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THE COMPUTER TECHNOLOGY OF EXPERT RULES CONSTRACTION FOR THE TECHNICAL OBJECTS DIAGNOSIS SYSTEMS

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The expert rules organizing techniques by expert's information and without one for electrical motor's diagnosis system moreover these rules correcting technique by reason-consequences monitoring have discussed here.

КОМП'ЮТЕРНА ТЕХНОЛОГІЯ ПОБУДОВИ ЕКСПЕРТНИХ ПРАВИЛ ДЛЯ СИСТЕМ ДІАГНОСТИКИ ТЕХНІЧНИХ ОБ΄ЄКТІВ.

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Подано методики організації експертних правил (ЕП) системи диагностики електричних машин (ЕМ) с застосуванням експертної інформації та без неї (автономно), а також методика коректування цих правил за результатами причино-слідчих спостережень.

КОМПЬЮТЕРНАЯ ТЕХНОЛОГИЯ ПОСТРОЕНИЯ ЭКСПЕРТНЫХ ПРАВИЛ ДЛЯ СИСТЕМ ДИАГНОСТИКИ ТЕХНИЧЕСКИХ ОБЪЕКТОВ[1]

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Представлены методики организации экспертных правил (ЭП) системы диагностики электрических машин (ЭМ) с использованием экспертной информации и без неё (автономно), а также методика корректировки этих правил по результатам причинно-следственных наблюдений.

Ключевые слова: электрическая машина, экспертные правила, эксперт, диагностика, распределение.

The presented techniques of the expert rules organizing give a possibility to intellectualizing the technical object's diagnosis system not only by expert's intellect potential

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using. It is possible by techniques of the automatically rules correcting and creating new on the cause-outcome monitoring results. These techniques apply are especially important for the individual and small quantity-produced object's diagnosis, i.e. for objects without statistical dependencies between damages and checking parameters.

This diagnosis system is based on expert system procedures. The main tasks of the diagnosis system are the object’s real condition's identification; the defects and damage's diagnosis on early stage; the forecasting of the future object’s technical conditions; the planing of the operative actions and the maintenance planing.

To avoid of some limits on the diagnosis reliability estimation and to make open system to the list of possible damages is adding the not identificated damage. This damage is corresponds with all other unannounced damages.

Assume that the checking parameters are the diagnosis symptoms characterizing values. In a general case expert is building the knowledge base rule as if one of the checking indexes is large or less then established value. So claiming that there is one of possible damage. The entering data (established operating index value), that points to damage, has diapason from ***T1*** to ***T2***. *In this case* $\boldsymbol{T1 \geq 0}$, *and* $\boldsymbol{T1 \leq T2 \leq \infty}$. The function of probably distribution $\boldsymbol{P(\omega)}$ of damage from correspondence operating index ω has visibility:

$$P(\omega) = 1 - exp(-\alpha\omega^{\beta}) \quad , \quad \text{when } \omega \geq 0 \quad ;$$

(1)

$$P(\omega) = 0, \qquad \text{when } \omega < 0$$

where $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ -factors of Veibul distribution, that estimated dependency the data distributions disperse. Those data are getting from experts about index’s values characterized limits of correspondence interval. This kind of distribution is selected on base of the more than 100 Ukraine plant’s high voltage AC motor’s and generator’s damages statistic, during 30 years.

The estimations of $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ factors would get from equations determinate the expectation $\boldsymbol{M(\omega)}$ and disperse $\boldsymbol{D(\omega)}$ of the correspondence operating indexes. We will assume that expectation is the maximum (minimum) long permissible value of concrete index, disperse calculating on denoted deviation.

$$M(\omega) = \frac{\Gamma(1 + 1/\beta)}{\alpha^{1/\beta}} \quad ,$$

$$D(\omega) = \frac{\Gamma(1 + 2/\beta) - \Gamma^{2}(1 + 1/\beta)}{\alpha^{2/\beta}}$$

Where $\Gamma(.)$ -- Gamma-function.

These nonlinear equations deciding by $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are making with restriction that $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ could be positive and real figures.

