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PROGNOSTIC SYSTEM BASED ON THE MONTE CARLO METHOD FOR DETECTING VIBRATIONS

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Abstract

The objective of this work is to choose the Monte Carlo method to predict the future behavior of a vibration system to make estimate the remaining time before the failure. The positive results obtained with the Monte Carlo method. We have seen the effectiveness of this method and the need to adopt it in the prognosis system in the industrial system.

Keywords: Monte Carlo – prognosis – vibration - time remaining before failure - industrial system.

1. Introduction

Approaches of forecast guided by data try to extract from a review of data of surveillance of the models of evolution of the functioning of the going watched Justus system' in its deterioration. In trajectory monitoring, the error of prediction is also significant quantity, because it is in office of this error that the parameters of the chase model can be correct. It is the principle of predictive order in subscriber trunk dialing.

In the field of the signal treatment, the volume of data is important in general. This returns the difficult calculation of the solutions of normal equations of the valuators because of problem of stocking. On the other hand, signals often depend on time. It is interesting to be able to include this dependency in comparison with time into the process of estimate in order to define procedures working real-time or capable of performing the online data processing to give information on the state of health of the equipment, by giving the current indications of performances and to predict the future indications waited by functioning. Indeed, the systems of forecasts were widely adapted in several industrial applications. The objective of this job is to set up Monte method Carlo as an approach of a predictive system, for the development of the surveillance of the state of deterioration of the industrial systems. Indeed, in this job they are going to take into account in vibratory phenomena as indicators of faults, also will be used to give the predictions of fault. On the basis of symptoms noticed to develop the forecast system devoted to turbines with gas.

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2. The Monte Carlo method for prediction

In this part we will introduce the method of Monte Carlo as an approach in the impact of the predictive system in very many scientific and technological sectors. Power developed by computers allowed these methods to become operational and to stretch in different domains such as finance, mathematics, physics, molecular biology and genetics, telecommunications, networks, operational research and many others else. Generally [1], the use of this method recuperates all domains where the use of scientific methods collides with difficulties. In this context, two big domains are differentiated where method of Taken up Carlo can be successfully used for the process of predictive diagnosis.

In a general way, simulation allows to study and to test a given system complex correlations of which are known, to measure the effects of some changes in correlations on the behavior of the system, to test new situations [3].

When in simulation an unpredictable element intervenes, they speak about unpredictable simulation.

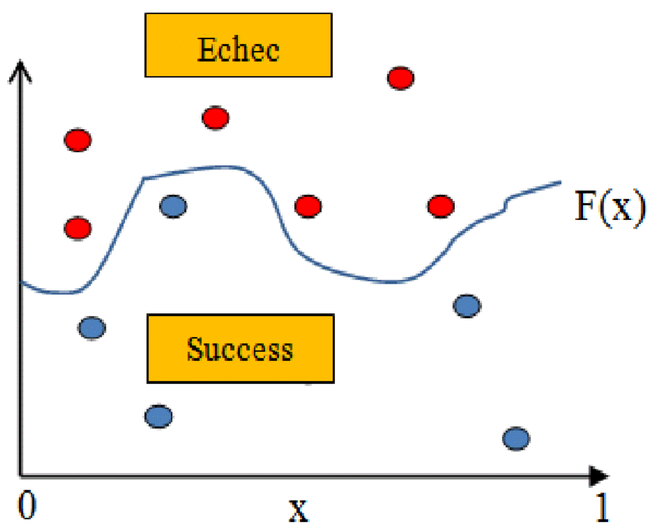

Fig 1. Random simulation by Monte Carlo

3. The Carlo Monte Prediction Approach

The Monte Carlo method consists of repeating a large number of predictions, taking different values for parameters subject to vagueness, and calculating the standard deviation of the solubility distribution obtained. However, the choice of the many values that one enters in the model is not innocuous, as it must be associated with the same law of probability as that followed by the input parameters.

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In order to clarify this last sentence, it must be understood that the distribution of each input parameter must follow the same law of probability as the experimental measurements. For example, if the law of probability around the mean value measured for the value of the melting temperature follows a normal law, the random drawing of the melting temperature for the Monte Carlo method will have to follow the same law.

