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# A Bibliometric Review of Research Developments in Cutting Force Error of Machine Tools in China

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**Abstract: This study employs bibliometric methods, supported by specialized analytical tools such as CiteSpace and VOSviewer, to conduct a systematic analysis of literature related to machine tool cutting force error published in the China National Knowledge Infrastructure (CNKI) database between 2010 and 2024. By examining dimensions such as publication volume, author and institutional distribution, and keyword co-occurrence, the study reveals the developmental trajectory, research hotspots, and frontier trends in this field in China. The findings indicate that over the past fifteen years, the volume of publications on cutting force error has shown a steady upward trend, with research efforts primarily concentrated in universities and research institutes, and a gradual strengthening of industry - academia - research collaboration. Major research topics include cutting force error modeling, measurement technologies, and compensation methods. In recent years, the integration of emerging technologies - such as artificial intelligence and big data - with cutting force error research has become an increasingly prominent trend. This study provides valuable insights for researchers seeking to identify future research directions and foster technological innovation, while also offering a theoretical foundation for enterprises aiming to optimize their manufacturing processes.**

**Keywords: Machine Tool Cutting Force Error; Bibliometric Analysis; Research Progress; Research Hotspots; Frontier Trends**

## 1. Introduction

In the field of machining, machine tool cutting force error is one of the key factors affecting machining accuracy, surface quality, and tool life. Precisely managing cutting force errors significantly improves machining precision, reduces defect rates, and boosts productivity, playing a vital role in advancing high-quality manufacturing. With the manufacturing sector advancing toward greater sophistication and intelligence, studies on cutting force errors have intensified, yielding a growing body of research findings. However, amid the surge of publications, systematically clarifying the research landscape and identifying key hotspots and emerging trends has become a central concern for scholars and industry practitioners.

As a science evaluation approach grounded in mathematics and statistics, bibliometric analysis enables the quantitative examination of literature volume, authorship, institutions, and keywords to uncover research trends, development trajectories, and emerging frontiers in a given discipline. This study focuses on Chinese literature related to machine tool cutting force errors published between 2010 and 2024 in CNKI, utilizing bibliometric methods and integrating visualization tools like Cite Space and VOSviewer to systematically examine the field's current research landscape and evolving trends. The objective is to offer theoretical insights for subsequent studies and to promote the improvement of China's research capacity in cutting force errors and the innovative development of related technologies.

## 2 Methodology and Data Sources

### 2.1 Methodology

This research applies bibliometric methods with the aid of CiteSpace and VOSviewer for literature analysis. CiteSpace is a powerful bibliometric visualization software capable of mapping author collaborations, institutional networks, keyword co-occurrences, clustering structures, and temporal trends to analyze core researchers, institutions, topical focuses, and cutting-edge directions. The software also detects burst keywords, revealing dynamic changes in research frontiers across various time spans. VOSviewer primarily performs keyword co-occurrence analysis, clustering, and visual mapping. It provides a visual overview of topic distributions, inter-topic linkages, and the clustering of high-interest themes. This helps uncover the knowledge architecture and evolution path of the research field.

### 2.2 Data Sources

The data were retrieved from China National Knowledge Infrastructure (CNKI), with a search range covering January 1, 2010 to December 31, 2024. The search strategy was defined as: topic = (“machine tool cutting force error” OR “cutting force error” OR “machine tool cutting force” AND containing “error”). A rigorous manual screening process was conducted to guarantee the precision and relevance of the retrieved data. Irrelevant documents were excluded, such as those discussing only the theory of machine tool cutting force without error analysis, or popular science articles on machine tools. A total of 186 valid documents were obtained. CNKI, as a prestigious academic platform in China, indexes a wide array of journal papers, dissertations, and conference proceedings. It provides a relatively comprehensive reflection of China's research achievements in the field of machine tool cutting force error.

## 3. Developmental Stratification of Cutting Force Error Studies in Chinese Machine Tools

### 3.1 Chronological Analysis of the Literature

Analyzing the trend in publication volume on machine tool cutting force error research in China from 2010 to 2024 clearly reveals the evolution of research enthusiasm in this field. The overall publication volume exhibits an upward trend and can be roughly divided into three stages.

