People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific research
M'hamed Bougara University, Boumerdes
Institute of Electrical and Electronic Engineering,
Laboratory of Signals and Systems (LSS)

ALGERIAN JOURNAL OF SIGNALS AND SYSTEMS

ISSN : 2543-3792

Title: **Reliability modelling using Weibull distribution on real-time system in oil drilling installations**

Authors: **Mohamed Ben Rahmoune[1], Mouloud Guemana[2] and Ahmed Hafaifa[1]**
Affiliations:
(1) Applied Automation and Industrial Diagnostics Laboratory, University of Djelfa 17000 DZ, Algeria
(2) Faculty of Science and Technology, University of Medea 26000 DZ, Algeria.

Page range: **189- 198**

Volume : 2 Issue : 4 (December 2017)
A special issue of the International Conference on Advanced Engineering in Petrochemical Industry (ICAEPI'17)
November 28-30, 2017, Skikda, Algeria

Laboratory of Signals and Systems
Address : IGEE (Ex-INELEC), Boumerdes University, Avenue de l'indépendance, 35000, Boumerdes, Algeria
Phone/Fax : 024 79 57 66
Email : lss@univ-boumerdes.dz ; ajsyssig@gmail.com

Reliability modelling using Weibull distribution on real-time system in oil drilling installations

Mohamed Ben Rahmoune, Mouloud Guemana and Ahmed Hafaifa

Applied Automation and Industrial Diagnostics Laboratory, University of Djelfa 17000 DZ, Algeria
Emails: m.benrahmoune@univ-djelfa.dz , a.hafaifa@univ-djelfa.dz
Faculty of Science and Technology, University of Medea 26000 DZ, Algeria.
Email: mouloud.guemana@univ-medea.dz

Abstract: Recently, reliability has become a key parameter of quality and decision support, covering many aspects, such as failure analysis systems. A reliability analysis is essential for the study of operating safety in industrial systems. In this paper, we summarised evaluation methods and real-time reliability analyses. This work proposes solutions to real-time reliability modelling, as applied to an industrial pump. The model will be used to increase the lifespan of the equipment, to help develop suitable maintenance plans and to assign a probability to good operating system examined to choose the best dedicated industrial pump technology solutions.

Keywords: *reliability estimation, reliability analysis, reliability modelling, real-time system, availability, maintenance, failure, maintenance costs.*

1. INTRODUCTION

To address the needs of the market and increasingly severe economic competition, manufacturers have expanded their facilities and made them more complex, which has increased both safety risks and the risk of breakdowns [1-6]. In an industrial plant, to ensure safe practices and minimise unnecessary risks, techniques such as diagnoses, monitoring, regular maintenance, and supervision are common in high-risk environments like oil facilities. Additionally, equipment reliability is a major concern of many types of installations because data reliability is required for many important activities and affects the quality and shelf life of products and the quality of services. To maintain equipment reliability, failure risks must be minimised through various activities, including assessing the availability and monitoring the performance of the equipment, performing regular maintenance, and making necessary modifications [9-10].

At installations, a proper reliability model identifies the main functions of the plant and the required equipment and raw materials to meet the production demands at any given time. The availability of the equipment can be improved by following an organised maintenance schedule based on real data. In this study, we identify the most critical elements a piece of equipment and determine the reliability parameters based on a real-time system to reduce production costs and to avoid malfunctions. Our tests on actual data pump identified the reliability indicators that allowed us to verify the equipment performance and to confirm the appropriate operating parameters specified by the manufacturer.

With the increasing complexity of mechanical components, it is increasingly difficult to estimate equipment reliability based only on failure predictions. Many components degrade before reaching total failure. The ability to measure the level of degradation will help in providing valuable information on the reliability of the equipment. In this work, to increase its lifespan and to develop suitable plans for maintenance, we proposed solutions to the real-time reliability modelling of an industrial pump. Additionally, we assessed various industrial pump technology solutions to select the best dedicated operating system.

2. REAL-TIME SYSTEMS

A real-time system processes information to design an effective industrial process, within the constraints of the operating conditions. It differs from conventional information processing systems in that the value of a given product depends on the calculation of a correction and on the date the data are available [24, 26-27]. The respect time constraints are a predominant factor in assessing the operating quality of a system. To address the "real-time" aspect of a system, we chose a definition based on the problem being treated. Thus, we incorporated as appropriate, a robust, rapid response, real-time system to directly interact with a physical process and a reagent system. For the considered system, the response time is related to the dynamics of an industrial control pump. In this application, the time constraints on real-time reliability calculations revealed the predictable behaviour and fault tolerance of cavitations in the examined pump.

