

Strategic Inventory Management of Mechanical Seals: An Approach to Efficient Industrial Maintenance

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*Gestão de Estoque Estratégica de Selos Mecânicos: Uma
Abordagem para Manutenção Industrial Eficiente
Gestión estratégica de inventario de sellos mecánicos: Un enfoque
para un mantenimiento industrial eficiente*

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Abstract:

Strategic inventory management is a key factor for the operational efficiency of industrial environments, especially when it involves critical components such as mechanical seals. These devices, responsible for sealing rotating systems, are essential to ensure the continuity of production processes and prevent failures that may lead to financial and operational losses. This study aimed to analyze inventory management strategies applied to mechanical seals in industrial settings, focusing on the improvement of maintenance processes. A qualitative bibliographic review was carried out, based on books, scientific articles, and technical documents available in databases such as Google Scholar, Scielo, PubMed, and institutional virtual libraries. The theoretical analysis was structured around three axes: strategic inventory management, industrial maintenance, and mechanical seal characteristics. The results indicated that integration between logistics, engineering, and maintenance, combined with the use of criticality analysis tools and technical indicators, contributes to increased operational reliability and cost reduction. It was concluded that the adoption of strategic inventory management practices for these components can represent a competitive advantage when based on accurate data and aligned with real operational needs.

Keywords: Inventory Management; Industrial Maintenance; Mechanical Seals; Operational Reliability; Spare Parts.

Resumo:

A gestão estratégica de estoques representa um fator determinante para a eficiência operacional das indústrias, especialmente quando se trata de componentes críticos como os selos mecânicos. Estes dispositivos, responsáveis pela vedação de sistemas rotativos, são essenciais para a continuidade dos processos produtivos e para a prevenção de falhas que podem gerar prejuízos financeiros e operacionais. O presente estudo teve como objetivo analisar estratégias de gestão de estoque aplicadas aos selos mecânicos em ambientes industriais, com foco na melhoria dos processos de manutenção. Para isso, foi realizada uma revisão bibliográfica com abordagem qualitativa, baseada em livros, artigos científicos e documentos técnicos disponíveis em bases como Google Acadêmico, Scielo, PubMed e bibliotecas virtuais. A análise teórica foi dividida em três eixos: gestão estratégica de estoques,



manutenção industrial e características dos selos mecânicos. Os resultados evidenciaram que a integração entre logística, engenharia e manutenção, aliada à utilização de ferramentas como a análise de criticidade e indicadores técnicos, contribui para o aumento da confiabilidade operacional e redução de custos. Concluiu-se que a adoção de práticas estratégicas de gestão para esses componentes pode representar um diferencial competitivo, desde que fundamentada em dados e alinhada às reais necessidades da operação.

Palavras-chave: Gestão de Estoques; Manutenção Industrial; Selos Mecânicos; Confiabilidade Operacional; Peças de Reposição.

Resumen:

La gestión estratégica de inventarios representa un factor determinante para la eficiencia operativa de las industrias, especialmente en lo que respecta a componentes críticos como los sellos mecánicos. Estos dispositivos, responsables de sellar sistemas rotativos, son esenciales para la continuidad de los procesos de producción y para la prevención de fallos que puedan generar pérdidas financieras y operativas. El presente estudio tuvo como objetivo analizar las estrategias de gestión de inventario aplicadas a los sellos mecánicos en entornos industriales, centrándose en la mejora de los procesos de mantenimiento. Para ello, se realizó una revisión bibliográfica con un enfoque cualitativo, basada en libros, artículos científicos y documentos técnicos disponibles en bases de datos como Google Scholar, Scielo, PubMed y bibliotecas virtuales. El análisis teórico se dividió en tres ejes: gestión estratégica de inventarios, mantenimiento industrial y características de los sellos mecánicos. Los resultados mostraron que la integración entre logística, ingeniería y mantenimiento, combinada con el uso de herramientas como el análisis de criticidad e indicadores técnicos, contribuye al aumento de la fiabilidad operativa y a la reducción de costes. Se concluyó que la adopción de prácticas de gestión estratégica para estos componentes puede representar una ventaja competitiva, siempre que se basen en datos y estén alineadas con las necesidades reales de la operación.

Palabras clave: Gestión de inventario; Mantenimiento Industrial; Sellos mecánicos; Fiabilidad operativa; Piezas de repuesto.

1. Introduction

Strategic inventory management has become a key tool for ensuring operational efficiency and competitiveness in industrial companies. In highly dynamic production environments, such as the industrial sector, the availability of spare parts, especially mechanical seals, is crucial for process continuity and the prevention of unscheduled downtime. Because mechanical seals seal rotating equipment, they are critical to the proper functioning of pumps, compressors, and mixers and directly affect safety, operational integrity, and production losses.

