UDC 622

DESIGHN OF MOTION CONTROL SYSTEM FOR 3D ENGRAVING MACHINE

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1. Introduction

Engraving machines are generally divided into two categories according to their carving forms: laser engraving machines and mechanical engraving machines; Classified by axis: ordinary engraving machines, four axis linkage engraving machines, and five axis linkage engraving machines can be widely used in industries such as advertising and gift making, wood and stone processing, circuit board drilling processing, packaging production, seal carving, etc. [1], and have moved from factory workshops to individual users such as schools and families. The engraving machine is essentially a CNC milling machine with CNC turning and milling functions, but traditional CNC milling machines have complex structures, large volumes, high energy consumption, and high prices [2]. The installation also requires skilled professional operators. Maintenance may also incur secondary costs, which brings great inconvenience to ordinary families and individual users.

The 3D engraving machine designed in this paper is actually a CNC milling machine with XYZ three-axis linkage and electric spindle rotation angle θ, based on the Gugao motion controller, carries out servo driving control on the engraving movement in real time. The engraving contour has high precision. It is equipped with a wide range of frequency conversion speed regulation electric spindle, which ensures smooth cutting and strong load capacity. This solution adopts a gantry three-axis structure, which is small in size, low in cost, easy to maintain, flexible and safe in operation, and suitable for school teaching and practical training as well as individual DIY users at home.

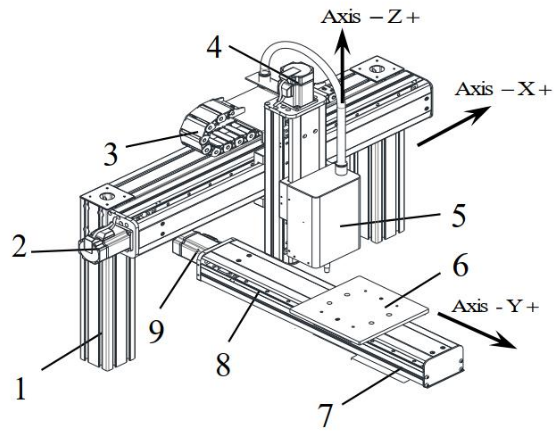
2. Design Indicators and System Structure

The overall working parameters and accuracy indicators of this system are shown in Table 1.

Table 1 Main working parameters and design indicators of the system

SN	Name	Parameter
1	Distance of run	X*Y*Z: 300mm*300mm*100mm
2	Spindle	90W Self cooling electric spindle, maximum speed: 50000r/min
3	Frequency transformer	750W, Frequency range: 0.5--1200Hz
4	Repetitive positioning accuracy	0.05mm

The mechanical structure of the system is shown in Figure 1, consisting of a gantry support, base, fixture installation platform, and other mechanical bodies, a linear sliding module in the XYZ three-axis direction, as well as a workpiece fixture and carving tool. Inside the linear sliding module, it is composed of transmission and execution mechanisms such as couplings, ball screw pairs, guide rails, and motors. The gantry structure is stable, the ball screw transmission efficiency is high up to 98% [3], and the overall positioning accuracy is high.



1 - Gantry bracket 2 - Servo motor of AxisX 3 - Drag chain 4 - AxisZ Stepper motor
5 - Spindle 6 - Fixture installati on platform 7 - slide 8 - Ball screw 9 - Servo motor of AxisY

Fig.1 Mechanical structure of engraving machine

The control system of the 3D engraving machine consists of a controller, servo driver, encoder, stepper motor driver, and frequency transformer, with the control objects being XYZ axis and spindle motors. Among them, the X-axis and Y-axis are powered by servo motors, which use encoders to feedback displacement to the main controller; The Z-axis is driven by a stepper motor to reduce costs; Install limit switches on each axis. By combining the XYZ three axis motion, the tool can move in any direction in three-dimensional space; The spindle is driven by an asynchronous motor controlled by a frequency converter, which enables high-speed rotation of the cutting tool to achieve workpiece milling and engraving processing. The system structure schematic diagram is shown in Figure 2.

