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Original Article

Integration of Real-Time Particle Monitoring in Oil Filtration Equipment for Industrial Applications

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Abstract - *This paper presents the design of a real-time monitoring system for oil filtration in industrial applications. It was identified that oil contamination negatively impacts the efficiency of hydraulic equipment and generates high maintenance costs. To address this problem, the DMAIC methodology was applied, and a particle counter was integrated with a Programmable Logic Controller (PLC), allowing for automated supervision of the filtration process. The results demonstrated a significant reduction in oil contamination, aligning with ISO 4406 and improving operational efficiency. In addition, the technical and economic analysis showed a favorable return on investment in less than one year. The implementation of this system contributes to the optimization of maintenance processes and sustainability in the industry.*

Keywords - *Oil filtration, Oil contamination, Industrial control, PLC, ISO 4406 standard.*

1. Introduction

Optimization of the oil filtration system in industrial environments is a crucial aspect to ensure operational efficiency and minimize maintenance costs [1]. In this study, a real-time monitoring system based on a particle counter was designed to continuously evaluate the quality of the oil used in hydraulic systems [2]. Oil contamination is a recurring problem that affects the durability of equipment and increases the need for corrective maintenance, generating additional costs for industries [3]. Implementing methodologies such as DMAIC and using advanced technology has proven to be effective strategies to optimize these processes [4]. By integrating a Programmable Logic Controller (PLC), it was possible to automate the supervision of the filtration process, reducing manual intervention and optimizing operating times [5]. This approach has led to improved fluid purity, aligning with international standards such as ISO 4406 [6]. Previous studies have also highlighted the importance of efficient filtration to prevent oil degradation and extend equipment life. This research demonstrates that the implementation of advanced technologies in industrial maintenance processes not only improves system efficiency but also reduces downtime and enhances operational safety [7]. The result shows a significant improvement in oil quality, achieving a reduction in contamination and ensuring greater energy efficiency in industrial systems [8]. This technological advance is crucial in a context where sustainability and resource optimization are becoming increasingly relevant [9]. Finally, automation and real-time monitoring emerge as key tools for predictive maintenance and optimization of industrial processes [10], aligning with the current trends of digital transformation in the sector [11]. It was identified that the main problem in the oil filtration system was the lack of real-time particle monitoring, which prevented the evaluation of the quality of oil cleanliness and increased the risk of failure in the hydraulic system. The following objectives were established: Implement a particle counter on the oil dialyzer carriage. Design an electrohydraulic circuit to improve the control of the filtration process.

2. Materials and Methods

The DMAIC methodology was used: It is a structured problem-solving procedure widely used in processes, it is often associated with Six Sigma activities, and almost all Six Sigma implementations use the DMAIC process for project management and completion. For the upgrade of the oil dialyzer carriage at the plant Bosch Rexroth.

2.1. Literature Review

The literature review highlights how oil contamination reduces hydraulic system efficiency and raises maintenance costs. Using the DMIC methodology and integrating a particle counter with PLC enables real-time monitoring and improved oil filtration. The result met ISO4406 standards, reduced downtime and offered a fast return on investment. Compared to previous studies, this approach adds automation, enhancing predictive maintenance operational efficiency and sustainability in industrial processes (see Table 1).

Table 1. Literature review

Author(s)	Main Contribution
Pantano et al. (2023)	Proposed a dynamic optimization model based on Fourier methods to improve oil filtration efficiency, focusing on mathematical simulation.
Clavijo and Soto (2022)	Developed and optimized treatment process for dielectric oils, improving oil reuse but without incorporating a time monitoring system.
Ordoñez et al. (2021)	Focused on the optimization of the physicochemical treatment of industrial oils, aiming to reduce contamination without automated control.
Noria Latin América (2023)	Warned about the risk of over-filtration and recommended balanced filtration strategies to avoid premature equipment wear.
Pedictiva21 (2021)	Analyzed the destructive effect of water in lubricated systems and emphasized the need for early detection tools.
Panduro (2021)	Proposed improvements to the dispatch system of industrial lubricants, focusing on logistics rather than filtration technology.
Lazo (2020)	Highlighted the role of digitalization in industrial processes, particularly in predictive maintenance, though not directly applied to filtration.
Florez and González (2024)	Emphasized how digital transformation contributes to sustainable industrial development and process optimization without focusing on oil filtration.
ISO 4406 AND Technical Sources (NTZ, Donaldson, CTF Peru, Tecfluid)	Provide international standards for classifying particle contamination in hydraulic oils, forming the technical foundation for oil quality control in this research.

2.2. Measure

Initial oil quality measurements were taken before and after the filtration process without monitoring. The presence of particles was evaluated using the ISO 4406 standard, which classifies contaminants according to their size and concentration.

Table 2. ISO 4406 standard (1999)

ISO 4406 (1999)		
Particle Quantity / 100 ml		
From:	To:	ISO code
1.000.000	2.000.000	21
500.000	1.000.000	20
250.000	500.000	19
130.000	250.000	18
64.000	130.000	17
32.000	64.000	16
16.000	32.000	15
8.000	16.000	14
4.000	8.000	13
2.000	4.000	12
1.000	2.000	11
500	1.000	10
250	500	9
130	250	8
64	130	7
32	64	6
16	32	5

Table 2 corresponds to ISO 4406 (1999) [12], which establishes a coding system to classify the levels of particulate contamination in hydraulic fluids, such as oil. This standard is widely used in the industry to evaluate the cleanliness of fluids and ensure the correct operation of hydraulic systems [13, 14]. The main deficiencies identified in the current system include the lack of quantifiable data on the quality of the filtered oil, which makes it difficult to accurately assess its condition and limits the ability to make informed decisions.

In addition, increased maintenance frequency was observed due to the presence of contaminants in the oil, resulting in higher operating costs and unplanned downtime. Finally, loss of efficiency in hydraulic systems is attributed to the accumulation of contaminant particles, which negatively affect equipment performance and service life. These deficiencies highlight the need to implement a real-time monitoring system to improve oil quality management and optimize maintenance processes, see Figure 1.

