Chapter 30
Integrated Laser In Situ Auxiliary Device

Hongda Li, Guangfeng Shi, Jiyu Gao, Youliang Li, Mingbo Liang, and Siwei Meng

Abstract Hard and brittle materials (germanium, silicon, ceramics, etc.) have the characteristics of good chemical stability, high temperature resistance, corrosion resistance, oxidation resistance, high strength, and hardness. It is widely used in all walks of life. However, due to shortcomings such as high brittleness and low fracture properties, it brings many difficulties to processing. There are mainly brittle fracture zones on the surface of the workpiece and a low material removal rate, which leads to long processing completion time and severe tool wear during processing. In response to the above problems, laser-assisted machining (LAM) is introduced. The surface of the workpiece to be processed by laser radiation is converted from light energy into heat energy to achieve the purpose of softening the material, combined with traditional processing. Laser-assisted machining (LAM) greatly reduces the cutting force, reduces the generation of micro-cracks on the surface of the workpiece, improves the surface finish, and reduces tool wear. In this paper, an integrated laser auxiliary device is designed for laser-assisted technology to realize the integration of "in situ" and "off-site". The device adopts a modular design, which can adjust the laser incident angle and the size of the laser spot radius according to factors such as cutting tools and processing requirements, which not only improves the energy utilization rate of the laser but also facilitates adjustment and installation.

30.1 Introduction

Laser-assisted machining (LAM) is a combination of laser and traditional metal processing technology. The processing area on the workpiece is softened by high-energy laser beam heating to reach the optimal cutting temperature of the material.

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Cutting at this temperature can make the deformation of the material easier, the cutting force, cutting specific energy, surface roughness, surface damage, and tool wear are reduced, and the processing efficiency and material removal rate are also improved. Tian [1] carried out an experimental study of laser-assisted polishing (Lab) mp35n, annealing, and hardening of AISI 4140. The experimental results show that, compared with the traditional polishing, the workpiece after lab can obtain higher compressive residual stress, improve surface finish, and reduce tool wear. In 2000, Rozzi [2, 3] of Purdue University established the temperature field model of laser-assisted turning Si3N4 ceramic cutting domain for the first time. The finite volume method was used to establish the model, and the three-dimensional transient temperature field of the workpiece was well described. Rozzi successfully predicted the surface temperature of the workpiece, compared it with the actual measured temperature, and verified the effectiveness of the model. In addition, some scholars carried out in-depth research on the composite process test. Dandekar [4] has carried out a laser-assisted cutting test on titanium alloy and tested the surface finish and hardness of the workpiece after the test. The test results show that the hardness of the workpiece after laser-assisted cutting has not changed, and the microstructure of the material is observed under the metallographic microscope, and the grain has no obvious change, but the surface roughness of the workpiece has been improved. Rashid [5] carried out a Lam experiment on ti-10v-2fe-3al alloy material and found that Lam technology can effectively improve the machinability of alloy material. Anderson [6, 7] used Lam technology to process stainless steel P550, Inconel 718, and other materials. From the perspective of cutting specific energy, the effects of cutting parameters on cutting force, tool life, and workpiece surface quality were studied. There is also a research institute that has developed a laser auxiliary device for laser-assisted technology. The laser in situ auxiliary processing device is shown in Fig. 30.1 [8, 9]. The laser is coupled with the tool head of transparent material and acts on the processing area of the processed material.

As shown in Fig. 30.2, the laser off-set-assisted machining device uses the laser to soften the material before the tool processes the workpiece. The existing laser-assisted devices are mono-functional and cannot adjust the laser incidence position flexibly. The laser is susceptible to the effects of cutting fluids and chips during machining, and the machined surface can be affected as a result. Some devices hollow out the inside of the tool holder to ensure beam transmission, which can easily cause instability during machining, and the small welding area between the tool holder

