Design and Finite Element Analysis of Ultrasonic Composite Abrasive Vibration Polishing Equipment

To cite this article: Hongqiang Wan *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **538** 012003

IOP Conf. Series: Materials Science and Engineering **538** (2019) 012003 doi:10.1088/1757-899X/538/1/012003

Design and Finite Element Analysis of Ultrasonic Composite Abrasive Vibration Polishing Equipment

Hongqiang Wan, Peiying Han, Quanli Han, Shuai Ge, Fancong Li

School of Mechanical Engineering, Xi'an Technology University, Xi'an, China

413162931@qq.com; 1003575444 @qq.com; hanqljx@163.com; 260686289@qq.com; sufeiling@qq.com

Abstract. In order to develop a workpiece surface polishing equipment with high performance and high precision, the overall structural design and parameter selection of ultrasonic composite abrasive vibration polishing equipment were mainly completed. Secondly, static analysis of the crankshaft connecting rod piston mechanism is performed by ANSYS Workbench software. We can know that the crankshaft connecting rod piston mechanism has the most concentrated stress at the contact between the small end of the connecting rod and the connecting rod shaft. And the stress value is 121.04MPa but less than the allowable stress value of the connecting rod. Therefore, the strength of the crankshaft connecting rod piston mechanism meets the design requirements, and the modal analysis of the crankshaft is carried out, and the crankshaft right crank displacement deformation amount is the most. It provides a theoretical basis for the optimization design of the crankshaft later and provides a reference for the research of ultrasonic composite abrasive vibration polishing equipment.

1. Introduction

With the development of modern science and technology, the demands on surface quality of the workpiece is much higher in areas such as aerospace, medical, and optical. In order to improve the quality and efficiency of machined surface polishing, it is necessary to design a workpiece surface polishing equipment.

According to experimental study，the workpiece surface quality after compound ultrasonic vibration polishing is better than the workpiece surface after a single compound ultrasonic vibration polishing. Therefore, scholars at home and abroad is dedicated to developing ultrasonic composite vibration polishing equipment[1-4]. For example, Suzuki H, and othershave[5] come up with a second - order longitudinal vibration and four - order bending vibration of composite ultrasonic polishing method allows the polished surface roughness of workpiece reaches 8nm. Han Lei[6] proposed ultrasonic vibration assisted polishing equipment, which can improve the workpiece surface while polishing workpiece strength.

This article proposes a ultrasonic composite abrasive vibration polishing equipment, which is a processing technology of compound surface which combines three kinds of methods together: ultrasonic vibration cutting, machining of mechanical vibration and free abrasive machining. For Static and modal analysis simulation of mechanical vibration unit is carried out by ANSYS Workbench to verify the security and stability of mechanical vibration unit when work.

IOP Conf. Series: Materials Science and Engineering **538** (2019) 012003 doi:10.1088/1757-899X/538/1/012003

2. Overall Structure and Main Design Parameters of Equipment

Ultrasonic composite abrasive vibration polishing equipment is developed combing ultrasonic vibration cutting, machining of mechanical vibration and free abrasive machining. Its main mode of operation is the High speed vertical reciprocating motion of fixture and For machining workpieces drove by longitudinal vibration Unit. At the same time, stirring shaft in polishing slot allows abrasive suspensions rotating to achieve workpiece processing. In the bottom of the polishing slot is equipped with ultrasonic generator to make polishing slurry portrait vibrate with High frequency, which realize the polishing on the surface of the workpiece combined with mechanical vibration and abrasive rotation.

Soildworks software is a subsidiary of Dassault Systemes S. A. We can use it to Create part models more quickly and assemble virtually[7-8]. As shown in figure 1 is the three-dimensional models modle of the Overall structure of ultrasonic composite abrasive vibration polishing equipment through Soildworks software.

Ultrasonic composite abrasive vibration polishing equipment is mainly constituded by mechanical vibration unit, Z-axis motion unit and abrasive box unit. The three - dimensional models are respectively shown in figure 2, figure 3 and figure 4.