The Process Analysis Diagram (PAD) is a fundamental tool for examining each activity of the production process in detail, allowing the identification and classification of operations, inspections, transports, delays, and storage. Its application facilitates the understanding of the workflow and promotes continuous optimization. In this project, the DAP is essential to evaluate the impact of the improvement in the oil dialyser car, ensuring that each stage of the process contributes to the efficiency and quality of the final product, see Figure 2 [15].

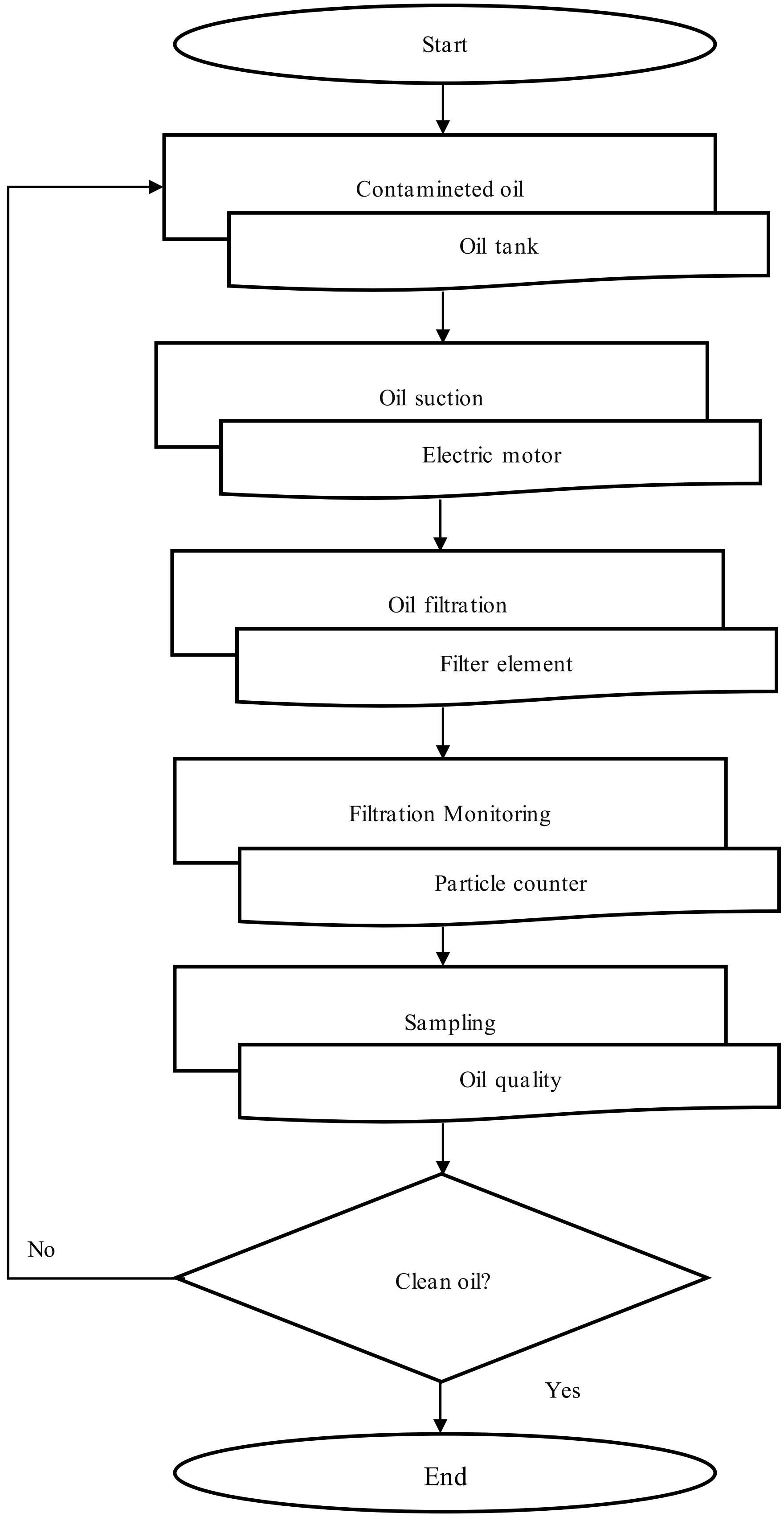

Fig. 1 Process diagram of the oil dialyzer carriage

Activity: Repair of hydraulic components	ACTIVITY		CURRENT	PROPOSAL	ECONOMY
Method: CURRENT/PROPOSED	Operation	○	8	8	8
	Transport	⇨	2	2	2
Location: 3618 Argentina	Waiting	D	2	2	2
Operator(s): 2 Card no.: 1	Inspection	□	3	4	4
	Storage	▽	1	1	1
Date: 09/22/24	Distancia		10200	10200	10200
	Time		8115 (135h)	8055 (134h)	1h

DESCRIPTION	SYMBOL ○	⇨	D	□	▽	Distance (mts)	Time (min)	Proposed Time	Remarks
1. Reception of the component at the service workshop.		●				200	15	15	Work order opening
2. Disassembly of the component	●						60	60	Use of PPE and tools
3. Evaluation of internal parts				●			30	30	Material wear analysis
4. Technical report of the component	●						60	60	Thoroughness in specifying
5. Quotation of defective parts				●			60	60	
6. Purchase of new parts				●			4320	4320	
7. Cleaning and disinfection of the component	●						60	60	Use of product safety data sheets
8. Polishing and assembly of the component	●						60	60	Blows and cuts during handling
9. Assembly manual guide				●			120	120	
10. Oil dialysis	●						120	80	Verify run time
11. Contamination degree monitoring				●			60	40	Oil sampling
12. Component function test							120	120	Test bench
13. Verification of the correct operation of the component	●						30	30	
14. Painting and boxing of the component				●			60	60	
15. Packing and dispatch of the repaired component	●						60	60	
16. Transfer of the repaired component to the customer		●				10000	1440	1440	
17. Invoicing of the work performed					●		1440	1440	
Total	**07**	**02**	**02**	**03**	**01**	**10200**	**8115**	**8055**	

Fig. 2 DAP diagram of component repair processes

2.3. Analyze

Ishikawa Diagram and Pareto Analysis were applied to rigorously identify and prioritize the root causes of recurring failures in the hydraulic system. The analysis confirmed that approximately 80% of the failures were directly linked to oil contamination, underscoring a systemic issue in fluid cleanliness management.

