WOJCIECH WIŁA, D.Sc.,E.E.
Institute of Electrical Engineering
Diagnostic Systems
Gdańsk

An expert system for diagnosing the state of marine electric machine insulation

SUMMARY

The paper presents an expert system for assessing the state of degradation of electric machine insulation.The system identifies the state of electric machine insulation by making use of the Bayesian decision rule and information from two different sources: the object itself and its environment, i.e. operating conditions. The hypothesis on the uniform probability distribution of reliability states is verified on the basis of the degradation hazards which exist in an assumed location and operation time of the machine; then classifiers of the reliability states are generated.

In the paper the causes and rules assumed in the program as well as simulation algorithm are described.

INTRODUCTION

A system (reliability state classifier) was developed which identifies the state of electric machine insulation by making use of the Bayesian decision rule and utilizing information from two different sources [4]. The first of them is the object itself and the second - its environment, i.e. operating conditions. To obtain the first type information the testing of the insulation state should be performed, but to get access to the second one the processes which occur in the machine environment have to be known. Identification of the machine insulation state $Y(t_0)$ is the Bayesian decision which accounts for the obtained result in i-th reliability state X_i, i = 1,2,...,I :

$$D\{Y(t_0)\} = X_i \tag{1}$$

if the occurrence probability of the reliability state X_i satisfies the following equality under the condition that the insulation state $Y(t_0)$ occurs :

$$P[X_i / Y(t_0)] = \max_j P[X_j / Y(t_0)] \qquad j = 1,2,\ldots,i,\ldots,I \tag{2}$$

where the conditional probability $P[X_i / Y(t_0)]$ is determined in accordance with the Bayes formula :

$$P(X_i / Y) = \frac{P(X_i)P(Y / X_i)}{\sum_{j=1}^{I} P(X_j)P(Y / X_j)} \tag{3}$$

and :

$P(Y / X_i)$ - the a-posteriori probability determined on the basis of the investigation of the influence of the combined environment stresses (defining the reliablity state X_i) on the physical state of the machine insulation Y

$P(X_i)$ - the a-priori probability known before investigation of the insulation state, which is based on the general knowledge of stress and failure physics.

The identification task of the conditional probability distribution $P(Y / X_i)$ is analogous to the image recognition problem by means of empirical patterns. The method, algorithm and program of the identification are presented in [2], whereas the identification problem of the a-priori probability distribution $P(X_i)$ in the task of the machine insulation state identification is described in [4]. In this paper the method and algorithm for one situation, out of four analyzed in [4], is described , i.e., the case of the a-priori probability identification by using the computer simulation based on the knowledge system dealing with insulation environment stresses.

EVALUATION MODEL OF INSULATION ENVIRONMENT STRESS

The reliability state X is a quantified feature of the machine insulation state Y, i.e. result of its assessment performed for a specific purpose. Therefore the state X is an element of the features space Ω_x defined in the insulation state space Ω_y. The state X, the reliability assessment output, defines the set L of the environment stress factors ψ_l, $l = 1,2,3,\ldots, L$, which describe the physical phenomena occurring in the machine environment. It forms an assessment of the insulation stress situation, performed from the prevention point of view. The prevention problem directly determines the space of the discriminable reliability states of machine insulation, Ω_x , and defines them by means of the logic functions defined, in the stress set, as the variables with the quantified levels $M = \{m_1, m_2, ... m_l, ..., m_L\}$:

$$X_i = F(\psi_1, \psi_2, ..., \psi_l, ..., \psi_L) \quad (4)$$

where :

$$\psi_l = \{\phi_1, \phi_2, ..., \phi_m, ..., \phi_M\} \quad (5)$$

The reliability features space Ω_x can be, in principle, deemed identical with the preventive decision space.The identification systems are usually designed for the specific degradation mechanisms which characterize the specific machine environment $Z(\Psi)$. Elaborating the universal systems is also possible if the environment influence on the decision which makes the identification of insulation state possible, is neglected. In this case $P(X_i)$ is assumed uniformly distributed over the entire range < 1, I > of the discrminable reliability states [2]. Such system is universal but not perfect because it does not utilize the knowledge on machine insulation working conditions, always obtainable although with difficulty, which appear during the operation time in the machine environment $Z(\Psi)$, determined by the variables ζ_s, τ_r:

$$Z(\Psi) = f(\zeta_1, \zeta_2, ..., \zeta_s, ..., \zeta_S, \tau_1, \tau_2, ..., \tau_r, ..., \tau_R) \quad (6)$$

where :

ζ - S variables identifying the machine operation location
τ - R variables identifying the machine operation time.

