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Review

Research Progress and Application of Vibration Suppression Technologies for Damped Boring Tools

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Abstract

Deep hole structures are widely used in the fields of aerospace, engineering machinery, marine, etc. During the deep hole machining processes, especially for boring procedures, the vibration phenomenon caused by the large aspect ratio of boring tools seriously restricts the machining accuracy and production efficiency. Therefore, extensive research has been devoted to the design and development of damped boring tools with different structures to suppress machining vibration. According to varied vibration reduction technologies, the damped boring tools can be divided into active and passive categories. This paper systematically reviews the advancements of vibration reduction principles, structure design, and practical applications of typical active and passive damped boring tools. Active damped boring tools rely on the synergistic action of sensors, actuators, and control systems, which can monitor vibration signals in real-time during the machining process and achieve dynamic vibration suppression through feedback adjustment. Their advantages include strong adaptability and wide adjustment capability for different machining conditions, including precision machining scenarios. Comparatively, vibration-absorbing units, such as mass dampers and viscoelastic materials, are integrated into the boring bars for passive damped tools, while an energy dissipation mechanism is utilized with the aid of boring tool structures to suppress vibration. Their advantages include simple structure, low manufacturing cost, and independence from an external energy supply. Furthermore, the potential development directions of vibration damped boring bars are discussed. With the development of intelligent manufacturing technologies, the multifunctional integration of damped boring tools has become a research hotspot. Future research will focus more on the development of an intelligent boring tool system to further improve the processing efficiency of deep hole structures with difficult-to-machine materials.

Keywords: damped boring tool; machining; vibration suppression; active vibration reduction; passive vibration reduction

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1. Introduction

With the development of the modern manufacturing industry, the requirements for component processing quality are constantly increasing in such fields as aerospace, engi-

neering machinery, automotive, marine, etc. [1–3]. High-performance machining is one of the most widely used methods to guarantee component quality due to its high processing efficiency, high dimensional accuracy, and excellent machined surface integrity. Among different machining processes, deep hole machining faces great challenges due to its high technical complexity and manufacturing cost [4,5]. Deep hole components have been regarded as typical difficult-to-machine structures.

In deep hole machining, boring is commonly chosen as a key procedure following the drilling process to achieve tight dimensional tolerance and increase the machined surface quality [6]. Due to the large aspect ratio of deep hole structures, the boring tools used in these processes also feature a larger aspect ratio compared to tools used for ordinary hole processing. Consequently, the large overhang length of the boring tool is prone to inducing vibration during the machining process [7–9]. The machining vibration tends to deteriorate the dimensional accuracy of hole structures, which would lead to a reduction in assembly accuracy between different components. Meanwhile, the machined surface roughness of the workpiece is generally increased under machining vibration conditions that would affect the machined surface performance adversely. Furthermore, the dramatic vibration between the tool and workpiece during the machining process may generate excessive noise, exacerbate cutting tool wear, and even cause tool breakage or workpiece damage [10,11]. Consequently, how to improve the machining stability of boring tools and effectively improve their anti-vibration performance has become a research focus for both industries and academic areas.

According to different vibration resistance methods, current research about damped boring tools can be divided into active vibration reduction methods and passive vibration reduction methods [12]. The active damped boring tools work through the integration of sensing, control, and execution systems to achieve a real-time vibration resistance function, thereby improving the machined surface quality and component dimensional accuracy. High-sensitivity sensors are embedded in the boring bars to capture vibration signals in situ during the boring process. These signals are transmitted to the control system for working status analysis and data processing [13]. Afterward, corresponding control instructions are generated by the control system based on the vibration signal, and the actuator can be driven to exert a compensation force opposite to the vibration direction. Through these actions, machining vibrations of the boring tools are effectively suppressed. Comparatively, passive damped boring bars rely on structural design and material properties to absorb or dissipate vibration energy, while they do not need external energy input to reduce the amplitude of boring bar vibration during the machining process [14]. Due to the diverse vibration reduction mechanisms and structural characteristics of vibration damped boring tools, they exhibit different machining performances in different application scenarios. Therefore, it is necessary to review and analyze the state of the art and the application of vibration damped boring tools. It is expected to lay a technological foundation for the design of damped boring tools and provide guidance on the appropriate selection of damped tools for specific component machining.

During machining processes, vibrations are generally categorized into three types, free vibration, forced vibration, and self-excited vibration, each defined by distinct mechanisms and characteristics. Free vibration is triggered by transient disturbances or initial impacts. In the absence of sustained energy input, it is governed by the inherent properties of the system, with its frequency determined by the natural frequency of the machine tool–cutting tool–workpiece system. This type of vibration is typically observed as a transient response that gradually decays due to damping. Forced vibration is driven by external periodic or non-periodic excitation sources (such as spindle imbalance, gear errors, transmission irregularities, or periodic fluctuations in cutting forces), sharing the same frequency as the

excitation source. When the system frequency approaches its natural frequency, resonance can be induced, leading to a significant amplification of vibration amplitude that adversely affects machining accuracy and tool life. Self-excited vibration is most commonly manifested as cutting chatter [15], which is generated through positive feedback mechanisms, such as regenerative effects during the cutting process. Unlike free or forced vibration, it can be sustained without external excitation and is often characterized by large amplitudes and irregular waveforms. Severe risks to workpiece surface quality and overall machining stability are, therefore, posed by this vibration type.

In summary, free vibration is described as a transient response that decays naturally, forced vibration is characterized as being driven by external excitation, and self-excited vibration is sustained by internal energy feedback within the system. These three types exhibit significant differences in energy sources, frequency characteristics, and machining impacts. To ensure machining system stability and quality, identification and suppression of these vibrations are required, typically through dynamic modeling and experimental monitoring. The literature indicates that a high slenderness ratio is the primary cause of boring bar vibration [16]. Among the available methods, active damped boring tools and passive damped boring tools are effective means for suppressing tool vibration [17].

This paper systematically reviews the state of the art of vibration damped boring tools from the perspectives of different reduction mechanisms and structural characteristics of boring bars. Active and passive damped boring tools constituted with different damping structures are analyzed. By comparing the machining performance accompanied by the advantages and disadvantages of various types of vibration damped boring bars, the limitations and superiorities of specific boring tools in practical applications are discussed. Based on the summarization of current research progress, the development trend of vibration damped boring tools and associated vibration reduction technologies is outlined. The review can provide guidance on the design and application of damped boring tools for specific components machining, especially deep hole structures, and help to explore new ideas for the development of new damped tools to further improve the cutting performance.

2. Active Damped Boring Tools

With the continuous development of intelligent structures and materials technology, different active vibration damped boring tools emerged, and their associated functions are also improved [18,19]. According to varied driving and control mechanisms, active vibration damped boring tools can be divided into such types as piezoelectric-driven tools, magnetostrictive actuator tools, magnetorheological fluid damped tools, electrorheological fluid damped tools, and dynamically adjustable damped bars. Active vibration damped tools possess good vibration suppression performance, real-time response abilities, and an active adjustment function to various vibration conditions. Consequently, active vibration damped tools demonstrate significant potential in the application of precision machining areas.

2.1. Piezoelectric-Driven Damped Boring Tools

In piezoelectric-driven damped boring tools, vibration control forces are produced through the electrostrictive effect of piezoelectric materials. The deformation of piezoelectric ceramic elements or thin films under an applied electric field is utilized to drive the boring tools, which then generate high-frequency vibrations that effectively suppress vibrations induced by external loadings. Owing to their high sensitivity, rapid response, and efficient energy conversion characteristics, piezoelectric materials have been regarded as highly suitable for vibration suppression [20]. Consequently, their application in the design of vibration damped boring tools has been extensively investigated.

Within the framework of active vibration reduction technology, piezoelectric actuators have been identified as essential components for vibration control in boring processes, owing to their fast response speed, compact size, and high driving accuracy. Active suppression of vibrations in slender boring bars during machining was achieved by Tanaka et al. [21] through the use of piezoelectric actuators. The experimental results verified that the active damping system was able to adapt to variations and fluctuations in vibration frequency, thereby improving machined surface integrity and enhancing process stability by two to five times. Furthermore, a vibration damped boring bar with an active error compensation function, designed by Chiu and Chan [22] on the basis of piezoelectric ceramics, was shown to automatically adjust tool displacement induced by cutting forces during boring. This design demonstrated considerable potential for machining processes with variable cutting depths.

Akesson et al. [23] used an active vibration reduction system with an embedded layout of a piezoelectric ceramic analog controller, which can reduce the vibration level of the boring tool by about 50 dB. Kong et al. [24] applied piezoelectric ceramics as sensors and actuators to develop an active damped boring tool, combining them with control circuits designed to implement control algorithms. Meanwhile, a dynamic finite element model of the boring vibration system was established. Theoretical calculation and experimental analysis showed that the active damped system can effectively suppress vibration during the boring process. Matsubara et al. [25] designed a vibration reduction system with piezoelectric actuators and inductive resistive circuits. An equivalent dynamic model was established using stacked piezoelectric actuators, while inductance and resistance parameters were optimized using the equal peak method. Two piezoelectric actuators were installed within the boring bar, and the schematic diagram of the boring tool, accompanied by the experimental setup, is shown in Figure 1. The experimental results showed that the designed shock absorber can effectively suppress the vibration of the boring tool.

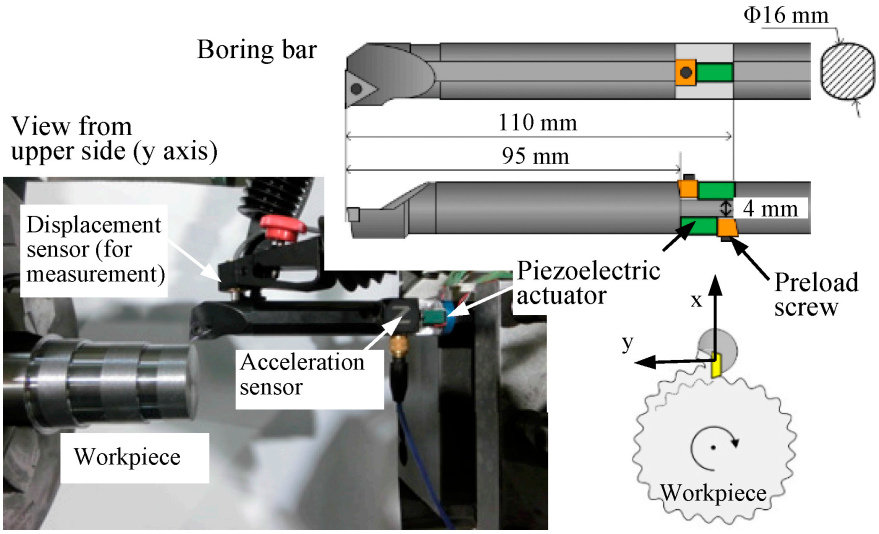


Figure 1. Typical structures of the active vibration damped boring tool based on the piezoelectric actuator and an associated experimental setup [25].

Combined passive and active damping strategies based on piezoelectric actuators have gradually attracted attention in the research of boring vibration control due to their advantages, such as simple structure and efficient response. Combined active and passive vibration reduction structures have demonstrated significant effectiveness in improving structural damping, vibration suppression, and machining stability. Venter et al. [26] embedded piezoelectric actuators in the cutting tool holder to develop a damped boring

tool based on mixed active and passive vibration reduction strategies. In the passive vibration damping strategy, the piezoelectric layer is connected to the inductor resistor shunt circuit, while the piezoelectric layer is connected to the velocity feedback control system for the active vibration damping strategy. The effectiveness of such mixed damping strategies was verified through analyzing the frequency response function and stability lobe diagram of the reference point located at the free end of the cutting tool holder. The research results indicated that both strategies can reduce vibration amplitude by increasing structural damping, thereby improving the stability of the boring process.

The effect of passive piezoelectric shunt damping on vibration during boring processes was investigated by Yigit et al. [27]. In this study, a piezoelectric actuator with electrical impedance was connected to the boring bar, and the circuit was adjusted to match the frequency required for the boring process. The optimization of circuit parameters was carried out according to the machining conditions. A representative experimental setup of a piezoelectric shunt vibration damped boring tool is presented in Figure 2. Modal characteristic test results indicated that, under optimized circuit parameters, the stability limit was increased by 95%. Furthermore, in contrast to boring experiments, the absolute stability limit of the machining process was improved from 50 μm to 175 μm, corresponding to an increase of 250%.

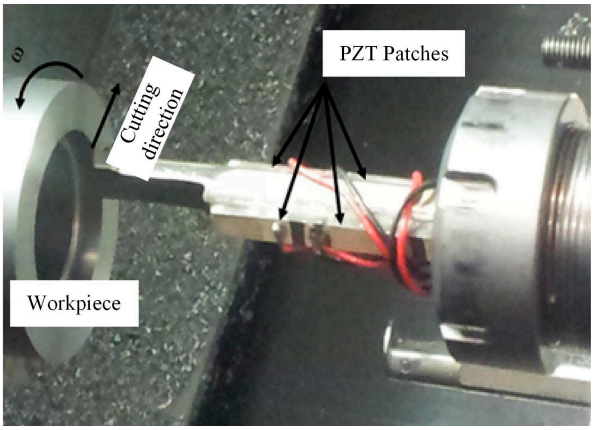


Figure 2. A representative experimental setup of a piezoelectric shunt vibration damped boring tool [27].

As an efficient active vibration control device, piezoelectric patches can significantly improve the dynamic stability and machining performance of boring tool systems through the electromechanical coupling effect. Tang et al. [28] studied the application of piezoelectric patches in the vibration control of boring tools. In their study, a nonlinear differential equation describing the vibration characteristics of the boring tools was derived based on the Kelvin–Voigt viscoelastic model, the nonlinear Von Karman strain theory, and the Euler–Bernoulli beam theory. The motion equation was discretized using the Galerkin method, and the effects of different system parameters on the machining stability and vibration behavior, in addition to the vibration suppression response of the boring tool, were systematically analyzed. The simplified model of the boring tool and the associated piezoelectric patch model are shown in Figure 3. The research results indicated that piezoelectric patches could increase the stable cutting area and effectively reduce the vibration amplitude of the boring tool system. When a voltage of 20 V was applied, the maximum stable cutting depth of the boring tool could reach up to 2.52 μm, which was 115% higher than that of the boring tool without piezoelectric patches.

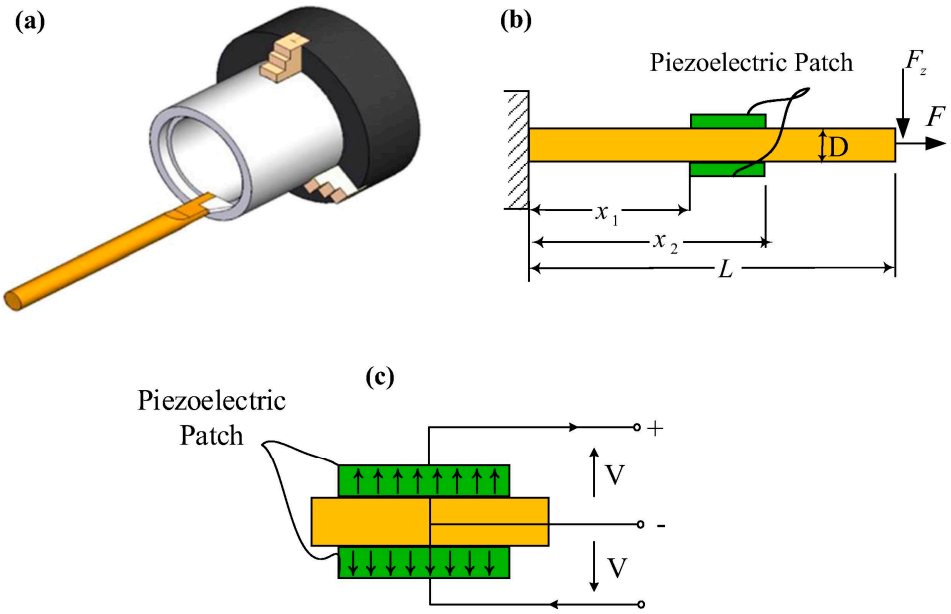


Figure 3. Simplified model of the boring tool integrated with piezoelectric patch structures: (**a**) schematic diagram of the boring process, (**b**) geometrical structures and external loading of the boring tool, (**c**) configuration of piezoelectric patches [28].

Based on the above summarization, piezoelectric actuators have demonstrated superior dynamic control capabilities, convenient structural integration, and high response sensitivity in active vibration damped boring tools. Piezoelectric actuators have become significant core components to realize vibration control during the deep hole machining process. Through integrating with multiple sensors, controllers, and signal processing circuits, piezoelectric actuators can not only regulate small displacements caused by vibrations during cutting processes but also effectively suppress multimodal vibrations to improve machining stability and surface quality. With the rapid development of artificial intelligence and adaptive control algorithms, piezoelectric components are expected to further integrate with intelligent sensing networks. Consequently, the intelligent vibration damping system will realize such functions as self-perception, self-diagnosis, and self-adjustment capabilities.

Piezoelectric devices still have some limitations, as their performances are easily affected by temperature and other environmental factors, while their long-term working stability also needs to be improved. Meanwhile, the high cost of high-performance control systems also restricts their widespread application in industries. Therefore, future research is required to focus on the improvement of damping system stability and the reduction in damping component cost, which is beneficial for promoting the practical applications of active vibration damped boring tools developed with piezoelectric actuators.