A minimum performance is required for the real-time reliability calculations; however, the time constraints of the model must also be satisfied which can be achieved through the use of appropriate scheduling algorithms. A common practice is to oversize the system to ensure the time constraints are met. Moreover, the system environment directly impacts the real-time applications of shared industrial facilities. Most industries rely on a strategy based on performance, security, and competitiveness [7, 15, 18 and 22].

In this present study, we proposed solutions based on actual measurements to the real-time reliability calculations of an industrial pump (shown in Figure 1), to increase its lifespan and to help develop suitable maintenance schedules. Using our solutions, we also determined the parameters and characteristics of a good operating system to choose an optimal industrial pump.

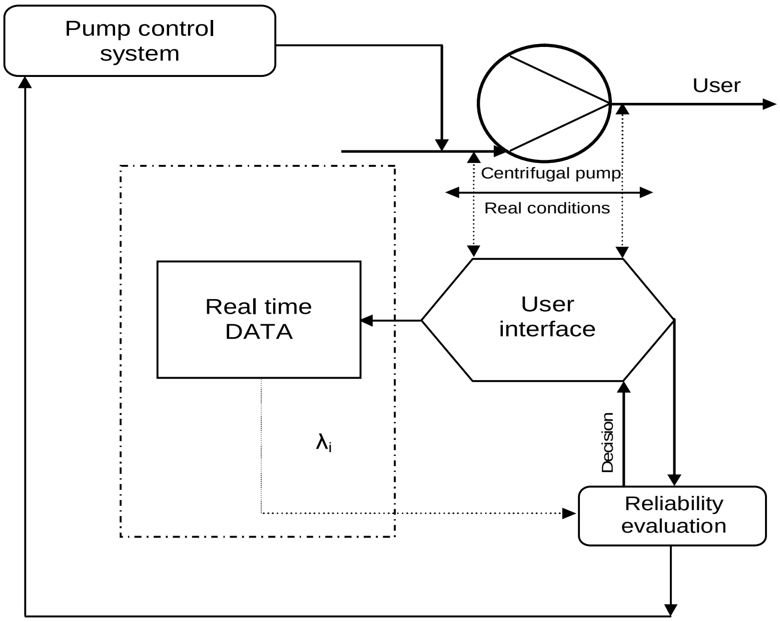

Fig.1 Reliability evaluation based on real-time system

This approach to real-time-calculated reliability enables the management of pump controls and all units that interface with the user. This is done by evaluating the input-output data, which depend on the anomalies detected by the real-time system, for the development of reliability parameters of different maintenance plans. Indeed, a real-time system interacts with a number of different types of hardware in an increasingly complex external environment to meet time constraints and ongoing reliability factors. The set of activities and tasks that meet the specific real-time calculations for reliability systems, in this case, a pump system, are shown in Figure 2.

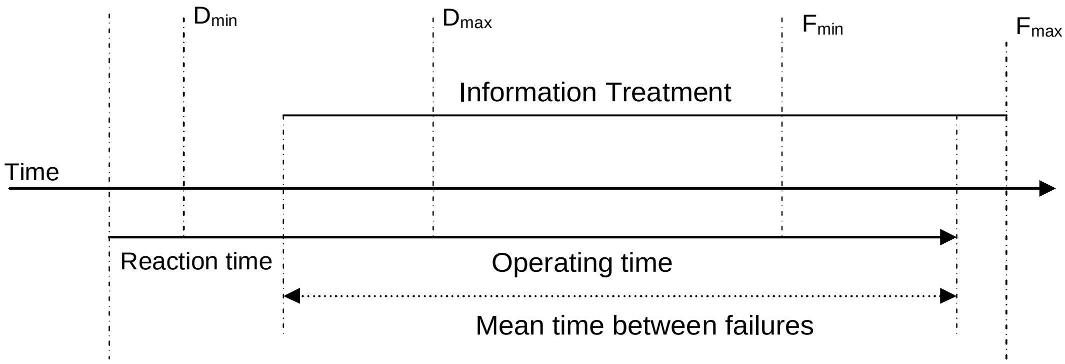

Fig. 2. Real-time system tasks

In this work, the problems related to real-time systems for modelling the reliability of an industrial pump in real-time will be discussed so that a high-confidence solution that satisfies the external time constraints can be found to determine the lifetime of the examined pump.

