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DIAGNOSIS OF BEARING FAULTS IN A CENTRIFUGAL COMPRESSOR USING STOCHASTIC PROCESSES: GAMMA AND LÉVY

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Abstract: *Predicting the failures of certain industrial systems has become essential for improving reliability. This prediction is based mainly on the analysis of the evolution of the level of degradation of the system. For systems whose state of deterioration is not directly observable, when the latter is subjected, during its use, to measurable degradation phenomena such as wear, vibration, temperature rise*

We propose an approach based on stochastic processes which represent a mathematical structure for modeling, mainly models of continuous degradation and more particularly the Gamma process and the Levy process.

In this article, we present the monitoring of sliding bearing degradation at the level of a compressor, the purpose of which is to evaluate the operating time, as well as the evolution over time of the change, the physical quantities present in this study are vibration and bearing temperature.

The measurements forming the sample of the temperatures and vibrations recorded on a sliding bearing are tested by using an Easy-fit 5.4 statistical software, the overall idea of which is to compare the distribution of the data collected (measurements carried out) , with respect to the theoretical distribution function. Followed by simulation of the evolution of the physical quantities studied have been proposed.

The simulation results of the evolution of the vibration confirm that the latter properly follows a Gamma process, while the temperature variation is described by a Levy process.

Key words: *Degradation, Stochastic process, Levy process, Gamma process, Simulation.*

1. INTRODUCTION

In current industrial fields, most processes, linked to production in view of their are increasing due to a growing need for dependability as well as through the integration of new technologies. To improve equipment maintenance by anticipating failures, Predictive maintenance of complex dynamic systems is therefore part of a relatively new field of research; it relies on monitoring supervision tools and failure prognosis.

Many materials or systems degrade over time before breaking down. To simulate these degradations, and to better understand the causes of breakdowns of these systems, or these materials, we need to develop models, enabling degradation data to be taken into account, and link them to possible failures. Models that describe the degradation of systems are of major interest because they make it possible to understand the dynamics of degradation. What's more, they play a central role when it comes to improving reliability, and the systems maintenance policy. For that, we choose the stochastic processes (or random).

Stochastic modeling of degradation processes, is a decisive element in the estimation of probabilistic models, in which this estimate will be based on extrapolated estimates of system degradation analysis, and evaluation, whose purpose is to act in a timely manner vibration analysis, the latter is the most used for monitoring the operation of rotating machinery, it makes it possible to detect the majority of the defects in such a system.

Stochastic models, and particularly models of continuous degradation, have been the subject of numerous studies, to define the law of degradation of the systems, this law is necessary to describe such a gamma process. The gamma process is a stochastic process for modeling an increasing degradation over time, this process has been used successfully in many applications

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with real data [1], [2], [3]. The gamma process is frequently used in the literature, since this process reflects the non-reversibility of degradation, which may be physically appropriate (monotonous deterioration).

In this process, the evolution of degradation over time as a function of the gamma law [4]. We will confine ourselves to the stationary gamma process, that is to say, when the evolution of the average degradation over time is linear. A Gamma process describes a trajectory of positive independent enhancement impairments, that can be stationary or non-stationary. This process has been successfully used in many applications with real data [1], [3]. Process X (t) is a stationary Gamma process (α, β) [5], [6], [7], [10], [11], [12] if:

- $X(0) = 0$
- $X(t)$ is a process with independent and positive increments.
- For all $t > 0$ and $\Delta t > 0$, the Law of increase $X(t + \Delta t) - X(t)$ is a gamma $Ga(\alpha \Delta t, \beta)$ Law of density:

$$f(x) = \frac{\beta^{-\alpha\Delta t}}{\Gamma(\alpha\Delta t)} x^{\alpha h\Delta t-1} e^{-x/\beta} \qquad (1)$$

With:

$\boldsymbol{f(x)}$**:** Density function, $\boldsymbol{\Delta t}$**:** time change

$\boldsymbol{\alpha}$: Shape parameter, **β:** scale parameter $\boldsymbol{x}$**:** the random variable that expresses the vibratory values, $\boldsymbol{h}$**:** the time step, $\Gamma(x)$ is the Euler Gamma function defined by:

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt \qquad (2)$$

A continuous time stochastic process associates a random at any time $t \geq 0$, it is therefore a random function of t.

