP from temperature of oil known.

Let us consider algorithm of ordering of data of speed of change DP. Let in empirical table ET (Π) databases the sequence of results of tests of park TR of a power supply system is placed.

1. We spend sample of measurement set DP;
2. From this sample systematized given measurements DP for concrete TR on time. These data include:

2.1. Initial data (result of measurement DP at input of unit TR in work during the moment t_0

For separate units the moment of implementation coincides with the moment of implementation TR. Chances when these moments are various).

2.2. Results of measurement DP in process of increase in service life $t_j > t_0$; $j = p, M_i$; M_i - number of measurements DP for i-th TR.

3. Under the formula (2) speed of change of relative values DP during the moment t_{j-1} and t_j is calculated with $j = 1, M_i$;
4. The negative values $\vartheta[Iz(\Pi, t)]$ corresponding this or that form of restoration of deterioration are excluded from consideration.

Results of calculation are brought in empirical table ET (Π) together with data about service life ($t_{сл,j} = (t_{j-1} + t_j)/2$), design features TR and conditions of operation.

Enter concept of rated speed of change DP and designate as $\vartheta_н(\Pi)$. Further assume, that $\vartheta_н(\Pi) = (\Pi_д - \Pi_o)/T_{sl}$, where T_{sl} - normative service life TR. Hypothetical law of change DP thus corresponds to a line af fig.1. It is obvious, that $t_4 < T_{sl}$. And that it has not occurred, necessary to restore deterioration TR in an interval $t_3 \div t_4$. The parity speed of change DP on sites $(t_0 \div t_1)$ and $(t_1 \div t_2)$ does not satisfy to a condition (6), but equality $\Pi(t)$ and $\Pi_д$ occurring the moment $t_5 >> T_{sl}$. In other words, a condition (6) and $\Pi(t) < \Pi_д$ are often inconsistent.

As fuller characteristic of conformity of technical condition TR shown requirements are served with a condition not excess of size of relative change $\vartheta[\Pi(t_2 - t_1)]$ of unit. Calculations spent under the formula:

$$\delta\vartheta(\Pi, t) = \vartheta(\Pi, t) / \vartheta_н(\Pi) \qquad (7)$$

If now in the formula (7) to substitute values $\vartheta(\Pi, t)$ and $\vartheta_н(\Pi)$ and to consider (3), receive:

$$\delta\vartheta[Iz(\Pi, t)] = \delta\vartheta(\Pi, t) = \left[\frac{T_{sl}}{(t_2 - t_1)}\right] \cdot \left[\frac{\Pi(t_2) - \Pi(t_1)}{(\Pi_д - \Pi_o)}\right] = T_{sl} \cdot \vartheta[\Pi, (t_2 - t_1)] < 1 \qquad (8)$$

What as much as possible admissible value DP should be after restoration of deterioration during the moment t_3 to provide non-failure operation of work TR till the moment of time T_{sl} at speed of deterioration on an interval $(t_{sl} \div t_3)$ no more $\vartheta[\Pi, (t_3 - t_2)]$. Designate a size as well as $\Pi^*(t_3)$ and calculate it under the formula:

$$\Pi^*(t_3) = \{\Pi(t_3) - (t_{sl} - t_3)\frac{[\Pi(t_3) - \Pi(t_2)]}{(t_3 - t_2)}\} \qquad (9)$$

Thus, shown, that:

- not excess current value DP of maximum permissible size DP does not testify yet to absence of defect TP. The reasons of such discrepancy are or the overestimated (underestimated) value $\Pi_д$, or the underestimated (overestimated) value of admissible change of speed $\vartheta(\Pi, t)$. This conclusion based on known in the theory of reliability process of deterioration of materials («a curve life») when after the normal period (speed of deterioration is constant) there comes the period of ageing and catastrophic deterioration (speed of deterioration nonlinear increases);
- Excess of speed of change DP more than on 10% in comparison with preceded value is not necessarily connect with occurrence of local defect. It speaks casual character of change $\vartheta(\Pi)$ and essential influence of some factors (design features and conditions of operation);
- Essential growth speed of change DP and not excess of predicted value of residual service life of normative size is a significant attribute of presence of the defect demanding restoration;
- Relative value of speed of change DP $\delta\vartheta[Iz(\Pi, t)]$ in view of reference value DP allows to compare with speeds of change various DP.