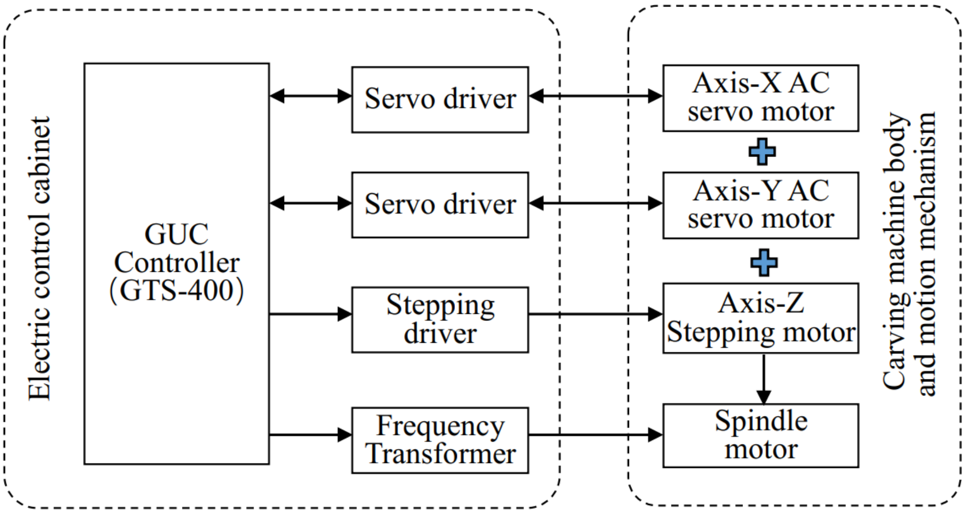


Fig.2 Control System Scheme for Engraving Machine

The control system adopts Gugao GUC-T series CPAC (integrated industrial computer and motion controller) embedded multi axis motion controller, as shown in Figure 3. Under the Otostutio or Windows Visual Studio environment, it can also develop customized control programs. Cooperating with servo motor driver, stepping motor driver, frequency transformer, drive and control the XYZ axis and spindle motor of the engraving machine, and use auxiliary limiters, pulse encoders to achieve the position and speed planning, detection, and closed-loop control of acceleration and other information, then ultimately achieve a precise trajectory synthesis and engraving functions for spindle tools.

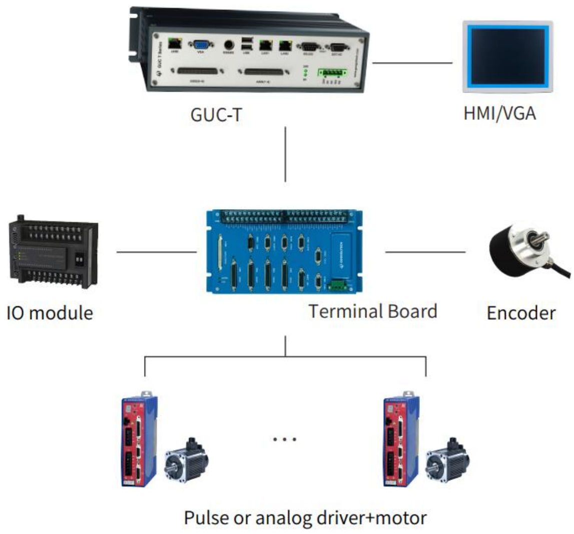


Fig.3 Core device architecture of control system

3. Motion control and speed planning

The acceleration and deceleration control of the axis is one of the key technologies in the development of motion control systems, which directly affects the smoothness and synthetic motion accuracy of transmission components and machining operations. Common acceleration and deceleration control methods include linear acceleration and deceleration (T-curve acceleration and deceleration), trigonometric function acceleration and deceleration, exponential acceleration and deceleration, S-curve acceleration and deceleration, etc. [3]. The T-curve represents the linear mathematical relationship between speed and time, with the advantage of simple expression and fast calculation speed. However, at the turning point of acceleration and deceleration, its acceleration will cause a jump, which means the impact phenomenon of axis movement will occur. In order to obtain a smoother speed curve, this paper uses the PVT mode, and uses a series of data points' "position, speed, time" parameters to describe the axis's motion law, thus realizing the S curve motion planning.

