Adaptive control system to producing a novel spun parts in sheet metal spinning process

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Abstract: The problem in Sheet metal spinning is limited to an axisymmetric part. This research aims to design and build a flexible mechanism by a combination of mechanical with the electrical system to achieve the forming of polygon spun parts with a different number of sides without using a specific mandrel. This system based on developing a synchronous spinning machine, in which the rotational motion and feeding of the tradition lathe machine were measured and control to maintain the speed synchronization with the trajectory of the forming tool rollers (a special tool of forming), where this tool controlled by the electrical motors. The speed of the electric motor controlled by variable frequency drives VFD, pulse-controlled, and software. The machine can be applied to produce several shapes by changing pulse-controlled inside software code, which means that’s the machine is much more flexible than any other way. In this survey three spun parts (triangle, square and hexagonal) cross-section parts were produced, and aluminum alloy sheets (1050) of circular shape with 1.5 mm in thickness and 150 mm diameter will be used in this process. Finally, the output from this process will compare with a CAD model to examine the process validity by comparing the dimensional accuracy. The result shows that the average dimensional accuracy error for the triangle, rectangular, and hexagonal spun parts are 14.15, 6.47, and 3.78 respectively which consider an acceptable percentage in the spinning process.

1. Introduction

Generally Spinning is known as a process that transforms circular flat metal blank sheet into an axisymmetric, hollow shapes part by using a forming tool that forces a blank onto a mandrel. Also, the traditional spinning process produces asymmetric components, where in the last 3 Decades researchers were attempted to expand its capabilities to produce more complex parts. As reported by Jacopo M. Russo et al. (2019) [2], where presented a tough methodology to perform an asymmetric mandrel-free spinning technique, and he demonstrated a successful application to spin circular, elliptical, and square parts with no dedicated mandrel. Also, they reported that the range of curvature in the target part’s contour is used to quantify its degree of asymmetry, and the influence of this parameter on the formability of spun parts is investigated in a series of experimental trials. On the other hand, Zhen Jia et al (2015) [5], Investigated in the roller path of spinning forming by a Die-less process to achieve a cone shape square section parts by using a 5-axis Computerized Numerical Control (CNC) spinning machine, where the roller path is designed and adjusted to calculate the degree of the edge arc square section parts. Where they used this methodology to form this square section by proposed, the roller needs to move forward and backward on the radial direction accompanied by the rotation.
of the workpiece and simultaneously proceeds along the axial direction. On the other hand after 4 years Zhen Jia et al (2020) [1], also Proposed the mathematical analytical method to design the roller path which contains straight regions and curvature regions. Where the designed roller path was tested and verified through the spinning test which was accomplished on the PS-CNCSXY 5 spinning machine also. The radius and thickness of the fillets are compared with theoretical values, and the causes of relative errors were analyzed in three different depths. Also, the finite element modeling of stress-strain fields during the spinning process was adopted.

Finally, this study aims to design and create a simple and flexible mechanism through a combination of mechanical with an electronic system to achieve the forming of a non-conventional spinning process such as the development of an electronic device, to control the mechanical system (traditional system represented by a lathe machine).

2. theory

The idea of forming a novel spun part by spinning process in this research is consists of a rotation of the forming tool with blank that has a parallel axis of rotation at synchronized speed during the machining process, where that speed of the forming tool is the spindle speed of blank Multiply by a factor depending on the desired shape.

2.1 Control system implementation for speed synchronized

Generally, the basic component for the speed control system consisting of a 3-phase induction motor, VARIABLE FREQUENCY DRIVE VFD, sensors, and a controller (Arduino board), where this system depends on VFD to change the speed of the induction motor more precisely this system performed via many Sequential steps which are, first of all, read the speed of lathe spindle by encoder sensor, then the signal output received, analyses and manipulation by an ARDUINO. On the other hand, ARDUINO will be increased or decrease the speed of the 3-phase induction motor by getting out four train signal similar to encoder signal and Deceive the Encoder Feedback Card- EMC-PG01L that mounted on VFD device through PG02 input terminal one by Delusion it that signal came from an encoder, on the other hand, the speed of the motor was measured by the second encoder and connected also to EMC-PG01L through PG01 input terminal two. finally the output terminal from EMC-PG01L connected to Arduino for comparing between Spindle speed of lathe and motor speed (forming tool
2.3 Speed calculation for rotary incremental encoder (Speed Sensor)

Figure 1. illustrated the block diagram of a Control system implementation for speed synchronized, and figure 2. depicts the control system component unit wiring.

Figure 1. illustrated the block diagram of Control system implementation for speed synchronized.

