Research on Conceptual Design of Laser Shock Processing Equipment

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Abstract. In order to develop the laser shock processing equipment, the technical features and the design requirements are analysis. The concept scheme of laser shock processing equipment is built and the functions are defined. The technology and specifications is discussed relating to the concept scheme.

Introduction

Laser shock processing (LSP) is a new technology to improve metal material fatigue resistance, wear resistance and corrosion resistance utilizing the plasma shock wave generated by strong laser beam [1]. It has the advantages of non-contact, non-heat affected zone, strong controllability. It has great application prospect and promotion value on the aerospace, automotive industry, petrochemical industry, nuclear industry, marine, medical industry and other fields [2].

In recent years, despite the increasingly urgent demand, but the related research is not active enough because of the restrictions of equipment. There are many uncertainty factors during the extremely complex LSP equipment development [3]. Above reason significantly limits the research and application of LSP equipment. In view of this situation, this paper focuses on concept design of LSP equipment. A conceptual system of LSP equipment is built. And the requirements, structure, operations, technology of the conceptual system is discussed.

LSP technology

Basic concept of LSP

When high power density (GW/cm), short pulse (10 ~ 30ns) laser is applied to the metal surface, the energy absorbing coating absorbs laser energy quickly and produces a lot of dense high-temperature (>10K), hypertension (>1GPa) plasma at the same time. The plasma to absorb laser energy rapidly warming expands. Then the explosion forms high intensity shock waves forcing on metal surface. When the shock wave pressure exceeds the dynamic yield strength of material, plastic deforming begins. At end of the deforming, metal surface obtains high compressive residual stress due to the impact of regional material around the reaction. Residual compressive stress will decrease the alternating load in the tensile stress level. The existence of residual compressive stress can cause the crack closure effect to extend the life of fatigue crack growth. LSP has the following characteristics [4,5]: high pressure, high energy, ultra high strain rate. Other surface strengthening technology can hardly achieve these properties.

Design specifications on LSP equipment

According to the analysis, in order to make LSP as a mature technology to be widely applied in engineering, the design of LSP equipment should meet the following requirements:

(1) LSP device should be developed with the suitable structure form.

(2) Integrated control system should be designed to construct a collaborative environment with constrained layer, electrical and mechanical system, optical shaping system, and so on. Control system should ensure LSP process quality with the functions of process monitoring, laser beam energy monitoring, constrained layer thickness monitoring.

(3) Technology research of LSP should be done including technology parameter analysis and LSP operation process design. Coating material and constraint layer thickness are the main parameters to influence process quality. Parameters database should be established for parameter optimization according to experiments. The process type and the impact times, machining trajectory can be designed according the parameter requirements.
Monitoring system of LSP processing should be developed. LSP processing surface quality is described by residual stress, surface roughness, surface deformation, micro hardness. Therefore, LSP strengthening effect can be inspected through the surface quality.

**Concept scheme of LSP equipment**

The functions of LSP equipment include path planning, process simulation and process database management. LSP equipment concept is made up of software and hardware systems as shown in Figure 1. Hardware system includes laser device, NC equipment and water feeding device. Laser device is used to generate short pulse of the high peak power density laser. NC equipment is responsible for which the laser beam relative to the machined surface to achieve arbitrary curvilinear motion. The water feeding device covers a uniform and stable water layer on metal target. The software system mainly comprises a trajectory planning system, machining process simulation system, machining process monitoring system and the technology database. The trajectory planning system is a computing system to generate machining trajectory. The task of the machining process simulation system is the simulation of NC machining. The tasks of the machining process monitoring include the functions of process parameters monitoring, impact process control, fault diagnosis. The process database provides reasonable LSP parameters for the actual production.

![Fig. 1 Overall structure of the LSP equipment](image1)

Concept research of LSP equipment implies reliability design. The main objective is to achieve coordinate through connecting separate subsystems into a complete overall. So, the concept should be studied on optical plastic plan, control system, LSP technology system, quality monitoring system, process database development, machining path planning, simulation of machining process.