2.2. Magnetostrictive Actuator Damped Boring Tools

The deformation characteristics generated by magnetostrictive materials under the action of an external magnetic field can be used to control the vibration of boring tools. Magnetostrictive actuators can provide high power output and regulate vibration behavior through the adjustment of current or magnetic field strength, and they have been widely used in vibration damped boring tools [29].

Electromagnetic drive technology provides an effective solution for achieving high-precision radial displacement control to tackle the machining accuracy challenge caused by workpiece deformation during the boring process of non-circular holes. Zhang et al. [30,31] proposed a specific electromagnetic drive method for boring of non-circular holes in small-

sized precision parts to address the deformation issue during the machining process. The machining system is composed of a rotating electromagnetic element consisting of a stator and a rotor, which can provide a non-contact driving force for the boring tool. When the coil current in the stator pole changes, the driving force will correspondingly change and drive the rotor to produce the required micro-displacement in the radial direction. To achieve high-precision stepwise rotational motion, Zhou et al. developed a giant magnetostrictive rotational actuator [32]. It is mainly composed of a rotor, a stator, a driving mechanism, etc. Figure 4 shows the overall structural schematic diagram.

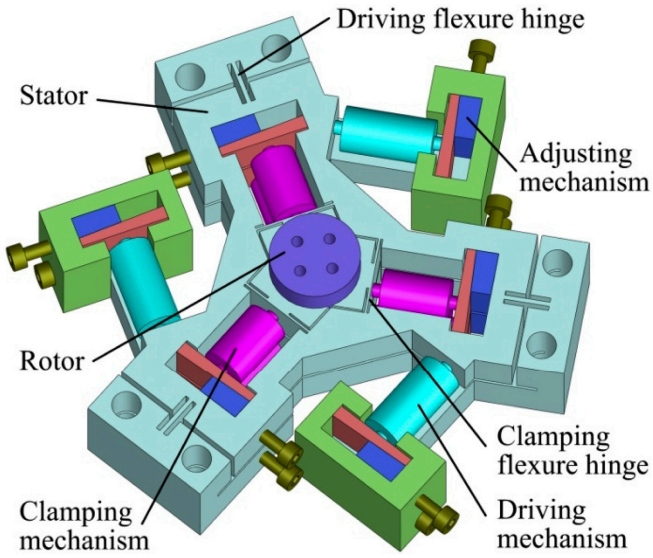


Figure 4. Schematic diagram of the giant magnetostrictive rotary actuator [32].

Based on boring experiments, the machining trajectory of the boring tool center was measured at low speeds, and the results showed that the radial micro-displacement of the boring tool mainly depends on the applied control current. In addition, relevant research about the design and modeling methods of deformable elements was conducted with finite element methods to explore their deformation characteristics and influence factors of output micro-displacement. After optimization, the maximum stress of the elastic deformation unit was reduced by 30%, which was conducive to achieving precise control of radial micro-displacements of boring tools.

The combination of high-precision real-time measurement and reliable non-contact actuators has provided an important basis for vibration control of boring tools and the improvement of machining accuracy. A real-time testing method for micro-displacement measurement during the boring of non-cylindrical pinholes in precision pistons was proposed by Wang et al. [33]. This method was implemented in a non-contact, interference-free mode, with tool displacement data dynamically collected through two vertically arranged eddy current sensors. Multiple experimental verifications confirmed that this approach was capable of effectively measuring the micro-displacement of boring tools with high accuracy and stability. In another study, a non-contact linear magnetic actuator for vibration suppression of boring tools was developed by Lu et al. [34]. The actuator, consisting of four identical magnetic units, was installed on a CNC lathe, as illustrated in Figure 5. Sensors were integrated within the actuator to monitor boring tool displacement in real-time, thereby enhancing the dynamic stiffness of the boring tool and improving vibration stability of the machining system. The boring experimental results demonstrated that, at a spindle speed of 1000 r/min, the boring stability was increased by 400%, while the stable cutting depth was improved from 0.03 mm to 0.12 mm. This magnetic actuator has, therefore, been

regarded as showing great potential for application in the fabrication of large boring bars used in machining heavy-duty diesel engine cylinders and power turbine housings.

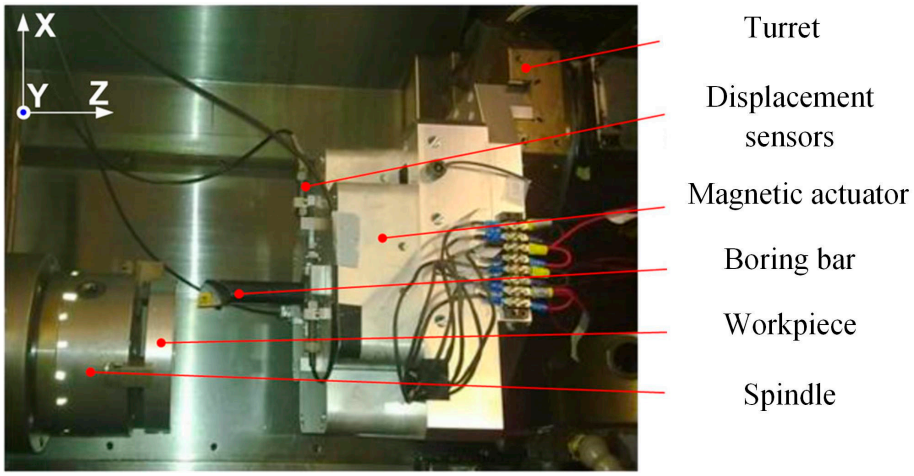


Figure 5. Typical components of a representative damped boring tool realized based on a magnetic actuator [34].

The development of magnetic actuators with multiple degrees of freedom, combined with an advanced active control strategy, effectively improves the dynamic stiffness and damping performance of boring tools. Chen et al. [35–37] designed a magnetic actuator with three degrees of freedom that can move independently in two radial and rotational directions, thereby achieving effective suppression of lateral and torsional vibrations. During the boring process, this actuator can significantly improve the damping and static stiffness of the boring tool, as shown in Figure 6. The experimental results showed that the static stiffness increased from 0.69 N/μm to 3.75 N/μm with a 5.43-fold increase in stiffness. When the spindle speed was 750 r/min without the use of an active damping controller, machining vibration occurred at a cutting depth of 0.04 mm. Comparatively, no vibration occurred at a cutting depth of 0.08 mm when an active damping controller was used. In addition, four different controllers were designed to suppress boring tool vibration and improve vibration suppression stability during the machining process. Owing to the active damping controller, the maximum stable cutting depth increased from 0.03 mm in the uncontrolled state to 0.13 mm. At a spindle speed of 1500 r/min and a cutting depth of 0.04 mm, the machined surface roughness was 6.95 μm without using the controller, while the machined surface roughness decreased to 0.67 μm with using the vibration controller, and the cutting stability of the boring tool was significantly improved. Finally, a novel multifunctional magnetic actuator was proposed, which can not only suppress machine tool vibration but also enable real-time measurement of cutting forces. The cutting force was estimated based on the displacement of the armature and the control current of the actuator. The experimental results showed that the damping controller can effectively suppress the vibration of boring tools and significantly improve the depth of vibration-free cutting.

Magnetostrictive actuators effectively suppress boring tool vibration through the inverse magnetostrictive effect and the multiple-parameter coupling action. Bak and Son [38] utilized the inverse magnetostrictive effect in Terfenol-D and adopted an open-loop control strategy to reduce boring tool vibration by generating a reverse signal through magnetostrictive actuators. Their experimental results indicated that the vibration amplitude gradually decreased with the increase in DC power input, for which the flutter attenuation rate was 0.5708, and the vibration amplitude decreased by about 43%. Liu et al. [39] proposed a multiple-parameter coupling design method that combined a deformable boring tool with an embedded giant magnetostrictive actuator to construct a dynamic model

of the deformable boring bar, while nonlinear programming techniques were used to solve the multiple-parameter coupling problem between the magnetostrictive actuator and deformable boring bar. The designed embedded magnetostrictive intelligent boring system is shown in Figure 7. The first natural frequency of the deformable boring bar and spindle assembly of the system was tested as 370.7 Hz, which could satisfy the frequency requirement of greater than 100 Hz during the machining process. Further experimental results indicated that the system could meet the performance requirements for precision machining of non-circular cylindrical piston pinholes.

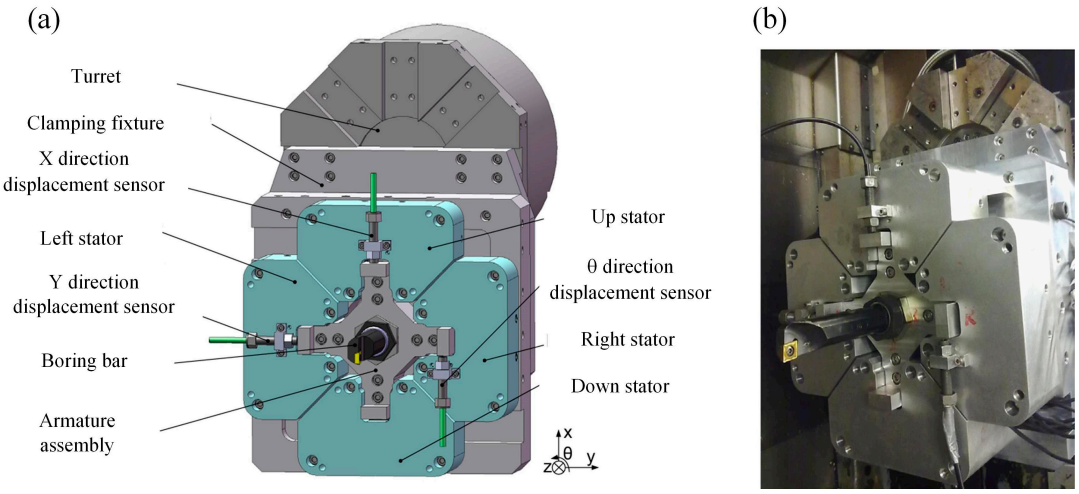


Figure 6. Magnetic drive type vibration reduction boring bar: (**a**) schematic diagram, (**b**) photo of the boring tool setup [35].

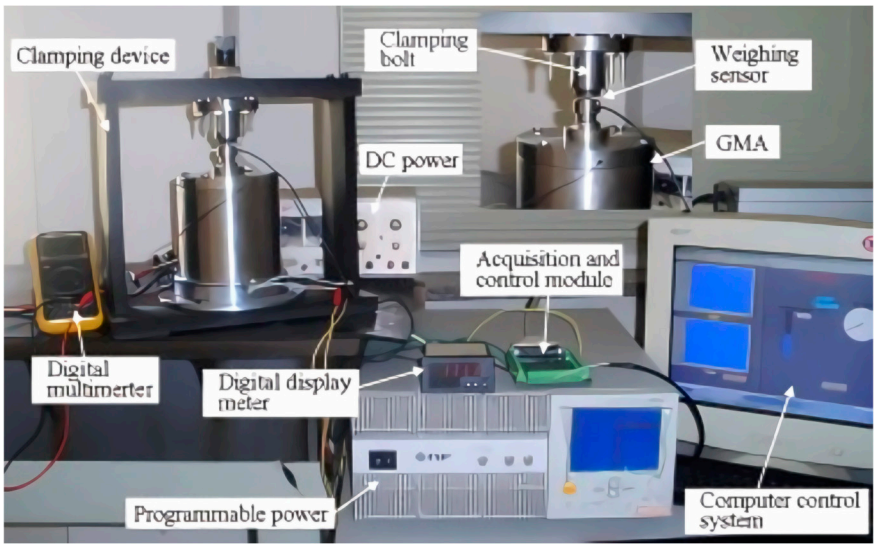


Figure 7. System of the giant magnetostrictive actuator with a constant output force [39].

In summary, magnetostrictive actuators exhibit significant advantages in boring tool vibration reduction, such as fast response, high torque output, and compact structure characteristics. Through multiple-parameter coupling designs and nonlinear control methods, magnetostrictive systems can achieve precise manipulation for complex targets and meet the requirements of high-speed and high-frequency deep hole machining. They are expected to further promote the integration of magnetostrictive actuators with sensing and data processing technology, based on which multifunctional integration of vibration reduction, measurement, and diagnosis can be achieved to enhance the deep hole machin-

ing equipment towards high-performance directions. The current open-loop control of magnetostrictive actuators has limited their robustness, leading to difficulties in coping with changes in system parameters and external disturbances. In addition, the design of multiple degrees of freedom control and coupled dynamic models is complex, requiring high integration of different algorithms and hardware. Therefore, future research is suggested to focus on developing intelligent control algorithms and more efficient multiple degrees of freedom control strategies for boring tool components and utilizing digital twin technology to establish accurate dynamic models.

Machine learning has been increasingly applied in intelligent manufacturing, where significant advantages have been demonstrated in surface roughness prediction and tool condition monitoring [40,41]. It has been reported that a mapping relationship established between cutting forces, vibration signals, and surface roughness through data acquisition can achieve more than 10% higher accuracy in online prediction compared with direct fitting [42]. It has also been shown that data-driven methods based on audio and vibration signals are capable of fully extracting machine status information during machining, with classification accuracies reaching up to 100%, thereby confirming their effectiveness in condition monitoring [43]. In addition, the integration of vibration analysis with deep learning has been applied to chatter detection, and its potential has been demonstrated even under suboptimal sensor placement and actual machining noise interference [44]. For tool wear monitoring, a modified residual network (MSW-1D ResNet) has been proposed, in which raw cutting signals are directly utilized as input, thus eliminating manual feature extraction and enhancing modeling efficiency [45]. Furthermore, deep learning-based condition detection methods utilizing vibration signals have been systematically summarized in the existing literature [46].

Yesilli et al. proposed an alternative classification and flutter detection method based on the K-Nearest Neighbor (KNN) algorithm [47]. This approach combines time series similarity with machine learning techniques, achieving a prediction accuracy of up to 98%. Furthermore, by incorporating an approximate search with elimination algorithms, the method enables rapid detection, making it suitable for online flutter detection. As shown in Figure 8, the turning experimental setup and the classification of the KNN classification example are presented. Although purely data-driven approaches have been shown to excel in feature learning and condition recognition, their predictive accuracy has been constrained by insufficient training data and risks of misclassification. Therefore, optimization of the overall workflow is considered dependent on the identification of key sensor metrics and the systematic evaluation of their impact on model performance [48]. In contrast, physics-based methods are observed to generate false alarms during transient excitations or near-stable boundaries, while empirical methods have relied on experimental data for chatter detection model training. To overcome these limitations, a hybrid approach combining machine learning networks with models based on self-excited vibration theory was proposed by Rahimi et al. [49], and improved accuracy and robustness in chatter detection were achieved. To facilitate the acquisition of state signals during machining processes, intelligent toolholders were developed and designed, as shown in Figure 9. Overall, the integration of machine learning with vibration signal analysis is recognized as providing robust support for surface quality prediction and tool condition monitoring in smart manufacturing. Nevertheless, further development has been regarded as necessary in model optimization and multi-source information fusion.

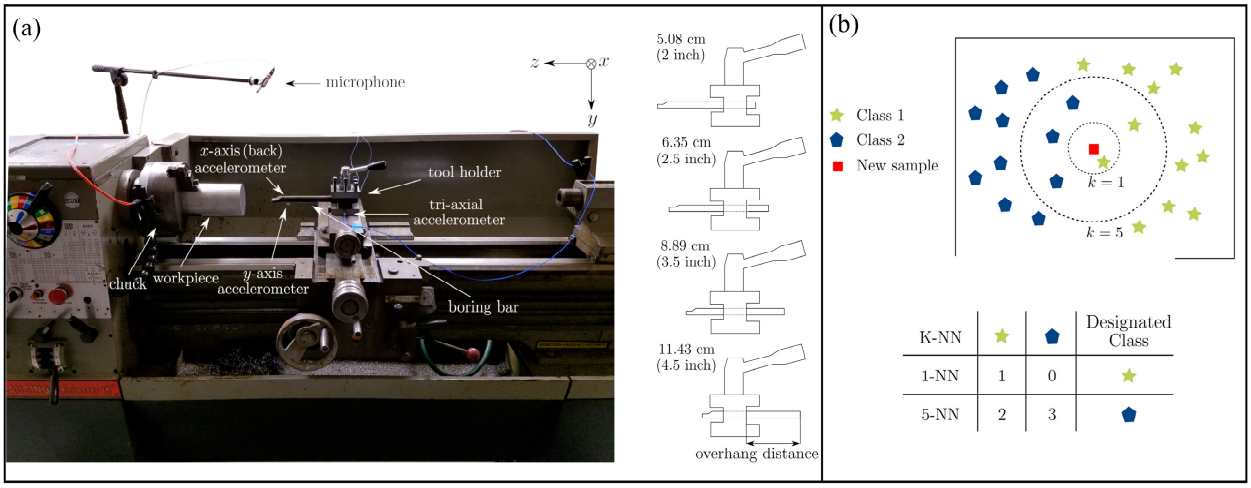


Figure 8. The turning experimental setup and the classification of the KNN classification example [47]: (**a**) turning experimental setup, (**b**) schematic of the KNN algorithm.

