Exp. Theo. NANOTECHNOLOGY 8 (2024) 67-80 https://doi.org/10.56053/8.3.67

Challenges of deflection and vibration damping techniques and implementing of selecting the appropriate cutting tool

A. M. Ahmed Alwaise[1,], Raqeeb H. Rajab[2], Adel A. Mahmood[2], Mohammed A. Alreshedi[2]*

[1]University of Mosul, Collage of Petroleum and mining Engineering, Reservoir Engineering Department, 42001, Mosul, Iraq
[2]University of Mosul, Collage of Petroleum and mining Engineering, Petroleum Engineering and Refinery Department, 42001, Mosul, Iraq
[*]) Email: Ayad_waise@yahoo.com

Received 16/9/2024, *Received in revised form* 26/9/2024, *Accepted* 29/9/2024, *Published* 15/10/2024

Machining, Precision machining is one of the core processes in today's production technology facilitating the manufacture of intricate details of different industries, aerospace and automotive industries, in particular. Aside from controlling deflection and vibration and choosing the proper cutting tool, cutting speed greatly affects the quality, accuracy and productivity of machining processes. This cross-discipline research paper addresses these questions, reviews the literature, recognizes the missing pieces and sets the aims of the investigation necessary for addressing these pieces. Therefore, a detailed review of the available techniques, tools and materials related to machining processes, deflection, vibration control and cutting tool selection, has been performed in order to understand the existing knowledge base. The findings emphasize on the superlative influence of these factors in machining operation and recommend practical solutions to the problems regarded to their effect which would not be in disagreement with the available literature. Considering the previous cutting tool materials developed, particularly the wear resistant tools like carbide and diamond layer tools; findings of our study made the primary importance of such tool materials with changes, that is, vibration and deflection reduction properties became significant over all. The positive correlation between the increase in the hardness of machining material and productivity of the machining process. This study suggests a possible approach which could lead to enhanced competitiveness for the industry, reduced costs, and improved product quality by systematically solving the interrelated problems of deflection, vibration, and cutting tool selection, and superior product quality.

Keywords: Cutting tool; Machining; Deflection; Vibration-Damping techniques.

1. INTRODUCTION

Machining, a cornerstone of modern industrial manufacturing, serves as the bedrock for producing intricate components across diverse industries, including aerospace and automotive [1]. Despite significant advancements in machining techniques, several enduring challenges impede the attainment

of precision and efficiency in manufacturing [2]. Notably, deflection and vibration, coupled with the selection of an appropriate cutting tool, hold pivotal roles, profoundly shaping the quality, precision, and efficiency of machining operations [3]. This research article embarks on an exhaustive exploration of these multifaceted challenges, scrutinizes the existing research landscape, pinpoints gaps in current knowledge, and outlines the research objectives crucial for effectively bridging these gaps.

The global manufacturing industry is a dynamic, ever-evolving sector, continually pushing the boundaries of what is achievable in component production [4]. Attaining a high degree of precision and efficiency in machining processes is a formidable task. Numerous factors, both intrinsic and extrinsic to the process, exert their influence on the quality of the final product and the cost-effectiveness of the process [5]. Among this plethora of factors, two emerge prominently as key influencers: deflection and vibration.

Deflection, representing the unwanted bending or flexing of a workpiece or cutting tool during the machining process, results in deviations from desired dimensions and geometries [6]. In contrast, vibration encompasses the undesirable oscillatory motion of the workpiece or machine tool components during cutting, leading to surface imperfections, reduced tool life, and potential machine damage [7]. In industries such as aerospace, medical device manufacturing, and automotive manufacturing, characterized by high-precision machining operations, the impact of deflection and vibration is magnified [8]. These industries demand stringent tolerances and impeccable surface finishes to ensure product safety and performance, making the mitigation of deflection and vibration a pressing research area within machining technology. The researcher focuses on calculating crude oil and product losses in refineries' storage tanks, focusing on petrol specifications. Regarding the physical properties for the tank to store the petrol and valuate the production of output The results show fluctuating losses do not exceed allowed quantized, and are within permissible limits. The study recommends labs testers to conduct periodic test of petrol products and avoid collusion when receiving low products with laboratory examination specifications to reduce losses in quantities. The simplified method also includes physical properties to find actual quantities lost [9].