The position, velocity, and time satisfy the following functional relationship:

$$\begin{cases} p = at^3 + bt^2 + ct + d \\ v = \dfrac{dp}{dt} = 3at^2 + 2bt + c \end{cases} \qquad (1)$$

According to equation (1), if the "position, speed, and time" parameters of two adjacent data points are given, it can be obtained that:

$$\begin{cases} at_1^3 + bt_1^2 + ct_1 + d = p_1 \\ 3at_1^2 + 2bt_1 + c = v_1 \\ at_2^3 + bt_2^2 + ct_2 + d = p_2 \\ 3at_2^2 + 2bt_2 + c = v_2 \end{cases} \qquad (2)$$

By solving the equation system (2), the undetermined parameters a, b, c, and d can be obtained, and the motion laws of the adjacent two data points can be determined. Establish a new C# engineering project in Windows Visual Studio, add in the Gugao motion control function library, and utilize its function mc.GT_PvtTable() can automatically solve these 4 parameters based on the given PVT data points [4]. According to the process shown in Figure 4, the planning of "position, speed, and time" can be completed by calling functions of this library such as controller initialization, servo on, PVT mode planning, and servo off.

```
Step1 Initialization:
        mc.GT_Open();//Open Motion controller
        mc.GT_Reset();
Step2 Servo on:
        mc.GT_Axis(1);// Set Current Axis
        mc.GT_AxisOn();
Step3 PVT Motion control:
        mc.GT_PrfPvt();// Switch to PVT mode
        mc.GT_PvtTable();// Send 4 points into datatable
        mc._SetPvtLoop();//Set to run in a loop
        mc.GT_PvtStart();
Step4 Servo off:
        mc.GT_Axis(1);//Set current axis
        mc.GT_AxisOff();
```

Fig.4 Steps of programming in PVT mode

Table 2 Test Point Data

Datasets	Data Ponts	Time (ms)	Positions (pulse)	Velocity (pulse/ms)
1	P1	0	0	0
	P2	1000	5000	7.5
	P3	2333	15000	7.5
	P4	3333	20000	0
2	P1	0	0	0
	P2	750	1667	6.6669
	P3	2250	18333	6.6669
	P4	3000	20000	0

The two sets of data points in Table 1 are the construction data for PVT testing, and the test results are shown in Figure 5. The position and velocity curves have achieved control of the S-shaped curve, and the acceleration has also achieved continuous and smooth linear increase and decrease. The motion control of the entire axis has achieved a good transition, and the system will not encounter impact problems.

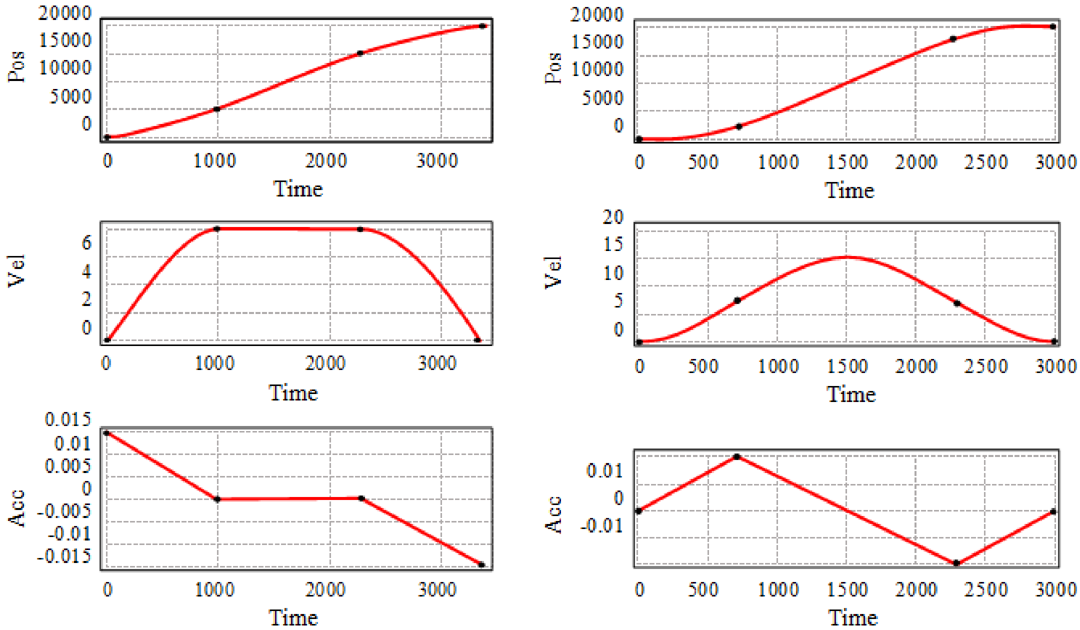


Fig.5 Steps of programming in PVT mode

4. Decoding and Execution of OpenCNC System

Implementing decoding support for NC code and interface with existing CAD/CAM technology is a guarantee for the engraving machine to have strong graphic processing capabilities. The NC program code contains a large amount of instruction information for machine tool motion and control. Decoding is the process of extracting motion instructions and information from the NC code segment by segment, in which a set of structural arrays can be defined to store.

