Research and Manufacture of CNC Water jet incremental forming machine tool

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Abstract—High Pressure Water Jet Incremental Sheet Metal Forming (HPWJISMF) brings higher process flexibility and better tools to workpiece interface conditions. AWJISMF is quite suitable for the production of multi-varieties and small batch products and trial-manufacture of new products. But up to now, there is not suitable machine tool for HPWJISMF. The facility for HPWJISMF designed consists of three main components. A high-pressure pump capable of delivering a constant volume flow of 30 L/min at maximum pressure 120 MPa, a table with a working area of 600 × 600 mm and a controller. The workbench has three translational degrees of freedom and the nozzle has two rotational degrees of freedom. The machine tool operates flexibly. The conical parts are processed on the machine tool. The parts meet the machining accuracy after measurement.

1. Introduction

Conventional sheet metal forming processes are essential for modern manufacturing industry. These processes require substantial capital investments and long die-preparation times. These sheet metal forming processes can produce large quantities of parts in a rapid, efficient, and cost-effective manner for mass production, and die and punch costs can be amortized across many parts [1]. For the rapid development of industrial products, a great deal of research works has been concerned with shortening the lead time and reducing the production cost. It has been attempted to raise the flexibility of the forming process by using tools with variable geometry. Nevertheless, the production of a workpiece depends on the possible geometry of the tool, so that flexibility is restricted. In addition, the high costs for the forming machine remain the same. In order to meet these requirements, High Pressure water Jet Incremental Sheet Metal Forming (HPWJISMF) has been tried which is a die-less forming process that uses hemispherical/spherical or other shaped ended tools to form the sheet progressively by a series of local deformations. Many researches focus on the process. However, the development of equipment has not been paid attention [2-3].

We have designed a five-axis HPWJFISMF machine tool with three translational degrees of freedom of workbench and two rotational degrees of freedom of the nozzle, in order to study the technology of HPWJFISMF. This five-axis machine tool adopts an open control system with PC and motion controller, which can somewhat meet accuracy demand with good openness, practical applicability and augment ability. With Windows as the operating environment, VC+6.0 as the platform, object-oriented method as software development technique, functional modules of the system controlled by hierarchical
construction and the development of human-computer interaction interface, it possesses strong flexibility [4].

2. High pressure water system
The essence of HPWJISMF is to replace the common metal tools with "water knife". The force required for plastic deformation of materials is the striking force of water jet on the plate [5]. The material deformation force is very large. So, the pressure of water jet is also very large. We have designed the system that can produce high-pressure water. The system is composed of low-pressure water system and hydraulic pressurization system which increases the pressure of the low-pressure water system. The schematic diagram is shown in Figure 1.

![Schematic diagram of high-pressure water system](image)

Fig.1 The schematic diagram of high-pressure water system

The low-pressure water generated by the rotation of the water pump increases the water pressure through the reciprocating motion of the booster cylinder. The maximum water pressure offered by the high-pressure water generating device is 100 Mpa, the rated flow is 30 L/min. System water pressure is achieved by increasing the pressure of the pressurization system. The pressure change of pressurization system is realized by changing the speed of variable frequency motor and therefore the pressure control of this system is realized by frequency converter, through which the motor speed could get stepless control, thus makes the pressure of high-pressure water more flexible. An additional water tank could realize the recycling of water after filtration in order to save resources.

3. Mechanical structures system
At present, the forming equipment used in the research of sheet metal water jet incremental forming is still relatively simple. Most of them are transformed from water jet cutting machines, and the formed plates can only be on the X, Y plane driven by the workbench. Meanwhile, the nozzle can only move along the Z direction. The facility should not be regarded as a restriction factor of the experimental research and verification of the forming mechanism. Therefore, it is particularly important to develop a
set of five axis water jet incremental forming machine tool.

According to the principle of HPWJIMT, the mechanical structure of HPWJIMT is developed. The mechanical structure of the HPWJIMT is shown in Figure 2. Figure 3 shows the physical photos of equipment.

