Optimization of equipment availability of a gas-pumping unit

B. Kopey (1)*, **D. Khalimi** (2)

[1] *Ivano-Frankivsk National Technical University of Oil and Gas;*
15, Karpatska str., Ivano-Frankivsk, 76019, Ukraine

[2] *Reliability of Hydrocarbons Equipment and Materials Laboratory (FEPML), University of Boumerdes;*
35000, Algeria

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Abstract

The control of mechanical equipment availability is based on the knowledge of its behaviour and thus optimizes the timing of corrective intervention. The equipment can operate both in good conditions and even in the state of degradation, causing the unscheduled high-cost intervention at any moment. During our study we have optimized turbocharger availability by probabilistic modelling based on the turbocharger`s state parameters that define its degradation.

Key words: *availability, bearing, frequency repair, maintenance costs, optimization, reliability.*

Introduction

The installation of a natural gas compressor plant consists of a whole set of equipment connected to one another, and their forced stoppages disturb all the natural gas transportation system. The operating system reliability is preserved if there is provided for the reliability of operation of each apparatus, machine, piping and any device related to the technological circuit [1]. One can envisage preventive repair works in order to maintain and restore good equipment performance [2]. Due to the fact that these operations are not undertaken until wear has reached a critical point and the equipment inevitably breaks down, and in order to avoid frequent replacement of expensive parts, which can be under permanent or periodical supervision by means of non-destructive test methods, it is offered in the article to consider repairs based on the current state of degradation of equipment parts. To benefit from the advantages of the maintenance policy it is necessary to determine the optimal periodicities of equipment repair cycles [3].

In this context, it is necessary to determine the optimal inspection periodicities of the equipment using a probabilistic approach. We study the case where turbocompressors are installed in compressor plants to increase gas pipeline transport capacity. Furthermore, we consider turbocompressors with simulated component series from a reliability point of view.

The following are the most frequent forms of wear in a compressor: adhesive wear or wear by metal to metal contact, wear by surface fatigue, corrosive wear, erosive wear and abrasive wear. Wear of the turbocompressors' journal lines are of various types and can relate to technological causes (design of bearings, capacity of the lubrication system, construction, assembly and filtration), metallurgical causes (type of antifriction coating), behavior and quality of lubricating oils. In case of abnormal wear, the longevity strongly decreases and the journal line generally ends up as the host of irreversible incidents that prohibit any operation of the compressor.

Probabilistic approach to the problem under consideration

The state of degradation of an element is determined by variations of a state parameter x. If the value of the x parameter exceeds a certain threshold x_r, which is tolerated and defined by the repair technology or technical specifications x_e, then the repair becomes necessary, and is regarded as a breakdown. The parameter x forms random process variations in time [4]. The parameter x has a certain distribution $F(x,t_0)$, the density $f(x,t_0)$, the expectation $E_{x,0}$ and the standard deviation $S_{x,0}$ at the section corresponding to $t_0 = 0$ (Fig. 1). During the operating time these characteristics vary as follows:

$$E_{x,t} = E_{x,0} + \alpha E\, t\,, \tag{1}$$

$$S_{x,t} = S_{x,0} + \alpha S\, t\,, \tag{2}$$

where αE and αS are constant coefficients.

After a certain operating time *t*, the distribution of the parameter x will be $F(x,t)$ with characteristics determined by expressions (1) and (2).

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* Corresponding author:
kopeyb@nung.edu.ua