Noted above a ratio have been received in the assumption of constant speed of deterioration on an interval of service life TR (T_{sl}) and not excess DP of maximum permissible value ($\Pi_д$). In real conditions of operation, TR can appear that this assumption is erroneous. A principal cause to that is heterogeneity of set results of measurement DP and noted above discrepancy of limiting values DP and speeds of change DP to real process of deterioration.

So that to raise accuracy of the forecast of a residual operating time to excess DP of maximum permissible value it is necessary to consider first of all stochastic character of deterioration TR and to develop:

1. The method of classification of retrospective data of speed of change DP on groups of variety of attributes (VP).
2. The method of an estimation of reliability of the assumption of constant speed of deterioration on an interval of time T_{sl};

As a matter fact, the first method provides an opportunity of application of the second method. According to the terminology accepted in mathematical statistics, agree to name set of data of calculation relative speed of deterioration park TR of a power supply system a final data set (FDS), and a data set, chosen of FDS on the set version of one or of some attributes - sample.

Agree that data of relative values of speed of change DP TR collected and placed in the empirical table (ET). In columns ET the serial number of measurement, numerical values $\delta\vartheta[Iz(\Pi,t)]$, the name of distinctive attributes are consistently registered. To distinctive attributes concern not only nameplate data TR, i.e. its design features, but also attributes of conditions of operation TR, such as: service life, an operating time after major overhaul, the name of the enterprise and substation, etc.

Designate number of considered distinctive attributes through n, and number of variety of attributes (VP) - through r_i with $i=1,n$. Set of results of calculation $\vartheta[Iz(\Pi)]$ concrete DP, forming FDS, we shall designate as $\{\delta\vartheta[Iz(\Pi_{v,j})]\}_\Sigma$, where $v=1,k$; k - number DP; $j=1,M_v$; M_v - number of realizations for j-th DP, and set of realizations $\vartheta[Iz(\Pi)]$ of sample with set VP - as $\{\delta\vartheta[Iz(\Pi_{v,j})]\}_B$ with $v=1,k$ and $j=1,M_{v,B}$; $M_{v,B}$ - number of realizations $\vartheta[Iz(\Pi)]$ for v-th VP in sample (B).

II. QUALITY MONITORING OF IMPOSING APPEARANCE OF SAMPLE OF REALIZATIONS $\{\delta\vartheta[Iz(\Pi_{v,j})]\}$.

The method is based on a following axiom: if sample of realizations $\delta\vartheta[Iz(\Pi,t)]$ for some from set VP, having the greatest absolute value of the maximal divergence of statistical function of distribution (s.f.d.) from s.f.d. FDS, it is representative, other samples of set of versions of considered attributes are representative also all.

Under representative, we shall understand sample, the maximal divergence s.f.d. Which from s.f.d. FDS satisfies to a condition:

$$\alpha_k < \{1 - F_m^*[\Delta F_Э^*(\delta)]\} >> F_m^*[\Delta F_Э^{**}(\delta)] \tag{10}$$

where: $\delta_{v,j}=\delta\vartheta[Iz(\Pi_{v,j},t)]$- symbolic notation; $\alpha_k = 1-R$; α_k - mistake of the first sort; $\Delta F_э^*(\delta)$ - the greatest divergence between s.f.d. FDS (designate it as $F_\Sigma^*(\delta)$) and s.f.d. Samples (designate its $F_B^*(\delta)$). Calculated under the formula:

$$\Delta F_э^*(\delta) = max[\Delta F^*(\delta_j)] \tag{11}$$

where: $j=1,M_{v,B}$

Let's agree size $\Delta F_э^*(\delta)$ to name the greatest deviation empirical distributions $\Delta F_\Sigma^*(\delta_j)$ and $\Delta F_B^*(\delta_j)$.