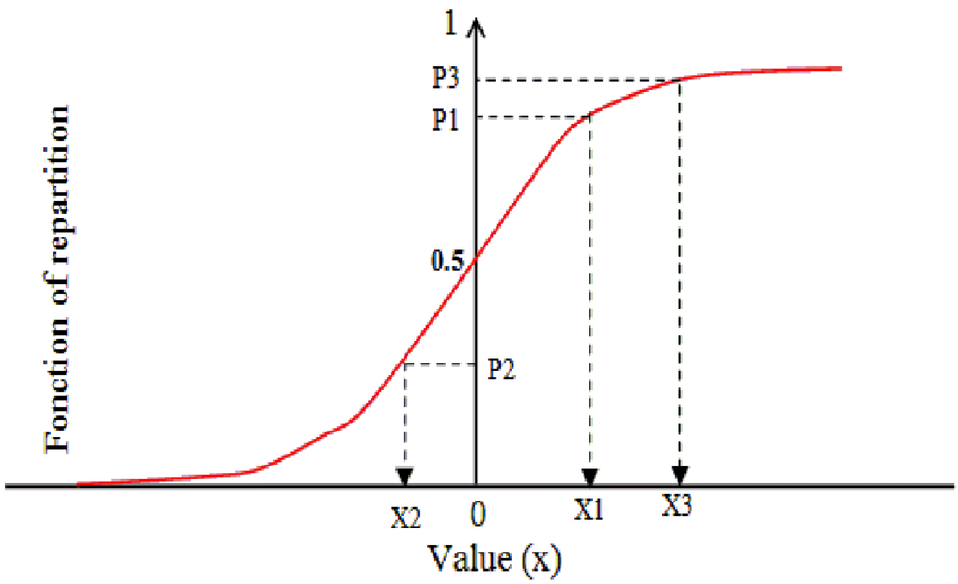

Fig 2. Normal law distribution function centered in 0 and standard deviation 1

In the case of this study, it is precisely considered that the measurement of each vibration property follows a normal law. This Law Is Witten as follows, noting μ the mean measured and σ the standard deviation around this mean:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{(x-\mu)}{\sigma}\right)^2\right] \quad (1)$$

To implement the Monte Carlo method, a large number of values between 0 and 1 are randomly drawn, which must follow an equiprobable law in order not to favor any of them. These values between 0 and 1 are then used to determine the random input parameters. To do this, a reverse normal distribution function is used. The normal distribution function corresponds to the probability of obtaining a value between -∞ and the random variable x (Figure.2). This function is written:

$$p(x) = \int_{-\infty}^{x} \frac{1}{\sigma\sqrt{2\pi}} \; exp\left[-\frac{1}{2} \left(\frac{(x-\mu)}{\sigma}\right)^2\right] dy \quad (2)$$

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4. Principle of the Monte Carlo method

One of the procedures for calculating a quantity by the Monte-Carlo method is to first put it in the form of a hope, at the end of this step; it remains to calculate this quantity by an expectation *E(X)* of the random variable *(X).* For this calculation, it is necessary to know how to simulate a random variable according to the law of *(X)*. A sequence $(X_i)_{1\leq i \leq N}$ of *N* realizations of the random variable *(X).* We estimate *E(X)* by:

$$E(X) \approx x = \frac{1}{N}(x_1 + \cdots + x_N) \tag{3}$$

The main objective of the Monte Carlo method is to allow a prediction of the future evolution of a phenomenon. Its development in the field of automation is based on this principle. Another interest, perhaps more critical to scientific research, is to understand the theoretical significance of these different processes. It is clear, however, that this interpretation depends on the nature of the phenomenon studied.

The evaluation of failures in distribution systems is mainly concerned with predictive assessment of failures. Past performance is measured through analysis of the collected failure data. Historical data are required for predictive assessment to provide inputs to the evaluation model. The purpose of the predictive assessment is to forecast the system load point and reliability indices presented in Figure.03.

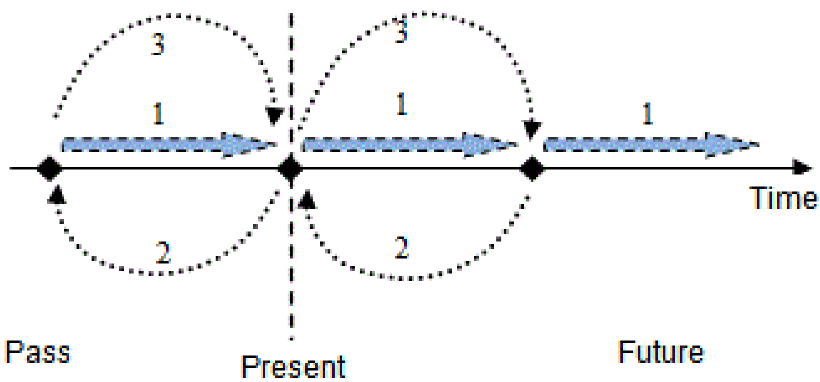

Fig 3. Process for continuously improving methods of evaluating the system against time

The steps are:

- Predict future performance;
- When the prediction time interval has passed, analyze performance observations and compare with predictions that have been made;
- Improve the model used for predictions using obtained preview based on past performance, repeat the process.

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Prediction process practice has four phases (Figure 4):

- Detection of the defect developing in the data acquisition phase.
- Establishing the second phase by the Monte Carlo estimate.
- Test of the validity of the estimated model.
- Prediction phase of remaining life and decision making.