(1) The operating principle of Z-axis motion unit is that the screw rotate through belt drive driven by motors to lead screw nut and screw nut along the screw pump.

(2) The operating principle of abrasive box unit is that wear particle mixing device rotates driven by motors to realize the polishing effect of free abrasive on workpiece surface and which can prevent free abrasive precipitating, ultrasonic oscillator posted on the department of abrasive bottom polish the workpiece surface via ultrasonic vibration.

(3) The operating principle of mechanical vibration unit is that the crankshaft rotate driven by motors and turn the turning of the crankshaft into the vertical movement of a fixture through the piston mechanism to achieve the vertical movement of the workpiece as shown in figure 4.

The main advantages of the device:

(1) It improves the quality and efficiency of machined surface polishing combing ultrasonic vibration cutting, machining of mechanical vibration and free abrasive machining

(2) It can realize the polishing effect of free abrasive on workpiece surface and it can prevent free abrasive precipitating in the meanwhile under the effect of abrasive mixing structure.

3. Finite-element Analysis of Mechanical Vibration Unit

3.1. Static Analysis of Mechanical Vibration Unit

ANSYS Workbench is of a wide used application of finite element analysis software, which can carry on static analysis, dynamic analysis and collision Analysis, and so on[9-10]. So it is very convenient to carry out static analysis on the crankshaft connecting rod piston mechanism in order to verify whether the strength of crankshaft connecting rod piston mechanism in ultrasonic composite abrasive vibration polishing equipment meets the design requirements. The following is the implementation process.

(1) Import model. Save the crankshaft connecting rod piston mechanism model drawn by Soildworks in the Parasoild format and import it into ANSYS Workbench for static analysis.

(2) Set the parameters of crankshaft. Select 45 steel as the material of crankshaft and its elastic modulus is 206GPa, its poisson ratio is 0.3, and its density is 7.85g/cm^3. Select straight carbon steel as the material of bolt and piston pin and its elastic modulus is 206GPa, its poisson ratio is 0.24, and its density is 7.3g/cm^3. Select cast iron as the material of piston and its elastic modulus is 126GPa, its poisson ratio is 0.24, and its density is 7.0g/cm^3.

(3) Meshing. Partite in the method of using hexahedral mesh. Set unit mesh size of the crankshaft, connecting rod and piston is 4mm, set unit mesh size of the plain bearings, bolts and piston pins is 4mm. The number of nodes after meshing is 182403, the number of units is 61643. Mesh diagram as shown in figure 5.

IOP Conf. Series: Materials Science and Engineering **538** (2019) 012003 doi:10.1088/1757-899X/538/1/012003

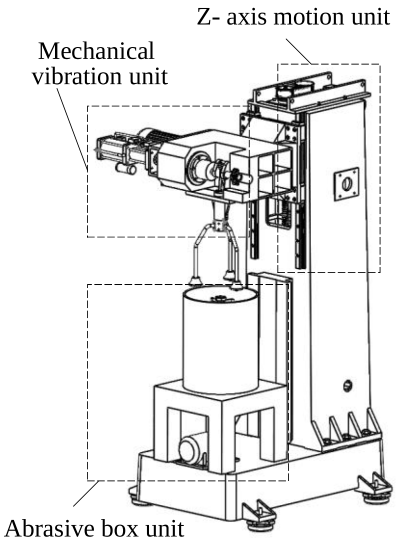


Figure 1. Overall structure of ultrasonic composite abrasive vibration polishing equipment.

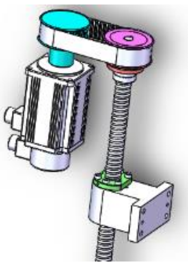


Figure 2. Abrasive box unit

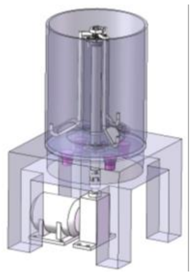


Figure 3. Z - axis motion unit.