$$\Delta F^*(\delta_j) = \left|F_\Sigma^*(\delta_j) - F_B^*(\delta_j)\right| \tag{12}$$

$$F_{\Sigma,i}^*(\delta) = i / M_v \tag{13}$$

$$F_{B,i}^*(\delta) = i / M_{v,B} \tag{14}$$

$F_m^*[\Delta F_m^*(\delta)]$- s.f.d. The greatest divergence between s.f.d. FDS $F_\Sigma^*(\delta)$ and modeled on $F_\Sigma^*(\delta)$ s.f.d. Samples $F_{B,m}^*(\delta)$.

$$\Delta F_m^*(\delta) = max[\Delta F_m^*(\delta_j)] \tag{15}$$

where: $j=1,M_v$, and

$$\Delta F_m^*(\delta_j) = \left|F_{\Sigma,m}^*(\delta_j) - F_{B,m}^*(\delta_j)\right| \tag{16}$$

$$F_{m,i}^*[\Delta F_{m,i}^*(\delta)] = i / N \tag{17}$$

where: N - number of modeled realizations of the greatest divergence between $F_\Sigma^*(\delta)$ and $F_{B,m}^*(\delta)$.

$F_m^*[\Delta F_m^{**}(\delta)]$ - s.f.d. The greatest divergence between s.f.d. FDS $F_\Sigma^*(\delta)$ and modeled on $F_B^*(\delta)$ s.f.d. Samples

$F^{**}_{B,m}(\delta)$.

$$\Delta F^{**}_{m}(\delta) = max\left[\Delta F^{**}_{m}(\delta_j)\right] \quad (18)$$

where: $j = 1, M_v$, and

$$\Delta F^{**}_{m}(\delta_j) = \left|F^{**}_{\Sigma,m}(\delta) - F^{**}_{B,m}(\delta_j)\right| \quad (19)$$

$$F^{*}_{m,i}\left[\Delta F^{**}_{m,i}(\delta)\right] = i / N \quad (20)$$

To check of a condition (10) precede:

1. Formation of sample of measurements for each variety of considered attributes;
2. Under formulas (11÷14) the greatest empirical divergence of all versions i-th an attribute is calculated with $i = 1, n$;
3. The greatest divergence among $\Delta F^{*}_{Э,i}(\delta)$ Is calculated with $i = 1, n$. Designate its $\Delta F^{*}_{Э,m}(\delta)$.
4. The hypothesis about imposing appearance of the sample corresponding size $\Delta F^{*}_{Э,m}(\delta)$. Is checked. if sample is representative, according to an axiom other samples for set VP are representative also all. In other words, FDS it is homogeneous, and it is non-uniform - otherwise.

III. METHOD OF CHECK OF THE ASSUMPTION OF CONSTANT SPEED OF DETERIORATION

Casual character of speed of change DP essential influence on this size of operational factors cause difficulties of recognition on retrospective data of law of change in time. Construction of confidential area with the set factor of trust does not allow to solving a task in view since so as speed of deterioration on an interval T_{sl} is constant, appear assumptions of nonlinear laws of its change are fair.

Below the method of check of the assumption of constant speed of change DP, based, as well as a method of classification of data, on statistical modeling units and theories of check statistical hypotheses is resulted. The integrated block diagram of algorithm promoting representation about a method is resulted on fig.2. We shall consider some features of program realization of algorithm.

Block 1. FDS is formed of realizations $\delta\vartheta\left[Iz(\Pi,t)\right]$ ET (δ). Designate this FDS as $\{\delta\vartheta\left[Iz(\Pi,t)\right]\}_{\Sigma} = \delta_{\Sigma}$;

Block 2. S.f.d. $F^{*}_{\Sigma}(\delta)$ Pays off under the formula:

$$F^{*}_{\Sigma,i}(\delta) = i / M_{\Sigma} \quad (21)$$

where: M_{Σ} - number of lines ET (δ).