The increases in such a process are the differences $Y_s - Y_t$ between its values at different times $t < s$ [8].

With:

$\boldsymbol{s}$**:** Any time

A process $Y(t)_{t\geq 0}$ is a stationary Levy process if it satisfies the following properties [6], [7], [9], [11], [12]:

- $Y(0) = 0$.
- $Y(t)$ is a stochastic process with independent increments with continuous trajectories
- $Y(t + s) - Y(s)^d = Y(t)$ that is to say Y(t + s) - Y(s) is independent of $(X(u): u \leq s)$ where u is the drift coefficient.
- $Y(t + s) - Y(s)^d = Y(t)$ is a law of Levy of $t \rightarrow$Y(t) is almost certainly continuous on the right and limited on the left.
- For all $t > 0$, the law of increase density:

$$f(x) = \sqrt{\frac{\sigma}{2\pi}} \frac{e^{-0.5\sigma/x-\gamma}}{(x-\gamma)^{3/2}} \qquad (3)$$

With:

$\boldsymbol{\gamma}$**:** Location parameter, **σ:** scale parameter, $\boldsymbol{x}$**:** the random variable that translates the temperature values.

2. METHODOLOGY OF WORK

The purpose of this paper is to describe the degradation process of a plain bearing (fig.1) installed on a compressor (fig.2) at the RAK1 oil refining complex in Algeria, this compressor takes the following characteristics:

Equipment type: barrel multi stage compressor

Vehicle fluid: gas process

Maximum operating pressure: 21, 8 kg / Cm^{2}G design pressure

Test pressure: 32.8 kg / Cm^2 G

Calculation temperature: 130 °C

Operating temperature: 112 °C maximum

Fig.1. the plain bearing studies

Fig.2. Compressor installation studied

Here is the diagram, which represents the installation of our machine with these bearings. Let us choose point 34, and take the vibratory and temperature values of this stage according to the history of the machine.

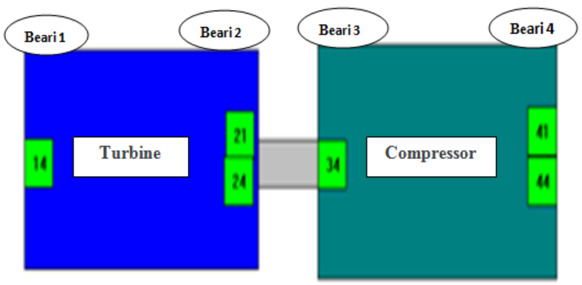

Fig.3. Machine diagram

Monitoring the operation of the compressor, allowed us to collect the data available presented in Tables 1 and 2.

Table 1

Vibration measurements

Numbers	Vibration; (g)	Numbers	Vibration; (g)
1	3.57	16	2.22
2	0.59	17	0.60
3	0.91	18	1.89
4	1.00	19	1.56
5	0.95	20	0.84
6	1.13	21	1.78
7	2.21	22	2.43
8	1.89	23	1.45
9	1.10	24	2.45
10	3.38	25	2.99
11	1.33	26	2.67
12	2.92	27	2.31
13	1.96	28	1.22
14	0.57	29	0.89
15	0.62	30	0.78

Table 2

Temperature measurements

Numbers	T (°C)	Numbers	T (°C)
1	58	11	73
2	65	12	52
3	52	13	62
4	55	14	53
5	66	15	66
6	60	16	52
7	52	17	70
8	60	18	57
9	65	19	59
10	53	20	68

Before beginning the simulation to describe the law of the variation of the parameters of behavior such as the vibration, and the temperature, a statistical analysis must be performed to verify the adequacy of the sample distribution in relation to a particular law.

3. DATA ANALYSIS

3.1 Statistical test of adjustment of the vibratory values collected

First link, vibratory measurements are tested by statistical software Easy-fit 5.4, in the overall idea of this test is to compare the distribution of collected data (measurements made) by providing a theoretical distribution function. From Figures (4) and (5) respectively the probability density function and the distribution function follow a Gamma law.