In practice this technique realization we propose by modified equation (1) in visible

$$P(\omega) = exp(-\alpha(2 - \frac{\omega}{\tau})^{\beta}) \,,$$

(2)

where ω -measured value of operating index; τ -the long permissible value of operating index. In this way for cases when e.g., a operating index is temperature of the motor’s winding and as event -- slot insulator break-through

$$\alpha = -\frac{\ln(P_e)}{(\nu/\tau)^{\beta}},$$

where Pe -the probability of damage that denoted by expert for a index value ν. During determine the damage on the real operating index value ω we take account as $\frac{\omega}{\tau} \geq 2$, so it's equal 1. For cases when e.g., for noted damage the index is wending resist

$$\alpha = -\frac{ln(P_e)}{(\tau/\nu)^{\beta}}.$$

During determine the damage on the real operating index value ω we take account as ω

we take account as $\frac{\omega}{\tau} \geq 2$ so it's equal 0.

For the pairwise independence of events (damages) it is demands that expert's information and independently created rules could not duplicating. On this reason we did make an operative knowledge base and stationary one. The operative knowledge base is creating in next direction. For each damage Ai $(i=1,2...n)$ and parameter Bj $(j=1,2...k)$ by looking for the stationary knowledge base we can find the rules with same Ai and Bj. Assume we find $m*i*j$ rules, e.g., m experts (system is an expert too) informed us about probabilities of damages Ai depending on parameter Bj value. For these rules we can receive parameters of the probability's distributions. Since for these rules describe we use a Veibul distribution (2) we have assume that index α_i are equal to constant e and index β_i, $(i=1,2... m*i*j)$ are defining on special technique [1]. Each expert has a weight index of his information.

Analysis of the damages and damage’s reasons on the Ukraine plants are showing, that a damage state is raising not immediately and has an own prehistory. On example, on the Khmelnitsky sugar plant from 1985 to 1994 years were observed the electrical motors of circular pumps, fuel pumps and irrigate station's pumps. They power are from 400 to 800 kW, on 6 kV voltage. In result we have gotten the distribution of damages on years and on kinds. In this way was fixed the operating indexes during special tests, that is, were made the cause-outcome observes.

Here we show a one of methods of expert system programming to autonomic knowledge base rules organizing by the special tests operating indexes. Those indexes are describe the degradation of observed object exploring conditions with criteria of independence [2].

It is assume we have new operating indexes values; those fixed on the periodic special tests’ results of identical objects’ group for certain period. For searching of the stochastic dependence of damage from list to every operating indexes we are use the independence criteria ζ. Calculate of the independence criteria's statistics in case of the two signs; every of them has two classes [2], drawing the table for every new rule [1]

Table 1

	Operating index is normal	Operating index is over	Total
Failure is in	*d*	*b*	*a+d*
Failure is not in	*c*	*a*	*a+c*
Total	*c+d*	*a+b*	

where ***a,b,c,d*** -- are numericals of the correspondent damage arise. If a leaded exploration time [1] of the observed objects is not equal we can prognosis the certain index's values with smaller leaded exploration time to a damage time of the object with largest leaded exploration time to the damage. The independence criteria's statistic is computing by equation [2]

$$\varsigma=(ad-bc)^2(a+b+c+d)/[(a+b)(c+d)(a+c)(b+d)] \qquad (3)$$

and compare with a table value of Pirson's distribution value χ^2 with a number of freedom degree $n=1$ and to set trusting probability (for example $\alpha=0{,}001$) [3,6].

For example, on table 1 data will building tow rules on index -- Slot insulator's coefficient of absorbtion, and on outcome -- "winding shortage on frame" (table 2) and "mechanical bearing damage" (table 3)

Table 2

	Operating index is normal	Operating index is over	Total
Failure is in	5	18	23
Failure is not in	189	0	189
Total	194	18	212

Table 3

	Operating index is normal	Operating index is over	Total
Failure is in	39	3	42
Failure is not in	155	15	170
Total	194	18	212

On the first case independence criteria statistic is equal

$$\zeta_1=\frac{(0*5-189*18)^2*(0+18+189+5)}{(18+0)*(5+189)*(0+189)*(18+5)}=161{,}64.$$

On this case the data are contradict to independence hypothesis (probability < *0,001*).

