Study on the Miniaturized Machine Tool for Combined Machining

Xiaoxiao Liu [1,a], Xiang Cheng[2,b,*], Fei Wang[3,c], Guangming Zheng[4,d], Xianhai Yang[5,e]

[1]School of Mechanical Engineering, Shandong University of Technology, Zibo 255049, China

[2]School of Mechanical Engineering, Shandong University of Technology, Zibo 255049, China

[3]School of Mechanical Engineering, Shandong University of Technology, Zibo 255049, China

[4]School of Mechanical Engineering, Shandong University of Technology, Zibo 255049, China

[5]School of Mechanical Engineering, Shandong University of Technology, Zibo 255049, China

[a]email: lxiaoyy@163.com, [b]email: chengxiang@sdut.edu.cn, [c]email: wf930327@163.com, [d]email: zhengguangming@sdut.edu.cn, [e]email: yxh@sdut.edu.cn

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Abstract. In order to achieve both the processes advantages of fused deposition modeling (FDM) and mechanical cutting, a novel miniaturized machine tool with combined processing capabilities is designed and developed. The miniaturized machine tool is designed using the gantry structure and its overall size is 700 mm×640 mm×780 mm. The machine tool has three linear axes and one rotary axis. The control system is constructed using the MACH3 system. The finite element software Abaqus is applied to analyses and optimization of the designed model. Experiment has been conducted to fabricate the spinal cone fusion implant and the developed miniaturized machine tool has been successfully evaluated.

Introduction

Combined machining is the tendency for part fabrications with multi processes. Namely, the part can be fabricated on one machine tool with limited setups. Combined machining makes different machining processes combined on a machine to reduce the number of machine tools and fixtures, and to eliminate handling and storage among processes. Consequently, the machining precision will be improved and the processing efficiency will be enhanced. This not only can satisfy the demand of users in cutting area, reduce the parts delivery and inventory, and ensure the machining accuracy, but also meet the demand of the modern society of energy conservation and emissions reduction. Combined machine processing can shorten the processing cycle and improve the machining precision of workpiece [1]. In order to improve the productivity, the development and manufacturing of NC combined processing machine tool has become a development trend of numerical control ones. The development of the combined processing technology will bring revolutionary changes to the production of the future [2].

Both 3D printing by adding materials and mechanical cutting by reducing materials [3] are the machine tools with rapid development at present. With the continuous development of technology, the application field of them will be more and more wide. But there is limited miniaturized machine tools which combine the 3D printing with mechanical cutting capabilities. Based on the demands, a miniaturized FDM and milling machine has been designed and developed. It is significant for the study of combined processing technology as well as the improvement of the 3D printing features and promoting the development of miniaturized combined processing machine tools.

Design of the miniaturized machine tool

High precision demand of micro milling machine presents the higher requirements to the structure of the combined machine tool. The designed machine tool adopts gantry structure. Three axes adopt stepper motors with the step angle of 1.8 degrees and 1/16 subdivision. Transmission adopts ball screws with 5mm lead and high precision linear guides to ensure the movement precision requirements. In order to guarantee the performance of the designed machine tool structure, finite element software Abaqus is used to analyze and optimize the structure. The travels of three straight line axes X, Y, Z are 400mm, 200mm and 400mm, respectively. The axis Y is placed on the bed and the workpiece is placed on the axis Y. The axis X is placed on the gantry frame and the axis Z is placed on the axis X. The rotary B axis is fixed on the Z axis. The milling spindle and the FDM printing head are fixed on the B axis. In order to improve the rotation precision, the cantilever shaft adopts step motor with large torque capabilities. Considering the conflictions of machine stiffness and weight, the machine tool bed, column and X-axis slide adopt high-strength aluminum alloy. The designed miniaturized machine tool is shown in Fig.1.

