MULTIDISCIPLINARY JOURNAL EPISTEMOLOGY OF THE SCIENCES

Volume 2, Issue 2
April–June 2025

Quarterly publication

CROSSREF PREFIX DOI: 10.71112

ISSN: 3061-7812, www.omniscens.com

Multidisciplinary Journal Epistemology of the Sciences

Volume 2, Issue 2
April–June 2025

Quarterly publication
Made in Mexico

The Multidisciplinary Journal Epistemology of the Sciences accepts submissions from any field of knowledge, promoting an inclusive platform for the discussion and analysis of epistemological foundations across various disciplines. The journal invites researchers and professionals from fields such as the natural sciences, social sciences, humanities, technology, and health sciences, among others, to contribute with original articles, reviews, case studies, and theoretical essays. With its multidisciplinary approach, it aims to foster dialogue and reflection on the methodologies, theories, and practices that underpin the advancement of scientific knowledge in all areas.

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Multidisciplinary Journal Epistemology of the Sciences Vol. 2, Issue 2, April-june 2025, is a quarterly publication edited by Dr. Moises Ake Uc, C. 51 #221 between 16B and 16C, Mérida, Yucatán, Mexico, C.P. 97144, Tel. 9993556027, Web: https://www.omniscens.com, admin@omniscens.com. Responsible Editor: Dr. Moises Ake Uc. Rights Reservation
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Multidisciplinary Journal Epistemology of the Sciences

Volume 2, Issue 2, 2025, April–June

DOI: https://doi.org/10.71112/nchv3d08

ANALYSIS OF ELECTRICAL LOSSES IN MACHINE-TOOLS BY USING PREDICTIVE MAINTENANCE THERMOGRAPHY

ANÁLISIS DE PÉRDIDAS ELÉCTRICAS EN MÁQUINAS-HERRAMIENTAS MEDIANTE LA APLICACIÓN DE MANTENIMIENTO PREDICTIVO DE TERMOGRAFÍA

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DOI: https://doi.org/10.71112/nchv3d08

Analysis of electrical losses in machine-tools by using predictive maintenance thermography

Análisis de pérdidas eléctricas en máquinas-herramientas mediante la aplicación de mantenimiento predictivo de termografía

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ABSTRACT

This study examines electrical losses in a machine tool workshop using thermography as a predictive maintenance tool. The methodology involved a detailed thermographic inspection of the electrical systems of a compressor, milling machine, and lathe machine, identifying overheating and critical areas during operation. Findings revealed multiple faults, including air leaks, contractor overheating, and faulty electrical connections, all of which contributed to elevated energy consumption. Implementing corrective and preventive measures based on these thermographic insights led to notable energy savings, with estimated reductions of 0.363 kW·h for the milling machine, 0.341 kW·h for the compressor, and 0.322 kW·h for the lathe machine. These results highlight thermography's value in optimizing energy efficiency and emphasize predictive maintenance's role in enhancing operational efficiency and sustainability in industrial settings.

Keywords: energy efficiency; predictive maintenance; thermography; electrical losses; machine-tool

RESUMEN

Este estudio tiene como objetivo analizar las pérdidas eléctricas en un taller de máquinas-herramienta mediante el uso de la termografía como técnica de mantenimiento predictivo. La metodología incluyó una inspección detallada de los sistemas eléctricos de un compresor, una fresadora y un torno, mediante una cámara termográfica para identificar sobrecalentamientos y puntos críticos en condiciones de operación. Los resultados mostraron diversas fallas, como fugas de aire, sobrecalentamiento en contactores y conexiones eléctricas defectuosas, lo cual contribuyó al consumo energético excesivo de estos equipos. Al implementar actividades correctivas y preventivas basadas en los hallazgos termográficos, se lograron mejoras significativas, con ahorros energéticos estimados de hasta 0.363 kW·h en la fresadora, 0.341 kW·h en el compresor y 0.322 kW·h en el torno. Estos resultados subrayan la efectividad de la termografía en la optimización energética y refuerzan la importancia del mantenimiento predictivo para mejorar la eficiencia y sostenibilidad en entornos industriales.

Palabras clave: eficiencia energética; mantenimiento predictivo; termografía; pérdidas eléctricas; máquinas-herramientas

Received: May 31, 2025 | Accepted: June 16, 2025

INTRODUCTION

The increase in electrical energy consumption in machine tool workshops is largely due to rising production demands, which require extended and continuous operation of equipment (Scharnhorst et al., 2024). Factors such as machine aging, component wear, and inadequate maintenance contribute to inefficient energy use, as machinery operates under less-than-ideal conditions that demand more power for standard tasks (Chang et al., 2021).