Reliability modelling based on real-time systems

Reliability models found in the literature can be divided into two main groups: functional models, which describe the system from a definite time perspective, and dynamic models, which describe the behaviour of operating time in a definite time system [8, 11, 17, 19, 23 and 25]. Functional models are generally based on another stochastic process, which is only used to describe the behaviour of the system while ignoring the execution order of events. These models allow for the calculation of the failure probability for a particular structure but not for the calculation of the synchronisation properties of a system. While the synchronisation properties are undoubtedly valuable, their usefulness in the analysis of real-time systems is questionable because these systems require functionally and temporally correct behaviours [14, 16 and 20].

The synchronisation properties of a real-time system are as important as the functional properties and ensure the development of an accurate model [26]. However, this type of model is not rigorous enough to sufficiently describe the properties. In contrast, time-dependent models are much less developed. A few studies have been done in developing algorithms to calculate the average execution time of a set of processes in the presence of distrust, i.e., operating in a degraded mode.

In fact the first task in the analysis of reliability is to find the value and reliability of the study. The procedure for each component was separately tested. Then, we determined the reliability of the system [12, 21 and 25]. This task allows us to identify the properties and dependencies of system reliability study. Reliability is defined in terms of probability, the failure rate, the mean time between failures and probabilistic parameters, such as cumulative distribution functions. A cumulative distribution function $F(t)$ is defined as the probability that over a random interval, a random variable is not large at time t:

$$F(t) = \int_{-\infty}^{t} f(t)dt \qquad (1)$$

where $f(t)$ is the probability density function of the random variable. The reliability function $R(t)$ is given by:

$$R(t) = 1 - F(t) = \int_{t}^{\infty} f(t)dt \qquad (2)$$

By differentiating equations (1) and (2), the failure probability is obtained:

$$f(t) = \frac{-dR(t)}{dt} \tag{3}$$

The failure probability in a given time interval between T1 and T2 can be expressed by the following reliability function:

$$R(t_1) - R(t_2) = \int_{t_1}^{\infty} f(t)dt - \int_{t_2}^{\infty} f(t)dt \tag{4}$$

The failure rate is given by $\lambda(t)$, which is defined as the ratio between the probability of failure in a time interval $[t_1, t_2]$ and the product of the probability of failure at t1 and the length of this interval:

$$\lambda(t) = \frac{R(t_1) - R(t_2)}{(t_1 - t_2)R(t_1)} = \frac{R(t) - R(t+\Delta t)}{\Delta t R(t)} \tag{5}$$

For most industrial systems, the failure rate follows a bathtub-shaped curve as shown in figure 3.

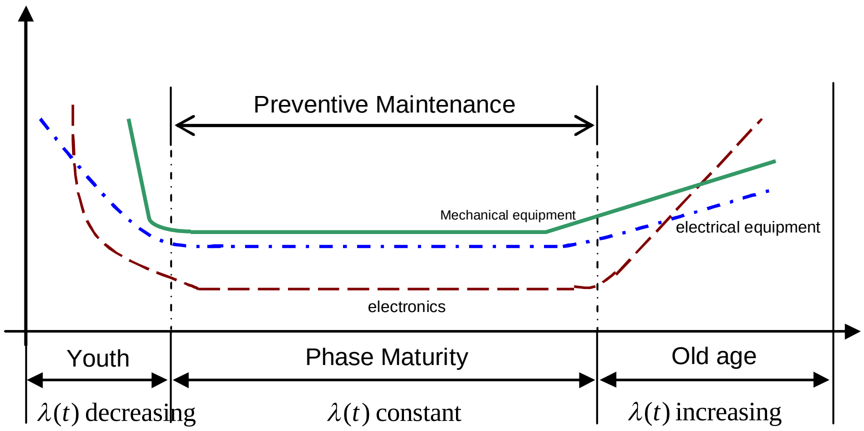

Fig. 3. Failure rate in versus time

In this curve, the first period shows a characteristically high failure rate, which rapidly decreases due to training and intense usage [13-14]. The second period, or "useful life", is characterised by a low, but constant failure rate. The individual components have proven their robustness in solving common problems, and the equipment is in its mature phase. And finally, the last period, or “old life”, is characterised by rapidly increasing wear and failure rates.