Block 3. Sample (δ_B) is formed from (δ_{Σ}), which realizations satisfy to a condition:

$$0{,}75\, T_{sl} < t_j \le T_{sl} \quad (22)$$

with $j = 1, M_B$, where: M_B - number of sample units (B).

Block 4. S.f.d. $F^{*}_{B}(\delta)$ Pays off under the formula:

$$F^{*}_{B,i}(\delta) = i / M_B \quad (23)$$

Block 5. The greatest empirical divergence s.f.d. $F^{*}_{\Sigma}(\delta)$ also $F^{*}_{B}(\delta)$ calculated under the formula:

$$\Delta F_{Э}(\delta) = max\left\{\left|F^{*}_{\Sigma}(\delta_j) - F^{*}_{B}(\delta_j)\right|\right\} \quad (24)$$

Block 6. Average values of speed of change DP FDS and samples under formulas pay off:

$$M^{*}_{\Sigma}(\delta) = \left\{\sum_{j=1}^{M_{\Sigma}} \vartheta_j\left[Iz(\Pi,t)\right]\right\} / M_{\Sigma} \quad (25)$$

$$M^{*}_{B}(\delta) = \left\{\sum_{j=1}^{M_{B}} \vartheta_j\left[Iz(\Pi,t)\right]\right\} / M_{B} \quad (26)$$

Further management is transferred to modeling (m) s.f.d. The greatest divergence N of realizations $F^{*}_{\Sigma,m}(\delta)$ and $F^{*}_{B,m}(\delta)$ (block 7). It is originally modeled s.f.d. $F^{*}_{B,m}(\delta)$ A method of "inverse functions" on the basis of M_B random numbers with uniform distribution in an interval [0,1] and s.f.d. $F^{*}_{\Sigma}(\delta)$, accommodations of sample of M_B realizations of speed of change DP in ascending order and calculation of probability of display of these realizations under the formula (23). It is formed FDS and s.f.d. $F^*_{\Sigma,m}(\delta)$, under the formula (16) the greatest divergence $\Delta F^*_m(\delta_j)$ is calculated. These calculations repeat N time, is under construction s.f.d. $F^*_m[\Delta F^*_m(\delta)] = R(\delta)$ and at last is calculated s.f.d. $\alpha(\delta) = 1 - R(\delta)$ (block 8).