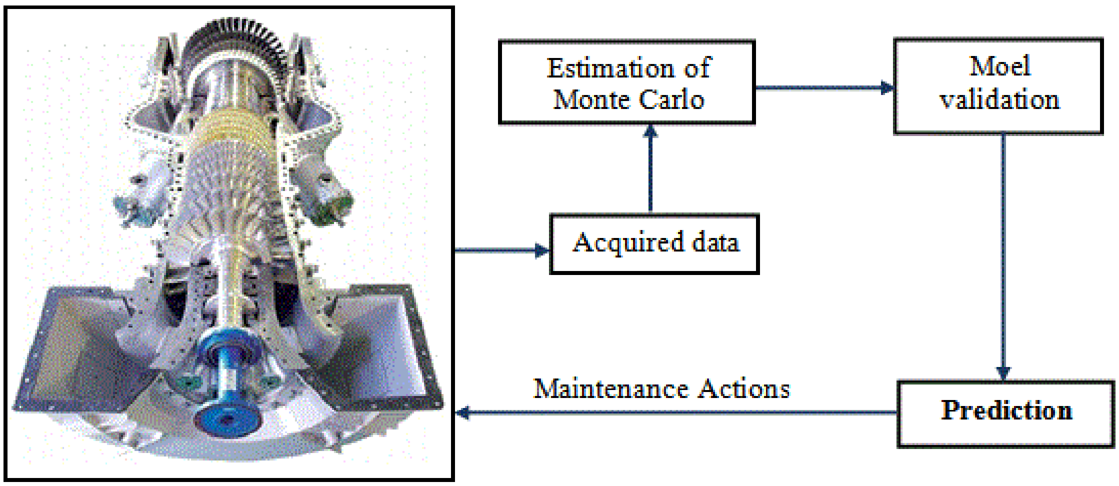

Fig 4. The stage of prediction by Monte Carlo

The method of Monte Carlo in mathematical statistics is a mathematical algorithm which consists in repeating experience with unpredictable primitive stocks this method is generally used in the mathematical systems of simulation and of engineering. This method includes five stages:

1. Determine the possible range of stocks of income;

2. Generate unpredictable stocks for stocks of income in the defined borders;

3. Apply calculations requested in these stocks;

4. Accumulation of current results with the previous results;

5. Repeat process some times (the accuracy of results augments with the number of repetitions)

5. Calculation of integral by the method of Monte Carlo

5.1 Calculation of the integral by hope

The calculation of integral $I=\int_{\Omega} f(x)dx$ by the method of Monte Carlo the integral following came down to solve:

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$$\mathrm{I} = \int_{[0.1]^{\mathrm{d}}} f(X)\mathrm{d} \quad (4)$$

In that case, the method of Monte Carlo consists in writing integral this in form of hope of (f) which is the general implementation of the average of *(f)* on [0, 1]^d, and with u an unpredictable variable according to uniform law on [0, 1]^d:

$$I = E(f(U)) \quad (5)$$

The integral as follows is approximate:

$$I \approx I_N = \frac{1}{N}\sum_{i=1}^{N} f((x_i)) \quad (6)$$

The point's x_i are chosent in the interval Ω, so when the number of points *N* increases the approximation will be more precise and we have:

$$I = \int_\Omega f(x)dx = \lim_{N\to\infty} I_N = \lim_{N\to\infty} \frac{1}{N}\sum_{i=1}^{N} f(x_i) \quad (7)$$

To see techniques a little more clear, we approach the calculation of the integral on interval [a, b] of ℝ, that is calculate the integral = ∫*f (x).* Are x_1, x_2... x_N unpredictable points in interval [a, b], after the calculation of $f(x_1)$, $f(x_2)$,..., $f(x_N)$,, it is possible to write following general formulation:

$$I = \int_a^b f(x)dx \approx \frac{b-a}{N}\sum_{i=1}^{N} f(x_i) \quad (8)$$

These results are results of two other important results; it is about the law strong in big numbers and the theorem of central border.

5.2 Theorem of law strong in big numbers

Or (X_i, i≥ 1), a continuation of achievements of unpredictable variable.X. Theys assume that

E ($|X|$) < +∞. Then, for almost everything ω (i.e. $\exists\ N \in \Omega$ with p (N) = 0 and ω∈ N))

$$E(x) = \lim_{N\to\infty} \frac{1}{N}(X_i(\omega) + \cdots + X_n(\omega)) \quad (9)$$

5.3 Theorem of central border

Or (X_i , i ≥ 1) a continuation of independent unpredictable variables and of the same law as (X), such as E ($|X^2|$) < +∞

On notices σ^2 the variance of X:

$$\delta^2 = E((X - EX)^2) = E(X^2) - (\,EX^2) \qquad (10)$$

Converge in law on a reduced centered gaussienne. That is to say:

$$\forall\, a < b \;\;, \lim_{N\to\infty} P(\frac{\delta}{\sqrt{n}}\, a \;\le\; \epsilon_n \le \frac{\delta}{\sqrt{n}} b) = \int_a^b e^{\frac{-x^2}{2}}\, \frac{1}{\sqrt{2\pi}} dx \qquad (11)$$

This method does not depend on the regularity of *(f)* which must be just measurable.

Often they try to calculate one integral more general:

$$I \approx \int_{R^d} g(x)dx = \int g(x_1, \dots, x_d)\, f(x_1, \dots, x_d) dx_1, \dots dx_d \qquad (12)$$

By considering *(f)* positive and $\int_{R^d} f(x)dx = 1$, , they will get then:

$$I = E\,(g(x)) \qquad (13)$$

Where (X) is an unpredictable variable with value in R^d of law (f). So it is possible to approach the integral *(I)* by following expression:

$$I \approx I_N \;= \frac{1}{N}\sum_{i=1}^{N} g(X_i\,) \qquad (14)$$

It is the law strong in big numbers that allows justifying the convergence of method, and the theorem of the central border which specifies the speed of convergence. To have an idea of the interest of method, it is necessary to be able to assess the made error defined by

$$|\;\varepsilon_N| \;\; = |\; E(g(X)) - \frac{1}{N}\sum_{i=1}^{N} g(X_i\,) \qquad (15)$$

The theorem of the central border gives an asymptotique of errorε_N, but of unpredictable nature. In that case, the law of error ends up resembling a law centered gaussienne. In applications, they replace ε_N with a gaussienne centered by variance $\frac{\delta^2}{N}$.

