APPLICATION OF MARKOV CHAIN FOR MONITORING THE BEARING ROLLER DEGRADATION

BOUZAOUIT A. [1*], BENNIS O. [2], BENOTMANE Z. [3]

[1] *"LRPCSI Laboratory", University: 20th, August 1955 of Skikda, Algeria*

[2] *PRISME Institute, Chartres, University of Orleans, France*

[3] *Finance Division ARCELOR MITTAL, Annaba, Algeria*

Abstract: The present study is an assessment to assign reference 2309CK bearings installed on a centrifugal fan from States expressing a (probability) level of degradation from "Good" to "Degraded". We seek to model the dynamics of change of state with a homogeneous Markov chain. In addition, it is possible to use the transition matrix associated to Markov chain to an operation analysis for the determination of the rotating machine reliability. The proposed model (transition matrix or graphic form) allows to know the turnover probability throughout life degradation.

Keywords: conditional maintenance, bearings, Markov chain, statistical analysis.

1. INTRODUCTION

In many situations, a bearing aging manifests itself by a cracking which affects one of the principal components such as the inner ring, the outer, cage or rolling elements (balls or rollers). In industry, vibration analysis is currently considered a very important technique for monitoring the State of rotating machinery [1]. In addition, any running machine induced vibrations.

These are direct translations of the dynamic forces generated by moving parts and thus occupy a privileged place among the quantities to be considered for a machine monitoring. Vibration analysis is made to detect possible malfunctions and follow their evolution to plan or suspend a mechanical intervention. It is also used to track the bearings' degradation. This allows, among other things, to assess the lifetime usage thanks to the evolution of vibratory level in time.

In this article, we are interested in the evaluation of the vibration level issued by piezoelectric accelerometers installed on bearings' housings and compare it to that authorized by international standards, which are called upon to speak on the operation quality of one or more bearings at regular time intervals (the vibration measurement frequency). It is known that the bearings' vibration evolution translates degradation [2,3], because of tiredness (fatigue) of material, poor lubrication, a bad mounting as well as pollution. Obviously there are exceptions to this rule as is the case of the adjustment period (increased vibration, and it will be amortized).

* Corresponding author, email bouzaouit21@yahoo.fr

The tendency curve, presented in Figure 1, is a graph representing the evolution of the overall value of vibrations emitted by dynamic's efforts affecting the bearing. Through the curve, there are two areas.

We noted above, the experience in the vibratory field of a part and the bearings, on the other hand, is the basis of this study; it is used for determining the limit date before the complete bearings' degradation. Statistical analysis usually proposed in this framework is based on survival models. However, their objective is relatively restricted in the sense that they aim at determining the duration necessary to the bearing to pass from a healthy (good) state to a degraded state from which the change of this bearing becomes imperative.

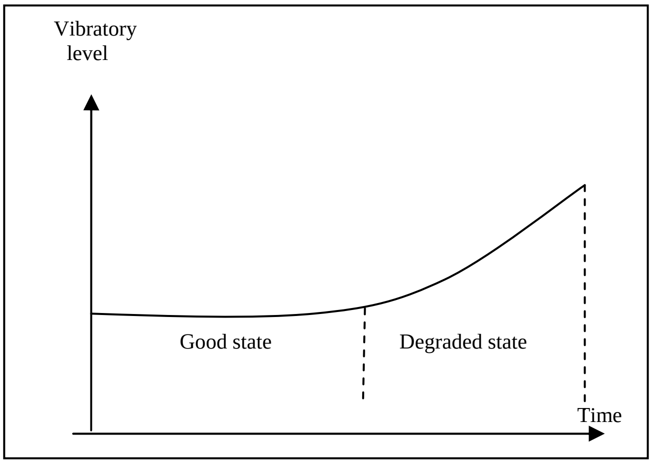

Fig. 1. The tendency curve.

The approach discussed here can also have a dynamic vision of the evolution of the real bearings state. An evaluation is given to statements expressing a bearing vibration levels ranging from "good or healthy" to "degraded", and we consider these terms as a state homogeneous Markov chain, and as we fit a first order Markov model.

2. METHODOLOGY

The evolution of the bearings' degradation is expressed by a transition from a "good" state to another "degraded" through an intermediate "means permissible or" state is neglected in this study. These states are given by an integer describing the number of states considered: 1, 2, ..., N (in our case N = 2). Further, we will consider that the vibratory measurements made in time reflect a bearing deterioration that requires a change.

In this perspective, we will obtain an increasing sequence consisting of statements along the lines of the degradation of the bearing in question (we do not take into account the maintenance actions performed during a change of state). For example, if a bearing is the unacceptable or degraded state at the time t, it cannot be in a good state at time (t +1), that is to say, each degradation is followed directly by a change.

Our study associates a mathematical model (transition Markov matrix [4]) to the results of a statistical study already done on the degradation of a bearing [5]. The bearing is installed on a centrifugal fan at the level of a steel complex. The observations are made for a running time of 28 months (t = 0,..., 27), classified into 13 age classes, each representing two months, that represents the frequency (periodicity) of vibration measurement. The data are represented by the Table 1.