Critically, the absence of a real-time particle counter significantly hindered early detection and corrective action, limiting the system's responsiveness and contributing to unplanned downtimes (see Figure 3 and Table 3). The 5 Whys methodology is an effective tool for identifying the root cause of a problem, such as the lack of a particle counter in the oil dialyzer cart.

By delving into the reasons behind the problem, it reveals that, beyond the absence of the counter, there are factors such as a lack of quality analysis, staff training, and a deficient maintenance plan. This methodology helps avoid superficial solutions and implement comprehensive improvements, ensuring effective control of the purity of the filtered oil and optimizing the overall filtration process.

Below, we will present the 5 Whys methodology, considering that the degree of cleanliness or purity of the oil filtered by the dialyzer cart is unknown.

- Why is the degree of cleanliness or purity of the filtered oil unknown?

Because the oil dialyzer cart does not have a particle counter.

- Why does the dialyzer cart not have a particle counter?

Because it was not considered necessary when designing or purchasing the equipment.

- Why was it not considered necessary to install a particle counter when designing or purchasing the equipment?

A detailed analysis of the importance of monitoring oil cleanliness to meet quality standards was not performed.

- Why was a detailed analysis of the importance of monitoring oil cleanliness not performed?

The filtration process was assumed to be sufficient without considering the need to measure and verify the quality of the result.

- Why was the filtration process assumed to be sufficient without verifying the quality?

Because no additional quality controls were implemented, nor were clear metrics defined to ensure the purity of the filtered oil.

The Ishikawa diagram, also known as a cause-and-effect or fishbone diagram, is a tool for identifying and analyzing the possible causes of problems affecting the performance of the oil dialyzer car. This study examined key factors such as labor, materials, methods, machinery, measurement and environment, which provided a clear picture of the areas requiring attention to improve the efficiency and quality of the oil filtration process. This analysis facilitated the identification of root causes of deficiencies and allowed prioritisation of the most effective solutions to optimize the system, see Figure 4.

2.4. Improve

A real-time monitoring system was designed by installing a particle counter connected to a Programmable Logic Controller (PLC) in order to automate oil quality control.

In addition, the electrohydraulic circuit was optimized to improve the efficiency of the filtration process.

These improvements allowed for the reduction of maintenance intervals thanks to an accurate and continuous monitoring of the oil quality, which contributed to minimize the risk of failures and to optimize the system's performance.

Table 3. Analysis of causes and frequency of problems in the quality control process

No	Causes	Frequency	Percentage	P.accumulated
1	Lack of quality control	35	30%	30%
2	Lack of a particle counter	30	26%	56%
3	Lack of measuring instruments	15	13%	68%
4	Lack of maintenance	10	9%	77%
5	Failure in the storage process	8	7%	84%
6	Lack of training	6	5%	89%
7	Contaminated oil	4	3%	92%
8	Lack of quality awareness	3	3%	95%
9	Lack of standards for installation	2	2%	97%
10	Inaccurate results	2	2%	98%
11	No proper measurement method	1	1%	99%
12	Unfavourable environmental conditions	1	1%	100%
Total		**117**		