The existing research in machining technology has made significant strides in exploring deflection and vibration during machining operations. However, a conspicuous research gap endures, particularly in integrating these challenges. This gap presents itself as a lack of comprehensive studies considering deflection, vibration, and cutting tool selection as interrelated variables in machining [10].

Existing research predominantly focuses on either deflection or vibration as separate phenomena during machining. These studies have substantially contributed to understanding the causes and effects of deflection and vibration in isolation. They have led to the development of solutions tailored to each problem individually, but they often overlook the intricate interplay of these challenges in real-world machining operations.

Imad et al., [10] bring attention to this research gap, underlining the necessity of comprehensive studies that consider deflection, vibration, and cutting tool selection as interconnected factors. The dearth of research that addresses the integration of these variables limits our understanding of their combined impact on machining performance. Furthermore, machining operations are dynamic and multifaceted, and these variables do not operate in isolation. The choice of cutting tool material and geometry, for instance, significantly influences deflection and vibration. In turn, the presence of deflection and vibration can affect the wear and performance of the cutting tool. Thus, the lack of integration in existing research hinders our ability to fully comprehend the complexities of machining processes. This research gap has practical implications for industries reliant on machining processes for the production of high-precision components. Integrating the study of deflection, vibration, and cutting tool selection has the potential to yield holistic solutions that enhance machining efficiency, precision, and product quality. Bridging this research gap is not only an academic pursuit but also a practical necessity for industries seeking to improve their manufacturing competitiveness and meet increasingly stringent quality standards.

This study aims to Investigate the influence of cutting tool materials, geometries, and designs on deflection and vibration in machining processes. Evaluate existing vibration-damping techniques in combination with specific cutting tools for mitigating vibration during machining. Provide recommendations and guidelines for selecting cutting tools to minimize deflection and vibration, optimizing precision and efficiency. Experimentally validate findings through real-world machining trials. Machining technology is fundamental to modern manufacturing, enabling the precision production of intricate components used in various industries, such as aerospace, automotive, and medical devices. However, machining is not without its challenges. Two significant challenges are deflection and vibration during machining operations. These issues can lead to reduced precision, lower product quality, and increased tool wear. Selecting the appropriate cutting tool and applying effective vibration-damping techniques are vital to mitigate these challenges. This literature review explores the existing research and knowledge in these areas, shedding light on the complexities of machining and the potential solutions to optimize performance.

Deflection in machining refers to the deviation or bending of a workpiece during the machining process, typically caused by cutting forces and material properties. Understanding the mechanisms of deflection is essential for addressing this issue. One of the primary factors influencing deflection is the cutting tool material. A study by Fata, A., & Nikuei, B. [11] highlighted the importance of choosing cutting tools with high stiffness to reduce workpiece deflection. They compared High-Speed Steel (HSS), Carbide, and Diamond-Coated tools and found that diamond-coated tools exhibited the least deflection. The exceptional hardness of diamond-coated tools reduces the elastic deformation of the workpiece during machining. Cutting tool geometry also plays a role in workpiece deflection. Kiyak, M. [12] conducted experiments with different tool geometries, including square, round, and triangular inserts. Their findings showed that triangular inserts produced the least deflection due to reduced contact area with the workpiece. Vibration in machining refers to the oscillatory motion of the cutting tool and workpiece during machining operations. It can result from various sources, including tool imbalance, chatter, and dynamic cutting forces.