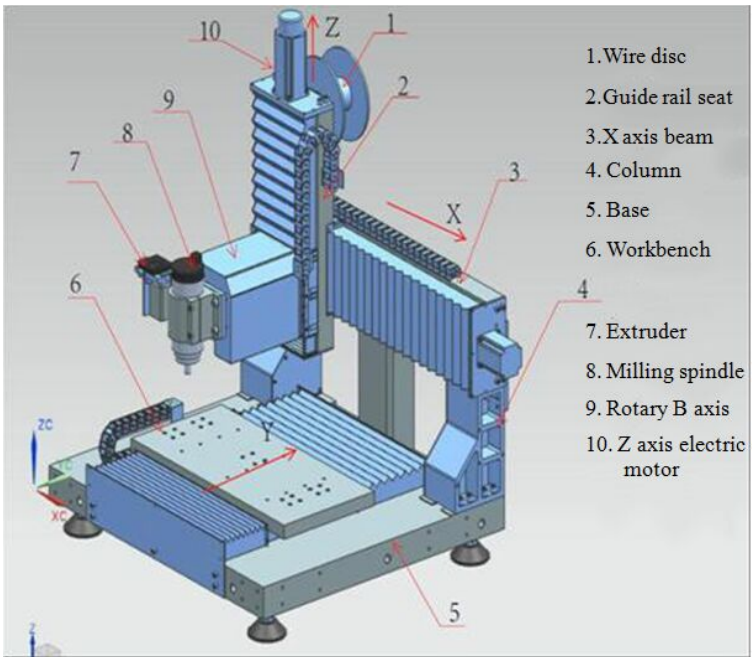


Fig.1 The miniaturized machine tool designed with combined FDM and milling capabilities

Finite element analysis

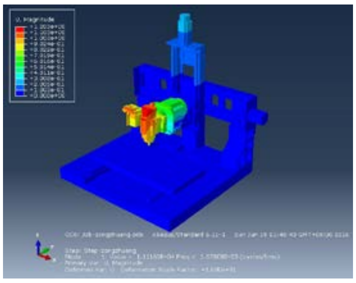
The integral modal analysis and static analysis of machine structure have been conducted using the FEM software Abaqus in order to enhance the structural performances, improve the machining accuracy and avoid excessive deformations due to structure resonance and small machine weight. The optimal structure has obtained through the analysis of the modal data of the key components of the designed machine tool.

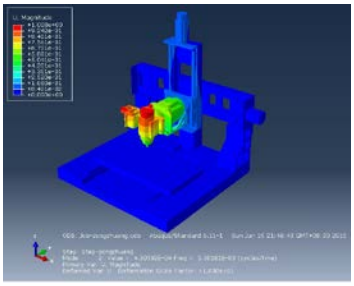
In the process of modal analysis, the Block Lanczos method is used to extract the modal and analyze thirty steps modal conditions of machine massive structure. The modal frequency and mode of vibration of the top steps are shown in Table.1, which modal frequency and mode of vibration plots are shown in Fig.2.

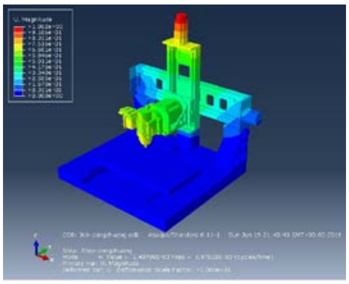
Optimization of the designed machine tool has been carried out based on structural static mechanics. The deformation of key components before and after the optimization is comprehensively compared. The optimal structure has been obtained. The three dimensional design of the key components is shown in Fig.3.