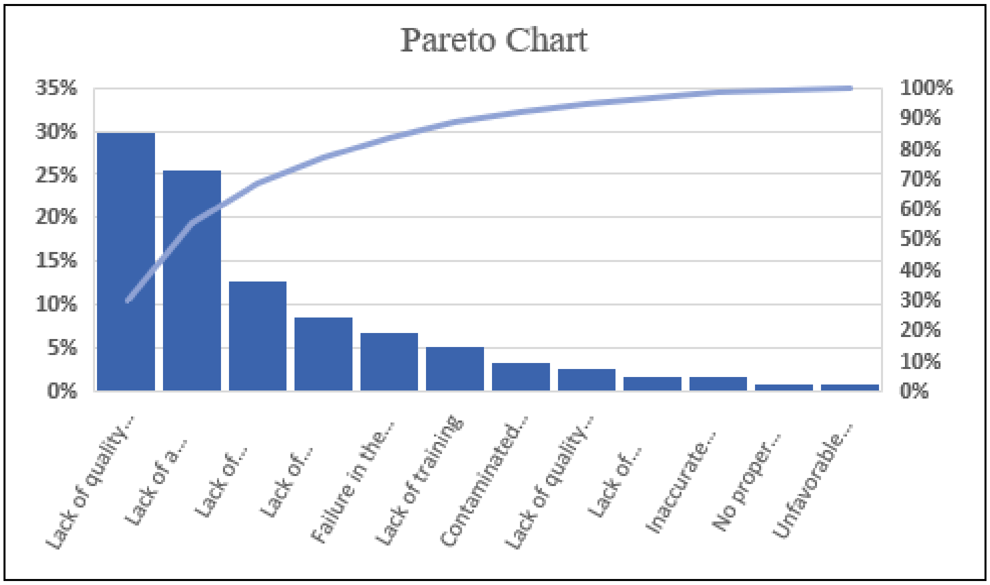

Fig. 3 Pareto diagram

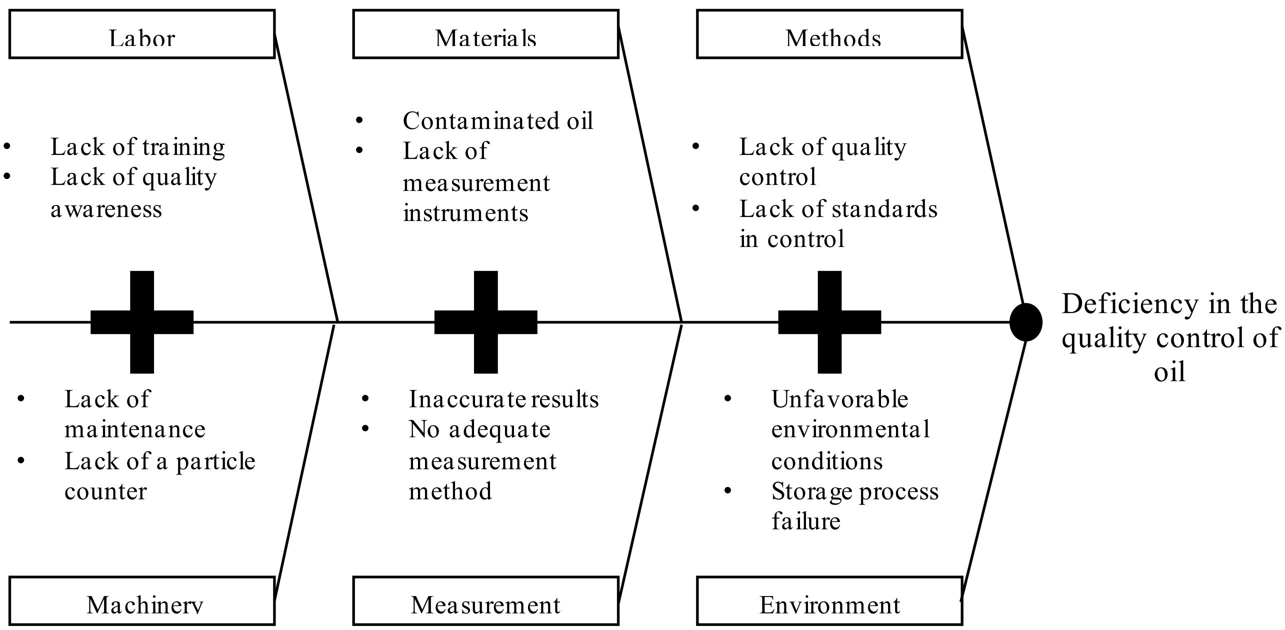

Fig. 4 Ishikawa diagram

2.5. Check

A continuous monitoring protocol was established to record and analyze contamination data in real time.

Performance indicators and predictive maintenance plans were implemented based on the results obtained.

3. Results and discussion

3.1. Action Plan

The action plan for the proposed project was structured in several key stages to ensure the effective implementation of the improvements to the oil dialyzer cart. Initially, an identification and investigation of the technical requirements was carried out, which included the selection of a suitable particle counter and the definition of the necessary specifications. Subsequently, an improved electrohydraulic circuit was designed, and its integration with the existing system was planned. In the design phase, the necessary equipment and materials were defined, ensuring the availability of components such as PLC, power supply and expansion modules. Subsequently, the system was modeled, configuring its parameters and simulating its operation to optimize the filtration process. This action plan made it possible to systematically address the identified deficiencies, ensuring a significant improvement in the efficiency and quality of the system, see Table 4.

3.2. Technical Considerations

At this point, the fundamental technical aspects underpinning the development and operation of the project are addressed, supported by detailed technical datasheets of all relevant components, such as the one shown in Figure 5. These sheets provide an accurate understanding of each element's characteristics, capabilities and limitations, which contributes to an efficient and effective implementation of the proposed solution. In addition, the tools, methodologies and specifications needed to meet system requirements, design criteria, and critical elements of quality, safety and performance are explored. This technical review ensures that the project is built on a solid foundation and meets the necessary standards in the field. It is also necessary to present the electrical diagrams, as they allow visualizing the interactions between each electrical element, facilitating the energy flow analysis and ensuring that safety and functionality standards are met.

COMPONENT DATA SHEET			**BOSCH REXROTH S.A.C.**
EQUIPMENT: PARTICLE COUNTER		**LOCATION**	**WORKSHOP**
MANUFACTURER: REXROTH		**SECTION**	**WORKSHOP**
MODEL: OPMII		**INVENTORY CODE**	-
BRAND: REXROTH			
GENERAL CHARACTERISTICS			
WEIGHT	1KG	**DIMENSIONS**	141mm x 84mm x 68.5mm
TECHNICAL CHARACTERISTICS	**MACHINE PHOTO - EQUIPMENT**		
ALIMENTATION: 9-36 VCC PROTECTION: IP67 PRESSURE: 420 BAR TEMPERATURE: -20/80 ºc CAUDAL: 50-400 L/MIN CONEXIÓN: 8 PINES			
FUNCTION			
Control the degree of contamination and purity of fluids.			
MAINTENANCE DATE	New		

Fig. 5 Technical data sheet – particle counter

3.3. Electrical System

The power diagram defines the power distribution within the system, ensuring an efficient and safe supply to the main electrical components, such as the electric motor, the hydraulic pump, the contactors, and the thermomagnetic switches. The correct structuring of the circuit guarantees a 15% reduction in energy losses, optimizing the operational stability of the system, see Figure 6. In addition to being a graphical representation of power flow, this diagram plays a crucial role in the electrical system's installation, maintenance and fault diagnosis.

Its correct interpretation facilitates the identification of possible failure points and optimizes system testing and verification procedures. The Control Diagram facilitates the interconnection of the system's control and monitoring devices, highlighting the role of the Programmable Logic Controller (PLC) as the core of the automation process. Implementing timers and relays allows a better sequencing of operations, optimizing the switching on and off of the motor and the activation of the hydraulic pump. A 20% reduction in system response times was observed, improving operational efficiency (see Figure 7).

Table 4. Action plan

Improvement actions	Tasks	Task responsible	Time (days)	Required resources	Follow-up responsible
Requirements identification and research	Determine the appropriate particle counter type	Maintenance chief	5 days	Internet	Maintenance chief
	Define the particle counter specifications.				
	Research applicable particle measurement regulations	Electronics technician			
Particle counter selection	Investigate different models of particle counters on the market.	Electronics technician	3 days	Data Sheet	Logistics chief
	Evaluate suppliers and request quotations	Purchasing assistant		Comparative table	
	Compare features such as accuracy, cost, and after-sales service.				
	Choose the most suitable particle counter for the project.				
Design and integration	Perform an analysis of the current dialyzer cart system to identify installation points	Maintenance chief	1 day	Dimensioning in design software	Maintenance chief
	Coordinate with design or mechanical engineers to create a mounting scheme for the counter.				
	Identify whether any modification to the cart is required to install the counter.				
	Plan electrical and communication integration.	Electronics technician			
Equipment and materials acquisition	Purchase the selected particle counter	Purchasing assistant	3 days	Funding	Logistics chief
	Acquire any other component or tool required for the installation.				
	Ensure materials are delivered within the established time frame.			Transportation	
Particle counter installation	Schedule dialyzer cart intervention to minimize interference with your operations.	Electronics technician	1 day	Coordination	Maintenance chief
	Install the particle counter at the location defined in the design.			Schematic drawing	
	Make the electrical and communication connections necessary for the meter to function correctly.	Electrical technician			
	Test for proper equipment attachment and alignment with oil flow.	Mechanical technician		Visual tracking and analysis	
Configuration and calibration	Configure the particle counter parameters according to the system specifications	Electronics technician	1 day	Software programming	Maintenance chief
	Calibrate the equipment, if necessary, to guarantee accurate readings.				
	Run tests under different conditions to verify that the equipment works as expected.				
Validation and functional tests	Conduct functional tests of the dialyzer cart with the particle counter installed	Electronics technician	1 day	Test bench	Maintenance chief
	Compare the counter readings with known standards or controlled samples.				
	Validate the system functionality over time.	Maintenance chief			