After extracting the motion instructions and parameter information of the NC code, it is also necessary to calculate and generate the actual motion trajectory of the tool [5], [6]. The actual motion trajectory of the tool is a composite target that controls the motion of each axis. The generation of the actual motion trajectory of the tool first converts the workpiece coordinate value of the tool into the machine coordinate value based on the programming method of the machining program and the setting of the workpiece coordinate system. Then, based on the tool compensation setting, the actual motion trajectory of the tool during contour machining is calculated.

Coordinate mapping is a prerequisite for achieving multi-axis coordinated motion. The establishment of coordinate mapping is to map the motion described in the coordinate system to the corresponding axis through the coordinate mapping relationship, and establish the kinematics transitive relation between the motion of the coordinate system and the motion of each axis. The prototype of the coordinate mapping command function provided by Gugao motion control is:

mc.GT_ MapAxis(short Axis_Num,double *map_count)

Axis_Num is the axis number, and after calling the coordinate mapping command, the axis operates in coordinate motion mode. The actual position of the axis is recorded as Axis_N. The unit is pulse. Array map_Count consists of five elements, denoted as Cx, Cy, Cz, Ca, and C. The mapping relationship described by the above functions can be simply described as the following calculation formula:

$$Axis\_N = Cx \times x + Cy \times y + Cz \times z + Ca \times a + C \quad (3)$$

The motion of the mapped control axis is a linear combination of coordinates X, Y, Z, and A. Due to the fact that the engraving system in this paper only uses three-axis motion synthesis, and the fourth axis is the main axis, it can be simplified as:

$$Axis\_N = Cx \times x + Cy \times y + Cz \times z + C \quad (4)$$

If it is only used for planar graphic carving and the Z-axis is a given value, there is no need for mapping. Call function GT_LnXY() can achieve two-dimensional linear interpolation and call the function GT_ArcXYC() or GT_ArcXYR() can achieve two-dimensional arc interpolation [7]. Figure 6 shows the linear interpolation and circular interpolation tests completed by this system after converting and decoding short NC codes, simulating the processing situation of no-load operation, and the interpolation operation works well.

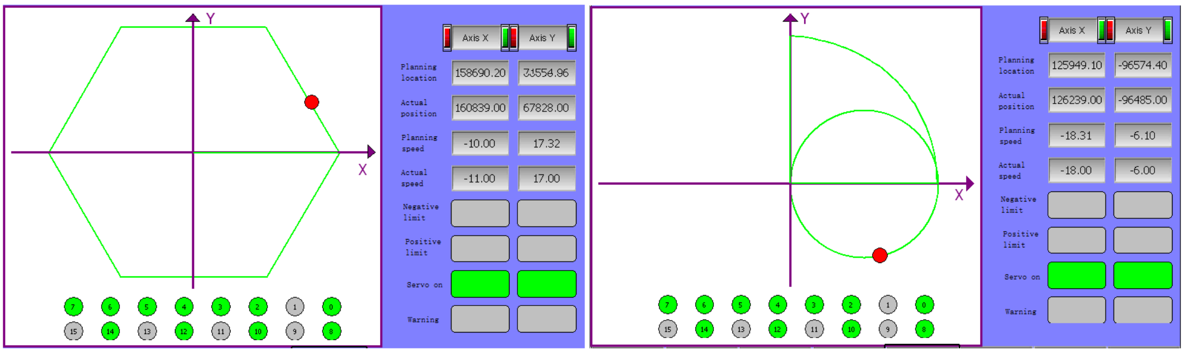


Fig.6 Line and arc interpolation testing supported by OpenCNC decoding

5. Conclusion

Taking the XYZ three axis and the spindle rotation angle θ as the control object, A carving machine with Gantry structure has been designed for individual family users or practical teaching in schools. We have optimized the control scheme, especially in the tool control plan for planar contour machining, using closed-loop servo drive to ensure the accuracy of planar machining graphics; In the Z-axis feed direction, a common stepper motor driving plan is selected, which effectively reduces the overall cost of the entire machine while meeting the needs of most PCB, PVC, stamp, and wood flat carving scenarios. At the same time, the advanced multi-axis motion controller is adopted in this paper, and its PVT motion mode is used to further optimize the stability of the motion of each axis; The injection of OpenCNC system support library can better integrate with current CAD/CAM technology, making the engraving machine more practical and get wide market application prospects.

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