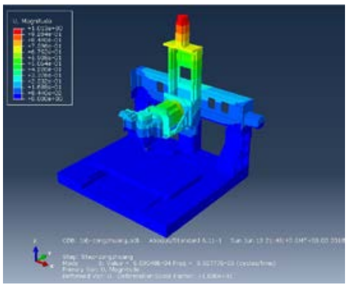
Table.1 The top six order modal of vibration

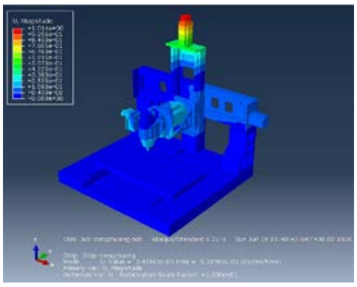
Order number	Natural frequency （Hz）	Mode of vibration
1	168	The rotary B axis swings around the X axis.
2	330	The rotary B axis and the Z axis swing around the X axis.
3	392	The rotary B axis and the Z axis swing around the X axis.
4	597	The rotary B axis swings around the X axis;the X axis swings around the Z axis.
5	938	The Z axis swings around the X axis.
6	946	The X axis twists around the Z axis.


(a) First-order vibration mode


(b) Second-order vibration mode


(c) Third-order vibration mode


(d) Fourth-order vibration mode


(e) Fifth-order vibration mode

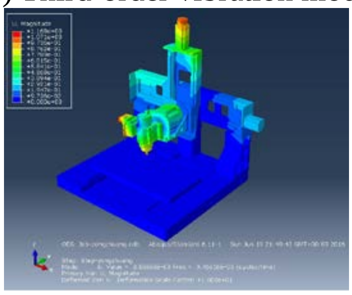
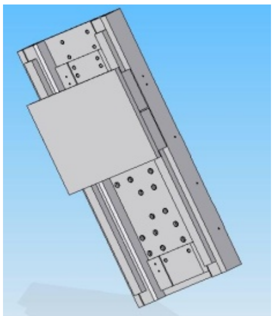
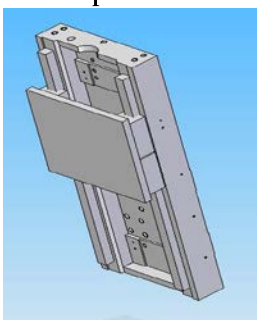
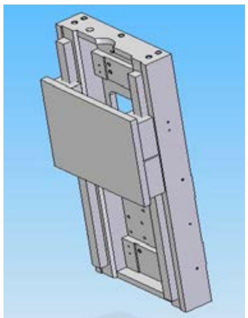
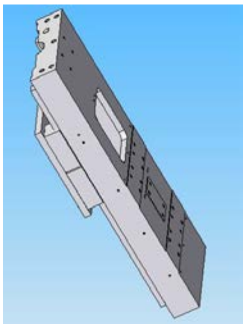

(f) Sixth-order vibration mode

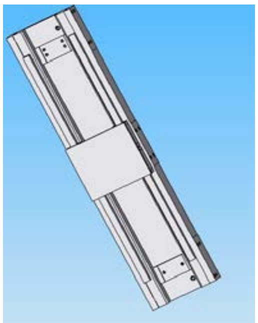
Fig.2 The top six order modal

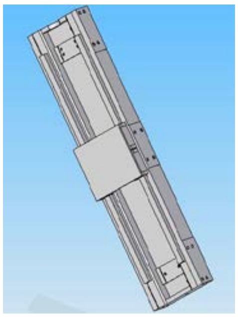

(a) The Z axis scheme 01

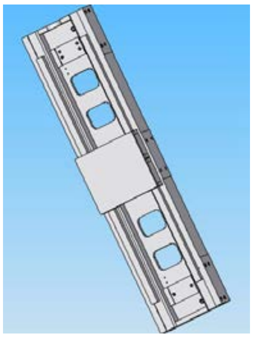
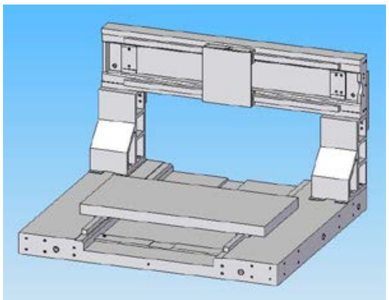
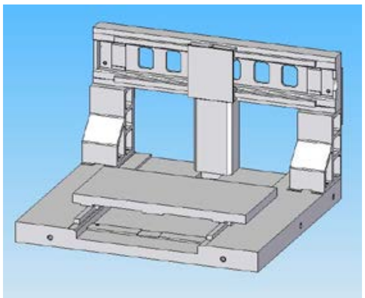