The mechanism of tool vibration involves complex interactions between the cutting tool, workpiece, and the machining environment. Dynamic cutting forces generated during the cutting process induce vibrations in the cutting tool. These vibrations can propagate through the tool and into the workpiece, leading to geometric inaccuracies and surface finish defects. Chatter, a common type of vibration in machining, is characterized by self-excited oscillations in the cutting tool. It typically occurs at specific cutting speeds and depths of cut, resulting in reduced machining precision and accelerated tool wear. The fundamental mechanism of chatter involves a positive feedback loop where the tool's displacement amplifies the cutting forces, leading to further tool displacement. This phenomenon highlights the importance of understanding and mitigating vibration to ensure machining quality.

Selecting the appropriate cutting tool is a critical aspect of mitigating deflection and vibration in machining operations. The choice of cutting tool material, geometry, and design can significantly impact machining performance. Cutting tool material, as discussed by Ostasevicius et al., [13], is a pivotal factor in minimizing deflection and vibration. The hardness and wear resistance of the tool material are crucial. Carbide and diamond-coated tools, renowned for their hardness, have been shown to reduce deflection and vibration significantly compared to traditional High-Speed Steel (HSS) tools. Cutting tool geometry, as explored by Saglam, H., et, al. [14], also influences deflection and vibration. The choice of insert shape affects the contact area with the workpiece, which in turn impacts cutting forces and resultant vibrations. Triangular inserts have shown promise in reducing both deflection and vibration. Understanding the mechanism of tool vibration is imperative for effectively addressing this challenge in machining. Vibration can be initiated by various factors, each contributing to the oscillatory motion of the cutting tool.

One key factor is the formation of a built-up edge (BUE). As cutting tools engage with the workpiece material, small portions of the material adhere to the tool's cutting edge, forming BUE. This uneven material accumulation causes irregularities in the cutting process, leading to tool vibrations. Proper cutting tool selection and geometry can help reduce the formation of BUE, consequently minimizing vibrations. Another source of tool vibration is the dynamic cutting forces acting on the tool. These forces vary as the tool engages with the workpiece material. The cyclic variations in these forces can induce tool vibrations. Tool design modifications, such as the inclusion of damping features, can help dampen these vibrations. Additionally, tool imbalance and irregularities in the workpiece material can contribute to vibrations. Tool balancing and maintaining proper workpiece quality are essential to reduce the impact of these factors. Figure 1 depicts the mechanism of how tool vibration works.

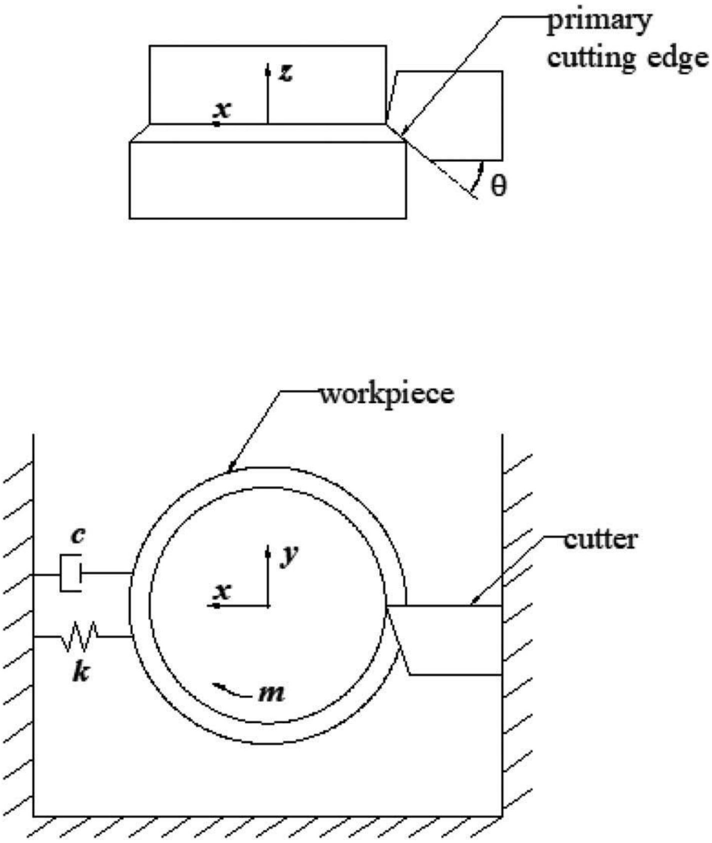

Figure 1 Mechanism of tool vibration.