In practice, the instantaneous rate of failure is defined as the failure rate limit when the time interval is infinitesimally small, as given by equation (6):

$$\begin{aligned} h(t) &= \lim_{\Delta t \to 0} \left[\frac{R(t) - R(t+\Delta t)}{\Delta t R(t)} \right] \\ &= \frac{-1}{R(t)} \left[\frac{dR(t)}{dt} \right] = \frac{1}{R(t)} \left[\frac{-dR(t)}{dt} \right] \end{aligned} \tag{6}$$

Substituting in Equation (3), the instantaneous rate of failure is obtained:

$$\begin{aligned} & h(t) = \frac{f(t)}{R(t)} \Rightarrow h(t) = \frac{-1}{R(t)} \left[\frac{dR(t)}{dt} \right] \\ & \Rightarrow \frac{dR(t)}{dt} = -h(t)dt \end{aligned} \tag{7}$$

Then, after integrating both sides of equation (7), the instantaneous failure rate becomes:

$$\int_0^t \frac{dR(t)}{dt} = -\int_0^t f(t)dt$$
$$\Rightarrow \ln(R(t)) - \ln(R(0)) = -\int_0^t h(t)dt \quad (8)$$

where $R(0)=0$ and $R(1)=0$ and $R(t)=\exp\left[-\int_0^t h(t)dt\right]$.

Equation (8) is the general expression for the reliability function. If $h(t)$ can be considered constant (i.e., $\lambda(t)=Cst$), the reliability function becomes:

$$R(t) = e^{-\lambda t} \quad (9)$$

where the average failure MTTF is simply the expected value of the time of failure:

$$MTTF = \int_0^\infty tf(t)dt = \int_0^\infty t\left[-\frac{dR(t)}{dt}\right]dt \quad (10)$$

Then, following an integration by parts, we arrive at the expression of the average failure:

$$MTTF = \int_0^\infty R(t)dt \quad (11)$$

The mean time between failures (MTBF) applies to repairable systems in which components are immediately replaced after failure and is expressed as:

$$MTBF = \frac{T(t)}{r} \quad (12)$$

where $T(t)$ is the total operating time, and r is the number of failures in the exploited system. The mean time between failures can be calculated in a different way:

$$R(t) = e^{-\lambda t} = e^{-t/\theta} = e^{-t/MTBF} \quad (13)$$

where $\theta = \frac{\sum_{i=1}^{n} t_i}{n}$ is the average life duration, t_i is the time of failure of the ith component in the population, and n is the total number of components in the system. In this case, $\lambda = \frac{1}{MTBF}$.

To improve the reliability of industrial systems is to find the best way to increase reliability. The most commonly used methods to achieve this include minimising the complexity of the system and increasing the reliability of individual components in the system. These methods are practiced, for example, in regular maintenance of faulty components or preventative maintenance of at risk components that have not yet failed. In this case, the total reliability of a system of components in a series is given by:

$$R_s(t) = \prod_{i=1}^{n} R_i(t) \quad (14)$$

where $i \in \{1, n\}$ and $R_i(t)$ is the reliability of the component i.

The total reliability of a system of components in parallel is given by:

$$R_s(t) = \left(1 - \prod_{i=1}^{n} \left(1 - R_i(t)\right)\right) \quad (15)$$

where $i \in \{1, n\}$ and $R_i(t)$ is the reliability of the component i.

The improvement of the reliability of an industrial system is based on this approach. The development of system reliability is approached by predicting and evaluation experimental data and conducting an operational reliability assessment.

3. VALIDATION OF REAL-TIME RELIABILITY MODELLING

During the processing of reliability data in the presence of external events, specific operating environments, and subject to time constraints, it is imperative to determine the order in which the activities of the pump system were examined. The approach proposed in this paper seeks to control the changes in the operating time of each pump component. We built a reliability model that allows us to predict the evolution of the process when the components are subjected to various events and external actions. In this part of the work, several validation tests were carried out. Figures 4, 5, 6 and 7 show the results of the validation tests for the tool that used exponential distributions with λ = 0.5 and t = 10 h to calculate the reliability function, the probability density, the MTBF and the instantaneous failure rates of the pump.

