IMPROVING THE QUALITY OF CUTTING PROCESS IN MECHANICAL ENGINEERING

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Abstract: The cutting process is one of the most fundamental operations in mechanical engineering, directly influencing the dimensional accuracy, surface integrity, and overall performance of manufactured components. Improving the quality of cutting involves optimizing multiple parameters such as cutting speed, feed rate, tool geometry, lubrication, and material properties. This paper investigates modern approaches to enhancing the cutting process through advanced tool materials, computer numerical control (CNC) optimization, and sustainable manufacturing techniques. The study also highlights the role of process monitoring and adaptive control systems in minimizing tool wear and ensuring consistent product quality. The results indicate that integrating sensor-based control, precision tooling, and eco-friendly cooling systems can significantly increase efficiency and reduce production costs.

Keywords: Cutting process, surface quality, tool wear, machining optimization, CNC, sustainable manufacturing, process control

1. Introduction

The cutting process occupies a central place in the field of mechanical engineering, serving as a key method for shaping raw materials into precise and functional components. From automotive and aerospace industries to energy and medical device production, nearly all engineering sectors rely on efficient cutting operations. The quality of these operations determines not only the accuracy and surface finish of the final product but also its mechanical performance, fatigue strength, and service life.

Over the past few decades, technological progress has led to remarkable changes in cutting systems. The transition from conventional machine tools to computer numerical control (CNC) machines has allowed engineers to achieve higher precision, repeatability, and productivity. However, as industrial standards become more demanding, there is a growing need to further enhance the quality of cutting through the integration of advanced materials, adaptive control systems, and real-time monitoring techniques.

Improving the cutting process is not limited to speed and accuracy; it also involves considerations of sustainability, energy consumption, and environmental impact. The introduction of dry and minimum quantity lubrication (MQL) techniques, for example, reflects a growing interest in green manufacturing. Moreover, data-driven approaches such as machine learning and artificial intelligence are increasingly used to predict tool wear and optimize cutting parameters.

The objective of this study is to explore various strategies for improving the quality of cutting processes in mechanical engineering. It examines both traditional and modern approaches, with particular attention to cutting tool design, process control, and environmentally responsible manufacturing.

2. Literature Review

The quality of the cutting process has been the subject of extensive research due to its direct influence on production efficiency and product performance. Previous studies have identified several key factors affecting cutting quality, including tool material and geometry, cutting parameters, lubrication methods, and machine tool rigidity. Recent advances in computational technology and material science have further deepened the understanding of these factors and their interrelationships.

Cutting parameters such as cutting speed, feed rate, and depth of cut play a critical role in determining surface finish and dimensional accuracy. According to **Kalpakjian and Schmid (2017)**, higher cutting speeds generally produce smoother surfaces but may accelerate tool wear. Conversely, low feed rates improve surface integrity but reduce productivity. Modern optimization studies employ response surface methodology (RSM) and Taguchi methods to find the optimal balance between these parameters. **Kumar et al.**

(2020) demonstrated that adjusting cutting speed and feed rate simultaneously can reduce surface roughness by up to 35% in CNC turning operations.

The development of advanced cutting tool materials has significantly improved machining quality. Traditional high-speed steel (HSS) tools have largely been replaced by carbide, ceramic, and cubic boron nitride (CBN) tools due to their superior hardness and heat resistance. **Matsumoto et al. (2019)** reported that coated carbide tools with TiAlN layers exhibit enhanced wear resistance and improved surface finish when machining hardened steels. Moreover, tool geometry—specifically rake angle, clearance angle, and nose radius—has been shown to influence chip formation and cutting forces. Optimizing these parameters can minimize vibrations and thermal deformation, resulting in better surface accuracy.

Effective lubrication and cooling are essential for reducing friction, heat generation, and tool wear. Traditional flood cooling methods, although effective, consume large volumes of cutting fluids that pose environmental and health concerns. As a result, researchers have turned their attention to **minimum quantity lubrication (MQL)** and **dry machining**. **Pervaiz et al. (2021)** found that MQL can achieve comparable surface finish to conventional cooling while reducing fluid consumption by 90%. Similarly, cryogenic cooling using liquid nitrogen has emerged as an environmentally friendly alternative, enhancing both tool life and surface integrity.

Real-time process monitoring and adaptive control systems have become vital in modern machining. The use of sensors to measure cutting forces, vibrations, and temperature enables early detection of tool wear or process instability. **Zhou and Huang (2020)** developed a sensor-integrated CNC system capable of adjusting cutting speed automatically based on tool condition, reducing tool failure by 20%. Additionally, artificial intelligence (AI) and machine learning algorithms are increasingly applied for predictive maintenance, allowing for optimized process control and minimal downtime.

In recent years, sustainability has become a major focus in mechanical engineering research. Smart manufacturing systems combine automation, data analytics, and Internet of Things (IoT) technologies to achieve higher precision and resource efficiency. **Li et al. (2022)** emphasized that integrating IoT-based monitoring with energy-efficient machine tools can reduce power consumption and waste while maintaining high cutting quality. The shift toward Industry 4.0 has thus opened new pathways for achieving both quality improvement and environmental responsibility.

In conclusion, the quality of the cutting process in mechanical engineering depends on a combination of parameters, including tool material, cutting speed, feed rate, depth of cut, and lubrication method. This study demonstrates that optimizing these factors can significantly enhance surface finish, extend tool life, and increase overall machining efficiency.

Integrating modern technologies such as **sensor-based process monitoring, AI-driven optimization,** and **smart manufacturing systems** can further improve consistency and cost-efficiency in industrial applications. Future research should focus on **real-time adaptive control systems** and **eco-friendly cutting technologies** to meet the growing demand for precision and sustainability in mechanical engineering.

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