(b)The Z axis scheme 02


(c) The Z axis scheme 03 the front


(d) The Z axis scheme 03 the opposite


(e) X beam scheme 01


(f) X beam scheme 02

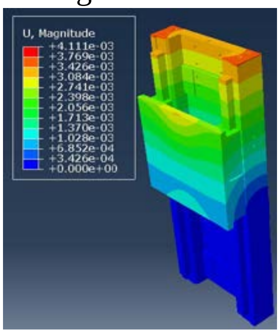




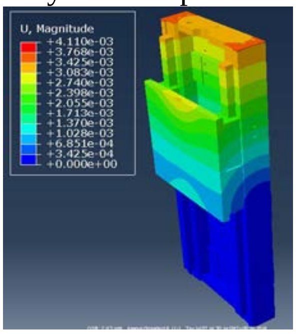
(g) X beam scheme 03 (h) Bed scheme 01 (i) Bed scheme 02

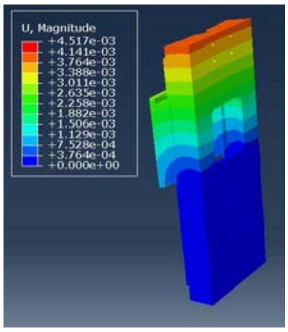
Fig.3 Typical schemes of key components of the designed machine tool

The force bearing of axis Z bases is 145N, which is the whole weight of cantilever components and the motorized spindle. The torque bearing of Z axis is 23.200Nm. The force bearing of axis X beam is 280N, which is equal to the weight of axis X and cantilever components. The torque bearing of axis X is 42Nm. The force bearing of of the base is 680N, which is the sum of weight of axis X, axis Z and cantilever components. Axis Z column and the base is made of aluminium alloy material. The gantry of axis X is made of 45# steel.

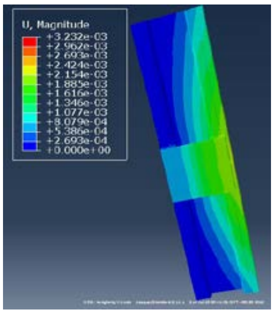
According to the finite element analyses and optimization, the results are shown in Fig.4.

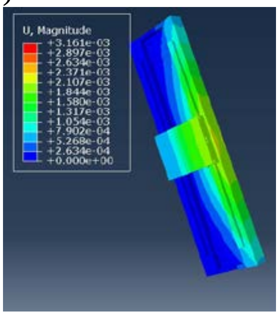


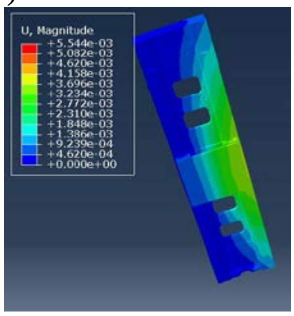




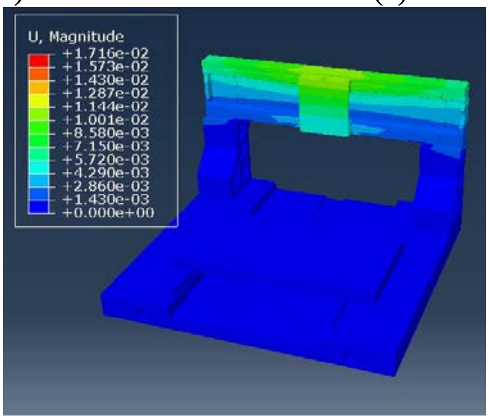
(a) The Z axis scheme 01 (b) The Z axis scheme 02 (c) The Z axis scheme 03

