Journal of Applied Science and Engineering Innovation, Vol.5, No.4, 2018, pp.125-128
ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

Four-axis Linkage 3D Printing Structure Design of Blood Vessel Stent

WU Xiao-qiang[1], ZHANG Chun-you[1], WANG Li-hua[1], LI Li[1]

[1] *College of Mechanical Engineering, Inner Mongolia University for the Nationalities, Tongliao 028000, China*

Abstract: With the rapid development of our country's economy, people's lifestyles have undergone profound changes, especially the aging of the social population and the acceleration of urbanization. Aiming at the design problem of complex mesh thin-wall tube structure for vascular stent, a new four-axis linkage 3D printing manufacturing technology was proposed based on FDM principle. The basic principle of the four-axis linkage 3D printing forming process is described. The design scheme of the four-axis linkage 3D printer device is proposed. The mechanical structure, the control system hardware and software are elaborated in detail, and the printer device is finally manufactured.

Keywords Vascular stent; Four-axis linkage; 3D printing; Structural design

INTRODUCTION

The prevalence of risk factors for cardiovascular disease is significant, leading to a continued increase in the number of people suffering from cardiovascular diseases, accounting for more than 40% of the deaths of residents [Arroyo D et al., 2017]. Vascular stents, as the core part of stent interventional therapy, have undergone three stages of metal bare stents, drug-coated metal stents and fully biodegradable stents in the development of nearly three decades. Since the current medical technology still cannot achieve the removal of the stent from the body, it can be said that the stent implantation is an irreversible process. If the patient has recurrence of thrombus after stent implantation, the same part cannot be implanted again, and the permanent stay of the metal stent will cause great trouble for the patient and it will take lifelong medication, so the drug-coated stent is not fundamental. The problem of permanent retention of first-generation vascular stents was addressed [Arai D D et al., 2016].

As a new generation of coronary artery stents, biodegradable polymer stents have a good biocompatibility and a suitable degradation rate, which can effectively solve the safety problems of the existing stents in the implantation of diseased vessels. This method is the frontier of research in the field of interventional medical devices. However, the existing technology for manufacturing polymer stents has the problems of destroying the biological activity of the material, poor surface quality, size singulation, or high cost. In recent years, with its unique advantages, 3D printing technology has shown tremendous potential for the development of personalized manufacturing of biomedical devices.

Therefore, this article first summarizes the geometric structure of the stent, through analysis and comparison of the stent support unit to affect its radial support performance and has a connection unit to ensure that the stent has a good flexibility. Secondly, a new kind of composite unit polymer stent structure was designed by taking into account several factors such as stent radial support performance, material coverage, vessel diameter and bending degree, symmetry of the stent structure, and the cross-sectional shape of the ribs.

STRUCTURAL DESIGN OF BLOOD VESSEL STENT

The vascular stent is first compressed and assembled on the balloon, delivered through the catheter to the area of the disorder, and then slowly expands and expands the stenotic blood vessels under inflation of the balloon, and finally the balloon is unloaded and withdrawn together with the catheter [Buttafoco L et al., 2017]. After the balloon is unloaded, the stent undergoes slight radial elastic retraction, but the major plastic deformation remains to provide support for the blood vessel.

Basic Form

The early blood vessel stent structure can be divided into a single support unit blood vessel support and a blood vessel support supporting and connecting the composite unit according to its connection manner. The former only has supporting units, and then the entire supporting structure is formed by contacting and contacting the supporting

Corresponding Author: WU Xiao-qiang, College of Mechanical Engineering, Inner Mongolia University for the Nationalities, Tongliao, 028000, China.

units. Although this kind of structure is compact in form and has strong radial support performance, its axial shortening rate is relatively high, and its flexibility is not good. It is difficult to deliver to lesions through tortuous blood vessels in the compressed state, so it has been gradually supported. The vascular stent structure connecting the composite unit is replaced. Although the number of support units supporting the stent connected to the composite unit is reduced, resulting in a decrease in the radial support performance of the stent structure, the added connection unit structure greatly enhances the overall suppleness of the stent and enhances the delivery of the stent in the human body. The operability can also reduce the axial shortening of the stent.

Structural Design

Vascular stent undergoes three deformation processes during its use, and the radial expansion of the stent under balloon inflation is an important part of the entire stent. During the expansion and expansion of the entire stent balloon, the stent not only undergoes plastic deformation but also undergoes a certain amount of elastic deformation. Because the radial and axial rebound behavior of the stent will have an important impact on the actual treatment effect of the stent, relevant performance indicators that the stent structure needs to meet must be clearly understood in the stent design work, and be fully considered in the stent structure design process.

