

Proposal of a maintenance system for a HACOC HK 210 centrifugal pump

Propuesta de un sistema de mantenimiento para una bomba centrífuga HACOC HK 210

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Abstract: An effective maintenance system was established to guarantee the durability of HACOC HK 210/200r12cbTB2 centrifugal pump due to frequent failures and minimize repair and replacement costs. For this purpose, an analysis of the equipment was carried out to understand its operation, main components and common failures. A maintenance plan was developed, including procedures, tools and necessary techniques to perform maintenance on the equipment. The new maintenance plan or cycle has a duration of 7,300 machine-hours with 25 overhauls, 20 minor repairs, 4 medium repairs and a general repair. The time between medium repairs is ($t_{rm} = 1\ 460$) machine-hours, the period between minor repairs is ($t_r = 292$) machine-hours and the period between interventions is ($t_o = 146$) machine-hours.

Keywords: fluid pumping, fluid transfer, mechanical failure prevention

Resumen: Se estableció un sistema de mantenimiento efectivo para garantizar la durabilidad de la bomba centrífuga HACOC HK 210/200r12cbTB2 debido a la existencia de frecuentes fallas y minimizar los costos de reparación y reemplazo. Para ello se realizó un análisis del equipo para comprender su funcionamiento, principales componentes y fallas comunes. Se desarrolla un plan de mantenimiento que incluyó los procedimientos, herramientas y técnicas necesarias para llevar a cabo el mantenimiento del equipo. El nuevo plan o ciclo de mantenimiento presenta una duración de 7 300 horas-máquinas con 25 revisiones, 20 reparaciones pequeñas, 4 reparaciones medianas y una reparación

general. Con un tiempo entre reparaciones medianas de ($t_{rm} = 1\ 460$) horas-máquinas, el periodo entre reparaciones pequeñas ($t_r = 292$) horas-máquinas y el período entre intervenciones ($t_o = 146$) horas-máquinas.

Palabras claves: bombeo de fluido, transferencia de fluidos, prevención de fallas mecánicas

Introduction

Centrifugal pumps are essential for several applications, ranging from water supply to chemicals transfer in industrial processes. These machines transform mechanical energy into hydraulic energy, allowing efficient movement of large liquid volumes (Rojas, Aguirre & Botterón, 2021; Costa dos Santos, Bovério & Pereira da Silva, 2023).

Failures in centrifugal pumps occur due to issues arising from the fluid or operational and mechanical problems. Centrifugal pump failures lead to changes in the operational phase, reducing efficiency and causing functional failure (Audisio, 2023).

To ensure its optimal performance, an effective maintenance management that combines preventive and corrective strategies is key. This includes proper lubrication, shaft alignment, vibration monitoring, and critical components inspection. Implementing preventive maintenance in production plants to optimize processes is important to prevent equipment failures before they occur, which is essential in industrial processes (Castillo-Serpa, Brito-Ballina & Fraga-Guerra, 2009; Espinosa-Martínez *et al.*, 2020; Arroyo & Obando, 2022; Pulido de León *et al.*, 2024).

According to Pérez (2018), machine analysis is fundamental to guarantee its functionality, optimize performance, and prevent failures. It is performed by applying techniques such as vibration analysis, thermography, and ultrasound to detect mechanical, electrical, or structural problems.

This work provides an effective maintenance system to guarantee HACOC HK 210/200r12cbTB2 centrifugal pump durability in order to avoid failures and minimize repair and replacement costs.

Materials and Methods

HACOC HK 210/200r12cbTB2 centrifugal pump was analyzed (Figure 1). Table 1 presents its technical details.



Figure 1. HACOC centrifugal pump.

Table 1. Technical specifications of HACOC centrifugal pump

Pump Name	HACOC
Brand	HK 210/200r12cbTB2
Model	N 28012
Flow Rate (Q)	151m3/h
Manometric Head (H)	198 mH2O
Number of revolutions (n)	2950 rpm
Power (P)	50/50 Kgf/cm2
Manufacture year	1989

Table 2 details the technical condition of its components based on a survey applied to technicians and operators.

