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Design and Test of Semi-Active Vibration-Reducing System for Lathe

[1] Hongsheng Hu, [1] Juan Wang, [2] Zhengqi Lin
[1] Jiaxing University, No. 56, Yuexiu Road (South), Jiaxing City, Zhejiang, 314001, China
[2] Pinghu Electronic Co. Ltd., Huanggu Town, Pinghu City, Zhejiang, 314203, China
Tel.: +86 57383643091, fax: +86 57383643091
[1] E-mail: hhs999@mail.zjxu.edu.cn

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Abstract: In this paper, its theory design, analysis and test system of semi-active vibration controlling system used for precision machine have been done. Firstly, lathe bed and spindle entity were modeled by using UG software; Then modes of the machine bed and the key components of spindle were obtained by using ANSYS software; Finally, harmonic response analysis of lathe spindle under complex load was acquired, which provided a basis of MR damper's structure optimization design for a certain type of precision machine. In order to prove its effectives, a prototype semi-active vibration controlling lathe with MR damper was developed. Tests have been done, and comparison results between passive vibration isolation equipment and semi-active vibration controlling equipment proved its good performances of MR damper. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Lathe, Semi-active vibration control, MR damper.

1. Introduction

Shock and vibration often result in instantaneous transcendental damage and fatigue failure of structure, performance failure of instrument, overall performance drop of structure and poor dynamic characteristics of equipment [1-3].

In recent years, with the rapid development of science and technology, its vibration of precision lathe has been paid more attention [4-7]. Compared with other mechanisms used in damper and actuators for smart structures, the MR material could produce a much greater yield stress. Shock absorbers, vibration dampers and prosthetic devices are the examples of exciting applications of the MR material concerning semi-active control of vibrations or torque transfer.

2. Finite Element Model of Lathe

In this paper, ML360 MANIX micro-precision cutting-milling complex lathes was choose as the object in order to establish three-dimensional solid mode and analyze its dynamic characteristics. Fig. 1 shows its structure of this type of lathe.

Fig. 1. MANIX ML360 micro-precision lathe.

MANIX ML360 micro precision cutting-milling machine was modeled in UG environment (Fig. 2).

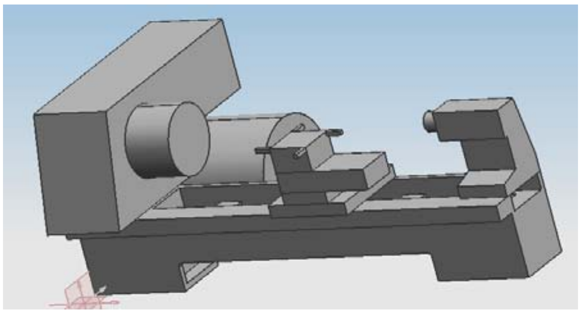


Fig. 2. UG machine solid modeling.

The spindle is an important component of lathe. During machining process, its dynamic performance has a greatly impact on the workpiece's machining accuracy, surface roughness and the effect of production.

In order to ensure the high-precision of machined parts, the spindle system has to have good dynamic characteristics. Therefore, it is of important significance to research the dynamics of the spindle system.

The Micro Precision MANIX ML360 cutting-milling machine spindle is made of 45 steel, with elastic modulus EX of 2.06 × 1011Pa, the Poisson ratio PRXY of 0.3, and the density of 7800 kg/m^3. In its assembly of spindle, the ball bearings have been used. The former branch of spindle uses taper spindle support dual cylindrical roller bearings to withstand the radial force, improving the radial stiffness of lathe spindle and its rotation accuracy. The angular contact ball bearings mounted back was to bear axial force, reducing the spindle axial run out and improving the axial stiffness; taper cylindrical roller bearings of the latter bearing play a vital role in the radial support. In vibration mode analysis, combine 14 spring-damper unit in the analysis was choose in order to achieves the desired effect, and it could be found that the spindle boundary simulations is very consistent with the actual spindle through a bearing mounted on the supporting. In order to ensure the machining accuracy and safety of spindle work, the maximum speed can not exceed 75 % of its first critical speed.