They often introduce the error of the method of Monte Carlo; they are by giving gap-type of error ε, which is by giving an interval of confidence to 95 % for result. The interval of confidence of method in 95 % is:

$$[I_1, I_2] \;= [I_N - 1.96\frac{\delta}{\sqrt{n}}\,, I_N + 1.96\frac{\delta}{\sqrt{n}}] \qquad (16)$$

In general the calculation of value of σ is approximate by the method of Monte Carlo:

$$\frac{1}{N}\sum_{i=1}^{N}[g(X_i\,)^2] - [\,\frac{1}{N}\sum_{i=1}^{N} g(X_i\,]^2 \to \delta^2 \qquad (17)$$

Accessible method, of more this speed does not change if they are in big dimension, and it does not depend on the regularity of function.

5.2 Calculation of integral by the method of rejection

The estimate of one integral can also be made by using the methods of simulation of uniform law in some parts$\mathbb{R}^2$. To simplify notations, 0 will be assumed here only g(X)≥ 0. It is known that the integral of a function is the aerie under the curve of this one. Estimate the integral:

$$I = \int_R g(X) \geq f(x)dx \tag{18}$$

Cost therefore to estimate the aerie of the part:

D = { (x, u) ∈$\mathbb{R}^2$, 0 ≤ u ≤g(X)f(x)} de $\mathbb{R}^2$:

$$I = \int_{\mathbb{R}} g(X)f(x)\, dx = \lambda\,(D) \tag{19}$$

To estimate this aerie, It is possible to go about things in the following way. Choose a domain *D′* containing *D*, pull *(N)* dawned uniformly in *D′* and calculate the proportion *fn* of them which falls in *D*: this quantity estimates *I / λ (D′).* Finally, they estimate (I) therefore by *λ (D)*.fn.

6. Calculation of aerie of prediction (Approximation of RUL)

The Method of Monte Carlo allows the resolution of some determinist numerical problems. The problems of a way approached with a simulation are resolved. In this paragraph we introduce shortly the approximation of the number π by the estimate of the surface of a quarter of circular disc of ray 1. In that case, they pull by chance from co-ordinates (a) and (t), each in the range [0.1 [.

If $a^2 + t^2 <1$ then the point P of coordinates (a, t) belongs to the quarter disc D of center (0,0) and radius 1. The probability that P belongs to D is π/4. (Ratio of area of D and the square enclosing it). So, if we draw at random n points, and if P of them belongs to D, we expect to have: $p/n \approx \pi/4$. We thus derive an approximation of π equal to 4p/n. this approximation makes it possible to draw at random a point cloud circle.

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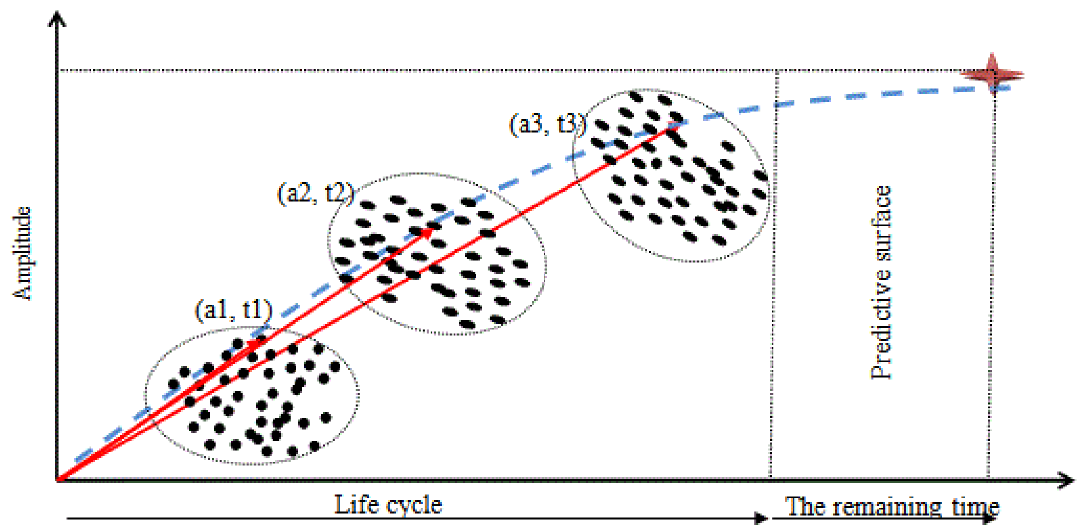

Fig 5. Approximation of the remaining time by the Monte Carlo prediction

7. Experiments and interpretations

This part is devoted to the application of the Monte Carlo method as an approach to determine the deterioration threshold of the gas turbine due to the vibratory phenomenon. Using the actual data that was recorded for three times in a step of (01) a day. We have collected the data within three months. Using this data as a number available for simulation.

