Research on Teaching Reform of Experimental Measurement of Temperature Field and Thermal Deformation of Machine tool

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Abstract: With innovation and reform proposal of intelligent manufacturing 2025 in China, the precision of machine tool is required to be higher in the field of intelligent manufacturing, and the thermal deformation of machine tools is one of the main factors affecting machining accuracy. The measurement of temperature field and thermal deformation of machine tool has become one of the most important contents in undergraduate teaching experiments in many colleges and universities. In view of the shortcomings of the traditional teaching of the experiment, which only uses some instruments for finite point measurement, an experimental teaching scheme is supplemented by vibration for full-state testing, along with a new testing technology is proposed in this paper. All of them are expected to enrich testing means, expand the students' horizons, improve students' ability of testing, data processing and analysis, increase students' interest in learning, and enhance students' comprehensive design ability of machine tool fixture. The practice shows that the experimental teaching plays a positive role in cultivating students' knowledge mastery ability and using theoretical knowledge to solve problems, thus greatly improve the teaching effect.

1. Introduction
The measurement of temperature field and thermal deformation of machine tool is one of the very important contents in undergraduate teaching course experiment. Today, with the rapid development of manufacturing industry in the world and intelligent manufacturing 2025 in China, intelligent manufacturing requires higher and higher accuracy of machine tools. At the same time, in the era of intelligent manufacturing, the role of machine tools in manufacturing is also very important [1]. With the high-speed and ultra-high speed operation of machine tools, the problem of thermal deformation of machine tools is becoming more and more serious, which seriously affects the accuracy of machine tools [2]. At the same time, people increasingly agree with the view that machining precision often depends on the size of structural thermal deformation, and higher than the dynamic stiffness [3]. Even some German machine tool experts believe that reducing the thermal deformation of machine tools is the theme of future research work. According to the analysis, in the manufacturing error of modern machined parts, the error caused by thermal deformation of machine tool is sometimes up to 50%, and the proportion will reach 40% to 70% in precision machining [4]. Therefore, for the study of the temperature deformation of the machine tool, the temperature field distribution of the machine tool and the dynamic characteristic analysis based on the temperature field are established. The purpose of which is to calculate the machine tool deformation and the changes of various parameters caused by the change of temperature in the machining process, so as to determine the error, provide parameters
for other methods to eliminate deformation, such as subsequent machining compensation, and finally improve the machining accuracy of the machine tool [5]. Undergraduate stage is an important stage of professional personnel training, in this stage, effective experimental design training and ability training is of great important.

2. The reasons, influences and test of thermal deformation

During the operation of the machine tool, the heat will cause the temperature rise of the machine tool, and the distribution of each heat source is uneven, which leads to the uneven temperature rise and thermal expansion of each part of the machine tool, and further causing the thermal deformation of the machine tool. Thus it can be seen that after the thermal deformation of the machine tool, the relative position of each part in the process system will also be changed. The correctness of its relative motion will be destroyed, furthermore, the precision grade that can be achieved by the machine tool itself will be reduced, and finally changed the size of the workpiece and affect the machining accuracy. Therefore, it cannot meet the technical requirements. The main effects of thermal deformation of machine tools are as follows [6]:

- Due to the uneven distribution of heat sources and the heat generated by each part of the machine tool, the temperature rise and thermal expansion of each part of the machine tool are uneven, which changes the relative position of each moving part and affects the machining accuracy.
- Due to the change of the clearance of the sliding surface, the bearing capacity of the oil film is reduced, and the working conditions of the machine tool will deteriorate.
- Because the workpiece heats up and is different from the temperature of the measuring tool, this will affect the measurement accuracy.

The influence of thermal deformation on automatic machine tools, automatic lines and high-precision machine tools is more serious. Among them, the thermal deformation of the machine tool will also have an impact on the geometric accuracy and positioning accuracy of the machine tool [7]. Its influence degree will often exceed several times of the specified tolerance, so that the workpiece cannot meet its technical requirements, affect the use of the workpiece or directly lead to the scrapping of the workpiece.