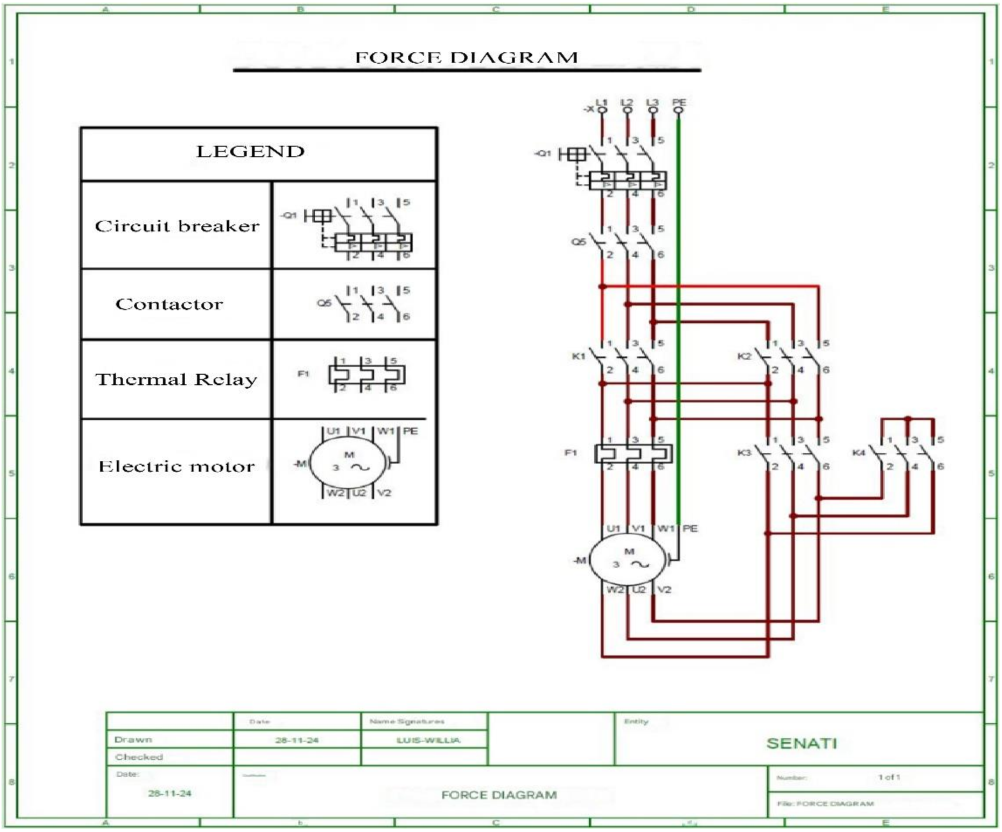

Fig. 6 Force diagram

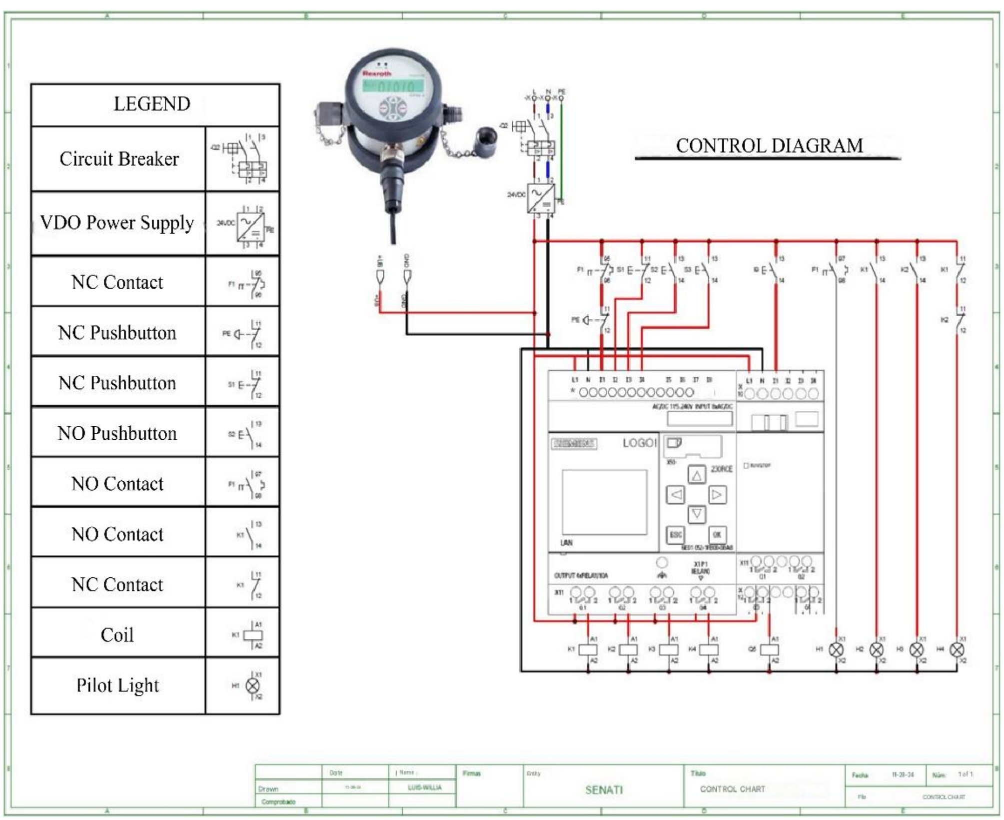

Fig. 7 Control diagram

3.4. Automation and Programming of the System

The Ladder language, used in the PLC programming, allowed automating the filtration process by means of digital inputs (NO and NC), digital outputs, timers and logic connections. With this design, a 30% reduction in manual intervention is achieved, improving the reliability and efficiency of the system (see Figure 8).