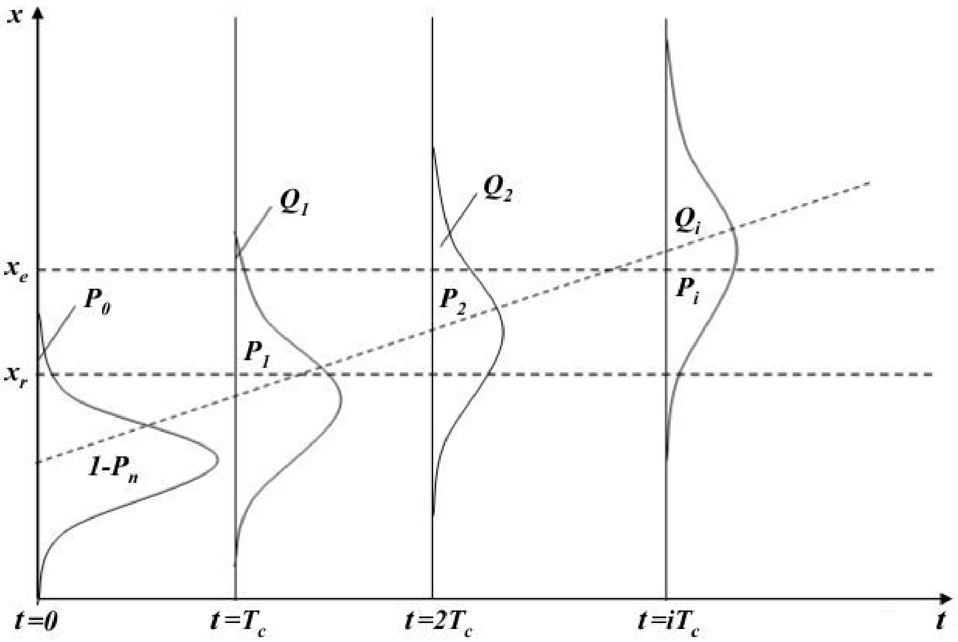

Figure 1 – Diagram of the random process variations of the x parameter

If the periodicity of the cycles related to repair of the given equipment is T_c the total probability of undergoing a non-planned intervention after the ith period of the cycle is given by the expression:

$$Q_i = [1 - F(x_e, iT_c)]\prod_{j=0}^{i} F(x_r, jT_c), \qquad (3)$$

where iT_c is the time duration till the ith period of the repairing cycle, $F(x_e, iT_c)$ is the distribution function of the state parameter x_e related to the moment iT_c.

The probability of undergoing planned intervention at time $t = iT_c$ is presented by the following expression:

$$P_i = [F(x_e, iT_c - F(x_r, iT_c)]\prod_{j=0}^{i} F(x_r, jT_c). \qquad (4)$$

In case of dividing the repair cycle into s intervals and according to Bayes` theorem [5], the probability, which corresponds to an unplanned stoppage or the equipment failure is given by the expression:

$$Q = \lim_{s\to+\infty}\sum_{i=1}^{s}[1 - F(x_e, iT_c)]\prod_{j=0}^{i} F(x_r, jT_c). \qquad (5)$$

The total probability corresponding to the replacement of parts for the equipment under consideration is given by the expression:

$$P = \lim_{s\to+\infty}\sum_{i=1}^{s}[F(x_e, iT_c) - F(x_r, iT_c]\prod_{j=0}^{i} F(x_r, jT_c) .(6)$$

In this case, the average service time of the part is given by the expression:

$$T_m = \lim_{s\to+\infty}\left(\sum_{i=1}^{s} Q_i T_i^{*} + \sum_{i=1}^{s} P_i T_i^{**}\right), \qquad (7)$$

where $T_i^{*} = (2i-1)T_c/2$ and $T_i^{**} = iT_c$.

Mathematical expectancy of the possible total costs for planned and unplanned interventions of the equipment with respect to a given part is given by the expression:

$$E(T_c) = C_d Q + C_p P = C_d (Q + \lambda_c P), \qquad (8)$$

where C_d are total costs of an unplanned intervention, C_p are total costs of a planned intervention

$$\lambda_c = C_p / C_d .$$

The specific cost of repair of the part under consideration is [5]:

$$U_s = E(T_c)Y / Tm, \qquad (9)$$

where $Y = (x_e - x_r)/\alpha E$ is possible average duration of the part operation until the failure is $(x \succ x_r)$ if the preventive intervention is not carried out.

The optimal periodicity is determined by the resolution of the equation:

$$dU_s / dT_c = 0. \qquad (10)$$

Results and discussion

We have considered a journal bearing of a turbocompressor with the friction surfaces at the bearing interface being separated by a continuous layer of lubricant. If the conditions of assembly, operation and lubrication are satisfactory, then the lifetime of a journal bearing depends mainly on the fatigue strength and the surface-to-surface contact. The contact between the journal and the bearing having been repaired is not integral and after a certain operating time the roughness of adjusted surfaces becomes blunt, and friction surfaces are changed. At the same time the dimensions of the parts vary with time in a random way.

Having compared the results of measurement of the dimensions of worn and new parts, obtained using a micrometer, with their nominal values, we obtain the empirical distributions with a certain random variable which is regarded as a state parameter of the part under

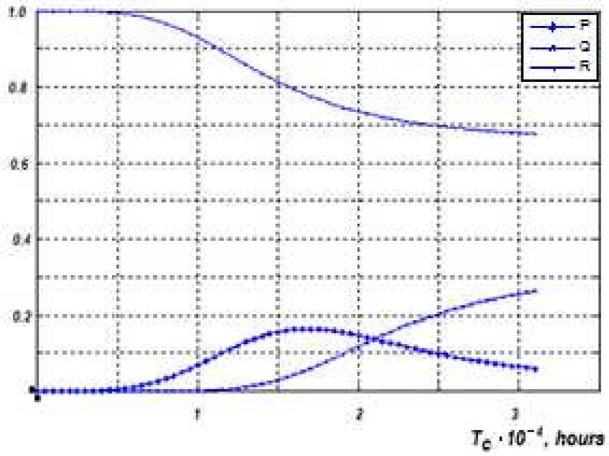

Figure 2 – Dependence of the probabilities *Q*, *P* and *R* on the repair cycle periodicity of the journal bearing of the turbocompressor under consideration