Outdated technology in certain machines also prevents optimal energy utilization, exacerbating consumption levels. This escalation in energy use is linked to issues such as electrical losses and component overheating, which accelerate equipment wear and increase failure frequency. These inefficiencies drive up operating costs, with significant increases in electricity bills for workshops with intensive machinery use. Additionally, accelerated wear due to inefficient operation shortens equipment life and raises maintenance and replacement expenses. Environmentally, higher energy consumption contributes to greater emissions, especially in areas reliant on fossil fuels for electricity generation, thus impacting climate change (Rahman et al., 2022).

Detecting and addressing electrical energy losses in industrial settings, particularly in machine tool workshops, is essential for economic, operational, and environmental reasons. Energy losses represent unnecessary resource usage, which directly impacts operational costs (Bosu et al., 2023). In workshops with power-intensive machinery, such as lathes, milling machines, and Computer Numerical Control systems (CNC), even minor inefficiencies accumulate into substantial energy waste, affecting overall profitability. Effective identification and correction of these losses improve energy use, reduce electricity costs, and optimize resource management for the workshop (Himeur et al., 2021).

Operationally, energy losses frequently signal deeper equipment issues, including faults in electrical components such as motors, cables, frequency converters, and control systems, as well as mechanical wear that can increase friction or cause misalignment. For instance, a machine motor operating inefficiently due to overheating or faulty connections not only consumes excessive energy but is also at risk of permanent damage. Laouadi et al. (2020) demonstrated that early detection of such issues by monitoring and correcting energy losses facilitates more effective preventive and predictive maintenance, reducing unplanned downtime and extending equipment lifespan.

From a sustainability standpoint, addressing energy losses also brings significant environmental benefits. Bogdanov et al. (2021) examined the transition toward more sustainable electricity generation, noting that fossil-fuel reliance in energy production contributes to greenhouse gas emissions. Therefore, any reduction in energy usage directly reduces the carbon footprint of a workshop and the broader industry. As environmental responsibility grows in importance, energy efficiency practices not only help to cut costs but also support regulatory compliance and enhance corporate reputation.

By employing predictive maintenance techniques like thermography, which enables real-time detection of thermal anomalies and energy inefficiencies, workshops can implement strategies that are both sustainable and efficient. This approach aligns productivity with environmental stewardship, making energy management an integral part of achieving operational excellence. In sum, the identification and mitigation of electrical energy losses in machine tool workshops represent a strategic pathway toward economic efficiency, enhanced operational reliability, environmental sustainability, and high production quality.

Predictive maintenance is a strategy defined by Falekas and Karlis (2021) that relies on continuous or periodic monitoring of equipment conditions to detect signs of deterioration or impending failures before they occur. Unlike preventive maintenance, which occurs at set intervals, predictive maintenance intervenes only when data suggests a failure is imminent. This approach helps optimize downtime, minimize repair costs, and extend equipment life by ensuring interventions happen only when necessary (Antonino-Daviu, 2020). Predictive maintenance plays a vital role in preventing failures in machine tools by facilitating early identification of issues. By continuously monitoring the equipment's condition, early signs of wear or malfunction in critical components can be detected, enabling timely interventions that reduce unexpected downtimes and enhance equipment availability. Additionally, it reduces unnecessary energy consumption associated with malfunctioning components (Hoffmann et al., 2020).

Thermography is a predictive maintenance technique that uses thermal imaging to detect temperature anomalies in equipment (Venegas et al., 2022). It involves the use of thermographic cameras to capture infrared radiation emitted by objects, converting it into a visible image where varying temperatures are represented by different colors. This technique is especially valuable in industrial settings, as it can identify components operating at abnormal temperatures, signaling problems like excessive friction, poor insulation, loose electrical connections, circuit overloads, or motor and transmission failures.

According to Balakrishnan et al. (2022), thermography works by detecting infrared radiation, which is emitted by all objects based on their temperature. Higher temperatures correspond to greater infrared radiation emissions, which the thermographic camera detects and converts into a thermal image. This contrast makes it possible to quickly identify problem areas that may not be visible through conventional inspection.

The thermographic camera is a key tool for detecting electrical leaks, which are a major cause of energy losses and failures in industrial electrical systems. These leaks typically manifest as temperature increases in affected areas due to unwanted current flow through faulty materials or connections (Valencia-Bacilio et al., 2023). Thermography, with its high precision in detecting temperature differences, enables the identification of these leaks in components such as cables, distribution boards, and transformers without interrupting equipment operation. Its application is essential for preventing significant issues like short circuits, fires, or equipment damage. Thus, thermographic cameras play a critical role in optimizing predictive maintenance, managing energy consumption, and preventing electrical risks, thereby enhancing the safe and efficient operation of industrial systems (Ortega et al., 2021).