On the second case

$$\zeta_2=\frac{(15*39-3*155)^2*(15+3+155+39)}{(15+3)*(155+39)*(15+155)*(3+39)}=0{,}12.$$

The rule based on the table 3 data has no sense, and a probability of slot insulator damage with absorption coefficient value decreasing to 1,5 is over 0,999, i.e.,

$$\chi^2_{1,0.999} = 10,83.$$

After finding of the dependency between operating index's values and probably damages we can define the distribute indexes for the new rules.

The knowledge base forming result is the table of probability's distribution factors (α_{ij} и β_{ij} $i=1,...,\kappa;$ $j=1,2,...,m$.), for the correspondence rules on the κ operating indexes and m damages.

For the making equations those allowed to correct indexes of probability distribution we will use the maximum plausibility method [2]. By the known Veibul probability distribution density [3]

$$f(t) = \alpha\beta t^{\beta-1} exp(-\alpha t^{\beta}), \tag{4}$$

the plausibility function $\boldsymbol{L}$ determine. For the different values of a observed index t_i, by that took place damages on the identical objects r or units the plausibility function has visible

$$L = [\prod_{i=1}^{r} \alpha\beta t_i^{\beta-1} exp(-\alpha t_i^{\beta})][exp(-\alpha t_{ô}^{\beta})]^{n-r},$$

where n -total objects number; $t_{ô}$ -real controlling index value.

The estimations of values α and β is making by [2]

$$\frac{d\,ln\,L}{d\alpha} = 0, \qquad \frac{d\,ln\,L}{d\beta} = 0.$$

In result we gotten [4] an equation system

$$\frac{r}{\alpha} - \sum_{i=1}^{r} t_i^{\beta} - (n-r)t_{ô}^{\beta} = 0;$$

$$\frac{r}{\beta} - \sum_{i=1}^{r} ln\,t_i - \alpha[\sum_{i=1}^{r} t_i^{\beta}\,ln\,t_i + (n-r)t_{ô}^{\beta}\,ln\,t_{ô} = 0$$

if assume

$$t_i^{*} = \frac{t_i}{t_{ô}}$$

and take account that this rule correcting method is correct when t_i is tend to 1, we can assume

$$t_i^{\beta} \approx 1+\beta \ln t_i ,.$$

In practice this told that with the quite large differences between real and waiting index's values do not take a right to correct the rule. The equation system determine values $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$, has a visually

$$r(1/\alpha - 1) - \beta \sum_{i=1}^{r} \ln t_i - m t_{\hat{o}}^{\ \beta} = 0;$$

$$r/\beta - \sum_{i=1}^{r} \ln t_i - \alpha[\sum_{i=1}^{r} \ln t_i + \beta \sum_{i=1}^{r} (\ln t_i)^2 + m t_{\hat{o}}^{\ \beta} \ln t_{\hat{o}}\ ] = 0.$$

where $\boldsymbol{m=(n\text{-}r)}$.

Now, as take account that a determines of $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ values are gives to the expert's arbitrary so value's $\boldsymbol{r}$, $\sum_{i=1}^{r} \ln t_i = \xi$ and $\sum_{i=1}^{r} (\ln t_i)^2 = \zeta$ become abstract figures. Will take a note that we correct factor $\boldsymbol{\beta}$ only. This factor takes influence to the form of probability distribution's curve. Factor $\boldsymbol{\alpha}$ has no needs to correct since it's characterize the distribution's scale ad as will be shown down could be cite to any value. As after start of the object monitoring take place a damage with correspondence operating index t_2 so observed equation system take a visible

$$r(1/\alpha - 1) - \beta_1 \xi - m(t_1/t_2)^{\beta_1} = 0, \tag{5}$$

$$r(1/\alpha - 1) - \beta_2 \xi - m + 1/\alpha = 0, \tag{6}$$

$$r/\beta_1 - \xi - \alpha[\ \xi + \beta_1 \zeta + m(t_1/t_2)^{\beta_1} \ln(t_1/t_2)] = 0, \tag{7}$$