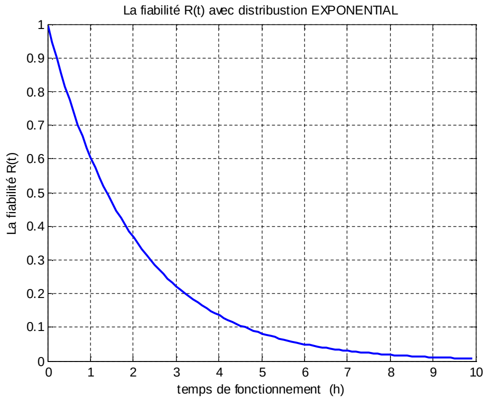

Fig. 4. Reliability function using exponential distribution

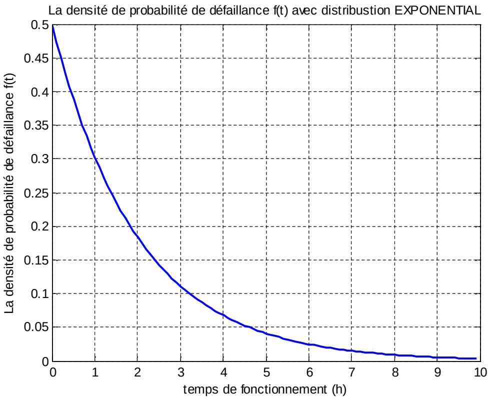

Fig. 5. Probability density using exponential distribution

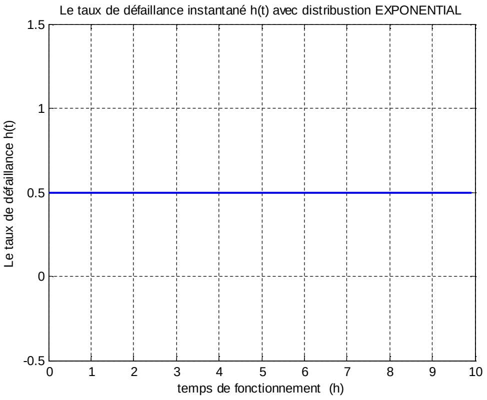

Fig. 6. Failure rate using exponential distribution

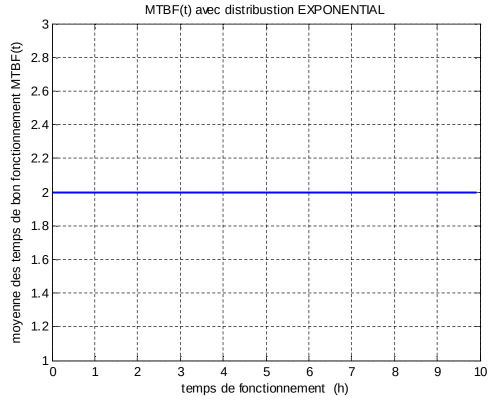

Fig. 7. MTBF means uptime using exponential distribution

Other tests were performing using the Weibull distribution, which characterised the behaviour of the pump system as one of three stages according to the value of β. The Weibull distribution is defined by two parameters, parameter β and the shape parameter of life (i.e., the amount of time for 63.2% of the components to fail). Figures 8, 9, 10 and 11 present the reliability and instantaneous failure rates for a Weibull distribution using λ = 10 and t = 10 h.