Table 2. Technical condition of HACOC centrifugal pump components

Pump Components	Technical Condition
Case	Good
Impeller	Regular
Shaft	Regular
Mechanical Seal	Poor
Bearings	Poor
Volute Chamber	Good
Suction Inlet	Good
Discharge Outlet	Good

Criticality Analysis

Criticality analysis enables the establishment of strategies to design or improve maintenance plans, prioritizing processes, systems, and equipment within the production

process (Enriques-Gaspar *et al.*, 2020; Cedeño-Moreira & Gorozabel-Chata, 2021; Charcopa-Paz, Herrera-Suárez & Carrillo-Anchundia, 2024).

This work employs the weighted factors criticality model based on risk theory developed by Woodhouse (1994). This semi-quantitative, practical, and simple method uses the formula:

$$\text{Criticality} = \text{Frequency} \times \text{Consequence}$$

Frequency: Number of system or process failures.

Consequence: Operational impact and flexibility, maintenance costs, safety, and environment.

Consequence = (Operational Impact × Flexibility) + Maintenance Costs + Safety and Environmental Impact.

Table 3. Weighted criticality factors (Angelmendizabal, 2024)

Failure Frequency	Weight
≥ 8 failures/month	4
5 to 8 failures/month	3
2 to 4 failures/month	2
≤ 1 failure/month	1
Operational Impact (OI)	
Immediate halt of all production	10
Affects more than 50% of production	7
Affects less than 50% of production	4
Does not affect production	1
Operational Flexibility (OF)	
No identical or similar equipment available	4
The system can continue functioning	2
Identical or similar equipment available	1
Maintenance Cost (MC)	
More than 10 USD	3
From 5 USD to 10 USD	2
Less than 5 USD	1
Impact on Safety, Environment and Hygiene (ISEH)	
Affects human safety	8
Affects environment causing reversible damage	6
Affects facilities causing severe damage	4
Causes minor damage	2
Causes environmental impact without violating norms	1

Availability Calculation

Sánchez Aguilar (2016) proposes determining availability with the formula:

$$D_{ISP} = \frac{H \cdot T - H \cdot P \cdot M}{H \cdot T}$$

Where:

H·T = operating hours (h)

H·P·M = maintenance downtime hours (h)

Methodologies for Maintenance Type Selection

Choosing the most appropriate system depends on factors such as machine type, associated production, and its relevance in the process. To determine the optimal maintenance cycle, various methodologies specifically applied to the machine were analyzed, using the criterion proposed by Morrow (1986).

Machine-level Criterion

Machine evaluation is carried out by considering key aspects based on coefficients quantifying each relevant factor, which are:

C1: High acquisition cost

C2: High production loss cost

C3: Absence of duplicate machine

C4: Possibility of diagnosis with available instrumentation

C5: Global parameters measurement (vibration, temperature, flow)

C6: High maintenance cost (materials and human resources)

C7: Significant lifespan loss due to disassembly

C8: Machine failure severe economic consequences

Coefficients meeting the conditions are assigned a value of 1; the rest receive a 0 value. Based on them, additional coefficients are calculated.

Predictive Maintenance Coefficient:

$$C_{\text{PRED}} = \frac{C_1 + C_2 + C_3 + C_6}{4}$$

Corrective/Preventive Maintenance Coefficient:

$$C_{CRR/PREV} = \frac{C_{PERDIDAS} + C_{FALLAS}}{5}$$

Where:

$$C_{PERDIDAS} = C_1 + C_2 + C_6$$

$$C_{FALLAS} = C_7 + C_8$$

Table 4 shows the coefficient values according to the maintenance system based on the selection rule.

Table 4. Selection rules

Coefficient Values	Maintenance System
$C_{CORR/PREV} = 0$	Corrective
$C_{PRED} \leq 0,25 / C_7 = 1$	Preventive according to reliability indices
$C_{PRED} > 0,5 / C_4 = 4 / C_5 = 1$	Preventive with parameter and symptom measurement
$0,25 \leq C_{PRED} \leq 0,5 / C_4 = 1 \text{ y/o } C_5 = 1$	Preventive with parameter and symptom measurement
$C_{PRED} \geq 0,5 / C_4 = 1$	Predictive

