Research on Precision Control of Electron Beam Rapid Prototyping

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Keywords: electron beam rapid prototyping, precision control, technical difficulties.

Abstract. Electron beam rapid prototyping has the advantages of high efficiency, various processing materials, non-pollution and flexible control, and it is the main trend of mental materials rapid prototyping. However, as electron beam rapid prototyping technology starts lately and develops poorly, some problems, such as poor forming accuracy and small-sized products, remain to be settled. This paper introduces several methods of electron beam rapid prototyping precision control, and some technical difficulties of electron beam rapid prototyping are analyzed. Finally, we conduct prospect on the electron beam rapid prototyping technology.

1. Introduction

Electron Beam Rapid Prototyping (EBRP) is the combination of electron beam technology and rapid prototyping technology. It is a metal material rapid prototyping technology that integrates computer technology, automatic control technology, high energy beam technology, numerical control technology and so on. When working, raw materials are melted according to the section contour information under the control on electron beam of computer, and finally get the whole product. Compared with laser rapid prototyping, EBRP has the advantages of high efficiency, non-pollution and flexible control, which is the main trend of rapid prototyping manufacturing for metal products [1].

At present, domestic industry areas, such as aerospace and automobile manufacturing, has a big demand for high precision electron beam rapid prototyping equipment. However, nowadays, its precision is unable to meet the requirements of complex components for aerospace applications.

2. Electron Beam Rapid Prototyping precision control

EBRP technology includes Electron Beam Melting Technology (EBM), Electric Beam Selective Sintering Technology (EBSS), Electric Beam Solid Freedom Fabrication Technology (EBSFF) and so on [2]. EBRP machine consists of focusing system, deflecting & scanning system, motion system, raw material supplying device, etc. The basic structure of electron beam melting equipment is shown in figure 1. According to the figure, we can easily get the key factors affecting accuracy of EBRP: structure of raw material supplying device, accuracy of focusing and deflecting & scanning system. In addition, the quality of slicing and rationality of scanning path can also pose great influence on accuracy. Next, we will analyze emphatically from these aspects.
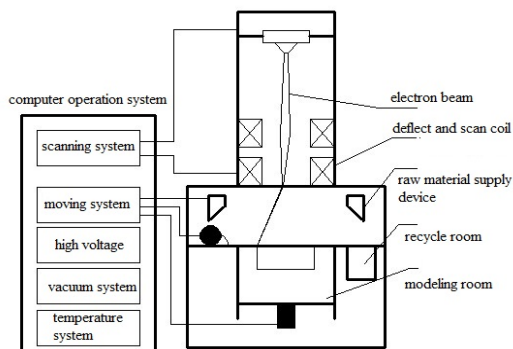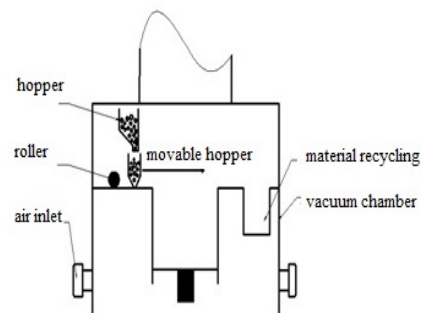

Fig. 1 Structure of electron beam melting equipment

Fig. 2 Structure of vacuum chamber

2.1 Slicing processing

When manufacturing a product, a three-dimensional CAD model needs to be built first to drive the orbit of electron beam. But as rapid prototyping system can only identify 2D data, which means CAD model must be transformed into 2D data in advance. This process is commonly known as hierarchical slicing. Slicing means using a series of planes which parallel to the 3D model to intercept entity model, then 2D data of each layer is available. Through hierarchical slicing, 3D processing is transformed as 2D processing, which can simplify electron beam controlling strategy.

There are mainly three kinds of slicing: (1) converting CAD model to STL model, then slicing STL model; (2) slicing the CAD model for hierarchical data directly; (3) measuring solid body to obtain hierarchical data. The first method was widely used, but the poor quality of STL data itself leads to low slicing accuracy. While the third method does not need CAD model, it is only suitable for application in specific situations. The second method is widely used. Yun-xia Chen [3] developed Autoslice Macro based on Visual LISP, which can realize independent control on direction and thickness of slicing.

Slicing is the first step during rapid prototyping processing. Accuracy of slicing will affect the quality of products directly. To improve the precision, we should choose reasonable slicing method. What is more, we had better to decrease the thickness and increase the number of layer.

2.2 Structure of raw material supplying device

We should supply raw materials continuously during EBRP. Raw material supplying device is responsible for processing material flow in the whole process. Similar with laser rapid prototyping, EBRP requires raw material controlling device to realize the function of storage, supplying, compaction and Z axis moving. Because of the particularity of EBRP, there are some special requirements for the raw material supplying device and vacuum chamber [4]:

(1) The size of vacuum chamber affects the cost mostly and directly. So, under the precondition of meeting the technology requirements, we should narrow its size as much as possible.

(2) The focusing, deflecting & scanning of electron beam are based on magnetic field. To avoid the influence on the orbit of electron beam, magnetic materials are strictly forbidden.

(3) EBRP may use powder as raw material. So, it is essential to reduce the effect on raw material when raw material supplying device or vacuum pump works.

Based on the requirements above, raw material supplying device should have two buckets, one is movable and the other is still. In addition, the materials of vacuum chamber and other mechanical parts should be nonmagnetic. What is more, we should increase the quantity of air inlets and the air inlets should be set up reasonably. One structure of vacuum chamber is shown in Figure 2.

2.3 Reasonable planning of scanning path

EBRP requires high scanning speed. Reasonable planning on scanning path is of great importance.