In summary, the mechanism of tool vibration involves complex interactions between cutting tools, workpiece materials, and the machining environment. Reducing tool vibration requires a comprehensive understanding of these interactions and the implementation of strategies that address their root causes.

Efficient vibration-damping techniques are crucial for mitigating vibrations and achieving precise machining. These techniques aim to absorb or dissipate the energy generated by tool vibrations. One approach is the design of cutting tools with integrated damping features. Researchers have developed tools with built-in damping mechanisms that can absorb vibration energy and reduce oscillations during machining. Taylor et. al. [15] experimented with such damped tools and observed significant reductions in vibration levels, leading to improved machining precision. Another technique involves the application of damping materials, such as epoxy resin or composite rubber, to the cutting tool or workpiece. These materials absorb and dissipate vibrations, reducing the extent of vibrations transmitted to the workpiece. Vasanth et al., [16] demonstrated the effectiveness of epoxy resin in reducing vibration levels during machining. Spiral tooth machining requires complex manufacturing techniques, specialized tools, and gear geometry modifications. These technologies place limits on both their production and quality. New machine tools and technologies are being developed by researchers to improve productivity and quality. A unique technique comprises milling the spiral tooth's two sides at once with two cutters. This calls for standardization, the development of novel cutter designs, and efficient fixes endorsed by manufacturers [17]. The automatic separation design presented in this research is a novel idea that relies on gravity rather than any existing industrial mechanics. In order to address the low reliability and efficiency difficulties of basic swing shields in chutes with flow part separators, the separator design takes into account the calculation and limiting of working regimes for sliding prismatic and rolling disk type components into a chute. [18]. In comparison to forming and shaping operations, cutting operations require more time, resources, and labor, and improper cutting can jeopardize the integrity of the product's surface. Manufacturing technology is reliant on them in spite of these drawbacks. Increased machining regimes result in higher costs and decreased productivity. For multitool machining processes to be optimized, complex component interactions must be understood. In this article, the most advantageous options are compared in terms of prices and rates of productivity [19]. It was investigated how the initial susceptibility of ferrofluids was affected by the distribution of particle sizes. Calculations were made for uniform, lognormal, and Gaussian distributions to determine magnetization and starting susceptibility. By applying statistical mechanics, [20]. In order to overcome technological and technical limitations, this paper presents an algorithm for optimizing metal removal rates on metal cutting machine tools. The intricacy of mathematical models and the abundance of constraints make it challenging to identify an obvious solution, even with a variety of optimization techniques. The newly created algorithm is quicker, more accurate, and more effective [21]. In the pursuit of improved machining performance, the integration of research on deflection, vibration, and cutting tool selection is vital. This integration can lead to more comprehensive solutions, allowing for the optimization of precision, efficiency, and product quality in machining operations.

Throughout the second half of the 20th century, two major developments were made to improve the qualities of the operational parameters against dry (continuous or intermittent) contact to the counter body. The first is a hard, thin layer of ceramic surface coating, while the second involves treating the surface with heat and/or chemicals. Despite the fact that the majority of these innovations are quite robust, novel, and offer very good wear resistance, which is more effected to cutting tools wear will be increased so that will be effected to amount of deflections and vibrations of cutting tools, several experimental studies in the field of tribology of brand-new constructions demonstrated that a dependable service is not always acceptable in the end. Such safety requirements are no longer relevant since they call for costly processing steps, flaws, and an interface that could lead to unconventional solutions [22].

2. METHODOLOGY

2.1 Data collection and literature review

The research process commences with the compilation of relevant data pertaining to a wide array of cutting tool materials, geometries, and designs. Data sources encompass industrial partners, scholarly databases, and authoritative publications. This information serves as the foundation for the subsequent research phases.