The influence of thermal deformation on the workpiece is reflected in the following three aspects:

- During the working process of the linear displacement change machine tool, after the heat generated by gear friction and bearing, the spindle parts of the machine tool move in different directions, thus destroying the initial installation and debugging accuracy of the machine tool. It also causes changes in different positions on the worktable.
- The thermal deformation in working process of the machine tool causes the change of spindle angle position of the machine tool or the angular displacement of the worktable relative to the spindle axis, resulting in the change of the parallelism or verticality of the spindle axis relative to the worktable and causes the machined surface to be not parallel or vertical to the base.
- The change of parts straightness causes the moving plane bending or the guide rail bending, which leads to the straightness error when the moving parts move. For example, the deformation of machine tools such as guideway grinder and gantry planer is mainly on the guideway, which has a great influence on the accuracy of the workpiece.

At present, the laboratory mainly through the lathe thermal deformation and temperature field test to determine the spindle centre line in the space displacement change, the reasons can be summarized as follows: Firstly, the calorific value of the bearing before and after the spindle is different, and the thermal expansion of the front box wall is larger than that of the rear end wall, which makes the centre line of the spindle in the vertical plane, at the same time, the vertical positioning surface of the spindle box is inclined to rise upward on the basis of the vertical positioning surface of the spindle box. In the horizontal plane, the spindle box is offset forward on the basis of the lateral positioning surface of the spindle box. Secondly, the lubricating oil in the spindle box absorbs the friction heat during the operation of the transmission parts, and after splashing and stirring, it forms a heat source, which is transmitted to bed through bottom of the box, and the bed is deformed after being heated. This will
change the position of the vertical and lateral positioning base of the spindle box in the vertical direction of the bed body.

Therefore, in modern mechanical design and advanced manufacturing technology, especially in the process of high speed and high precision machining, in order to ensure the precision of the machined parts, corresponding measures must be taken to reduce the influence of thermal deformation on machine tools, so the machining accuracy is improved. In this process, the measurement of temperature field and thermal deformation of machine tool is the key to analyze the thermal characteristics of machine tool.

3. Thinking of experimental teaching and design of teaching content

The experimental link inspires students to apply theory to practice, and at the same time, to deepen the understanding and mastery of theoretical knowledge through practical operation, which is a positive cycle of mutual promotion and mutual promotion process. The effect of experimental teaching will directly affect the cultivation of students' ability to solve practical problems by using basic theoretical knowledge [8]. Therefore, how to set up the relevant experiments reasonably, so that the students can understand the thermal characteristics of the machine tool through experimental testing and analysis, master the relevant testing techniques and analysis the measures to reduce the thermal deformation of machine tools, which is directly helpful to the cultivation of students' innovative ability and theoretical analysis ability, and meets the needs of the goal of personnel training in schools.

In order to meet the needs of training talents for engineering application-oriented undergraduates and outstanding engineer training programme [9], according to the requirements of basic courses, basic and practical experiments and modern testing techniques are combined for the purpose of improving the machining accuracy of machine tools. The goal of improving students' thinking and analysis ability was set to cultivate students' engineering consciousness and innovative spirit, and to design scientific and reasonable experiments for measuring temperature field and thermal deformation of machine tools.

Through a series of experimental training and the analysis and processing of experimental data, students' ability to analyze and solve problems can be gradually improved, and a number of pragmatic and innovative students that has the ability to analyze and solve problems of high-quality engineering application-oriented and outstanding talents can be trained for the school in future.