In recent decades, industrial maintenance systems have grown significantly more complex, requiring more precise, strategic inventory management aligned with real production needs. Mechanical seal unavailability can cause delays, increase operating costs, and compromise productivity. On the other hand, excess inventory creates costs from storage, obsolescence, and tied-up capital, highlighting the need to balance demand, replenishment, and availability for critical items.

The main problem is how to optimize mechanical seal inventory management to ensure efficient industrial maintenance without increasing the company's operating costs. Although various inventory management practices exist, many organizations still struggle to establish appropriate strategic criteria for managing technical items, especially highly critical ones such as mechanical seals.

Given this scenario, the present research is justified by the topic's practical and academic relevance, as it proposes to examine inventory management solutions focused on industrial maintenance, contributing to increased operational reliability, reduced costs, and improved logistical performance. Tools such as the ABC curve, criticality analysis, and integration with predictive maintenance systems can, when used effectively, turn spare parts management into a competitive advantage.

In this sense, this study aims to analyze inventory management strategies for mechanical seals in industrial environments, focusing on improving maintenance processes and operational efficiency. It also aims to present effective practices adopted by companies in the sector, highlighting the importance of integrating maintenance, supply, and logistics planning to ensure more assertive and rational inventory management.

2. Theoretical Framework

2.1 Strategic Inventory Management in Industry

Strategic inventory management consists of practices and tools that plan, control, and optimize the movement of materials within an organization, balancing logistics costs with the availability of inputs needed for operations. In the industrial context, this approach takes on an essential role, especially when

dealing with critical components such as mechanical seals, whose absence can directly compromise equipment performance and cause unplanned downtime. Therefore, inventory management becomes more than an operational function and takes on a strategic role, contributing to the company's sustainability and competitiveness (Araújo; Barros, 2021).

Given the scope of this work, which examines the relationship between mechanical seal management and industrial maintenance efficiency, it is essential to understand how effective inventory structuring directly affects production reliability. In industries with high equipment turnover and reliance on specific parts, the absence of a replacement plan based on technical criteria can lead to delays, rework, wasted resources, and even operational accidents. Furthermore, strategic inventory management must be integrated into maintenance planning to enable proactive responses to operational and technical demands and ensure the smooth flow of industrial activities, even in the face of unforeseen events (Souza; Barbosa, 2024).

Authors such as Martins and Alt (2021) highlight that materials management in modern organizations should be based on performance indicators and criticality analyses, allowing replacement items to be categorized by their importance to the operation. In this sense, tools such as the ABC Curve and XYZ Analysis are widely used, enabling prioritization of items with the greatest impact on the production process. Complementing this view, Costa and Moraes (2021) argue that lean practices, such as the just-in-time system and reducing inactive inventories, can promote greater efficiency and reliability, provided they align with actual demand behavior and the predictability of failures.

Despite consensus on the importance of inventory management, disagreements remain about how to apply it, especially for technical items and spare parts. While authors such as Carvalho and Pereira (2023) advocate an approach based on the predictability of failures and consumption history, suggesting technically sized minimum stock levels, other authors, such as Cavalcante et al. (2020), draw attention to the risks of this practice in contexts of uncertainty, where the replenishment lead time is high, and suppliers lack stability. In these cases, more conservative practices with larger safety stocks may be more appropriate, even if less economical.

These discrepancies also reveal limitations in the most widespread approaches, especially in companies that deal with multiple pieces of equipment from different origins and technologies. Standardizing parts, while desirable, is not always feasible, which increases management complexity. Furthermore, traditional tools such as the ABC curve, while useful, do not always capture an item's technical criticality. As Machado and Lopes (2020) highlight, classifying items solely by monetary value may be insufficient when equipment failure risks safety, the environment, or continuous production. In these cases, combining qualitative and quantitative tools is more effective.

Connecting this discussion to the central problem of this study, strategically managing mechanical seals is a significant challenge in industrial inventory planning. These components have technical particularities that require specific control and replenishment criteria. Criticality analysis is indispensable for defining appropriate inventory policies, but its application depends on integration across maintenance, supply, and engineering. For Pereira and Santos (2023), effectiveness in managing these items is only achieved when a multidisciplinary approach is adopted, based on historical failure data, operational reliability, and productive impact, elements often neglected by generic inventory control models.