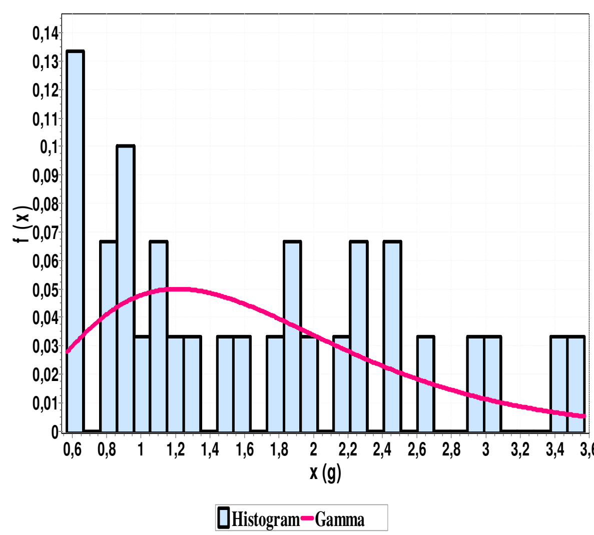

Fig.4. Probability density function the gamma law

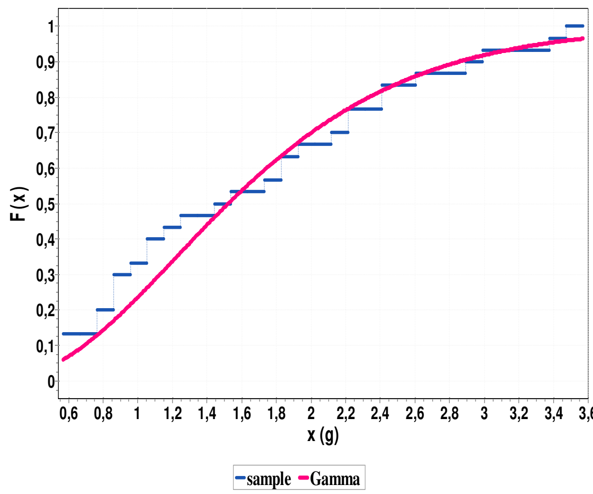

Fig.5. Distribution function the gamma law.

The realization of a statistical test, on the sample of vibratory measurements, at the level of the studied plain bearing shows that the values of the vibrations follow a gamma law, with a standard deviation β=0.46304and average α=3.6145. The Kolmogorov-Smirnov statistical test, performed for the adjustment of observed data, that are accepted by the decision rule regardless of the degree of risk α=[0.1; 0.2 ; 0.01; 0.02; 0.05].

3.2 Statistical test of adjustment of the sample of the temperatures

The same methodology is applied for the verification, of the adequacy of the temperature values measured at the bearing level. The figures (6) and (7) shows that the evolution of temperature following a Levy process.

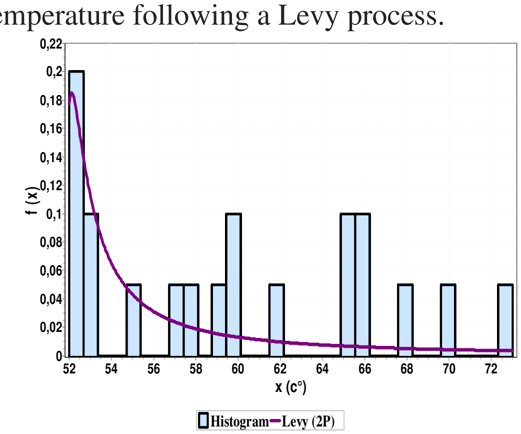

Fig.6. Probability density function of the Levy law (σ=1,6937et γ=51, 55) for bearing temperature

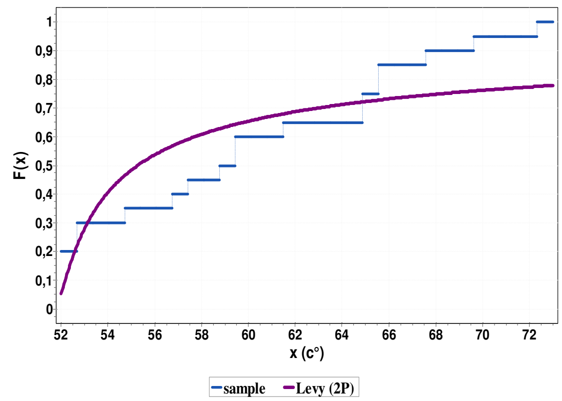

Fig.7. Distribution function of the Levy law (σ=1,6937et γ=51, 55) for bearing temperature

With regard to the Levy process, followed by the temperature values measured on the smooth bearing of the compressor, we confirmed the adequacy of the adjustment of the latter to a Levy law with two parameters whose values are as follows:σ=1,6937and γ=51,55.