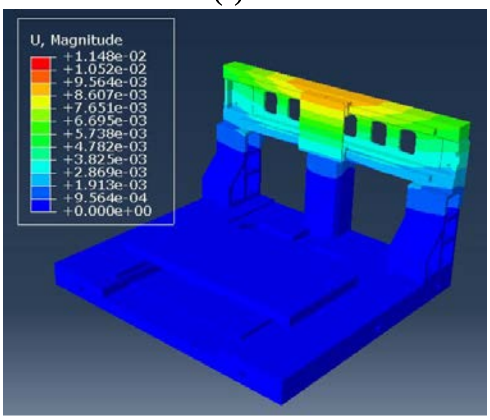






(d) X beam scheme 01 (e) X beam scheme 02 (f) X beam scheme 03





(g) Bed scheme 01 (h) Bed scheme 02

Fig.4 Analysis of key components of the designed machine Tool

The optimization analysis shows that the second design scheme has the highest stiffness. The stiffness difference of scheme 02 and scheme 03 is very small for axis Z and axis X beam. The bed solution of scheme 02 is obviously better than that of scheme 01. Under the condition of considering about the overall quality and rigidity of the machine, scheme 03 is the best solution for axis Z and axis X beam. Scheme 02 of the bed is the best one.

Control system design

The slave computer of the system uses the motion control card MACH3. MACH3 movement control card can meet the CNC software function requirements which include parallel port connect through the computer and controlling NC equipment as well as mutual I/O functions. By adopting onboard DC-DC isolation power supply, even using single power supply (DC 12V-24V), it can still guarantee the stability of the controlling system.

According to the global design of the control system, the electrical elements are reasonably distributed on the control box. The designed electrical schematic diagram is shown in Fig.5.