2.2 Industrial Maintenance: Types, Strategies, and Operational Impacts

Industrial maintenance refers to the technical, operational, and managerial actions that preserve, restore, and optimize the performance of an organization's physical assets. It encompasses everything from simple corrective repairs to complex strategies for monitoring and predicting failures. In production, its role goes beyond correcting defects; it aims to ensure operational continuity, process safety, and equipment availability. Advancing industrial technologies and increasingly complex systems have made maintenance a strategic activity that directly affects companies' productivity and competitiveness (Bastos; Silva, 2022).

Within this study, which analyzes the strategic inventory management of mechanical seals, industrial maintenance emerges as the essential link between logistical planning and operational performance. Mechanical seals are critical in rotating systems and require planned replacement aligned with scheduled or preventive maintenance cycles. Missing this component during maintenance can cause delays, financial losses, and increased equipment downtime. Furthermore, the type of maintenance adopted—corrective, preventive, predictive, or detective—directly influences the spare parts management policy, so inventories must meet the requirements of each approach (Ferreira; Gomes, 2023).

From a theoretical standpoint, several authors classify maintenance according to its nature and purpose. Corrective maintenance, for example, occurs after a failure and is reactive and often more expensive. Preventive maintenance, by contrast, is scheduled at predefined intervals, regardless of the equipment's actual condition. Predictive maintenance, in turn, relies on monitoring operational variables, allowing more precise interventions, while detective maintenance seeks to identify hidden failures in critical systems. Cavalcante et al. (2020) point out that the more advanced the maintenance strategy, the greater the need for integration between the sectors responsible for parts management, which includes inventory control of components such as mechanical seals.

However, scholars disagree on the effectiveness of each strategy in different industrial contexts. While authors such as Marinho and Vasconcelos (2022) argue

that predictive maintenance is the most efficient model for reducing costs and avoiding unexpected failures, other researchers, such as Lima and Oliveira (2021), draw attention to the limitations of this approach in companies with low technological maturity or with difficulties in accessing reliable data. In these cases, preventive maintenance is still more applicable, even if it results in premature component replacements. This divergence highlights that the choice of maintenance model should consider not only the type of equipment and its criticality, but also the technical, human, and financial resources available to the organization.

Criticism is also directed at how many companies manage spare parts, ignoring how maintenance strategy affects inventory structure. Freitas et al. (2024) observe that, even in companies that adopt predictive maintenance, the absence of integrated supply policies can compromise expected operational gains. Furthermore, overstocking as a form of "insurance" against failures reveals a planning flaw, creating hidden costs from storage, obsolescence, and idle capital. For Rodrigues and Medeiros (2022), avoiding these problems depends on precise analysis of asset reliability, which enables sizing minimum technical inventories and predicting actual demand for replacement components.

The relationship between maintenance and inventory management becomes even more critical when dealing with highly complex, specialized components such as mechanical seals. Because of their sealing function and operation under high pressures, temperatures, and rotation, these items have a limited lifespan, and failures can have a high impact. The lack of an adequate maintenance model compromises the predictability of when these items need replacement, which directly affects inventory planning. Pereira and Santos (2023) highlight that correctly identifying the mean time between failures (MTBF) and the mean time to repair (MTTR) is essential for defining efficient supply policies, especially in industrial environments with continuous production and little room for unplanned interruptions.

2.3 Mechanical Seals: Function, Reliability and Replacement Management

Mechanical seals are fundamental devices in industrial systems that operate with pressurized fluids, their main function being to seal rotating shafts in pumps, compressors, agitators, and other equipment. Their operation prevents leaks that could compromise process performance, cause economic losses, create environmental risks, and threaten workplace safety. Unlike simpler sealing solutions, such as gaskets, mechanical seals offer greater efficiency, durability, and reliability, and are therefore widely used in sectors such as petrochemical, food, pharmaceutical, and mining (Lima; Oliveira, 2021).

Within the scope of this research, which addresses the strategic management of critical parts inventories for industrial maintenance, mechanical seals deserve special attention because of their technical complexity, long replacement times,

and high operational impact if they fail. Inadequate management of these components can result in unforeseen shutdowns, production losses, and a significant increase in emergency maintenance costs. Therefore, analyzing the reliability of these items and planning their replacement are critical to ensuring continuity of industrial processes and equipment integrity (Ferreira; Gomes, 2023).

From a technical standpoint, mechanical seals are composed of static and rotating elements that operate in constant contact under pressure and temperature. Their failure generally results from wear, excessive vibration, installation errors, or degradation of the sealing materials. Considering this, authors such as Pereira and Santos (2023) advocate management based on indicators such as mean time between failures (MTBF) and estimated service life, as well as adopting predictive maintenance that allows planned replacement before complete failure. Rodrigues and Medeiros (2022) point out that, in addition to technical monitoring, correct stock sizing should consider supply time and seal availability in the market.

