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Comprehensive Survey of Vibration Control Technology in Machining

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Abstract

This paper summarizes vibration control methods in the process of machining, and the current research progresses, in view of the difference in vibration control technologies and methods, from several aspects such as the eliminating vibration control technology, the isolating vibration control technology, and absorbing vibration control technology, etc .Simultaneously with the continuous improvement of the traditional control method, the organic combination the new material technology and intelligent control methods will also be the future trend of development.

Keywords: *Machining; Cutting vibration; Vibration control*

1. Introduction

Vibration is a common phenomenon in nature and engineering. It has drawn attention since the World War II when fighters and other military equipment got damaged due to vibration. Though there are lots of equipment and processes working by using the vibration in engineering, in general vibration is harmful both to the system itself and the environment, since it directly affects function of equipment, reduces the working accuracy and efficiency of machinery, intensifies abrasion of components, and even cause structural fatigue damage, which affect the security and reliability of the machinery and engineering facilities. Therefore, for most of the machinery, and engineering structures, the possible vibration magnitude is generally required to be controlled within a certain range. Vibration control is by eliminating, isolating, absorbing, damping, and other technical measures to reduce and prevent the spreading of the vibration in the machinery and engineering structures. According to the difference of vibration control mechanism, control methods can be divided into two types, passive control and active control. Passive control has won a wide range of applications due to the absence of external energy, simple device structure, and relatively good effect and reliability in many occasions. But with the development of science and technology, people raise the demand in vibration environment, and in vibration characteristics of products and structures, while passive control has been difficult to meet the requirements. Active vibration control means, in the process of vibration control, according to the vibration of structure or system detected by the sensors, applying control strategy, and through real-time computing, driving actuators to exert a certain force or moment to structure or system, thus suppressing the vibration of the structure or system. It is playing an increasingly important role in the field of mechanical processing.

A variety of mechanical and structural vibration is common in engineering technology, which is called mechanical vibration. In many cases, mechanical vibration is the negative factors in system, because the existence of vibration will affect the precision of the instrument, speed up the structural fatigue and damage, and shorten the service life of machines and the structure. Furthermore noise caused by vibration has become a big public hazard of human living environment. Vibration problem is increasingly protruding,

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which makes studies related to vibration control develop rapidly in recent decades. From different point of view, the classification of the vibration control is shown in Figure 1 [1]:

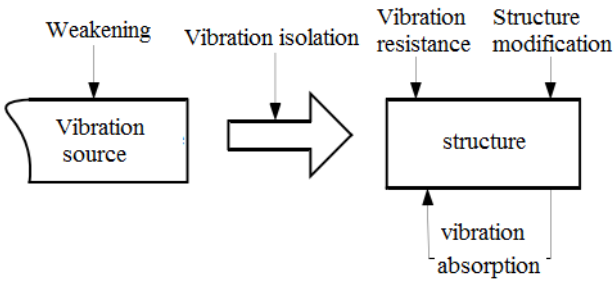
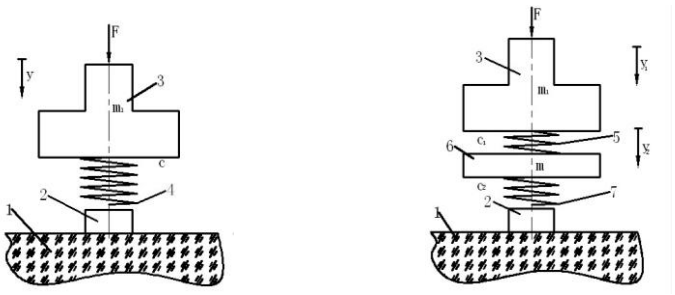


Figure 1. The Classification of the Vibration Control

2. The Eliminating Control Technology

Eliminating control technology controls the vibration of vibration source. In 1911 F. W. Lanchester put forward vibration absorber for the first time when applying for patent in Britain; in 1928 W. E. Dally published monograph "Thomas Lowe Gray" in which the electric vibration absorber devised for the first time; in the process of machining, Wang Zhen [2], in view of the defect that the surface of brittle non-metallic materials may get cracked or even broken by the vibration in the process of high speed and efficient mirror grinding, analyzed the vibration machining system with the method of theoretical mechanics, established its mathematical model (Figure 2) and designed experimental vibration free device on the basis of the two-stage vibration damping principle.