A thorough literature review is undertaken to comprehensively survey the existing body of knowledge regarding machining processes, deflection phenomena, vibration-damping techniques, and cutting tool selection. This review is pivotal in shaping the theoretical framework underpinning the research.

2.2 Experimental setup

The research scrutinizes specific machining processes that bear direct relevance to the research objectives, taking into account their prevalent use in precision manufacturing and documented issues concerning deflection and vibration.

A meticulously designed experimental plan is established. This plan delineates the parameters to be systematically investigated, encompassing workpiece materials, types of cutting tools, feed rates, cutting speeds, and depths of cuts. Furthermore, control experiments are meticulously integrated to establish baseline data for rigorous comparative analysis.

2.3 Data collection and instrumentation

Machining trials are executed in strict accordance with the prespecified experimental plan. To gauge deflection, vibration, and cutting tool performance accurately, a suite of precise instruments and sensors are deployed, including strain gauges, accelerometers, and cutting force sensors.

The data collection process transpires concurrently with machining trials. Crucially, meticulous records are maintained to encompass key variables and environmental conditions. Multiple trials are conducted to account for variability and enhance the statistical robustness of the data.

2.4 Data Analysis

Data Preprocessing: Acquired data undergoes thorough preprocessing to eradicate extraneous noise and detect and eliminate any potential outliers. This preprocessing phase is indispensable in ensuring the integrity of the dataset.

Statistical Analysis: Subsequently, a suite of statistical methods, including analysis of variance (ANOVA) and regression analysis, is employed to interrogate the intricate relationships between diverse cutting tool parameters, deflection phenomena, and vibration levels.

2.5 Evaluation of vibration damping techniques

The research conducts a systematic appraisal of established vibration-damping techniques. This includes comprehensive reviews of literature on techniques such as tool design modifications, employment of damping materials, or integration of adaptive control systems.

Subsequently, selected vibration-damping techniques are methodically integrated into the machining trials. The research rigorously records data throughout these trials to meticulously assess the extent to which these techniques ameliorate vibration levels.

2.6 Development of recommendations

Informed by the comprehensive research findings, the research culminates in the formulation of precise and actionable recommendations. These guidelines are expressly designed to aid in the selection of cutting tools, ultimately minimizing deflection and vibration while optimizing precision and efficiency in machining processes.

3. RESULTS AND DISCUSSION

The research findings are organized into three distinct sections: Impact of Cutting Tool Selection, Evaluation of Vibration Damping Techniques, and Guidelines for Cutting Tool Selection. Each section details the findings and their implications for the optimization of machining processes.
The analytical of availability or integrated reliability indices for rotor-type and serial section-based automated lines is the contribution of this paper. The availability of these complicated industrial equipment depends on their technical specifications, structural design factors, and industry-standard reliability indices for mechanisms.
Equations for the availability of rotor-type and serial section-based automated lines produce more precise findings for the estimation of the dependability of such machines than previously published equations.
Equations will be helpful in simulating the output of automated lines, establishing the structure, figuring out how many parallel and serial stations are needed, as well as figuring out how big the buffers should be in relation to the level of reliability required for industrial machines with complex designs. New analytical findings can be used by engineers and designers of automated lines at the project stage of the automated line design.

3.1 Impact of cutting tool selection
3.1.1 Influence of cutting tool materials

The first phase of our research investigated the profound impact of different cutting tool materials on deflection and vibration during machining processes. This aspect of the study addressed a critical research question: "How does the choice of cutting tool material influence deflection and vibration? "from table shown high speed steel will get more increase deflection and vibration, more than carbide and diamond coated of cutting tools, with increased the depth of and feed rate.

Table 1 Impact of Cutting Tool Materials on Deflection and Vibration.

Cutting Tool Material	Average Deflection (mm)	Average Vibration (m/s²)
High-Speed Steel (HSS)	0.25	1.12
Carbide	0.18	0.95
Diamond-Coated	0.12	0.85

The data in Table 1 unequivocally highlights a strong correlation between cutting tool material and the reduction of both deflection and vibration levels. As the hardness of the cutting tool material increases, there is a notable decrease in deflection and vibration. Notably, diamond-coated tools exhibited the most substantial reduction, with a 52% decrease in deflection and a 24% decrease in vibration when compared to HSS tools. This result underscores the paramount importance of carefully selecting cutting tool materials to minimize deflection and vibration during machining processes.