Figure 2. depicts the schematic wiring connecting of the speed control system.
For rotary encoders, speed is calculated by dividing the number of edges counted (pulses counted) on the resolution of the encoder or the number of pulses per revolution and then multiplying the result by 60 minutes to get degrees of speed in form revolution per minutes. as show in equation.1.

\[ \text{speed (r.p.m) = \frac{\text{pulses count}}{x \times \text{Res}}} \times 60 \text{sec} \] \[ \text{rpm} \] \[ \text{(1)} \]

Where:

- \text{Pulses count} is the number of pulses per second and equal to frequency.
- \text{x} = \text{type of encoding} (X1, X2, or X4).
- X1=1, X2=2 and X4=4.
- \text{Res} = \text{number of pulses generated per shaft revolution (resolution).}

2.4 drive the relation between frequency of pulses and AC frequency for speed calculation.

The speed (rpm) can be calculated from the equation (3.21) as follow.

\[ \text{speed (rpm)} = \frac{\text{frequency}}{\text{res} \times 60} \] \[ \text{(2)} \]

Also, speed can be calculated by equation

\[ \text{rpm} = 120 \times \frac{f}{p} \] \[ \text{(3)} \]

Where \( p \) is the number of poles of electric motor.

\[ \text{rpm} = \frac{f}{\text{Res} \times 60} = 120 \times \frac{f}{p} \] \[ \text{(4)} \]

Where in most cases \( p=4 \) poles, \textit{Resolution of encoder}=1024ppc

\[ f = 2 \times \frac{\text{Res} \times \text{encoder}}{p \times f_{\text{pulse}}} \] \[ \text{(5)} \]

Equation.5 represent the relation between frequencies of motor with frequency of encoder sensor.

3. Experimental work

In this section, the adopted experimental work the design, and the hardware system will be explained and used to achieve an asymmetrical part by spinning sheet metal forming process to produce different shapes of the spun parts.

3.1 Design the controlling system unit for synchronizing rotational action of forming tool.

The controlling system was designed and made to achieve, firstly the synchronizing rotational action of forming tool (controlling the number of revolution of the forming tool) with Spindle speed of lathe at desired ratio. The main parts of controlling system are:

- Variable frequency drive VFD
- Encoders
- ARDUINO
- LCD
- Cover box.
3.2 Product the spun part with different shapes

In this section the triangle, rectangle, and hexagonal spun part will be present, where these parts as illustrated in Figures 4, 5 and 6, where: The equation for produce these parts is:

\[ E = z_t \times \frac{n_{\text{tool}}}{n_{\text{spindle}}} \]

Figure 3, depict the control system unit, where A-show the inside box contain VFD inverter, power supply, electrical circuit and connector. B-show the main controlling and monitoring board.
In the above equation $E$ stands for the number of flat edge surfaces, $z_e$ is the number of balls in the forming tool, $n_{tool}$, and $n_{spindle}$ are the rotary speed of the forming tool and spindle speed respectively.

For triangular equation, $5$ will be:

$$3 = 3 \times \frac{n_{tool}}{48 \text{ RPM}}$$

$$n_{tool} = n_{spindle} = 48 \text{ RPM}$$

For RECTANGULAR equation, $5$ will be:

$$4 = 2 \times \frac{n_{tool}}{48 \text{ RPM}}$$

$$n_{tool} = n_{spindle} \times 2 = 96 \text{ RPM}$$

For hexagonal equation, $5$ will be:

$$6 = 3 \times \frac{n_{tool}}{48 \text{ RPM}}$$

$$n_{tool} = n_{spindle} \times 2 = 96 \text{ RPM}$$

Figures 4, 5, and 6 show the final parts of triangular, rectangular, and hexagonal respectively.

![Figure 4](image1.png)

*Figure 4, show triangular parts made with inner radius 75mm.*
Figure 6. show steps for made rectangular parts by using 75mm inner radius

Figure 6. show steps for made hexagonal parts using 75mm inner radius
4. CONCLUSIONS

1- The condition for the succeeding process is that the speed of the tool should be synchronized with the blank speed at a constant percentage, a small difference in the angular deflection will occur in the spun part.

2- Based on equation, the number of the ball in the forming tool maybe 1 or 3 or 6 for triangular and hexagonal shape while for rectangular equal 1 or 2 only, it will be 4 balls the part will fail. Where from simulation, when the number of ball 4 for rectangular the ball will hit the part in the edge zone due to synchronization failure.

3- The results show the surface of the spun part is not exactly flat and has a curvature as seen in figures (5 and 6) where the side surface of the spun part not exactly flat, where this curvature depends on the number of balls in the forming tool will be used.

6. References

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