（a）Single-stage vibration free （b）Two-stage vibration free

1- workpiece 2- grinding wheel 3- Fixed to the wheel body of machine tool spindle 4、5、7- Damping elastic element6- Two-stage damping device between components

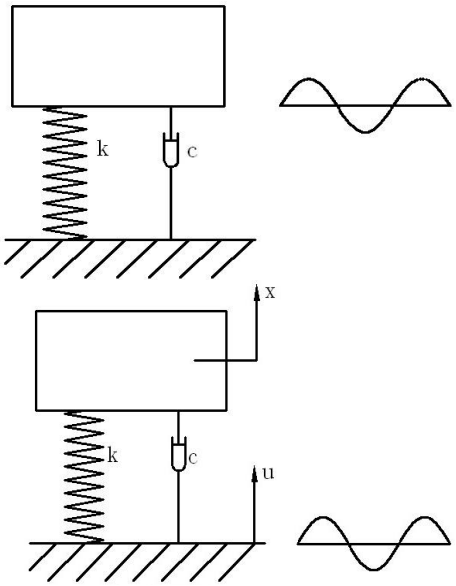
Figure 2. Damping Model

Although by changing the grinding wheel rotation speed and the consumption of cooling liquid (traffic), adjusting the stiffness and lifting force of cooling fluid layer, people can minimize the vibration intensity of the process, but these must be under the premise of achieving smoothly change of grinding wheel rotation speed. The adjustment method only can be realized in the numerical control machines, which is a great limitation.

Li Shijie [3] analyzed the main types and reasons and the harm of the vibration in the process of turning, and put forward the measures to reduce or eliminate the vibration from the perspectives of cutting tools, fixtures, and cutting process. To eliminate or weaken vibration source, it is the most effective and thorough way, but in many cases cannot be implemented, related researches are relatively few at home and abroad.

3. The Isolating Control Technology

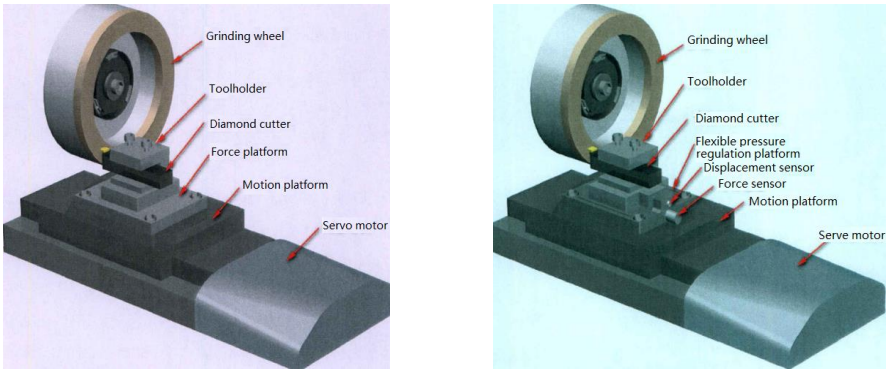
The essence of adding flexible link between the source and the system of vibration, or installing appropriate vibration controlling or vibration isolating equipment for isolating direct force or motion exciting vibration is attached a subsystem (vibration isolator) between the vibration source and the subsystem. From the energy point of view, the isolation of vibration source is to change the system of energy spectrum structure, to reduce the effort of suppressing the vibration through the energy of frequency, and eliminate the bad influence of vibration by hindering the transmission of vibration. Reducing the transmission of force exciting vibration is the first kind of vibration isolation, also referred to as isolating force or active vibration isolation for short. Reducing the transmission of motion exciting vibration is the second kind of vibration isolation, also referred to as estrangement or passive vibration isolation for short, as shown in Figure 3 which shows two isolation models [4]



（a）The first kind of vibration isolation （b）The second type of vibration isolation