Hadziefendic et al. (2020) emphasized the importance of periodic thermographic inspections. Targeting critical components like motors, variable speed drives, or transmission systems allows the identification of temperature patterns indicating potential problems. For example, a motor running at higher temperatures may signal overheating, overloading, or internal friction, while hot spots in a variable-speed drive could indicate faulty connections or damaged parts. If left unaddressed, these thermal anomalies can reduce energy efficiency, increase electricity consumption, and decrease overall machine performance.

This study aims to identify and reduce electrical losses in a machine tool workshop by applying thermography as a predictive maintenance technique. The methodology enables the non-invasive detection of critical heat points in electrical systems, helping identify overheating and energy losses before they lead to major damage or reduced equipment efficiency, facilitating necessary corrective actions. The paper is structured as follows: the Methodology section outlines the data collection process for machines in both operational and idle conditions. The Results section details the corrective and preventive actions based on the identified issues, with a focus on energy efficiency. In the Discussion, comparisons with existing literature are made, highlighting the significance and originality of this study. The Conclusions section synthesizes the key findings of the work.

METHOLOGY

The experimental method involves the collection of data through observation and measurement of variables in controlled or natural settings. In this case, data was collected on-

DOI: https://doi.org/10.71112/nchv3d08

site, meaning the research was conducted in the actual environment where the machines operate. This approach allows for the capture of operational parameters and the real performance of the equipment. During the investigation, specific measuring devices, such as multimeters, ammeters, and a thermographic camera, were used to monitor key operational parameters like current, voltage, and temperature. This data helps identify primary electrical faults and establish correlations between machine performance and operational conditions. By applying the experimental method, the research addresses practical issues, contributing to improvements in efficiency and safety within electrical installations.

Three machines in the workshop have accumulated the most operating hours, suggesting they have been in continuous use for extended periods and may require a thorough review to detect potential electrical and mechanical faults. The first machine is a 5.5 HP double-piston compressor, designed to deliver an airflow of 500 L/min and reach a maximum pressure of 180 psi. This makes it suitable for applications requiring high-pressure compressed air. The compressor is equipped with a three-phase induction motor, operating at a current of 13.9 A and a voltage of 220 V. Its transmission system uses a double pulley to allow for the adjustment of operational speed and torque, optimizing its performance under varying load conditions. A detailed analysis of electrical parameters was conducted, including voltage and current measurements to ensure the equipment is operating within the manufacturer’s recommended limits. Voltage readings showed a value close to the nominal, registering 218.2 V from the main distribution board, as shown in Figure 1.

DOI: https://doi.org/10.71112/nchv3d08

Figure 1

Measuring compressor motor voltage

This voltage is appropriate for the motor's operation, indicating a stable power supply. During the air compression process, when the compressor activates to pressurize the system, a current of 13.82 A was measured. This value is slightly lower than the specified value, suggesting that the motor is operating efficiently without significant electrical overload during this cycle. This is important for diagnosing the machine's health, as the amperage within the recommended range reduces the risk of overheating and potential electrical failures that could affect the equipment's durability. These operational data are essential for evaluating the compressor's performance and stability, serving as a reference for implementing predictive maintenance strategies that can prevent failures and extend the lifespan of this critical machine in the workshop.

Figure 2a shows the electrical system installation diagram designed for the proper connection and operation of the double-piston compressor, highlighting the arrangement of control and protection elements such as the contactor, breaker, and power supply lines. This setup ensures both efficient operation and the safety of the equipment and work environment. It is important that the configuration minimizes electrical risks while guaranteeing that the

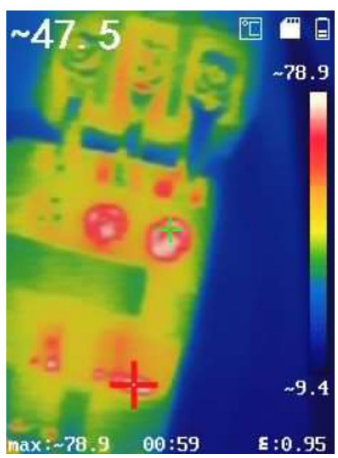
DOI: https://doi.org/10.71112/nchv3d08

compressor receives the voltage and current specified by the manufacturer during each compression cycle. To assess the condition of the electrical components under real operating conditions, thermography was used to inspect the compressor's contactor while it was running.