The a-priori knowledge can be utilized in the identification system by combining it with an expert system for stress assessment. In the paper a solution is presented of the learning problem of the machine insulation reliability state classifier by using the a-priori probability computer simulation and stress knowledge system.

DESCRIPTION OF TASK OF THE EXPERT SYSTEM

The task of the expert system is to change the hypothesis on the equally probable occurrence of the machine insulation stress. A premise of changing is the identification of degradation hazards which occur in an assumed place and time of operation of a specified class of machines (protection class, insulation heat resistance class, machine type, kind of loading etc). The expert system's rules of changing the uniform distribution are generated by a simulator on the basis of the degradation hazard of machine insulation, defined by a specified place and time of operation in the form of a measurable function determined in the reliability states space Ω_x .

The simulator is the computer program forming a part of the software for discriminative analysis of machine insulation states [7]. The simulator solves the problem of identifying the insulation states of the marine electric machines. Therefore the knowledge system, on which inferring about the a-priori distribution is based, is strictly limited to the situations which can occur at sea and on board and be connected with maritime economy environment. The knowledge system contains information on the following stresses: NaCl and other air pollutants such as dust and sand, temperature increase, high humidity, dew, and insulation ageing.

The general simulation scheme is presented in Fig.1.

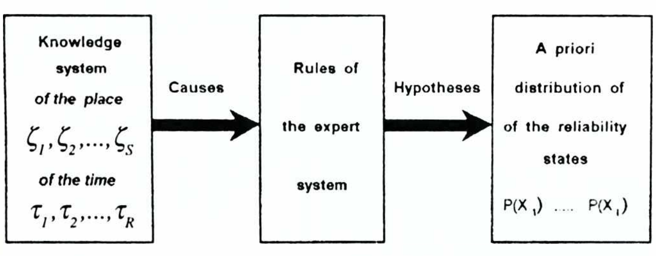

Fig.1. The general scheme of the a-priori distribution simulation to identify the electric machine insulation states

CAUSES FOR SIMULATING THE A-PRIORI DISTRIBUTION

The system makes use of J = S + R active, bivalent, nominal and undeniable facts. The facts are active in the sense that the system asks about their values each time and that they are located in the cause part of the inference rules. The facts are introduced to the system, which identify the stress situations to more precisely specify the a-priori information used in the task of diagnosing the insulation states of marine electric machines. The specifying deals with changing the hypothesis on the uniform distribution of occurrence probability of the assumed insulation stress situations.

The active facts identify a hazard situation of the diagnostic task with regard, in the case of marine electric machines, to the three following reasons (S = 6, R = 4) :

- the environment deteriorating influence characterized by the variables :

  ζ_1 - climatic zone
  ζ_2 - weather state
  τ_1 - season
  τ_2 - time spent at sea

- the influence of the electric machine supersystem and its remaining elements, characterized by the variables :

  ζ_3 - ship type (cargo type)
  ζ_4 - onboard place of operation (mechanism type)
  ζ_5 - state of electric machine bearing
  ζ_6 - state of electric machine sliding contact

- the influence of electric machine operation history, characterized by the variables :

  τ_3 - preventive actions taken in the past
  τ_4 - predicted lifetime.