3. Dynamic Response of Lathe

Its aims of analyzing the response characteristics of the spindle system are to calculate displacement and stress of the spindle system under excitation and to obtain the dynamic response of the system and its amplitude-frequency curve.

Cutting force, as an excitation force with the exciting force of 600 N, load in the UX direction, of which the frequency ranges from 10 to 240 Hz. Taking The former anchor (l μx), intermediate point (2 μx) and rear support points (3 μx) and using the results of modal analysis to analyze it by the modal superposition method. We can see the results in Fig. 3, Fig. 4 and Fig. 5.

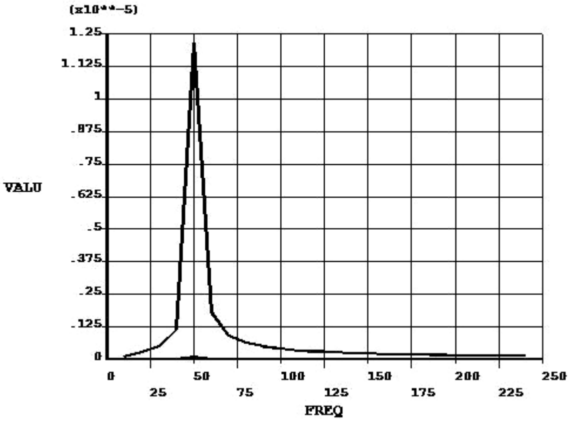


Fig. 3. Amplitude-frequency diagram of the spindle former anchor.

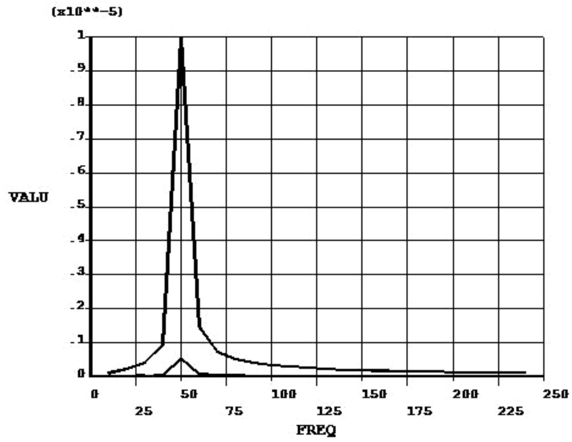


Fig. 4. Amplitude-frequency diagram of the spindle central support points.

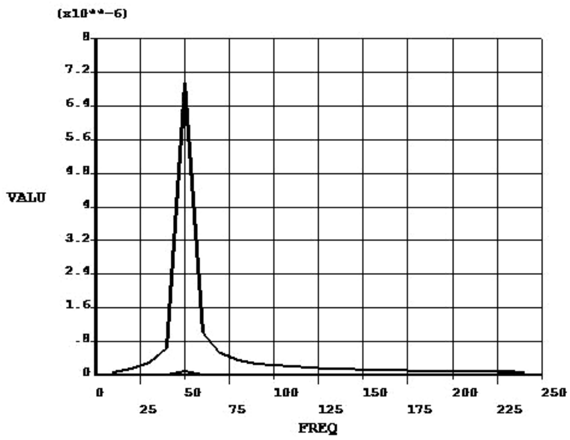


Fig. 5. Amplitude-frequency diagram of the spindle rear support points.

Through the spindle harmonic response analysis of the amplitude-frequency diagram it could be seen: the front support points, central and rear support points are in the resonance. The maximum displacement is 0.01 μm, 0.52 μm, 0.08 μm corresponding to the minimum dynamic stiffness of the spindle 60000 N/μm, 1154 N/μm, 7500 N/μm.

The main measures of improving the dynamic characteristics of the spindle are to improve the bearing stiffness and damping of the spindle assembly [8]. The bending vibration and rocking of the spindle system performance are particularly evident in the front of the spindle. Therefore, the bearing stiffness and damping of the former anchor play a decisive impact on the vibration of the spindle system.