$$\frac{r+1}{\beta_2} - \xi - \alpha[\ \xi + \beta_2 \zeta] = 0, \tag{8}$$

where $\boldsymbol{\beta_1}$ -preliminary defined value; $\boldsymbol{\beta_2}$ -new value. In the four equation's system we have four unknown values $\boldsymbol{\xi}$, $\boldsymbol{\zeta}$, $\boldsymbol{r}$ and $\boldsymbol{\beta_2}$ with not varied $\boldsymbol{\alpha}$. Will rewriting the equations (5-8) with the next changes: $\beta_2 = \beta_1 + \gamma$ and the t_1 value will define by equation that determine after deciding the equations (5,6) dependable γ when $\gamma=0$

$$t_1 = t_2(1 - \frac{1}{2m})^{1/\beta}.$$

We have take account that ξ less then 0, we can define a condition when γ is a positive and negative value

$\gamma > 0$ when $m(1 - t_1/t_2{}^{\beta}) > 1/2$ and

$\gamma < 0$ when $m(1 - t_1/t_2{}^{\beta}) < 1/2$.

The deciding of equations; system (5-8) with account to the enumerated before changes is lead to equation

$$\alpha\zeta\gamma^2 + (\frac{r}{\beta} + \alpha\beta\zeta - \beta\frac{(t_1/t_2)^{\beta}\ln(t_1/t_2)}{1-(t_1/t_2)^{\beta}})\gamma - $$
$$-(1 + \frac{(t_1/t_2)^{\beta}\ln(t_1/t_2)}{1-(t_1/t_2)^{\beta}}) = 0,$$

that is the quadratic equation dependable γ. To the quadratic equation would has two equal roots its discriminant must equal to 0. In this case γ value is determine from expression

$$\gamma = -\frac{\beta}{2} - \frac{5(m[(t_1/t_2)^{\beta} - 1] + 1/2) + 2m(t_1/t_2)^{\beta} + \beta\frac{(t_1/t_2)^{\beta}\ln(t_1/t_2)}{1-(t_1/t_2)^{\beta}}}{4m(t_1/t_2)^{\beta}[-1/\beta - \ln(t_1/t_2)]}$$

Will use the Pierson’s criteria with 2m freedom degree and confidence probability 0,01 or 0,05 $\chi^2_{0.95,2m}$ for the refined factor β value changing suitability estimating

$$\delta = (2m/\chi^2_{0.95,2m})^{1/\beta_2} - 1.$$

The significance estimation value could not more than 0.2 to take this procedure of refining the advantageous.

Will looking for as example the procedure of rules correcting the one that describe the resource forecast of the AC motors’ slot insulator condition. The insulator resource is determine by the explore regimes, temperature and number of becoming regimes. The dependence from temperature [5]

$$\lg T = A + \frac{B}{273 + \vartheta}$$

where ***A,B*** -constants which dependence from the insulator constructs and technological distinctions. AC motors' insulators could be workable when are over warming in a long time during that could be changing the working regimes those substantially influencing on the insulators' resource. That's why as a calculation of the equation we propose one takes account that in average in 700 switch's regimes per hour so the insulator resource is decrease in 2.4 times [5]

$$t = 10^{(A + \frac{B}{273 + \vartheta})} e^{(-0{,}00125\,\nu)}$$

where **ν** average number of switches; **θ** - measured temperature of insulator.
For example will determine resource of the insulator band ЛС-ФЛЭП-Т based and impregnated with compound ПК-11 for electrical motor 2ЭДКОФ250М4 by this equation. The factors values in this case are *A=-5,32* and *B=4261,29*, that correspondence to nominal resource 180,000 Hs. Adjustment explored time would determined from equation

$$t' = t\,\frac{180000}{10^{(-5{,}32 + \frac{4261{,}29}{273 + \vartheta})} e^{-0{,}00125\,\nu}}$$

where ***t*** -real explore time on discretizied on index's distances that characterized the explore regimes. On the figure 1 is show a result of this equation using, i.e., was determined the referenced and real time.
In this example the nominal insulator resource is 180,000 hours. However in practice are probable different explore and technological distinctions of the concrete insulator that arise in motors' exploration process. The determined curve is describing by Veilbul distribution equation with correspondence factors α and β. The curve bend is characterizing by β factor.