However, opinions differ on the most effective way to manage mechanical seal replacement. While some experts advocate adopting minimum stock levels based on statistical analyses of consumption and operational criticality, others warn of the risks in environments with high variability in processes and equipment. Freitas et al. (2024) observe that, in many companies, seals lack standardization, which hinders immediate replacement and requires maintaining multiple versions in stock, increasing logistical costs and control complexity. In this scenario, practices such as model standardization and integration with strategic suppliers are recommended, although not always feasible in older or heterogeneous industrial plants.

Criticism is also directed at the exclusive use of quantitative tools, such as ABC and XYZ curves, in managing mechanical seals. This methodology, while useful for classifying items by value or frequency of use, may overlook how component failure affects the production process. Machado and Lopes (2020) emphasize that, in many cases, mechanical seals classified as low turnover are, in fact, extremely critical, and their absence can represent significant losses. Therefore, combining quantitative methods with qualitative criteria, such as operational impact and replacement time, better supports efficient inventory policies.

In relation to the central problem of this study, the lack of specific strategies for managing mechanical seals represents a significant gap in most approaches to industrial maintenance and supply. Although literature reinforces the importance of these components, cases where companies face supply disruptions due to poor forecasting and planning remain common. Souza and Barbosa (2024) emphasize that, to overcome this challenge, companies must integrate maintenance, engineering, and logistics, promoting information flow that

enables demand anticipation and agile replenishment of items essential to operations.

3. Method

To develop this study, a literature review was conducted using a qualitative approach with an exploratory and descriptive character. The choice of this type of methodology was justified by the need to understand, analyze, and interpret the main concepts, practices, and results already consolidated in the scientific literature on the management of mechanical seal inventories and their relationship with the efficiency of industrial maintenance. The focus was on gathering theoretical information to build a solid basis for analyzing the proposed problem and to support the discussions carried out throughout the research.

The research sources were selected through systematic searches in recognized academic databases, such as Google Scholar, SciELO, and PubMed, in addition to consulting the institutional virtual libraries of public and private universities. We used specific descriptors on these platforms, such as "industrial inventory management," "predictive maintenance," "mechanical seals," "spare parts inventory," and "operational reliability." The study also considered technical books and academic theses published in the last five years, prioritizing national and international authors with recognized contributions in logistics, maintenance engineering, and asset management.

The selection criteria included timeliness, relevance to the topic, source credibility, and theoretical coherence with the study's objectives. After data collection, the data were organized into thematic summaries to systematize information by analytical categories: inventory management, maintenance strategies, and characteristics of mechanical seals. Subsequently, the content was analyzed through critical and interpretive reading, relating different authors, comparing perspectives, and identifying conceptual convergences and divergences.

The data tabulation was done manually, using comparative tables, concept maps, and thematic summaries, which facilitated the organization of arguments throughout the text. The data analysis aimed to identify the main factors influencing the efficiency of mechanical seal inventory management, as well as the impact of the choice of maintenance strategy on the availability of these items. This process allowed the article's development sections to be theoretically grounded and enabled a critical discussion aligned with the research objectives.

4. Results and Discussion

This study used an exploratory and descriptive approach, with a theoretical foundation divided into three main axes: strategic inventory management,

industrial maintenance, and mechanical seals. The research was based on a systematic bibliographic survey of technical books and scientific articles published in the last five years, focusing on the integrated analysis of inventory and maintenance. The central proposal was to understand how the strategic management of mechanical seals can improve industrial maintenance efficiency, reduce operational costs and increase the availability of productive assets.

In the chapter on strategic inventory management, the results showed that adopting methodologies such as the ABC and XYZ Curves, combined with operational criticality analyses, is an indispensable tool for prioritizing replacement items (Martins; Alt, 2021; Machado; Lopes, 2020). The review data indicate that companies that integrate inventory management into maintenance planning perform better in parts availability, obsolescence reduction, and logistics cost control. However, the review found that quantitative methods remain prevalent, which limits control effectiveness for technical items such as mechanical seals, whose criticality is tied not only to financial value but also to the operational impact of their absence (Araújo; Barros, 2021).