2010–2014: Preliminary Development Phase（38 research papers published).

During the period from 2010 to 2014, research on machine tool cutting force errors in China entered a phase of theoretical exploration and foundational development. The primary focus was on the mechanisms underlying cutting force errors, their influencing factors, and traditional approaches to measurement and modeling. Researchers investigated the effects of tool geometry, cutting parameters, and work piece materials on force deviations, and established empirical error models through orthogonal experiments and multivariate regression techniques [1, 2]. Conventional measurement tools such as strain gauge [3] and piezoelectric dynamometers were widely adopted for cutting force data acquisition [4]. These efforts laid a solid theoretical groundwork for subsequent advancements in intelligent modeling and real-time compensation strategies [5], marking a critical stage in the transition from passive error estimation to proactive error control in machining processes [6].

2015–2019: Stage of Research Acceleration（62 research papers published）

During the period from 2015 to 2019, driven by the in-depth implementation of the “Made in China 2025” initiative, China’s research on machine tool cutting forces entered a phase of rapid development. The research themes continuously expanded, shifting from traditional empirical modeling and measurement analysis toward interdisciplinary integration. A wide range of intelligent methods—such as finite element simulation, neural networks, and fuzzy control—were actively introduced to enhance the predictive accuracy and adaptability of cutting force models [7, 8]. Simultaneously, emerging force sensing technologies, including fiber-optic sensors, strain gauge arrays, and MEMS-based systems, were widely applied, enabling higher-frequency and higher-precision data acquisition during machining processes [9, 10]. Moreover, cutting force error compensation began to evolve toward online and intelligent control, with increasing efforts focused on developing closed-loop control strategies based on real-time data feedback. This period was characterized by a dual emphasis on theoretical advancement and practical engineering application, with a diversification of technical approaches. As a result, the research focus began to transition from merely achieving accurate measurements ("measurement precision") to realizing precise control ("control accuracy") in the machining environment [11-13].

2020–2024: Stage of Comprehensive Advancement（86 research papers published）.

Between 2020 and 2025, research on machine tool cutting force error in China entered a stage of deepening and expansion. On the basis of sustained high publication volume and steady growth, the scope of research content and technical approaches became increasingly diversified and intelligent. On one hand, researchers placed growing emphasis on the coupling mechanisms between cutting force and other error sources such as thermal deformation, geometric inaccuracies, and dynamic responses. Error mechanism analysis and predictive modeling were carried out using dynamic models and time-series-based approaches [14-16].

On the other hand, emerging measurement technologies—such as fiber-optic sensing and MEMS-based sensors—along with advanced algorithms including deep learning and Fourier neural operators, began to play a pivotal role in dynamic estimation and intelligent compensation of cutting force errors [17-19].

Furthermore, the research frontier has gradually expanded toward complex five-axis machining, interconnected monitoring via the Industrial Internet of Things (IIoT), and intelligent tooling systems. These advancements have accelerated the transition of cutting force error research from isolated point-based monitoring to systematic, multi-source online control and optimization, thereby providing critical support for achieving high precision and high reliability in intelligent manufacturing equipment [20,21].

## 3.2 Mapping the Distribution of Scholarly Contributions

### 3.2.1 Authorship analysis

The author collaboration network was constructed using CiteSpace to investigate the key contributors and their cooperation patterns in China's research on machine tool cutting force errors. According to the map, larger nodes represent authors with more publications, and thicker links suggest stronger collaborative ties between authors. The analysis reveals that a large, cohesive group of core authors has yet to form in this field. Nonetheless, several highly productive authors have made significant contributions, particularly in areas like cutting force error modeling and measurement methods. They have played a vital role in advancing research in this area.

From the perspective of author collaboration, although most researchers still tend to work independently or within small teams, a growing trend of cross-institutional and cross-regional cooperation is becoming increasingly evident. For instance, research teams from Chongqing University and Shanghai Jiao Tong University [22] have jointly engaged in studies on cutting force error compensation technologies. By integrating their respective strengths in theoretical research and engineering application, they have achieved a series of notable research outcomes. Such collaborative models are conducive to promoting knowledge sharing and technological innovation, thereby enhancing the efficiency and quality of research efforts.