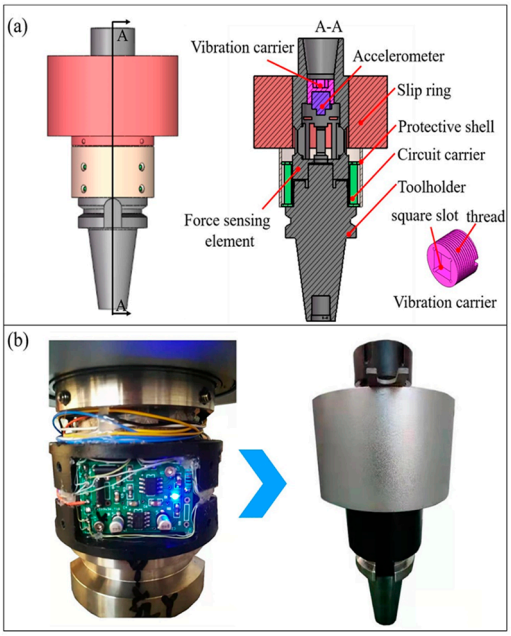


Figure 9. Smart tool holder [45]: (**a**) vibration-sensing design, (**b**) testing and assembly.

To address the challenge of adapting active vibration control systems to complex operating conditions, intelligent adaptive algorithms and digital twin models have been introduced for predictive parameter adjustment. System robustness is significantly enhanced while the need for costly trial-and-error adjustments has been reduced. By integrating passive and active control hybrid solutions, reliability and low cost have been ensured, while selective active intervention has been enabled during critical operating conditions. In this way, an optimal balance between economic efficiency and performance has been achieved.

2.3. Magnetorheological Fluid Damped Boring Tools

Under the action of an external magnetic field, magnetorheological fluids experience reversible changes in viscosity and stiffness. They exhibit good controllability and rapid response characteristics, thus enabling dynamic adjustment of vibration reduction systems [50]. By controlling the external magnetic field strength, the flow characteristics of magnetorheological fluid can be altered to suppress the vibration of the boring tools.

By combining intelligent control of magnetorheological fluid with a parameter excitation mechanism, the damping and natural frequency of boring tools can be adjusted. A vibration control method for boring tools based on magnetorheological fluid was proposed by Mei et al. [51,52]. The magnetic system inside the boring tool was designed through finite element analysis, and a Euler–Bernoulli dynamic beam model of the boring tool was established to further evaluate the influence of magnetorheological fluid on machining stability. The experimental results showed that, at an excitation frequency of 1 Hz and with a square wave current of 0–2 A, the machined surface roughness was reduced from 5 μm to 1 μm under identical boring conditions, while the time domain vibration acceleration signal of the boring tool was significantly decreased. At the same time, machining chatter was effectively suppressed by adjusting the damping and natural frequency of the machining system.

Afterwards, the energy method was used to analyze the cutting dynamic stability under different natural frequencies of the boring tool structures. The natural frequency of the tool structure and the spindle speed have been recognized as main factors that affect the cutting stability, and experiments were conducted using excitation currents with different waveforms and frequencies. The results indicated that the optimum machining performance was achieved at a square wave current with a frequency of 4–6 Hz and an amplitude of 0–2 A. Yao et al. [53] used the averaging method to study the effect of parameter excitation on van der Pol-Duffing oscillators with time-delayed feedback. The experimental device for modal testing of boring tool vibration is shown in Figure 10. Through stability analysis, it was found that when the excitation amplitude was large enough with appropriate frequencies, various waveform parameter excitations demonstrate good vibration suppression effects.

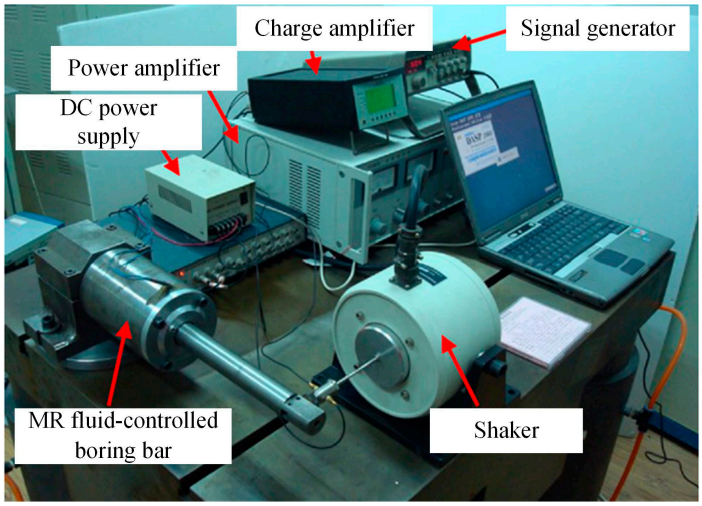


Figure 10. Experimental setup for the shaker modal testing of the magnetorheological fluid-controlled boring tool [53].

Magnetorheological fluid exhibits good adjustability and vibration reduction effect during the boring process, which can achieve adaptive control of cutting tool stiffness and damping through adjusting the current, thereby improving the cutting stability and machining quality. Pour and Behbahani [54] designed an integrated mechatronics model by adjusting the stiffness and damping of the cutting tool with magnetorheological dampers, resulting in a 50% increase in stable cutting depth. Biju and Shunmugam [55] developed a frequency-adjustable boring tool based on magnetorheological fluid damping media, as shown in Figure 11. The dynamic characteristics of the designed boring tool were obtained based on impact and vibrator excitation tests, based on which a stability lobe diagram was

drawn. The results showed that as the input current increased, the stability lobes moved upward and to the right. The boring experiments indicated that when the input current was 3.5 A, the vibration amplitude of the boring tool decreased by 29–44%, while the machined surface roughness and workpiece roundness decreased by 14–59% and 5–41%, respectively. Niu et al. [56] established a single degree of freedom nonlinear dynamic model for boring bars and used the fractional derivative Bingham model to describe the damping force of magnetorheological fluids. Their study adopted a semi-active on–off control strategy to suppress the host resonance response of the machining system and obtained an approximate analytical solution with the averaging method. Compared with magnetorheological fluids under passive control, semi-active on–off control can improve the vibration reduction effect of the boring tool system.

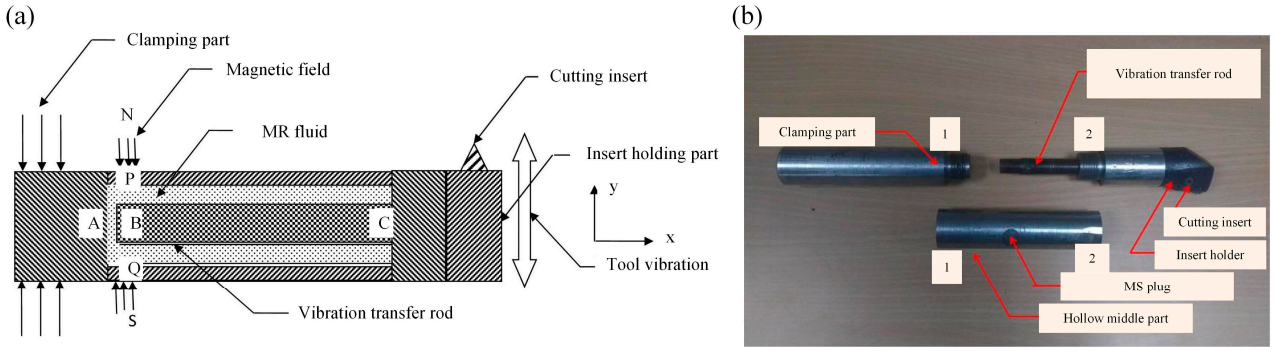


Figure 11. Development of the magnetorheological fluid-based tunable frequency boring tool, (**a**) schematic of the boring tool structure, (**b**) components of the boring tool [55].

Prabhu et al. [57] used a semi-active radial arrangement of magnetorheological fluid dampers to suppress boring bar vibration. The average main frequency during the boring process increased as the input current increased from 0 to 3 A. Meanwhile, boring experiments were conducted on low-carbon steel workpieces at different spindle speeds, and the results showed that both machined surface roughness and vibration acceleration were effectively reduced.

To enhance the comprehensive performance of magnetorheological fluid in the deep hole machining process, researchers have tried to explore the combination path of multi-functional damping structures and intelligent control methods. Saleh et al. [58,59] designed a type of sponge magnetorheological vibration damped boring tool. The damper can provide effective damping in all radial directions around the boring bar. The magnetorheological damper consisted of three main components, including a sponge layer of dual-dispersed magnetic fluid, an electromagnetic coil component, and a damper bracket.

The three-dimensional model of the boring tool and magnetorheological damper is shown in Figure 12. Under different cutting conditions, boring experiments were conducted on Inconel 718 and Al7075 workpiece materials, and the results showed that the machined surface qualities of different workpieces were improved. During machining of Inconel 718 workpiece material, the vibration-free cutting depth of the absolute stability limit was increased from 0.05 mm to 0.23 mm. Subsequently, a sliding mode control method of the magnetorheological fluid damper was proposed, and a variable gain super twisted sliding film control algorithm was designed to overcome the discontinuity problem in traditional sliding film control. Through boring experiments on Al7075 workpiece material, the radial stable cutting depth was increased from 0.03 mm to 0.10 mm, and the machined surface roughness was decreased by 50–80%.

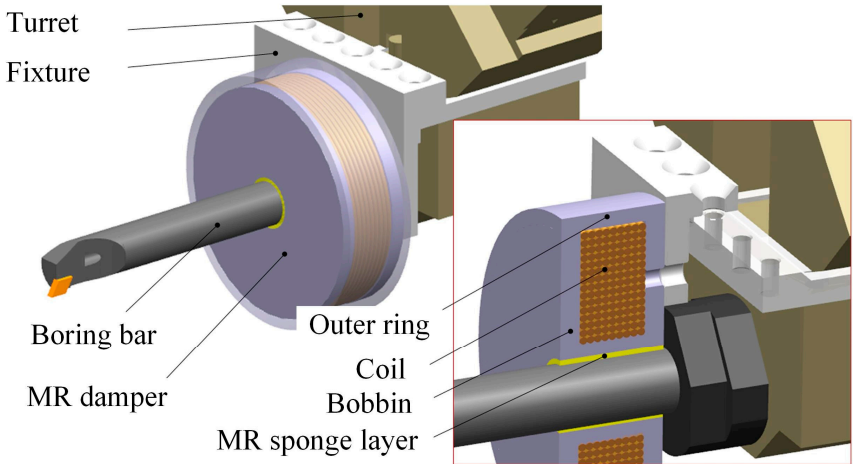


Figure 12. CAD model of the boring tool integrated with magnetorheological (i.e., MR in the figure) damper components [58].

The vibration suppression performance of boring tools can be effectively improved by magnetorheological fluid dampers through dynamic modeling, material optimization, and composite structure design. A dual degree of freedom dynamic model of a magnetorheological fluid dynamic damper was established by Hou et al. [60], and the Lyapunov method was applied to analyze system stability under semi-active control. Compared with passive control systems, the semi-active speed control mode was shown to provide superior suppression of vibration amplitude. Magnetorheological dampers with optimized fluid properties were designed by Aralikatti et al. [61], who investigated the effects of oil viscosity and hydroxyl iron particle concentration on maximum yield stress and effective damping range. Optimization of the component compositions was carried out using a genetic algorithm, and the effectiveness of the optimized design was subsequently verified through experiments. Boring experiments demonstrated that, with a magnetorheological damper, tool vibration was reduced by 28.66%, cutting force amplitude was decreased by 68.18%, and machined surface roughness was improved from 4.8 μm to 1.6 μm. In another study, a magnetorheological fluid foam damper was developed by Sarath et al. [62] to examine the influence of different polyurethane foam parameters and magnetorheological fluid properties on absorption efficiency and damping capacity. This damper was successfully applied to the boring tool system. The experimental results indicated that its application reduced the cutting force by 78%, improved the machined surface roughness by 91%, and decreased tool wear by 91%.

Magnetorheological fluid damping technology has certain superior performance in boring bar vibration control. Its performance can be quickly adjusted by applying an external magnetic field, based on which real-time suppression of boring tool vibration can be achieved, and the machined surface quality of workpieces can be effectively improved. In addition, magnetorheological fluid dampers possess such advantages as fast response, strong adaptability, and the capacity to meet the dynamic vibration reduction requirements under different working conditions. By combining advanced damping materials and new structural design, it can be expected to promote the development of magnetorheological fluid vibration reduction technology towards high-performance machining. However, the high manufacturing cost of magnetorheological fluid dampers still limits their wide application. The semi-active control algorithm for magnetorheological fluid damping is complex, and critical challenges occur in designing vibration reduction control systems and complex coupled dynamic models with multiple degrees of freedom. Therefore, the future research direction should be focused on the development of more efficient and robust

semi-active and active control algorithms to achieve precise control of a multiple degrees of freedom damping system. Meanwhile, a combination of intelligent sensing and adaptive control technology should also be explored to achieve real-time monitoring and dynamic adjustment of vibration status.

For intelligent control algorithms, adaptive control systems dynamically adjust damping parameters based on real-time vibration feedback, ensuring stable vibration suppression across operating conditions. Additionally, machine learning and deep learning models enable predictive identification of vibration trends for proactive intervention. Digital twin technology further enhances system robustness by enabling real-time simulation and optimization of control strategies through virtual modeling. These innovative designs, intelligent algorithms, and optimization strategies advance the widespread adoption of active vibration reduction technology in manufacturing while ensuring system stability and efficiency.

2.4. Electrorheological Fluid Damped Boring Tools

The flow characteristics of electrorheological fluids can be regulated under the action of an electric field, thereby affecting the damping characteristics of the working system. The response time of electrorheological fluid is in the millisecond range, and its viscosity and yield stress can be adjusted by precisely controlling the electric field strength, making it easy to be integrated with electronic control systems [63]. Continuous control of vibration reduction can be achieved with an electric current variable fluid damped boring tool through adjusting the electric field strength.

Researchers have proposed boring bar structures with variable stiffness components based on electrorheological fluid, which can dynamically control the stiffness and damping characteristics of the boring tool. Wang and Fei [64,65] developed a variable stiffness boring bar based on electrorheological fluid, with which the global stiffness and capacity dissipation characteristics of the boring bar can be adjusted through changing the electric field strength. The experimental results indicated that vibration reduction could be effectively achieved by continuously adjusting the stiffness of the boring bar during the machining process. Subsequently, the electrorheological fluid was adopted to suppress machining chattering.

The deformation mode of the electrorheological fluid depends on the applied electric field and strain amplitude. By utilizing the sensitivity of the fluid deformation mode to small changes in vibration amplitude, it is possible to prevent an increase in vibration amplitude. The experimental results demonstrated that the selection of electric field strength was related to the deformation amplitude of the electrorheological fluid during the machining process [50]. When the electric field strength was below 1.2 kV/mm, the amplitude of vibration acceleration gradually decreased, and the dynamic stiffness of the boring tool exhibited high sensitivity to small changes in cutting vibration amplitude. When the electric field strength was higher than 1.2 kV/mm, the amplitude of vibration acceleration gradually increased. The optimal electric field strength for chattering suppression was recognized as 1.2 kV/mm.

To achieve rapid detection and real-time suppression of chattering during boring process, an electrorheological fluid damped boring tool with adaptive adjustment capability has been developed. Wang and Fei [66,67] proposed an adaptive control system based on an electrorheological fluid damped boring bar. This system could automatically adjust the dynamic characteristics of the boring tool based on the information from the monitoring sensor signals. Using a radial basis function neural network based on locally optimum decision rules for signal reconstruction, the reconstructed acceleration signal was identified using a fuzzy ARTMAP neural network, and the chattering signal was extracted from

the power spectrum of the vibration signal. Within boring experiments, it was found that the best vibration reduction effect was achieved when the electric field strength was 0.8 kV/mm for machining with a spindle speed of 200 r/min, a feed rate of 0.08 mm/r, and a cutting depth of 0.1 mm. By utilizing the electrically controlled nonlinear dynamic characteristics of the electrorheological fluid, an intelligent boring tool with stable cutting, online detection, and adaptive adjustment can be developed.

The electrorheological fluid damped boring tool can achieve rapid online control of stiffness and damping of tools by adjusting the external electric field strength, which has the advantages of fast response speed and low energy consumption. Nevertheless, electrorheological fluids have low shear strength, limited damping capacity, and high integration difficulty. Future research directions are suggested to focus on developing low driving voltage, high performance, and stable new materials for electrorheological fluids. The design of miniaturized and highly integrated electronic control systems should also be explored, based on which wider engineering applications of electrorheological fluid damping technology can be promoted.

2.5. Damped Boring Tools with the Variable Parameter Dynamic Vibration Absorber

Power absorbers are structures consisting of additional mass, springs, and dampers. Such structures can adapt to vibrations with different frequencies by adjusting their internal damping, stiffness, and other relevant parameters. When the main vibration frequency changes, the dynamic absorber can automatically adjust its parameters to maintain a stable damping effect [68].