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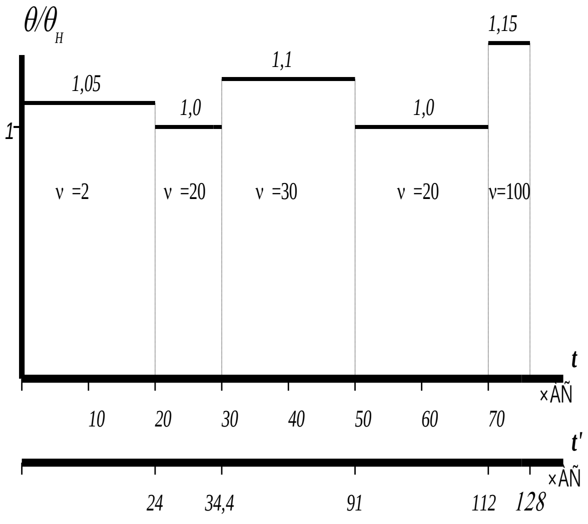

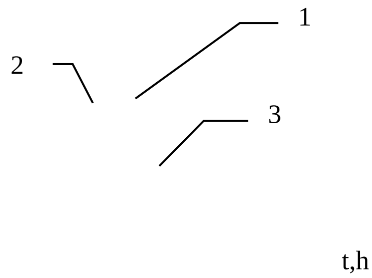

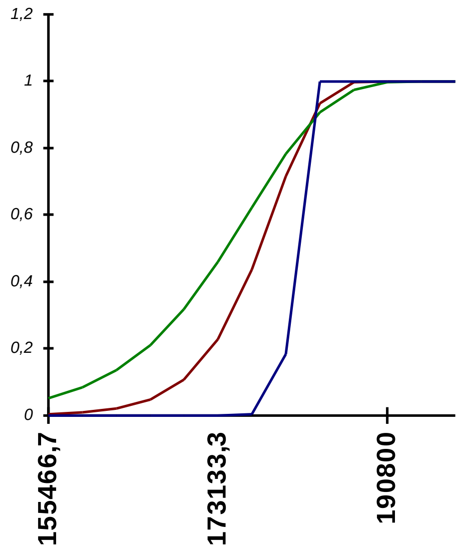

Fig. 1

Fig. 2

Table 4

	Adjustment insulator damage time of one of investigated slots on explore time t_2=100,000 h.			
Number of investigated slots n	1	2	5	10
Difference between prior and computed values of factor β γ	-16,76	-16,81	-16,84	-16,84
Significance estimation of factor β value δ	0,03	0,04	0,08	0,14
	Adjustment insulator damage time of one of investigated slots on explore time t_2=185,000 h.			
Number of investigated slots	1	2	5	10

n				
Difference between prior and computed values of factor β γ	154,6	204,5	240,5	253,9
Significance estimation of factor β value δ	0,002	0,003	0,007	0,016

Now will looking for how would change the curve form if will come the insulator condition changed before 180,000 exploiting hours and after. On the figure 2 are showing dependencies of insulator wear from adjustment explore time. The curve 1 is correspondence to the calculated dependency. The curves 2 and 3 are showing the corrected dependencies in cases when take place a substantial change of insulator's condition after 100,000 and 185,000 exploiting hours consequently.

In the table are showing dependencies between corrected index's values and number of investigated slot's cases when take place substantial changes of insulator's condition after 100,000 and 185,000 exploiting hours consequently. The factor βvalue is β=39,59.

Thus was determined that using of this method take possibility to correct distribution curve of insulator resource break probability on the concrete explore conditions with its estimation. The identically operations would be use to other units of motor. There are bearings or edge pockets of powerful motors. The factor to correcting may be any other operating index.

It is important for the diagnosis system to make account that we must to estimating the real time checking values, especially in the not nominal regimes of the technical object's working. The technique for the multy factors analysis is describing in [1].

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