If there is a large amount of radial rebound, the stent will not be able to achieve the desired support effect on the vessel wall, resulting in a poor healing effect [Placone J K et al., 2015]. Radial elastic retraction rate formula is as follows

$$R_{recoil} = \frac{R_{loading} - R_{unloading}}{R_{unloading}} \times 100\% \quad (1)$$

where $R_{loading}$ and $R_{unloading}$ respectively indicate the central radius of the stent when the radial load is maximum and the central radius of the stent after completely unloaded.

As the diameter of the vascular stent gradually increases during expansion, its axial length will decrease accordingly. A larger amount of axial rebound will reduce the accuracy of the stent positioning, and the stent has the risk of scratching the blood vessel's inner wall tissue during the axial rebound process, ultimately reducing the therapeutic effect. The axial shortening rate is calculated as follows

$$L_{ratio} = \frac{L_{initial} - L_{final}}{L_{final}} \times 100\% \quad (2)$$

where A and B indicate the length of the stent before expansion and the length of the stent after expansion, respectively.

DESIGN OF 4-AXIS LINKAGE 3D PRINTING SYSTEM

Basic Principles

Four-axis linkage 3D printing is a new type of manufacturing technology based on the principle of Fused Deposition Modeling (FDM). FDM molding technology is an important type of 3D printing technology, mainly used for molding thermoplastic polymer material models. Therefore, FDM is very suitable for the manufacture of polymer stents. In the fused deposition molding process, a thermoplastic polymer wire is transported from a feeding device to an extrusion device having a heating function, heated to a molten state according to a set process temperature, and uniformly extruded. Finally, the layers are piled up on the forming platform and cooled and solidified to obtain the parts.

Printing Device Design

According to the principles of the four-axis linkage 3D printing process, the corresponding printing device needs to have the following core parts: a control assembly, a frame, a print head device, a feeding device, and each moving axis assembly. The XYZ three-axis motion of the four-axis linkage 3D printer is similar to that of an ordinary FDM 3D printer, so the mechanical structure of the more mature FDM 3D printer can be directly selected. The mechanical structure of the mainstream FDM 3D printer is divided into three main types according to the transmission mode: XYZ type, Core XY type and Delta type. After a comparative analysis, the three motion axes of the XYZ printer are independently controlled by three stepper motors (sometimes the Z axis has two motors synchronously controlled). The three axis drives are independent of each other and do not require coordinate conversion, and they have high precision of motion. With good stability and easy installation, it is more suitable for the movement requirements in the X, Y and Z directions in this design.

Control System Hardware Design

The four-axis linkage 3D printer is a mechatronic system device. The hardware circuit is the basis for the operation of the entire 3D printer control system and its performance is directly related to the performance of the entire printing system. The hardware of the four-axis linkage 3D printer control system mainly includes four parts: a main control module, an information interaction module, a temperature control module, and a motion control module. The system composition is shown in Figure 1.

Control System Software Design

The control system software of the 3D printer includes two parts: an upper computer and a lower computer. The upper computer and the lower computer perform two-way communication through a specific communication protocol and form a two-layer structure of control. The function of the upper computer software is to set the printing parameter information, and the CAD model file is sliced and processed according to the requirements of the forming process, and then the processing unit is refined. The upper computer generates the model processing path code and sends it to the lower computer for execution.

In the printing process, the movement of each axis of the 3D printer can be roughly divided into two types of linear motion trajectories and circular motion trajectories. Arc trajectory motion is essentially a large number of tiny linear motion units fitted, so linear motion is the basis of the motion control unit. The linear trajectory planning process designed in this paper is shown in Figure 2.The temperature control unit is mainly responsible for the temperature control of the printer head and the A-axis surface. The temperature inside the nozzle

