THE ANNALS OF “DUNĂREA DE JOS” UNIVERSITY OF GALATI
FASCICLE III, 2015, VOL. 38, NO. 1, ISSN 2344-4738, ISSN-L 1221-454X
ELECTROTECHNICS, ELECTRONICS, AUTOMATIC CONTROL, INFORMATICS

EQUIPMENTS STATE EVALUATION USING FUZZY METHODS

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Abstract: The paper presents an optimal renewal strategy for the diagnosis of the equipments real state using fuzzy methods. For the calculation of the probability estimations, the facilities provided by fuzzy medium within the MATLAB have been used.

Key words: reliability, diagnosis, Markov model, fuzzy methods.

1. Introduction

A high reliability of the technical equipments can be achieved through of the application the optimal renewal strategies to minimize the fault risk as well as the average service cost. The hereby work deals with the matter of the diagnosis of the equipment real state with a positive wear for establishing the real time of the optimal renewal strategy. The used structure scheme to establish the parameters of the optimal strategy is shown in figure 1.

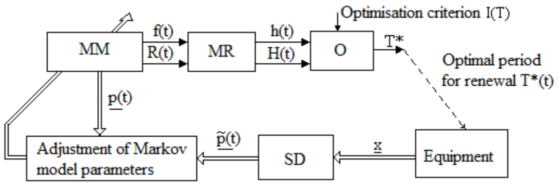

Figure 1. The structure scheme for renewal strategy

The key-words:
-MR – renewal model;
-MM – Markov model of reliability equipment;
-O – the optimisation block which establishes the optimal renewal solution, T^*, through the minimizing of one performance criterion I(T).

The application of the progressive renewal strategy implies the adjustment of the MM to the current state of the equipment [1]. For such a reason the SD diagnosis system (fig.1) is used and the respective system is the subject matter of the hereby work.

The diagnosis system is characterized by the following particularities:

- The information issued by the diagnosis system must be compatible with that of the MM block. Such information together with the state vector of MM is used for the self-adjustment of the Markov model parameters to establish the renewal strategy parameters according to a up to date model;
- The methods of diagnosis are based on the signal processing and it applies methods of artificial intelligence.

2. State equipments evaluation

In order to achieve an accurate prediction of the proximal renewal moment, the Markov model parameters are to be adjusted periodically in such a way to reflect with accuracy the real evolution of the equipment wear state. Thus it is necessary to define the wear state of the equipment in correlation with the admitted states of the Markov model. The evaluation of the real state of the respective equipment can be performed as follows:

- analysing the process measured values, values with slow evolutions in time;
- using diagnosis methods based on the model;
- using classic diagnosis methods based on the processing methods of the measured signals spectres of the process;
- specific methods of the given equipment.

It does not matter the methodology that one can choose for the real state of the equipment, but the modality of state equipment definition and the estimation of the $\tilde{p}_i(t)$ probabilities of those states according to the measured data, included in the vector $\underline{x}$ (see fig.1). The first evaluation modality of the equipment state is to be presented: the analysis of the slow evolution of some measured variables of the process. As a rule, the method that is to be presented can be applied not only for physical slow variables measured directly from the process, and for achieved values through the application of other diagnosis methods (values of criterion type according to which the diagnosis can be performed).

The evaluation stages are:

1. **The establishment of the process value used for such a purpose.** They are chosen in such a way to reflect better the evolution of the respective equipment

This paper was recommended for publication by Viorel Nicolau

wear. Example: for a bearing one can measure: its temperature, vibrations amplitude and/or the noise level produced by it. According to technical specifications of the equipment for each selected variable the limits defining its working state and the wear state are to be established.

2. **The definition of the state characterizing the equipment.** For the respective stage the variables measured combinations defining a certain state are to be established. This can be achieved only by knowing the equipment very well as well as its technical and technological requirements and its performances, which are to be achieved. The matter of the states definition is the more complex, the larger number of the measured variables and the number of the variation fields considered for such values for the definition of the wear state are.

3. The estimation of the equipment state using fuzzy methods

The equipment state diagnosis as per taken values of the supervised equipment by means of the translators can be performed by a method based on fuzzy methods. As per the methodology presented in §2, the sets of the first stage are not defined in a crisp way but as fuzzy sets. Thus, for each measured variable, x_i, $i = \overline{1, m}$, the following elements are to be established:

- the number of linguistic values, VL_j, $j = \overline{1, N_i}$, for the respective variable;
- the support of the fuzzy sets afferent to the considered linguistic value:

$$S_{ij} = \left\{ x_i \mid x_{ij\,min} \le x_i \le x_{ij\,max} \right\}, j = \overline{1, N_i}, i = \overline{1, m} \quad (1)$$

- the form and the parameters of the affiliation function $\mu_j(x_i)$, $j = \overline{1, N_i}$.