Table 1. Technical characteristics of the gas turbine study

builder: General Electric	Turbine Power at 80: 9400 hp
Type : MS 3002	Débit de consommation combustible (100% HP à 27 °C): 3.84m^3/h
Serial number: 244370	Max exhaust temperature: 516.6 ° C
HP speed and axial compressor: 7100rpm	Exhaust pressure: 1.0093 bar
Nbr axial compressor stage: 15	Starter system: Turbo stator
Nbr floor HP wheel: 01	Direction of rotation: anti-clockwise
BP speed: 6500 rpm	Number of shaft: (02) two shaft
Nbr Wheel BP: 01	

Here we obtain a method that would use all available data. So, we can assume here, using Monte Carlo simulation. In addition, we compared the three readings and the model obtained by the simulation.

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Three periodicity of measurement were designated to determine the predictive margins from the simulation were established. We have the global vibration signal (figure.06)

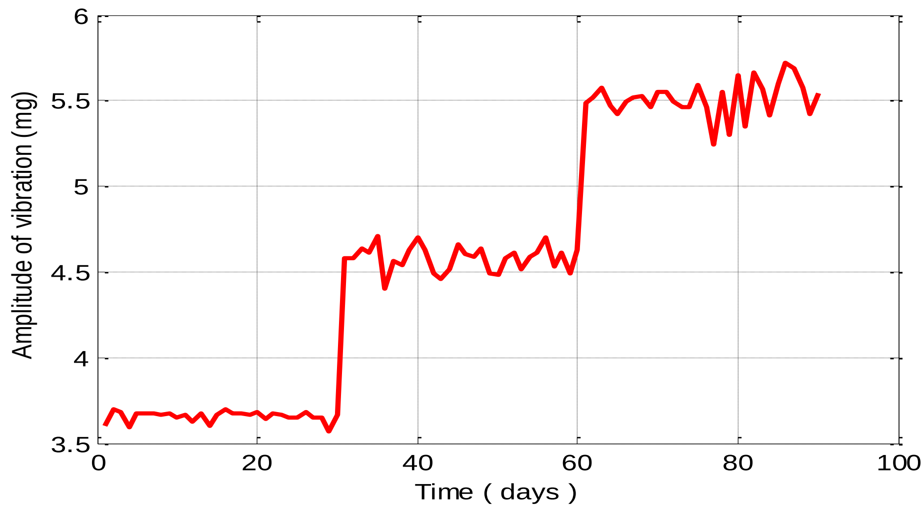

Fig 6. General cycle of the vibration signature

In figure 7, it is noted that the point clouds contain the actual vibration signal in three margins (three vibration cycles), which means that there is an envelope to predict the best access to predict.

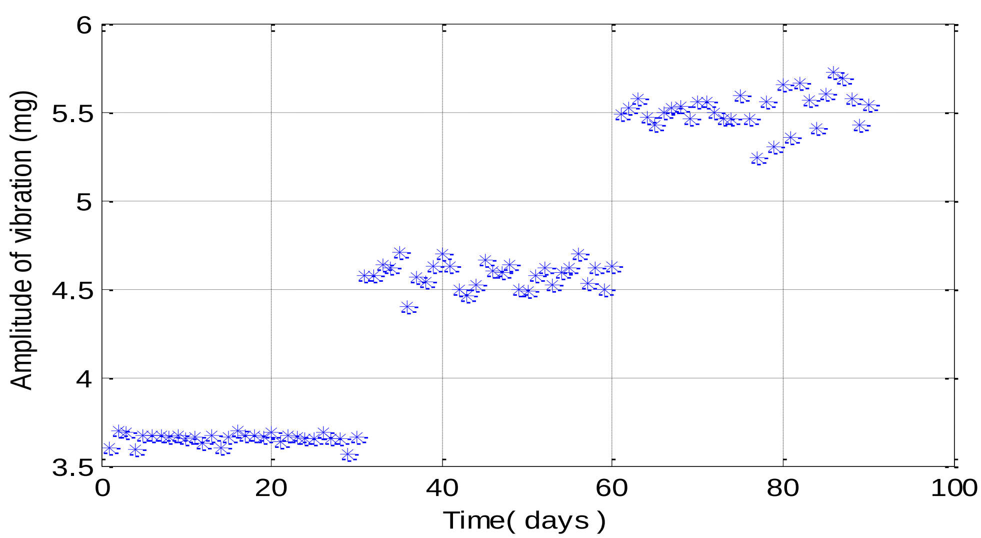

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Fig 7. The point clouds of vibration

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Then the global signal partition as follows:

- Period of undergraduate vibration during first cycle of 30 days (month of February)

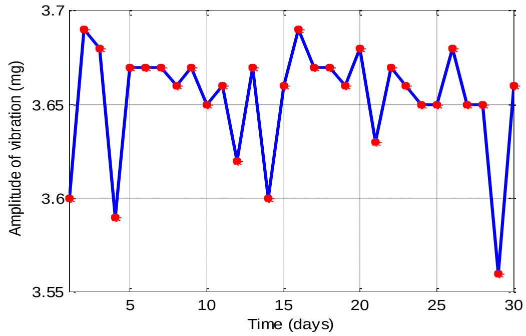

Fig 8. First vibration cycle

- Periodicity of the second vibration cycle during the second 30-day margin (March month), where the vibration threshold reaches 4.7mg.