One of two values can be attributed to particular facts, which dychotomically split the hazards caused by the facts into „large" and „small" ones. The program contains ten (J = 10) following questions :

1. Has the machine been already repaired ? (Yes/No)
2. Has the ship been in operation for a long time ? (Yes/No)
3. Has the ship's voyage been carried out during the damp-hot seasons ? (Yes/No)
4. Is the ship at sea usually for a long time ? (Yes/No)
5. Is the state of sliding contact impaired? (Yes/No)
6. Is the state of machine bearing impaired ? (Yes/No)
7. Does the ship carry bulk cargoes ? (Yes/No)
8. Have the high sea states occurred during the ship voyage ? (Yes/No)
9. Is the machine located on an exposed deck ? (Yes/No)
10. Has the ship's voyage been carried out in the tropical regions ? (Yes/No)

HYPOTHESES OF THE EXPERT SYSTEM

The system contains I final, multivalent, nominal and undeniable facts (in the case of marine electric machines: I = 12), which are included in the conclusive rules. The final facts are the a-priori probabilities $P(X_i)$ of occurrence of the reliability states X_i determined during discrimination analysis and defined by the degradation stresses (2) identified by the location variables $\{\zeta_1, \zeta_2, ..., \zeta_S\}$ and time variables $\{\tau_1, \tau_2, ..., \tau_R\}$. The facts are the hypotheses tested by the expert system. Their order code and names which appear in the task in question are as follows :

X_1 - highly cold state
X_2 - highly heated state
X_3 - wear-out-cold state

X_4 - polluted-dry state
X_5 - wear-out-heated state
X_6 - weakened-dry state
X_7 - unaged-damp state
X_8 - aged-damp state
X_9 - polluted-damp state
X_{10} - polluted-weakened state
X_{11} - weakened-damp state
X_{12} - polluted-weakened-damp state

RULES OF THE EXPERT SYSTEM

The system generates the probability distributions of occurrence of the reliability states X_i, i = 1,2,...,I , as the binary functions of the location ζ_s , s = 1,2,..., S , and time τ_r , r = 1,2,..., R , as follows :

$$P_s(X_i,\zeta_1,\dots,\zeta_S,\tau_1,\dots,\tau_R) \tag{7}$$

$$J = S + R$$

The system generates 2^J rules (7); each of them identifies a specific machine operation environment. The generating principles are the following :

- The active fact which achieves the value 0, does not change the hypothesis on the uniform probability distribution P(X) and in consequence the degradation does not grow.
- Inadequacy of the uniform distribution model of the a-priori probability P(X) grows as the number of facts achieving the value 1 increases.
- The particular active facts influence the hypothesis on the uniform a-priori probability distribution, with different intensity.
- The hierarchy of active facts $\{f_a(j)\}$, j=1,2,...,J and of final facts $\{f_k(i)\}$, i=1,2,...,I, is such that it corresponds to the monotonic change of the degradation hazard when an event of the stress situation $i = 1,2,\dots,I_m$, $I_m \le I$ occurs, but the degradation hazard is equal (represented by uniform distribution) when an event of the remaining stress situations $i = I_m + 1,\dots,I$ occurs.

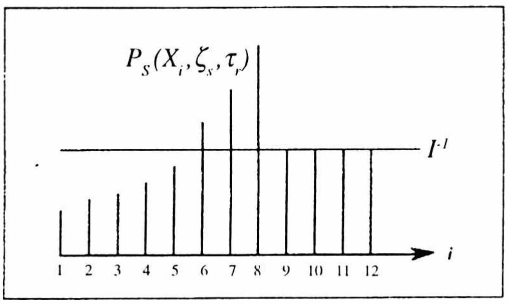

Fig.2. An example of the a-priori probability distribution generated by the expert system for the machine environment stress identification

The confidence hierarchy of the active facts during verification of the hypothesis on the uniform a-priori probability distribution model in solving the task in question can be described as follows [2] :

$$\{f_a(j)\} = \{\zeta_6,\tau_3,\zeta_5,\tau_2,\tau_4,\tau_1,\zeta_4,\zeta_3,\zeta_1,\zeta_2\} \tag{8}$$

and the order of the final facts, which corresponds to the machine insulation degradation level, can be presented as :

$$\{f_K(i)\} = \{X_1,X_3,X_2,X_6,X_8,X_5,X_4,X_9,X_7,X_{11},X_{10},X_{12}\} \tag{9}$$

The simulator for marine electric machines is of 1024 rules, i.e. it can discriminate the same number of stress situations and attribute to them the same number of distributions of the a-priori probability P(X).