From the point of view of cultivating and training students' innovative level, it is necessary to strengthen students' ability of organic combination of theory and practice and develop students' problem-solving thinking. This paper is carried out from the following aspects:

- Through literature search and data review, the common methods and corresponding measures to reduce the thermal deformation of machine tools are analyzed. The workpiece heats up different from the temperature of the measuring tool will affect the measurement accuracy.
- The test methods of temperature field and thermal deformation of machine tool are studied, including temperature, vibration and displacement.
- The thermal characteristics of the machine tool are analyzed, and the influence of each heat source on the machining accuracy is studied.
- The influence of each heat source on the machining accuracy is analyzed by analyzing the changes of machine tool feed and machining parameters.
- Finally, the corresponding experimental instructions are compiled.

By setting up the comprehensive experiment, the advanced temperature field and thermal deformation testing technology of machine tool can be introduced into practical teaching, and the combination of scientific research experiment and teaching experiment can be used by students. At the same time, it can greatly stimulate students' interest in learning and innovative ability.

In machining, the machining accuracy is determined by the correct position between the tool and the workpiece on the machine tool. During the operation of the machine tool, due to the action of the internal and external heat sources of the machine tool, the heat is generated and transmitted to the machine tool, resulting in a change in temperature in each part, and a certain thermal deformation is
caused by the change in temperature. Finally, the relative position of the tool and the workpiece is changed, which leads to the thermal error and the decrease of the machining accuracy of the machine tool. The relationship between the thermal dynamic process of the machine tool and the experimental test scheme is shown in Figure 1.

![Diagram of relationship between thermal dynamic and experimental test of machine tool](image)

**Figure 1.** Diagram of relationship between thermal dynamic and experimental test of machine tool.

This experiment mainly completes the measurement of the temperature field and thermal deformation of the machine tool, so that the students can master the relevant testing technology and data analysis ability, so it is necessary to design a reasonable test scheme for temperature, displacement and vibration to fully mobilize the thinking ability of students [10]. Through the analysis of the experimental data, the common methods and corresponding measures to reduce the thermal deformation of the machine tool are analysed. In addition, the influence of each heat source on the machining accuracy is also studied, at the same time, the feed and machining parameters of the machine tool can be changed, and it is help to study the influence of each heat source on the machining accuracy. Through this experiment, it not only strengthens the students' practical ability, but mobilizes the students' thinking and research ability.

### 4. Design of experiment implementation scheme

After the temperature rise of the lathe, the position of the center line of the spindle changes in space, and the vibration will occur during operation [11]. With the increase of offset, the vibration is more intense. In order to measure the offset of the center line of the spindle, the temperature field and thermal deformation of the traditional machine tool are basically tested by a single test rod supplemented by a micrometer. In order to fully mobilize the students' thinking ability and innovative design ability, this paper will be supplemented by the cross-checking scheme of vibration or displacement test:

- Selecting the paraxial point and the distal axial point on the test rod, so as to determine the offset of the center line of the spindle in its vertical plane.
- Install the vibration acceleration sensor on the horizontal and vertical position of the spindle chuck, the bearing seat of the spindle tail and the vertical position of the tail seat.
- The front and rear bearings of the main shaft, friction clutch, oil pump, oil pool, large gear sleeve, brake wheel and so on are arranged with temperature sensors.

The position of the micrometer and location of some vibration sensors are shown in figure 2.
The specific implementation steps of the experiment are as follows: Firstly, it is need to clean the inspection rod and the spindle cone hole, insert the inspection rod into the cone hole, and mark the original spindle position. Secondly, the magnetic micrometer seat should be fixed on the machine tool slide board and the micrometer is also need to installed in the horizontal and vertical positions, respectively. Thirdly, it is important to move the slide to the measuring position (near the axis point and the far axis point) the micrometer contact should be close to the inspection rod ‘a’, ‘c’ point, aim the watch needle at the ‘zero’, and then move the slide board, move the micrometer to the other end to measure ‘b’, ‘d’ points, and write down the reading and move the skateboard; Then, we need to install the vibration acceleration sensor on the horizontal and vertical position ‘e’ and ‘f’ of the spindle chuck, the vertical position ‘g’ of the tail seat and the bearing seat at the end of the spindle, at the same time, record the vibration data under each temperature test during operation. Fifthly, we can record the room temperature, open the spindle box cover, and use a point thermometer to measure the initial temperature of each heat source (spindle front and rear bearing, friction clutch, oil pump, oil pool, gear sleeve, brake wheel, etc.). Then the surface height of the oil pool is measured, and the data were recorded. Finally, the spindle needs to keeps the maximum speed empty and opens the cover every other 10 minutes. The temperature of each heat source is measured (the order of each measurement is consistent with the position of the measurement), and the measurement results are recorded in the result recording table.

