Article citation info:
HALIMI D, HAFAIFA A, BOUALI E. Maintenance actions planning in industrial centrifugal compressor based on failure analysis. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2014; 16 (1): 17–21.

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MAINTENANCE ACTIONS PLANNING IN INDUSTRIAL CENTRIFUGAL COMPRESSOR BASED ON FAILURE ANALYSIS

PLANOWANIE CZYNNOŚCI KONSERWACYJNYCH DLA PRZEMYSŁOWEJ SPRĘŻARKI ODŚRODKOWEJ W OPARCIU O ANALIZĘ USZKODZEŃ

The industrial maintenance implementation requires to the behaviour system analysis and their components. In this work, we optimize the maintenance actions to eliminate failures in the inspected industrial process. Our purpose in this work is to improve the components reliability in gas compression system, by the planning of the maintenance actions based on failure analysis using the intervention optimization in industrial centrifugal compressor plant. The finality of this proposed approach is proved by the improvement of the reliability performances and by the availability of this oil installation.

***Keywords**: Maintenance planning, reliability, availability, gas compression system, centrifugal compressor, optimization, failure analysis.*

Obsługa urządzeń przemysłowych wymaga analizy zachowań układów i ich części składowych. W niniejszej pracy zoptymalizowano czynności konserwacyjne tak, aby wyeliminować występowanie uszkodzeń w kontrolowanym procesie przemysłowym. Celem prezentowanej pracy było poprawienie niezawodności elementów układu sprężania gazu poprzez zaplanowanie czynności konserwacyjnych w oparciu o analizę uszkodzeń z wykorzystaniem optymalizacji interwencji w przemysłowej sprężarce odśrodkowej. O skuteczności proponowanego podejścia świadczy poprawa parametrów niezawodności oraz gotowość omawianej instalacji olejowej.

***Słowa kluczowe**: Planowanie obsługi, niezawodność, gotowość, układ sprężania gazu, sprężarka odśrodkowa, optymalizacja, analiza uszkodzeń.*

1. Introduction

Today the availability control in industrial systems, allow the industry to act on the production conformity, its costs of operations, competitiveness and commercial success. For correct exploitation, it is now not only offering a better plant supervision but also to achieve the optimum production with an implementation of fault diagnosis [5, 7, 9, 13, 16 and 21]. Indeed, the technological developments and the implementation of measurement tools of various parameters defining the material state; systematic preventive maintenance remains especially for components, whose failure can cause major problems in reliability terms, maintainability, availability and security [1, 3, 6 and 18]. In the oil and gas industry in the compression stations the turbo compressor provide the main function of the station, which requires these materials and especially during the period of large requests of gas, improved availability can be achieved by the organization of the maintenance actions schedule has made from the real data of site.

In this paper, we propose the use of the optimization techniques based on the number of intervention given by the failure rate, to improve the maintenance actions planning of a gas compression system. This gas pipeline installation, present in their operation a risk to passed in degraded mode and undergoes accidental defects.

In several applications, there are more than a few techniques that can be used for increase maintenance actions [14, 15, 19, 23, 24, 25 and 28]. By the basis of this work, we can confirm that the conditional maintenance optimizes the maintenance and especially to perform at the right time with the right cost. That after the proposed linearization of the failure rates with an objective function, we evaluates the cost summary of maintenance according to the numbers of interventions of the different components responsible for the unavailability of our compression system.

2. Maintenance cost based on failure rate analysis

Today, the race for profitability no longer possible to ignore the search for more efficient operation of its equipment [2, 4]. This is why we must constantly seek the best ways to combine technologies and applications to perfect the tools to make good decisions consistently in terms of maintenance and operations rate optimization with equipment availability [11, 27]. Conditional maintenance optimizes maintenance and especially to perform at the right time at the right cost. Indeed, the costs of a policy of routine maintenance are incompatible with the requirements of industrial business productivity today. In addition, the downsizing of many services, limited capacity to respond to incident, hence the need to anticipate failures using conditional preventive methods [8, 26].