Technical Condition Determination

Planned preventive maintenance uses a simple, practical method to assess the equipment's technical condition. After inspection, the condition is rated as good, regular, poor, or very poor. This involves calculating efficiency percentage including intermediate essential steps, such as:

$$Z_i = e \cdot c$$

Where:

Z_i: Classification of elements with the same evaluation

e: Number of elements with the same evaluation

c: Coefficient reflecting the current state of the element, dimensionless

c = 1 if the element is rated good

c = 0,8 if the element is rated regular

c = 0,6 if the element is rated poor

c = 0,4 if the element is rated very poor

Once the number of elements by their assigned evaluation scores, these products are summed using the equation:

$$Z = \sum_{i=1}^n Zi$$

Where:

Z: total rating of evaluated elements.

Dividing this result by the total number of rated elements and multiplying it by 100 yields the equipment efficiency level relative to its initial condition. This is calculated with the following formula:

$$\eta = \frac{Z}{n} \cdot 100$$

Where:

η : Efficiency obtained by executing the formula; (%)

n: Number of the equipment's evaluated elements

To classify the equipment's technical status according to the efficiency obtained from the defect analysis, it is necessary to use the analogy shown in table 5 as a reference.

Table 5. Efficiency-Technical Condition Relationship

Current Efficiency	Technical Condition
90-100 %	Good
75-89%	Regular
50-74%	Poor
Less than 50%	Very Poor

Maintenance Cycle Determination

According to González (2005), the maintenance cycle defines the services sequence between general repairs or from commissioning to first repair in new equipment. This cycle is essential in preventive maintenance, optimizing equipment use, ensuring safety, and reducing resource consumption. Duration of the cycle depends on the equipment's condition, age, and operator experience. For centrifugal pumps pumping petroleum, Divona *et al.* (2001) recommend:

Standard cycle: 8 overhauls, 2 minor repairs, 1 medium repair (G-O-O-Mi-O-O-Me-O-O-Mi-O-O-G).

Cycle for equipment with frequent problems: 25 overhauls, 20 minor repairs, 4 medium repairs (G-O-Mi-O-Mi-O-Mi..., repeated frequently).

Repair cycle periods

Once the maintenance cycle structure and duration are defined, time between two consecutive services and repairs can be known:

Period between medium repairs: it denotes the equipment operating time, expressed in machine-hours, between two planned medium repairs.

$$t_{rm} = \frac{T}{NM+1}$$

Period between repairs: it constitutes the equipment operating time, expressed in machine-hours, between two planned minor repairs

$$t_r = \frac{T}{NM+NP+1}$$

Period between interventions: it represents the equipment operating time between two maintenance services; in other words, between two immediate overhauls or between a repair and an overhaul.

$$t_o = \frac{T}{NM+NP+NR+1}$$

Where:

t_{rm} : Period between two medium repairs (machine-hours)

t_r : Period between two consecutive repairs (machine-hours)

t_o : Period between two maintenance services (machine-hours)

T: Repair cycle duration (machine-hours)

NR: Number of overhauls, dimensionless

NP: Number of minor repairs, dimensionless

NM: Number of medium repairs, dimensionless

Results and Discussion

Criticality Analysis

Criticality analysis identifies and evaluates potential failure modes of HACOC centrifugal pumps, facilitating prioritization of corrective and preventive actions. Understanding risks and consequences of every failure mode, reduces unexpected failures, minimizing downtime, repair costs, and production repercussions.

Additionally, this analysis optimizes preventive and predictive maintenance programs. It identifies the most critical component, as the graphic in Figure 2 shows; hence, working teams can focus their efforts on the most vulnerable areas, improving reliability and extending equipment lifespan.

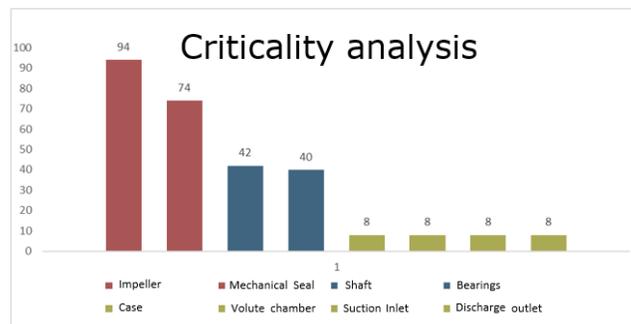


Figure 2. Criticality analysis.