Figure 3. Two Isolation Models

As early as in 1955, scientists in the United States proposed the research paper of active vibration isolation technology, in 1986 the United States launched and promoted an active vibration isolation system EVIS as a commodity. Until the end of last century, Schubert and others applied the piezoelectric element in active vibration isolation device. Since then all kinds of intelligent materials poured into the field of active vibration isolation, which to a great extent, promoted the development of active vibration isolation technology. Du Wenhao [5] when controlling the pressure of diamond grinding tools, used vibration isolation technology, to reduce the amplitude of displacement response of the controlled system inertial mass to external excitation, which achieved the control of the grinding pressure fluctuation, and ensured the stabilization of the grinding pressure. Figure 4 shows the contrast figures of cutting tool grinding devices before and after the improvement. Replacement of rigid load platform with flexible regulation platform, weakens the effects of high frequency vibration excitation on system inertial mass displacement, has the effect of passive vibration isolator, but under the limitations of experimental conditions, the related experiment equipment, and the manufacture cycle, currently only local precision grinding of diamond cutting tool can be realized.



（a）The original diamond tool grinding device　（b）The improved diamond tool grinding device

Figure 4. The Contrast Figures of Cutting Tool Grinding Devices before and after the Improvement

4. Control Technology of Vibration Resistance

Additional damper or damping element on the controlled object, can minimize the response by consuming energy. Extra damping components are also used to increase the damping.

5. Absorption Vibration Control Technology

Attaching a subsystem on the controlled object makes a certain frequency of the vibration controlled, is called dynamic vibration absorption, namely taking use of the vibration absorbing force generated by vibration absorber to reduce the response of the controlled object of vibration source excitation. Dynamic vibration absorber is also called tuned mass damper, TMD whose basic principle is changing the state of the vibration of the primary vibration system, and thus reducing the forced vibration response of main vibration system on its spectrum by attaching a substructure (*i.e.*, vibration absorption device) to the target system (i.e., the main vibration system), and appropriately choosing dynamic parameters and the coupling relationship with the main vibration system of the substructure. The history of the study on dynamic vibration absorber has been more than a hundred years since 1909, when FRAHM invented the dynamic vibration absorber, DVA. It has been widely used in practice, due to its simple structure, easy implement, and effective restrain of vibration of the equipment with smaller frequency change range.

5.1. The Liquid Damping Vibration Absorber

Liquid damping vibration absorber reduces the vibration by using the lateral force produced by the shaking of the liquid in gaps.

5.1.1. MRF Vibration Absorption: Damping vibration absorber is a newly invented vibration absorbing device which takes advantage of the unique characteristics of magnetic liquid and dissipates energy trough the viscous damping of the liquid.

Zhou Qian [6] and his colleges designed a kind of intelligent dynamic vibration absorber based on MRF (as shown in Figure 5), which is used, by changing external magnetic field, controlling the shear modulus of magnetorheological fluid to change the natural frequency of vibration absorber, and thus increase the vibration absorption band.

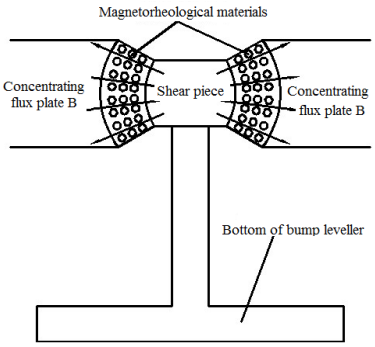


Figure 5. MRF Working Principle of the Dynamic Vibration Absorber

Yang Wenming [7] did vibration absorbing experiment research on the flexible cantilever beam of applying magnetic liquid damping vibration absorber (Figure 6), and concluded the vibration reduction effect under different parameters (as shown in Figure 7).

