National University of Science and Technology POLITEHNICA Bucharest
Doctoral School of Energy Engineering

Summary of the doctoral thesis

Theoretical and Experimental Research on the Reliability of Natural Gas Compression Installations Used in Energy Engineering

PhD student: *eng. CS III Andrei- Robert Isac*

Doctoral Committee:

President	Prof.dr.ing. Radu PORUMB- U.N.S.T. Politehnica București
Thesis Advisor	Prof.em.dr.ing. Dan Niculae ROBESCU- U.N.S.T. Politehnica București
Reviewer	CS I dr.ing. Valentin SILIVESTRU- I.N.C.D. Turbomotoare COMOTI
Reviewer	Prof. dr. ing. Valentin PETRESCU- Univ. “Lucian Blaga” Sibiu
Reviewer	Prof.dr.ing Bogdan POPA- U.N.S.T. Politehnica București

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Foreword

Although reliability-related topics are numerous, this paper aims to make a significant contribution to the reliability calculation of screw compressors used in industry. Based on maintenance activities and collected data, Chapter 3 presents modeling and simulations of screw compressor operation by monitoring highly important parameters and incorporating them into a new Weibull-type law.

The final chapter highlights the application of the author's proposed law in the context of the studied screw compressors, which brings the reliability prediction level close to the experimentally measured values in maintenance activities, with errors of up to 5% compared to the classical approach.

Description, Importance of the Subject, and Significance of the Work

The author has extensive experience of 12 years in the technical field, specializing in the repair and maintenance of screw compressors. Throughout this activity, he has encountered situations that have forced him to develop and implement innovative solutions. One of these challenges was the necessity of creating an efficient maintenance program for electrocompressors.

To achieve this, the author had to generate a reliability function, R(t), which allows for the monitoring and evaluation of compressor performance over time. This reliability function has become essential for establishing optimal preventive maintenance intervals and minimizing the risk of unexpected failures. Consequently, the author has succeeded in ensuring increased service life and high operational efficiency of the equipment, significantly contributing to improved productivity and reduced operating costs.

During the maintenance activities of screw electrocompressors, the author has identified a series of recurring issues in the operation of these machines. A detailed analysis of activities and rigorous monitoring of the equipment have allowed for the documentation of the main observed failures.

1. Current State of the Field of Reliability

Natural gas compression equipment (Fig. 1.1) is intended for both extraction fields in the oil industry and other applications. In the studied domain, these systems are equipped with screw compressors.

For the petroleum industry, these installations are located in natural gas compression parks associated with crude oil extraction or near gas extraction wells.

Fig. 1.1 Electrocompressor Installed in a Gas Extraction Park

The comprehensive analysis of all functional parameters, as well as the use of monitoring equipment for natural gas compression stations with this unique construction type, strictly used in the mentioned application, represents an innovation. Proper analysis of this system will enable its evolution into a highly accurate maintenance program through reliability analysis.

1.1 Reliability Concepts

Estimating the occurrence of defects at a predetermined time is essential for planning equipment, installation, or machinery failures. This process involves establishing a predefined lifespan for all their components. Such a design approach optimizes the operation of the analyzed equipment.

To enable a more in-depth observation of the data, system reliability and operational hypotheses will be used. The structure of the assembly of parts in a given circuit can be realized in several ways:

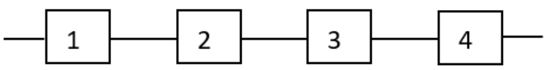


Fig. 1.2 Elements Connected in Series [author's image]

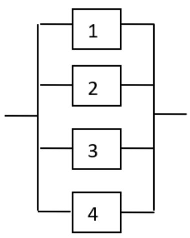


Fig. 1.3 Elements Connected in Parallel [author's image]

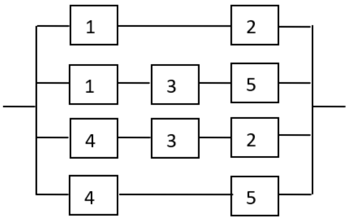


Fig. 1.4 Elements Connected in Parallel [author's image]

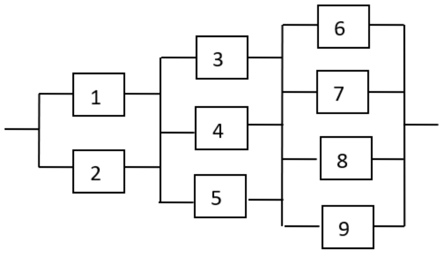


Fig. 1.5 Elements Connected in Parallel-Series [author's image]

1.2 Theoretical, Constructive, Experimental and Operational Reliability

a) Predictive Reliability represents the ability to estimate and forecast the reliability behavior of an assembly or subassemblies over a period of time;
b) Experimental Reliability is established in laboratories on prototypes, zero-series, and/or test specimens, using testing stands and reliability trials;
c) Operational (or Effective) Reliability refers to the ability of a system, equipment, or technological process to function according to technical specifications, without failures, within normal operating parameters, over a specific period of time.

1.3 Reliability Distribution Laws and Their Applicability

Adapting the defect distribution law is a complex and challenging decision, yet essential. This decision is based on data obtained regarding changes occurring within components before failure and on the continuous study of how the process approaches failure.