During the analysis, a temperature rise was detected at the connection terminals of the compressor's breaker, as shown in Figure 2b. This increase in temperature indicates additional resistance at the connections or potential loosening of the contact points. These issues could lead to localized overheating, which, if left unaddressed, may result in a more severe electrical failure or even a fire hazard. This finding underscores the need for preventive or corrective maintenance measures to ensure the safe and continuous operation of the compressor in the workshop.

Figure 2

Compressor contactor, a) installed, b) thermography

a)  b) 

Regarding the machine tools available in the workshop, there is a versatile universal milling machine capable of performing various cutting and finishing operations on materials such as steel, aluminum, and other metals. It is equipped with a three-phase motor operating at 220 V, consuming 6.5 A, with 2 HP of power, making it suitable for a wide range of machining tasks. To assess the operational condition of the milling machine and detect potential electrical faults, a thermographic camera was used, and the initial analysis is shown in Figure 3a. This device enabled the visualization of surface temperatures of electrical components, helping identify overheating areas or potential issues in the electrical system.

Upon analyzing the thermographic image, a significant temperature rise was observed in the electrical conductors, indicating additional resistance or a defect in the connection, which is generating heat. This can lead to insulation degradation, increasing the risk of short circuits or serious electrical failures. A detailed inspection of these conductors revealed noticeable wear on the insulation, particularly in terms of the thickness of the protective material. This wear can expose parts of the conductor, which not only increases the risk of short circuits but also compromises the safety of the personnel operating the machine.

Additionally, Figure 3b shows overheating in the milling machine's contactor, which is caused by improper connections where adhesive tape was used instead of proper terminals or connectors. This is an unsafe practice as it does not ensure a secure connection or adequate resistance to the current. Such overheating could indicate poor installation or an improvised repair that fails to meet the necessary safety and efficiency standards for this type of equipment. This underscores the importance of performing both preventive and predictive maintenance to reduce the milling machine's energy consumption, avoid operational disruptions, and ensure the safety of both the personnel and the equipment.

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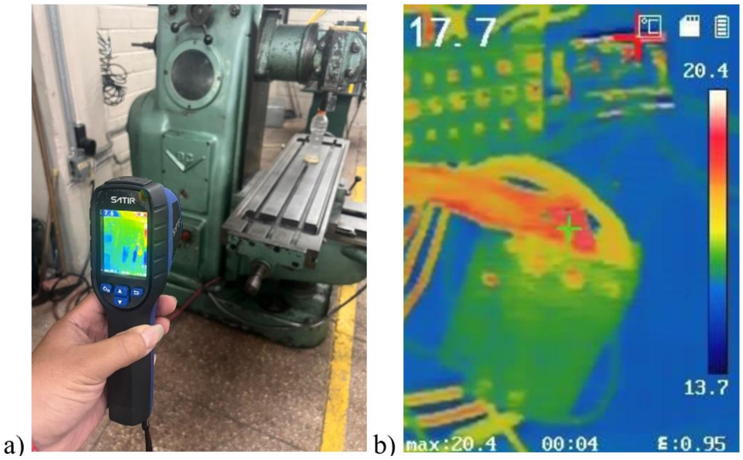
Figure 3

Analysis of electrical connections on the milling machine, a) visual inspection, b) thermography



During the operation of the milling machine, higher-than-expected electrical consumption was recorded, as shown in Figure 4. A detailed visual inspection revealed several issues with the electrical conductors, including sections of cables lacking proper insulation and improper splicing, compromising the quality of the connection.

Figure 4

Power consumption of the milling machine in use.

DOI: https://doi.org/10.71112/nchv3d08

Additionally, the insulating tape used in the splices was found to be burnt, indicating it could not withstand the operating conditions, contributing to overheating and excessive electricity consumption. These insulation and splicing problems negatively affect the milling machine's energy efficiency, posing a significant risk of electrical failures and potential damage to the equipment.

The next machine tool to be analyzed is a parallel lathe, equipped with a 2 HP three-phase motor operating at 220 V. Several risks have been identified when operating the lathe under current conditions. One major concern is the motor, which tends to overheat excessively during operation, as shown in Figure 5a. This overheating indicates that the motor is functioning outside its optimal parameters, potentially reducing its lifespan and compromising the safety of both the machine and its operators.

A particularly concerning finding is that, even when the machine is off, the electrical consumption does not drop to an insignificant level, as would be expected. Instead, a current draw of 1.2 A is observed, suggesting a potential current leak or a component that continues to consume power while in idle mode. This electrical loss could be attributed to issues with the motor's disconnect system or wiring problems, which not only increase electrical consumption but also present a risk of overheating or short circuits. Additionally, when inspecting the electrical connections while the lathe is in operation, particularly during machining, an unusual increase in temperature was detected in the electrical panel, as shown in Figure 5b. This temperature rise may indicate poor connections or improper current distribution within the panel, leading to increased resistance and energy loss.