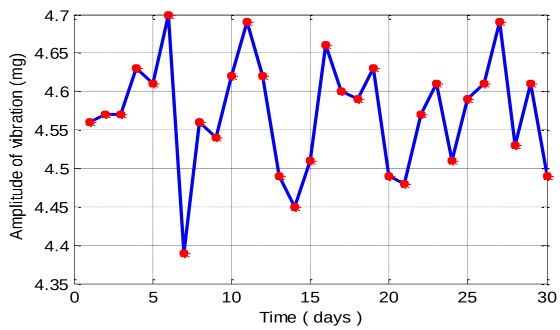

Fig 9. Second cycle of vibration

- Periodicity of the third vibration cycle during the third 30-day margin (April month), where the vibration threshold reaches 5.73 mg.

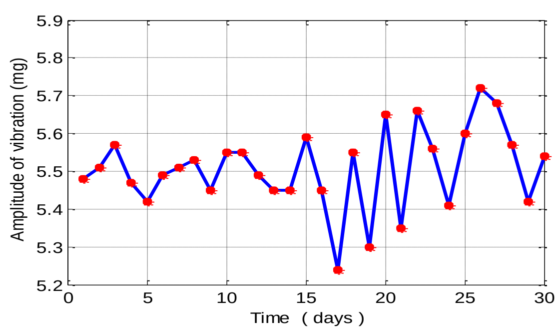

Fig 10. Third vibration cycle

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From the three periodicities one will make the prediction by the Monte Carlo simulation the three clouds of the points.

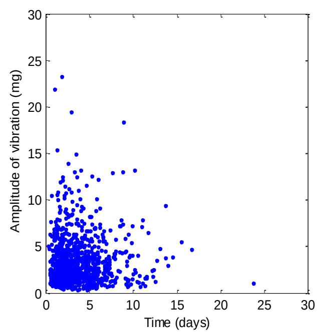

Fig 11. Result of the probabilistic approach of the first point cloud.

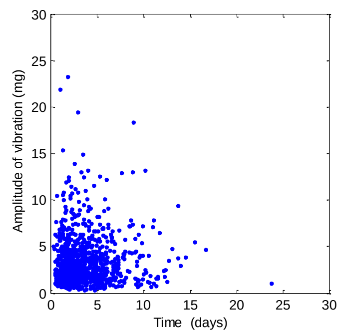

Fig 12. Result of the probabilistic approach of the second cloud of points.

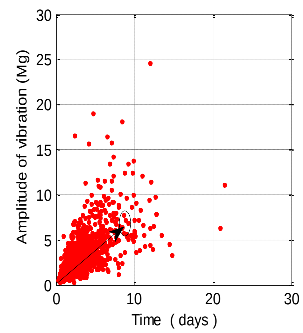

Fig 13. Result of the probabilistic approach of the cloud of points.

The reference trajectories, which are the average trajectory and the maximum permissible degradation, are generated as well as the random trajectories that follow the selected degradation process. To plot these random trajectories, we start from the initial degradation, which may be admissible, in t=90 days, then we simulate the successive points by the Monte Carlo simulation, as described in the section above. Figure.14 shows the random degradation trajectories according to the chosen process.

This figure illustrates a Monte Carlo draw is made for each point of vibration threshold increase and a trajectory game is created. A simulation from the deterministic model is then made a 2100 path band. The results of this probabilistic approach are shown in the figure below.

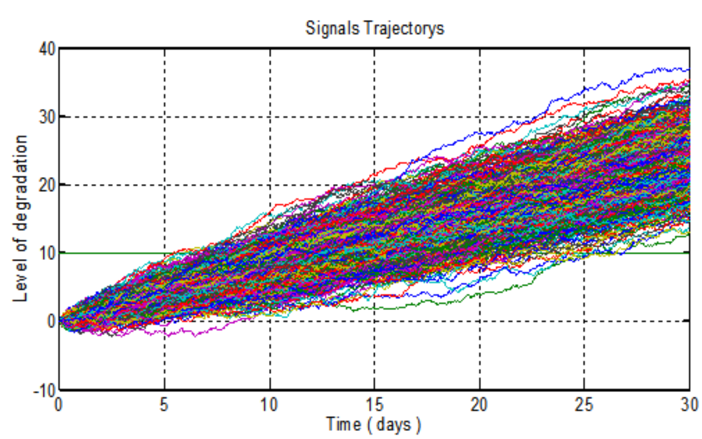

Fig 14. Result of course 2100 trajectory according to the probabilistic approach Simulation Monte Carlo

Figure 14 illustrates the fourth vibration cycle, the predicted signal that is extracted from a Monte Carlo draw was made for each vibration threshold increase

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point and a trajectory set is created. The results of this probabilistic approach are presented in Figure.15.