The former anchor includes the front bearings, spindle boxes and other related parts. And the vibration of the front bearing causes the former anchor to vibrate. Thus, increasing the stiffness of the front bearing is conducive to improve the stiffness and natural frequency of the spindle so as to avoid the resonance phenomenon in the high speed range and then improve the dynamic characteristics of the spindle.

The machine performance parameters: elastic modulus of 172×1011 Pa, Poisson's ratio of 0.3, and density of 7800 kg/m^2. Modal analysis includes only linear behavior analysis, so the linear unit must be defined. The unit is Soiled 45, and it is used for three-dimensional solid structure model. The unit has eight nodes, each node has three freedoms in X-Y-Z directions.

The unit has many characteristics such as plasticity, creep, swelling, stress stiffening, large deformation and large strain. It can absorb irregularly shaped cells and no loss of accuracy, there may be side by side displacement shape and mold plow for curved boundaries are well suited to the situation meshing machine mode. Through dynamic simulation it can be intuitive to understand the machine vibration in Fig. 6 and Fig. 7.

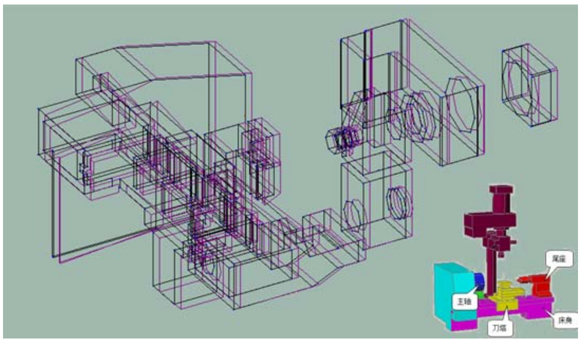


Fig. 6. Vibration graphics of machine in three-dimensional directions.

In order to isolate the external signal source, suspension method can apply to the vibration of lathes. As the lathe is a whole, it is realistic to use a single rope to suspend on it. Therefore, it is applied into the placing platform of lathes to suspend on it. The platform uses a steel plate with 120 mm length, 50 mm width and 8 mm thickness, which is suspended on by the rope. It could be made to reach a level by a level.

The small ultra precision lathe is arranged on the platform at the top, and then we use the level to make a correction again to ensure the machine in a level state with the distributed strain sensing system, we can find the feature points of the spindle, guide rail, spindle box and knife tower location. Then, these feature points are placed on the acceleration sensor. The sensor is connected to the charge amplifier, and then input to the multi-channel signal sampling system.

Fig. 8 shows the constructed platform for the analysis of lathe modal. In order to make the experimental structure reliable, a complete experimental system is also constructed. Sine signal of different frequencies and amplitudes which could be controlled is from the signal generator. After the signal goes through the power amplifier and input to the small vibration, vibration exciter generates the corresponding frequency to make the small ultra precision machine vibrate. Then through the acceleration sensor, we need to make a collection and preservation of the vibration signal to acquire the frequency response data and spectral data of the vibration signal. Test data analysis is to get various parameters affecting the performance of anti vibration of lathes, including the natural frequency, damping ratio, mode of vibration, dynamic stiffness, vibration response.

The analysis method can apply special analysis software, such as MEScope, Dasp etc. We can also use MATLAB, Origin, Excel general test data analysis software. After importing the 3D lathe model and obtain frequency response data, with the Fourier transform of the data, we can make a dynamic simulation of lathe vibration to obtain the natural frequencies, damping ratio, mode of vibration parameters.

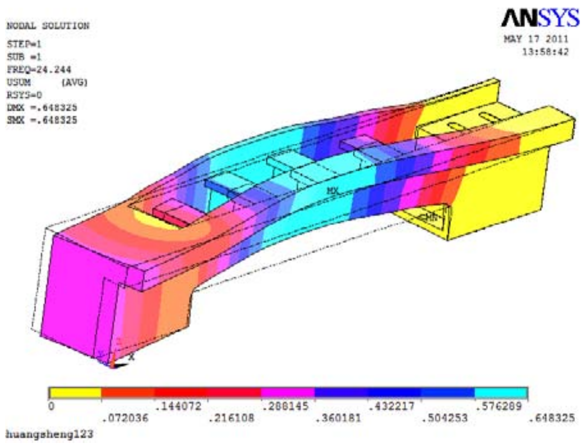


Fig. 7. Vibration mode diagram of the machine bed.