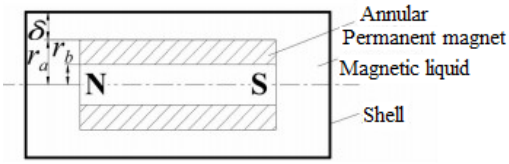


Figure 6. Magnetic Liquid Damping Vibration Absorber

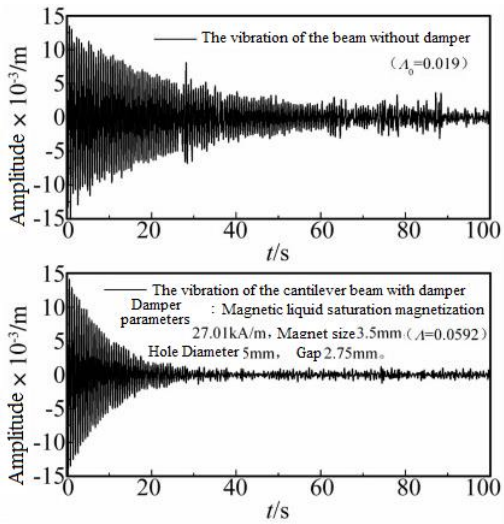


Figure 7. The Vibration of the Cantilever Beam before and after Vibration

According to the above figure, the effect of the magnetic fluid damping vibration absorber is good in absorbing vibration of the cantilever beam, but the vibration damping effect of the same magnetic liquid damping vibration absorber is obvious only to the vibration less than 1 Hz. At the same time, after contrast tests it is concluded that under the same parameters, damping effect of magnetic fluid with degree of saturation magnetization of 27.01 kA/m is best.

Magnetorheological fluid damper as a kind of semi-active controlled actuator, has the advantages of quick response, good stability, and continuous adjustability, which has become the control component of a new generation in structure vibration control.

5.1.2 The Electrorheological Fluid Vibration Absorption: In the 1940s, American scholar Winslow [8] for the first time attained a kind of special liquid electrorheological fluid, with the feature that its viscosity changed sensitively until curing under the effect of applied electric field, and he named the phenomenon electrorheological effect. The working principle of electrorheological fluid damper can be roughly divided into the Flow - Mode, Shear- Mode, and Squeeze - Mode [9], as shown in Figure 8.

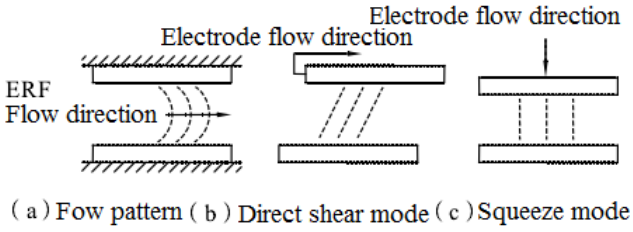


Figure 8. Electrorheological Fluid Damper Working Principle Diagram

In nearly 40 years, the liquid did not draw enough attention. It is not until the 1980s, did it attract attention of more than 10 countries such as Britain, the United States, Germany, Japan, etc. and more than 60 technical workers in the many scientific research institutions and institutions of higher learning and was widely used in national defense, the machine industry, aerospace, civil, and many other fields. In 1995 members of China's natural science fund committee LeiYuanzhong and Li Ming proposed electrorheological technology applied to automatic control of cutting chattering of machine tools [10] in the domestic for the first time. In 2000, Shaw Jinsinag [11] analyzed the vibration reduction mechanism and response characteristics of the cantilever beam with composite structure of electrorheological fluid, and found out its unique advantages compared with other active or semi-active controllers. In 1998 Wang Min[12] successfully applied electrorheological materials to flutter suppression research on intelligent boring bars of variable stiffness(shown in Figure 9), combining with the flutter prediction technology, realizing on-line prediction control over the boring chattering, achieved very good effect .

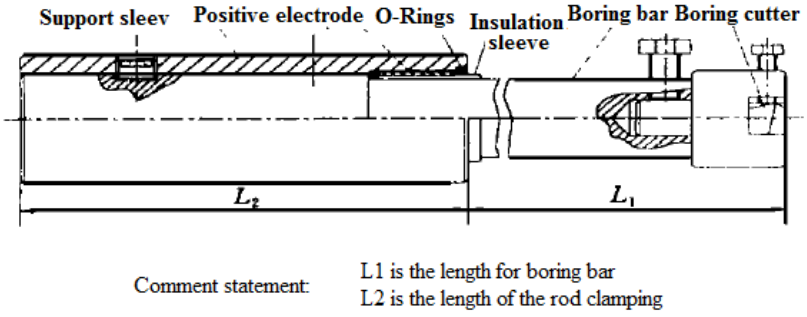


Figure 9. Based on the Electrorheological Technology Intelligent Boring Bar Structure