Active and adjustable power absorbers have become important components to realize vibration suppression and improve the vibration reduction performance of boring tools under complex machining conditions. Tewani et al. [69,70] analyzed the cutting stability of boring bars with active dynamic absorbers, in which an equivalent mass model for such a boring tool was proposed, and the cutting process, considering dynamic changes of the shear angle and friction angle, was applied to the centralized mass model. The vibration-free cutting boundaries of ordinary boring bars, boring bars with passive power absorbers, and boring bars with active power absorbers were compared. The results indicated that the maximum cutting depth in the stable cutting range significantly increased within the spindle speed range of 235–600 r/min. Moradi et al. [71] applied adjustable absorbers to boring tools and established a dynamic model with cantilevered Euler–Bernoulli beam theory. Meanwhile, a modal summation algorithm was adopted to determine the optimal specifications of the absorbers. The modal test results indicated that the first three natural frequencies of the boring tool with and without absorbers were almost the same. Research has shown that larger critical cutting depths can be achieved in higher-order frequency modes, thereby improving material removal rates. As shown in Figure 13, the automatically tuned boring bar system structure is presented. The stiffness of the shock absorber is adjusted automatically by the screw servo motor [72]. Liu et al. [73] proposed a vibration damped boring bar with a variable stiffness dynamic absorber, which was installed in the cavity at the front of the vibration damped boring bar. A dynamic model of the boring bar system was established, while the effects of excitation frequency and suspension length of the variable stiffness dynamic absorber on the amplitude ratio were analyzed. Through stimulation analyses, impact tests, and boring experiments, the amplitude of the acceleration curve was found to decrease from 19.64 m/s^2 to 10.53 m/s^2. The results demonstrated that under different cutting speed conditions, the vibration acceleration of a regular boring bar was more than twice that of the vibration damped boring tool. When the excitation frequency was constant, the best vibration reduction effect could be obtained through adjusting the overhang length of the boring tool. The stability cutting area and

chattering area under different excitation frequencies and overhang lengths were further determined through boring experiments.

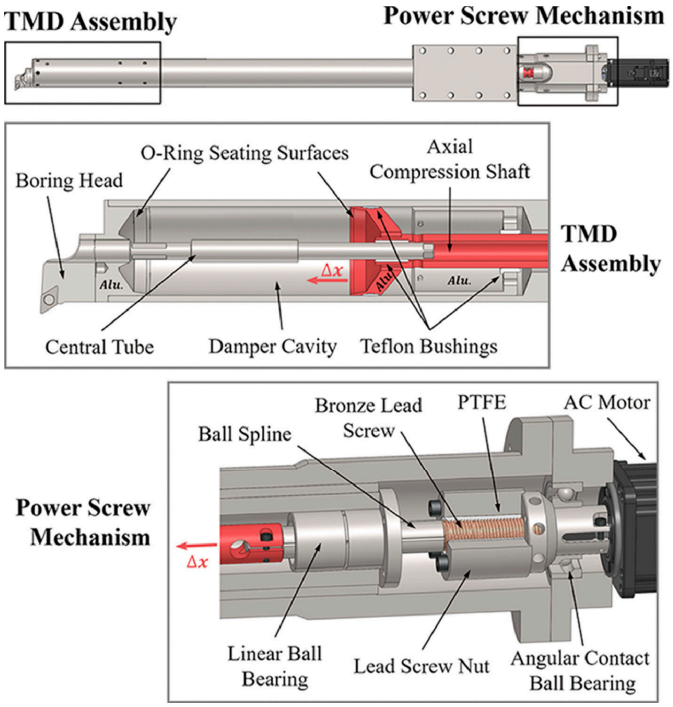


Figure 13. The structures of the adaptively tuned boring bar system [72].

To enhance the vibration reduction efficiency and robustness of boring tools, researchers have optimized the design and parameter configuration of dynamic vibration absorbers by integrating nonlinear energy absorbers, adjustable damping structures, and adaptive mass adjustment mechanisms. Lv et al. [74] developed a three degrees of freedom model of a boring bar system equipped with both a dynamic absorber and a nonlinear energy absorber and analyzed their combined effects on damping performance. The study revealed that while dynamic absorbers alone suppress vibrations, the addition of nonlinear energy absorbers further improves the vibration reduction capability and strengthens the overall system robustness. Similarly, Liu et al. [75] proposed a dynamic absorber incorporating a variable damping mechanism, in which the damping force applied to the mass block was controlled by adjusting the excitation coil voltage. A dynamic model was established to evaluate the influence of damping characteristics, and performance tests confirmed that decreasing the air gap length and increasing the voltage effectively reduced the vibration displacement of the mass block. Under different cutting parameters, the damping boring bar achieved a maximum vibration acceleration reduction of 34.7%, thereby verifying the feasibility of this design.

Shi et al. [76] proposed an equivalent linear method for hyperelastic rubber rings and analyzed the stiffness characteristics of rubber rings of different sizes in dynamic absorbers through experiments and numerical simulations. The dynamic characteristics of the boring bar were analyzed to determine the optimal stiffness and damping parameters for the vibration damped boring tool. Compared with ordinary boring tools, the vibration peak of the damped boring tool was reduced by more than 45%. Van Zyl et al. [77] modeled a large aspect ratio boring bar using Timoshenko beam elements for an adaptive mass damped tool and designed a universal mass damping absorber consisting of a hard alloy block, an oil bag, and two rubber O-rings. The adjustable boring bar assembly is shown in Figure 14. Research has shown that when the aspect ratio is 14, the production efficiency

of the tool can be increased by 70.6 times by adjusting the damping ratio and natural frequency compared to traditional boring tools. Meanwhile, the critical stable cutting depth was increased from 0.008 mm to 1.27 mm.

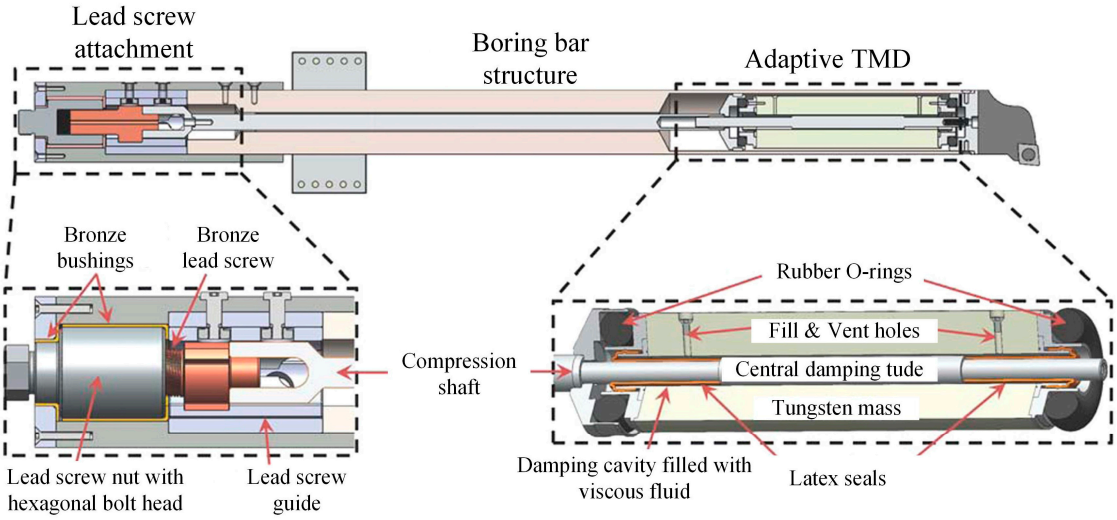


Figure 14. Schematic diagram of the boring tool structure with an adaptive tuning mass damper [77].

By adjusting the mechanical parameters of the vibration absorber to achieve adaptive vibration control, the vibration reduction effect of the boring bar can be improved at different excitation frequencies. Li et al. [78,79] designed a variable stiffness dynamic absorber inside the boring bar consisting of two rubber bushings. The relationship between theoretical stiffness and axial compression was established in their study, indicating that the stiffness of the dynamic absorber could be adjusted through changing the axial compression and allowing the boring tool to adapt to different excitation frequencies. The boring experimental results showed that by selecting an appropriate axial compression value, the cutting force and torque during the boring process could be reduced. Afterwards, theoretical calculations and simulation methods were used to identify the modal parameters of the dynamic absorber in the damped boring bar, and the vibration amplitudes of the boring tool under different spring stiffness conditions could be obtained. The optimal stiffness value of the dynamic absorber was determined through frequency scanning experiments on the vibration damping boring bar. In addition, a nonlinear model was developed to analyze the vibration stability during the boring process. The Runge–Kutta method was used to solve the dimensionless parameters of the model, and the results showed that the amplitude of the boring bar decreased by 37.6%. Through analyzing the effects of nonlinear parameters related to damping and stiffness of the absorber on the vibration characteristics of the boring bar, it was proposed that the cubic stiffness elements could be introduced to further reduce the vibration amplitude.

By adjusting the stiffness and damping of the vibration absorber, the damped boring tool embedded with a variable dynamic vibration absorber can achieve adaptive vibration control under different excitation frequencies and processing conditions. At the same time, combining with nonlinear model analysis and intelligent control technology, the robustness and adaptability of the variable parameter vibration absorber would be strengthened. The structures of vibration absorbers currently used are generally complex, and the dynamic modeling and nonlinear coupling effects of machining systems with multiple degrees of freedom have not been fully solved, which affects the control accuracy and response speed of damped tools. Future research directions are suggested to be focused on the design of intelligent vibration absorber components with simpler structures and more sensitive response capabilities. Meanwhile, dynamic modeling for machining systems with multiple

degrees of freedom and multiple physical field coupling effects should be strengthened, which can help promote the industrialization of high-performance intelligent vibration damped boring tools. As shown in Table 1, the types, working principles, and advantages of the active damped boring tools are summarized.

Table 1. Types of active damping boring tools, structural features, and advantages.

Research Methods	Boring Bar Type	Working Principle	Advantages	References
Experiments and theoretical calculations	Piezoelectric-driven damped boring bar	Piezoelectric ceramic elements deform under the influence of an electric field	High sensitivity, fast response, high energy conversion efficiency	[20–24]
Experiments and finite element analysis	Magnetostrictive actuator damped boring tool	Material deforms under the influence of an external magnetic field	High-precision radial displacement control	[29–34]
Finite element analysis and experimental and dynamic modeling	Magnetorheological fluid damped boring tool	Flow characteristics of magnetorheological fluids suppress tool vibration	Reversible changes in viscosity and stiffness	[51–55]
Structural design and experiments	Rheological fluid-damped boring tool	Rheological fluids modulate damping characteristics	Precise control of electric field strength to adjust viscosity	[64–66]
Dynamic models and experiments	Variable parameter damped boring tool	Adjust internal damping and stiffness to accommodate vibration	Automatic adjustment of parameters for the motion absorber	[68–70]

3. Passive Damped Boring Tools

The research on passive vibration damped boring bars has been widely reported and employed in practical industrial applications. According to different principles and design methods of vibration reduction, passive vibration damped boring tools can be divided into structure-optimized damped boring tools, material-optimized damped boring tools, damped boring tools with an impact damper, and friction energy dissipation damped boring tools [80,81]. Passive vibration damped boring tools have such advantages as simple structure, low cost, reliable vibration damping effect, strong applicability, and no need for external energy.

3.1. Damped Boring Tools with Structural Optimization

By changing the structure of boring tools and adding auxiliary supports or clamping devices, the stiffness and vibration reduction performance of the boring tool can be effectively improved.

The clamping conditions of boring tools have significant effects on the dynamic performance and machining stability of cutting tools. A reasonable clamping method can improve machining quality and cutting tool life. Åkesson et al. [82] studied the influence of different clamping conditions on the dynamic performance of boring tools and analyzed the effects of the number, diameter size, tightening torque, and tightening sequence of clamping screws on the characteristic frequency and cutting stability of boring tools. The experimental results of modal analysis indicated that different clamping conditions could cause differences in the dynamic characteristics of boring tools, and optimizing the clamping conditions could help to improve boring stability. Yan and Sun [83] proposed a method of suppressing boring tool vibration by adjusting clamping conditions, in which the stiffness and damping of the boring tool were improved through changing the natural frequency of the boring tool system.

The adjustable device consisted of four parts, a connecting plate, a tool baffle, a damping layer, and a tuning damper, as shown in Figure 15. Experimental verification showed that the clamping device could meet the vibration suppression requirements of the boring tool during the machining process. In the clamping scheme, the inner diameter of the tuning damper was 40 mm, and the length was 30 mm. Two screws were applied at the tail of the tool, one of which was a countersunk screw and the other was a ball screw. When the spindle speed was 1953 r/min, the stable cutting depth increased from 0.1185 mm to 0.6356 mm with an increase of 5.36 times. Meanwhile, the machined surface roughness decreased from 2.106 μm to 1.239 μm with a decrease of 41.2%.

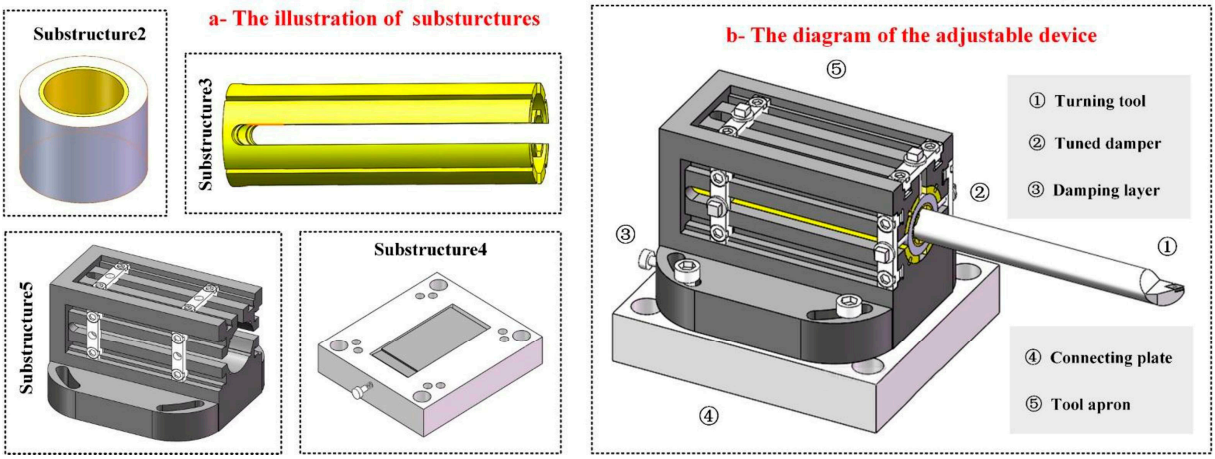


Figure 15. Schematic illustration of an adjustable clamping device used for the machining process [83].

The design of conical boring tools provides a new solution method for a vibration reduction in boring tools. Zhang et al. [84] designed a conical composite boring bar. The natural frequency of the boring tool was calculated using the modified decomposition method, and the convergence of the conical composite boring tool was verified in terms of vibration stability. Research has shown that the natural frequency of conical composite boring tools is affected by the layer angle, aspect ratio, thickness-to-diameter ratio, and composite material. Choosing smaller layer angles, taper ratios, or aspect ratios can result in higher natural frequencies. In addition, through analyzing the boring stability under different machining parameters, it was found that the boring stability increased with the decrease in the taper ratio, layer angle, or aspect ratio. Liu et al. invented a novel CFRP boring bar featuring a CLD structure. Compared to tungsten carbide boring bars, it exhibits a 35.4% increase in natural frequency and a 40% reduction in amplitude. Machining stability is maintained at a long-to-diameter ratio of L/D = 8.78 [85].

The use of auxiliary support in a deep hole boring device can effectively reduce boring tool vibration and deformation. Cai et al. [86] designed a deep hole boring device with auxiliary support, which can play a fixed and guiding role during the machining process, effectively reducing machining vibration and improving machining accuracy. The structure of the designed boring device is composed of a conical surface core rod and two adjustable brackets installed inside to control the radial movement of the adjustable brackets. Through boring experiments, it was shown that the error between different hole diameters processed by the device did not exceed 0.03 mm, and the machined surface roughness was below Ra1.6, which could meet the machining requirements.

Based on anisotropic stiffness design, the dynamic stiffness of the machining system during the boring process can be improved by optimizing the geometric shape of the boring tool. Takahashi et al. [87] proposed a method that utilized the anisotropy of boring tools to increase the dynamic stiffness during the cutting process. This method was based on

anisotropic design theory of infinite stiffness, and the optimal rotation angle of 148° and the optimal compliance ratio range of 1–3 were determined. The basic design method is shown in Figure 16, which utilizes the mode expansion effect caused by the horn shape to achieve anisotropic stiffness and improve machining stability. The study used the finite element method to simulate and analyze boring tools with aspect ratios of 4 and 10, and the results showed that it is necessary to select appropriate tool geometry and machining conditions to guarantee the stability of the boring process.

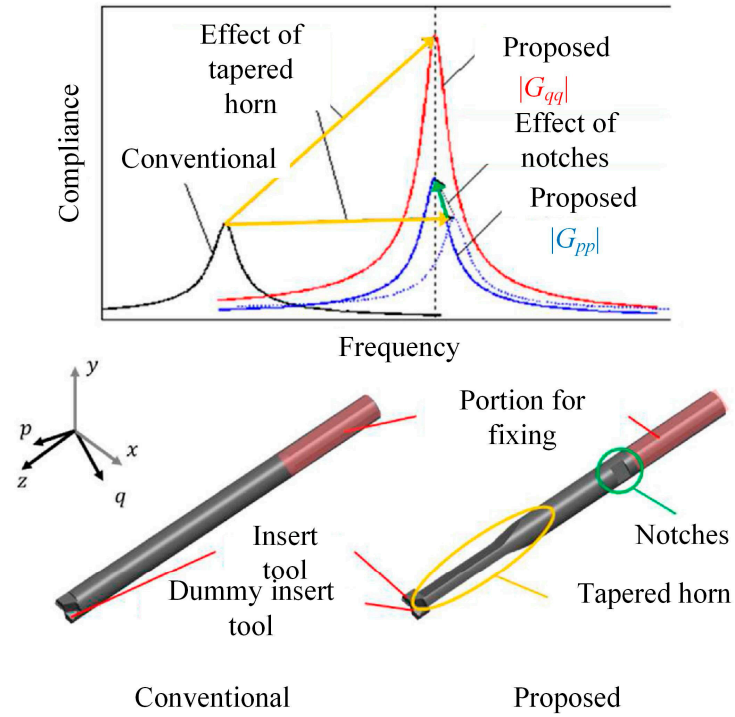


Figure 16. The structure and working characteristics of a self-designed boring bar with anisotropic attributes [87].