In Figure 2, criticality levels of HACOC centrifugal pump components are identified. Red elements have high criticality, indicating a higher failure probability with significant operational, safety, and production consequences. Blue components show medium criticality, and yellow components display low criticality. This classification is essential to prioritize corrective and preventive actions, reducing downtime, repair costs, and productivity impacts.

Pump Availability Analysis

HACOC centrifugal pump operates under an 18-hour daily rotational regime, totaling 6,570 hours annually. Maintenance stops amount to 120 hours a year, yielding 77.78% availability. This indicates the pump does not operate at maximum capacity; and indicates that failures and maintenance of key components such as bearings, shafts,

impeller, and seals require forced stops, resulting in production losses and increased operational and maintenance costs, especially due to the lack of spare parts.

Maintenance engineering shows availability and reliability indicators below the optimal range (90–94%), demonstrating the inefficiency of the current scheme. Indicators should be simple, adequate, valid over time, useful, and timely, according to Mora (2009).

Technical Conditions

Table 6 presents the technical conditions of HACOC centrifugal pump components based on surveys among mechanics, operators, and technicians interacting directly with the pump. Operators' opinions are valuable, complementing technical data and engineering evaluations. Considering their experience allows a more complete view of components conditions, enabling a more information-supported decision making on maintenance and pump improvement.

Table 6. Technical condition of HACOC centrifugal pump

Pump Components	Technical Condition	
Case	Good	1
Impeller	Regular	0.8
Shaft	Regular	0.8
Mechanical Seal	Poor	0.6
Bearings	Poor	0.6
Volute Chamber	Good	1
Suction inlet	Good	1
Discharge outlet	Good	1

Out of the evaluated centrifugal pump components, four were classified as good, two as regular, and two as poor. By summing the classification values, a total of 6.8 is obtained. Dividing this value by the total number of evaluated components (8) yields an index of 0.85, equivalent to an 85% efficiency. According to data shown in Table 6, the technical condition of the pump is regular.

Maintenance Type Selection

An adequate plan must consider several key aspects, including detailed knowledge of the pump's characteristics and technical specifications, such as pumping capacity,

operating pressure, and construction materials. Table 7 shows the results obtained from the evaluation coefficients based on machine-level criteria.

Table 7. Evaluation coefficients according to machine-level criteria

Coefficient	Description	Value
C1	High machine acquisition cost	1
C2	High cost due to production losses	0
C3	No existence of machine duplicate	1
C4	Possibility to performing machine diagnostics with available instrumentation	0
C5	Possibility of performing control measurements of global parameters such as: vibrations, temperature, and flow	1
C6	High machine maintenance cost	1
C7	High lifespan loss due to disassembly	0
C8	Severe economic consequences of a machine breakdown	1

Although maintenance costs are high, the equipment's disassembly and reassembly do not significantly affect its lifespan, although certain components failures can have considerable economic repercussions.

According to the evaluation coefficients presented in Table 7 and calculated using the equations, predictive maintenance and corrective/preventive maintenance have values of 0.7 and 0.6 respectively, considering losses (C_{losses}) and failures ($C_{failures}$) with values of 2 and 1. These indices suggest the application of a preventive maintenance program that includes measurement of parameters such as temperature, lubricants, and vibrations.

To reduce lubrication failures, initial oil analysis after repairs and adjustments in product selection are recommended, taking into account changing operational conditions. Furthermore, it is necessary to carry out routine analyses, considering that the pump, being a critical and not new piece of equipment, requires continuous attention.

Regarding mechanical vibrations, preventive and predictive maintenance should focus on identifying the predominant vibration amplitudes, determining their causes, and correcting the associated problems (Thielsen, 1970; Fajardo *et al.*, 2024).

Maintenance Plan Development

The maintenance cycle for each piece of equipment must be defined according to the individual analysis of the machine, considering experience and available data. Its duration, in machine hours, depends on the equipment characteristics, operating

conditions, and type of production. According to González (2005), the centrifugal pump is classified into industrial equipment groups 17 and 3. For this case, a maintenance cycle of 7,300 machine hours is established, within the range of 7,200 to 88,640 machine hours for general repairs according to the consulted reference.