For the second stage beside the definition of the states within the MM of the equipment the linguistic evaluation of the probability that the equipment is in the state S_k, $k = \overline{0, n-1}$ is to be achieved. The same number of linguistic values is to be taken in order to evaluate all the probabilities $p(S_k \mid \underline{x})$, the discourse universe is the set of the numbers within the interval [0, 1]. The followings are to be chosen:

- linguistic values, PL_l, $l = \overline{1, r}$;
- the support of the fuzzy sets afferent to the considered linguistic values:

$$\forall k,\ M_l = \{ p_k \mid p_{kl\,min} \le p_{kl} \le p_{kl\,max} \} \quad l = \overline{1, r}, \quad k = \overline{0, n-1} \quad (2)$$

- form and parameters of the affiliation function $\mu_l(p_k)$, $l = \overline{1, r}$, where r represent the number of the linguistic values by means of which the probabilities evaluation is done $p_k \equiv P(S_k \mid \underline{x})$.

The most difficult problem is the deduction of the linguistic values of the states probabilities according to the considered fuzzy sets for the linguistic evaluation of the measured variables x_i. The establishment as per the a priori information can solve this problem – an *n* sets of rules by means of which the evaluation is performed for all those *n* probability within MM. Thus for the variable of p_k state, the set of rules is under the form:

$$\text{s rule}: \underline{\text{IF}}\ x_1 = VL_\alpha \text{ AND } x_2 = VL_\beta \text{ AND} \ldots \ldots \text{AND } x_m = VL_\sigma\ \underline{\text{THEN}}\ p_k = PL_\upsilon \quad (3)$$

The evaluation of each set of rules can be achieved through the inference methods (MAX-MIN; MAX-PROD; SUM-PROD) and it has as result the deduction of the affiliation functions afferent to the overall conclusion of the respective set of rules.

Defuzzification allows the deduction of the crisp values, $\tilde{p}_k$, $k = \overline{0, n-1}$, representing the "answer" of the fuzzy evaluator for the p_k probability estimation.

To get the outlets that can be regarded as p_k (S_k| $\underline{x}$), probabilities estimation concerning the belonging to x vector for S_k states the setting of the outlets of the fuzzy evaluator is achieved. The fundamental scheme for the suggested method for the state equipment estimation is shown in figure 2.

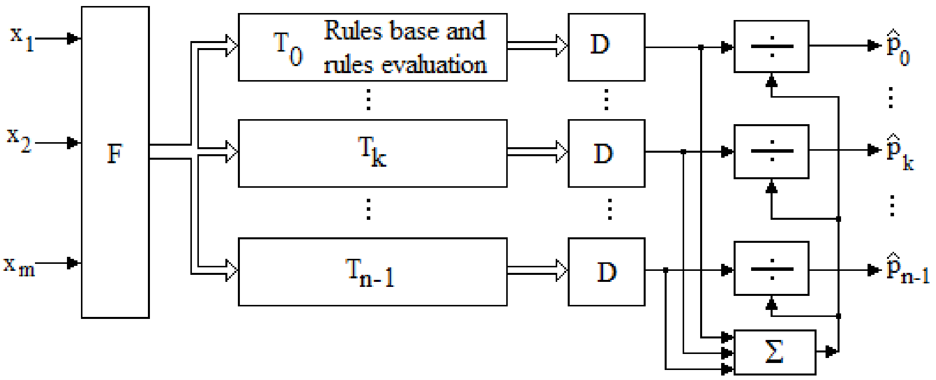

Figure 2. The structure of fuzzy classifier

4. Case Study

It was considered equipment characterised through two values, x_1 and x_2 with the variation fields:

$$20 \le x_1 \le 40 \quad \text{and} \quad 40 \le x_2 \le 70 \tag{4}$$

The setting of the variables within the field [-1, +1] is achieved as follows:

$$X_1 = f_1(x_1) = 0.1*(x_1 - 20) - 1 \tag{5}$$
$$X_2 = f_2(x_2) = 0.06666*(x_2 - 40) - 1 \tag{6}$$

Lets consider N_1=N_2=5, that is the evaluation of the input variables is performed through 5 linguistic values. The support of NB, NS, Z, PS and PB linguistic variables by means of which the set variable evaluation is done one can take them under the following form: [-1.0, -a]; [-b, 0.0]; [-c, +c]; [0.0, +b]; [+a, +1.0] for x_1 and x_2.