1.3.1 Poisson Distribution Law: The Poisson distribution is a discrete probability law, also known as the "law of rare events," because the likelihood of a defect (event) occurring is low. If, in the context of measuring a number of elements, the defect occurrence interval is considered very large (failures are rare events), the Poisson distribution is expressed through the probability density function P(k).

1.3.2 Exponential Distribution Law: This law is based on the idea that the probability of failure within a specific time interval is proportional to the length of the interval Δt and does not depend on how long the system has been operating, only on the fact that it has functioned correctly until that moment.

1.3.3 Normal Distribution Law: Also known as the Gaussian distribution, it is one of the most important distributions in statistics and probability. It is used to describe data that symmetrically distribute around a mean and follows a bell-shaped curve. This law can be applied for monitoring and improving production processes.

1.3.4 Weibull Distribution Law: The Weibull distribution is highly flexible and can model various failure rate curve shapes, determined by two parameters - shape and scale. It is widely used in reliability engineering to model the time to failure of components and systems. It can represent different phases of the lifecycle, such as infant mortality periods, wear - out periods, or intermediate useful life phases.

1.3.5 Gamma Distribution Law: Applied in modeling the time to failure for components with high variability in failure rates, this distribution is useful due to its flexibility in modeling various scenarios and equipment behavior.

1.3.6 Rayleigh Distribution Law: Used in researching wear phenomena in cutting tools, the Rayleigh distribution is derived from the Weibull distribution when $\beta = 2$. It is applied in various fields to model phenomena where the variable of interest depends on multiple independent and identically distributed components.

1.3.7 Alpha Distribution Law: This distribution is utilized in modeling the reliability of cutting tools in both industrial operation and laboratory conditions. The Alpha distribution helps evaluate and anticipate tool performance by determining the probability that they will function correctly over a given time period.

1.3.8 Binomial Distribution Law: Applied in situations where an element fails after a certain number of cycles. The binomial distribution is useful in surveys, quality control, medical experiments, and helps estimate probabilities and make decisions based on experimental results.

2. Maintenance and Reliability of Screw-Type Electrocompressors

In the field of compression equipment maintenance, the author has encountered a variety of issues that can affect the optimal operation of these machines. The interventions performed in compressor operational fields included both unplanned (emergency) repairs and scheduled maintenance according to the Maintenance and Operation Manual.

Equipment failures are classified according to Chapter 2.2, where the nature of the defects (mechanical, electrical/ automation etc.) is detailed, along with examples for each type.

2.1 Methods for Diagnosing Malfunctions

Fig. 2.1 Vibration Level Analysis - Viber X1 vibration analyzer measuring the compressor's vibration level

Fig. 2.2 Thermographic Analysis - Infrared view of the gas - oil separator vessel

Fig. 2.3 Borescope Analysis - Internal visualization of the condition of the screw rotors

Fig. 2.4 Lubricant Analysis - Portable equipment for oil analysis

Fig. 2.5 Noise Analysis - Acoustic field distribution - The author's maintenance activities at the studied compressor location - Measured values in dB (decibels). Measurements revealed that the area with the highest acoustic radiation was the compressor housing

2.2 Malfunctions Occurred During Operation

Malfunctions are both universally applicable and specifically identified by the author during maintenance activities. These categories include:

a) Mechanical malfunctions;
b) Electrical/ electronic (or automation) malfunctions;
c) Malfunctions caused by human factors;
d) Malfunctions due to the ambient environment.

2.3 Parameters Associated with Compressor Operation

a) Load Degree – The load degree of the compression system is determined by input and output parameters under the conditions of use in natural gas compression parks or associated domains, which this study examines. The suction pressure and the temperature of the aspirated gas directly influence the compression process, with the compressors used being volumetric type.
b) Vibration Level – Vibration level is considered the best parameter for identifying dynamic conditions such as balance (general vibration), bearing defects, and component stresses. Many mechanical failures manifest as excessive vibrations.

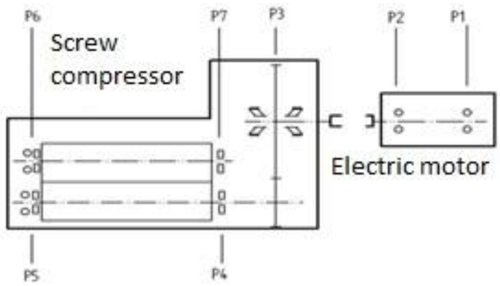


Fig. 2.6 Arrangement of measurement points for vibration levels on the compressor and drive motor.

c) Compressor Temperature in Discharge Zone – The operation of gas compression equipment generates heat (due to the thermodynamic operating principle), and in some cases, hot spots and infrared radiation may appear, detectable through thermal imaging. The causes of such radiation vary, including corrosion, power failures, excessive friction between moving metal parts, leaks of hot fluid, exceeding bearing temperatures, low oil flow etc.

The Weibull distribution law, proposed by the author, uses measured temperature parameters:

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \cdot \mathrm{e}^{-tt} \qquad (2.1)$$

where:

$$tt = \frac{measured\ working\ temperature}{shutdown\ limit\ temperature} \qquad (2.2)$$

3. Modeling and Simulations in Compressor Operation

There are many situations where the occurrence of failures cannot be characterized using either the normal or exponential distribution. This is due to the fact that failures result from mixed distributions, with some components already in the wear phase, while others have not yet entered their useful life period.