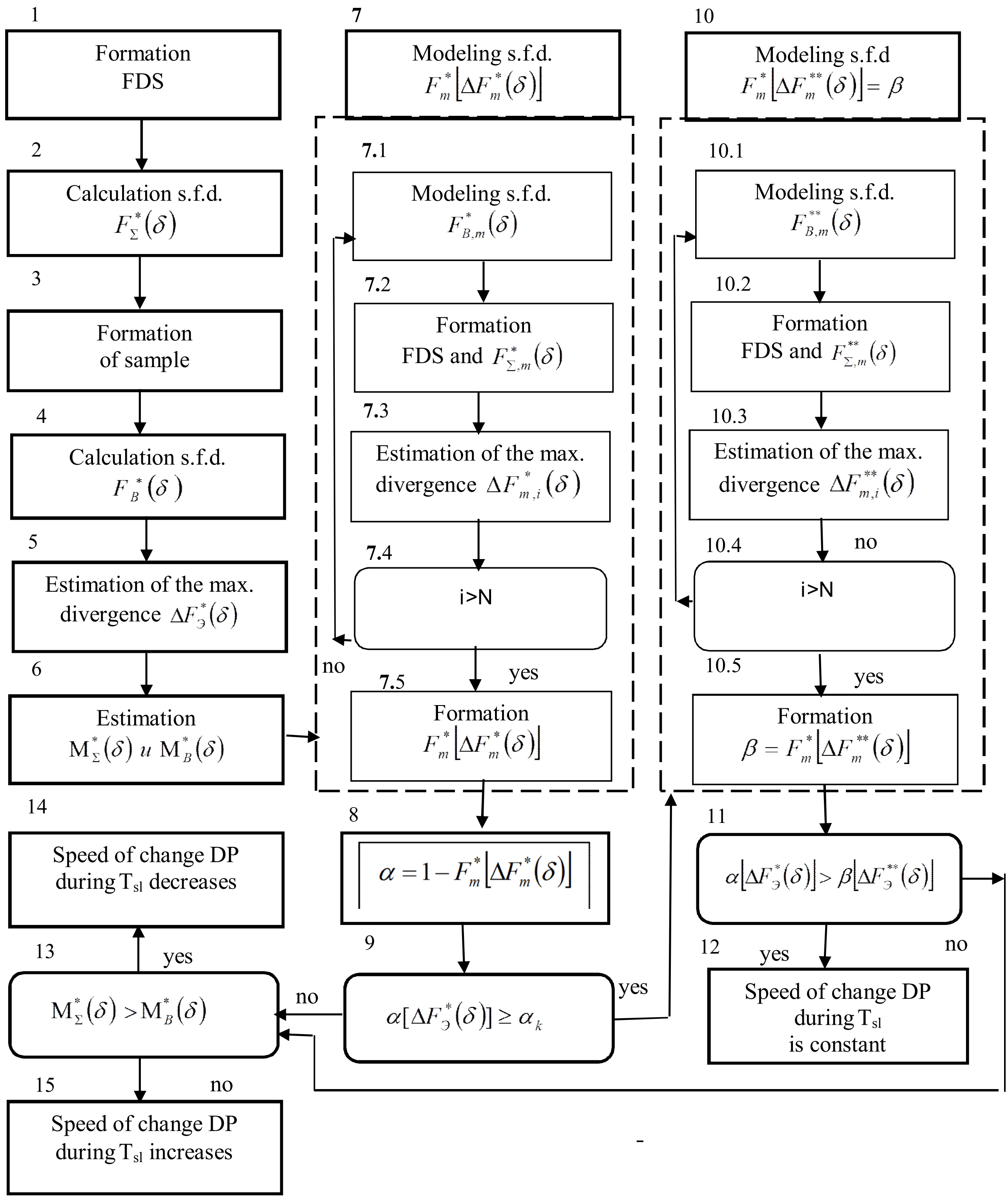

Fig.2 Integrated block diagram of algorithm of the statistical analysis of speed of change DP in current T_{sl}.

If it will appear, that $\alpha[\Delta F_Э(\delta)] < \alpha_k$, where α_k - critical value of a significance value it means, that on an interval [0,75T_{sl} ; T_{sl}] relative speed of change DP not casually differs from the average characteristic for FDS.

Moreover, the parity corresponds to decreasing speed of change DP (block 14), and a parity - to increasing speed of change DP (block 15).

If had data do not contradict a hypothesis H_o of constant speed of deterioration, i.e. $\alpha\left[\Delta F_Э^*(\delta)\right] \geq \alpha_k$, where α_k - critical size of a significance value management transferred the block 10 which is similar to the block 7 with that difference, that modeling of sample is carried out on distribution $F_B^*(\delta)$. In other words, the hypothesis H_2 about constant speed of deterioration on an interval normalized service life is checked.

If a mistake of the second sort for an empirical greatest divergence s.f.d. $F_\Sigma^*(\delta)$ Also $F_B^*(\delta)$ it appears it is less, than a mistake of the first sort it is possible to accept a hypothesis H_1 with the certain degree of confidence. If the return parity (the hypothesis H_2 is fair) takes place, management is transferred to the block 11 for an estimation of character of change of speed of deterioration.

CONCLUSION.

1. Operating experience, literary data testify to necessity to show care at use of criterion not excess of speed of deterioration of preceded value, and a diagnostic parameter - maximum permissible size. A principal cause to that is not the account of stochastic character of process of deterioration TR.
2. Methods of classification of retrospective data on independent groups of homogeneous data and estimations of reliability of the assumption of constant speed of deterioration during normative service life are developed. Consistency of data about constant speed of deterioration allows raise objectivity of the forecast of technical condition TR on the basis the guaranteed estimations.

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