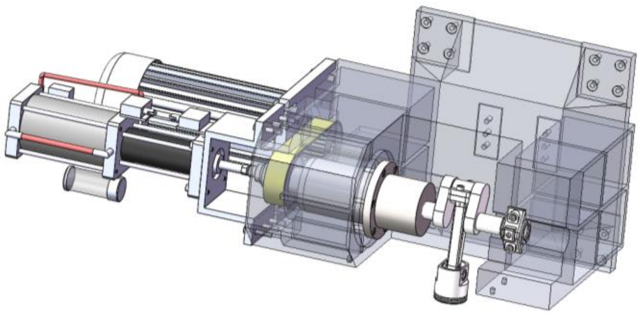


Figure 4. Mechanical vibration unit

Figure 5. Crankshaft connecting rod piston mechanism mesh map.

(4) Imposed loads and constraints. Set the pistons and bearing for all constraints and impose 15529N·mm by the right side of the crankshaft.

(5) View solution. Figure 6 is overall equivalent stress imagery of the crankshaft connecting rod piston mechanism. Figure 7 is the overall displacement image of crankshaft connecting rod. Figure 8 and figure 9 are respectively equivalent stress imagery of the crankshaft and connecting rod.

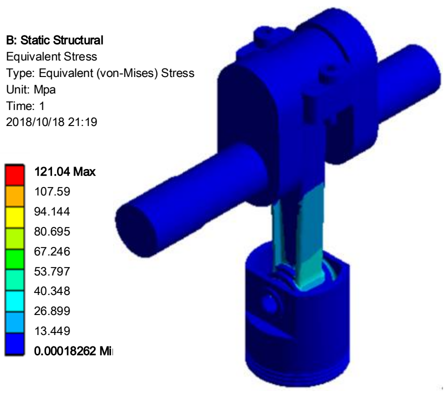


Figure 6. Overall equivalent stress imagery.

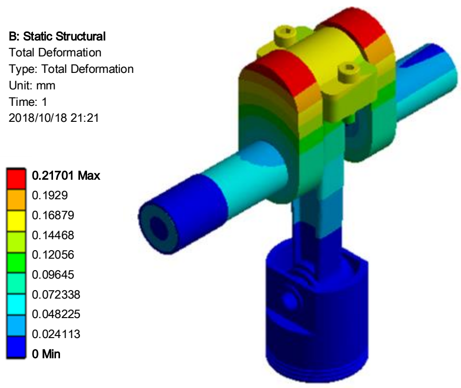


Figure 7. Overall displacement image.

IOP Conf. Series: Materials Science and Engineering **538** (2019) 012003 doi:10.1088/1757-899X/538/1/012003

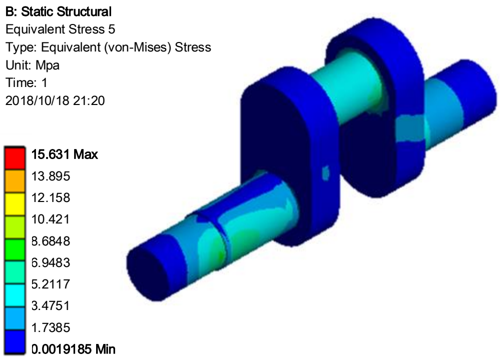


Figure 8. Equivalent stress imagery of the crankshaft.

Figure 9. Equivalent stress imagery of the connecting rod.

According to figure 3, the equivalent stress variation range in the crankshaft connecting rod piston mechanism is the most obvious, and according to figure 4, overall displacement is not obvious. So we study the overall equivalent stress conditions mainly. To clearly see the stress concentration in which part, we will separate analysis the stress of the crankshaft and connecting rods. According to figure 5, the stress on crank shaft is the most concentrated, and the largest stress is 15.631MPa which is less than the maximum allowable stress (120MPa). So the strength of crankshaft meet design requirements. According to figure 6, the stress on the contact between connecting rod and its small end is the most concentrated, and the largest stress is 121.04MPa which is equal to the maximum equivalent stress values of connecting rod and crankshaft of a piston mechanism. So the maximum equivalent stress of the crankshaft connecting rod piston mechanism is on its crankshaft. Because the maximum equivalent stress of the connecting rods is less than the connecting rod (585.92MPa), the strength of connecting rod meets design requirements, and the entire design of mechanical vibration unit is rational.

