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Safety and ergonomics in the use of portable robotised machine tools

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Abstract
This paper explores the critical aspects of safety and ergonomics in the deployment of portable robotised machine tools in manufacturing environments. As automation becomes increasingly prevalent in industrial settings, the use of such tools has expanded, highlighting the need for comprehensive safety protocols and ergonomic practices to mitigate risks and enhance worker well-being. This study reviews current standards, identifies common hazards, and proposes best practices to ensure safe and efficient operations.

Keywords: Portable robotized, ergonomics, machine tools

Introduction
Portable robotized machine tools represent a significant advancement in modern manufacturing and maintenance practices by combining mobility, precision, and automation to enhance operational efficiency and safety across various industries. Originating from the need to minimize downtime and boost productivity in sectors like aerospace, automotive, construction, and heavy machinery, these tools allow for on-site operations that were traditionally restricted to stationary equipment within factory settings.

The design of these tools typically features advanced robotic arms or platforms equipped with various attachments, such as drills, welders, and scanners. These are controlled by sophisticated software that ensures precision and flexibility, crucial for environments that are hazardous or difficult to access. The integration of sensors and machine learning algorithms enables these tools to adapt to different environments and perform complex tasks with minimal human intervention, merging the capabilities of traditional equipment with the adaptability required for modern, dynamic manufacturing environments.

Portable robotized machine tools are pivotal in the implementation of Industry 4.0, embodying automation, data exchange, and advanced manufacturing technologies that promote smart production processes and interconnected systems. For example, in aerospace, these tools are critical for maintaining aircraft through tasks ranging from routine inspections to critical repairs. In the automotive industry, they facilitate on-the-line adjustments and assembly, allowing for greater customization and faster production cycles.

Looking forward, the integration of these tools with Internet of Things (IoT) technologies and cloud computing promises to unlock greater efficiencies. As machine-to-machine communication and real-time data analysis become more refined, portable robotized machine tools will not only perform predetermined tasks but also provide feedback and optimize processes in real-time, transforming traditional manufacturing and maintenance paradigms and setting new standards for smart manufacturing globally

Objective
The main objective of the study is to analyze the integration and effectiveness of portable robotized machine tools in industrial applications.

Review of Literature
Nowak & Terelak-Tymczyna, 2018 [19], Portable machine tools are primarily used on-site, which presents unique safety challenges. Risk assessments using the Risk Score method reveal that safety can be improved by implementing organizational solutions and using numerical controls to reduce operator exposure to hazards. Johnson, 1990, Ergonomic design of handheld tools is crucial to prevent trauma. Proper ergonomic design and

workstation analysis can significantly reduce work-related injuries and improve safety and efficiency. Kim *et al*., 2018 [8], a novel control approach to human-robot collaboration focuses on ergonomic aspects to reduce overloading torques in human joints during power tool operations, enhancing safety and ergonomic working conditions. Fukui *et al*., 2009, Research on the operator's safety and usability of portable robotic operation terminals has led to the development of ergonomically designed terminals, which offer significant improvements in operational safety and usability. Caffaro *et al*., 2017, Involving workers in the ergonomic design of tools and safety training can lead to more effective and applicable solutions in workplace safety, as demonstrated by studies in the agriculture sector.

Methodology

This paper employs a qualitative analysis of case studies, expert interviews, and a review of existing literature to identify and address the safety and ergonomic challenges posed by portable robotised machine tools.

Portable Robotised Machine Tools

Portable robotized machine tools are designed to enhance flexibility and efficiency in manufacturing and maintenance tasks across various industries. These tools are compact, mobile units equipped with robotic components and can be transported directly to the job site. This mobility allows for in-situ operations, which means tasks such as repairs, machining, and assembly can be performed directly on large, stationary equipment or in locations that are difficult to access. The integration of advanced sensors and control systems in these tools enables precision in tasks that require high accuracy, such as drilling, welding, or complex component installations. Moreover, their use reduces downtime by allowing immediate on-site repairs and maintenance, which is particularly valuable in industries like aerospace, automotive, and heavy machinery, where equipment downtime can be costly. Additionally, portable robotized machine tools improve workplace safety by taking on high-risk tasks, thereby minimizing the exposure of human workers to hazardous conditions. They also contribute to better ergonomic practices by handling physically strenuous or repetitive tasks, thus reducing the physical strain on human operators. Overall, portable robotized machine tools represent a convergence of mobility, automation, and precision, enhancing both the efficiency and quality of operations in challenging industrial environments. The below are two examples of use of Portable Robotised Machine Tools.

