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A design of the incremental sheet forming system operating with the assistance of ultrasonic vibrations

Nguyen Thanh Son
Faculty of Mechanical Engineering, Vinh University of Technology Education, Vietnam

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ABSTRACT: In this work, the process of designing, fabrcating, installing and operating a system for implementing the incremental sheet forming process with the asisstance of ultrasonic vibration was carried out. Ultrasonic transducer and forming tool is carefully selected and designed to ensure working in the ultrasonic frequency range. A vertical milling machine has been completely converted into a CNC machine, capable of performing direct programming or importing CNC programs into the machine via USB port.The results of system operation show that the signal of the force component in the axial direction (Fz) is significantly reduced. This proves that the system has been designed according to requirements.

KEYWORDS: Ultrasonic-assisted, Incremental sheet forming, CNC, system.

I. INTRODUCTION

Nowadays, ultrasonic vibration (UV) is increasingly used to assist in cutting processes, such as turning process[1], milling process[2],[3], and drilling process[4]; or to assist in plastic deformation processes such as wire drawing process[5], deep drawing process[6], and extrusion process[7].Previous studies show that the cutting force decreases andsurface roughness is reduced when UV is applied[1],[2],[3],[4].Besides, ultrasonic vibration has the effect of reducing contact friction between the tool and the chip and between the tool and the workpiece surface, so the durability of the cutting tool increases.For the plastic deformation process, ultrasonic vibration causes dislocations to move more easily, so the plastic deformation ability of the material is improved, and the deformation force is reduced.Besides, the continuous impact at ultrasonic frequency between the deforming tool surface and the workpiece surface causes the temperature in the deformed area to increase, which is also a reason to improve the deformability and reduce the deforming force.Because of these reasons, ultrasonic vibration is increasingly widely applied in the field of plastic deformation machining, especially in the incremental sheet forming (UV-USF) process.

The ISF process has many potential applications in various manufacturing fields[8],[9], such as in the technology of manufacturing automobile shells, household appliance shells, and electronic device shells; even in creating prosthetic bones for applications in the biomedical field.The ISF process can use specialized machines, such as AMINO, Figur G15, EURECAT; however this option has high investment costs.The option of using milling machines or robots with ultrasonic work sets is often complicated.

Therefore, in this work, we introduce a system design specifically used in the UV-ISF process with the asisstance of ultrasonic vibrations applying to form sheet products.

II. BASIS OF DESIGN

Figure 1 presents a diagram of the UV-ISF proces.

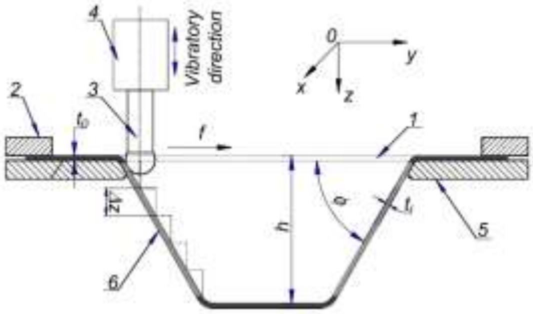

Figure 1. Diagram of UV-ISF process

The initial blank (1) is clamped between holder (2) and back-plate (5). The forming tool (3) is connected to an ultrasonic transducer (4), which makes it vibrate in the vertical direction. At the end of the forming process, the final product (6) is received. It should be noted that the tool may or may not rotate. Previous studies show that the rotation speed of the tool has almost no effect on the forming forces. In this work, the forming tool was selected not to rotate in all experiments.

Besides, previous studies show that the component of deformation force in the axial direction (Z direction) is often much larger than in the horizontal direction (X and Y directions)[10],[11]. Therefore, the requirement is that the system must vibrate along the tool axis (Z direction) to reduce the deformation force component in this direction.

III. DETAILED DESIGN, FABRICATION, INSTALLATION AND OPERATIONOF THE UV-ISF SYSTEM

To design the system, we first selected an ultrasonic transducer.In this study, the commercial ultrasonic transducer YP-5525-4Z (China) was selected, as shown in Figure 2.The detailed dimensions of the ultrasonic transducer are shown in Figure 3.According to the manufacturer's announcement, this transducer works at a frequency of 20 kHz, with a capacity of 2 kW (See Figure 4a).