3.2. Modal Analysis of the Crankshaft

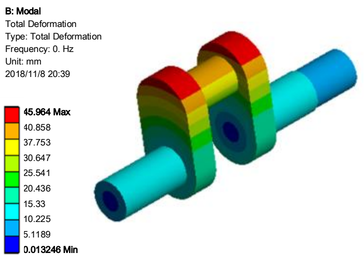
Modal analysis of crankshaft aims to study the characteristics of crankshaft vibration to provide a reference for optimal design of crankshaft in the future. Import the crankshaft in ANSYS Workbench, set the crankshaft material properties, divide the grid and imposing constraints and loads. According to the actual working situation of the crankshaft, left end of the crankshaft is fixed, and runout of the right end of the crankshaft is restricted by sliding bearing. Because the crankshaft vibration analysis and lower order modes of the crankshaft are closely connected, this article solves the top 6 order mode of the crankshaft through ANSYS Workbench. The natural frequency of the order for the modal as shown in table 1.

Table 1. Natural frequency of the first 6 order parameters

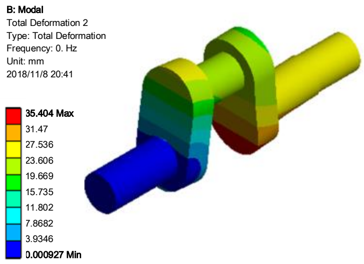
Mode	Frequency[Hz]	Mode	Frequency[Hz]	Mode	Frequency[Hz]
1	0.	**3**	2794.7	**5**	3711.2
2	1485.8	**4**	3121.4	**6**	5792.1

According to table 1, we can get the crankshaft vibration frequency, and vibration modal analysis of the plansfrom of each order modes figure 8. Natural frequency of the first order is 0, at which point the crankshaft rigid body vibrate, as shown in figure 8. The second order natural frequency is 1485.8Hz, and the crankshaft overall bending vibrate. The third and the fifth order is torsional vibration of crankshaft. The 4th order is longitudinal vibration of crankshaft. The 6th order is the transverse vibration of crankshaft. According to figure 10, the vibration and deformation of the third order mode is the largest, and it is at the bottom of the crank handle. According to modal vibration graph of 1-6 order modes, the vibration and deformation of crankshaft is primary at the right end of the crank.

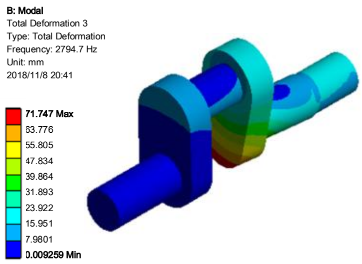
IOP Conf. Series: Materials Science and Engineering **538** (2019) 012003 doi:10.1088/1757-899X/538/1/012003



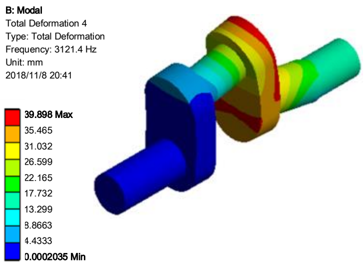
Modal analysis chart of 1th-order



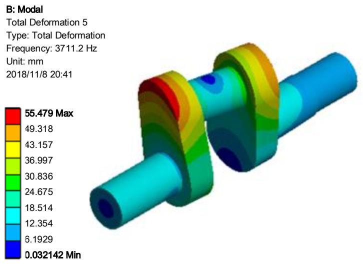
Modal analysis chart of 2th-order



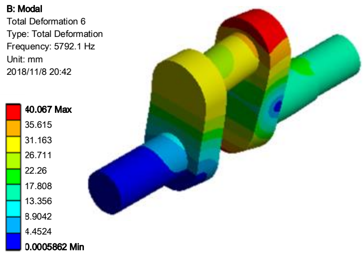
Modal analysis chart of 3th-order



Modal analysis chart of 4th-order



Modal analysis chart of 5th-order



Modal analysis chart of 6th-order

Figure 10. Natural frequency of the first 6 order parameters.