**Optical plastic scheme**

It needs optical plastic which laser eventually reaches the working surface forming circular beam or square beam shown at the left of Figure 2. Optical plastic scheme is made up of the reflector, uniform light path and focusing optical path shown at the right of figure 3. The laser waveguide structure through multiple internal reflecting is divided into several parts. And then all parts at the output port of superimposed take together to form a spot.

![Fig. 2 Light spot and optical plastic scheme](image2)
Control system

Open distributed control system is a part of LSP equipment. Laser, NC equipment, constraint layer forming equipment, monitoring equipment and the auxiliary functions control system are connected by IPC / PLC. It can make system components to work together and to do information exchange. So, control system can realize the digital, automatic, real-time control. Control system block diagram is shown as Figure 3. The main functions include process control function, real time monitoring function, alarm function, remote video function.

Fig. 3 The function frameworks of control system

Quality monitoring system

It is hard real-time monitoring for quality characterization parameter if applied directly to the surface residual stress, surface roughness and surface deformation parameters because that the monitoring process is complex and time-consuming. Monitoring the impact of acoustic energy value and the natural frequency of the machined part is a way with rapid, accurate, low cost and nondestructive measurement. The structure of monitoring device is shown as figure 4. The functions include impact sound energy monitoring and natural frequency monitoring.

Fig. 4 The structure of the quality monitoring system

LSP technology system

LSP Technology is an important aspect of device development. Its main task is to explore the influence of process parameters on machining quality in order to provide optimal process parameters setting for process systems. LSP equipment is a complex process system. Various process parameters will have a certain impact on the quality function as shown in Figure 5. Therefore, the main tasks of LSP study include the study on main failure modes and mechanics analysis, the LSP mechanism research, the theory analysis and experiment of different parameters influence.

Fig. 5 LSP system of process parameters [6]
**Process database development**

The process database is designed based on the process experimental data. It is the basis for the optimization of LSP parameters. The database system uses SQL Server as the background database, chooses the distributed C/S mode, supports network communication. Figure 6 illustrates the process database principle. The tasks of database development include the study of LSP technology data management and data mining techniques, the research of LSP parameters of multidisciplinary design optimization technology, the development of LSP integrated software environment for parameter optimization and machining trajectory planning.

![Fig. 6 Process database system structure](image)

**Machining path planning**

In order to achieve LSP with a shielding phenomenon, trajectory planning is the most important function to prevent interference between laser beams and other parts. Main technical programmes are shown as Figure 7. LSP model with processing parameters is the input of path planning module. And the output is program code used for device control. The code is given by the off-line way. And then, it is put into the motion actuating mechanism through the local network to realize LSP trajectory control. The main tasks of LSP path planning include: the development of LSP path planning strategy; the research of machining path, interference avoidance method, laser optimal attitude; the computer modeling, simulation and analysis on LSP; the design of best LSP path.

![Fig. 7 Machining path planning](image)

**Simulation system framework**

![Fig. 8 Simulation system framework](image)
Simulation of machining process

The main function of machining process simulation is to simulate machining process to avoid unnecessary losses caused by programming errors. Figure 8 describes the overall function flow of simulation system. The main features include the import feature of digital model, kinematics simulation, the path validation, dynamic simulation.

The operating procedure

Through automated control equipment to achieve the overall integration, LSP equipment is a complete set of system. Equipment operation is achieved by interface definition simply. Data communication between the various subsystems is via the local network. The top of LSP operation process is shown as Figure 9. First of all, machined parts need to complete normal heat treatment and paste coating. Before machining, equipment system should be detected to ensure the normal operation of all features. The quality detection in real time is responsible for checking no melting trace and crack on the surface of the part during LSP machining. The detection data can be used in real time to control laser energy, pulse width, constraint layer thickness, and so on. The residue of the coating material should be promptly cleaned up after LSP machining. The last step is for processing parts of the factory inspection. If eligible, machine part can be delivered either factory.

Conclusions

For achieving the LSP technology and equipment requirements, a complete set of LSP device concept is presented. Elaborate on the demands of the concept scheme, structure and operation. The content of this article can guide the LSP equipment development. The LSP technology has great application prospect and promotion value.

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