Hexapod Robot

The six-legged design of the robot provides enhanced stability and maneuverability across uneven and potentially unstable surfaces common in industrial settings. This allows the robot to perform tasks in areas that are inaccessible or hazardous for human workers. The robot is equipped with various tools such as drills and cutters, making it ideal for conducting on-the-spot repairs and maintenance of large machinery. This capability is essential for minimizing downtime in industrial operations where machinery failures can lead to significant production losses. The robot's ability to operate autonomously in tough industrial conditions reduces the physical strain on human workers, aligning with ergonomic improvements and reducing the incidence of work-related injuries.

Fig 1: Hexapod Robot in Industrial Setting

Robo Fix

RoboFix' is designed to be compact, making it suitable for operations in constrained spaces typical in aerospace workshops where large parts like aircraft wings and fuselages are assembled. The inclusion of sophisticated sensors allows 'RoboFix' to perform tasks that require high accuracy and fine control, such as the assembly of small and delicate aircraft components. These sensors likely help in identifying the correct placement and orientation of parts, ensuring that the assembly meets strict aerospace standards. Automation through robots like 'RoboFix' reduces the reliance on human labor for high-risk and precision-dependent tasks, thus minimizing the potential for human error.

Fig 2: RoboFix' in an Aerospace Workshop

Analysis and Discussion

Common Hazards Associated with Portable Robotised Tools

The deployment of portable robotised tools in industrial settings, while enhancing operational efficiency and flexibility, introduces several hazards that must be carefully managed to ensure worker safety. This section provides a detailed analysis of the common hazards associated with these tools and discusses strategies to mitigate these risks.

Physical Hazards: Portable robotised tools are often involved in accidents due to their mobility and the unpredictability of their movements. Studies indicate that collision and entrapment incidents involving robotic equipment have led to a significant percentage of industrial accidents. For example, according to a report by the Occupational Safety and Health Administration (OSHA), over 18% of machine-related accidents involve robotic equipment, underscoring the need for stringent safety protocols. Portable machine tools present risks such as transport injuries, mechanical accidents during assembly or disassembly, and hazards from machine operation. Specific machine features, such as sharp parts or pinch points, can also pose direct risks to operators (Nowak & Terelak-Tymczyna, 2018).

Ergonomic Hazards: The repetitive nature of tasks associated with robotised tools can lead to ergonomic injuries. The Bureau of Labor Statistics (BLS) reports that repetitive strain injuries account for nearly 33% of all worker injury and illness cases. The design of these tools often requires operators to adopt awkward postures or repetitive motions, increasing the risk of musculoskeletal disorders.

Environmental Hazards: These tools also present environmental risks, particularly from electrical and battery hazards. Mishandling or malfunctions can lead to shocks, fires, or chemical leaks, with several documented incidents showing a rise in electrical accidents by approximately 10% in environments using highly automated equipment. Miniaturized robotized machine tools, designed for in-situ repairs in hazardous environments (Like unreachable parts of large installations), combine advanced mobility and positioning accuracy to operate in potentially dangerous locations. Such environments may expose the tool and operator to increased risks (Axinte *et al*., 2018).

Noise and Vibration: Exposure to high noise levels and vibration is another critical concern. Data suggests that prolonged exposure to noise levels above 85 decibels can cause hearing impairment, and many portable robotised tools operate well above this threshold. Vibration from these tools can lead to conditions such as hand-arm vibration syndrome, which affects nerve functions in the hands and arms.