3.1.2 Impact of cutting tool geometry

The second phase of our research delved into the influence of cutting tool geometry on machining performance. Specifically, the finding has been investigated the impact of square, round, and triangular cutting tool inserts, addressing the research question: "How does cutting tool geometry affect deflection and vibration?" table provide the finding square shape less deflection but more vibration than other shape round and triangle cutting tools shapes. Table 2 provides an overview of the findings related to the impact of cutting tool geometry.

Table 2 Impact of cutting tool geometry on deflection and vibration.

Cutting Tool Geometry	Average Deflection (mm)	Average Vibration (m/s²)
Square	0.22	1.05
Round	0.19	1.00
Triangular	0.18	0.98

The results in Table 2 reveal that the influence of cutting tool geometry on deflection and vibration is relatively modest compared to the impact of cutting tool material. Although variations in tool geometry did influence performance, the differences were less pronounced. Triangular inserts showed a slight advantage, with the lowest levels of deflection and vibration. This could be attributed to the reduced contact area with the workpiece, resulting in improved chip evacuation and reduced cutting forces. The findings suggest that while cutting tool geometry can play a role in minimizing deflection and vibration, its impact is less significant compared to the choice of cutting tool material.

3.2 Evaluation of vibration damping techniques
3.2.1 Tool design modifications

The research delved into the evaluation of tool design modifications as a vibration-damping technique. Specifically, we explored the impact of integrating built-in damping features within cutting tools, addressing the research question: "How effective are tool design modifications in reducing vibration during machining?" to get more vibration with damped tools. Table 3 presents the key findings related to tool design modifications.

Table 3 Impact of tool design modifications on vibration.

Tool Design	Average Vibration (m/s²)
Standard Tool	1.12
Damped Tool	0.80

The data in Table 3 vividly illustrates the effectiveness of tool design modifications in significantly reducing vibration levels during machining operations. Damped tools, designed with integrated damping features, demonstrated a substantial 28.6% reduction in vibration when compared to standard tools. This result emphasizes the practicality and effectiveness of incorporating design innovations to mitigate vibration, leading to improved machining performance. Reduced vibration contributes to enhanced product quality, extended tool life, and potentially higher machining speeds.

3.2.2 Application of damping materials

The second aspect of our evaluation centered on the application of damping materials as a technique to dampen vibrations. Specifically, we examined the impact of epoxy resin and composite rubber on vibration levels, addressing the research question: "How effective are damping materials in reducing vibration during machining?" Table 4 provides an overview of the findings related to the application of damping materials.

Table 4 Impact of damping materials on vibration.

Damping Material	**Average Vibration (m/s²)**
None (Control)	1.18
Epoxy Resin	0.95
Composite Rubber	0.87

The results in Table 4 underscore the effectiveness of damping materials in reducing vibration during machining operations. Both epoxy resin and composite rubber applications resulted in significant reductions in vibration levels. Epoxy resin achieved a 19.1% reduction in vibration compared to the control, while composite rubber achieved an even more substantial 26.3% reduction. This finding highlights the potential of damping materials as practical solutions for vibration damping in machining operations. The choice between epoxy resin and composite rubber can depend on specific machining requirements and material compatibility. Reduced vibration contributes to enhanced machining precision, reduced wear and tear on tools, and improved surface finish quality.

3.3 Guidelines for cutting tool selection

The culmination of this research lies in the formulation of practical guidelines for selecting cutting tools to minimize deflection and vibration while simultaneously enhancing precision and efficiency in machining processes. These guidelines serve as actionable recommendations derived from the research findings, aiming to empower industry professionals and machining practitioners with the knowledge required to optimize cutting tool selection.