The proposed maintenance cycle includes 25 overhauls, 20 minor repairs, and 4 medium repairs. The period between general repair is set at 1,460 machine-hours. Minor repairs are scheduled every 292 machine-hours, while the interval between maintenance interventions is 146 machine-hours. This structure ensures a reliable maintenance cycle, anticipating premature failures and guaranteeing system reliability

Preventive Maintenance Procedure planned for a maintenance cycle covering 25 overhauls, 20 minor repairs, 4 medium repairs, and 1 general repair according to Bloch (1998).

Summary of Maintenance Activities

Overhauls (every 15 days): visual inspection, vibration and temperature measurement, alignment and lubrication system verification, performance tests.

Minor Repairs (every 15 days): seal replacement, bearing adjustment, impeller cleaning, and relief valve adjustment.

Medium Repair (every 3 months): Complete pump disassembly, bearing replacement, worn parts reconditioning, and mechanical adjustments.

General repair (every 1 year and 3 months): Thorough disassembly, critical parts replacement, reconditioning, and performance tests.

Tools and Techniques: Hand tools, measurement equipment (vibrometer, thermometer, laser aligner), crane or hoist, and safety procedures.

These activities guarantee the pump's performance and reliability, maintaining its operability and reducing the risk of failure.

Conclusions

Maintenance theoretical foundations of were established, providing a basis to develop the objectives and a foundation from previous works.

A methodology was defined to calculate availability and select a maintenance system, based on a detailed machine-level analysis of the centrifugal pump's critical components.

The new maintenance cycle has a duration of 7,300 machine-hours, with 25 overhauls, 20 minor repairs, 4 medium repairs, and 1 general repair. The intervals are: 1,460 machine-hours between medium repairs, 292 machine-hours between minor repairs, and 146 machine-hours between maintenance interventions.

Bibliographic References

Angelmendizabal.com. (27 de mayo de 2024). *Ejemplo práctico para realizar un análisis de criticidad*. <https://angelmendizabal.com/mantenimiento/ejemplo-practico-para-realizar-un-analisis-de-criticidad>

Arroyo, C. S. & Obando, R. F. (2022). Importancia de la implementación de mantenimiento preventivo en las plantas de producción para optimizar procesos. *E-IDEA Journal of Engineering Science*, 4(10), 59-69. <https://doi.org/10.53734/esci.vol4.id240>

Audisio, O. A. (2023). Turbomáquinas hidráulicas: modos de falla y su incidencia en el mantenimiento. *JIDeTEV*, (13). <https://autoresjidetev.fio.unam.edu.ar/index.php/jidetev/article/view/313>

Bloch, H. P. (1998). *Practical Machinery Management for Process Plants. Volume 1. Improving Machinery Reliability*. Gulf Professional Publishing.

Castillo-Serpa, A.M., Brito-Ballina, M.L. & Fraga-Guerra, E. (2009). Análisis de criticidad personalizados. *Ingeniería Mecánica*, 12(3), 1-12. <http://www.redalyc.org/articulo.oa?id=225114976001>