Fig. 30.1 Laser in situ auxiliary processing device

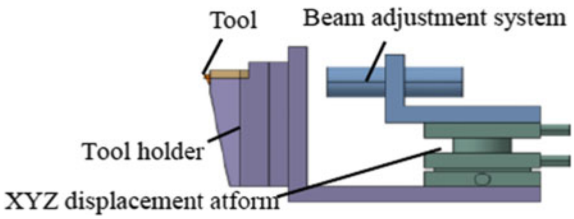
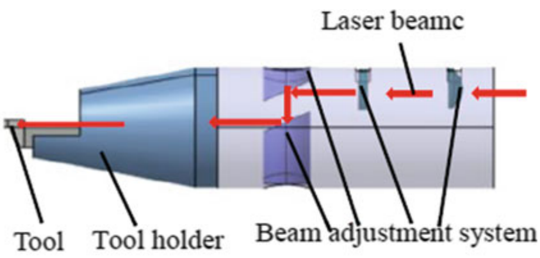
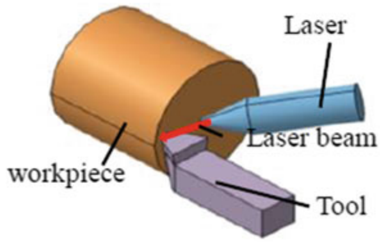


Fig. 30.2 The scheme of laser off-position auxiliary processing device



a. Laser coaxial off-position auxiliary processing device



b. Laser non-coaxial off-position auxiliary processing device

and tool can lead to insufficient stiffness. From the above, it can be seen that laser-assisted technology plays a vital role in processing difficult-to-machine materials, and a large number of scholars have conducted many in-depth studies. In response to the above phenomena and problems, the research of this paper was carried out. The existing laser-assisted device was optimized and an integrated laser-assisted device was developed.

30.2 The Overall Program

30.2.1 Overall Program Design

In this paper, the integrated laser in situ assist device is designed in three aspects, which are tool holder structure design, laser transmission structure design, and laser optical path design. The tool holder structure adopts a modular design, including three parts: tool holder mounting base plate, tool holder mounting cover plate, and sleeve. The main advantages of this tool holder are flexible installation, easy movement, and the ability to integrate with different types of machine tools. The laser transmission structure consists of three main parts: the convex lens adjustment module, the reflector adjustment module, and the laser adjustment module. The structure of the laser transmission is designed with the advantage of easy adjustment and adjustable laser spot radius size. The laser optical path design includes the optical path design for

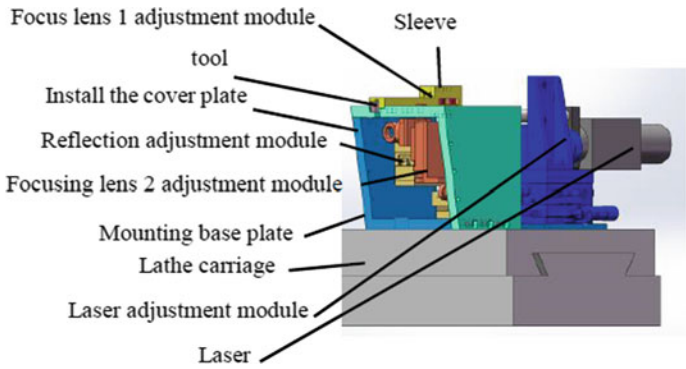


Fig. 30.3 Assembly diagram of laser assist device

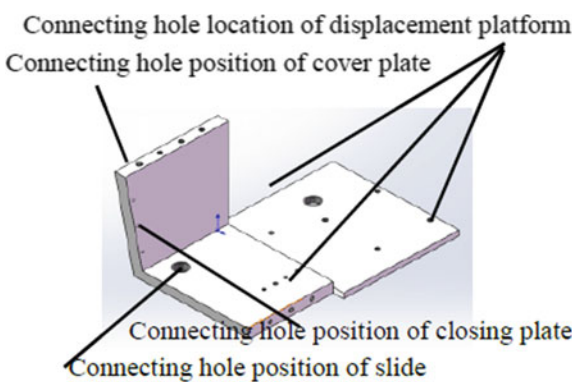
two forms of laser incidence. Two types of “in-situ” and one type of “out-of-situ” incidence integration have been achieved. The advantage of laser light path design is high laser utilization. The overall scheme is shown in Fig. 30.3.