Structural optimization of boring tools can improve machining efficiency and reduce vibration by optimizing geometric shapes or adding auxiliary supports. Improvement of the boring tool structure is beneficial for achieving lightweight design, expanding stable cutting areas, and realizing high-performance machining targets. However, there are also technical challenges for structural optimization of boring tools due to such factors as manufacturing process limitations, complex tool structures leading to high costs, and difficulties in accurately controlling dynamic tool response under actual working conditions. In the future, intelligent materials and adaptive damping structures can be combined to improve the integration ability of the boring tool structure and achieve an efficient and stable boring process.

For structural optimization design, multi-layer sandwich structures incorporating metal damping constraint-layer configurations are developed. Interlayer friction and shear deformation enhance energy dissipation efficiency. Replaceable or micro-adjustable damping blocks/filler particles are embedded within the tool body to improve adaptability to varying vibration frequencies. Finite element and topology optimization methods are employed to refine tool geometry and material distribution, maximizing damping performance while ensuring structural integrity.

3.2. Damped Boring Tools with Material Optimization

The choice of boring bar material directly affects its stiffness or damping behavior, which in turn affects the vibration reduction performance of the boring tool. At present, most studies apply high stiffness or high damping materials to boring tools, which can effectively absorb vibration energy and reduce vibration amplitude.

Composite boring bars have significant advantages in improving the stability and vibration reduction effect within the boring process due to their excellent stiffness and damping characteristics. Nagano et al. [88] developed a composite boring bar with asphalt-based carbon fiber-reinforced plastic. The core rods of boring tools were designed with four different shapes of steel bars. The experimental results indicated that the boring bar embedded with a cross-shaped steel core presented the best vibration reduction performance. When the aspect ratio was seven, it exhibited excellent cutting performance compared to traditional cemented carbide boring bars. Lee et al. [89,90] designed and manufactured a rotary boring bar with high-stiffness asphalt-based carbon fiber epoxy resin composite materials. By testing the damping performance of core materials, the damping part of the composite boring bar was selected, and its machining performance was verified in the boring of an aluminum specimen for the engine cylinder block. The experimental results have shown that when the spindle speed was 2500 r/min, a composite boring bar with a length-to-diameter ratio of 10.7 could still maintain stable cutting, while the maximum length-to-diameter ratio for the stable cutting of tungsten carbide boring bars was 8. The natural frequency, damping ratio, and dynamic stiffness of composite boring bars were tested as being 72%, 168%, and 28% higher than those of cemented carbide boring bars. The metal cutting ability of composite boring bars was tested as being 33% higher than that of cemented carbide boring bars. Wang et al. [91] designed a damped boring bar with a layered composite structure composed of carbon fiber composite and metal materials. Finite element simulation analysis showed that the designed boring tool is more suitable for the high-speed boring process.

Improving the dynamic performance and damping characteristics of the boring tool system is the key to enhancing boring stability and machining quality. Sortino et al. [92] proposed an innovative hybrid dynamic model for boring tool systems based on finite element beams and empirical models. This study conducted modal testing on boring bars made of different shapes and materials, as well as boring bars with different diameters and aspect ratios. The impact experimental setup and adopted finite element model are shown in Figure 17. The experimental results indicated that the damping value was mainly affected by the aspect ratio of the boring bar and the tool material. Ordinary boring bars have lower natural frequencies and a smaller damping ratio and are susceptible to resonance due to the influence of excitation frequencies.

Khatake and Nitnaware [93] applied passive dampers to minimize the loss of static stiffness of the boring tool, and the experimental results showed a significant improvement in the machined surface quality of workpiece materials. Akdeniz and Arslan [94] used high-damping material $TiNi_3$ to prepare a boring bar. The experiment test showed that the amplitude of vibration acceleration was decreased by 43.1%. Compared with commercial boring bars, the vibration acceleration during the machining process was reduced by 60.2% with the optimized boring bar.

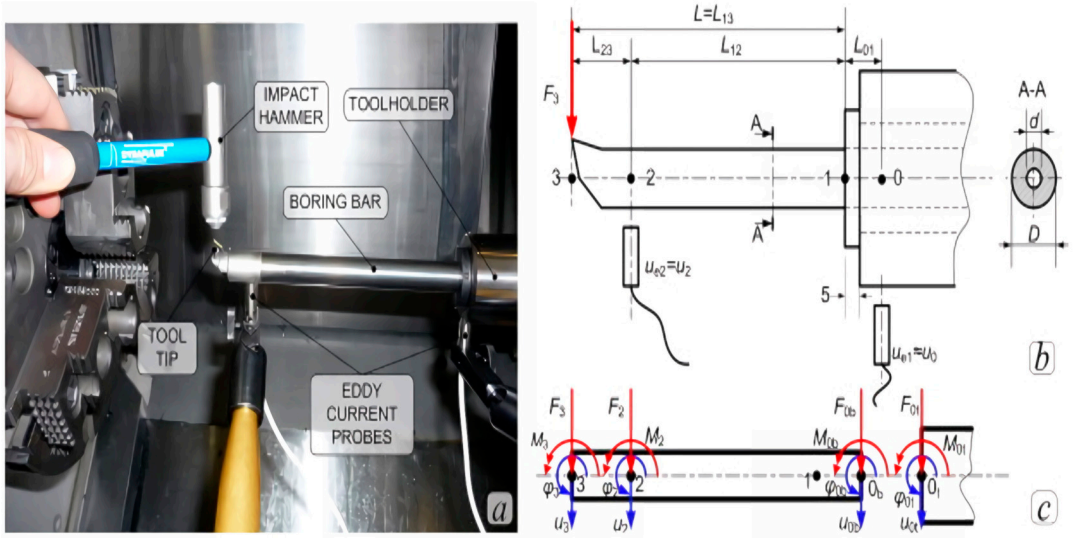


Figure 17. Experimental setup and model of boring tools. (**a**) Experimental setup for impact testing of boring tools, (**b**) schematic representation of the tooling system, (**c**) adopted FE model [92].

The design of boring tools with a constrained composite damping layer significantly enhances the vibration reduction effect and cutting stability of the boring tools. Song et al. [95] proposed a specialized boring tool design and optimization method with constrained damping bars based on the theory of constrained damping layer beams and the finite element method. The designed boring tool was composed of four modules: the tool head, substrate layer, and damping layer. By changing the dynamic stiffness through the constraint layer and improving the damping performance through the damping layer, it was found that the vibration reduction ability of the boring tool was five times higher than that of ordinary boring bars. Zhang et al. [96] developed a theoretical analysis model for predicting the chattering stability of a composite boring bar with constrained damping layers. Their model was developed based on the Euler–Bernoulli beam theory and the complex stiffness method of constrained damping layers. The dynamic model of the vibration damped boring tool was derived, and the structural parameters of the boring bar were optimized. Nanda and Srinivas [97] studied a passive constrained damped boring bar with a mixed damping layer and validated its dynamic behavior through finite element modeling. Compared with traditional boring tools, the vibration displacement of boring tools with constrained damping layers was reduced by more than five times. Lu et al. [98] prepared a boring bar with composite materials and a constrained damping layer structure optimized based on the finite element method. The dynamic characteristics of the damped boring bar were analyzed using the bending strain energy method and cantilever beam theory. The modal testing results showed that when the aspect ratio was 8.4, the damped boring bar demonstrated a higher natural frequency and smaller vibration amplitude. The vibration attenuation time of the damped boring bar was 0.115 s, while that of the contrast cemented carbide boring bar was 0.167 s. Boring experiments showed that under the same machining parameters, the damped boring bar presented higher machining accuracy.

The application of new materials and structural design has promoted the development of high-precision boring tools. Ghorbani et al. [99] studied boring bars with longitudinal grooves of different cross-sections filled with epoxy granite. By measuring the vibration acoustic signals during the machining process, it was found that the amplitude in the vertical direction of the boring bar could be reduced from 79 m/s^2 to 13.7 m/s^2, and the amplitude in the horizontal direction could be reduced from 132 m/s^2 to 56 m/s^2. Compared with ordinary boring bars, the developed vibration damped bar improved the cutting tool dynamic stiffness, while the natural frequency of the boring bar was reduced,

and chattering during the machining process was effectively suppressed. Moreover, the vibration damped boring bar improved the machined surface quality by 30% during the boring process. Singaravelu et al. [100] embedded copper-based shape memory alloys into boring bars and studied the effect of different machining parameters on cutting performance. Their experimental results showed that at a cutting depth of 0.25 mm, a feed rate of 0.08 mm/r, and a spindle speed of 300 r/min, the cutting temperature, boring tool displacement, machined surface roughness, and tool wear of the damped boring tool were reduced by 19.2%, 55%, 59.9%, and 78.1% compared with the ordinary boring tool, respectively. Inspired by the vibration damping mechanism in woodpecker heads, a biomimetic damping boring bar was developed, as shown in Figure 18 [101]. This biomimetic damping enhances modal parameters and cutting stability. Compared to carbide tools, the natural frequency increased by 20% and the stiffness improved by 1.7 times.

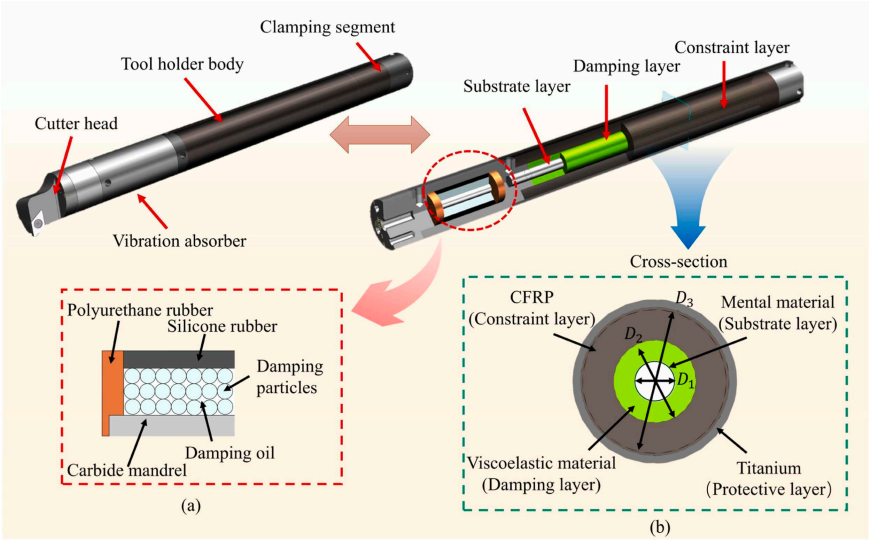


Figure 18. Bionic vibration damping boring bar process. (**a**) Schematic diagram of the damping material design for the shock absorber, (**b**) Schematic diagram of the damping structure of the constraint layer of the tool holder body [101].

Surface coating technology, as an important method to improve the vibration reduction performance and processing quality of boring tools, has demonstrated significant application potential. Fu et al. [102] used a plasma-enhanced chemical vapor deposition method to deposit a carbon-based nanocomposite damping coating on a boring bar. By comparing the performance of the coated boring bar and the uncoated boring bar, the results showed that the coated tool could reduce the absolute sound level during the boring process by about 90% and significantly improve the workpiece machining accuracy, reaching twice that of the uncoated boring tool. Meanwhile, adding anti-vibration coating did not present other adverse effects on the cutting performance of tools. Chockalingam et al. [103] conducted a nickel phosphorus chemical coating treatment on high carbon steel boring bars to reduce tool vibration and studied the effect of different treated pH values on the damping effect of coating materials. The experimental results indicated that the pH value and heat treatment process played an important role in improving the damping performance of the boring bar.

The damping characteristics of the rotating conical boring bar have significant effects on the stability of the cutting system. Ren and Zhang [104] and Zhang et al. [105] studied the effect of damping on the stability of a rotating conical boring system. Based on Hamilton's principle and Euler–Bernoulli beam theory, the partial differential motion equation of the boring bar was derived. By comparing the stability prediction results in the frequency

domain and time domain, it was found that the rotation effect and internal damping of the boring bar are key factors affecting the dynamic characteristics and cutting stability of the boring system. Furthermore, a dynamic model of a rotating conical composite boring bar was developed, which included internal and external damping effects to predict the vibration stability during the boring process.

The material optimization of the boring bar effectively improves its dynamic stiffness, damping performance, and cutting stability through introducing high-damping materials or functional coatings that can significantly reduce machining vibration and improve machining accuracy. Material optimization of boring tools still faces such challenges as high material costs, complex manufacturing processes, and insufficient long-term performance stability verification. Future potential directions can be focused on the development of new high-performance damping composite materials, the design of multifunctional damping structures, and the application of nanocoating technology to further promote the machining performance of damped tools.

Regarding the development and application of novel damping materials, carbon fiber-reinforced composites, ceramic matrix composites, or metal matrix composites are employed to achieve a balance between high stiffness and high damping. Adaptive smart materials, such as shape memory alloys (SMAs) and magnetorheological/electrorheological elastomers, are introduced to adjust stiffness and damping characteristics in response to external conditions (e.g., temperature, magnetic fields, or electric fields), enabling semi-active regulation. Nano-functional fillers (e.g., graphene and carbon nanotubes) are employed to enhance material energy dissipation capacity and stability.

3.3. Damping Boring Tools with Shock Absorbers

Shock absorbers mainly achieve vibration reduction through continuous nonlinear collision between two objects. During the collision process, the kinetic energy of the system is continuously dissipated. Using impact dampers installed inside the boring bar as damping components can absorb or dissipate vibration energy during machining processes [106].

The impact damper effectively enhances the vibration reduction capability and cutting stability of the boring tool through external structural design. Ema and Marui [107] designed a vibration damped boring tool with external installation of impact dampers and installed impactors on the top, side, and along the central axis of the boring bar. The center axis of the impactor was 40 mm away from the cutting edge, and the structure of the boring tool is shown in Figure 19. The effects of three different installation methods of impact dampers on the vibration reduction performance of boring tools were studied. The experimental results showed that all three types of impact dampers could achieve effective vibration reduction in the vertical vibration direction. Compared with commercial boring tools, the vibration damped boring bars effectively improved the machining efficiency of workpieces.

Lawrance et al. [108] conducted boring experiments by installing spring-controlled impact dampers on the tool holder and systematically analyzed the vibration reduction performance of different damper materials. Research has shown that low-carbon steel presents excellent mechanical properties. According to boring experiments conducted on AISI4340 steel with an impact damper installed on the head of the boring bar, it was found that a 42% reduction in cutting force, a 48% reduction in tool vibration, and a 55% improvement in machined surface quality were obtained. The impact damper can effectively suppress the vibration of the boring tool, accompanied by an improvement in machined surface smoothness.

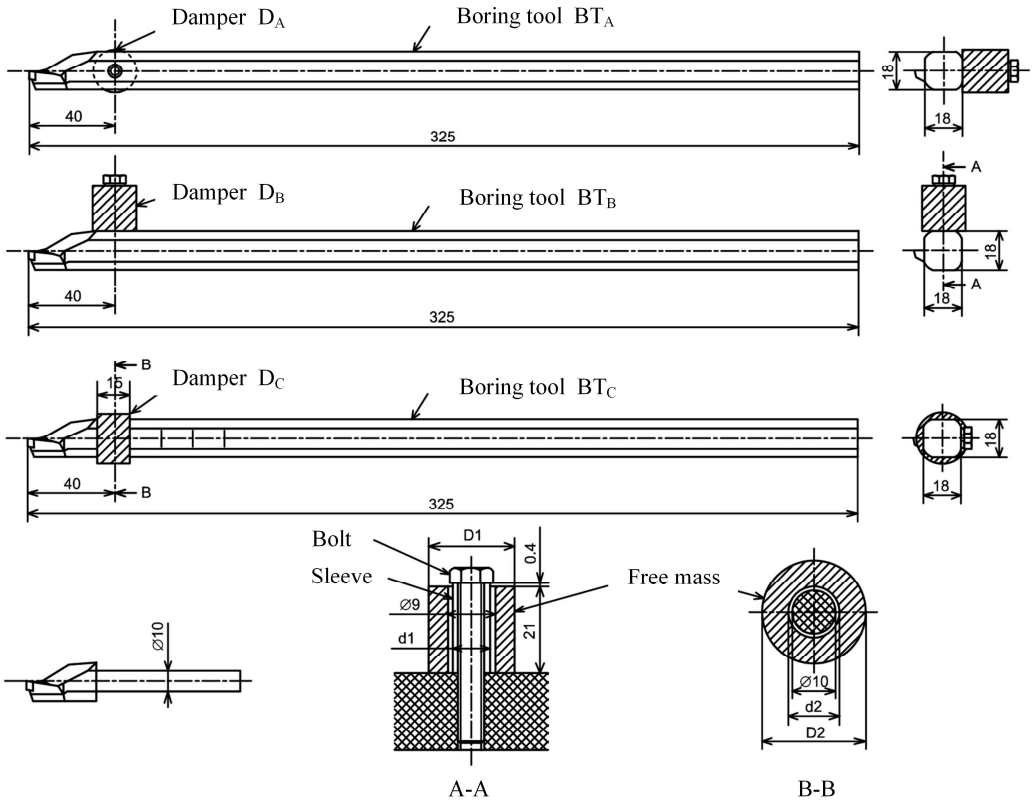


Figure 19. Schematic diagram of boring tools integrated with impact dampers [107].

