Design of Saddle-Type Seam Welding Gun Posture Adaptive Actuating Mechanism

Wang Yong¹, Bian An-gen², Wang Lei¹
¹School of mechanical Engineering, Nantong Vocational University, Nantong, Jiangsu, 226001, China
²Jiangyin JiaYou Engineering Materials Co., Ltd, Jiangyin, Jiangsu, 214400, China
wyntvu@163.com

Abstract. The two pipes are connected orthogonally to form a saddle-shaped intersecting line. The welding device uses a double-cam compound motion mechanism to achieve automatic welding of saddle-shaped curved seams. The small cam is used to control the up and down movement of the welding torch to track the seam trajectory, and the large cam is used to control the welding torch head and the welding point. A reasonable welding angle is maintained by the normal plane. For the cams of the key components of the above device, this article uses a three-dimensional CAD modeling design of the tube and tube orthogonal to obtain a saddle-shaped intersection line, obtain a certain number of discrete point coordinates on this space curve, and inversely obtain its contour by applying the principle of inversion.

1. Introduction

Thin-walled steel pipes are widely used, especially in parasols, beach chairs and other things, which require orthogonal or oblique welding between pipes[1]. The two pipes are orthogonally connected, and the intersection line is a saddle-shaped space curve. Automated welding of such spatial curves is still a difficult task [2-4], and manual welding which has the characteristics of high labor intensity, high technical requirements from welders, and low welding quality still occupies a considerable portion.

This article aims to design an automatic welding device with simple structure, low manufacturing cost, accurate positioning, high repeatability and zero error accumulation, without using expensive robots[5-8] or multi-axis controllers[9,10] that need to be programmed. Workers can achieve the goal of mass production with almost no welding experience.

Two thin-walled tubes orthogonal welding is discussed as an example. The outer diameter of the two thin-walled tubes are 42mm each, one of the thin-walled tube is an elbow with an angle of 120°, and the other wall tube is a straight tube and is vertically orthogonal to the front tube. The two tubes are orthogonally connected to form a saddle-shaped intersection line. This welding device uses a double-cam compound motion mechanism, using only one motor as a power source to drive the main shaft to rotate and transmit it to the cam shaft through the bevel gear. The rotation of the main shaft causes the workpiece to perform a rotary motion, and the cam shaft drives the large and small cams to rotate. The small cam is used to control the up and down movement of the welding torch to track the welding track, and the large cam is used to control the welding torch head to always maintain a reasonable welding angle with the normal plane of the welding point. This article focuses on the structure and design method of the torch actuating device, which is the key component of this automatic welding device.
2. Design of welding torch actuating device
This device uses a double-cam compound motion. The reciprocating linear movement of the torch in the vertical direction and the arc movement of the torch with the welding point as the center point is achieved through the transmission of motion between the roller and the push rod. Because the cam mechanism is used, the mechanism is simple and compact, and the transmission is reliable.

![Three-dimensional modeling diagram of the welding device.](image)

It is well known that the contour shape of the cam determines the movement of the follower. So, the cam contour curve needs to be reversed according to the movement of the follower when designing. There are two methods for designing the cam contour curve: the graphic method and the analytical method. Because the trajectory of the welding torch head described in this article including the small cam pushing the slider to move linearly, the large cam pushing the triangular top plate to move linearly, and the triangular top plate pushing the welding torch seat performing arc motion inside the welding torch holder with arc shape is a compound motion, the calculation workload would be large if the mathematical model is used to analyze the solution, and there would be a cumulative error, this article uses an intuitive and simple graphical method and production practice to determine the large and small cam profile curve.

CAD software is used to model the orthogonal intersection line of the real thin-walled tube, and divide it into several parts according to the direction of the work table’s rotation. Corresponding to each point on the intersection line, the accurate position of the welding torch head can be easily obtained. And then the corresponding positions of the followers can be measured correctly. Using the "reverse method" principle, according to each vertical displacement of the follower and corresponding angular position, the position points on the contour line of the large and small cams can be gotten. The more the value of the angle is divided, the more the position points on the contour curve and the more accurate the contour of the cam after fitting.

3. Design of the small cam
It can be seen from Figure 2 that the saddle-shaped space curve is composed of four identical working paths, each of which has a rotation angle of exactly 90 degrees. Here, the difference between the inner and outer sides of the opening angle (120 degrees elbow) is ignored.
Figure 2. Schematic diagram of the intersection of two orthogonal tubes.

3.1. Determining the base circle diameter
The smaller the base circle of the cam, the more compact the mechanism is. However, if the radius of the base circle is too small, the pressure angle will increase and if the pressure angle exceeds the allowable value, the efficiency of the mechanism will be low, and even the self-locking will lead to the deterioration of the work of the mechanism. The base circle diameter D is chosen as 66mm.

3.2. Determining the discrete points
Through three-dimensional modeling, 10 points are selected on the intersecting curve of 0-90 degree, where 0 degree is the most extreme position of the vertical tube, which is the lowest point of the intersecting line. Obtain the distance of the displacement of the follower at each point according to the three-dimensional model (see Table 1), which is used to determine the outline of the small cam.