30.2.2 *Tool Holder Structure Design*

The structure design of the base plate for tool holder installation

The tool holder mounting base plate is the foundation of the unit and is connected to the mounting cover to support the overall unit and mount the main components. As shown in Fig. 30.4, the bottom plate of the tool holder is installed with an L-shaped plate, and the cut surface of a certain angle is connected with the closed plate.

Fig. 30.4 Base plate for tool holder mounting



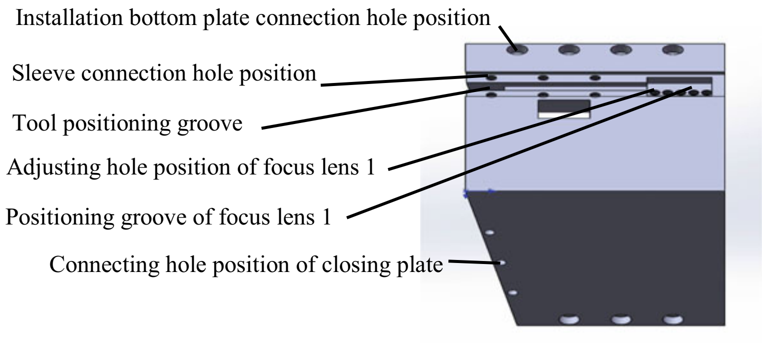


Fig. 30.5 Tool holder mounting cover plate

Tool holder mounting cover plate structure design

The tool holder mounting cover plate should ensure the positioning and clamping of the tool and the positioning and adjustment of the focusing mirror 1. The structure of the tool holder mounting cover is shown in Fig. 30.5, which is machined from an L-shaped plate and cut using the same angle as the tool holder mounting base plate. The mounting holes include the connection holes to the sleeve (M4 bolts), the connection holes to the mounting base plate, the height adjustment holes for the focus mirror 1 and the connection holes for the closure plate. The connection of the sleeve to the mounting cover enables the positioning of the tool for clamping. The distance from the focusing lens to the tool is adjusted by the focusing lens 1 positioning slot.

Sleeve structure design

The function of the sleeve is to position the tool for clamping, to realize the clamping and adjustment of the focusing mirror 1, and to protect the transmission of the laser beam. A diagram of the sleeve structure as shown in Fig. 30.6, with tool positioning slots in the sleeve, connected to the tool holder mounting cover by M4 bolts to enable tool clamping. There is a positioning slot for the focusing mirror 1 inside the sleeve, and the mounting bracket is adjusted in height and horizontal direction by bolts to

Fig. 30.6 Sleeve structure diagram

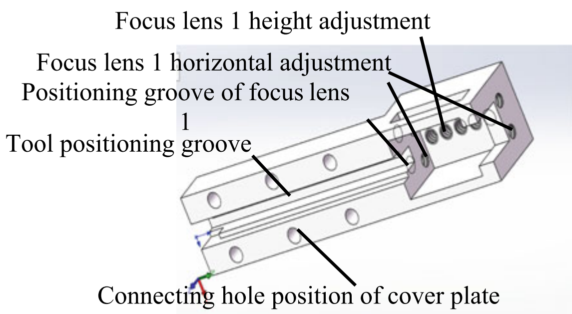
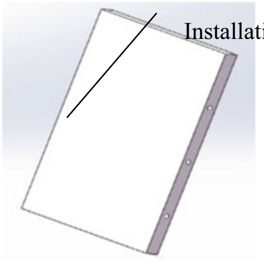


Fig. 30.7 Structural drawing of the closure plate



realize the size and position adjustment of the focusing spot, and the positioning slot of the mounting bracket is marked with a scale for easy adjustment. There is a laser beam channel inside the sleeve, the width of which is smaller than the width of the tool positioning slot. The laser beam can be applied to the workpiece through the tool in situ coaxially, or off situ coaxially.

Closed plate structure design

The closure plate ensures that the cutting fluid and chips do not affect the laser energy during the machining process, achieving high efficiency and quality machining. The closure plate connects the mounting cover and the mounting base plate, as shown in Fig. 30.7.