Particle damping technology can effectively enhance the dissipation capacity and vibration control effect of boring tools by regulating the particle size and filling rate. Kumar et al. [109] studied the influences of the size and filling rate of copper/lead particles on the damping ratio control efficiency of boring tools. Experimental tests on the vibration reduction effect of different types of particles showed that the best damping effect occurred when copper particles with a diameter of 4.75 mm were used, for which a vibration displacement reduction of 80% was obtained. As the particle size increases, impact damping becomes the main vibration reduction mechanism. As the particle size decreases, the frictional shear force increases, thereby improving the vibration reduction effect. Biju and Shunmugam [110] developed a boring bar based on particle impact damping. A cavity was set at the front end of the boring bar, partially filled with spherical particles. By analyzing the boring tool performance through impact and vibration experiments, it was found that the combination of a particle size of 3.17 mm and a volume fraction of 50% could effectively reduce the amplitude response of the boring bar. Under the same processing parameters, using a particle vibration damped boring bar improved workpiece roundness by 12.08–61.76% and reduced machining vibration amplitude by 25.81–71%. The collision of particles reduces regenerative vibration through energy dissipation, effectively increasing the stability of boring processes. Meanwhile, the radial vibration of the boring bar has significant effects on the machined surface morphology.

Particle damping technology mitigates boring bar vibration, enhances machining surface finish, and reduces tool wear by embedding metallic particles inside the bar. Devaraj et al. [111] applied fine particle impact damping to boring bars and demonstrated its effectiveness in improving the surface quality of machined parts. In another study, Chockalingam et al. [112] inserted copper and zinc particles in equal proportions into the boring bar, and the experimental results revealed that vibration displacement amplitude and machined surface roughness were reduced by 55% and 80%, respectively. Similarly, Singh et al. [113] filled the rear end of the boring bar with steel particles and investigated per-

formance under different conditions, including varying overhang lengths, spindle speeds, and feed rates. Their findings confirmed that particle damped boring bars significantly improve surface quality and effectively minimize tool wear.

The use of impact dampers and particle impact damping technology can improve the vibration reduction performance of boring bars, not only extending the overhang length to achieve stable deep hole machining but also significantly improving the machined surface quality of workpieces. Thomas et al. [114] conducted a comparative analysis of three damped boring bars with different-sized impact dampers to verify their vibration reduction performance. By comparing the machined surface roughness, tool vibration, and tool life, the results showed that using an impact damper to reduce boring vibration can effectively increase the overhang length of the boring bar, thereby achieving stable machining of deeper holes. De Aguiar et al. [115] studied the improvement effect of particle impact passive dampers assisted by compressed air on the machined surface roughness of workpieces. By analyzing the effects of different particle materials, particle sizes, and filling ratios on vibration reduction performance, the experimental results indicated that particle materials have the greatest effect on the machined surface roughness, followed by the particle size and filling ratio. When the overhang length was 120 mm, the workpiece machined surface roughness generated with the vibration damped boring bar was reduced by 60%.

Filling stainless steel balls inside the boring bar to form an impact damping structure can reduce vibration and tool wear during the boring process. Lawrance et al. [116,117] developed a vibration damped boring bar filled with stainless steel spheres as impact dampers. The Taguchi method was used to conduct experiments on the selected machining parameters, and the signal-to-noise ratio method was used to analyze the experimental results. Compared with ordinary boring bars, the impact damped boring bar filled with stainless steel spheres reduced the machined surface roughness by 78% and tool wear by 80% during the machining process, indicating that the damped boring bar can effectively suppress tool vibration. Subsequently, researchers designed and fabricated impact damped boring bars with variable materials, sizes, and filling ratios and further studied the effects of such factors on the vibration reduction performance of boring bars. Through experimental optimization of different parameters, the results showed that the best vibration reduction effect was achieved with a particle size of 2 mm. For boring experiments of AISI4340 steel with the impact damped boring tool, the cutting force was reduced by 90% and the tool vibration was reduced by 95%.

The combination of particle impact and tuned mass dampers applied to boring bars can improve machining stability within different ranges of the length-to-diameter ratio. Thomas et al. [118] proposed prediction models of particle impact dampers and tuned mass dampers for boring tools to determine vibration displacement amplitudes at natural frequencies. Their results indicated that the damped boring tool with particle impact dampers exhibited higher machining stability over a wider overhang range. The length-to-diameter ratio range for stable boring of the particle damped boring bar is 3–8, while that for stable boring of the tuned mass damper boring bar is 4.50–7.75.

Particle damping technology can also effectively improve the vibration reduction performance and machining quality during the boring process by optimizing the internal damping structure of boring bars. Ramu et al. [119] studied the different damping performances of damped boring tools with single-element dampers, multiple elements in horizontal arrangement, and multiple elements in vertical arrangement. For the boring bar with a length-to-diameter ratio of 7.5, copper and zinc particles were used as particle dampers. Multiple damping units, including horizontal and vertical arrangements, were designed to flexibly distribute damping within the boring bar. By evaluating the dynamic

properties of the damped boring tools, such as modal characteristics, the logarithmic decay rate, and the damping ratio, it was found that the boring tool with multiple damping elements arranged in the vertical direction exhibited the best vibration reduction performance during the boring process. A minimum machined surface roughness of 0.84 μm and a lowest cutting temperature of 252 °C were achieved during the cutting process with such damped tools. Furthermore, Figure 20 illustrates that the cavity of the anti-vibration tool is composed of a metallic lattice structure [120]. Damping particles are embedded within the lattice structure inside the tool. The dynamic absorption effect of the particles and filler within the lattice enhances the system's dynamic stiffness.

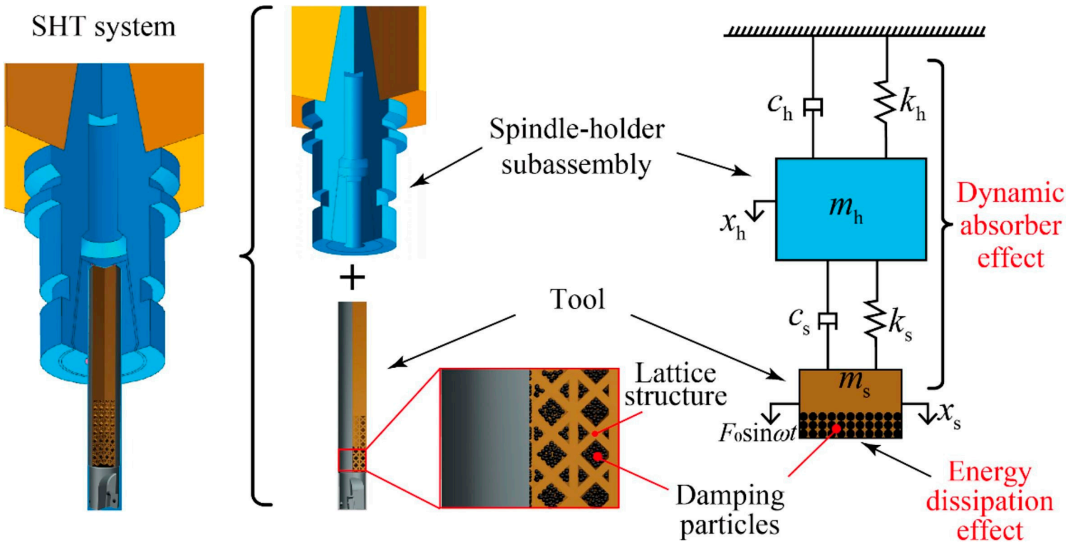


Figure 20. Vibration-resistant cutting tools combining the crystal structure with particle damping [120].

Particle damping boring bar achieves vibration suppression through rational design and optimization of particle parameters. Tian et al. [121] designed a particle damped boring bar with the structure. The modal characteristics of the boring bar were analyzed using the finite element method, and the energy dissipation mechanism of the damping particles inside the boring bar was studied with the discrete element method. The effects of particle parameters on energy dissipation were studied through discrete element simulation, and the optimal combination of particle parameters was determined. Modal testing and cutting experiments were conducted to measure the modal parameters and vibration signals of boring bars with different particle configurations. The experimental results showed that using YG6 tungsten carbide particles with a size of 1 mm and a filling rate of 90% could achieve the best damping effect. Compared with traditional cemented carbide boring bars, the damping ratio of the damped tool was increased by 70%, based on which the cutting stability and machined surface quality were significantly improved.

The impact damped boring tools improve the damping ratio and dynamic stiffness of the boring bar through embedding high-damping materials inside or on the surface of the boring bar. The impact damped tools can effectively suppress chattering during the machining process, improve the machined surface quality, extend the cutting tool life, and expand the aspect ratio range of boring bars in a stable machining status. Such damped tools have significant vibration reduction effects, high processing stability, strong adaptability, and the capability to improve machining performance through structural parameters optimization.

3.4. Damped Boring Tools with Friction Energy Dissipation Components

Friction materials or friction dampers can also be used to improve the damping performance of boring tools. Friction damping generally utilizes the friction between objects to dissipate the vibration energy of different structures and achieve a vibration reduction effect. Friction dampers, as an effective damping component, have been gradually used in damped boring bars.

Friction damping technology has become an effective way of suppressing high-frequency vibrations due to its simple structure and good dissipation ability. Edi and Hoshi [122] used friction dampers to suppress high-frequency vibrations in the precision boring process. The basic structure of friction dampers includes a mass body and a permanent magnet. The mass body consumes vibration energy through friction, while the permanent magnet adjusts the performance of the damper to achieve the vibration reduction effect together. To evaluate the effects of introducing elastic damping elements with different parallel groove structures into friction systems, Lu et al. designed and machined multiple parallel groove configurations on the surface of the damping elements, as shown in Figure 21 [123]. The research findings indicate that systems equipped with such damping elements can effectively suppress friction-induced vibrations and significantly improve their wear characteristics.

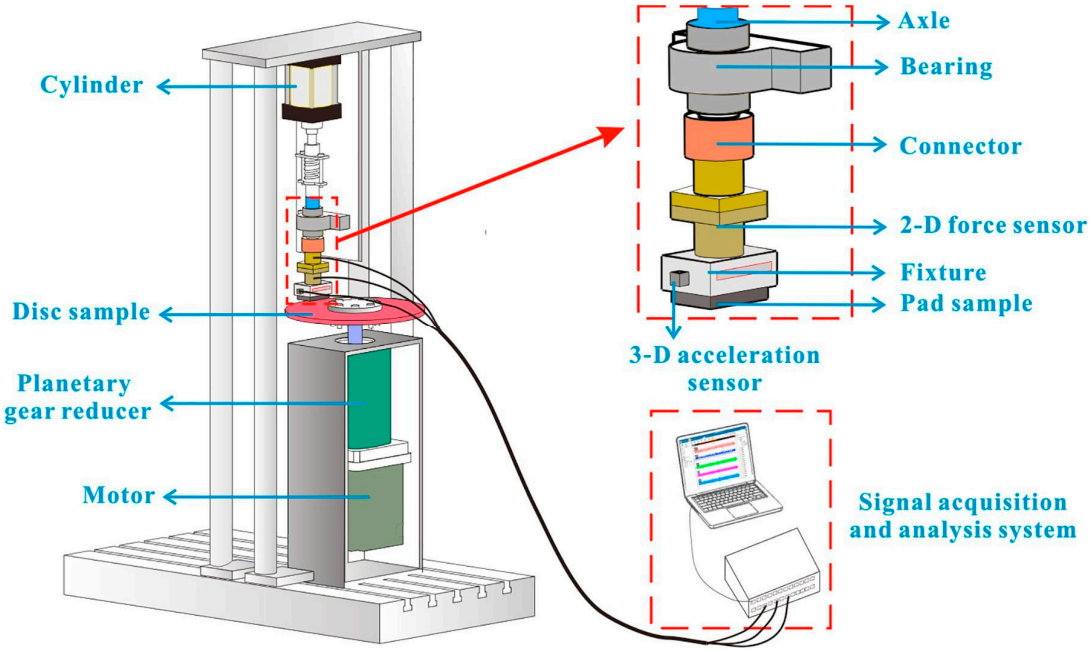


Figure 21. Structures of the boring bar with friction damping components [123].

The squeezed liquid film damping technology dissipates vibration energy through liquid friction, which can be used to reduce the vibration amplitude of boring bars. Zhao et al. [124,125] used squeezed liquid film damping technology in the precision boring process. The system consisted of a damping sleeve and a machined hole, which formed a gap between the outer surface of the damping sleeve and the inner surface of the machined hole to be filled with liquid. When the spindle rotated and the boring bar experienced radial vibration, the two surfaces approached each other, causing the liquid within the gap to be squeezed, thereby forming a squeezed liquid film. The damping force generated by squeezing the liquid film was essentially pure liquid friction, which could effectively dissipate the vibration energy of the boring bar. In practical experiments, the vibration amplitude was reduced by 20% after adopting this technology, while the average machined surface roughness was reduced by 40%. The liquid film damped precision boring system

was regarded as a vibration reduction system with multiple degrees of freedom, and the vibration reduction design parameters could be optimized through a simulation model, which has been verified in an actual machining process. Shao et al. [126] conducted static excitation vibration experiments, dynamic experiments, and boring experiments to verify the machining performance of damped boring tools. The experimental results indicated that as the damping coefficient increased, the vibration amplitude did not decrease monotonically, and there existed an optimal damping value instead. The liquid film damping system can significantly improve the dynamic performance of the machine tool in precision boring without adversely affecting other machining performance, which can improve machining efficiency and enhance the machining quality of precision holes.

The combination of nonlinear tuned mass dampers and dry friction technology provides a solution for vibration control and stability improvement of boring systems. Wang et al. [127,128] proposed a nonlinear tuned mass damper that included additional elastic-supported dry friction elements. The proposed nonlinear tuned mass damper can effectively suppress the vibration amplitude of the real part of the frequency response function of the machining system. A mathematical model for the damped processing coefficient of a nonlinear tuned mass damper was established with the first-order harmonic balance method. The experimental results showed that using a nonlinear tuned mass damper with a mass ratio of 0.01 could increase the critical stable cutting depth by 150–180%. Afterwards, a mathematical model of the friction damper was established to describe the forces at the friction interface between the friction damper body and the matrix structure.

Friction damped boring bars realize vibration suppression through internal longitudinal cavity design and parameter optimization. Hayati et al. [129] developed a friction damped boring bar with longitudinal holes inside and proposed a mathematical model for calculating energy dissipation. Through this model, the structural parameters of the damper were optimized, including the number and size of longitudinal holes. Four longitudinal holes with a diameter of 4.99 mm and a depth of 235 mm were prepared within the boring bar. Afterwards, a pin with a diameter of 5 mm was pressed into the holes. Compared with ordinary boring tools, the damping ratio of friction damped boring bars increased by an average of 34.9%, and the stiffness increased by an average of 2.4%. The vibration reduction performance of the friction damped boring bar was evaluated through sound analysis and machined surface quality at different cutting speeds. The experimental results showed that the friction damped boring bar significantly reduced the sound amplitude during the machining process. Under the selected cutting parameters, it could effectively improve the machining stability and machined surface quality.

The vibration damped boring tools integrated with friction energy dissipation components dissipate vibration energy through the friction damping mechanism and have the advantages of simple structure, flexible adjustment, and significant vibration reduction effects. They can improve machining stability and surface quality under high-frequency vibration conditions. However, their damping performance is greatly affected by the friction material, contact state, and environment, resulting in insufficient friction loss and damping performance attenuation. Future development can focus on the research and development of new friction materials, intelligent control of friction interface states, and design of multifunctional composite damping structures to meet high-precision vibration reduction requirements in complex processing environments. As shown in Table 2, the types, structural features, and advantages of the passive damped boring tools are summarized.

Table 2. Damped boring tool types, structural features, and advantages.

Research Methods	Boring Bar Type	Structural Features	Advantages	References
Experiment and structural design	Structure-optimized damping boring tool	Auxiliary support or clamping device	Enhance the rigidity and vibration damping performance of boring tools	[82–84]
Finite element simulation and experiment	Material-optimized damping boring tool	High-stiffness or high-damping materials	Absorb vibration energy and reduce vibration amplitude	[88–90]
Structural design and experimentation	Damping boring tool with a shock absorber	Continuous nonlinear collisions achieve vibration reduction	Damping components absorb or dissipate vibrational energy	[107–110]
Structural design and experimentation	Damping boring tool for friction components	Friction material or friction damper	Simple structure and excellent dissipation capability	[122–125]

4. Conclusions

As a key technology for improving deep hole machining accuracy and increasing machining efficiency, vibration damped boring tools have played an important role in manufacturing industries and attracted wide attention in academic areas. With increasing demand for processing quality in manufacturing industries, it is urgent to further enhance the development of vibration damped boring tools technology. Vibration damped boring tools can be divided into active vibration damped bars and passive vibration damped tools, according to different working principles, while different damped tools have their own advantages and disadvantages. This paper systematically reviews the research progress and application of these two types of vibration damped tools, which can help guide the tool design and the appropriate selection of different tools for specific applications. The main conclusions are as follows.