Figure 2.The photo of the ultrasonic transducer

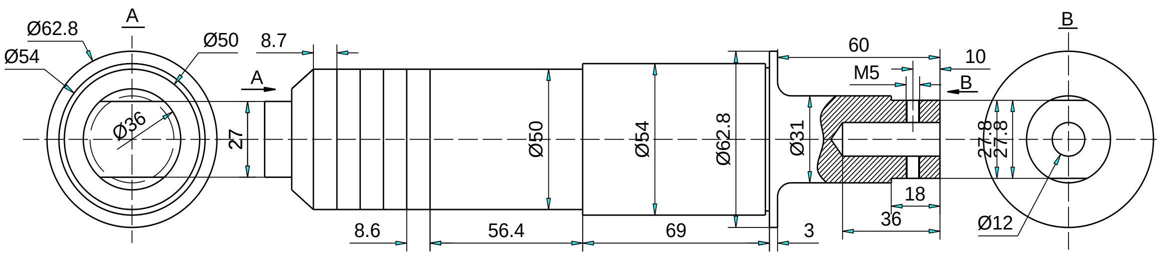

Figure 3.Detailed dimensions of the ultrasonic transducer

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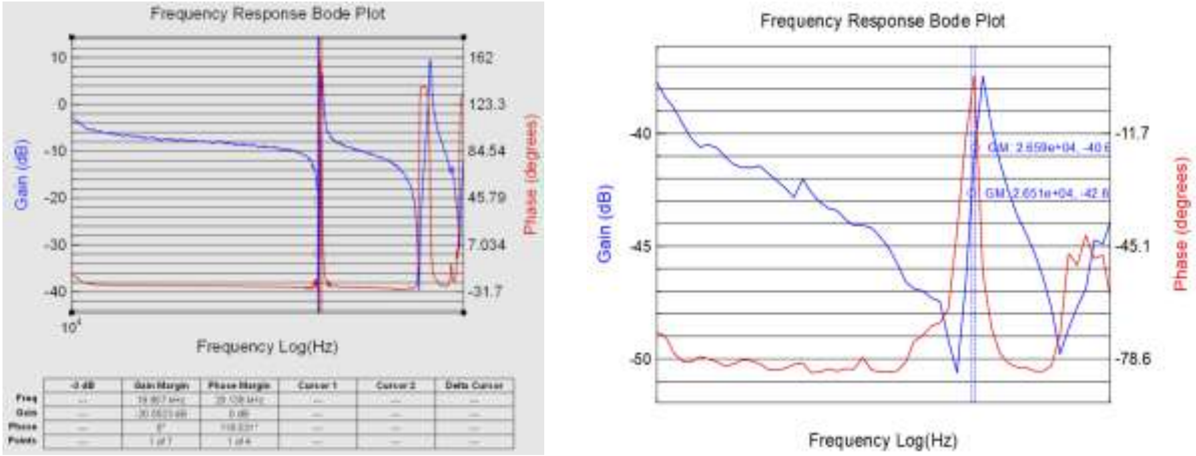

(a) Originalultrasonic transducer (b)After installing the ultrasound system on the machine

Figure 3.Results of scanning the resonant frequency of the ultrasonic transducer

Deformation tool made of C45 steel with diameter d = 12mm, was carefully designed to ensure rigidity for operating. At the same time, the length of deformation tool was selected to ensure operation in the ultrasonic frequency range[12]. After designing, manufacturing and assembling the deformation tool onto the ultrasonic transducer, the system's resonant frequency scan results are shown in Figure 4b.Obviously, the resonant frequency of the system is in the ultrasonic frequency region.

The selected processing machine is a CNC machine improved from the VHR AP vertical milling machine of Shizuoka (Japan).To create a true 3-axis CNC machine, this milling machine is specifically designed and improved as follows:

(i) First, the Y, Y, Z axis drive motors are respectively replaced by hybrid servo motors controlled by corresponding controllers;

(ii) Second, the original slide rail used to move the locomotive vertically (Z axis) is replaced by a ball slide rail system consisting of 02 rails and driven by ball screws;

(iii) Third, add a central control system to perform programming and deploy control commands according to shaping trajectories to the motors to perform the shaping function of the machine.

After renovation, a real CNC machine was created. Figure 4 presents the UV-ISF system after design, fabrication and assembly.For the system to work, the CNC program is first imported to the central controller (1) via USB port or programmed directly on the control panel.Control commands are executed by the X, Y, and Z axis drive motors.In which, the Z-axis driving motor rotates the ball screw (3) causing the machine head (2) to slide on two sliding rails (4).The deforming tool (7) is installed on the transducer (5) thanks to 04 screws, while the transducer (5) is fixed on the machine head due to the clamp (6). Therefore, when the machine head moves up and down along the Z axis, it will cause the deforming tool to move vertically to shape the product.To support the forming process, the workpiece (8) is clamped tightly on the clamp (9). A 3-component dynamometer (10) is used to measure the forming force components.The machine table (11) moves thanks to motors driving the X and Y axes, so the UV-ISF process can shape products with any complex profiles.For the transducer to work, an ultrasonic power supply (12) is used to power the transducer.Figure 5 illustrates the beginning and end of forming.