2.1. The hypotheses considered

In this study, we assume the following assumptions:

- It is assumed that the bearing mounting operation is performed according to the manufacturer's instructions, so the maintenance operations are neglected, because the considered bearing is greased for life.

- Vibrations registered during the adjustment period are neglected.

Table 1. Statistics results.

Age class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Centre for age class (months)	3	5	7	9	11	13	15	17	19	21	23	25	27
Number of damaged bearings	0	14	12	10	9	8	7	6	5	4	4	2	2
Cumulative number of damaged bearings	0	14	26	36	45	53	60	66	71	75	79	81	83
Degradation probability	0.00	0.17	0.31	0.43	0.54	0.64	0.72	0.79	0.85	0.90	0.95	0.97	1.00
Survival probability	1.00	0.83	0.69	0.57	0.46	0.36	0.28	0.21	0.15	0.10	0.05	0.03	0.00
Degradation probability by age class	-	0.17	0.17	0.17	0.19	0.21	0.23	0.26	0.29	0.33	0.49	0.49	-
The average degradation probability at time (t) if the bearing is in good state at time (t-1) →													**0.28**

The function of degradation probability for each age class is given by the Figure 2:

Fig. 2. Degradation probability by age class.

2.2. The model presentation

We can then define the "transition probability" law of a state **i** into a state **j** by:

$$P_{ij} = P(X_n = j | X_{n-1} = i), \tag{1}$$

We propose to associate a Markov chain which reflects its degradation to each bearing (or each attribute), and it is possible to estimate the model parameters given by the graph which expresses the different states and their relationship. Here we have two states. So we draw two circles, each symbolizing events: A = good state, B = degraded state. We must now draw the relation between these events. We take each point independently. Starting from point (A), two situations may happen. That is to say, the bearing is good; in this case it is an arrow that returns to (A) because (A) is the state "good". If we judge considering the vibration level that it has become degraded, then it is an arrow in the direction of (B).

Starting from point (B), we can also have the two states "good" and "degraded", but from the hypotheses (1) which supposes that a bearing degraded at the moment (t) cannot be good at the moment (t+1), because the degradation requires the change of the bearing, the arrow goes to (B).

Each arrow represents the evolution about the state change probability of an age class to another according to the previous age. Since this probability, we can write next to each arrow the value of the corresponding probability, the graphical model is represented by (Figure 3).

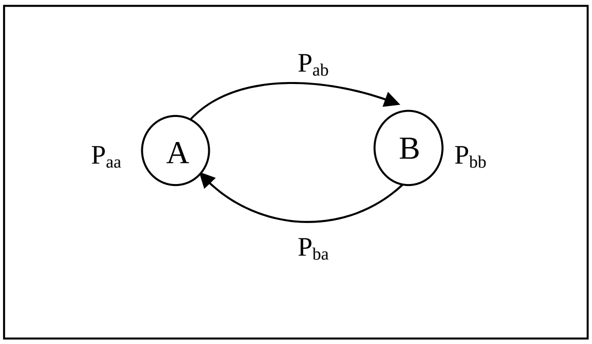

Fig. 3. Graphical model.

2.3. The transition matrix representation

Then, the transition matrix is represented in the following way:

$$M = \begin{bmatrix} P_{aa} & P_{ab} \\ P_{ba} & P_{bb} \end{bmatrix}, \quad (2)$$

We see that the bearings state change is a Markov process given by previous transition matrix.

It is known that a Markov transition matrix has specifications such as: the coefficients of the matrix (P_{aa}, P_{ab}, P_{ba} etP_{bb}) must be lower or equal to 1, and that the sum of the coefficients of the same row is equal 1.

In the end, to calculate the degradation probability of a bearing according with the proposed Markov model, it is sufficient to calculate the power of the transition matrix for each age class.

Generally, for age classes (n=1,2,3,...13) the corresponding probability shall be calculated as follows:

$$X^{(n)} = X^{(n-1)}.M \quad (3)$$

Either;

$$X^{(n)} = X^{(0)}.M^{n} \quad (4)$$

2.4. Verification of the model

According to the data shown in Table 1, the mean probability of bearing degradation for a given age class is 0.28; this probability is to be a bearing degraded at the time (t) knowing that he is in good condition at the time (t-1), it corresponds to P_{ab}, then P_{aa} must be equal (1- P_{ab}), so P_{aa} = 0. 72.