1. The active damped boring tools are performed through an external driving system to achieve the effect of vibration reduction in real-time, which has strong adaptability and machining accuracy. Active vibration damped boring tools mainly include piezoelectric-driven damped tools, magnetostrictive actuator damped bars, magnetorheological damped tools, electrorheological fluid damped tools, and dynamically adjustable damped tools. The above-mentioned boring tools can be adjusted according to the frequency changes of vibration during the machining process using different driving methods, thereby improving machining stability. These technologies provide a foundation for the intelligent and functional development of vibration damped boring tools. However, the complexity and high equipment cost of active vibration damped tools limit their widespread application in the industrial field. Future research directions can be focused on the reduction in the tool preparation cost and further improvement of the machining system stability.
2. Passive vibration damped boring tools are performed through structural optimization, damped material integration, and other passive methods to improve the tool damping performance and suppress machining vibration. Their advantages include a simple tool structure, low preparation cost, good stability, etc. Passive vibration damped boring tools mainly include structure-optimized damped boring tools, material-optimized damped boring tools, damped boring tools with an impact damper, and friction energy dissipation damped boring tools. Passive vibration reduction technology is suitable for various processing environments and is suitable for long-term, stable processing tasks. The main limitation for the damping effect of passive damped boring tools lies

in the static characteristics and material properties of the tool design, and the damped tools cannot be adjusted in real-time according to actual machining vibration changes. Future research directions can be focused on new damping materials and structures to further improve their damping performance and adaptability.

3. The rise of hybrid vibration damping technology provides new ideas for breaking through the limitations of active and passive vibration reduction methods. Through integrating passive structures and active control systems in the boring tools, closed-loop control of vibration signal sensing, processing, and responding can be achieved. It not only expands the frequency domain range of vibration reduction for the boring tools but also significantly improves the robustness and response flexibility of the machining system under complex working conditions. Hybrid damped tool systems are particularly suitable for processing tasks with variable frequencies and unstable cutting loads, which can help to improve the reliability and accuracy of the manufacturing process. However, such systems also face challenges such as high integration difficulty, high energy consumption, and complex control algorithms. Future research directions can be focused on the collaborative optimization of system miniaturization, intelligent control algorithms, and multifunctional integration, in order to promote the widespread application of hybrid vibration damping technology in various machining environments.
4. The integration of artificial intelligence and digital technology is constantly expanding the functional boundaries of vibration damped boring tools. With the rapid development of sensor technology and artificial intelligence, intelligent damped boring tools can collect significant information such as vibration, temperature, and tool wear in real-time. Through machine learning and data-driven modeling, machining status can be evaluated in real-time, and damped tools can be dynamically adjusted to optimize cutting performance. At the same time, digital twin technology has shown great potential in the design of vibration damped boring bars and cutting tool status monitoring, which enables rapid iteration and tool failure prediction in virtual environments. Future research directions can be focused on the strengthening of the integrated design of damped tool software and hardware, the development of high-precision and low-latency machining data process platforms, and industrial promotion of damped boring tools in different machining scenarios.

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References

1. Wang, B.; Liu, Z.; Cai, Y.; Luo, X.; Ma, H.; Song, Q.; Xiong, Z. Advancements in material removal mechanism and surface integrity of high speed metal cutting: A review. *Int. J. Mach. Tools Manuf.* **2021**, *166*, 103744. [CrossRef]
2. La Monaca, A.; Murray, J.W.; Liao, Z.; Speidel, A.; Robles-Linares, J.A.; Axinte, D.A.; Hardy, M.C.; Clare, A.T. Surface integrity in metal machining-Part II: Functional performance. *Int. J. Mach. Tools Manuf.* **2021**, *164*, 103718. [CrossRef]
3. Kishawy, H.A.; Becze, C.E.; McIntosh, D.G. Tool performance and attainable surface quality during the machining of aerospace alloys using self-propelled rotary tools. *J. Mater. Process. Technol.* **2004**, *152*, 266–271. [CrossRef]
4. Zabel, A.; Heilmann, M. Deep hole drilling using tools with small diameters—Process analysis and process design. *CIRP Ann.* **2012**, *61*, 111–114. [CrossRef]
5. Ahmed, A.; Lew, M.T.; Diwakar, P.; Kumar, A.S.; Rahman, M. A novel approach in high performance deep hole drilling of Inconel 718. *Precis. Eng.* **2019**, *56*, 432–437. [CrossRef]
6. Kong, L.; Cao, S.; Chin, J.-H.; Si, Y.; Miao, F.; Li, Y. Vibration suppression of drilling tool system during deep-hole drilling process using independence mode space control. *Int. J. Mach. Tools Manuf.* **2020**, *151*, 103525. [CrossRef]
7. Xiao, W.; Zi, Y.; Chen, B.; Li, B.; He, Z. A novel approach to machining condition monitoring of deep hole boring. *Int. J. Mach. Tools Manuf.* **2014**, *77*, 27–33. [CrossRef]
8. Katsuki, A.; Onikura, H.; Sajima, T.; Mohri, A.; Moriyama, T.; Hamano, Y.; Murakami, H. Development of a practical high-performance laser-guided deep-hole boring tool: Improvement in guiding strategy. *Precis. Eng.* **2011**, *35*, 221–227. [CrossRef]
9. Vopát, T.; Kuruc, M.; Pätoprstý, B.; Vozár, M.; Jurina, F.; Bočáková, B.; Peterka, J.; Görög, A.; Straka, R. The selection of cutting speed to prevent deterioration of the surface in internal turning of C45 steel by small-diameter boring bars. *Machines* **2024**, *12*, 68. [CrossRef]
10. Du, W.; Wang, L.; Shao, Y. A semi-analytical dynamics method for spindle radial throw in boring process. *J. Manuf. Process.* **2023**, *96*, 110–124. [CrossRef]
11. Quintana, G.; Ciurana, J. Chatter in machining processes: A review. *Int. J. Mach. Tools Manuf.* **2011**, *51*, 363–376. [CrossRef]
12. Gokulu, T.; Defant, F.; Albertelli, P. Stability analysis of multi-insert rotating boring bar with stiffness variation. *J. Sound Vib.* **2024**, *586*, 118497. [CrossRef]
13. Li, H.; Xia, Y.; Su, G.; Li, B.; Du, J. Ultrasonic vibration-assisted chatter suppression for deep hole boring of stainless steel. *Int. J. Adv. Manuf. Technol.* **2024**, *131*, 1691–1703. [CrossRef]
14. Liu, Q.; Zhang, H.; Liu, X.; Gao, D.; Zhang, M. A review on intelligent cutting tools. *J. Mech. Eng.* **2021**, *57*, 248–268.
15. Wiercigroch, M.; Wiercigroch, M.; Budak, E. Sources of nonlinearities, chatter generation and suppression in metal cutting. *Philos. Trans. R. Soc. Lond. Ser. A Math. Phys. Eng. Sci.* **2001**, *359*, 663–693. [CrossRef]
16. Moetakef-Imani, B.; Yussefian, N.Z. Dynamic simulation of boring process. *Int. J. Mach. Tools Manuf.* **2009**, *49*, 1096–1103. [CrossRef]
17. Pooja, J.; Waghmare, R.V.; Patil, G.S. Waghmare. A review on vibration mitigation of boring bar using passive damping techniques. *Int. J. Res. Eng. Technol.* **2015**, *4*, 138–141.
18. Park, G.; Bement, M.T.; Hartman, D.A.; Smith, R.E.; Farrar, C.R. The use of active materials for machining processes: A review. *Int. J. Mach. Tools Manuf.* **2007**, *47*, 2189–2206. [CrossRef]
19. Teti, R.; Jemielniak, K.; O'Donnell, G.; Dornfeld, D. Advanced monitoring of machining operations. *CIRP Ann.* **2010**, *59*, 717–739. [CrossRef]
20. Habib, M.; Lantgios, I.; Hornbostel, K. A review of ceramic, polymer and composite piezoelectric materials. *J. Phys. D Appl. Phys.* **2022**, *55*, 423002. [CrossRef]
21. Tanaka, H.; Obata, F.; Matsubara, T.; Mizumoto, H. Active chatter suppression of slender boring bar using piezoelectric actuators. *JSME Int. J. Ser. C Dyn. Control Robot. Des. Manuf.* **1994**, *37*, 601–606. [CrossRef]
22. Chiu, W.M.; Chan, K.W. Design and testing of piezoelectric actuator-controlled boring bar for active compensation of cutting force induced errors. *Int. J. Prod. Econ.* **1997**, *51*, 135–148. [CrossRef]
23. Akesson, H.; Smirnova, T.; Claesson, I.; Håkansson, L. On the development of a simple and robust active control system for boring bar vibration in industry. *Int. J. Acoust. Vib.* **2007**, *12*, 139–152. [CrossRef]
24. Kong, F.; Liu, P.; Liu, C. Simulation and experimental study on active control of boring vibration based on piezoelectric intelligent structure. *J. Vib. Shock.* **2010**, *29*, 5.
25. Matsubara, A.; Maeda, M.; Yamaji, I. Vibration suppression of boring bar by piezoelectric actuators and LR circuit. *CIRP Ann.* **2014**, *63*, 373–376. [CrossRef]
26. Venter, G.S.; Silva, L.M.D.P.; Carneiro, M.B.; da Silva, M.M. Passive and active strategies using embedded piezoelectric layers to improve the stability limit in turning/boring operations. *Int. J. Adv. Manuf. Technol.* **2017**, *89*, 2789–2801. [CrossRef]
27. Yigit, U.; Cigeroglu, E.; Budak, E. Chatter reduction in boring process by using piezoelectric shunt damping with experimental verification. *Mech. Syst. Signal Process.* **2017**, *94*, 312–321. [CrossRef]

28. Tang, B.; Akbari, H.; Pouya, M.; Pashaki, P.V. Application of piezoelectric patches for chatter suppression in machining processes. *Measurement* **2019**, *138*, 225–231. [CrossRef]
29. Aksoy, S. *Magnetostrictive Actuators*; Elsevier: Oxford, UK, 2022.
30. Zhang, K.; Zhang, Y.; Liu, C. Study on a magnetic actuation mechanism and its performance simulations. In Proceedings of the 2006 2nd IEEE/ASME International Conference on Mechatronics and Embedded Systems and Applications, Beijing, China, 13–16 August 2006; pp. 1–5.
31. Zhang, K.; Yu, J.; Li, Y.; Miao, Y. A structural analysis and optimum of a deformable unit for revolving magnetic actuation mechanism. In Proceedings of the 2008 IEEE International Conference on Automation and Logistics, Qingdao, China, 1–3 September 2008; pp. 1637–1642.
32. Zhou, J.; He, Z.; Rong, C.; Xue, G. A giant magnetostrictive rotary actuator: Design, analysis and experimentation. *Sens. Actuators A: Phys.* **2019**, *287*, 150–157. [CrossRef]
33. Wang, B.; Wu, Y.; Wu, X.; Liu, X.; Peng, H. Real-time measuring method to measure the micro-displacement of a rotating cutter in precise piston noncylinder pinhole boring. *Int. J. Adv. Manuf. Technol.* **2014**, *70*, 1931–1937. [CrossRef]
34. Lu, X.; Chen, F.; Altintas, Y. Magnetic actuator for active damping of boring bars. *CIRP Ann.* **2014**, *63*, 369–372. [CrossRef]
35. Chen, F.; Lu, X.; Altintas, Y. A novel magnetic actuator design for active damping of machining tools. *Int. J. Mach. Tools Manuf.* **2014**, *85*, 58–69. [CrossRef]
36. Chen, F.; Hanifzadegan, M.; Altintas, Y.; Lu, X. Active damping of boring bar vibration with a magnetic actuator. *IEEE/ASME Trans. Mechatron.* **2015**, *20*, 2783–2794. [CrossRef]
37. Chen, F.; Liu, G. Active damping of machine tool vibrations and cutting force measurement with a magnetic actuator. *Int. J. Adv. Manuf. Technol.* **2017**, *89*, 691–700. [CrossRef]
38. Bak, C.; Son, H. Magnetostrictive actuator for chatter vibration suppression of boring bar. In Proceedings of the 2018 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), Auckland, New Zealand, 9–12 July 2018; pp. 103–106.
39. Liu, H.; Jia, Z.; Wang, F.; Zong, F. Research on the constant output force control system for giant magnetostrictive actuator disturbed by external force. *Mechatronics* **2012**, *22*, 911–922. [CrossRef]
40. Yao, Z.; Zhang, P.; Luo, M. Extreme learning machine oriented surface roughness prediction at continuous cutting positions based on monitored acceleration. *Mech. Syst. Signal Process.* **2024**, *219*, 111633. [CrossRef]
41. Isavand, J.; Kasaei, A.; Peplow, A.; Wang, X.; Yan, J. A reduced-order machine-learning-based method for fault recognition in tool condition monitoring. *Measurement* **2024**, *224*, 113906. [CrossRef]
42. Pan, Y.; Kang, R.; Dong, Z.; Du, W.; Yin, S.; Bao, Y. On-line prediction of ultrasonic elliptical vibration cutting surface roughness of tungsten heavy alloy based on deep learning. *J. Intell. Manuf.* **2022**, *33*, 675–685. [CrossRef]
43. Han, S.; Mannan, N.; Stein, D.C.; Pattipati, K.R.; Bollas, G.M. Classification and regression models of audio and vibration signals for machine state monitoring in precision machining systems. *J. Manuf. Syst.* **2021**, *61*, 45–53. [CrossRef]
44. Kounta, C.A.K.A.; Arnaud, L.; Kamsu-Foguem, B.; Tangara, F. Deep learning for the detection of machining vibration chatter. *Adv. Eng. Software* **2023**, *180*, 103445. [CrossRef]
45. Zhang, P.; Gao, D.; Lu, Y.; Ma, Z.; Wang, X.; Song, X. Cutting tool wear monitoring based on a smart toolholder with embedded force and vibration sensors and an improved residual network. *Measurement* **2022**, *199*, 111520. [CrossRef]
46. Tama, B.A.; Vania, M.; Lee, S.; Lim, S. Recent advances in the application of deep learning for fault diagnosis of rotating machinery using vibration signals. *Artif. Intell. Rev.* **2023**, *56*, 4667–4709.
47. Yesilli, M.C.; Khasawneh, F.A.; Otto, A. Chatter detection in turning using machine learning and similarity measures of time series via dynamic time warping. *J. Manuf. Process.* **2022**, *77*, 190–206. [CrossRef]
48. Sun, L.-C.; Cheng, R.-C.; Chen, K.-S. Evaluation of transducer signature selections on machine learning performance in cutting tool wear prognosis. *Int. J. Adv. Manuf. Technol.* **2025**, *119*, 6451–6468. [CrossRef]
49. Rahimi, M.H.; Huynh, H.N.; Altintas, Y. On-line chatter detection in milling with hybrid machine learning and physics-based model. *CIRP J. Manuf. Sci. Technol.* **2021**, *35*, 25–40. [CrossRef]
50. Li, Y.; Li, J.; Li, W.; Du, H. A state-of-the-art review on magnetorheological elastomer devices. *Smart Mater. Struct.* **2014**, *23*, 123001. [CrossRef]
51. Mei, D.; Kong, T.; Shih, A.J.; Chen, Z. Magnetorheological fluid-controlled boring bar for chatter suppression. *J. Mater. Process. Technol.* **2009**, *209*, 1861–1870. [CrossRef]
52. Mei, D.; Yao, Z.; Kong, T.; Chen, Z. Parameter optimization of time-varying stiffness method for chatter suppression based on magnetorheological fluid-controlled boring bar. *Int. J. Adv. Manuf. Technol.* **2010**, *46*, 1071–1083. [CrossRef]
53. Yao, Z.; Mei, D.; Chen, Z. Chatter suppression by parametric excitation: Model and experiments. *J. Sound Vib.* **2011**, *330*, 2995–3005. [CrossRef]
54. Pour, D.S.; Behbahani, S. Semi-active fuzzy control of machine tool chatter vibration using smart MR dampers. *Int. J. Adv. Manuf. Technol.* **2016**, *83*, 421–428. [CrossRef]