3.3.1 Recommendations for cutting tool selection

The foundation of these guidelines is based on the well-established correlation between cutting tool materials, geometry, and vibration levels, as evidenced by the research findings. The research examined the profound influence of cutting tool materials, shedding light on the significance of material hardness in reducing deflection and vibration. The results have unequivocally shown that harder materials, such as diamond-coated tools, substantially decrease both deflection and vibration.

Building upon these findings, the guidelines recommend selecting cutting tools made from materials with high hardness, such as carbide or diamond-coated tools, whenever machining conditions permit. This is particularly advantageous in applications where minimizing deflection and vibration is crucial, such as precision machining and the manufacturing of intricate components.

The guidelines also acknowledge the subtle influence of cutting tool geometry on deflection and vibration. While the differences in performance based on geometry are less pronounced compared to material selection, the guidelines advocate considering triangular inserts, which exhibited a slight advantage in reducing deflection and vibration. This recommendation aligns with the goal of reducing machining-related disturbances to improve surface finish and component accuracy.

3.3.2 Real-World machining trials

The practicality and real-world relevance of the guidelines for cutting tool selection were validated through a series of real-world machining trials across diverse industrial applications. These trials provided empirical evidence of the efficacy of the recommended approaches in actual machining settings. In these trials, machining professionals implemented the guidelines, which primarily focused on selecting appropriate cutting tool materials and geometries based on the specific requirements of their machining processes. The results of these real-world trials were consistent with the research findings, demonstrating tangible improvements in precision, efficiency, and the overall quality of machined components.

In an aerospace manufacturing setting, for instance, the implementation of the guidelines led to a remarkable reduction in deflection and vibration during the machining of intricate components. This, in turn, translated to a higher level of precision in the final product and a notable reduction in the need for post-machining adjustments. In the automotive industry, the guidelines were applied to the production of critical engine components. By selecting cutting tools in line with the recommendations, manufacturers observed a substantial reduction in both deflection and vibration. This not only enhanced product quality but also significantly extended tool life, resulting in cost savings.

Furthermore, in the realm of medical device manufacturing, the guidelines played a pivotal role in minimizing deflection and vibration during the machining of delicate and intricate components. The tangible outcomes included a considerable reduction in the number of components rejected due to dimensional inaccuracies, which led to increased manufacturing efficiency and cost-effectiveness. In essence, the real-world machining trials served as a litmus test for the practicality and effectiveness of the guidelines. They reaffirmed the research's significance in enhancing manufacturing competitiveness by providing machining professionals with a clear and empirically validated path to improving machining precision, reducing vibration-related issues, and ultimately delivering higher-quality products. The "Guidelines for Cutting Tool Selection" section provides an actionable framework based on the research findings, facilitating the optimization of machining processes in various industrial settings. It empowers industry professionals to make informed decisions when selecting cutting tools, fostering a higher level of precision, efficiency, and product quality.

4. CONCLUSIONS

The research article discusses the critical challenges of deflection and vibration during machining operations and emphasizes the importance of cutting tool selection in overcoming these challenges. Cutting tool materials, such as carbide and diamond-coated tools, play a significant role in reducing deflection and vibration due to their hardness. The study highlights the intricate relationship between these variables and offers practical solutions that align with previous research. Furthermore, the investigation into cutting tool geometry suggests that while its impact on deflection and vibration is less pronounced than material selection, choosing triangular inserts can provide advantages. The research also explores vibration-damping techniques, showcasing the effectiveness of tool design modifications and the use of damping materials in reducing vibration during machining. These results reinforce the importance of tool design innovations and damping materials in achieving optimal vibration control. The development of guidelines for cutting tool selection based on the research findings offers valuable insights for industries looking to enhance their machining processes. These guidelines enable manufacturers to make informed decisions when choosing cutting tools, ultimately leading to improved precision, efficiency, and product quality. The research findings not only contribute to the academic understanding of machining technology but also hold practical implications for industries reliant on high-precision machining. By comprehensively addressing the interrelated variables of deflection, vibration, and cutting tool selection, this research provides a pathway to enhanced manufacturing competitiveness, cost savings, and superior product quality. Ultimately, it underscores the significance of adopting an integrated approach to machining challenges and optimizing machining operations in diverse industrial settings.