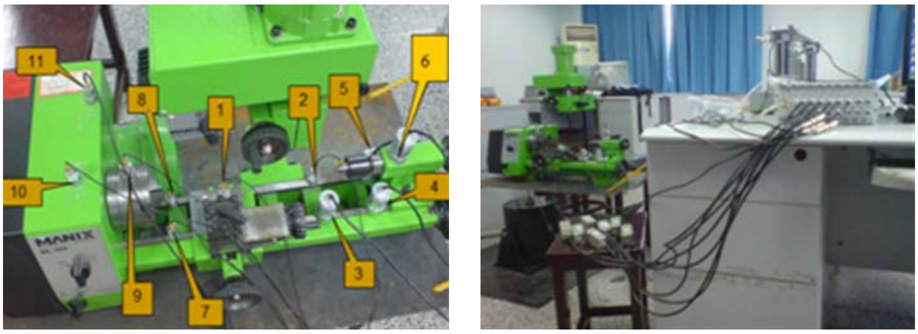


Fig. 8. Dynamic test.

4. Design of Semi-Active Vibration Controlling System

4.1. Overall System Design

To design the machine semi-active damping system with MR damper and to determine the parameters of the main components from mechanics, electronics, electromagnetic, automatic control and other subjects; Using UG software to establish the entity model of the magneto rheological damper and ANSYS software to analysis the electromagnetic field of the magneto rheological damper, and then modifying the critical dimensions of the damper based on the simulation results in order to optimize the structure of magneto rheological damper.

The research group designed the semi-active damping device used on machine based on semi-active magneto rheological damper. It includes a base plate 1 and a vibration isolation platform 9; four sets of sleeve are fixed on four corners between base plate 1 and vibration isolation platform 9, each sleeve contains an upper sleeve 6 and a lower sleeve 2, the supine surface of the upper sleeve 6 is bolted with the vibration isolation platform 9, the lower surface of lower sleeve 2 is bolted with base plate 1 , the lower cylindrical wall of the sleeve 2 is provided with steps; linear bearing 4 is mounted between sleeve 6 and sleeve 2, the horizontal directions of the upper sleeve and lower sleeve are positioned by bearing 4 and it is fixed on the step, then making vertical position. Magneto rheological damper 3 are installed in the sleeves, outside the MR damper 3 is spring 5, the lower end of the spring 5 is fixed end, it is welded to the inner bottom surface 2, the upper end of the spring 5 is a free end for easy disassembly. The base 1 and the inner surface of the vibration isolation platform 9 are mounted with the pick-up sensor 8. Piston rod through the upper sleeve 6 and vibration isolation platform 9, tighten the fixing nut 7. The precision machine semi-active damping system schematic is shown in Fig. 9.

From Fig. 9, the machine bed semi-active damping system also includes a control system which is connected one by one with a signal conditioning, a signal acquisition, a ARM controller and a current controller; the other side of the signal conditioner is connected with a pick-up sensor; the other side of the current controller is connected to the MR Damper.

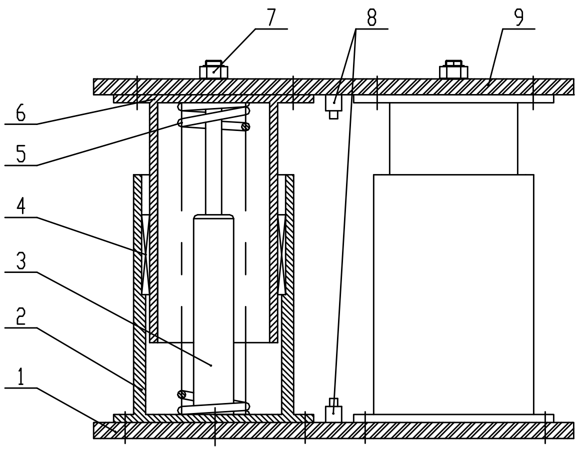


Fig. 9. Principle structure of semi-active damping device for lathe.