Fig. 2 Mechanical structure diagram of five-axis HPWJIF machine tool
1-X axis servo motor; 2-ball screw for driving X-axis; 3-machine base; 4-Y axis servo motor; 5-Ball screw for driving Y-axis; 6-working platform; 7-machine tool fixture; 8-inclined rotating parts of nozzle; 9-nozzle fixing parts; 10-ball screw for driving Z-axis; 11-Z axis servo motor; 12-machine guard covers; 13-high-pressure inlet pipe; 14-low-pressure outlet pipe

Fig. 3 the physical photos of HPWJIF

The machine body is mainly composed of a vertical body and a cross motion slide type structure. Its mechanical system mainly includes the machine base, inclined rotating parts of nozzle, linear moving parts of X, Y and Z axes, fixture, sealing and waterproof parts, etc. There are five axes in five different directions: X, Y, Z, A (moving around X), and C (moving around Z).

When large angle parts need to be formed, the nozzle needs to be tilted at a certain angle. The pressurized water jet vertically shoots at the formed part. Therefore, the nozzle tilting mechanism is designed. Figure 4 shows the 3D-model diagram.

When the nozzle needs to be tilted at a certain angle, the B-axis servo motor is start. The power is transmitted to the ball screw through the B-axis coupling which drives the push rod to move in a straight line along the z-axis direction. The movement of the push rod along the Z-axis causes the relative slip
between the rolling bearing connected at the end of the push rod and the sliding groove support.

![3D-model diagram of nozzle tilting mechanism](image)

Fig.4 3D-model diagram of nozzle tilting mechanism

4. **Control system design**

The controller is based on computer PCI bus, which can control 1-8 axes servo motor at the same time with 16 universal I/O input and output. The semi closed loop position control mode is used in the control system. The control system includes six parts: main program control part, high-pressure water system control part, Single axis motion control part, motion state detection part, machining trajectory simulation part and G code display part.

The software control part of the system is developed with C++ as development language and VC6.0 as development environment. Under Windows XP[6], this system has developed its unique software for motion control system with powerful DLL provided by GTS – 800-PCI motion controller.

The main functions of the main program control part include initializing the motion control card, closing the card, reading and judging the G code file, controlling the machining process of the whole part and returning to the origin.

The functions of the control part of the high-pressure water system mainly include the remote control of the start and stop of the pipeline pump through the PC, the switch of the frequency converter and the opening and closing of the unloading valve, and the monitoring and regulation of the high-pressure water pressure.

The function of single axis motion control part is to control each axis separately, such as point motion, jog motion. The control part is convenient for testing of equipment.

The motion state detection part can detect the limit of the machine tool and the real-time position of each axis. Meanwhile, display the status of each part of the machine tool and give feedback and prompt alarming in time.

The machining path simulation part can display the coordinate position of the nozzle movement. It can track the line to which the instruction is executed at any time, so that the correct trajectory design can be simulated and analyzed before machining.

5. **Processing experiments verification**

Galvanized steel plate is selected as the plate for the experiment. A conical table part with a depth of
25.5418mm and a forming angle of about 43° is formed from outside to inside from top to bottom. The maximum outer diameter of the track circle is 140mm and the minimum outer diameter of the track circle is 90mm. The formed parts are shown in Fig. 5. Figure 6 shows the machining process diagram. After 13 passes, a cylindrical part with approximately straight side wall was formed. The process parameters for forming the part are as follows: nozzle diameter 0.8mm, water jet pressure 105 MPa, target distance 8mm, nozzle feed speed 600 mm / min, transverse layer spacing 1mm, and the included angle between jet and vertical direction is 0.

6. Conclusion
When forming the side wall of the large angle or straight wall parts, if water jet doesn’t change incident angle, the angle between the jet and the sheet metal surface, the force which is perpendicular to the sheet metal surface, plastic deformation and parts’ forming accuracy and efficiency will become smaller with parts forming depth increasing. When using water jet forming metal bellows, nozzle should rotate around the central axis of the tube. A five-axis water jet forming equipment is designed in order to solve the above problem.

Based on the principle of water jet dieless forming, five-axis water jet forming prototype was researched and the developed. Qualified forming parts was forming through a large number of processing experiments, this provides a good platform for further study of water jet sheet metal forming theory.

After design of the machine tool is completed. We need to use this equipment to study the mechanism of high-pressure water jet incremental forming of complex parts. It is necessary to focus on the changes of stress, strain and thickness of plates under the action of jet.

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