4. Conclusion

(1) Through reasonable parameter selection and structure design, the development of ultrasonic composite abrasive vibration polishing equipment is completed, the parameters of the device is got, and the three - dimensional model of ultrasonic composite abrasive equipment is drawn using Soildworks. In order to study whether the strength of the mechanical vibration unit meets the design requirements

(2) Use ANSYS Workbench software to static analysis the crankshaft connecting rod piston mechanism, and the maximum equivalent stress of the crankshaft and connecting rods are less than the allowable stress the value, so the strength of crankshaft connecting rod piston mechanism meets the design requirements.

(3) Use ANSYS Workbench to modal analysis the crankshaft and we find that the largest vibration and deformation of crankshaft occurred in the 3rd - order, and the deformation of right crank of crankshaft is the largest. In order to reduce the amount of deformation, we can shorten the out of the right side of the crankshaft axis length and increase the constraint on the right side of the crankshaft runout, or we can thicken the crank.

This study provide a new design concept and theoretical basis for similar ultrasonic composite vibration polishing equipment. The next research work is to explore the principle of material removal on workpiece surface and deduce the expression formula of displacement and stress on workpiece surface under the action of concentrated force and average distributed force perpendicular to workpiece surface.

Acknowledgement
This study is funded by Scientific research project of Key Laboratory of Shaanxi Provincial Department of Education (16JS047). And by Shaanxi key laboratory research project (17JS060).

References

[1] WAN Hongqiang, HAN Peiying, GE Shuai, LI Fancong. Development of Ultrasonic Vibration Polishing Method on Workpiece Surface. Diamond & Abrasives Engineering, 2018, 38(02): 94-100.

IOP Conf. Series: Materials Science and Engineering **538** (2019) 012003 doi:10.1088/1757-899X/538/1/012003

[2] Yang Xiaopeng. Design and Experimental Research on Spindle of Ultrasonic-EDM Combined Machining for Metal Matrix Ceramic Coating Materials. Shanxi: Taiyuan University of Technology, 2018.
[3] Zhang Yu. Research and Application of Multi-energy Mechanism and Optimal Control in Ultrasonic Composite Electrical Processing. Jiangsu: Yangzhou University, 2018.
[4] Sun Jixin. Design and Application of Precision Ultrasound and Compound Electrolytic Machining Technology for Hard-to-Machine Parts. Jiangsu: Yangzhou University, 2018.
[5] SUZUKI H, HAMADA S, OKINO T, et al. Ultraprecision Finishing of Micro-aspheric Surface by Ultrasonic Two-axis Vibration Assisted Polishing. CIRP Annals-Manufacturing Technology, 2010, 59(1): 347-350.
[6] Han Lei. FEM Analysis and Experimental Research on the Technique of Ultrasonic Flexural Vibration Assisted Lapping/Polishing of Hard and Brittle Materials. Changchun: Jilin University, 2015.
[7] Gao Jianqiang, Yu Ping, Gao Shilong, Zhang Yinpigeon. The Design and Simulation of Centrifugal Glass-Wool Board Drilling Mechanism. Mechanical Design & Manufacture, 2014 (01): 7-10.
[8] Chen Long, Fu Yanzeng, Yang Shuo, Jiang Xue. Research on DF Deep Hole Machining System Based on the Soildworks Animation Simulation. Journal of Hebei Institute of Architectural and Civil Engineering, 2017, 35 (03): 119-122.
[9] Gao Yaodong, Yan Penghe. Motion Simulation and Design Optimization of Hydraulic Support by ANSYS. Mechanical Design & Manufacture, 2018 (08): 202-205.
[10] Wu Min, Xie Longhan. Ansys Workbench Finite Element Analysis and Simulation . Beijing: Electronic Industry Press, 2014.