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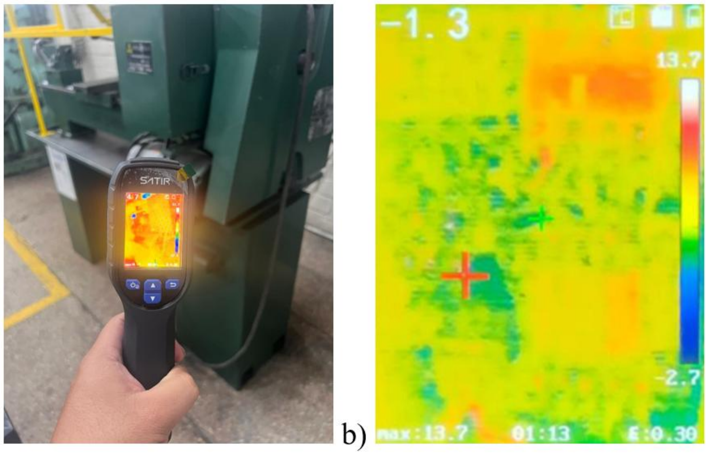
Figure 5

Analysis of electrical connections on the lathe, a) visual inspection, b) thermography

a) b)



RESULTS

After reviewing and analyzing the collected data, a comprehensive maintenance plan was developed, incorporating corrective, preventive, and predictive activities aimed at improving electrical energy consumption and ensuring the safe operation of the machines. The plan began with interventions on the compressor, where issues in wiring and contactor connections were identified. Corrective maintenance focused on addressing existing faults affecting the compressor's performance. This involved repairing and replacing defective cables with worn or incomplete insulation, which were causing electrical losses. Additionally, the contactors were readjusted, as they were not closing properly, resulting in small current leaks. Precise adjustments ensured a firm and stable connection.

Loose connections were also found, increasing resistance and causing overheating. These were tightened to improve the current flow. These corrective interventions led to an immediate reduction in electricity consumption when the compressor was off, eliminating energy leaks and improving operational safety, as shown in Figure 6. Preventive maintenance, on the other hand, was designed to reduce the risk of future failures and improve energy consumption through scheduled activities. One of the preventive tasks involved cleaning and organizing the wiring system, which helped prevent friction damage and improved airflow, reducing the risk of overheating. In addition, regular inspections of insulation on conductors and connections were implemented, as deteriorating insulation can cause current leakage and increase the risk of short circuits.

Figure 6

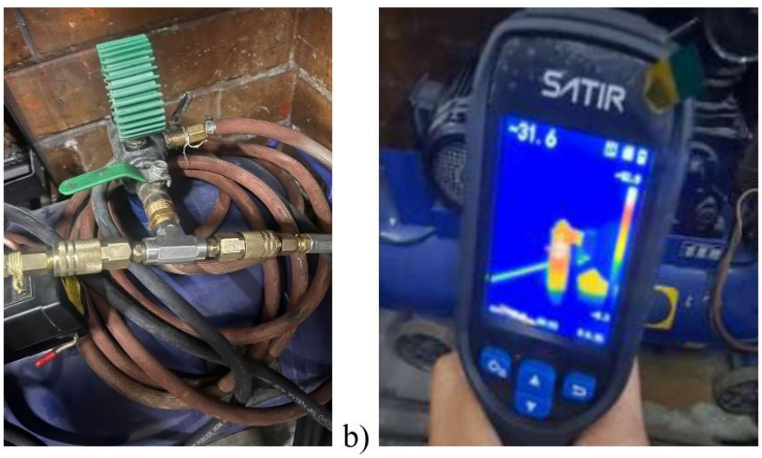
Review of zero energy consumption of the compressor in an idle state.

The use of the thermal imaging camera in this context provided an accurate assessment of the compressor's operating conditions and its components, enabling the identification of issues that might not be easily detected with conventional methods. The thermal camera visualized the heat generated by the functioning components, making it easier to spot anomalies such as air leaks and overheating areas. This provided important data for diagnosing and correcting faults. Issues like inadequate sealing or improper adjustment of connections were impacting the compressor's efficiency and posing risks to both energy consumption and system safety. The thermal camera's ability to highlight these leaks allowed for immediate corrective actions.

Figure 7a illustrates the verification process of the coupling adjustments and the condition of the compressor's air outlet components. A thorough inspection of these parts was vital to ensure proper sealing and adjustments. After making these corrections, another inspection with the thermal camera was conducted, as shown in Figure 7b, confirming that the previously detected air leaks were no longer present. This confirmed the effective resolution of the issues related to the mechanical couplings.