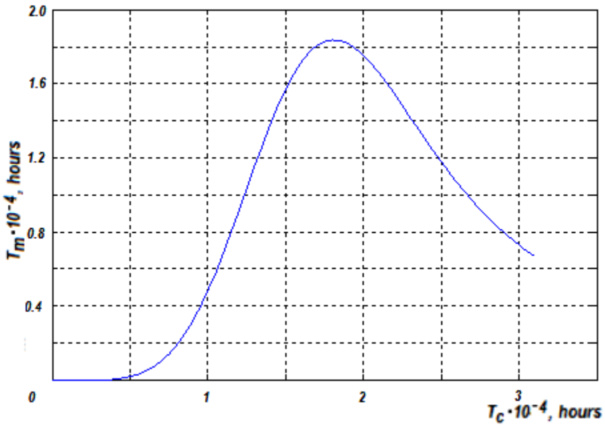

Figure 3 – The average service time T_m of the part

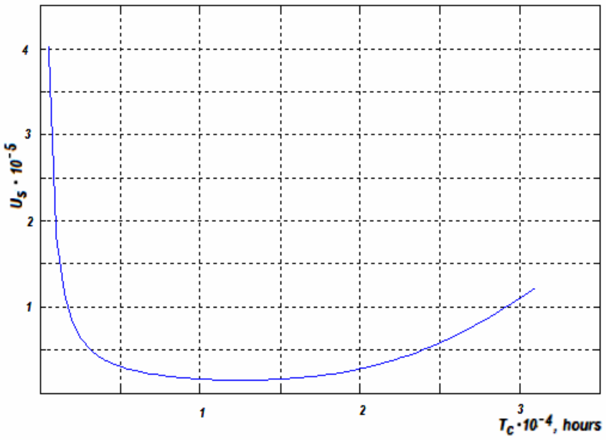

Figure 4 – Specific cost $U_s(T_c)$

consideration. The treatment of wear measurement results obtained at the initial time $(t = 0)$ shows that the state variable x follows a normal distribution law with parameters $E_{x,0} = 0.18\, mm$ and $S_{x,0} = 0.025\, mm$ for the journal bearings in turbocompressors. Based on the results of wear measurement that correspond to 12,000 operating hours of 20 turbocompressors exploited under identical conditions and by using the expressions (1) and (2) we have determined the values $\alpha E = 28 \cdot 10^{-8}\, mm/h$ and $\alpha S = 35 \cdot 10^{-8}\, mm/h$. In addition $x_r = 0.3\, mm$, $x_e = 0.38\, mm$ and $\lambda_c = 0.38$.

The computation results are presented in Fig. 2. The average time of good performance of journal bearings up to the repair point is estimated by the expression (7) and its dependence on the value of the period T_c is shown in Fig. 3. The value of the optimal repair periodicity of the turbocompressor bearing, obtained on the basis of expression (9), is estimated at 15,500 *hours* (Fig. 4).

Conclusion

The comparison of the obtained results and the value of the actual periodicity of repair cycle shows that resort to a probabilistic approach allows a 28% increase of the working life of the journal bearing in compressors under consideration, that is to say an increase of 3,500 operating hours. This improvement has a great significance from the point of view of the equipment efficiency and availability.

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Оптимізація коефіцієнта готовності обладнання газоперекачувального агрегата

Б. Копей[1]*, Дж. Халімі*[2]

[1]*Івано-Франківський національний технічний університет нафти і газу;*
вул. Карпатська, 15, м. Івано-Франківськ, 76019, Україна

[2] *Університет М'амед Буггара;*
35000, Алжир

Контроль коефіцієнта готовності механічного обладнання газоперекачувального агрегата засновано на аналізі їх стану, що дає можливість оптимізувати терміни коригувальних операцій технічного обслуговування. Обладнання може функціонувати у нормальному стані, а також у стані деградації, але в будь-який момент може викликати незаплановане втручання зі значними витратами. У дослідженні з використанням ймовірнісної моделі оптимізовано коефіцієнт готовності турбонагнітача залежно від параметрів її стану, що визначають його деградацію та потік відмов.

Ключові слова: *витрати на обслуговування, коефіцієнт готовності, надійність, оптимізація, підшипник, частота ремонту.*