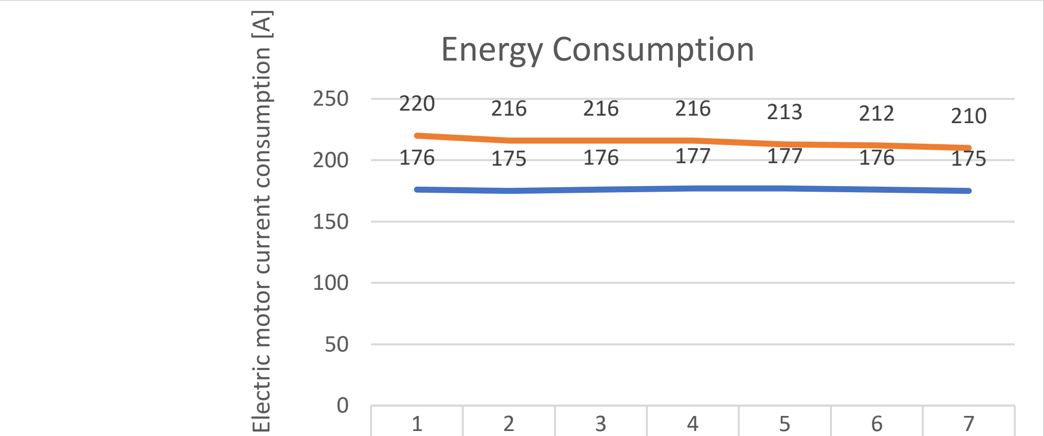
To analyze such a situation, the Weibull distribution provides a probability density function f (t, η, β, γ), which is applicable for determining the time until the first failure.

3.1 Study of the Operation of a Compression Line

Monitoring was conducted on a natural gas compression line (electrocompressor assembly) consisting of two screw compressors - one operating at low pressure and the other at high pressure - which are interdependent. The study involved tracking loading parameters, vibration levels, and compressor temperature (measured in the discharge area).

3.1.1 Load Level

Considering the two compressors, their power consumption was monitored during operation, with the next steps aimed at defining specific load levels.



	1	2	3	4	5	6	7
Low pressure compressor	176	175	176	177	177	176	175
High pressure compressor	220	216	216	216	213	212	210

Fig. 3.1 Power Consumption of a Compression Line [author's image]

To calculate the power consumed by the electric motor, the following formula will be used:

$$P = \sqrt{3} \cdot U \cdot I \cdot \cos\ \varphi \qquad (3.1)$$

Power Consumed by Low and High - Pressure Compressors Table 3.1

Time (Hour)	08:00	09:00	10:00	11:00	12:00	13:00	14:00
Compressor No. 1 (P [kW])	92,33	91,81	92,33	92,86	92,86	92,33	91,81
Compressor No. 2 (P [kW])	112,37	110,32	110,32	108,79	108,79	108,28	107,26

The load level for the studied equipment can vary between 70% and 100%, with occasional short - term operation exceeding 100%. When applying these values to the Weibull distribution with additional parameters proposed by the author, the notation ω is defined as follows:

$$\omega = \frac{compessor\ load\ level}{100} \qquad (3.2)$$

Thus, the function proposed by the author takes the following form:

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \cdot \mathrm{e}^{-(\omega-1)} \qquad (3.3)$$

where: θ - Mean Time Between Failures (MTBF) and *t - Operational period*.

Using the formula (3.2) proposed by the author, the load level of the compressors is:

Load Level of Low and High-Pressure Compressors (ω) Table 3.2

Time (Hour)	08:00	09:00	10:00	11:00	12:00	13:00	14:00
Compressor No. 1	0,839	0,835	0,839	0,844	0,844	0,839	0,835
Compressor No. 2	0,851	0,836	0,836	0,824	0,824	0,820	0,813

3.1.2 Vibration Level

When applying additional parameters to the Weibull distribution, the following situation can be identified based on the power consumed by the equipment in the work areas:

- Medium installation (Group 2) with power ranging between 15 kW and 300 kW, as defined by ISO 10816 - 3. In the studied applications, this is the most common case, leading to the following relationship proposed by the author:

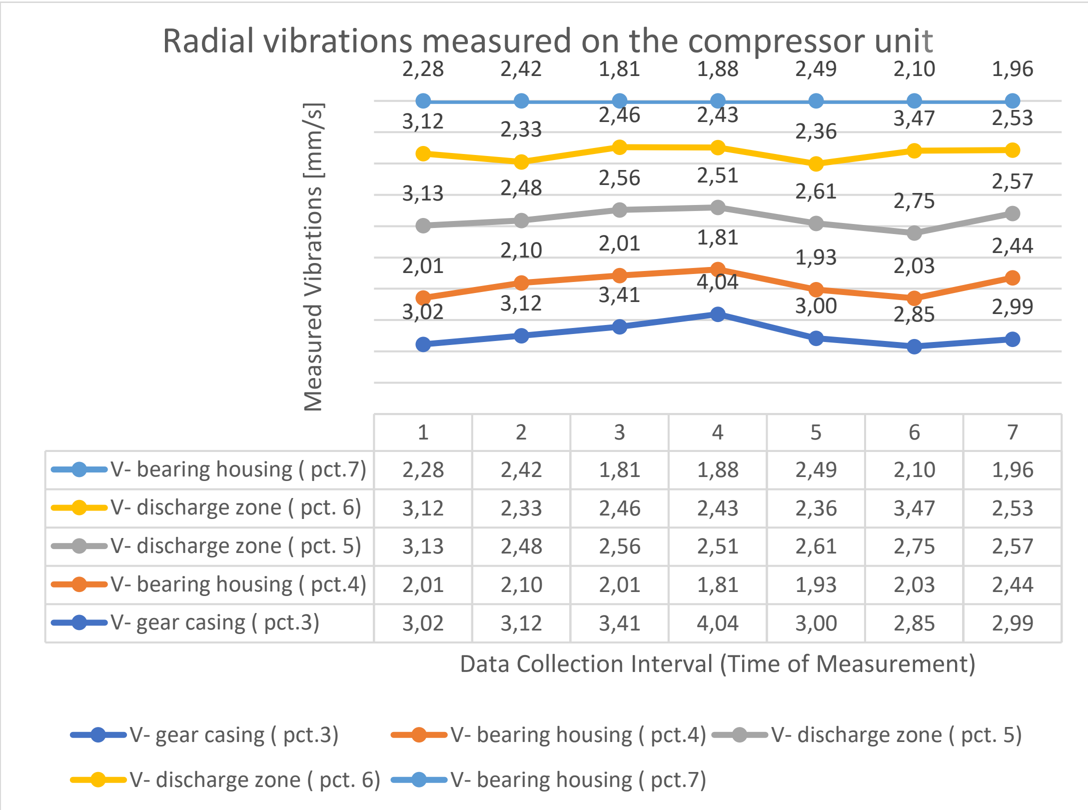
$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \cdot \mathrm{e}^{-(\mathrm{v}-1)} \qquad (3.4)$$

Based on the author's accumulated experience, the Weibull distribution is supplemented with the e^v parameter, which is critical for accurately analyzing the reliability of natural gas compression installations.

where:

$$v = \frac{\text{measured vibration level [mils/s]}}{4{,}5\ \text{mils/s}} \qquad (3.5)$$

The limitation of the vibration level to 4,5 mils/ s for flexible foundations, in accordance with ISO 10816-3, under restricted operating conditions, is of major importance. Introducing these limits ensures that, based on the obtained results, the compression installation can be shut down, thereby minimizing potential failures caused by excessive vibration levels.



	1	2	3	4	5	6	7
V- bearing housing (pct.7)	2,28	2,42	1,81	1,88	2,49	2,10	1,96
V- discharge zone (pct. 6)	3,12	2,33	2,46	2,43	2,36	3,47	2,53
V- discharge zone (pct. 5)	3,13	2,48	2,56	2,51	2,61	2,75	2,57
V- bearing housing (pct.4)	2,01	2,10	2,01	1,81	1,93	2,03	2,44
V- gear casing (pct.3)	3,02	3,12	3,41	4,04	3,00	2,85	2,99

Fig. 3.2 Measured Vibrations on the Compression Unit (Vertical) [author's image]

3.1.3 Temperature

The Weibull distribution law proposed by the author, considering the temperature parameters measured, is:

$$R(t) = \cdot\, e^{-\left(\frac{t}{\theta}\right)^{\beta}} \cdot e^{-tt} \qquad (3.6)$$

The additional parameter "tt" can have different values depending on the studied equipment (electric motor, compressor, electrical drives, pumps, oil coolers, separator vessels etc).

Fig. 3.3 Thermographic Analysis of the Compression Unit

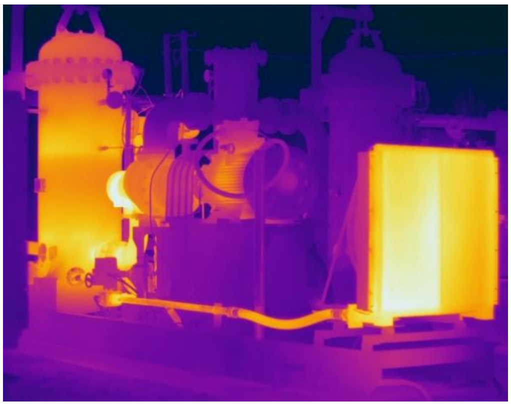


Fig. 3.4 Thermographic Analysis of Low-Pressure Compression Skid

3.2 Reliability Simulations for Screw Compressors

Simulations allow the evaluation of compressor performance under different operating conditions. This helps optimize design and identify critical parameters that influence efficiency and reliability.

To analyze the reliability of compression equipment, three compressors of the same type, but with different performance levels, were studied. They were monitored during operation for over four years, enabling the identification of key working parameters that impact equipment functionality.