In order to develop a set of multi-functional online integrated research platform based on the need of the project research, which completed the design of auxiliary, algorithm simulation, controller management, hardware online real-time simulation function, promote technological upgrading machine semi-active vibration control system research and development products and continuous innovation, MR damper integrated research platform is based on the requirements of design. MR damper intelligent integrated research platform mainly consists of three parts: 1) suspension simulation test device; 2) the MR damper control system; 3) MR damper integrated research system. The block diagram is shown in Fig. 10.

From Fig. 10, vibration signal waveforms: sine wave, triangle wave, triangular wave, random wave, and external input waveform, and so on. Control methods including force and displacement closed-loop control circuit which can realize the full digital PIDF control, the control mode can switch smoothly. Machine semi-active vibration control system integrated test platform can be realized on the lathe semi-active vibration control system test with the comprehensive performance of various test and fatigue durability of magnetorheological damper, including shock absorber on a variety of specifications for performance testing; Sensor including the displacement, force, velocity, acceleration sensor and collecting various information sources; Vibration source Simulating the external disturbance input as the incentive for lathe bed; Signal generation and control device used to produce a variety of analog excitation signal, amplifies transmitted to the excitation source, sensor signal collection, interaction and management of computer. Construction of the 1/4 semi-suspension physical simulation test platform for technical indexes: the maximum static test force: ±20 KN, indicating accuracy of ± 1 %, precision range 2 %–100 % FS; the maximum dynamic test force: +20 KN, dynamic fluctuation degree ≤±1%; actuator displacement: ±100 mm, indicating accuracy of ±0.5 % FS; with the servo valve flow: 160 L/min; start friction ≤0.05 MPa; effective output ≥0.98; differential transformer measurement (LVDT) using a high precision displacement sensor Liaoning Fuxin production; load sensor spoke type force sensor level 0.03; actuator support: ±20 KN support, adjust the locking device.

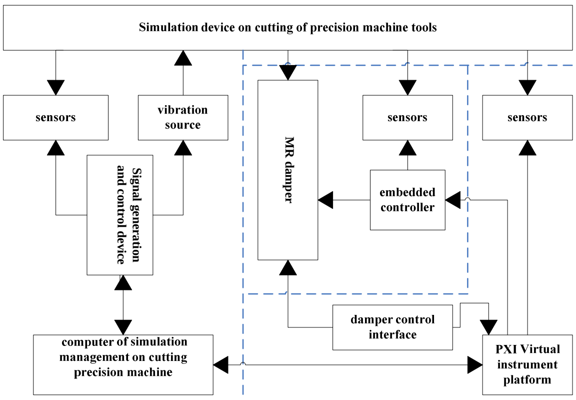
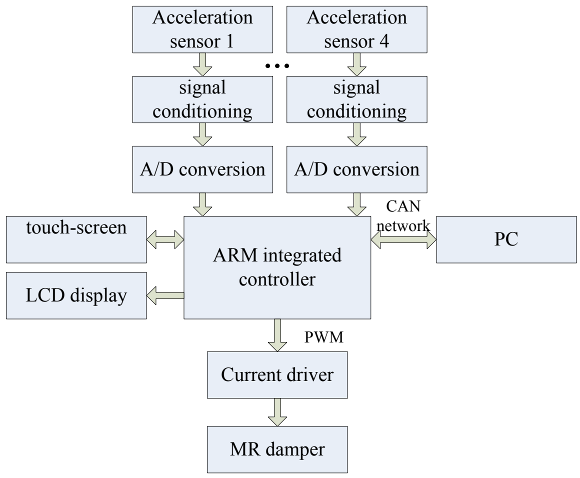


Fig. 10. Integrated test platform.