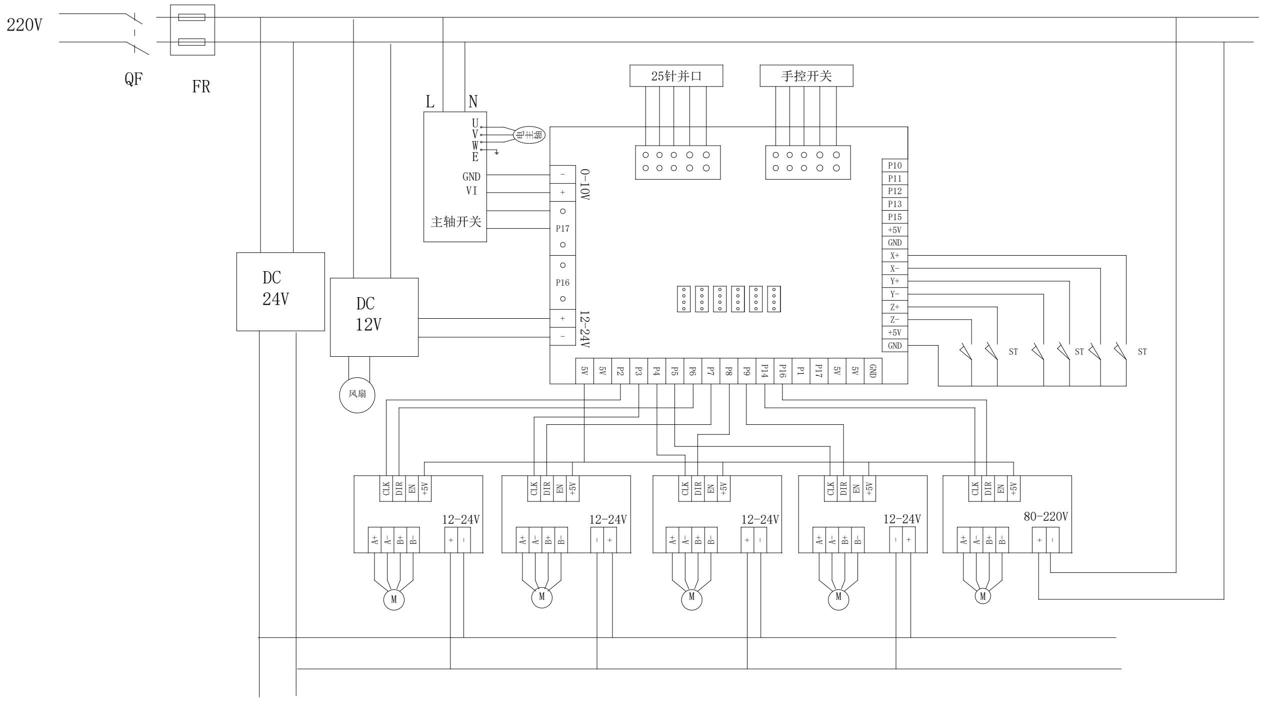


Fig.5 Simple electrical schematic diagram for the designed machine tools

Since the machine tool motion controller uses the MACH3 control card without the function of temperature control, the temperature control unit of 3D printer uses independent temperature controllers to respectively control the temperature of print head and hot bed. The structure diagram is shown in Fig.6.

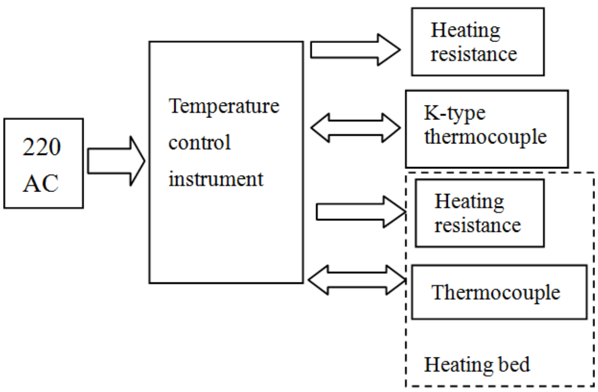


Fig.6 Flow chart of temperature control system

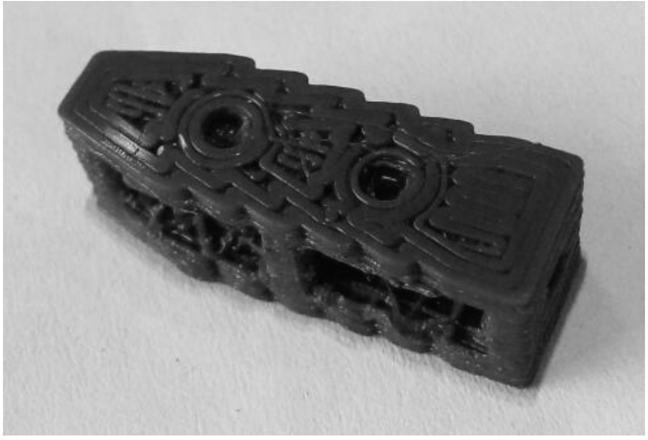


Fig.7 The fabricated spinal cone fusion implant

Experimental evaluation

On the developed combined machine tool, the spinal cone fusion implant made of peek material has been printed. After completion of printing, the temperature of the spinal cone fusion implant remains. The milling spindle is used to drill and tap a thread hole with the diameter of 3mm. The successfully fabricated spinal cone fusion implant is shown in Fig.7, which verifies the feasibility of the developed miniaturized machine tool.

Conclusion

A miniaturized machine tool with FDM and mechanical cutting functions is designed and developed. The MACH3 control system and the style of external temperature control can not only realize precision milling, but also implement precision 3D print on the stable of the machine tool. After printing, the thread hole can be created to fabricate workpiece without reinstallations. Experiments show the feasibility of the introduced miniaturized machine tool. It greatly improves the precision and efficiency of parts with complicated geometrical features.

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