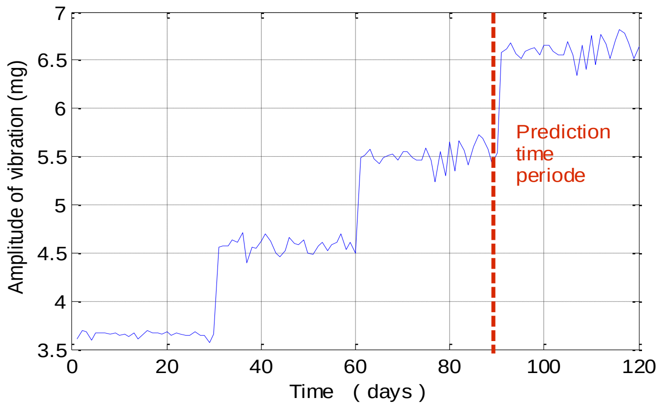

Fig 15. Trend Curve with Prediction Phase

Figure 16 shows a clear upward trend, this trend increase suggests the presence of a vibratory signature of the turbine. The prediction of the residual life from the moment t=90 days up to the instant t=112 days where the amplitude point will reach the incident point $\text{Amplitude} = 6{,}76\ mg$. In this case we find that the $remaining\ life = 22 days$, which means that it is sufficient to perform all maintenance work. Here we can say that our Monte Carlo prediction system has been successful to a certain extent.

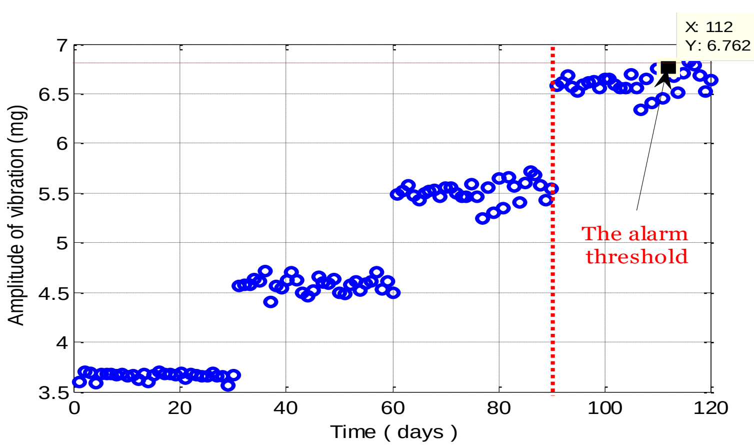

Fig 16. Predicting Future Values of a Periodic Signal

Figure 17 shows a comparative extract of the three vibration cycles and the predicted vibration cycle (fourth cycle). We notice that the error resulting from the first comparison between vibration 1 and vibration 2 (in green) is very close to the error resulting from the second comparison between vibration 2 and vibration 3 (in red) and the error resulting from third comparison between vibration 3 and vibration 4 (in blue).

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In order to compare the error function, note that there is an intermediate obtained by the error function which makes us say that the Monte Carlo method validates the approximation between the four vibration cycles.

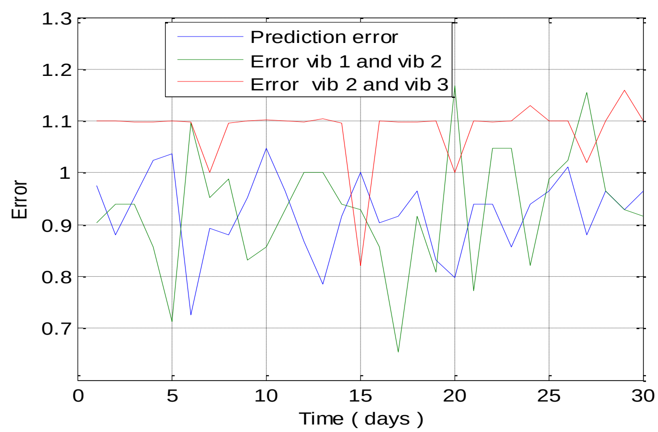

Fig 17. Global errors between the fourth margins

Figure 18, which shows some correlation between actual and predicted values, shows us the method used, which means that the prediction method has a very important distinguishing role.

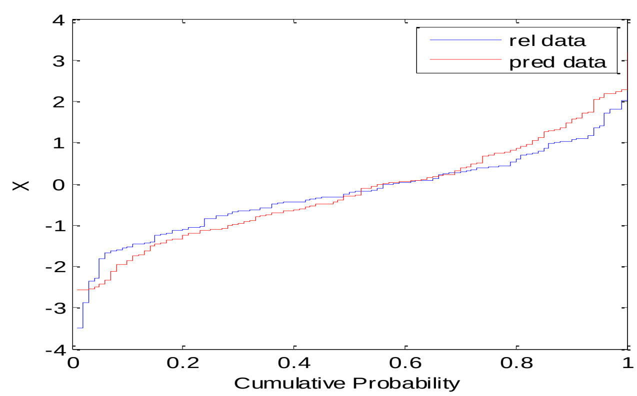

Figure 18. Curve of comparison between the predicted values and the real values

Table 02 shows the various measurements taken during the three periodicities and our predicted measurements during the fourth margin; we note the critical amplitudes to compare it with the amplitudes of prediction. The Monte Carlo method generally shows better performance, because the quality of the forecasts is still globally satisfactory, with the amplitudes predicted.