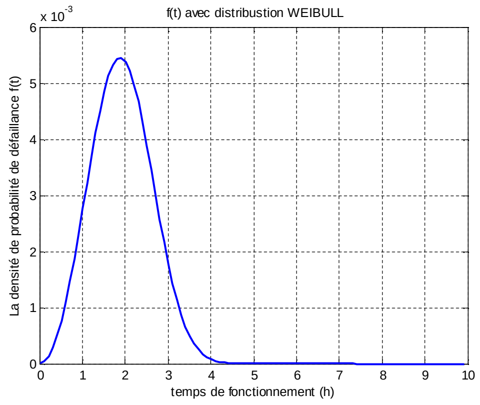

Fig. 8. Probability density using Weibull distribution

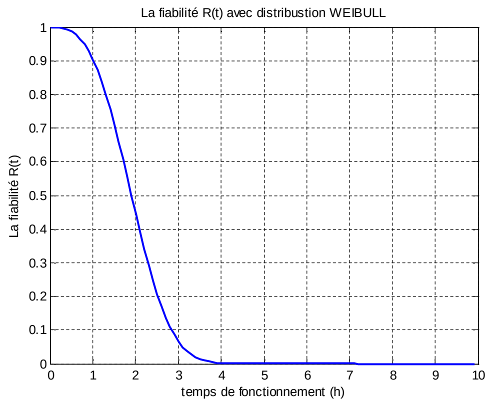

Fig. 9. Reliability function using Weibull distribution

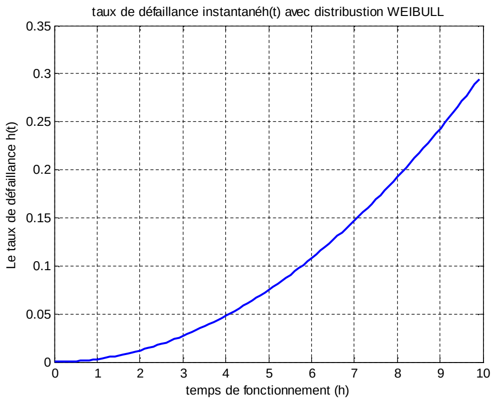

Fig. 10. Failure rate using Weibull distribution

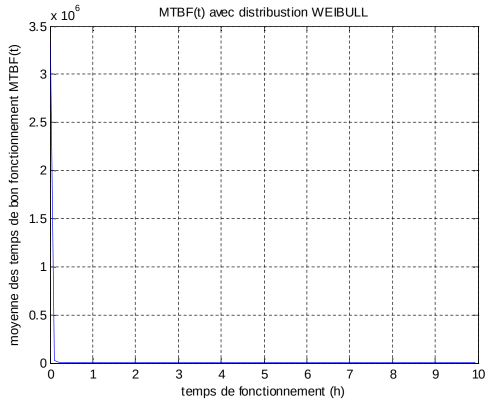

Fig. 11. MTBF means uptime using Weibull distribution

In this work, the normal distribution was also examined because this pattern is commonly observed in many phenomena. The normal distribution is defined by the mean value μ and the standard deviation σ . Figures 12, 13, 14 and 15 show the results obtained for a normal distribution with the failure rate in the form of a normal function, with $\sigma = 0.3$, $\mu = 0.5$ and t=10 h.