To estimate the maintenance cost based on the estimated number of intervention in $[0,T]$, we use the equation (1), taking the random variable h as the number of failures in the time interval $[0,T]$, the model is as follows [12, 17]:

$$P(T,h) = \frac{a^h}{h!} e^{-\alpha} \tag{1}$$

where $P(T,h)$ is the probability of failure in the interval $[0,T]$ and α is the expected value of the number of failures in the interval $[0,T]$:

$$a = \int_0^T \lambda(t)dt \tag{2}$$

If there is a material composed mainly of sub assemblies whose failure rate rose linearly, we can write:

$$\lambda_i(t) = \lambda_i + k_i t \tag{3}$$

And the failure rate overall, considering the components in series in terms of reliability, can be written as follows:

$$\lambda(t) = \lambda_0 + \sum_1^m k_i t \tag{4}$$

With $\lambda_0 = \sum_1^m \lambda_i$

Performing a repair at subsets i decreases its failure rate to its initial value $\lambda_i(t)$ during the time λ_i for the scheduled period T .

Using equation (2), the expected number of failures in the interval $[0,T]$ is written as follows:

$$\alpha = \lambda_0 T + \sum_1^m \frac{k_i T^2}{2} \tag{5}$$

We consider the structure and the periodicity of interventions planned maintenance system on a time interval $[0,T]$. Planned periods are designated by $\Delta_1, \Delta_2, \Delta_3, ..., et\, \Delta_m$ for a material whose m components require routine maintenance previously scheduled, so we can write:

$$\begin{aligned} t &= t_1 + i\Delta_1 \\ t_3 &= t_1 + i\Delta_1 + j\Delta_2 \\ &..................... \\ t_m &= t_1 + i\Delta_1 + j\Delta + ... + p\Delta_m \end{aligned} \tag{6}$$

Where $i, j, .., p$ is the number of planned interventions applied consecutively subsets 1.2 and $m-1$ during the time t_m . In this way the expression of the failure rate can be presented by $\lambda(t_1, t_2, t_3, ..., t_m) = \lambda(t_1, i, j, ..., p)$. Denote $n_1, n_2, n_3, ..., et\, n_m$ the amount of time periods whose durations are respectively $\Delta_1, \Delta_2, \Delta_3, ..., et\, \Delta_m$ staggered period $[0,T]$ such as:

$$\begin{aligned} n_1 &= \frac{\Delta_2}{\Delta_1} \\ n_2 &= \frac{\Delta_3}{\Delta_2} \\ n_3 &= \frac{\Delta_4}{\Delta_3} \\ n_m &= \frac{T}{\Delta_{m-1}} \end{aligned} \tag{7}$$

It is not difficult to find the connections between the amount of time periods of duration $\Delta_1, \Delta_2, \Delta_3, ..., et\, \Delta_m$ and the amount realized on the $[0,T]$ period of planned repairs respectively [10]:

$$\begin{aligned} n_{p1} &= (n_1 - 1)\prod_2^m n_i \\ n_{p2} &= (n_2 - 1)\prod_3^m n_i \\ n_{p3} &= (n_3 - 1)\prod_4^m n_i \\ n_{pm} &= (n_m - 1) \end{aligned} \tag{8}$$

The expected number of failures in the time interval $[0,T]$ for the case of linear variation of failure rates over time and after the division of the time axis into intervals equal to Δ_1, and their summation is calculated as follows:

$$a(t_1, n_1, n_2, n_3, ..., n_m) = n_m \sum_{p=0}^{n_m - 1} ... \sum_{j=0}^{n_2 - 1} \sum_{i=0}^{n_1 - 1} \int_0^{\Delta_1} \begin{bmatrix} \lambda_0 + k_1 t_1 + k_2(i\Delta_1 + t_1) + k_3(i\Delta_1 + j\Delta_2 + t_2) + \\ ... + k_m(i\Delta_1 + j\Delta_2 + ... + p\Delta_{m-1} + t_1) \end{bmatrix} \tag{9}$$

The timing of the implementation of prophylactic repair is falling failure rates corresponding to their initial values λ_i but these jumps do not lower the failure rate to the value λ_0 only when the realization of the general revision.

The failure rate $\lambda(t_1, i, j, ..., p)$ is equal to the expected number of failures [20, 22]. We can deduce that in the limiting case when performing an unlimited number of repair: the expected number of approaches to failure $\lambda_0 T$. After the integration of the equation (8), with some transformations we have:

$$a(t_1, n_1, n_2, n_3, ..., n_m) = \lambda_0 T + \frac{k_1 T^2}{2n_1 n_2 n_3 .. n_m} + \frac{k_2 T^2}{2n_1 n_2 n_3 .. n_m} + \frac{k_3 T^2}{2n_3 .. m} + ... + \frac{k_m T^2}{2n_m} \tag{10}$$