4.2. Measuring-Controlling System Design

In the design of semi-active vibration-reducing system for lathe, the wireless sensor network node is the kernel of its design. The nodes of wireless sensor network are a micro embedded system with information processing and communication ability [9-10]. In this system, the modular design is used for the node. Each node uses the same core module, different nodes with different expansion modules. As shown in Fig. 11, nodes based on MC13213 wireless micro processing module as the core, extending the wireless transmission unit (integrated power enhancements), serial communication interface, sensor interface, digital output interface and power supply interface, which constitute the core board. MC13213 wireless microprocessor module cut out parts of the circuit which is used to expand and test in the general RF module, working in the 2.4 GHz band, so it can realize the wireless system with simple scheme.

The core boards with a variety of sensors constitute sensor nodes and with control board constitute controller node. The sensor select common sensor and integrated sensor of velocity and acceleration, the data acquired will be transmitted to the Multi sensor signal conditioning unit on core board by current signal. In practical application, the controller node can also equipped with sensors which have sensor nodes function; in special circumstances, taking into account the need for energy of sensor node, if the sensor node is far from the base station, the controller node acts as a router, so the corresponding sensor node and controller node communication nearby, the controller node (router) exchange information with the base station.



(a)

(b)

Fig. 11. Principle and physical of Measuring-controlling system for lathe.

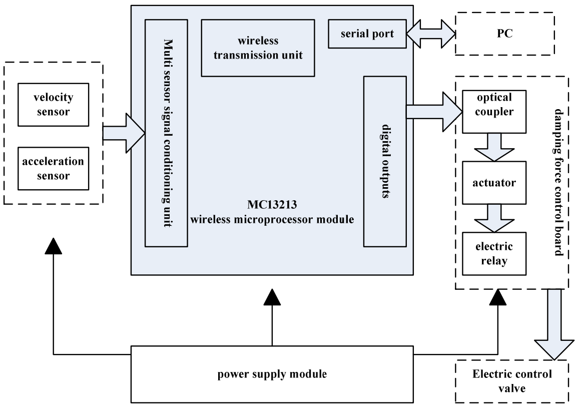


Fig. 12. Schematic diagram of wireless sensor network.

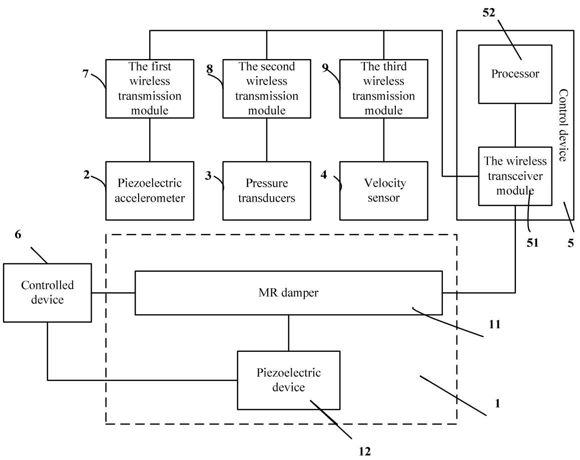


Fig. 13. Self-sensing, self-powered principle diagram of MR damper.

The research group designs a self-powered MR damper control system based on the wireless module design, the control system includes a self-powered MR damper, control devices, piezoelectric acceleration sensor, pressure sensor and speed sensor, the self-power MR damper comprises a magneto rheological damper and piezoelectric device, the piezoelectric device connected the controlled object with the MR damper and change the controlled object the vibration energy of the controlled object to electrical energy, the piezoelectric acceleration sensor has a first wireless transmission module and connected to the piston coil of the MR damper, the pressure sensor has a second wireless transmission module and connected to the piston rod of the MR damper, the speed sensor has a third wireless transmission module and connected to the piston rod of the MR damper, the control device comprises a wireless transceiver module and the signal processor, the wireless transceiver module receives signals from the first wireless transmission module, the second wireless transmitting module and the third transmission module, the processor generate a control signal according to the preset strategy to deal with the signal storage, the wireless transceiver module transmits the control signal to MR damper, schematic diagram shown in Fig. 12 and Fig. 13.