Figure 7

Maintenance of mechanical connections in the compressor, a) verification of adjustment in accessories, b) preventive thermography

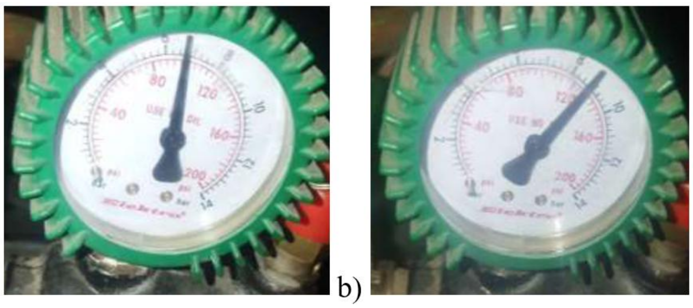


a) b)

Previously, it was observed that the compressor was experiencing significant pressure loss, even when idle. The compressor was set to maintain a pressure of 125 psi, but this pressure continually dropped to 90 psi, as shown in Figure 8a, triggering the compressor to restart and reach the set pressure. The pressure system was regulated by a pressure switch, as shown in Figure 8b, which controlled the compressor's on-and-off cycles based on the internal pressure of 125 psi. However, due to air leaks in the mechanical couplings and improperly adjusted connections, the compressor had to run continuously to restore the lost pressure. This not only increased energy consumption but also caused frequent on/off cycles, impacting overall performance.

Figure 8

Compressor pressure gauge, a) pressure loss previously, b) stability of the set pressure after maintenance activities.



a) b)

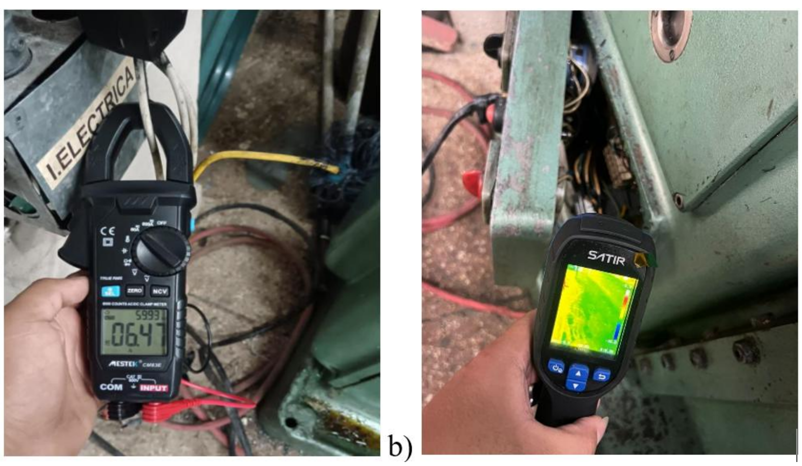
Corrective actions, including inspecting, adjusting, and replacing defective couplings and improving component connections, resolved these air leaks. With the leaks fixed, the compressor no longer needed to run continuously to maintain pressure, leading to significant energy savings. As a result of these corrections, an estimated energy savings of 0.341 kW·h was achieved, improving compressor efficiency and contributing to a reduction in operational costs associated with electrical consumption.

For the milling machine, targeted corrective actions were implemented to resolve previously identified electrical issues. The defective contactor, which had been causing overheating and unnecessary power consumption, was replaced. Additionally, conductor routing was reorganized to ensure proper channeling and protection. Following these adjustments, electrical consumption for the milling machine dropped from 7.1 A to 6.47 A, aligning more closely with the manufacturer's recommended maximum, as depicted in Figure 9a. This amperage reduction demonstrates that the improvements had a positive impact on the machine's energy efficiency, performance, and prevented excessive power use.

A thermographic camera was used to verify these improvements, with Figure 9b displaying the thermographic analysis results. The analysis confirmed that the previously observed hot spots, which indicated areas of overheating, were no longer present. This visual confirmation underscores that issues related to overheating and energy loss were effectively resolved, contributing to a safer and more efficient operation of the equipment. These corrective measures are estimated to achieve energy savings of 0.363 kW·h, enhancing the milling machine's operational efficiency and yielding direct benefits in reduced operational costs and environmental impact.