30.2.3 Laser Transmission Structure Design

Laser adjustment module

Two forms of incidence of the laser beam during laser-assisted processing, depending on the processing requirements, requiring the laser beam to be capable of a wide range of height adjustments. When the laser beam passes through the tool in situ, the change in the position of the incident point affects the laser beam exit position and direction, thus affecting the machining quality. Therefore, the position of the laser beam needs to be precisely adjusted before processing to ensure that the laser energy acts efficiently on the workpiece position required for processing. A specific structure diagram is shown in Fig. 30.8.

Focus mirror adjustment module

When processing with different tools and parameters, the required laser spot size is different, which requires a certain adjustable range for the focusing lens to meet the processing requirements. In this device, the focus mirror 1 is mounted on the focus mirror 1 mounting bracket, as shown in Fig. 30.9, using bolts for fastening (M3). Focus mirror 1 mounting bracket is located in the positioning slot of the tool holder mounting cover and sleeve, and the height position and horizontal position of

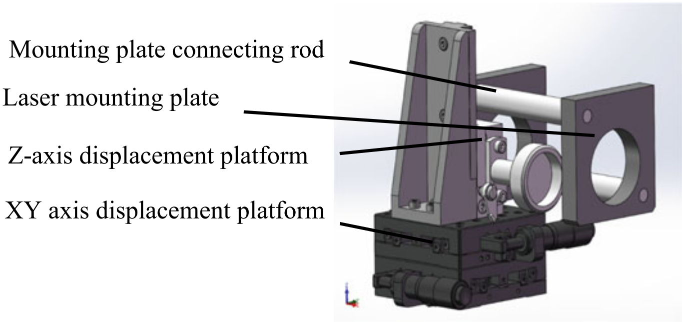
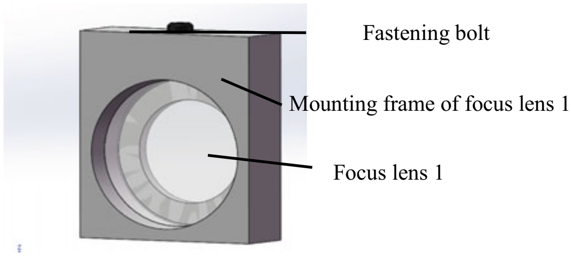


Fig. 30.8 Laser tuning module

Fig. 30.9 Focus lens 1 adjustment module



the focusing mirror are adjusted by the adjustment bolts on the mounting cover and sleeve.

The laser beam passing through the focusing mirror 2 is reflected by the reflector and then incident from the bottom of the tool holder at a certain angle. The focusing mirror 2 needs to be angularly adjusted according to the angle of the incident laser beam and also spatially positioned according to the different incident points. The focusing mirror 2 adjustment module is shown in Fig. 30.10.

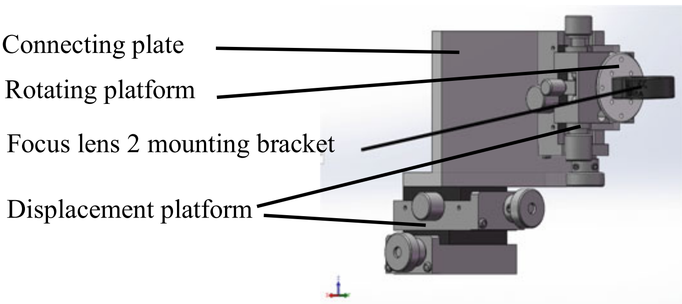


Fig. 30.10 Focusing lens 2 adjustment module

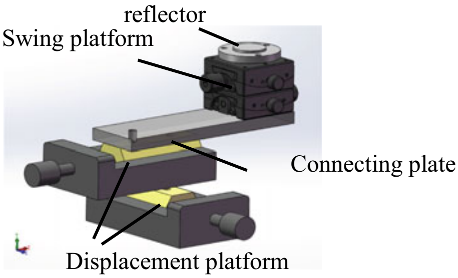


Fig. 30.11 Structure diagram of the reflection adjustment module

Reflector adjustment module

For different parameters tool, different processing requirements, the laser beam incidence angle, incidence position is different, which need to reflect the adjustment module to ensure that the angle and position of the reflector can be easily and flexibly adjusted. The structure of the reflection adjustment module is shown in Fig. 30.11. The reflector has a cooling system to prevent thermal distortion. The device uses air cooling to quickly transfer a large amount of heat brought by the laser beam irradiation to ensure that the reflector can continue to work properly.