In common with most engineering research, lathe semi active vibration control system research not only studied to the simple, effective and stability control strategy in depth, but also the feasibility study of the project concerned with practical. For the mainly purpose of integrated test platform development tool of semi active vibration control system is carries on the experimental research on the control method, the proposed measure and control effect, then verification and comparison, theoretical simulation of control methods, accurately and reliably found problems in process control, amend and improve on it, in order to lay a reliable basis for the practical study of the next step of the project. The research of MR intelligent damper based on embedded system demand for new need with design validation, verification and testing of the products, so the development platform of corresponding integrated research is crucial. The development of machine semi-active vibration control system integrated research platform should include design aided algorithm, fast test development tools, strong communication ability, can carry out proper regulation, which is applicable to the entire product development process. The rapid development and effective inspection products need high throughput test. The virtual instrument technology integrate commercial off the shelf technology with the software and hardware platform of innovation, which provides a unique solution for embedded design, industrial control and testing and measuring.

4.3. Analysis of Testing Results

In order to prove its correctness, three passive vibration controlling equipments, including JG type rubber vibration bonds with metal and rubber, SD shear vibration isolator and AGS-53A spring damping vibration isolator, a semi-active vibration controlling equipment, are respectively tested in this platform.

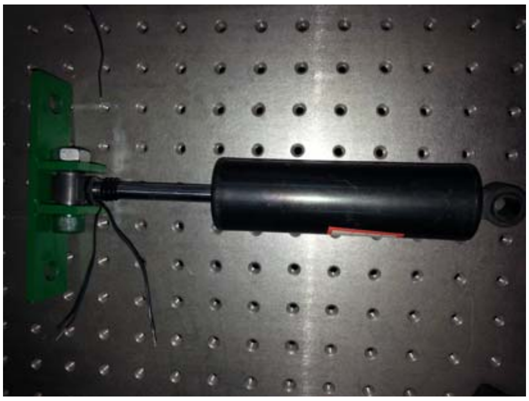
JG type rubber vibration bonds with metal and rubber (Fig. 14) and its elastomer uses axial symmetric cyclic shear type structure. What's more, its structure is compact so that its size is smaller than the damper of similar specifications. Moreover, it has the characteristics of convenient installation and replacement, maintaining the normal work in the range of -150 ^{0}C ~ +800 ^{0}C and having a good effect on vibration isolation for the isolation of about 1000 r/min.

Our research groups selects the type AGS-53A spring damper and SAGS-53A type spring-damper of Qingdao Aiborui Company and makes the same test on the two kinds of vibration absorber, Fig.15 for the test results. These two kinds of shock absorber have differences only in the appearance. AGS 53A type damper is marked with scales and another without, it is similar to the both damping effect. From the figure, as we can obtain the amplitude of these two shock absorber is about 8 MV, compared with a rubber shock absorber, the damping effect is greatly improved. Because of the shock absorber damping material, the impact resistance ability is improved. Because the main material of the two types of shock absorber is metal spring, which has better vibration absorbing capacity than other materials, compared with the other damper of different material, the spring-damper has better damping capacity and shock resistance.

JG rubber damper

SD shear vibration isolator

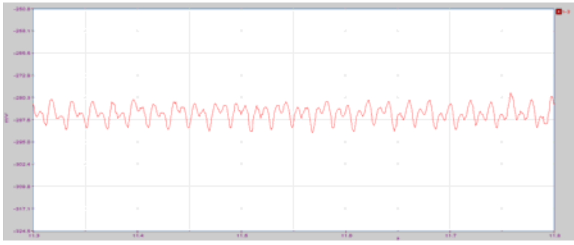
AGS-53A spring damping vibration isolator



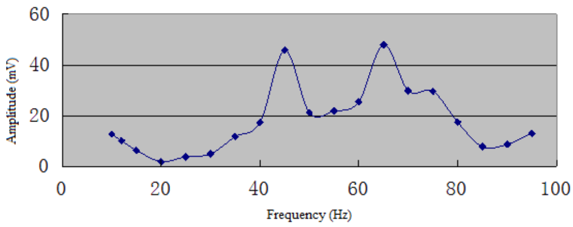
MR damper for lathe

Fig. 14. Vibration controlling equipments.