5. Experimental effect
After the implementation of the teaching reform of the experimental teaching strategy of measuring tool testing based on micrometer and vibration testing based on vibration acceleration sensor, some of the experimental tests are shown in figure 3.
The implementation of the experiment enables students to not only master the simple measuring tool test data analysis, but also apply the professional knowledge of vibration testing learned in the theory classroom to the practical experiment, and learn the methods of vibration data processing and analysis. Furthermore, it improves the practical ability of students to make use of knowledge and gets the sublimation of quality.

6. Conclusion
The vibration testing technology is introduced into the undergraduate experimental teaching of machine tool temperature field and thermal deformation, which makes up for the deficiency of simple test and analysis according to the instrument in the traditional experimental testing course, and promotes the students to carry on the design of sensor layout, enhance the students ability to process and analyse the vibration data. Through keeping pace with the times and advancing to the "golden lesson", we can further carry out in-depth practical teaching research and reform. At the same time, it stimulates students' interest in learning, arouses students' enthusiasm and initiative in learning, promotes students' cognition of new things, strengthens students' spirit of independent exploration, and improves teaching effect.

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References
[1] Wübbeke, J., Meissner, M., Zenglein, M. J., Ives, J., & Conrad, B. (2016) Made in China 2025: The making of a high-tech superpower and consequences for industrial countries. Mercator Institute for China Studies, 17: 2017-09.
[2] Mayr, J., Jedrzejewski, J., Uhlmann, E., Donmez, M. A., Knapp, W., Härtig, F., ... & Brecher, C. (2012) Thermal issues in machine tools. CIRP annals, 61(2): 771-791.
[3] Ramesh R., Mannan M. A., Poo A. N. (2000) Error compensation in machine tools—a review: Part II: thermal errors. International Journal of Machine Tools and Manufacture, 40(9): 1257-1284.
[4] Putz, M., Richter, C., Regel, J., & Bräunig, M. (2018) Industrial consideration of thermal issues in machine tools. Production Engineering, 12(6): 723-736.
[5] Xiang, S., Yao, X., Du, Z., & Yang, J. (2018) Dynamic linearization modeling approach for spindle thermal errors of machine tools. Mechatronics, 53: 215-228.
[6] Naumann A, Ruprecht D, Wensch J. (2018) Toward transient finite element simulation of thermal deformation of machine tools in real-time. Computational Mechanics, 62(5): 929-942.
[7] Ge Z, Ding X. (2018) Thermal error control method based on thermal deformation balance principle for the precision parts of machine tools. The International Journal of Advanced Manufacturing Technology, 97(1-4): 1253-1268.
[8] Jie F. (2008) The Problems and Countermeasures of Experimental Teaching in Innovation-Oriented Talents Training. Research and Exploration in Laboratory, 4: 23-25.
[9] Sun, Y., Jiang, G., Li, G. (2014) Application of modern simulation technology in a mechanical design course for outstanding engineers. World Trans Eng Technol Educ, 12(2): 203-208.
[10] Koenigsberger, F., & Tlusty, J. (2016) Machine tool structures. Elsevier, The Amsterdam.
[11] Yao, Q., Luo, M., Zhang, D., & Wu, B. (2018) Identification of cutting force coefficients in machining process considering cutter vibration. Mechanical Systems and Signal Processing, 103: 39-59.