Posing

$n_{p1} = 0,\ n_{p2} = 0, n_{p3} = 0 .... et\, n_{pm} = 1$, determining the value of the expected number of failures for the case

$$\begin{aligned} S = (C_A \lambda_0 T + C_{A1} \frac{k_1 T^2}{2n_1 n_2 n_3 .. n_m} + C_{A2} \frac{k_2 T^2}{2n_2 n_3 .. n_m} + C_{A3} \frac{k_3 T^2}{2n_3 .. n_m} + ... + C_{Am} \frac{k_m T^2}{2n_m}) + \\ C_1(n_1 - 1) n_2 n_3 .. n_m + C_2(n_2 - 1) n_3 .. n_m + C_3(n_3 - 1) n_4 .. n_m + C_m(n_m - 1) \end{aligned} \tag{11}$$

The mathematical model based n_i is given by:

$$\min S = C_A \lambda_0 T + \sum_{i=1}^{m} \left[C_{Ai} \frac{k_i T^2}{\prod_{j=i}^{m} n_j} + C_i (n_i - 1) \prod_{j=i+1}^{m} n_j \right] \quad (12)$$

3. Industrial application

In oil industry, the turbochargers must ensure to increased availability and especially during the large gas demand to meet commitments and contracts accorded with customers. On the maintenance plan and according to the manufacturer these machines require three types of revisions at 8000 h, 16000 h and at 32000 h often scheduled outside the period of wide application in the summer. With the application of schedule revisions, it was found that these machines break down – even during the often-wide demand because some components do not change automatically when revisions and cause excessive maintenance costs high not seen the failure prediction or forecasting the supply of replacement equipments. To minimize the exploitation risk, we address that is to strengthen the planning revisions by a systematic maintenance program based on maintenance cost components that greatly influence the availability of turbochargers. The practice has shown that 70% of the turbochargers defects are due: following

- M1 sheathing β1=1,88
- M2 Tightness ring β2=2,14
- M3 carring bearing β3=3,55
- M4 labyrinth support β4=2,09

To remedy this situation, we propose a maintenance strategy specific to this case and we determine the appropriate maintenance intervals. The figure 1, clearly show the trend on failure rates of components considered in our examined turbochargers.

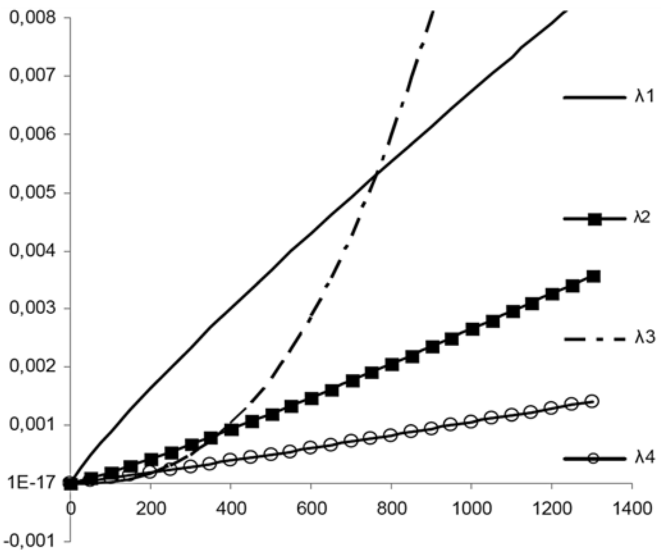

Fig. 1. Failures rates variation of the considered components

For the component 1, it is clear that it ages quickly compared to subset 2 and 4, and that these three elements have shape parameters β between (1.5 and 2.5), which corresponds to a mode of fatigue failure, which justifies their progressions almost linear. Regarding the component 4, at first he ages very slowly, and beyond (200 days), he begins to age more rapidly than the other component which justifies its failure mode is that the wear. It is clear that the failure rates of components 1, 2 and 4 (shown in figures 2, 3 and 4), we have a great linearity and especially during their active lifetimes.