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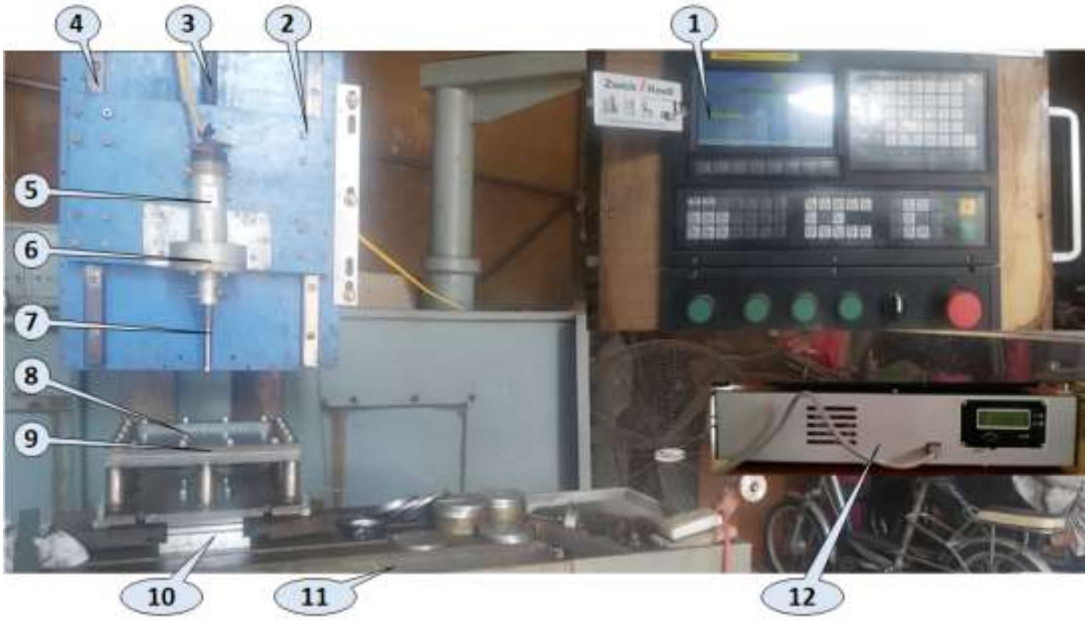
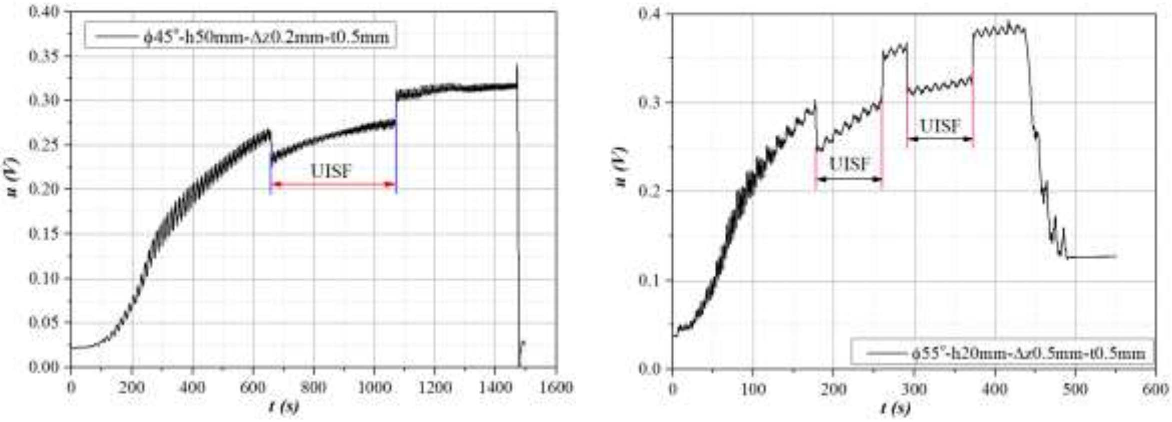


Figure 4.The UV-ISF systemafter design, fabrication and assembly:
1- central controller, 2- CNC machine head, 3- ball screw, 4- sliding rail, 5- ultrasonic transducer, 6- transducer clamp, 7- tool, 8- workpiece, 9- fixture, 10- three-component dynamometer, 11- table of CNC machine, 12- ultrasonic supply

(a)Start forming

(a)End offorming

Figure 5.Photos of the forming process



(a) Using contour tool trajectory (b) Using spiral tool trajectory

Figure 6.Test operation data of the experimental system when turning on and off ultrasonic vibration

Figure 6 presents some test results of the aluminum alloy plate forming system with a thickness of 0.5mm, using different types of tool feed trajectories.The results show that, when ultrasonic vibration is turned on, the obtained voltage signal of the force component Fz decreases significantly.This proves that the system has worked according to design requirements.

IV. CONCLUSION

In this work, the process of designing, fabrcating, installing and operating a system for implementing the incremental sheet forming process with the asisstance of ultrasonic vibration was carried out.Ultrasonic transducer and forming tool is carefully selected and designed to ensure working in the ultrasonic frequency range.A vertical milling machine has been completely converted into a CNC machine, capable of performing direct programming or importing CNC programs into the machine via USB port.The results of scanning the resonance frequency show that the system works in the ultrasonic frequency region.After completing the installation, the system was tested to shape an aluminum alloy plate with a thickness of 0.5mm with different tool trajectories.The results of system operation show that the signal of the force component in the axial direction Fz is significantly reduced. This proves that the system has been designed according to requirements.

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