SIMULATION ALGORITHM OF THE A-PRIORI DISTRIBUTION

For the active facts hierarchized in the above described way, generation of the final facts is carried out in compliance with the following algorithm [1] :

❶ The sequence $\{S^*\}_I$ is formed whose elements s_i^* obtain the values $\{0, I^{-1}, 1\}$ which are dependent on the value of the facts :

if $\bigcap_j f_a(j) = 0$ then $s_i^* = I^{-1}$

if $\bigcup_j f_a(j) \neq 0$ then $\bigcap_{i\in A} s_i^* = 0$

where :

j =1,2,...,J
i =1,2,...,I

A ={1,2,....,K} - the subset of the electric machine insulation serviceability states (in the case of the marine electric machines: A={1,2});

if $\bigcap_{j\in B} f_a(j) \neq 0$ and $\bigcup_{j\in B} f_a(l) = 0$ l>j, B={K,K+1,...,N}

then $\bigcap_{j\in B} s_j^* = 1$ and $\bigcap_{l\in C} s_L^* = I^{-1}$ C={N,N+1,...,J}

if the following criterion is satisfied :

$$\left[f_a(j-2)\bar f_a(j-1)\bar f_a(j)+f_a(j-1)\bar f_a(j)+\bar f_a(j-1)f_a(j)\right]\bar f_a(j+1)\dots\bar f_a(J)=1$$

then $s_j^* = 1$, otherwise $s_j^* = 0$.

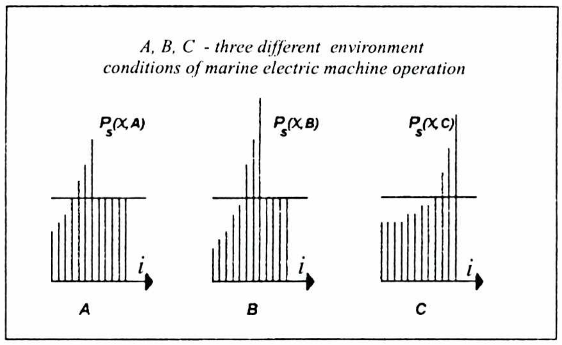

Fig.3. Examples of the a-priori probability distributions simulated for three, out of 1024, discriminable operation conditions of the marine electric machines

❷ The respective numbers of occurrence of the values 0 and 1 in the sequence $\{S^*\}_I$ are calculated :

Δ_0 - the number of occurrence of the value 0 in the sequence
Δ_1 - the number of occurrence of the value 1 in the sequence.

❸ The parameter β is calculated for the assumed value of the parameter α (< 0.099) of the a-priori probability distribution estimation model, as follows :

$$\beta = \alpha\frac{\sum_{i=1}^{\Delta_0}(\Delta_0+1-i)}{\sum_{i=1}^{\Delta_1}(\Delta_1+1-i)}$$

and the a-priori probability values are determined in the following way :

if $s_i^* = 1$ then $P_s(i) = (1+\beta i)I^{-1}$

if $s_i^* = 0$ then $P_s(i) = (1-\alpha[\Delta_o+1-i])I^{-1}$

The above described algorithm makes it possible to change the uniform distribution $P(i) = I^{-1}$ into the monomodal distribution $P_s(i)$ (Fig.2) with three reliability states X_n, X_{n+1}, X_{n+2} which are decisive of the machine insulation degradation in the assumed stress conditions whose a-priori probabilities are of the values which exceed the uniform distribution level :

$$P_s(i) > I^{-1} \qquad i=n,\ n+1,\ n+2 \qquad n=1,2,...,I$$

It is obtained at the expense of decreasing the probability levels of all the states less dangerous for a given machine group in a given operating situation :

$$P_s(i) < I^{-1} \qquad i < n$$

but maintaining the occurrence probabilities of generally more dangerous states, but not decisive in the considered situation, unchanged and kept on the same probability level :