On the basis of the data, the shock absorber can greatly improve the working environment of lathes and effects of different shock absorber damping are different. Compared with other shock absorber, the shock absorber of Qingdao Aiborui Company has small amplitude. Only from the viewpoint of vibration isolation, the increase of damping will reduce the vibration isolation effect. But in the actual working process of the machine, the external incentive, which in addition to harmonic signal may also contain some irregular impact, will cause free vibration of the equipment with the larger amplitude. The purpose is to make the free vibration quickly disappear by increasing the damping. It is more important for the damping that especially when the isolation object is at the start and stop to go through the resonance region. In terms of the test group, the spring – damper is able to fight well against the shock from the environment and do well on the vibration isolation of machine. Besides, vibration isolation effect of the absorber is better than others. Therefore, production of AGS-53A type and SAGS-53A type spring – damper of Qingdao Aiborui Company relative to other damper used in the experimental group, the most appropriate use is in small lathes used in the experiment.



Testing results of AGS-53A absorber vibration isolation



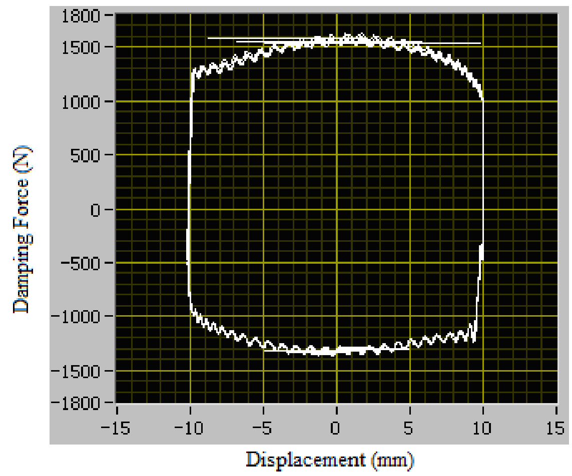
Amplitude diagram of JG type rubber

Fig. 15. Testing results of passive equipments.

According to the testing results Fig. 15 shows, when the frequency is 45 Hz, 65 Hz, 75 Hz, vibration amplitude is maximum, respectively 47.77 mV, 57.89 mV and 62.81 mV. Under the three vibration frequency, vibration isolation efficiency is all above 0.8 in basic, so damping effect of the absorber is best in the frequency according to results from Fig.15, when the vibration frequency within 65 Hz to 90 Hz, the isolation efficiency is over 0.8. Therefore, it can be considered that the working frequency of the absorber is within 60 Hz to 90 Hz

According to the test conditions, the simple harmonic vibration, amplitude is 10 mm, the highest speed is 0.3 m/s, the current value of 0.0, 0.2, 0.4, 0.6, 0.8, 1, 1.2 A, 1.4 A case records dynamometer, test results have been done.

Fig. 16 shows the power curve, in which horizontal coordinates express activities of MR damping displacement relative to the equilibrium point, unit is mm, longitudinal coordinates express damping force of MR damper, unit is cattle, in the indicator curve of MR damper, the upper half part express the change of the compression damping force, the lower half part express the change of recovery damping force, surrounded by the indicator diagram area represents a running MR damper vibration system a week consumed energy.



Temperature =20°C, maximum speed =0.1 m/s, excitation current =1.4 A

Fig. 16. Testing results of MR equipment.

5. Conclusions

In this paper, test of MR damper for lathe's vibration control problem were investigated and several conclusions were achieved. Compared to existing machine passive vibration control technology, the semi-active vibration control system the research group proposed has the following advantages:

1) Using a nested form, so that the entire device is divided into upper and lower parts and the structure is simple and easy to dismantle.

2) Upper sleeve and lower sleeve using nested forms and linear bearings, so that the entire device is limited up and down movement in order to prevent swaying, greatly improving the stability of the device;

3) MR Damper is step-less adjustable for damping force, so it has a large deformation, fast response, wide control range, and the effect is obvious, etc;

4) Using a pick-up sensors and the control system has a real-time adjustment on input current of the MR damper; the system also has a feedback control and it controls the vibration of the machine in different states to its optimal condition.

Acknowledgements

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