Table 2. The various measurements taken during the three periodicities and our predicted measurements during the fourth margin

N° of day	Vib 1(Jan)	Vib2(Feb)	Vib3(March)	Vib Pred (Apr)
1	3.6020	4.5663	5.4826	6.5826
2	3.6979	4.5783	5.5185	6.6185
3	3.6859	4.5783	5.5783	6.6783
4	3.5902	4.6381	5.4707	6.5707
5	3.6739	4.6142	5.4229	6.5229
6	3.6739	4.7098	5.4946	6.5946
7	3.6739	4.3989	5.5185	6.6185
8	3.6620	4.5663	5.5305	6.6305
9	3.6739	4.5424	5.4587	6.5587
10	3.6500	4.6261	5.5544	6.6544
11	3.6620	4.6979	5.5544	6.6544
12	3.6261	4.6261	5.4946	6.5946
13	3.6739	4.4946	5.4587	6.5587
14	3.6022	4.4587	5.4587	6.5587
15	3.6620	4.5185	5.5902	6.6902
16	3.6979	4.6620	5.4587	6.5587
17	3.6739	4.6022	5.2435	6.3435
18	3.6739	4.5902	5.5544	6.6544
19	3.6620	4.6381	5.3033	6.4033
20	3.6859	4.4946	5.6500	6.7500
21	3.6381	4.4826	5.3511	6.4511
22	3.6739	4.5783	5.6620	6.7620
23	3.6620	4.6142	5.5663	6.6663
24	3.6500	4.5185	5.4109	6.5109
25	3.6500	4.5902	5.6022	6.7022
26	3.6859	4.6142	5.7218	6.8218
27	3.6500	4.6979	5.6859	6.7859
28	3.6500	4.5305	5.5783	6.6783
29	3.5663	4.6142	5.4229	6.5229
30	3.6620	4.4946	5.5424	6.6424

8. Conclusion

In this study, we used data from a GE 3002 Gas Turbine and No. 4 Vibration Variable to test short-time pre-failure (RUL) prediction models. The exploration of these data revealed us the first week of the months (January, February and March) of the SC4 compression station located (Enadhor –Tiaret).

We proposed the Monte Carlo method as an approach for predicting future periodicity that illustrates the prediction phase. We therefore conclude that the dynamic vibration variable is particularly interesting for prediction of bearing deterioration of the turbine. We will present in this work the detection of change in vibration behavior. The predictions are in line with the observed values, which show that the Monte Carlo method offers a satisfactory prediction capacity. He also makes a good catch of the trend.

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References

Journals

Boulanouar Saadat, Abdellah Kouzou, Mouloud Guemana and Ahmed Hafaifa, Availability phase estimation in gas turbine based on prognostic system modeling. DIAGNOSTYKA the Journal of Polish Society of Technical Diagnostics (PSTD), 2017, vol. 18, no.02, pp. 3-11.

Boulanouar Saadat, Ahmed Hafaifa and Mouloud Guemana, Vibration analysis and measurement based on defect signal evaluation: Gas turbine investigation. Journal of Advanced Research in Science and Technology, 2016, vol. 3, no 1, pp.271-280.

Boulanouar Saadat, Ahmed Hafaifa, Ali Bennani, Nadji Hadroug, Abdellah Kouzou,Mohamed Haddar, Remaining Useful Lifetime Prediction of Gas Turbine Bearings Based on Experiment Vibration Signals Data. Journal of Vibration Testing and System Dynamics. Journal homepage.

D. DROUIN, P. Covington, R. Gauvin, "CASINO: A New Monte Carlo Code In C Language For Electron Beam Interaction - Part II: Tabulated Values Of The Mott Cross Section", Scanning, Vol.19, (1997) 20-28

D. DROUIN, A. Couture R., D. Joly, X. Tastet, V. Like, "CASINO V2.42- A Fast and Easy to Use Modeling Tool for Scanning Electron Microscopy and Microanalysis Users," Scanning, Vol. 29, (2007) 92-101.

Books

Celine BARANGER and Julien MATHIAUD, Monte-Carlo Method, 2012/2013.

LAURE ELIE BERNARD LAPEYRE, Introduction to Monte Carlo Methods, September 2001.

Emmanuel Grenier, What is the "good" standard deviation formula? Reims Management School.

Bernard. YCART, Monte Carlo Methods, UFR Mathematics and Computer Science René Descartes University, Paris.

Eric GILLON, Approximation of Pi by the Monte Carlo Method, 2008-2009.

Boulanouar Saadat, Ahmed Hafaifa, Abdallah Kouzou and Mouloud Guemana, Elaboration of prognostic system based on time series for decision-making in gas turbine monitoring. Third International Conference on Electrical Engineering and Control Applications. ICEECA'17. November, 21-23, 2017, Constantine, Alegria.

Dissertation

Boulanouar SAADAT, Development of a prognostic system for modeling the vibrations of a gas turbine by reducing maintenance costs, doctoral thesis, 2017 université Djelfa – Algeria.