Figure 9

Maintenance activities on the milling machine, a) correct amperage measurement, b) thermography



a) b)

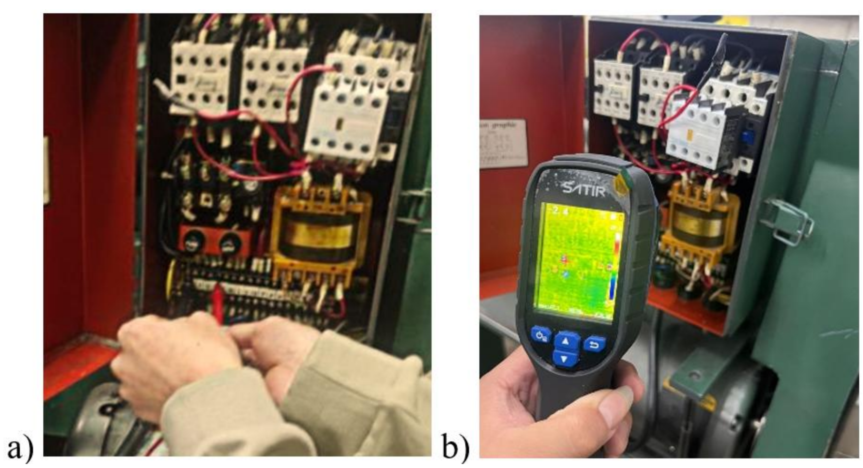
An overcurrent factor of 1.09 was identified in the lathe, indicating a 9% increase in electrical consumption due to faults in its electrical system. This overconsumption signaled a malfunction, causing the lathe to use more energy than necessary. This not only reduced operational efficiency and raised energy costs but also risked accelerated wear of the electrical components.

Further analysis identified the lathe's contactor as the primary issue, showing signs of overheating—likely due to accumulated internal wear from prolonged use. This defect limited the contactor's performance, increasing electrical resistance and thus raising energy consumption. Corrective maintenance involved replacing the faulty contactor with a new one, which was installed and tested in the lathe's electrical panel, as shown in Figure 10a. This replacement eliminated the overheating and improved the lathe's overall electrical efficiency, allowing it to operate within the recommended energy parameters.

A follow-up inspection using a thermal camera verified the results of the corrective actions. Figure 10b shows the thermographic analysis, confirming the absence of hotspots in the lathe's electrical system. These improvements resulted in an estimated energy saving of 0.322 kW·h, enhancing operational efficiency and reducing energy costs. Moreover, replacing the contactor and correcting the electrical faults help extend the equipment's lifespan, preventing potential failures or severe damage that could have occurred if left unaddressed.

Figure 10

Maintenance activities on the lathe, a) corrective on the contactor, b) predictive with thermography

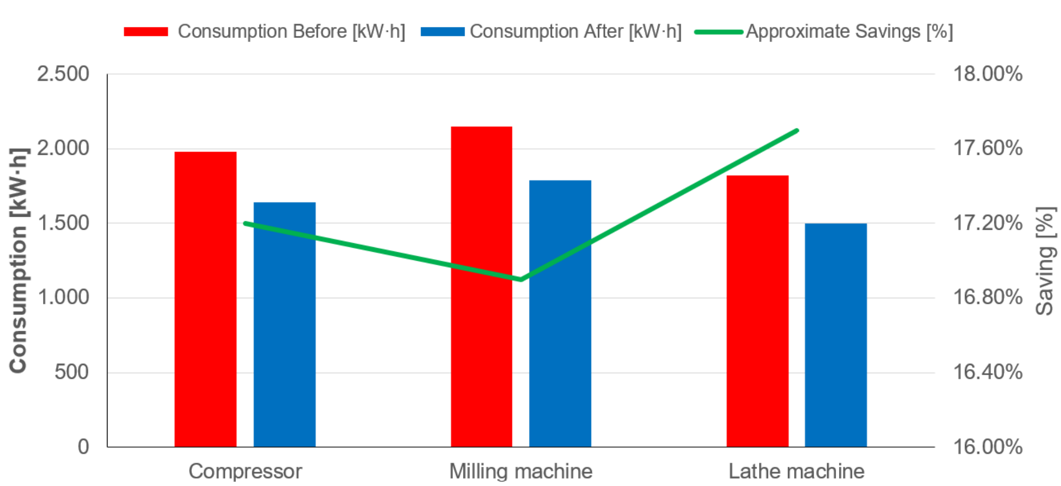


DISCUSSION

The study focused on three main machines, starting with a compressor that showed significant air leaks and inefficient operation, leading to unnecessary energy use, particularly while the compressor was off. Figure 11 illustrates how energy consumption changed after applying predictive maintenance based on thermographic inspections to three machine tools: a compressor, a milling machine, and a lathe. After addressing issues like overheating, air leaks, and poor electrical connections, a noticeable drop in power usage was observed, highlighting the practical benefits of using thermography to detect and resolve energy-related faults in industrial equipment. Electrical connections on a universal milling machine were also evaluated, where overheating in the contactor due to faulty wiring was detected. By replacing the contactor and organizing the conductors, energy savings of approximately 0.363 kW·h were achieved. Finally, an analysis of a parallel lathe identified a 9 % overcurrent factor, which was increasing energy consumption. Replacing the defective contactor and performing a thermographic inspection eliminated overheating and reduced power usage by 0.322 kW·h.