55. Biju, C.V.; Shunmugam, M.S. Performance of magnetorheological fluid based tunable frequency boring bar in chatter control. *Measurement* **2019**, *140*, 407–415. [CrossRef]
56. Niu, J.; Hou, J.; Shen, Y.; Yang, S. Dynamic analysis and vibration control of nonlinear boring bar with fractional-order model of magnetorheological fluid. *Int. J. Nonlinear Mech.* **2020**, *121*, 103459. [CrossRef]
57. Prabhu, L.; Satish Kumar, S.; Dinakaran, D.; Jawahar, R. Improvement of chatter stability in boring operations with semi active magneto-rheological fluid damper. *Mater. Today Proc.* **2020**, *33*, 420–427. [CrossRef]
58. Saleh, M.K.A.; Nejatpour, M.; Yagci Acar, H.; Lazoglu, I. A new magnetorheological damper for chatter stability of boring tools. *J. Mater. Process. Technol.* **2021**, *289*, 116931. [CrossRef]
59. Saleh, M.K.A.; Ulasyar, A.; Lazoglu, I. Active damping of chatter in the boring process via variable gain sliding mode control of a magnetorheological damper. *CIRP Ann.* **2021**, *70*, 337–340. [CrossRef]
60. Hou, J.; Niu, J.; Shen, Y.; Yang, S.; Zhang, W. Dynamic analysis and vibration control of two-degree-of-freedom boring bar with fractional-order model of magnetorheological fluid. *J. Vib. Control* **2021**, *28*, 3001–3018. [CrossRef]
61. Aralikatti, S.S.; Puneet, N.P.; Kumar, H. Determining the optimal composition of magnetorheological fluid for a short-stroke magnetorheological damper. *Sādhanā* **2023**, *48*, 120. [CrossRef]
62. Sarath, S.; Paul, P.S.; Lawrance, G. Characterization and performance analysis of magnetorheological foam damper for vibration control during boring process. *Multiscale Multidiscip. Model. Exp. Des.* **2024**, *7*, 837–854. [CrossRef]
63. Stanway, R.; Sproston, J.L.; El-Wahed, A.K. Applications of electro-rheological fluids in vibration control: A survey. *Smart Mater. Struct.* **1996**, *5*, 464. [CrossRef]
64. Wang, M.; Fei, R. Improvement of machining stability using a tunable-stiffness boring bar containing an electrorheological fluid. *Smart Mater. Struct.* **1999**, *8*, 511. [CrossRef]
65. Wang, M.; Fei, R. Chatter suppression based on nonlinear vibration characteristic of electrorheological fluids. *Int. J. Mach. Tools Manuf.* **1999**, *39*, 1925–1934. [CrossRef]
66. Wang, M.; Fei, R. On-line chatter detection and control in boring based on an electrorheological fluid. *Mechatronics* **2001**, *11*, 779–792. [CrossRef]
67. Wang, M.; Fei, R. Research on online monitoring technology of chatter in cutting process based on electrorheological materials. *J. Mech. Eng.* **2002**, *38*, 5.
68. Kela, L.; Vähäoja, P. Recent Studies of Adaptive Tuned Vibration Absorbers/Neutralizers. *Appl. Mech. Rev.* **2009**, *62*, 60801. [CrossRef]
69. Tewani, S.G.; Rouch, K.E.; Walcott, B.L. Cutting process stability of a boring bar with active dynamic absorber. In Proceedings of the ASME 1991 Design Technical Conferences, 13th Biennial Conference on Mechanical Vibration and Noise: Vibration Analysis—Analytical and Computationa, Miami, FL, USA, 22–25 September 1991; pp. 205–213.
70. Tewani, S.G.; Rouch, K.E.; Walcott, B.L. A study of cutting process stability of a boring bar with active dynamic absorber. *Int. J. Mach. Tools Manuf.* **1995**, *35*, 91–108. [CrossRef]
71. Moradi, H.; Bakhtiari-Nejad, F.; Movahhedy, M.R. Tuneable vibration absorber design to suppress vibrations: An application in boring manufacturing process. *J. Sound Vib.* **2008**, *318*, 93–108. [CrossRef]
72. Altintas, Y.; Lappin, D.; van Zyl, D.; Östling, D. Automatically tuned boring bar system. *CIRP Ann.* **2021**, *70*, 313–316. [CrossRef]
73. Liu, X.; Liu, Q.; Wu, S.; Li, R.; Gao, H. Analysis of the vibration characteristics and adjustment method of boring bar with a variable stiffness vibration absorber. *Int. J. Adv. Manuf. Technol.* **2018**, *98*, 95–105. [CrossRef]
74. Lv, J.; Niu, J.; Shen, Y.; Yang, S. Vibration control of linear boring bar by dynamic vibration absorber combined with nonlinear energy sink. *Chin. J. Theor. Appl. Mech.* **2021**, *53*, 3124–3133.
75. Liu, Q.; Li, J.; Ma, J.; Gao, D.; Han, J.; Li, J. Structure design and vibration control of vibration reduction boring bar with variable damping. *Int. J. Adv. Manuf. Technol.* **2024**, *134*, 5301–5319. [CrossRef]
76. Shi, H.; Ma, C.; Li, X.; Wang, G. Equivalent linearization of hyperelastic rubber rings in dynamic vibration absorber boring bar and simulation of its dynamic properties. *Eng. Res. Express* **2024**, *6*, 015517. [CrossRef]
77. Van Zyl, D.; Altintas, Y.; Ostling, D. Parametric design of boring bars with adaptive tuned mass dampers. *CIRP J. Manuf. Sci. Technol.* **2022**, *38*, 491–499. [CrossRef]
78. Li, L.; Ren, Y.; Shen, Z.; Lu, J.; Tong, L. Nonlinear system optimization of cutting tools with dynamic vibration absorbers in deep hole boring: A stability analysis. *Alex. Eng. J.* **2025**, *112*, 246–253. [CrossRef]
79. Li, L.; Yang, D.L.; Cui, Y.M. Optimization of machining performance in deep hole boring: A study on cutting tool vibration and dynamic vibration absorber design. *Adv. Prod. Eng. Manag.* **2023**, *18*, 371–380. [CrossRef]
80. Lawrance, G.; Paul, P.S.; Varadarajan, A.S.; Vasanth, X.A.; Raj, S.B. Suppression of tool vibration in boring process: A review. *J. Inst. Eng. Ser. C* **2019**, *100*, 1053–1069. [CrossRef]
81. Sun, J.; Sun, C.; Yan, Z.; Yang, W.; Zhou, C.; Zhang, P.; Shu, L. State-of-art, challenges, and outlook on deep hole boring: Chatter suppression, tool wear monitoring, and error measurement. *Int. J. Adv. Manuf. Technol.* **2025**, *136*, 2075–2105. [CrossRef]

82. Åkesson, H.; Smirnova, T.; Håkansson, L. Analysis of dynamic properties of boring bars concerning different clamping conditions. *Mech. Syst. Signal Process.* **2009**, *23*, 2629–2647. [CrossRef]
83. Yan, S.; Sun, Y. Enhancing tool dynamics and stability in internal turning with an adjustable clamping device under variable cutting conditions. *Mech. Syst. Signal Process.* **2024**, *208*, 111007. [CrossRef]
84. Zhang, C.; Ren, Y.; Ji, S.; Zhang, J. Analysis of the vibration and chatter stability of a tapered composite boring bar. *Shock. Vib.* **2020**, *2020*, 4190806. [CrossRef]
85. Liu, G.; Lu, L.; Su, W.; Li, J.; An, Q.; Zhang, L.; Mao, J. Design and chatter suppression of a CLD-structured CFRP boring bar for high-precision deep hole machining. *Int. J. Adv. Manuf. Technol.* **2025**, *139*, 1363–1378. [CrossRef]
86. Cai, H.; Dong, Z.; Zhang, Z.B.; Cui, S. Design of a new type of deep hole boring device. *J. Phys. Conf. Ser.* **2021**, *1748*, 062038. [CrossRef]
87. Takahashi, W.; Suzuki, N.; Shamoto, E. Development of a novel boring tool with anisotropic dynamic stiffness to avoid chatter vibration in cutting: Part 1: Design of anisotropic structure to attain infinite dynamic stiffness. *Precis. Eng.* **2021**, *68*, 57–71. [CrossRef]
88. Nagano, S.; Koizumi, T.; Fujii, T.; Tsujiuchi, N.; Ueda, H.; Steel, K. Development of a composite boring bar. *Compos. Struct.* **1997**, *38*, 531–539. [CrossRef]
89. Lee, D.G.; Hwang, H.Y.; Kim, J.K. Design and manufacture of a carbon fiber epoxy rotating boring bar. *Compos. Struct.* **2003**, *60*, 115–124. [CrossRef]
90. Lee, D.G.; Lee, C.S.; Lee, H.G.; Hwang, H.Y.; Kim, J.W. Novel applications of composite structures to robots, machine tools and automobiles. *Compos. Struct.* **2004**, *66*, 17–39. [CrossRef]
91. Wang, J.; Wu, F.; Han, Y.; Sun, D. Boring bar design with laminar composite structure and research on properties. *China Mech. Eng.* **2013**, *24*, 5. [CrossRef]
92. Sortino, M.; Totis, G.; Prosperi, F. Modeling the dynamic properties of conventional and high-damping boring bars. *Mech. Syst. Signal Process.* **2013**, *34*, 340–352. [CrossRef]
93. Khatake, P.; Nitnaware, P.T. Vibration mitigation using passive damper in machining. *Int. J. Mod. Eng. Res.* **2013**, *3*, 3649–3652.
94. Akdeniz, E.; Arslan, H. A new design of boring bar using $TiNi_3$ alloy to reduce vibration in turning operations. *Proc. Inst. Mech. Eng. B J. Eng. Manuf.* **2022**, *237*, 105–121. [CrossRef]
95. Song, Q.; Shi, J.; Liu, Z.; Wan, Y.; Xia, F. Boring bar with constrained layer damper for improving process stability. *Int. J. Adv. Manuf. Technol.* **2016**, *83*, 1951–1966. [CrossRef]
96. Zhang, Y.; Rong, Y.; Tian, J.; Ma, J. Chatter stability of the constrained layer damping composite boring bar in cutting process. *J. Vib. Control* **2019**, *25*, 2204–2214.
97. Nanda, B.K.; Srinivas, J. Investigation of stability in internal turning using a boring bar with a passive constrained layer damping. *FME Trans.* **2021**, *49*, 384–394. [CrossRef]
98. Lu, L.; Ni, C.; Liu, G.; Qian, B.; An, Q.; Cao, Z.; Zhang, L.; Li, J. Analysis and development of the CFRP boring bar for stability improvement. *Fibers Polym.* **2023**, *24*, 4413–4427. [CrossRef]
99. Ghorbani, S.; Rogov, V.A.; Carluccio, A.; Belov, P.S. The effect of composite boring bars on vibration in machining process. *Int. J. Adv. Manuf. Technol.* **2019**, *105*, 1157–1174. [CrossRef]
100. Singaravelu, C.; Varatharajan, P.; Ramu, G.; Alagappan, K. Investigation of damping characteristics on copper-based shape memory alloy frictional damper in boring process. *Arab. J. Sci. Eng.* **2021**, *46*, 11859–11870. [CrossRef]
101. Tian, J.; Li, J.; Liu, G.; Shi, J.; Wu, Y. Design and performance study of a bionic damping boring bar based on the woodpecker. *CIRP J. Manuf. Sci. Technol.* **2025**, *61*, 308–323. [CrossRef]
102. Fu, Q.; Lundin, D.; Nicolescu, C.M. Anti-vibration engineering in internal turning using a carbon nanocomposite damping coating produced by PECVD process. *J. Mater. Eng. Perform.* **2014**, *23*, 506–517. [CrossRef]
103. Chockalingam, S.; Natarajan, U.; Selvam, M.; Cyril, A.G. Investigation on machinability and damping properties of nickel–phosphorus coated boring bar. *Arab. J. Sci. Eng.* **2016**, *41*, 669–676. [CrossRef]
104. Ren, Y.; Zhang, Y. Investigation of chatter stability of cutting process with a rotating tapered cutter bar considering internal and external damping. *Int. J. Adv. Manuf. Technol.* **2020**, *107*, 1755–1771. [CrossRef]
105. Zhang, Y.; Ren, Y.; Zhang, J. Stability analysis of cutting process with internally damped rotating tapered composite cutter bar. *Math. Probl. Eng.* **2020**, *2020*, 2587820. [CrossRef]
106. Wang, D. Analysis of vibration energy dissipation performance of impact dampers. *J. Mech. Eng.* **2014**, *50*, 6. [CrossRef]
107. Ema, S.; Marui, E. Suppression of chatter vibration of boring tools using impact dampers. *Int. J. Mach. Tools Manuf.* **2000**, *40*, 1141–1156. [CrossRef]
108. Lawrance, G.; Paul, P.S.; Varadarajan, A.S.; Praveen, A.P.; Vasanth, X.A. Attenuation of vibration in boring tool using spring controlled impact damper. *Int. J. Interact. Des. Manuf.* **2017**, *11*, 903–915. [CrossRef]
109. Kumar, M.S.; Mohanasundaram, K.; Sathishkumar, B. A case study on vibration control in a boring bar using particle damping. *Int. J. Eng. Sci. Technol.* **2012**, *3*, 177–184. [CrossRef]

110. Biju, C.V.; Shunmugam, M.S. Investigation into effect of particle impact damping (PID) on surface topography in boring operation. *Int. J. Adv. Manuf. Technol.* **2014**, *75*, 1219–1231. [CrossRef]
111. Devaraj, S.; Shivalingappa, D.; Jangaler, R.S. Surface quality enrichment using fine particle impact damper in boring operations. *Int. J. Res. Eng. Technol.* **2014**, *3*, 531–535. [CrossRef]
112. Chockalingam, S.; Natarajan, U.; Cyril, A.G. Damping investigation in boring bar using hybrid copper-zinc particles. *J. Vib. Control* **2015**, *23*, 2128–2134. [CrossRef]
113. Singh, G.; Mann, G.S.; Pradhan, S. Improving the surface roughness and flank wear of the boring process using particle damped boring bars. *Mater. Today Proc.* **2018**, *5 Pt 2*, 28186–28194. [CrossRef]
114. Thomas, W.; Diniz, A.E.; Pederiva, R.; Suyama, D.I.; de Albuquerque, M.V. A new type of impact damper with long overhangs in the internal turning of hardened materials. *Procedia CIRP* **2019**, *82*, 255–260. [CrossRef]
115. De Aguiar, H.C.G.; Hassui, A.; Suyama, D.I.; Magri, A. Reduction of internal turning surface roughness by using particle damping aided by airflow. *Int. J. Adv. Manuf. Technol.* **2020**, *106*, 125–131. [CrossRef]
116. Lawrance, G.; Paul, P.S.; Ezhil, M.; Ashish, J.E.; Gokul, R.; Subhash, M. Influence of stainless steel impact damper on tribological properties during boring process. *Mater. Today Proc.* **2021**, *46*, 107–110. [CrossRef]
117. Lawrance, G.; Paul, P.S.; Jan, N.M.; Pravin, S.S. Investigation of particle damper on tool vibration during boring process. *Mater. Today Proc.* **2021**, *47*, 4696–4699. [CrossRef]
118. Thomas, W.; Peterka, J.; Szabó, T.; de Albuquerque, M.V.; Pederiva, R.; Kiss, L.P. Analytical and experimental investigation of the dynamic stability in passive damper boring bars. *Procedia CIRP* **2023**, *117*, 187–192. [CrossRef]
119. Ramu, G.; Sundaramoorthy, K.; Singaravelu, C.; Prasannavenkadesan, V. A novel hybrid particle damping in boring bar for effective machining and chatter suppression. *Sādhanā* **2024**, *49*, 276. [CrossRef]
120. Yang, Y.; Liu, H.-L.; Yuan, J.-W.; Kong, W.-L.; Wan, M.; Zhang, W.-H. Development of an anti-vibration cutting tool combining the lattice structures infill with damping particles. *Mech. Syst. Signal Process.* **2025**, *228*, 112425. [CrossRef]
121. Tian, J.; Wu, D.; Li, J.; Shi, J.; Liu, G. Design and energy dissipation analysis of a boring bar based on particle damping. *J. Vib. Eng. Technol.* **2025**, *13*, 51. [CrossRef]
122. Edhi, E.; Hoshi, T. Stabilization of high frequency chatter vibration in fine boring by friction damper. *Precis. Eng.* **2001**, *25*, 224–234. [CrossRef]
123. Lu, X.D.; Zhao, J.; Mo, J.L.; Zhang, Q.; Zhang, X.; Zhou, Z.R. Improvement of dynamical and tribological properties of friction systems by introducing parallel-grooved structures in elastic damping components. *Compos. Struct.* **2018**, *192*, 8–19. [CrossRef]
124. Zhao, Y.C.; Ma, F.; Yan, C.G.; Huang, H.B. Study on damping effect of liquid film in precision boring. *China Mech. Eng.* **2002**, *13*, 4.
125. Zhao, Y.C.; Huang, H.B.; Yan, C.G.; Zhao, L. Simulation study of extrusion liquid film damping system in precision boring. *J. Mech. Eng.* **2003**, *39*, 4. [CrossRef]
126. Shao, Q.; Zhao, Z.; Tian, X.; Wang, L. Research on effect of decreasing vibration with liquid film damping in precision boring. *Wirel. Pers. Commun.* **2018**, *102*, 1085–1094. [CrossRef]
127. Wang, M.; Zan, T.; Yang, Y.; Fei, R. Design and implementation of nonlinear TMD for chatter suppression: An application in turning processes. *Int. J. Mach. Tools Manuf.* **2010**, *50*, 474–479. [CrossRef]
128. Wang, M.; Zan, T.; Gao, X. Modeling and optimization of a friction damper for boring chatter control. *Adv. Mech. Eng.* **2015**, *6*, 690768. [CrossRef]
129. Hayati, S.; Shahrokhi, M.; Hedayati, A. Development of a frictionally damped boring bar for chatter suppression in boring process. *Int. J. Adv. Manuf. Technol.* **2021**, *113*, 2761–2778. [CrossRef]

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