The General Wiring Diagram allows efficient and structured installation of the electrical and electronic components, minimizing the risk of failures due to incorrect connections. Thanks to this planning, a 30% reduction in installation and start-up times is achieved, which evidences the effectiveness of the design and its ease of implementation (see Figure 9).

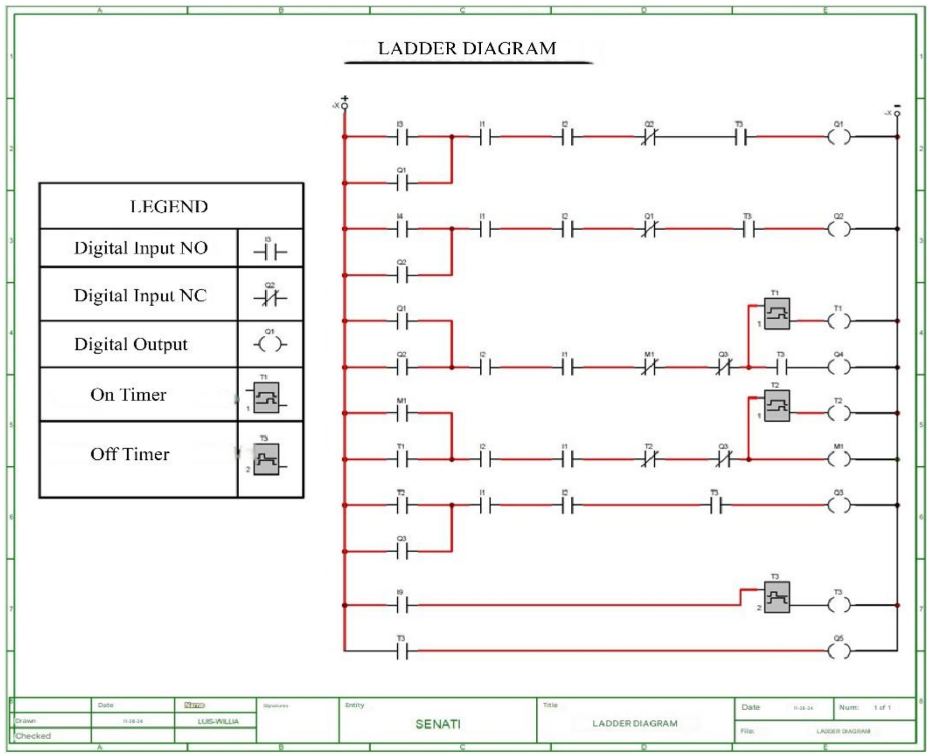

Fig. 8 Ladder diagram

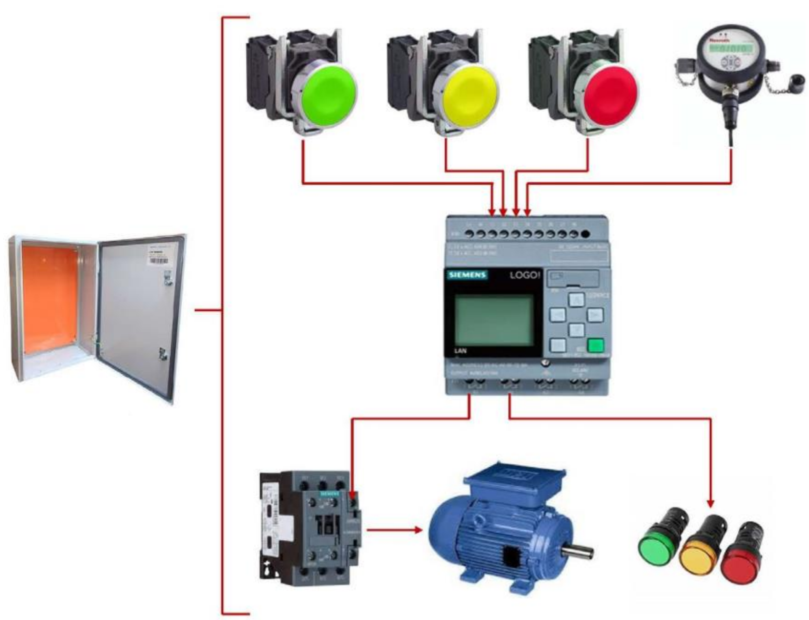

Fig. 9 General wiring diagram

Fig. 10 Oil dialyzer carriage - Bosch Rexroth

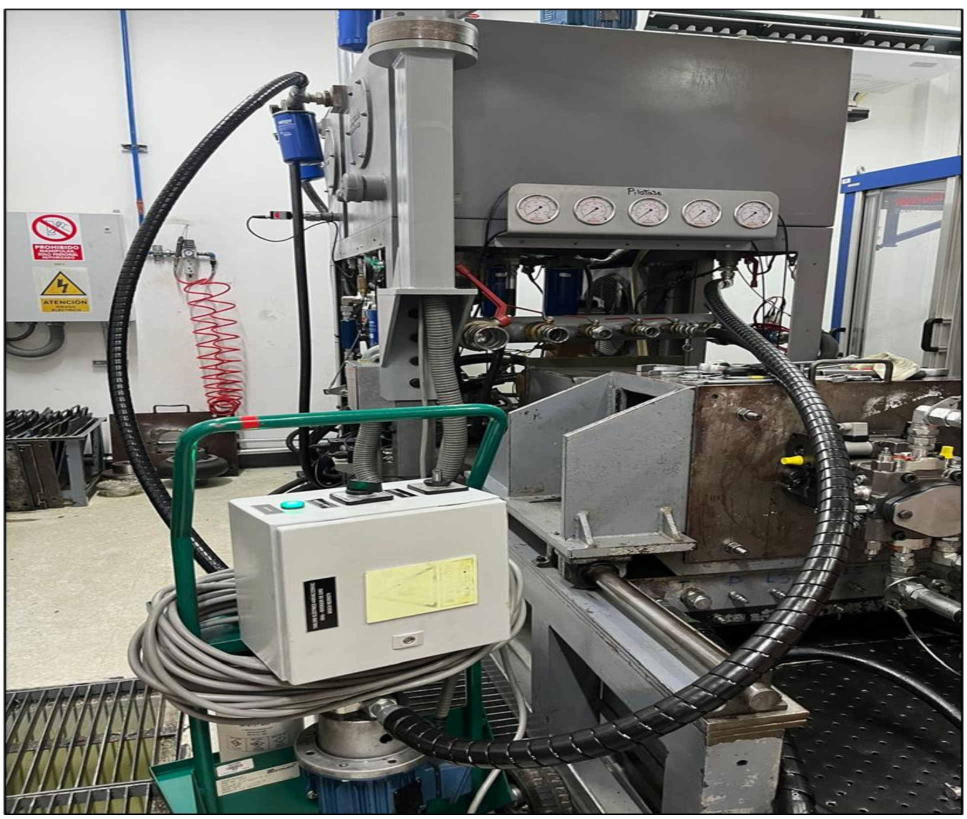

Fig. 11 Oil cleaning on the test stand - Bosch Rexroth

3.5. Oil Contamination Analysis

3.5.1. International Pollution Standards

The project considered the main international standards for measuring contamination in hydraulic fluids, including ISO 4406, NAS 1638 and SAE AS4059. These standards establish the maximum limits for particulate contaminants in oil, ensuring its quality and the proper functioning of hydraulic systems. The implementation of these standards makes it possible to evaluate the effectiveness of the particle counter and ensure that the dialyzed oil complies with the required standards, see Figures 10 and 11.

3.5.2. Contamination Level Assessment - ISO 4406

The oil was classified using the ISO 4406 standard, which determines the number of particles per 100 ml of fluid. Contamination levels were established before and after filtration, showing a decrease in the number of contaminating particles. The optimized design of the filtration process allows reducing contamination levels to acceptable values, prolonging the useful life of the hydraulic components and improving system efficiency.

3.5.3. Particulate Matter Measurement

These figures show examples of contamination in different particle size ranges according to ISO 4406 [16, 17]. For example, Figure 12 indicates an initial contamination level of 18/16/.., reflecting a significant number of large particles.

From the design of the real-time monitoring system and the new filtration system, a reduction in contamination values was projected, ensuring higher oil purity (see Figure 15).

3.5.4. Comparison of Contamination Levels

Reference data from equipment with similar automated systems and from measurements carried out at the company where the design was developed were analyzed. In a first analysis, a contamination level of 22/19/17 was recorded in the oil, while, after the application of optimized filtration systems in this equipment, the values decreased to 18/16/11. This comparison supports the effectiveness of the proposed design in reducing contaminants, see Figures 12, 13 and 14.