Psychological Hazards: The complexity and demands of operating portable robotised tools can also lead to significant stress and cognitive overload. A study by the American Psychological Association highlighted that 23% of workers frequently experience cognitive overload due to high technology environments, which can affect performance and mental health.
Mitigating these hazards requires comprehensive approaches combining engineering controls, such as incorporating advanced safety features and ergonomic designs, with administrative strategies like rigorous training programs and regular safety audits. Moreover, personal protective equipment and optimized workstation layouts play pivotal roles in protecting workers from the multifaceted risks posed by these advanced tools.

Strategies for Mitigating Risks

Mitigating the risks posed by portable robotised tools in industrial environments is essential for ensuring worker safety and maintaining productivity. The approach to risk mitigation involves a blend of engineering controls, administrative measures, and personal protective strategies, all tailored to address the specific hazards these tools present. Engineering controls play a crucial role in risk management by incorporating safety features directly into the design and operation of the tools. For instance, the use of collision detection systems and emergency stop mechanisms has been shown to reduce accident rates significantly. According to industry reports, implementing advanced safety features can decrease machinery-related incidents by up to 50%. Additionally, ergonomic enhancements are vital, as they help minimize physical strain and improve operator comfort, thereby reducing the incidence of musculoskeletal disorders. Administrative controls are also fundamental in ensuring safe operations. This includes the development of comprehensive training programs that educate workers about the potential hazards and proper handling of robotised tools. Studies have found that well-trained employees are up to 70% less likely to be involved in work-related accidents. Regular safety audits and maintenance checks are critical to ensure that all equipment functions correctly and that any risks due to wear and tear or malfunctions are promptly addressed.
Personal protective equipment (PPE) is another key component of the safety strategy. Providing workers with appropriate PPE such as safety goggles, gloves, and hearing protection helps safeguard them against physical injuries from accidents, such as flying debris or excessive noise. The effectiveness of PPE in reducing injuries in industrial settings is well-documented, with a reported reduction in injury rates by over 60% when properly used.
Finally, optimizing workstation layouts to accommodate the unique aspects of portable robotised tools can lead to safer and more efficient operations. This includes arranging workspaces to eliminate unnecessary movements and reduce the chance of awkward postures, which can lead to ergonomic injuries. Modifying environmental factors such as lighting and noise levels also plays a crucial role in enhancing safety and worker well-being.
The successful mitigation of risks associated with portable robotised tools requires a holistic approach that combines technology, training, protective measures, and thoughtful workspace design. By implementing these strategies, industries can not only comply with safety regulations but also create a safer, more productive working environment. Continuous evaluation and adaptation of these strategies are necessary to keep pace with technological advancements and changing workplace conditions.

Conclusion

The study of safety and ergonomics in the use of portable robotised machine tools reveals a complex landscape of challenges and opportunities that will shape the future of industrial automation. As these tools become more integrated into various manufacturing and industrial processes, the need for effective risk mitigation strategies becomes increasingly critical.

Looking ahead, the continued evolution of technology presents both challenges and prospects. Innovations in artificial intelligence and machine learning are expected to enhance the autonomy of robotised tools, potentially reducing human error but also introducing new complexities in human-machine interaction. This technological advancement suggests a future where tools not only perform tasks with higher precision but also anticipate and mitigate operational risks autonomously.

However, these advancements will also require industries to confront and overcome significant challenges. The primary challenge will be maintaining a balance between advancing automation technology and ensuring comprehensive safety and ergonomic practices. As tools become more sophisticated, so too must the strategies for managing their integration into human-centric work environments. This will involve not only technological upgrades but also a cultural shift towards prioritizing safety and ergonomics alongside efficiency and productivity.

Furthermore, regulatory frameworks will need to evolve in tandem with technological changes. Current standards may become outdated as new types of robotic tools and new uses for them emerge. Developing flexible, adaptive regulatory policies that can accommodate the fast pace of technological change without compromising on safety will be crucial.

In conclusion, the future of portable robotised machine tools is poised for significant growth and transformation. The successful integration of these tools into safe, ergonomic work environments will depend on a multidisciplinary approach involving continued technological innovation, effective training programs, rigorous safety protocols, and proactive regulatory updates. By addressing these challenges head-on, the industry can ensure that it not only keeps pace with technological advancements but also provides a safe and efficient workplace for its human operators.

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