It is clear that the failure rate of the three elements has a little change lointe linear regression, but errors during the active life and compensate (R2 = 0.887), we can say that the linearity can ensure prac-

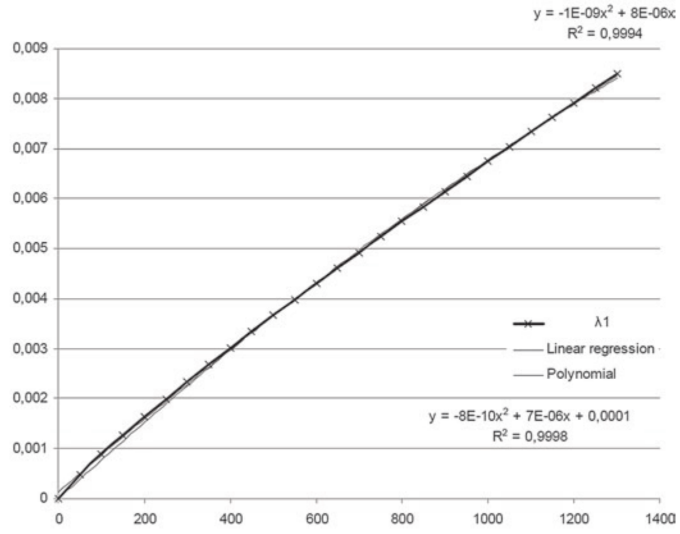

Fig. 2. Failure rate of component 01

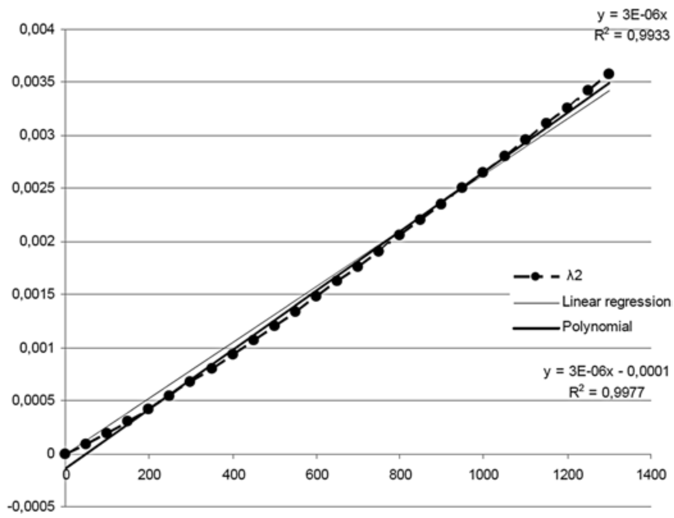

Fig. 3. Failure rate of component 02

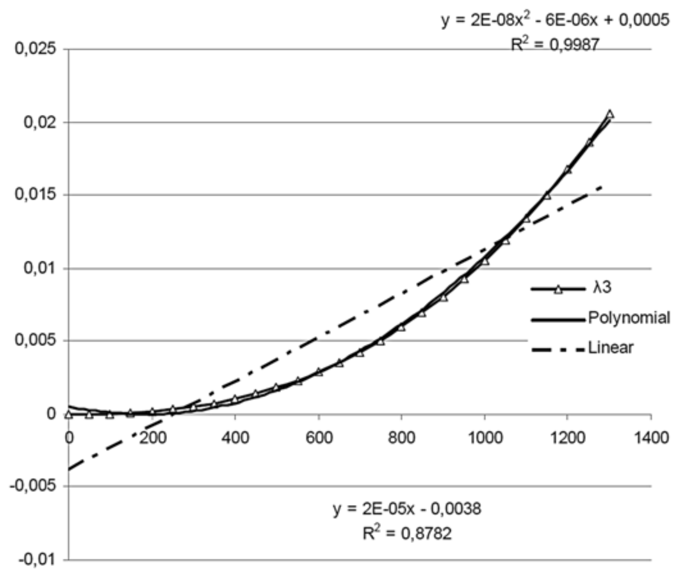

Fig. 4. Failure rate of component 03

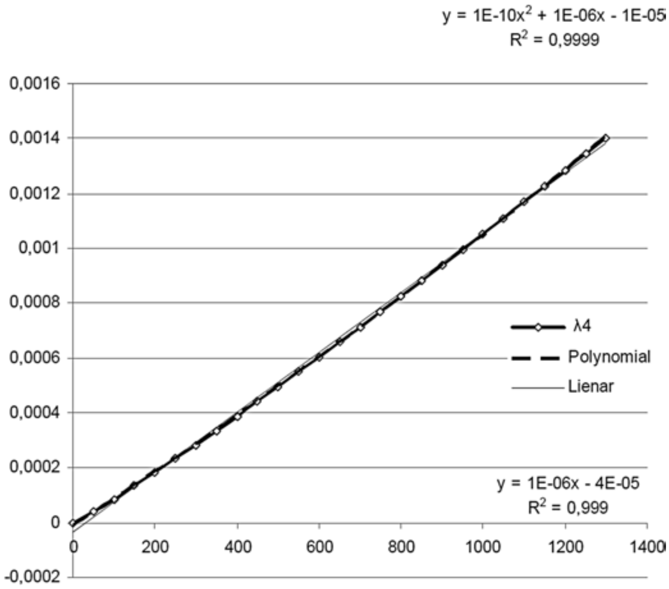

Fig. 5. Failure rate of component 04

tical results satisfactory. We can conclude that the maintenance operations and intervention of the examined turbochargers will be carried according to the flowing action plans, shown in figures 6, 7 and 8:

According to the data sheet 1:

- N4= 1,11 T4= 900 Days
- N3= 1,5 T3= 600 Days
- N2= 1,33 T2= 450 Days
- N1= 1,5 T1= 300 j

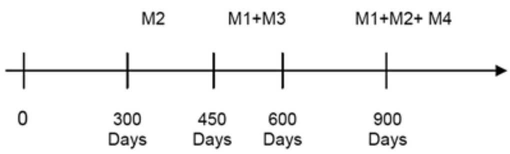

Fig. 6. Maintenance operations action plans according to the data sheet 1

According to the data sheet 2:

- N4= 1,25 T4= 800 Days
- N3= 1,6 T3= 500 Days
- N2= 1,25 T2= 400 Days
- N1= 1,6 T1= 250 Days

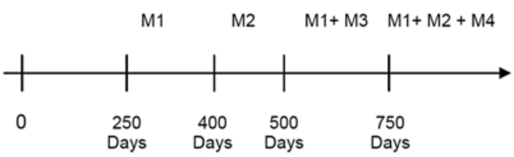

Fig. 7. Maintenance operations action plans according to the data sheet 2

According to the data sheet 3:

- N4= 1 T4= 1000 Days
- N3= 1,33 T3= 750 Days
- N2= 2,3 T2= 325 Days
- N1= 1,3 T1= 250 Days

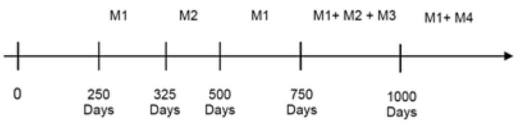

Fig. 8. Maintenance operations action plans according to the data sheet 3

Based on the feedback data, we estimate the laws of aging components of our system examined. Given the results obtained were classified according to their components considered failure modes identified based on estimated values of shape coefficient β:

- Components 1,2 and 4 form the first group for which the mode of failure is the most dominant fatigue according to the estimated values of the parameter β and which are (1.88, 2.14; 2.09) respectively.
- Component 3 is part of the second group, the failure mode is the most dominant wear (β = 3.55).

This has helped to develop approaches to maintenance optimization for each group separately and determine the optimal intervals to include additional repair the structure of the repair cycle recommended by the manufacturer.