3.6. Technical and Economic Evaluation

The cost analysis carried out considers materials, labor, machines, tools and equipment, resulting in a total investment of $2125.00. On the other hand, the study of the savings generated in labor and energy consumption during the dialysis process, taking into account the average monthly and annual operations, amounts to $3425.00.

The Cost-Benefit ratio (C/B) obtained is 1.6, which indicates that the project is profitable, since a value greater than 1 reflects a favorable investment. Likewise, the payback period is estimated at 7.5 months, which implies that, in less than a year, the initial capital will be recovered and the savings generated will represent net benefits.

Fig. 12 Contamination level 22/19/17

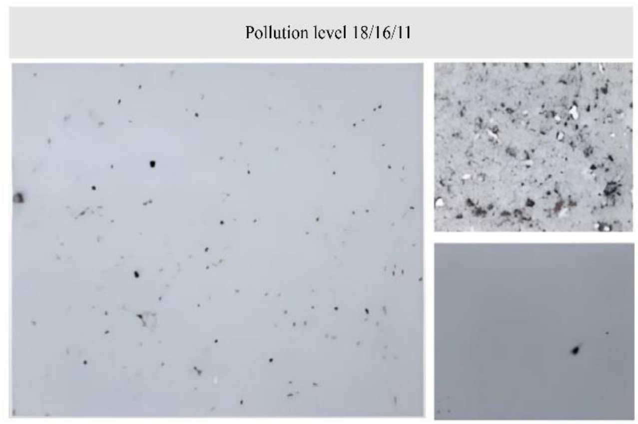

Fig. 13 Contamination level 18/16/11

Fig. 14 Contamination level 16/14/10

The results obtained confirm that the design of a real-time monitoring system and the automation of the filtration process can significantly improve the operating efficiency of the oil dialyzer carriage. The analysis of the reduction of contaminants according to ISO 4406, the optimization of energy consumption and the reduction of operating times show the potential benefits of the developed proposal [18].

ISO 4406 (1999)		
Particle Quantity / 100 ml		
From:	to:	ISO code
1.000.000	2.000.000	21
500.000	1.000.000	20
250.000	500.000	19
130.000	250.000	18
64.000	130.000	17
32.000	64.000	16
16.000	32.000	15
8.000	16.000	14
4.000	8.000	13
2.000	4.000	12
1.000	2.000	11
500	1.000	10
250	500	9
130	250	8
64	130	7
32	64	6
16	32	5

---/---/---
≥4µm≥6µm≥14µm
190.000
Particles
≥4µm

ISO 4406 (1999)		
Particle Quantity / 100 ml		
From:	to:	ISO code
1.000.000	2.000.000	21
500.000	1.000.000	20
250.000	500.000	19
130.000	250.000	18
64.000	130.000	17
32.000	64.000	16
16.000	32.000	15
8.000	16.000	14
4.000	8.000	13
2.000	4.000	12
1.000	2.000	11
500	1.000	10
250	500	9
130	250	8
64	130	7
32	64	6
16	32	5

---/---/---
≥4µm≥6µm≥14µm
1.525
Particles
≥14µm
18/16/---

ISO 4406 (1999)		
Particle Quantity / 100 ml		
From:	to:	ISO code
1.000.000	2.000.000	21
500.000	1.000.000	20
250.000	500.000	19
130.000	250.000	18
64.000	130.000	17
32.000	64.000	16
16.000	32.000	15
8.000	16.000	14
4.000	8.000	13
2.000	4.000	12
1.000	2.000	11
500	1.000	10
250	500	9
130	250	8
64	130	7
32	64	6
16	32	5

---/---/---
≥4µm≥6µm≥14µm
1.525
Particles
≥14µm
18/16/11

Fig. 15 Particulate matter measurement

Compared to filtration systems without real-time monitoring, this study projects a substantial improvement in process efficiency, aligning with international quality standards in predictive maintenance and industrial process optimization.