Figure 11

Electric consumption



The study reviewed existing research on energy efficiency and thermography in predictive maintenance for electrical equipment. Alvarado-Hernandez et al. (2022) utilized thermography to identify overheating in electric motors, resulting in reduced energy losses post-intervention, resounding the savings estimated in this study. Both studies underscore thermography as an effective predictive maintenance tool in manufacturing. Similarly, Venegas et al. (2020) emphasized that identifying thermal anomalies, such as hotspots and component overheating, enables timely correction, which reduces energy consumption. This technique has proven essential for failure prevention, energy conservation, and extending equipment lifespan, benefits mirrored in the assessment of the compressor, milling machine, and lathe.

Seabra-Paiva et al. (2019) used thermography to evaluate energy efficiency in industrial electric motors, showing that early fault detection and correction can lead to considerable energy savings. This study’s results align with those findings, reinforcing thermography as a predictive maintenance tool that enhances energy efficiency in machine tools. The observed reduction in energy consumption after addressing electrical issues supports the potential for meaningful energy savings using this approach. Similarly, Firdaus et al. (Firdaus et al., 2023) used thermography to identify hotspots and overheating in machine tool electrical systems, also highlighting its value in improving efficiency.

Most reviewed studies, such as Piselli et al. (2024), focus on thermography applications in large-scale equipment. However, this study emphasizes its unique applicability to smaller machinery like lathes and milling machines, which present particular challenges in detecting and resolving electrical issues for energy optimization. While some research broadly discusses improvements in energy efficiency, this study provides specific quantitative savings by analyzing energy consumption before and after intervention.

Future research could expand to a diverse range of equipment types, power levels, and industrial applications, assessing not only energy efficiency gains but also impacts on machine

DOI: https://doi.org/10.71112/nchv3d08

performance and operational costs. Moreover, combining thermography with other predictive maintenance techniques, such as vibration and oil analysis, could provide a more comprehensive equipment assessment, further enhancing maintenance effectiveness and cost efficiency.

CONCLUSIONS

The application of thermography as a predictive maintenance technique has shown a marked improvement in the energy efficiency of the analyzed machine tools. Specifically, addressing detected electrical issues, such as air leaks in the compressor, overheating in the milling machine and lathe contactors, and improving electrical connections, resulted in estimated energy savings of 0.341, 0.363, and 0.322 kW·h, respectively. These findings emphasize thermography’s effectiveness in identifying potential issues before they escalate, supporting both the extended lifespan of equipment and more energy-efficient operations.

Thermography has demonstrated itself as an efficient, non-invasive tool for industrial electrical inspections, enabling the detection of hotspots, overheating, and faulty connections that may not be visible through standard visual inspections. The thermographic images obtained provided essential insights into fault identification, such as degraded insulating coatings and suboptimal electrical connections, allowing for precise corrective actions. This confirms thermography's value as a key tool in predictive maintenance and energy efficiency management within industrial environments.

This study highlights the value of a comprehensive maintenance approach, integrating both preventive and corrective actions to resolve issues impacting the energy efficiency of machine tools. Corrective actions, like replacing defective contactors and optimizing electrical system configurations, along with continuous monitoring through thermography, have effectively reduced unnecessary energy consumption. These practices not only optimize energy resources but also enhance operational sustainability, addressing the modern industry's increasing demand for energy-efficient solutions.

Conflict of Interest Statement

The authors declare that they have no conflict of interest related to this research.

Authorship Contribution Statement

Angel Isaac Simbaña Gallardo: investigation, conceptualization, methodology, project administration, writing – original draft, writing – review and editing.

Edison Walter Intriago Ponce: methodology, investigation, supervision, writing – original draft

Cristian Orlando Guilcaso Molina: investigation, supervision, writing – review and editing.

Julio David Saquinga Daquilema: formal analysis, writing – review and editing.

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The authors declare that they used Artificial Intelligence as a support tool for this article, and also affirm that this tool does not in any way replace the intellectual task or process. After rigorous reviews with different tools confirming the absence of plagiarism, as evidenced in the records, the authors declare and acknowledge that this work is the result of their intellectual effort and has not been written or published on any electronic or AI platform.

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