4. SIMULATION OF THE EVOLUTION OF VIBRATORY VALUES

A MATLAB simulation of the gamma process is considered necessary, to allow us to describe increasing degradation trajectories, this can lead to a decrease in the degradation between two successive instants. The results of simulation, of the evolution of the vibrations according to the gamma process are represented by the figures (8) and (9).

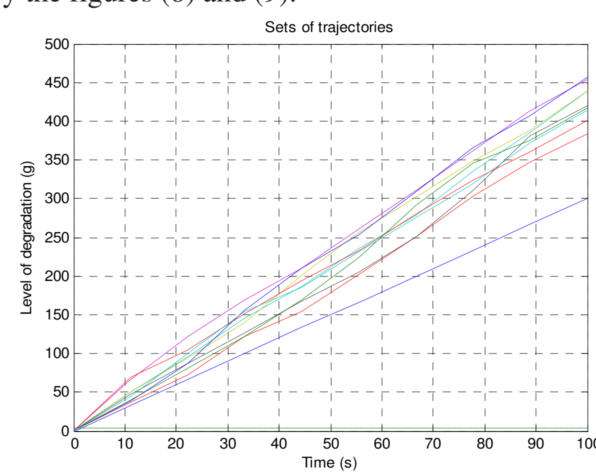

Fig.8. Plot of 10 trajectories according to the Gamma process of parameters (α = 3.6145 and β = 0.46304).

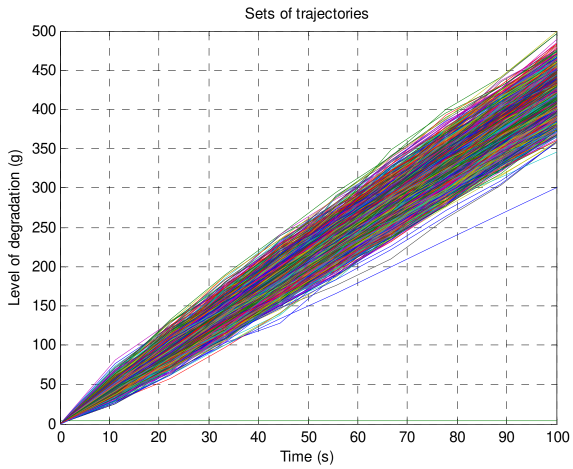

Fig.9. Plot of 1500 trajectories according to the Gamma process of parameters ($\alpha = 3.6145$ and $\beta = 0.46304$).

It is clear, from Figure (8) and Figure (9) that the level of degradation of the plateau reflects the evolution of the vibratory level, this evolution is proportional with time, which confirms that this degradation follows a gamma law. As a result, the simulation of 10 and even 1500 trajectories by the gamma process provides a good prediction.

5. SIMULATION OF TH TEMPERATURE VARIATION OF THE PLAIN BEARING

The simulation on MATLAB of the variation the temperature according to the Levy process (σ=1, 6937 and γ=51, 55) for a gamma law, allowed us to obtain the results presented by figures (10) and (11)

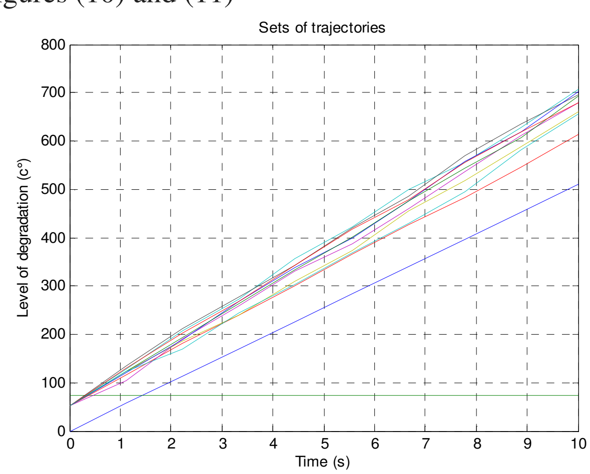

Fig.10. Plot of 10 trajectories according to the Levy process of parameters (σ=1,6937and γ=51, 55).