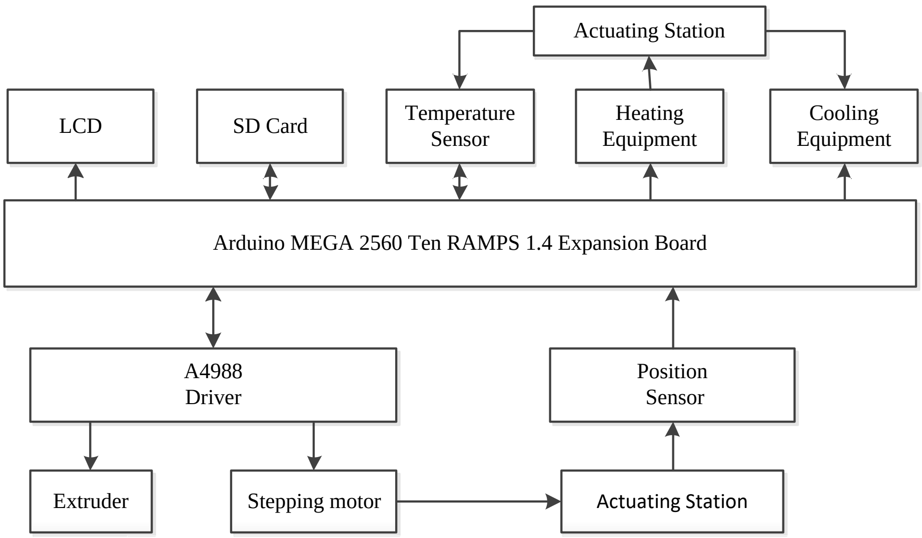

Figure 1 Components of Four-axis 3D Printing Machine

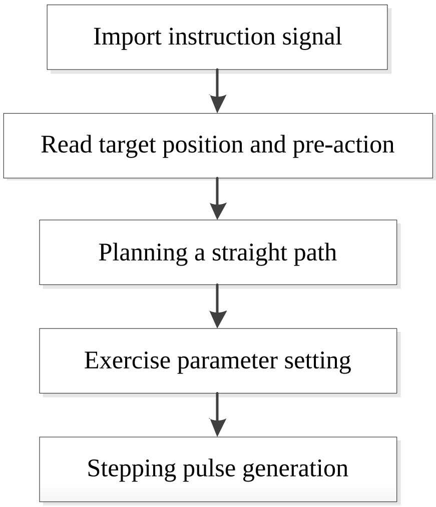

Figure 2 Linear motion planning process in Marlin

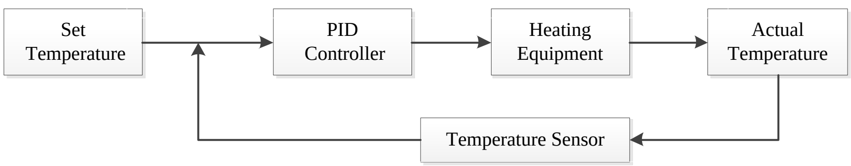

Figure 3 Schematic of Close-loop Temperature

chamber needs to be kept within a certain range to ensure that the extruded polymer material has a uniform viscosity and better fluidity. A certain temperature on the surface of the A-axis ensures that the first layer of the article adheres well to its surface, thereby effectively preventing warpage from occurring. Therefore, precise control of the surface temperature of the spray head and the A-axis is particularly important during the entire process. For this reason, the device temperature control unit adopts a closed-loop temperature control method based on PID adjustment. The structure is shown in Figure 3.

CONCLUSION

This article studies the issue of 3D printing of vascular stent. Firstly, the geometric structure of stents was analyzed and summarized. Based on the principle of fused deposition, a novel four-axis linkage 3D printing manufacturing technology was proposed for polymer stents. Secondly, the basic principle of four-axis linkage 3D printing is expounded, and the unique advantages of the complex mesh thin-wall tube structure such as the forming of vascular stents are described. Finally, a design scheme of a four-axis linkage 3D printer device is proposed.

REFERENCES

Arroyo D, Gendre G, Schukraft S, et al. Comparison of everolimus- and biolimus-eluting coronary stents with everolimus-eluting bioresorbable vascular scaffolds: Two-year clinical outcomes of the EVERBIO II Trial [J]. International Journal of Cardiology, 2017.

Arai D, Ishii A, Chihara H, et al. Histological examination of vascular damage caused by stent retriever thrombectomy devices[J]. Journal of Neurointerventional Surgery, 2016, 8(10).

Buttafoco L, Dijkstra P J, Poot A A, et al. Collagenous porous structures for the development of an artificial small diameter blood vessel[J]. Journal of Controlled Release, 2017, 87:295-298.

De D G, Setacci F, Bresadola L, et al. Aortic neck evolution after endovascular repair with TriVascular Ovation stent graft [J]. Journal of Vascular Surgery, 2016, 63(1):8.