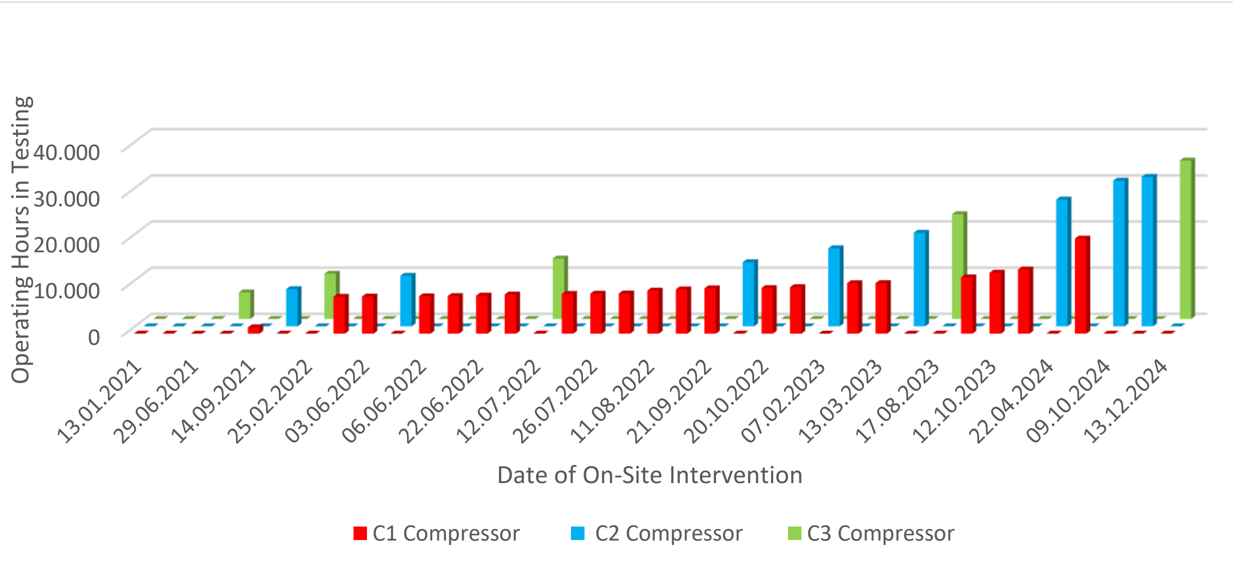


Fig. 3.5 Interventions on Compressors C1, C2 and C3 [author's image]

Based on the previous analysis, the Mean Time Between Failures (MTBF), represented by θ, can be calculated for the three studied compressors. The failure rate λ is determined as follows:

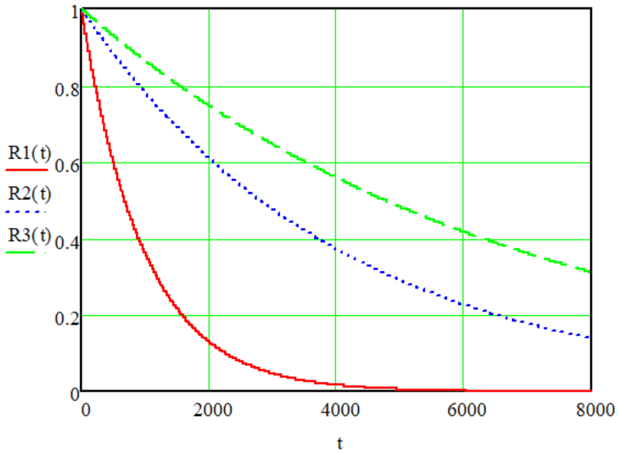
$$\lambda = \frac{Number\ of\ failures}{Operating\ Time\ (cycles)} = \frac{1}{\theta} \quad (3.7)$$

The resulting MTBF and failure rates for each compressor are presented in Table 3.3:

Mean Time Between Failures for Tested Compressors Table 3.3

Operating Time / Compressor	Compressor C1	Compressor C2	Compressor C3
MTBF	981	4.049	6.864
Failure Rate (Failures per Hour of Operation)	0,00101922	0,00024695	0,00014569

If t is selected as an interval of 8,000 hours (in this case, RC1 - Current Repair 1), which equals one year of continuous operation, the equipment reliability follows the graph presented.



Time (Operating Hours)

Fig. 3.6 Reliability of the Installation Using the Classical Weibull Law [author's image]

Where:

R1(t) – Reliability function for Compressor C1;

R2(t) – Reliability function for Compressor C2;

R3(t) – Reliability function for Compressor C3.

Thus, by selecting the following values for t, the equipment reliability over a given period can be obtained as shown in Table 3.4.

Reliability of equipment C3 using classical Weibull analysis Table 3.4

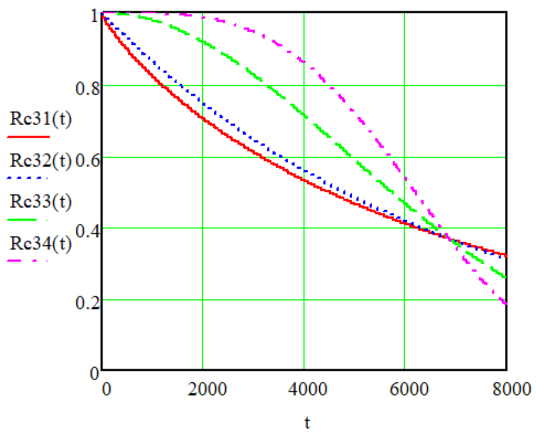
No.	t (operating hours)	R(t) value	Equipment reliability
1	24	0,997	99 %
2	48	0,993	99 %
3	168	0,976	97 %
4	720	0,900	90 %
5	4.000	0,558	55 %
6	8.000	0,312	31 %

3.3 Variations of the shape parameter, β, using the Weibull Law

Considering the shape parameter, β, graphs can be plotted for different equipment life stages:

Values of the shape parameter, β — Table 3.5

β Values	Equipment Life Stage	Test Value
β < 1	Infant Stage (Early Defects)	0,85
β = 1	Useful Life Stage (Accidental Defects)	1
β > 1	Wear Stage (Accidental Defects and Wear)	2
β >1	Wear stage (Accidental Defects and Wear)	3,5



Time (Operating Hours)

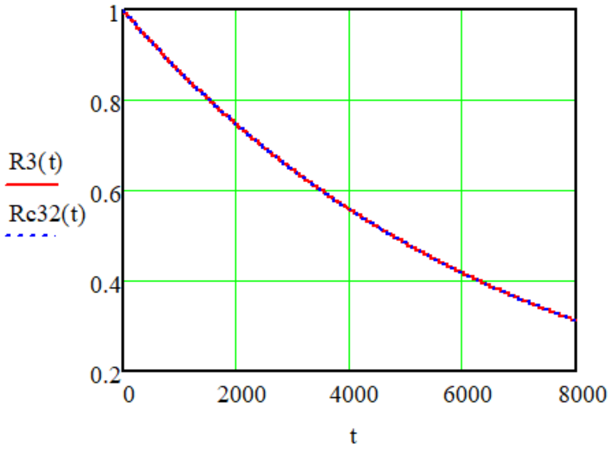
Fig. 3.7 Reliability of Compressor C3 Based on Life Stage [author's image]
Where:
Rc31 – Reliability function R(t) when β = 0,85
Rc32 – Reliability function R(t) when β = 1
Rc33 – Reliability function R(t) when β = 2
Rc34 – Reliability function R(t) when β = 3,5

3.4 The Author's Proposed Law

Considering the Weibull-type law proposed by the author, it includes three additional parameters as follows:

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \cdot e^{-(\omega-1)} \cdot e^{-(\nu-1)} \cdot e^{-tt} \tag{3.8}$$

By applying the normal values of the additional parameters from Table 3.6, the following graph is obtained:



Time (Operating Hours)

Fig. 3.8 The superimposition of the curves plotted with the classical law and the one proposed by the author with additional parameters, under operating conditions with normal values [author's image].

Where: Rc32(t) represents reliability using the author's law with normal values from Table 3.6, with a β value of 1; R3(t) represents reliability using the classical Weibull law.

The selection of additional parameters in the new law proposed by the author was carried out so that under normal operating conditions, the two laws (Weibull and the author's law) are almost identical. The calculation formulas for the three proposed parameters, "ω," "v," and "tt," were chosen based on their influence and importance in the functioning of the installation.

Values of the additional parameters proposed by the author Table 3.6

Proposed Parameters	Minimum Value	Normal Value*	Maximum Value (Compressor Stop Limits)
ω	0,70	0,85	1,20
v	0,20	0,55	1,57
tt	0,18	0,63	1,18

* Note: The normal values resulted from the average of the operating parameters measured during the author's maintenance activities.

In the modeling process, an average operational reliability time of θ = 8.000 hours was introduced, with a measurement interval of t = 10.000 hours. The law proposed by the author aims to indicate equipment reliability at different operating hours by varying additional parameters related to loading, vibration, and compressor temperature. The shape parameter, β, is set to 1.

Equipment reliability varying with load level Table 3.7

	Maintenance interval				
Distribution Law	720 hours (1 month)	4.000 hours (6 months)	8.000 hours (12 months)	16.000 hours (2 years)	32.000 hours (4 years)
R(t) Weibull Distribution	0,914	0,607	0,368	0,135	0,018
R(t) Author's law-Minimum Load	1,03	0,687	0,415	0,153	0,021
R(t) Author's law-Normal Load	0,887	0,589	0,357	0,131	0,018
R(t))Author's law-Maximum Load	0,625	0,415	0,252	0,093	0,013

Equipment reliability varying with vibration level Table 3.8

	Maintenance interval				
Distribution Law	720 hours (1 month)	4.000 hours (6 months)	8.000 hours (12 months)	16.000 hours (2 years)	32.000 hours (4 years)
R(t) Weibull Distribution	0,914	0,607	0,368	0,135	0,018
R(t) Author's law-Minimum Load	1,259	0,835	0,507	0,186	0,025
R(t)) Author's law-Normal Load	0,887	0,589	0,357	0,131	0,018
R(t)) Author's law-Maximum Load	0,32	0,212	0,129	0,047	0,006

Equipment reliability varying with gas discharge temperature Table 3.9

	Maintenance interval				
Distribution Law	720 hours (1 month)	4.000 hours (6 months)	8.000 hours (12 months)	16.000 hours (2 years)	32.000 hours (4 years)
R(t) Weibull Distribution	0,914	0,607	0,368	0,135	0,018
R(t) Author's law-Minimum Load	1,391	0,923	0,56	0,206	0,028
R(t)) Author's law-Normal Load	0,887	0,589	0,357	0,131	0,018
R(t)) Author's law-Maximum Load	0,512	0,34	0,206	0,076	0,01

3.5 Minimum and Maximum Reliability Values of Compressors

After introducing normal values for the additional parameters and studying the overlap with the classical law, the following formula was derived:

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \cdot e^{-(\omega-1)} \cdot e^{-(\nu-1)} \cdot e^{-tt} \qquad (3.9)$$