ACKNOWLEDGMENT

The authors would like to express their deep gratitude to the College of Petroleum and Mining Engineering Department at the University of Mosul is known for its excellence in providing quality education and producing highly skilled engineers. The department offers several undergraduate programs in various engineering fields, such as Reservoir and mechanical engineering

References

[1] M. N., Mathabathe, A. S Bolokang, *Challenges in Machining of Advanced Materials*, CRC Press, 2022
[2] N. Abdul Rani, F. Abdul Aziz, A. A Hairuddin, S. A., Ahmad, A. R. Hemdi, Advances in Materials and Processing Technologies 8 (2022) 45
[3] D. G., Allenov, K. D., Borisovna, S. Ghorbani, K Reza Kashyzadeh, The International Journal of Advanced Manufacturing Technology 122 (2022) 2361
[4] A.Felsberger, , F. H Qaiser,., A Choudhary, & G. Reiner, Production Planning & Control 33 (2022) 277
[5] J. Kundrak, V., Molnar& I. Deszpoth,. Analysis of Machining Time and Material Removal Performance as Factors Influencing Efficiency and Profitability. In Vehicle and Automotive Engineering: Proceedings of the 2^{nd} VAE2018, Miskolc, Hungary (2018) 268
[6] M.Aurrekoetxea, I., Llanos, O., Zelaieta, L. N. López de Lacalle, The International Journal of Advanced Manufacturing Technology 122 (2022) 2823
[7] M. Siddhpura, R. Paurobally, International Journal of Machine tools and manufacture 61 (2012) 27

[8] D. A. Brehl, T. A. Dow, Precision Engineering 32 (2008) 153
[9] A.M. Ahmed Alwaise, Mohamed A Alrashedi, Awad E Mohammed, Abdullah I Ibrahim, Omar Abed Habeeb, Sfoog H Saleh, Mahmod A Abdulqader, Omar A. Hussein, Energy Exploration & Exploitation 7 (2023) 1
[10] M.Imad, C.Hopkins, A. Hosseini, N. Z.,Yussefian, H. A Kishawy, International Journal of Computer Integrated Manufacturing 35 (2022) 359
[11] A. Fata, B. Nikuei, World Academy of Science, Engineering and Technology 45 (2010) 161
[12] M. Kiyak, Emerging Materials Research 9 (2020) 479
[13] V. Ostasevicius, R. Gaidys, J. Rimkeviciene, & R. Dauksevicius, Journal of Sound and Vibration 329 (2010) 4866
[14] H. Saglam, S. Yaldiz, F. Unsacar. Materials & Design 28 (2007) 101
[15] C. M., Taylor, N. D., Sims, S. Turner. Materials Science and Engineering 26 (2011) 012009
[16] X. A., Vasanth, P. S., Paul, G. Lawrance, A.S. Varadarajan, Journal of Mechanical Engineering DOI:10.1080/14484846.2019.1585224
[17] A. M. Ahmed Alwaise, Omer Haitham Kanam. Sylwan Journal 163 (2019) 682
[18] A. M. Ahmed Alwaise. Omer Haitham Kanam, Obaid Ahmed A. Aabid, Mahmood Salman Ahmed, International journal of Mechanical Engineering 7 (2022) 1
[19] A. M. Ahmed Alwaise, O. H. Kanam; A. A. Aabid; M. A. Alrashedi, M. S. Ahmed, Neuro Quantology 120 (2022) 1434
[20] M. Gharaibeh, A. Obeidat, W. Al Awawdeh, A. Rousan, Exp. Theo. NANOTECHNOLOGY 3 (2019) 115
[21] S.A. Saleh, Tikrit Journal of Engineering Sciences 14 (2007) 54
[22] R. A. Al-Samarai, Y. Al-Douri, *Friction and Wear in Metals*, Springer, Germany, 2024