5.1.3 Vibration Absorption of Other Liquids: Zhao Yongcheng [13] applied squeezing liquid film damping technique in the fine boring holes and designed squeezing liquid film damper for fine boring holes, and optimized the damper based on some structural parameters obtained in static tests and dynamic tests. The essence of the damping force of the damper is pure liquid friction energy dissipation of the boring bar vibration, which reduces the vibration amplitude. In the processing of fine boring holes, liquid film damping system can greatly improve the dynamic performance of machine tools, simultaneously does not reduce other performance indicators, (shown in Figure 10, 11, 12).

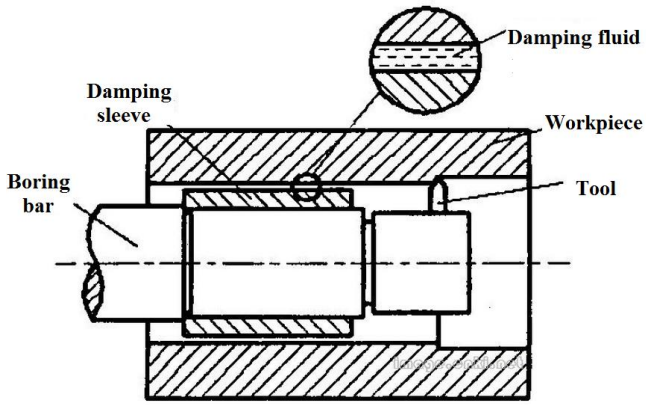


Figure 10. Fine Boring Squeeze Liquid Film Damping System Structure Diagram

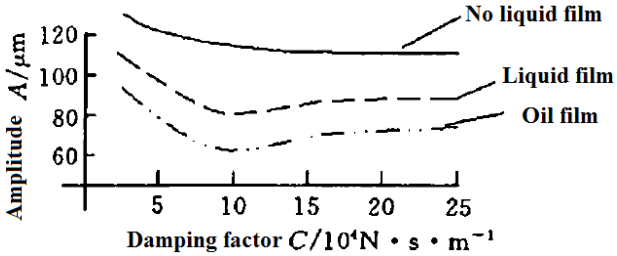


Figure 11. In the Static Test Amplitude and Damping Coefficient Curve

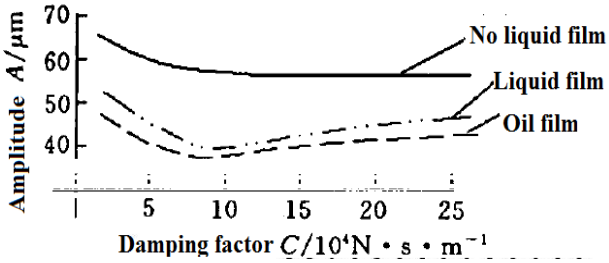


Figure 12. In the Dynamic Test Amplitude and Damping Coefficient Curve

Most of the present study focuses on designing model of the restoring force in magnetorheological fluid damper, while research for structural control strategy based on the restoring force model is few, the two seem not to be balanced. This article studies the control strategy, based on the restoring force model of Ou Jinping, makes full use of the features of continuous adjustability of magnetorheological fluid damper, establishes the mathematical model of the improved control strategy, and at the same time gives a simplified algorithm. In order to verify the effectiveness of the proposed control strategy, the computer program was compiled, simulation analysis was carried out on a engineering example. Results show that compared with the commonly used control strategy, the control strategy proposes in this paper has better control effect. Furthermore, with the improvement of the performance of the damper, the superiority of this control strategy will become more obvious; besides, this article also takes control analysis under the influence of delay into consideration. The results show that the control strategy has very good stability.