Compressor reliability over operating hours Table 3.10

Vibration values	24 hours		48 hours		168 hours		720 hours	
C1- 4,5 mm/ s	0,604	**60 %**	0,589	**58 %**	0,521	**52 %**	0,297	**29 %**
C1- 7,1 mm /s	0,341	**34 %**	0,333	**33 %**	0,295	**29 %**	0,168	**16 %**
C2- 4,5 mm/ s	0,615	**61 %**	0,611	**61 %**	0,594	**59 %**	0,518	**51 %**
C2- 7,1 mm/ s	0,348	**34 %**	0,346	**34 %**	0,336	**33 %**	0,293	**29 %**
C3- 4,5 mm/ s	0,617	**61 %**	0,614	**61 %**	0,604	**60 %**	0,557	**55 %**
C3- 7,1 mm/ s	0,349	**34 %**	0,347	**34 %**	0,341	**34 %**	0,315	**31%**

4. Experimental Research on Compressor Operation

The purpose of the experimental research was to validate the model applied in the simulations presented in Chapter 3, within a real-world application, using measured parameters before equipment failure. Additionally, the goal was to ensure that errors in relation to the author's proposed law were minimized and much closer to reality compared to the classical Weibull law.

4.1 Compressor C3 Experimentation

The reliability evolution of Compressor C3 involves analyzing multiple key parameters, similar to Compressors C1 and C2, which were measured for various failures occurring during operation.

Compressor C3 Failures Table 4.1

	Failure 1	Failure 2	Failure 3	Failure 4	Failure 5
M.T.B.F. (θ)	6.864 hours				
Hours until failure	5.760	4.032	3.288	9.674	11.616
Load	82 %	84 %	80 %	77 %	70 %
Vibration Level	2,8 mm/ s	2,9 mm/ s	3,0 mm/ s	3,1 mm/ s	3,4 mm/ s
Temperature	75 °C	77 °C	78 °C	81 °C	79 °C

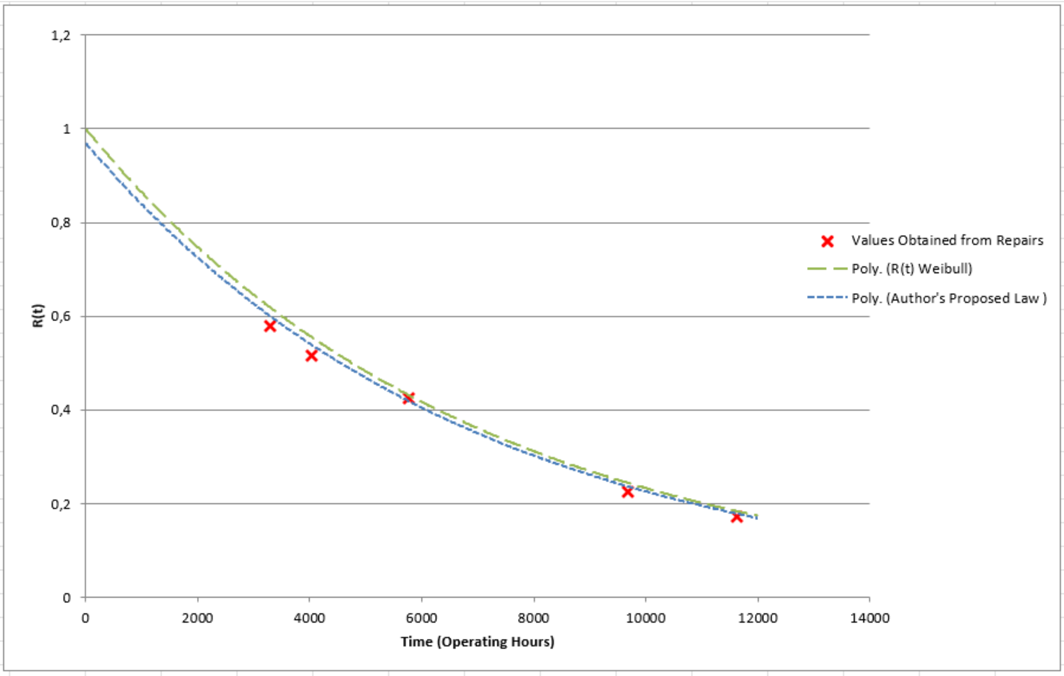


Fig. 4.1 Experimental values obtained from monitoring compressor C3 comparison between the classical Weibull law and the author's proposed law [author's image]

Comment: The points marked with a red X are much closer to the curve proposed by the author compared to the classical Weibull law. The author's curve includes adjustments and specific factors that are not considered in the classical Weibull model, making it better suited to reflect the real behavior of Compressor C3.

Errors obtained in the reliability calculation of compressor C3 Table 4.2

Comparative Analysis/ Errors	Failure error 1	Failure error 2	Failure error 3	Failure error 4	Failure error 5
Theoretical Formula Proposed by the Author vs. Obtained Results	1,1 %	4,6 %	3,6 %	5,1 %	3,3 %
Classical Weibull Formula vs. Obtained Results	1,9 %	7,4 %	6,4 %	7,9 %	6,1 %

Comment: The theoretical formula proposed by the author is more accurate, with lower errors compared to the classical Weibull law across all analyzed failures. This suggests that the author's formula could provide a better estimation of Compressor C3's reliability. The proposed law proves to be more precise, with significant differences in errors, ranging between 0.8% and 2.8%, demonstrating better accuracy in estimating reliability across all examined failures.