### 3.2.2 Institutional analysis

A statistical analysis of research institutions reveals that China's research on machine tool cutting force error is primarily concentrated in universities and research institutes. Institutions such as institutions such as Tianjin University, Shanghai Jiao Tong University, and Harbin Institute of Technology [23] are leading in publication output, establishing themselves as major forces in this research area. These institutions, supported by strong research capabilities, abundant human resources, and advanced laboratory facilities, have played a leading role in fundamental theoretical research and the development of key technologies.

The involvement of enterprises in the research on machine tool cutting force error has also been steadily increasing. Several large manufacturing companies, such as Beijing Shenyuanshining Technology Company Limited and Shanghai Aircraft Manufacturing Company Limited, have launched industry–university–research collaboration projects in partnership with universities and research institutes, aligning scientific research with their own production needs. These collaborations have successfully translated research outcomes into practical applications, achieving both technological innovation and economic benefits. For instance, the real-time cutting force error compensation system jointly developed by Tianjin Advanced Electromechanical System Design and Intelligent Control Key Laboratory and Tianjin University of Technology Electromechanical Engineering National Experimental Teaching [24] has significantly enhanced machining precision while reducing production costs.

### 3.3 Identification and Analysis of Research Hotspots

3.3.1 Keywords co-occurrence analysis

A co-occurrence analysis of keywords was conducted using VOSviewer, and a corresponding keyword network map was generated. In the visualization, larger keyword nodes represent higher frequencies, while the thickness of connecting lines reflects the strength of co-occurrence between terms. The analysis shows that keywords such as "cutting force error," "modeling," "measurement," "compensation," "finite element analysis," and "neural network" appear with high frequency. These keywords represent the central themes of China's research on machine tool cutting force errors.

3.3.2 Research hotspot clustering

Based on the keyword co-occurrence analysis, the clustering function of VOSviewer was used to group keywords, resulting in several distinct research hotspot clusters, mainly covering the following aspects:

(1) Cutting force error modeling: This cluster includes keywords such as "finite element analysis," "neural network," and "mathematical model". The finite element analysis method discretizes the cutting process to simulate cutting force error numerically, allowing for intuitive visualization of force distribution on the workpiece and tool, thus providing a theoretical basis for optimizing cutting parameters. Neural networks, with their powerful nonlinear mapping capabilities, can model complex relationships between cutting force error and factors such as cutting parameters and tool conditions, enabling accurate error prediction.

(2) Cutting force error measurement: This cluster is represented by keywords such as "measurement technology," "sensor," and "fiber optic sensing." Traditional cutting force measurement methods, such as resistance strain gauge dynamometers and piezoelectric dynamometers, offer high accuracy but suffer from issues like complex installation and high cost. Recently, advanced sensor technologies—such as fiber optic and MEMS sensors—have gained popularity in measuring cutting force error, owing to their high sensitivity, strong resistance to interference, and ease of integration. Moreover, non-contact measurement technologies such as laser and vision-based systems have gradually become research hotspots, offering new ideas and methods for cutting force error measurement.

(3) Cutting force error compensation: This cluster involves keywords such as "error compensation," "online compensation," and "intelligent compensation". Error compensation is an effective means of improving machining accuracy. By establishing compensation models, it adjusts the machine tool trajectory and tool parameters to correct cutting force errors. Early compensation methods mainly relied on empirical formulas and offline measurement data, resulting in relatively low accuracy. With the development of sensor and control technologies, real-time online compensation has become a research focus. It enables timely adjustment of machining parameters based on real-time cutting force error data, thus improving compensation effectiveness. At the same time, intelligent compensation methods based on artificial intelligence—such as expert systems, fuzzy control, and genetic algorithms—enable adaptive compensation under complex working conditions, further enhancing the intelligence level of error correction.