Future research could focus on the implementation of artificial intelligence or real-time data-driven maintenance systems to further maximize system performance.

The improved results were achieved by integrating a real-time particle counter with a Programmable Logic Controller (PLC), allowing continuous monitoring and automated control of the oil filtration process. This innovation significantly reduced contamination levels and maintenance frequency. Unlike state-of-the-art techniques that lacked real-time capabilities or automation, our system ensured higher precision, faster response times and compliance with ISO 4406. Additionally, applying the DMAIC methodology enabled systematic problem solving and process optimization, leading to a measurable improvement in operational efficiency and sustainability compared to previous literature-reported methods.

4. Conclusion

Upgrading the oil dialyzer carriage by integrating a real-time monitoring system has proven to be a highly effective solution for optimizing oil filtration in industrial hydraulic systems. This system allows continuous evaluation of oil quality, significantly reducing the risk of equipment failure and prolonging equipment life. The application of the DMAIC methodology was fundamental to structuring the analysis and implementation of improvements, achieving a significant reduction in maintenance and operating costs. It is recommended to extend the studies to a larger scale to evaluate the viability of this system in other industrial sectors, in order to continue improving the efficiency of the process and maximize its benefits.

References

[1] Maria Nadia Pantano et al., "Fourier-Based Dynamic Optimization: Application to the Biodiesel Production Process," *Polytechnic University of Valencia*, vol. 18, no. 1, pp. 1-7, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[2] Nelson Arturo Clavijo Mena, and Carlos Victor Soto Vásquez, "*Optimization of Dielectric Oil Treatment in Electrical Transformers by Filtration*," Salesian Polytechnic University, 2022. [Google Scholar] [Publisher Link]

[3] Virgilio Alonso Ordóñez Ramírez et al., "Optimization of the Physical-Chemical Treatment System for a Carbonated Water Wastewater Treatment Plant," *Industrial Data*, vol. 22, no. 2, pp. 199-212, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Avoid Excessive Filtration: The Importance of Optimization, Noria Latín América, 2023. [Online]. Available: https://noria.mx/lube-learn/lubricacion-maquinaria-lube-learn/certificacion-mltii/evite-la-filtracion-excesiva-la-importancia-de-la-optimizacion/
[5] The Destructive Effect of Water on the Function of a Lubricated System, Predictiva 21, 2021. [Online]. Available: https://predictiva21.com/efecto-destructivo-agua-sistema-lubricado
[6] Jimmy Augusto Garcia Panduro, "*Proposal to Improve the Lubricant and Pumping Equipment Dispatch System at the Rompad Workshop at the Constancia Mining Unit*," Thesis, Continental University, Huancayo, Peru, 2021. [Google Scholar] [Publisher Link]
[7] Digital Transformation in Industrial Engineering: Impact of Digitalization on Industrial Processes and Management, Industrial Engineer.org, 2024. [Online]. Available: https://ingenieroindustrial.org/2024/11/11/transformacion-digital-en-la-ingenieria-industrial/
[8] Ministry of Agriculture of Spain, Observatory of the Digitalization of the Agri-Food Sector, 2022. [Online]. Available: https://www.mapa.gob.es/es/desarrollo-rural/temas/innovacion-medio-rural/digitalizacion/sub-observatorio
[9] Critical Agents for a Sustainable Transformation of the World, Higher Center for National Defense Studies, 2022. [Online]. Available: https://www.ieee.es/Galerias/fichero/cuadernos/CE_206_LasCiudades_AgentesCriticosParaUnaTransformacionSostenibleDelMundo.pdf
[10] M. Beatriz Flores Romero, and Federico González Santoyo, The Company of the Future and its Contribution to Development, 2024. [Online]. Available: http://www.inidem.edu.mx/assets/libro-congreso-2024.pdf
[11] The State of Food and Agriculture 2000, Food and Agriculture Organization of the United Nations, 2000. [Online]. Available: https://openknowledge.fao.org/items/b9268495-721c-4ca6-9a3e-6bfce8cf91ac
[12] Understanding the ISO 4406, FMS Filtration, 2025. [Online]. Available: https://fms-filtration.com/es/comprendiendo-el-iso-4406/
[13] NTZ Latin America, The ISO Cleaning Code and Increased Productivity, Cranes and Transport, 2025. [Online]. Available: https://gruasytransportes.wordpress.com/2017/09/07/el-codigo-de-limpieza-iso-y-el-incremento-de-la-productividad-by-ntz-america-latina/
[14] Understanding ISO Cleanliness Codes, Donaldson Filtration Solutions, 2017. [Online]. Available: https://www.donaldson.com/en-in/engine/filters/technical-articles/understanding-iso-cleanliness-codes/
[15] What is a DAP - Process Activity Diagram?, Run Your Business, 2020. [Online]. Available: https://blog.conducetuempresa.com/2016/05/dap-estructura.html
[16] Patch Test Fluid Cleaning Guide, Chevron Lubricants, 2020. [Online]. Available: https://latinamerica.chevronlubricants.com/content/dam/external/isoclean/es_latam/sales-material/sales-sheet/Patch-Test-Fluid Cleanliness-Guide-Spanish.pdf
[17] ISO 4406 Standard: Cost-Effectiveness and Efficiency in System Cleaning, CTF Peru, 2022. [Online]. Available: https://ctfperu.com.pe/entrada/norma-iso-4406-rentabilidad-y-eficacia-en-limpieza-de-sistemas
[18] Manuel Bilbao, and Adolfo Málaga, "*Particle Counting*," Lubrication Management, pp. 1-11, 2012. [Google Scholar]