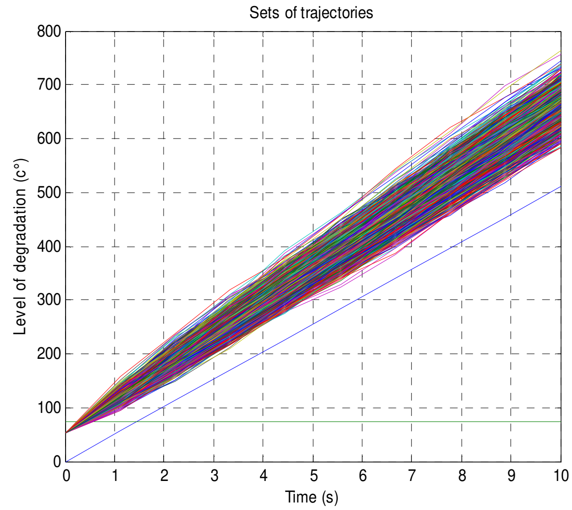

Fig.11. Plot of 1500 trajectories according to the Levy process of parameters (σ=1,6937and γ=51, 55).

From Figures (10) and (11), it is also confirmed that the simulation of the temperature variation of the smooth bearing of the compressor, for the drawing of 10 and even 1500 trajectories according to such a process Levy, provides a good prediction.

6. CONCLUSION

A stochastic process is a phenomenon of temporal evolution whose analysis, can be subjected to the calculation of probabilities. From the point of view of observation, a stochastic process is constituted by all of its achievements. Such an embodiment involves recording a sequence of events over time. The randomness of the evolution of a physical quantity, is shown by the fact that the repetition of the experiment leads to another temporal sequence.

By the present work, we have abordating the use of two stochastic degradation processes, to simulate the evolution of the vibration, as well as the temperature taken, at the level of the plain bearing, installed on a compressor at the level of the oil refining complex RAK1 in Algeria, and which are respectively the gamma process and that of Levy.

The presentation of a statistical analysis methodology using the Gamma and Levy process is given, for the purpose of checking the fit of the data collected against statistical laws such as, the law Gamma and Levy.

The adjustment of the samples of the monitored parameters enabled, us to successfully simulate the evolution of the vibration as well as the temperature. The simulation result, is important for the prediction of failures that can occur on the studied equipment.

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Diagnosticul defecțiilor portului într-un compresor centrifugal cu procese stochastice: gamma și lévy

Rezumat: Prezicerea eșecurilor anumitor sisteme industriale a devenit esențială pentru îmbunătățirea fiabilității. Această predicție se bazează în principal pe analiza evoluției nivelului de degradare a sistemului. Pentru sistemele a căror stare de deteriorare nu este direct observabilă, atunci când acesta din urmă este supus, în timpul utilizării sale, la fenomene de degradare măsurabile precum uzura, vibrațiile, creșterea temperaturii etc. etc. în principal modele de degradare continuă și mai ales procesul Gamma și procesul Levy. Propunem o abordare bazată pe procese stochastice care reprezintă o structură matematică pentru simulare. În acest articol, vă prezentăm monitorizarea degradării lagărelor glisante la nivelul unui compresor, al cărui scop este de a evalua timpul de funcționare, precum și evoluția în timp a schimbării, cantitățile fizice prezente în acest studiu sunt vibrațiile și temperatura rulmentului. Măsurătorile care formează eșantionul temperaturilor și vibrațiilor înregistrate pe un rulment glisant sunt testate cu ajutorul unui software statistic Easy-fit 5.4, a cărui idee generală este de a compara distribuția datelor colectate (măsurători efectuate), cu cu privire la funcția de distribuție teoretică. Au fost propuse urmăriți de simularea evoluției cantităților fizice studiate. Rezultatele simulării evoluției vibrațiilor confirmă faptul că aceasta din urmă urmează în mod corespunzător un proces Gamma, în timp ce variația temperaturii este descrisă printr-un proces Levy.

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