$$P_s(i) = I^{-1} \qquad i > n+2$$

FINAL REMARKS

- Accuracy of the expertise on the electric machine technical state can be improved by utilizing the knowledge on the machine insulation hazards and processes which occur in its environment. The knowledge is missed during elaborating an identification system as it is designed first of all for identifying the assumed states of object's degradation, but not to account for specific stress situations which usually are not known at that time.
- The proposed solution of the problem is presented in the form of a simulator. This is the program which changes the decision rule of the universal identification system which entirely neglects the a-priori diagnostic knowledge on insulation states, by making use of binary information to generate monomodal probability distributions of occurrence of distinguished states. In the case of ADISMO program for discriminative analysis of electric machine insulation states [1] it is applied to generate the set of simulation patterns of a-priori information used in the recognition learning process.
- The simulator, supplied with 1024 identification rules, makes use of 10 variables which characterize electric machine environment and exploitation process and makes it possible to calculate probabilities of 12 reliability status simultaneously.

NOMENCLATURE

$Y_{(t_0)}$, Y	-	machine insulation state (at t_0 instant)
X_i	-	i-th reliability state
I	-	number of reliability states
$P(Y/X_i)$	-	a-posteriori probability
$P(X_i)$	-	a-priori probability
Ω_x	-	space of reliability states
Ω_y	-	space of machine insulation states
L	-	number of stress factors
Ψ_l	-	*l*-th environmental stress factor
M	-	number of stress levels
Φ_m	-	m-th stress factor level
$Z(\psi)$	-	electric machine environment
ξ_s	-	s-th variable identifying the operating place
τ_r	-	r-th variable identifying the operating time
S	-	number of variables identifying the operating place
R	-	number of variables identifying the operating time
J	-	number of active facts of expert system
$P_s(X,\zeta,\tau)$	-	a-priori distribution generated by the expert system
$\{f_a(j)\}$	-	set of active facts
$\{f_k(i)\}$	-	set of final facts
$\{S^*\}_I$	-	auxiliary sequence of final facts, in respect to degradation level
A	-	subset of states of machine insulation serviceability
K	-	actual number of serviceability states
N	-	actual number of increased hazard states
Δ_0,Δ_1	-	numbers of elements of auxiliary sequence
α,β	-	distribution model parameters

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Appraised by Mieczysław Wierzejski, Prof.,D.Sc.,E.E.

Conferences

RESEARCH - EDUCATION - TECHNOLOGY

Under this slogan an international symposium was held in Gdańsk on 26÷27 June 1997, organized by the Faculty of Mechanical Engineering, Technical University of Gdańsk. The event was included into the Millenium Celebration Programme of Gdańsk. For the first time representatives of almost all institutions and universities which cooperate with the Faculty had an opportunity to meet in Gdańsk. The Symposium emerged from the annually organized seminars titled „ Science for Practice" which were alternately held at Hochschule Bremen and Technical University of Gdańsk. Last year the seminar was organized with the participation of Fachhochschule Stralsund.

Now 86 scientists and experts took part in the Symposium who represented the research centres and universities of Germany (33 persons), Sweden (3 persons), France (2 persons), the Czech Republic (2 persons), Belgium (1 person) and Great Britain (1 person). The remaining group of participants represented the Symposium's organizer. The German group came of the scientific centres of Berlin, Stralsund, Bochum, Koeln, Stur-Heiligenrode, Magdeburg, Bremen, Rostock and Wolfsburg.

29 read and discussed papers were devoted to a rather broad range of topics, a.o. to presentation of:

- the research activities of particular scientific centres
- the experiences gained from the participation in TEMPUS Joint European Projects
- some results of bilateral scientific cooperation
- results of particular advanced research projects
- schemes of postgraduate studies and other didactic problems.

The scientists of Germany prepared 14 papers, 10 were of Polish authorship. 2 papers were elaborated by Polish-German team, and the teams: Polish-Swedish, Polish-French and that of the Czech Republic (Brno) prepared one paper each.

The scientific contacts which the universities participating in the Symposium have maintained till now, as well as the fruitful results of the present meeting promise that next similar symposia would be also successful.