30.3 Laser Optical Path Design

Optical path system design, as shown in Fig. 30.12, is a schematic diagram of the beam transmission of the two laser incidence forms of the device optical path system, after the laser beam 1 departs from the laser and is focused by the focusing mirror 1, coaxially and in situ through the tool. After laser beam 2 is emitted by the laser, it is reflected by the reflector, focused by the focusing mirror 2, and then passes through the tool at an angle required by the processing, from the bottom of the tool in situ at an angle.

As shown in Fig. 30.13, the integration of "in situ" and "out-of-situ" is achieved, with two forms of incidence and four modes of action. Compared to existing laser-assisted equipment, it makes up for the shortcomings of homogenization while achieving high utilization of laser energy, and has easy mobility and is suitable for the integration of basically all CNC machine tools.

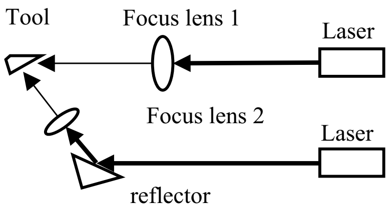


Fig. 30.12 Schematic diagram of laser beam transmission of optical path system

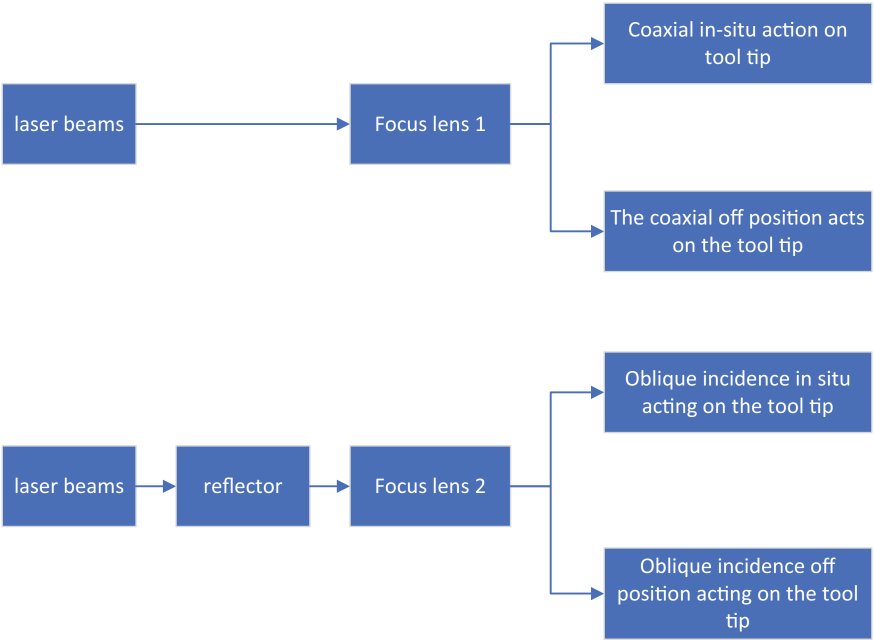


Fig. 30.13 Laser incidence mode

30.4 Conclusion

In this paper, based on the existing laser-assisted device, an integrated laser-assisted turning system is designed and developed to meet the processing requirements of hard and brittle materials. The 3D modeling of the tool holder structure and optical transmission structure in the integrated device is completed by using Soidworks. At the same time, the device has been built and applied to the laboratory test. The device has the following advantages:

(1) The device solves the single defect of the existing laser auxiliary device, and realizes the integration of out of position and in situ auxiliary.
(2) Compared with the laser in situ auxiliary device of a company, the stiffness of the device has been significantly improved.
(3) The laser in situ oblique incidence is realized to avoid the influence of cutting fluid and chips on the optical path.

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