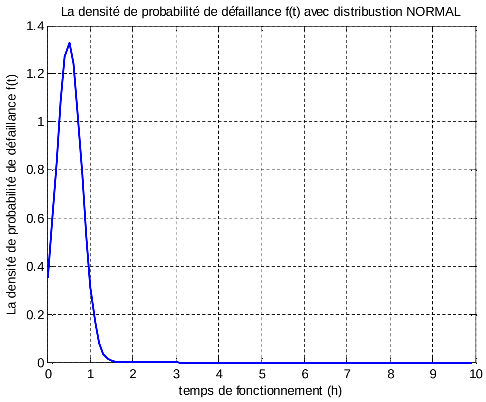

Fig. 12. Probability density using the normal distribution

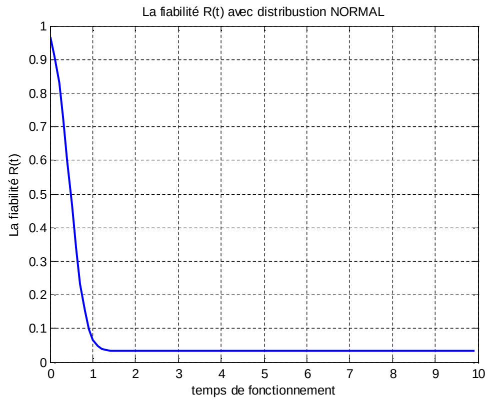

Fig. 13. Reliability function using the normal distribution

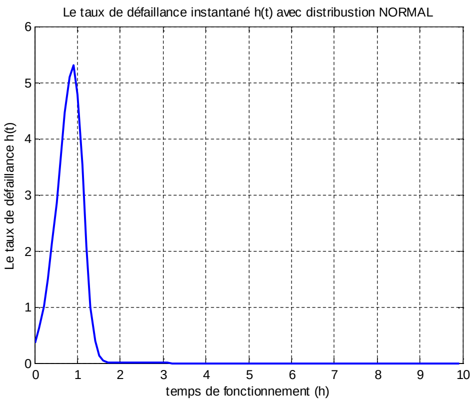

Fig. 14. Failure rate using the normal distribution

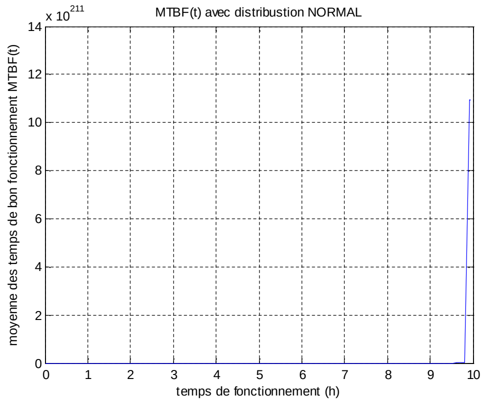

Fig. 15. MTBF means uptime using the normal distribution

4. CONCLUSIONS

Understanding the reliability of a system is an important economic issue for any business. The measurement of this quantity is a necessary first step. Many companies have found that reliability is an important factor that determines their competitiveness. Designers and users of complex systems show great interest in the reliability assessments of these overall systems, the individual hardware and software components and the interactions between different parts of the systems. Reliability covers multiple aspects: the failure analysis of systems, predictive capabilities, banking data reliability, testing, operational functions, predictive methods for safety, and quality assurance. In this work, we proposed solutions to real-time reliability modelling as applied to an industrial pump. The results of the study could be used to increase the lifespan of the pump and to help develop plans for suitable maintenance care. Additionally, the reliability model could be used to evaluate operating systems to choose an optimal industrial pump solution.

Given the obtained results, it can be argued that the following items are considered essential to improve the reliability and quality of pumps. The real-time approach allows for fault analysis by providing the means to better understand the costs and causes of failures. This will help in increasing the profitability of pumping stations. Additionally, the use of a real-time approach for modelling the reliability of the pump system can provide guidelines for maintenance and availability. We can conclude that real-time systems are good tools to help improve the reliability of the pump system industry.

References

[1] Chiacchio F., Cacioppo M., D'Urso D., Manno G., Trapani N., Compagno L., A Weibull-based compositional approach for hierarchical dynamic fault trees. Reliability Engineering & System Safety, vol. 109, January 2013, pp. 45-52.

[2] Daria Battini, Alessandro Persona, Fabio Sgarbossa, Innovative real-time system to integrate ergonomic evaluations into warehouse design and management. Computers & Industrial Engineering, vol. 77, November 2014, pp. 1-10.

[3] Djamel Halimi, Ahmed Hafaifa and Elahmoune Bouali, Maintenance actions planning in industrial centrifugal compressor based on failure analysis. The quarterly Journal of Maintenance and Reliability, vol. 16, no. 1, January 2014, pp. 17–21.

[4] Emad E. Elmahdy, Abdallah W. Aboutahoun, A new approach for parameter estimation of finite Weibull mixture distributions for reliability modeling. Applied Mathematical Modelling, vol. 37, no. 4, February 2013, pp. 1800-1810.

[5] Emilio Sarno, Vipin Kumar, Wei Li, A hybrid methodology for enhancing reliability of large systems in conceptual design and its application to the design of a multiphase flow station. Research in Engineering Design, vol. 16, no. 1-2, November 2005, pp. 27-41.

[6] Gaft Ya. Z., Desner O. G., Zadanovskii L. G. and Érdraikh V. S., Increasing the reliability of an axial chemical pump. Chemical and Petroleum Engineering, vol. 17, no 3, March 1981, pp. 125-127.

[7] Glovatskii O. Ya., Operating experience and reliability assessment of elements of pumping stations. Hydrotechnical Construction, vol. 23, no. 9, September 1989, pp. 532-537.

[8] Govind S. Mudholkar, Kobby O. Asubonteng, Alan D. Hutson, Transformation of the bathtub failure rate data in reliability for using Weibull-model analysis. Statistical Methodology, vol. 6, no. 6, November 2009, pp. 622-633.

[9] Hafaifa Ahmed, Belhadef Rachid and Mohamed Boumehraz, Reliability modeling based on incomplete data: oil pump application. Management Systems in Production Engineering Journal, vol. 3, no. 15, 2014, pp. 140□144.

[10] Hafaifa Ahmed, Ferhat Laaouad and Moulod Guemana, A New engineering method for fuzzy reliability analysis of surge control in centrifugal compressor. American Journal of Engineering and Applied Sciences, vol. 02 no. 04, 2009, pp. 676-682.