(1) Ensure continuous scanning path. EBRP has high frequency of scanning. By experiment, we found scanning path has great influence on raw materials. If the scanning path is discontinuous, raw materials are easily dispersed because of the temperature difference between newly and previous scanning area [5].

(2) Avoid great changes on the length of scanning path. Electron beam energy can't change timely when the length of scanning line changes suddenly. For example, as shown in figure 3, when α= 0° or 90°, the length of first scanning line shall mutate; but if α= 45°, the length of scanning lines is increasing gradually, which can ensure the quality of scanning.
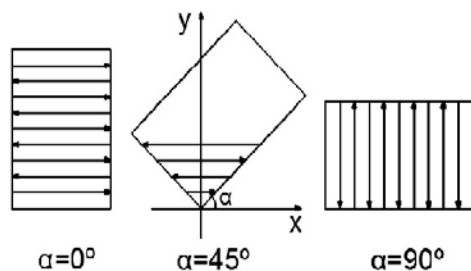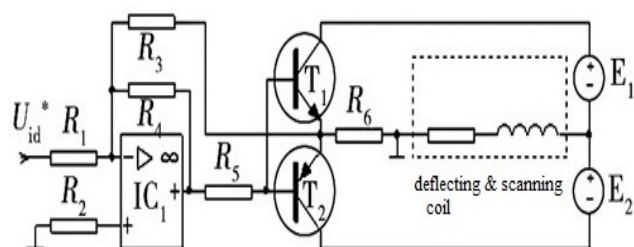

Fig. 3 Scanning path planning   Fig. 4 Power supply of deflecting & scanning coil

2.4 Accuracy of deflecting & scanning device

Deflecting & scanning coil controls the orbit of electron beam by changing its current. After electron beam goes through deflecting & scanning device, deflection angle φ, number of turns N_D, excitation current I_D and acceleration voltage U_r share the formula [6]:

$$N_D I_D = \frac{2.64b\sqrt{U_r \sin\varphi}}{a} \tag{1}$$

In the formula: b－pole spacing, a－effective thickness of pole shoe.

On the focusing plane, deviation distance from the center of electron beam is δ, vertical distance between focusing plane and the center of deflecting & scanning device is h, they share the formula:

$$\delta = h.\tan\varphi \tag{2}$$

According to (1) (2), when U_r is certain, the relationship between δ and I_D is nonlinear. Besides, magnetic leakage and material loss lead to more complex relationship. To improve accuracy of deflecting & scanning, practical experiment is done to establish database for dynamic compensation. Experiment is conducted by the following steps: divide deflecting & scanning area into several small areas and mark all the intersections, move electron beam spot to intersections, then record the given instructions on the screen. Parameters of every point inside the small area can be calculated by linear relation. At last, we convert the stored instructions into voltage signal by D/A converter and send it to $U_{id}*$ of deflecting & scanning power supply in figure 4. As parameters are obtained by observation system artificially, its accuracy is not very high and remains to be improved further.

2.5 Accuracy of focusing device

Focusing device can ensure the equal size of electron beam spot on the same working plane. During working, if focusing current remains constant, the electron beam spot will defocus. To curb defocus, focusing current must be compensated dynamically. Magnetic focusing device contains main focusing and auxiliary focusing power supply. By experiment, we can obtain main and auxiliary focusing parameters of intersections, parameters inside the small area are calculated by linear. Firstly, setting deflecting current and auxiliary focusing current zero and adjusting main focusing current until the electron beam spot focuses, record the main focusing current. Dividing scanning area into several small areas and keeping main focusing current unchanged, move electron beam spot to intersections, then adjust auxiliary excitation current to make it refocus again and record the current. Repeat the step until we get all the parameters. Finally, the auxiliary instructions are converted into voltage signal and sent to U_f* of auxiliary focusing power supply in figure 5. This focusing device can improve focusing accuracy extremely by dynamic compensation.
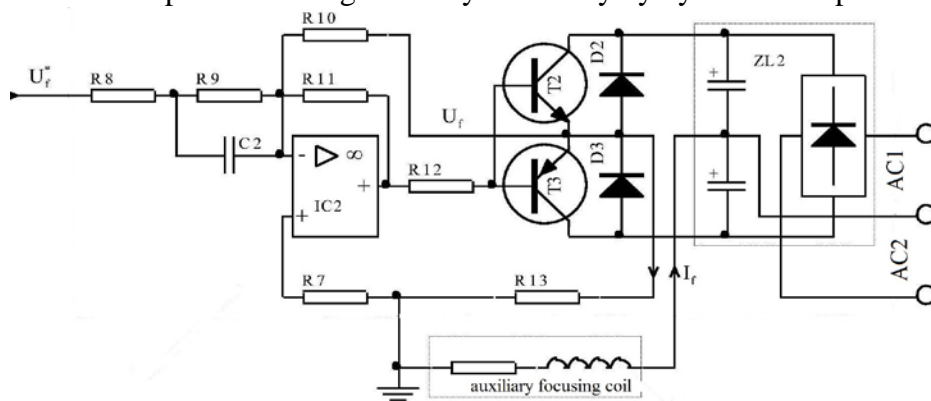

Fig. 5 Power supply of auxiliary focusing coil

3. Summary and prospect

The precision of EBRP mainly depends on slicing data, focusing accuracy, deflecting & scanning accuracy, scanning path and raw material supplying device. EBRP is developing in recent years and the gap between domestic and foreign is not very big. It is chance for us to keep pace with the advancement. Because the technology is still in the early stage of development, great efforts should be paid to realize the rapid prototyping of high accuracy and complexity parts.

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