Thus it can write the matrix of transition in the following form:

$$M = \begin{bmatrix} 0.72 & 0.28 \\ 0 & 1 \end{bmatrix}$$

Take the assumption that a bearing is considered good in the first age class of the study.

$$X^{(0)} = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

At the end of the second age class, one can predict:

$$X^{(1)} = X^{(0)}.M = M_1 = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} 0.72 & 0.28 \\ 0 & 1 \end{bmatrix}^1 = \begin{bmatrix} 0.72 & 0.28 \end{bmatrix}$$

Thus, after an age class (two months), there are 72% of chances that the bearing is still in good state, and 28% that it is degraded.

$$X^{(2)} = X^{(1)}.M = M_2 = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} 0.72 & 0.28 \\ 0 & 1 \end{bmatrix}^2 = \begin{bmatrix} 0.518 & 0.482 \end{bmatrix}$$

After four months of service (two age class), there is 51.8% of chances that the bearing is good.

For the age class 3;

$$M_3 = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} 0.72 & 0.28 \\ 0 & 1 \end{bmatrix}^3 = \begin{bmatrix} 0.373 & 0.627 \end{bmatrix}$$

And so on, for last age class 13 one obtains:

$$M_{13} = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} 0.72 & 0.28 \\ 0 & 1 \end{bmatrix}^{13} = \begin{bmatrix} 0.014 & 0.986 \end{bmatrix}$$

According to the suggested model, the probability of having a bearing degraded according to the age class is given by the Figure 4:

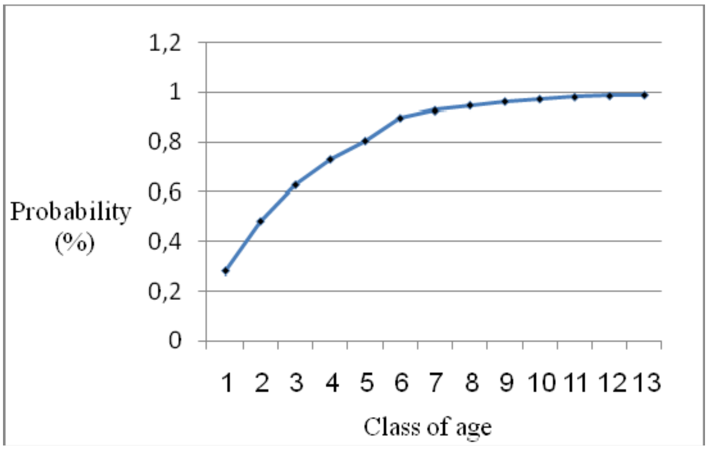

Fig. 4. Degradation probability by age class according to the model.

3. RESULTS AND DISCUSSION

The results show that our model provides a good estimate of the bearing degradation probability. Note that this probability plotted according to the model function (Figure 5) is look the same as that calculated using classical statistics methods (Figure 2), also based on the value of the correlation coefficient (r = 0.97), can confirm that the results calculated using a model are very close to reality.

As we have considered in this study bearing type (greased for life), track its status allows operation to change the necessary planning to end when improve the machine reliability. Our model provides the information you are looking to find out about the bearing actual condition.

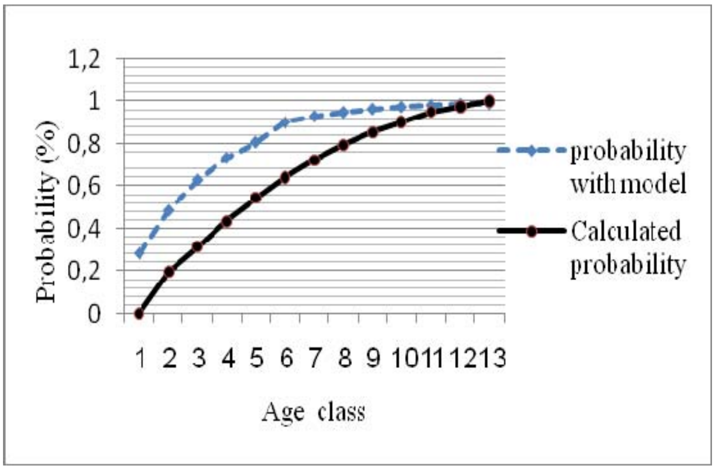

Fig. 5. Degradation probability by age class.

4. CONCLUSIONS

The present study shows that the Markov model proposed for monitoring the degradation evolution of bearing lubricated for life accurately describes the actual state and provides a good prediction of failure.

This model should also be able to assist in the planning of the predictive maintenance operation and avoid unplanned one.

The results presented provide information about the relative probabilities to actual states of the bearing studied. This opens the way for widespread study on other types of bearings with consideration of preventive operations' improvements in their functioning.

REFERENCES

[1] Boulenger, A., Pachaud C., Analyse vibratoire en maintenance. Surveillance et diagnostic des machines, 3e Edition, Dunod, Paris, 2007.
[2] SKF- Les roulements - technologie, calcul et dimension, 1980.
[3] SKF, Catalogue générale, 2002.
[4] Saporta, G., Probabilités, analyse des données statistiques., Technip, Paris, 1992.
[5] Bouzaouit, A., Chaïb, R., Hadjadj, E., Verzea, I., Statistical study on the bearing's degradation, RECENT Journal, 7(3), 2006.