[11] Isabel Sartori, Edilson M. de Assis, Adilton L. da Silva, Rosana L.F. Vieira de Melo, Ernesto P. Borges, e Silvio A.B. Vieira de Melo, Reliability Modeling of a Natural Gas Recovery Plant Using q-Weibull Distribution. Computer Aided Chemical Engineering, vol. 27, 2009, pp. 1797-1802.

[12] Kucheryavyi V. I., Mil'kov S. N., Statistical modeling of the lifetime of face seals in an oil-transfer pump. Journal of Machinery Manufacture and Reliability, vol. 38, no. 1, February 2009, pp 94-99.

[13] Li Zhengmei, Zhou Qiong, An Qi, Tang Jianping, Influences of eccentric unbalances on loads and life of auto water pump bearing. Mechanism and Machine Theory, vol. 46, no. 3, March 2011, pp. 253-263.

[14] Mansour Aghababaei Jazi, Chin-Diew Lai, Mohammad Hossein Alamatsaz, A discrete inverse Weibull distribution and estimation of its parameters. Statistical Methodology, vol. 7, no. 2, March 2010, pp. 121-132.

[15] Moeini Asghar, Kouroush Jenab, Mohsen Mohammadi, Mehdi Foumani, Fitting the three-parameter Weibull distribution with Cross Entropy. Applied Mathematical Modelling, vol. 37, no. 9, May 2013, pp. 6354-6363.

[16] Mokronosov E. D., Bogdanov V. V. and Eltyshev M. N., Increase in the operating reliability of a well sucker-rod pump. Chemical and Petroleum Engineering, vol. 43, no. 11-12, November 2007, pp. 756-758.

[17] Mouloud Guemana, Slimane Aissani and Ahmed Hafaifa, Use a new calibration method for gas pipelines: An advanced method improves calibrating orifice flowmeters while reducing maintenance costs. Hydrocarbon Processing Journal, vol. 90, no. 8, August 2011, pp. 63-68.

[18] Qing Zhang, Cheng Hua, Guanghua Xu, A mixture Weibull proportional hazard model for mechanical system failure prediction utilising lifetime and monitoring data. Mechanical Systems and Signal Processing, vol. 43, no. 1–2, 3, February 2014, pp. 103-112.

[19] Raif Sakin, İrfan Ay, Statistical analysis of bending fatigue life data using Weibull distribution in glass-fiber reinforced polyester composites. Materials & Design, vol. 29, no. 6, 2008, pp. 1170-1181.

[20] Saad J. Almalki, Saralees Nadarajah, Modifications of the Weibull distribution: A review. Reliability Engineering & System Safety, vol. 124, April 2014, pp. 32-55.

[21] Saad J. Almalki, Jingsong Yuan, A new modified Weibull distribution. Reliability Engineering & System Safety, vol. 111, March 2013, pp. 164-170.

[22] Schijve J., Statistical distribution functions and fatigue of structures. International Journal of Fatigue, vol. 27, no. 9, September 2005, pp. 1031-1039.

[23] Tieling Zhang, Min Xie, On the upper truncated Weibull distribution and its reliability implications. Reliability Engineering & System Safety, vol. 96, no. 1, January 2011, pp. 194-200.

[24] Tuominen Janne, Mikko Viinikainen, Pekka Alho, Jouni Mattila, Using a data-centric event-driven architecture approach in the integration of real-time systems at DTP2. Fusion Engineering and Design, vol. 89, no. 9–10, October 2014, pp. 2289-2293.
[25] Vitkovskii V., Kirillov I. R., Chaika P. Yu., Kryuchkov E. A., Poplavskii V. M., Nosov Yu. V., Oshkanov N. N., Performance-based reliability assessment of electromagnetic pumps. Atomic Energy, vol. 102, no. 2, February 2007, pp. 122-128.
[26] Zhaoqiang Wang, Wenbin Wang, Changhua Hu, Xiaosheng Si, Juan Li, A real-time prognostic method for the drift errors in the inertial navigation system by a nonlinear random-coefficient regression model. Acta Astronautica, vol. 103, October–November 2014, pp. 45-54.
[27] Zhejun Gong, Estimation of mixed Weibull distribution parameters using the SCEM-UA algorithm: Application and comparison with MLE in automotive reliability analysis. Reliability Engineering & System Safety, vol. 91, no. 8, August 2006, pp. 915-922.