The affiliation function can be under different forms such as: triangular or trapezoidal, form based on the S and Π function or singleton form etc.

The evaluation of the affiliation probability to the S_0 … S_2 states is done through the linguistic values Z, Z+, S, M and B defined by the affiliation function of singleton type. For the calculation of the probability estimations $p_k, k = \overline{0, n-1}$, the facilities provided by "fuzzy" medium within the MATLAB have been used. For the considered example starting from the fundamental scheme in order to deduce the estimations $\tilde{p}_0$, $\tilde{p}_1$ and $\tilde{p}_2$, as shown in the figure 2, a SIMULINK scheme has been obtained, see figure 3.

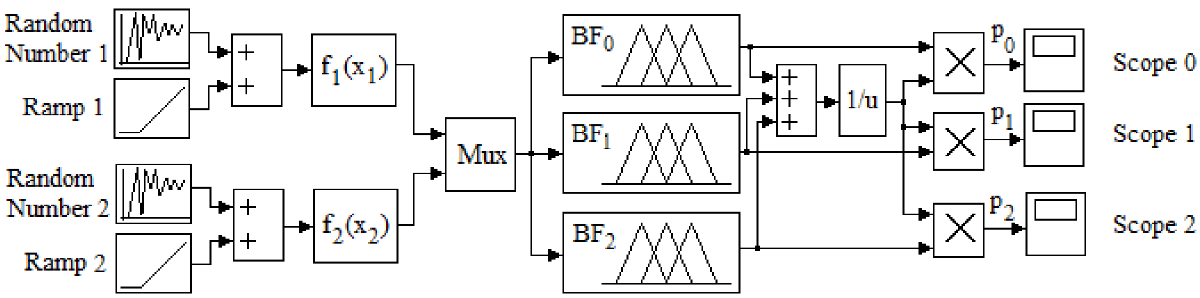

Figure 3. SIMULINK scheme of fuzzy classifier

For the input values, the variables of ramp type were taken into consideration with an overlapped noise. The fuzzy blocks contain 25 rules of type (3) each.

For the variables of the input values as per the relation (4) and free of noise introduced by means of the generation blocks of the random numbers, the equipment state probability is shown as in figure 4.

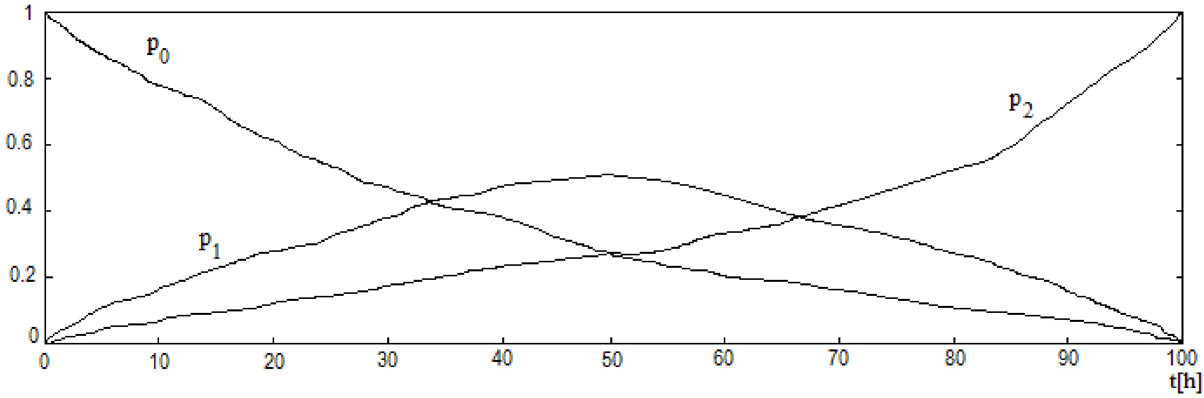

Figure 4. State evolution of probability without noise

5. Conclusion

As a result of the repeated simulations the proposed method for the diagnosis of the respective equipment state can be applied successfully. For the improvement of the answer issued by fuzzy classifier one can increase the number of linguistic values by which the input values are characterised having as result an increase of the numbers of rules of **IF…THEN** type, afferent to each fuzzy block.

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