4. Conclusion

The maintenance control in industrial plants is based on the knowledge of their behavior, therefore the right choice of the corrective action periodicity of maintenance. Between the good and the malfunction time of the system exploitation, there is a state in which can work as he can at any moment cause unscheduled action whose cost is often too high. In this work, we have determined the optimal timing of repair, to optimize the maintenance actions to eliminate failures in the inspected industrial centrifugal compressor. The finality of this proposed approach is proved by the improvement of the reliability performances and by the availability of this oil installation.

After solving the equation of cost summary based on the linearity of the failure rates of the components of a centrifugal compressor, we have conclude that, the results are very satisfactory with the implementation schedule of routine maintenance, as well as the supply of spare parts. In this paper and after a preset study reliability-one was interested in the most penalizing components in order to control the reliability of the turbo compressor from a few components. Illustrated work shows that the components whose failure mode is wear and from a certain period of normal operation; aging increases its acceleration resulting in a drop in physico mechanical materials and that these components is the result of wear. For parts against deteriorating fatigue have a constant acceleration in their aging which results in a failure rate of linearity.

After the linearization of the failure rates with the proposed objective function, we have evaluates the cost summary of maintenance, according to the optimal timing of repair, in our examined compression system. We result that developed approach of maintenance actions planning makes it possible to increase the working time of the examined compression system. The developed approach of maintenance actions planning allowing better performances in reliability of the examined gas compression system, at the moment of its exploitation for its maintenance.

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