In industrial maintenance, the research showed that the strategy adopted directly influences the supply model and inventory control. Organizations that use predictive maintenance have greater predictability of failures, allowing them to reduce inventory and direct resources to higher-risk items, such as primary seals like faces and critical secondary seals like *O-rings* (Bastos; Silva, 2022; Cavalcante et al., 2020). However, in industrial environments with obsolete infrastructure or a lack of monitoring technologies, preventive maintenance remains predominant, requiring larger safety stocks to ensure emergency response. This duality emerged as a frequent challenge in the companies analyzed by Ferreira and Gomes (2023) and Rodrigues and Medeiros (2022), who highlight the importance of operational and technological maturity in defining maintenance policy.

Regarding the chapter that specifically addressed mechanical seals, it was observed that their strategic function in industrial processes is unquestionable. Recent studies indicate that these components' failure is among the main causes of unscheduled shutdowns in sectors such as petrochemicals and sanitation (Lima; Oliveira, 2021; Pereira; Santos, 2023). The results show that, despite the high unit cost, the absence of these items poses a high risk to industrial plant performance. Freitas et al. (2024) highlight that many companies still lack standardized models, increasing inventory management complexity and directly affecting maintenance schedules. The comparison of the most consolidated management models showed that companies integrating maintenance, engineering, and logistics achieved greater efficiency in replacing mechanical seals and lower rates of operational unavailability (Souza; Barbosa, 2024).

Comparing the three thematic axes, the study found that efficiency in managing mechanical seals depends directly on the quality of strategic inventory planning

and the maintenance model adopted. The literature indicates that communication failures between sectors, a lack of reliable historical data, and the use of generic control methodologies are the main factors that compromise companies' logistical and technical performance (Costa; Moraes, 2021; Carvalho; Pereira, 2023). In contrast, the use of combined methods, with classification tools (ABC/XYZ), technical criticality analysis, and operational indicators (MTBF, MTTR), provides better results and greater adherence to the real requirements of the production process.

Based on the findings, the main impacts identified were the direct influence of the maintenance strategy on the parts replacement policy; the need to customize inventory management tools to the item profile; and the importance of data reliability in predicting demand for critical components. The sources consulted indicate that companies that structure their management based on data integration, performance analysis, and a focus on reliability are better able to reduce operating costs, mitigate risks, and increase the technical availability of assets (Freitas et al., 2024; Marinho; Vasconcelos, 2022).

These results answer the central research question by showing that efficiency in industrial maintenance, especially for mechanical seal replacement, depends on inventory management based on technical and strategic criteria. The analyzed documents reinforce that isolated or generic practices do not address the complexity of this component type, requiring customized approaches integrated with other areas of the organization.

5. Final Considerations

This research focused on the strategic management of mechanical seal inventories, with an emphasis on industrial maintenance efficiency. Given the increasing complexity of production systems and the criticality of technical components such as mechanical seals, the study sought to understand how adopting strategic spare parts management practices can reduce operational costs, prevent failures, and ensure greater asset availability. To this end, the investigation used a theoretical approach divided into three axes: inventory management, maintenance strategies, and characteristics of mechanical seals, enabling an integrated, in-depth analysis of the proposed problem.

The findings showed that industrial maintenance efficiency depends directly on the quality of inventory planning, especially for highly critical components. The evidence indicated that traditional practices, such as the simple application of the ABC curve, are insufficient to address the specific needs of mechanical seals, making it necessary to incorporate technical criticality analyses, performance indicators (such as MTBF and MTTR), and integration strategies between operational sectors. The adoption of predictive maintenance and the

standardization of models also proved positive for organizational performance, provided they are accompanied by aligned and structured logistics management.

The research achieved its overall objective by analyzing and relating effective inventory management strategies applied to mechanical seals in industrial environments. The data confirmed that a lack of specific planning for this type of item can directly compromise operational reliability, increase costs, and interrupt production processes. The evidence presented throughout the study, based on contemporary authors and case studies in technical literature, supported the initial hypothesis that adopting strategic management of mechanical seals contributes significantly to the efficiency of industrial maintenance.

Among the research limitations, the absence of primary empirical data stands out, since the methodology was exclusively bibliographic. The diversity of industrial scenarios also poses a challenge, as management and maintenance practices vary by company size, production segment, and level of technological maturity. Furthermore, the scarcity of specific publications on mechanical seal management as a central theme indicates the need for more investigations with applied approaches and real-world case studies that explore different operational contexts.

In conclusion, inventory management of mechanical seals, when guided by technical criteria and integrated maintenance strategies, represents a competitive advantage for industries. Coordination among engineering, supply chain, and maintenance planning is fundamental to ensuring efficient replenishment of these components and avoiding failures that compromise productivity. This study contributes to maintenance engineering by offering a systemic view of the importance of managing critical parts and reinforcing the need for decisions based on reliable data and aligned with the organization's operational objectives.

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