Table 1. Discrete points of the displacement of the small cam follower.

| Workpiece rotation angle (°) | 5   | 10  | 20  | 28.5| 40  | 50  | 60  | 70  | 80  | 90  |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Follower displacement (mm)   | 0   | 0   | 0   | 5.2 | 6.2 | 7.1 | 9.5 | 10.2| 11  |

3.3. Determination of outline of the small cam
After selecting the diameter of the base circle of the small cam contour, with the help of the data from Table 1, the maximum diameter of the small cam is 88mm, and the minimum diameter is 66mm, which cover 57 degree (double of 28.5 degree). The other point can be obtained from Table 1. The contour of the small cam can be fitted (Figure 3).

Figure 3. Schematic diagram of the overall structure of the small cam
4. Design of the large cam

4.1. Determining the base circle of the large cam
Taking into consideration that the welding torch is installed on the welding torch base, the welding torch base performs arc motion on the welding torch frame, and the welding torch has a certain length, so the up and down movement of the welding torch itself superimposes the welding torch. The change of posture angle will have an amplifying effect in the welding gun base movement. If the base circle of the large cam is too small, it will be difficult to control the angle of the welding gun during the rotation of the large cam. The base circle diameter of the large cam is chosen as 280mm.

4.2. Determination of discrete points on the contour line of the large cam
After selecting the base circle of the large cam, according to the movement of the torch base in the torch frame from 30 to 50 degree, the displacement of the follower corresponding to each rotation angle is determined (Table 2).

| Workpiece rotation angle (°) | 5   | 10  | 20  | 28.5 | 40  | 50  | 60  |
|-----------------------------|-----|-----|-----|------|-----|-----|-----|
| Follower displacement (mm)  | 0   | 0   | 0   | 0    | 9   | 16  | 32.5|
| Workpiece rotation angle (°) | 70  | 80  | 90  | 100  | 110 | 115 | 122.5|
| Follower displacement (mm)  | 40.4| 49.5| 58.4| 86   | 96  | 100 | 81  |
| Workpiece rotation angle (°) | 130 | 140 | 151.5| 160 | 170 | 180 |
| Follower displacement (mm)  | 50  | 20  | 0   | 0    | 0   | 0   |

4.3. Determination of outline of the large cam
After selecting the diameter of the base circle of the large cam contour, with the help of the data from Table 2, the maximum diameter of the large cam is

280+100+100=480mm,

And the minimum diameter is

280+0+0=280mm,

which also cover 57degree. However, the inner and outer sides of the intersection line of the opening angle (120degrees elbow) cannot be ignored. The large cam roller has a slightly longer distance when tracking the intersecting line of the second half, so the inner part of the geometrical profile of the large cam covers 150°. The overall outline of the large cam is shown in Figure 4.

Figure 4. Schematic diagram of the overall structure of the large cam
5. Conclusion
This device is based on the intersection line formed by the orthogonal thin-walled tube with a specific diameter and wall thickness to design the outline shape of the large and small cams and the arc-shaped slide rail of the welding gun frame. According to the ideas in this article, it can be very convenient to design cam shaped and arc-shaped slide rails suitable for other tube-to-tube welding with different pipe diameters, which are used for orthogonal welding of thin-walled pipes of various pipe diameters and wall thicknesses. To increase interchangeability and reduce costs, other parts of the device are chosen in general purpose, which can improve the conditions for the serial production of automatic welding equipment for thin-walled tube orthogonal welding. It also solves the problems of manual welding quality, low welding efficiency, and harsh environment. It greatly improves the welding quality and welding efficiency.

The double cams are used to achieve the tracking of the welding track and the change of the welding gun's posture. The designed thin-walled tube welding device has obvious features of simple structure, stable operation for a long time, high efficiency, easy use, easy maintenance and so on.

References
[1] Dai Yili, Yu Shengfu, Shi Yusheng, He Tianying and Zhang Lichao 2018 Int J Adv Manuf Technol962389–96
[2] Henwei Jia, Tianqi Wang, Liangyu Li, Junjie He 2020International Journal of Precision
Engineering and Manufacturing2145–55
[3] Yan Liu, Lei Shi, Xincheng Tian 2018 Int J Adv Manuf Technol952457–71
[4] Zhang Zhonghou, WU Chuansong 1997Transactions of the china welding institution1816-19
[5] Yan Liu, Lijuan Ren, Xincheng Tian 2019 T Int J Adv Manuf Technol105265-278
[6] Kiddee P, Fang Z, Tan M 2016Int J Adv Manuf Technol873589–603
[7] Mahajan A, Figueroa F 1997 Robotica5275–281
[8] Fridenfalk M, Bolmsjo G 2004Adv Robot181–21
[9] Lei Shi, Xincheng Tian 2015 Int J Adv Manuf Technol77955–964
[10] Huo Menyou, Zhang Zhonghou 2005Transactions of the china welding institution2674–77