The technique made up of damping sleeve and processed set of holes, is operated by filling the gap between the outer surface of the damping sleeve and the inner surface of processing holes with liquid. When the spindle is in operation, the boring bar does radial

vibration, the two surfaces of the gap approach each other, leaving the liquid inside the gap squeezed, forming a squeezed liquid film. Squeezed liquid film formed damping force against the change of the gap of the damper, the essence of the damping force is pure liquid friction, which is able to dissipate the vibration energy of the boring bar, reduce the vibration amplitude, so as to improve the dynamic performance of system, thus improve the quality of fine boring holes precessing.

5.2. Ballistic Damping Vibration Absorbing Device

Ballistic damping reduce the vibration through the kinetic energy consumption caused by non-perfect elastic collision, which realizes energy consumption by collision of two doing reverse motion [14]. Wang Min's ballistic damper consists of two parts, indenter and damping chamber [15]. Damping chamber vibrates with the boring bar as well as the bumper block. There exists a certain space between the damping block and the damping chamber, and the size of the gap between them must be designed properly, in order that the bumper block impacts the inner surface of the damping chamber when the two are just doing the opposite movement, only in which way, the energy consumption during the impact could help suppress vibration.

6. The Modification of the Structure

By modifying the dynamic characteristics parameters of controlled object the requirements can be met, that no subsystem is needed.

Wang Lanbo from the angle of mechanics of materials, optimized the structure of the ordinary tool rod. Horizontal crumbs slot or tilt crumbs slot is designed near the head of the rod according to the shape and size of chips. With information of the vibration frequency of the system, resonance with the cutting system can be avoided by changing the structure of the boring bar, which will accordingly change its natural [16], as shown in Figure 13.

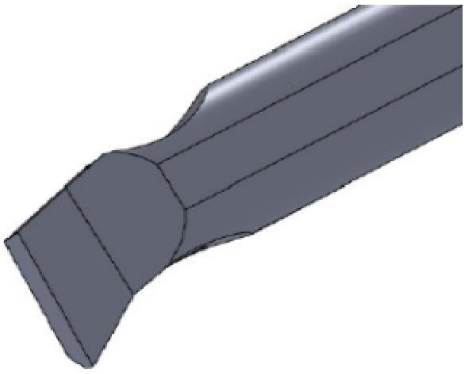


Figure 13. Vibration Reduction Design of Boring Bar Four

Sandvik Company developed the damping boring bar (as shown in Figure 14) independently, in which they increased its static stiffness by inserting cemented carbide with higher specific gravity in the outer wall to the boring bar; and according to different cutting conditions, designed the outer wall into ring wall, and injected mercury of higher density into it in order to increase the static stiffness.

Figure 14. Sandvik Damping Boring Bar

Toshiba of Japan bonds hard materials of stiffness and strength with the blade when designing damping boring bar (shown in Figure 15), also from the perspective of raising the static stiffness of the boring bar.

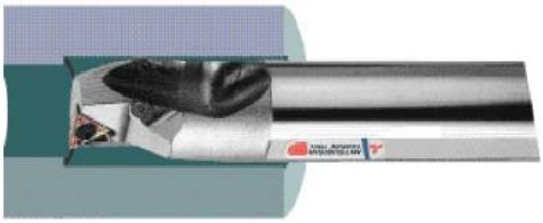


Figure 15. Toshiba Damping Boring Bar

7. Prospect

Under the long-term efforts of many scholars, and with the deepening of the vibration control research, the ultimate goal of vibration control of eliminating multiple resonance peaks of main vibration system in the broadband will finally achieved either through the development and application of new materials, or the perfection of the active and semi-active vibration control, or the use of hybrid technology. The Machining vibration control technology in rapid development has displayed a vibrant momentum.

(1) The shape memory alloy is a promising material of vibration control with its unique properties such as shape memory, super elasticity, hysteresis and thermal sensitivity, which allows it to automatically change its characteristics in order to better respond to the external load. Future research will focus on the characteristics of shape memory alloys, the establishment of mathematical model of materials table, the shape memory alloy damping devices and the experimental application of these devices.

(2) The advanced intelligent structure is highly integrated with many kinds of structure or structural components of the system, such as sensors, actuators, control systems, signal transceiver system, power supply and so on. It has a lot of bionic performances, such as self-adaption, self-recognition, self-repair, etc.

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