5. General Conclusions

This study aims to contribute to the reliability calculation of natural gas compression installations equipped with screw compressors. Compared to classical tools, the study proposes an improvement to the Weibull law by introducing new parameters closely linked to the vibration levels of the compression assembly (especially the main electric motor and screw compressor) and the thermal conditions under which these units operate.

Thus, the author's experience, accumulated over more than 12 years in screw compressor maintenance, along with the application of the new Weibull law, can be utilized in the reliability assessment of these types of equipment.

The author's proposed law, combined with modeling and simulations conducted throughout the study, has generated conclusive results that are practically applicable and highly relevant for improving the reliability of natural gas compression systems in industrial settings.

6. Original Contributions of the Author

The doctoral thesis addresses a highly relevant topic for manufacturers of compression equipment, especially for the National Institute for Research and Development in Turbomotors COMOTI. The subject of the thesis was driven by the manufacturer's need for a study on the operational reliability of screw compressors.

The author of the thesis has made the following original contributions in this work:

1. A comprehensive study on reliability issues, including the analysis of failure distribution laws, which is highly useful for maintenance studies.
2. A new failure distribution law, based on Weibull, was proposed, incorporating additional factors such as load level, vibration level, and temperature. The author's new law allows for the accurate determination of screw compressor reliability.
3. Through experimentation, the author has determined coefficient values introduced in the original distribution law, which are extremely useful for reliability calculations.
4. The author's proposed law includes critical elements - load level, vibration level, and temperature - which are essential for the operation of screw - type electrocompressors. These elements are not present in other failure distribution models.

7. Future Research Directions

The additional parameters used in the current application of the Weibull law can be refined by considering technological indices specific to the studied equipment. In this context, additional parameters may be introduced that are influenced by the quality of the lubrication oil in the system - a factor frequently reported in the operation of these machines, contributing to a high number of failures.

The introduction of a new method could lead to significant improvements in reliability and open new perspectives for research and development.

List of Published Works and Professional Activity

[1] **Robert Isac**, Teodor Stănescu, Valentin Petrescu- Infrared termography- Extending operating life of natural gas compression equipment with screw compressor units, CIEM 2023

[2] Teodor Stănescu, Valentin Petrescu, **Robert Isac**, Elena Presură- Chirilescu, Daniel Ușeriu, Gabriel Badea- Performance analysis of centrifugal blowers with inlet guide vane control under different inlet conditions- CIEM 2023

[3] **Robert Isac**, Daniel Crunțeanu „Investigation of low emission combustors using hydrogen lean direct injection”, Incas Bulletin, Volume 3, București, 09/2011;

[4] Robert Isac, Florin Frunzulică, Daniel Crunțeanu, "Aerodynamic study of active flow control using blowing jets over some trailing edge configurations", ICNAAM 2014

[5] Iulian Vladucă, **Robert Andrei Isac**, Vicențiu Liviu Ringheanu, Emilian Toma, Carmen Petre, Ramona- Manuela Stanciuc, Daniela Constantin, Mirela- Letiția Vasile- Reliability and maintenance of motor operated valves, in the romanian natural gas compression and distribution stations- Technium Vol. 21, 2024

[6] Valentin Petrescu, Teodor Stănescu, Eduard Vasile, **Robert Isac**, Daniel Lale- Theoretical and experimental research om the pressure variation in the compression chamber of the oil injected screw compressor- UPB Sci. Bull., Series D, Vol. 85, Iss 4, 2023

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[8] **Robert Isac**- Responsabil de contract- “Cercetări privind diagnoza şi predicţia timpului de bună funcţionare la turbomaşini”- Nucleu 11N/2016/ cod PN 16.26.03

[9] **Robert Isac**- Responsabil de contract- “Cercetări fundamentale în domeniul monitorizării şi diagnozei în timp real pentru mentenanța predictivă la mașini rotative utilizate în aplicații aerospaţiale şi navale, folosind simulări Hardware-in-the-Loop, semnale de vibrații şi acustice”- Nucleu 31N, PN 23.12.08.01

[10] **Robert Isac**- Responsabil de contract MN 013.P- Isac- MND Cehia reparație compresoare cu șurub de tip CU64GM;

[11] **Robert Isac**- Responsabil de contract- Expert Petroleum Solutions- Mentenanță și întreținere compresoare cu șurub de tipul CF246- zona Țicleni; 2014- prezent;

[12] **Robert Isac** Activități de ofertare tehnico- financiare pentru reparații compresoare OMV- Petrom, Mazarine Energy, Dacian Petroleum, Petrofac și Expert Petroleum;

[13] **Robert Isac**- Activități de mentenanță și întreținere la electrocompresoare cu șurub Contract 99008802 ECS și 99008642- 2012÷2025; Reparații și punere în funcțiune;

[14] **Robert Isac** Activități de ofertare tehnico- financiare pentru reparații turbosuflante ALCO TS 165 (TS5) și TS131(TS6);
[15] **Robert Isac-** Activități de ofertare tehnico- financiare pentru reparații turbosuflante HV- Turbo; Reparații și punere în funcțiune;
[16] **Robert Isac** - Activități de ofertare tehnico- financiare pentru reparații suflante cu lobi- AERZEN GM 7, GM11 și GM35; Reparații și punere în funcțiune;
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