(4) Multi-factor influence analysis: This cluster includes keywords such as "tool wear," "cutting parameters," and "workpiece material". Tool wear alters the geometry of the cutting tool, thereby affecting the magnitude and distribution of cutting forces, leading to cutting force errors. Cutting parameters—such as cutting speed, feed rate, and depth of cut—significantly impact cutting force error, and optimizing these parameters can effectively reduce error. Due to differences in physical and mechanical properties, various workpiece materials exhibit distinct cutting behaviors, which in turn affect cutting force error. Therefore, studying the influence patterns of tool wear, cutting parameters, and workpiece materials on cutting force error is of great significance for optimizing machining

processes and improving product quality.

### 3.4 Exploration of Cutting-Edge Research Trends

The burst detection function in CiteSpace was used to identify research frontiers in the field of machine tool cutting force error in China across different time periods. Burst terms refer to keywords with a high rate of change in frequency over a specific period, reflecting emerging research hotspots and trends. The analysis results indicate that:

(1) From 2010 to 2014, burst terms were primarily focused on "cutting force model," "error analysis," and "traditional measurement methods," indicating that research during this period emphasized basic theories and conventional approaches to cutting force error.

(2) From 2015 to 2019, keywords such as "finite element simulation," "neural network prediction," and "novel sensors" emerged as burst terms, highlighting the growing application of simulation, AI, and advanced sensing technologies in this research area [7-11].

(3) From 2020 to 2024, frequent burst terms included "deep learning," "big data analysis," "intelligent compensation system," and "industrial internet," indicating that the deep integration of emerging technologies with cutting force error research has become a new frontier.

In particular, the application of deep learning algorithms in cutting force error prediction allows for automatic feature extraction and enables high-precision prediction under complex working conditions. Big-data-based error diagnosis and compensation systems integrate multi-source data—such as machine operation data, process data, and tool condition data—to provide comprehensive support for error analysis and decision-making. The introduction of industrial internet technology enables data interconnectivity among machines and between machines and enterprise systems, providing technical support for remote monitoring and collaborative control of cutting force error.

## 4. Conclusion and Outlook

### 4.1 Conclusion

This study employs bibliometric analysis to systematically examine research on machine tool cutting force error in China from 2010 to 2024 and draws the following conclusions:

(1) Over the past fifteen years, the number of publications in this field has shown an overall upward trend, progressing through three phases: initial exploration, rapid development, and in-depth expansion. This reflects increasing academic attention to the field and the continuous improvement of its research framework.

(2) Research efforts are mainly concentrated in universities and research institutes, where several influential teams and institutions have emerged.

(3) The participation of enterprises has gradually increased, and industry–academia–research collaboration has been enhanced, facilitating the transformation and application of research outcomes.

(4) Research hotspots include cutting force error modeling, measurement, compensation, and multi-factor influence analysis. With technological advances, the integration of emerging technologies—such as artificial intelligence, big data, and the industrial internet—has become a new trend in cutting force error research.

(5) Research frontiers have shifted from basic theories and traditional methods to areas such as computer simulation, intelligent algorithms, novel sensing technologies, and multi-technology integration, demonstrating continuous innovation and development in this field.

### 4.2 Outlook

Although China has made significant progress in the study of machine tool cutting force error, several issues and challenges remain. Future research can be carried out in the following areas:

(1) Strengthen interdisciplinary integration: Further promote the integration of emerging technologies—such as artificial intelligence, big data, the Internet of Things, and the industrial internet—with cutting force error research, in order to explore new methodologies and techniques and enhance the level of intelligence and automation.

(2) Enhance industry-university-research cooperation: Emphasize the central role of enterprises in research, foster stronger collaboration among academic, research, and industrial sectors, and build sustainable

cooperative frameworks. Focus on industry-driven challenges to accelerate the commercialization of research and boost the competitive edge of China's machine tool industry.

(3) Advance personalized cutting force error research: With the manufacturing sector moving toward customization, there is an increasing need to study cutting force errors in relation to various machine tools, processes, and materials. Future studies should address these customized scenarios by developing specialized error models, sensing approaches, and compensation strategies to meet heterogeneous production demands.

(4) Establish unified research standards and protocols: At present, the lack of standardized methods for measurement, data handling, and model validation limits the consistency and universality of findings. Regulatory bodies and industry associations are encouraged to develop standardized guidelines to enhance result comparability, promote knowledge exchange, and facilitate the orderly development of the research domain.

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