- Cedeño-Moreira, W. J. & Gorozabel-Chata, F. B. (2021). Análisis de criticidad del equipamiento industrial de la línea de bovinos de un centro de faenamiento. *INGENIAR*, 4(8), 49-65. <https://doi.org/10.46296/ig.v4i8edespssep.0029>
- Charcopa-Paz, L.E., Herrera-Suárez, M. & Carrillo-Anchundia, B.J. (2024). Determinación de los factores que inciden en la confiabilidad de las bombas sumergibles de EPMAPSE. *Dominio de las Ciencias*, 10(2), 1196-1223. <https://doi.org/10.23857/dc.v10i2.3881>
- Costa dos Santos, A. F., Bovério, M. A., & Pereira da Silva, D. (2023). Análise técnica de intervenção corretiva em bomba centrífuga. *Sitefa*, 6(1), 1-11. <https://publicacoes.fatecsertaozinho.edu.br/sitefa/article/view/242>
- Divona, A.A., Dolan, A.J., Hendershot, J.R., Karassik, I.J., Messina, J.P., Cooper, P. & Heald, C. C. (2001). *Electric motors and motor controls*. Pump Handbook.
- Enriques-Gaspar, A., Díaz-Concepción, A., Villar-Ledo, L., Del Castillo-Serpa, A., Rodríguez-Piñero, A. & Alfonso-Álvarez, A. (2020). Tecnología para el análisis de criticidad de los sistemas tecnológicos en empresas biofarmacéuticas. *Ingeniería Mecánica*, 23(1), 1-11. <https://dialnet.unirioja.es/servlet/articulo?codigo=7337273>
- Espinosa-Martínez, J., Paz-Martínez, E., Pérez-Bermúdez, R. & Acosta-Pérez, I. (2020). Contribución del mantenimiento centrado en la confiabilidad para el estudio de fallos a equipos consumidores de energía eléctrica. *Centro Azúcar*, 47(1), 22-32. http://scielo.sld.cu/scielo.php?pid=S2223-48612020000100022&script=sci_arttext
- Fajardo, G. A., Sandoval, J. C., Cabrera Castillo, K. V. & Quintal Vázquez, J. F. (2024). Evaluar el efecto de la máxima amplitud de vibración de un sistema con amortiguamiento viscoso, generada por cavitación en bombas centrífugas. *Ciencia Latina*, 8(5), 10246-10259. https://doi.org/10.37811/cl_rcm.v8i5.14407
- González, F. (2005). *Teoría y práctica del mantenimiento industrial avanzado*. Editorial Fundación Confemetal. [https://books.google.es/books?hl=es&lr=&id=OzwXOAKv_QAC&oi=fnd&pg=PP11&dq=Gonz%C3%A1lez,+F.+\(2005\).+Teor%C3%ADa+y+pr%C3%A1ctica+del+mantenimiento+industrial+avanzado.+&ots=8Zp2HuK5ej&sig=eGs8su-sTV6kaV4ypWuFE3IfaAM](https://books.google.es/books?hl=es&lr=&id=OzwXOAKv_QAC&oi=fnd&pg=PP11&dq=Gonz%C3%A1lez,+F.+(2005).+Teor%C3%ADa+y+pr%C3%A1ctica+del+mantenimiento+industrial+avanzado.+&ots=8Zp2HuK5ej&sig=eGs8su-sTV6kaV4ypWuFE3IfaAM)

Mora, L.A. (2009). *Mantenimiento-planeación, ejecución y control*. Alfaomega Grupo Editor.

Morrow, L. (1986). *Maintenance Engineering Handbook*. Editorial McGraw-Hill.

Pérez, J. (2018). *Análisis de Máquinas: Métodos y Aplicaciones*. Editorial Tecno.

Pulido-de León, L. A., García-Treviño, I. L. Medina-Álvarez, M. A. & De Los Santos-Méndez, F. (2024). Optimización del plan de mantenimiento preventivo para equipos de mecanizado por arranque de viruta mediante análisis de fiabilidad y costos. *Ciencia Latina*, 8(5), 4759-4780. https://doi.org/10.37811/cl_rcm.v8i5.13929

Rojas, J.G., Aguirre, G.Y. & Botterón, F. (2021). Control de una bomba centrífuga monofásica comercial para irrigación de huertas rurales utilizando energía solar fotovoltaica. + *Ingenio. Revista de Ciencia, Tecnología e Innovación*, 3(2), 22-42. <https://ri.conicet.gov.ar/handle/11336/170438>

Sánchez Aguilar, M. (2016). *Modelo de gestión de mantenimiento preventivo para mejorar la disponibilidad de los equipos en una empresa de servicios*. (Master Degree Thesis, North Private University, Perú). http://repositoriodspace.unipamplona.edu.co/jspui/bitstream/20.500.12744/1776/1/Sanchez_2016_TG.pdf

Thielsen, A. (1970). *Mantenimiento predictivo y vibraciones mecánicas*. Editorial McGraw-Hill.

Woodhouse, J. (1994). *Criticality Analysis Revisited*. The Woodhouse Partnership Limited.