Prediction of applied forces in incremental sheet metal forming (ISMF) process by means of artificial neural network (ANN)

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ABSTRACT

The variation of applied forces in incremental sheet metal forming (ISMF) process is one of main issues in prediction of sheet failure. So, prediction of applied force values due to optimum designing of tool and fixture and appropriate selection of machine-tool, are necessary. These elements cause stabilization of process and increase sheet formability. In this paper by using experimental studies in relation to measuring of applied force in ISMF process, an artificial neural network (ANN) algorithm was defined and trained based on experimental data. Finally, predicted values by network and experimental tests were compared for these parameters: vertical step size, tool diameter, wall angle and sheet thickness. Also error value of prediction of neural network was determined.

KEYWORD


INTRODUCTION

In recent years, in sheet metal forming field, new types of forming processes were introduced in order to reduce the manufacturing costs and the time to market when pre series or prototypes need to be produced. Incremental forming is a flexible and innovative sheet metal forming process which allows complex shape shells forming without the need for any die. For these reasons, incremental forming is nowadays suggested for rapid prototyping (RP) and customized products [1-3]. Incremental forming is an emerging sheet metal forming technology [4] in which the tool motion is controlled numerically [5]. In this process, a head spherical or hemispherical tool based on defined path creates continuous and local deformation on sheet metal.

Applied forces in ISMF process regarding to variations of 4 parameters: vertical step size, tool diameter, wall angle and sheet thickness were measured by Duflou et al., experimentally. In this paper an artificial neural network based on these results was defined and trained. Then accuracy of this suggested algorithm was surveyed for the parameters which were mentioned above. Finally, neural network predicted applied forces in this process successfully.

BEHAVIOR OF APPLIED FORCE IN ISMF PROCESS

In this process, the behavior of measured force was affected by technical parameters such as: vertical step size, tool diameter, wall angle and sheet thickness, directly. In addition, bending operates as an effective mechanism in workpiece before reaching maximum point [6]. After the maximum point, a kind of stretching mechanism will be started. The force presents complicated trend which is issued from two different effects on sheet:

1. Thinning, this phenomenon intends to decrease required force.
2. Strain hardening of material, which cause to increase the force.

As shown in Fig.1, the variation of effective parameters is determined three different behaviors of the force [7].

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In this paper, force variation is assumed as steady state curve (SSc). It means that after the maximum point, forming force is constant; because, the effect of material thinning is compensated by strain hardening. Fig.2 shows the sheet which is in equilibrium state of force (F) and tension force (T).

If bending stresses and friction force are neglected in model of plain strain, tension force (T) will be calculated as below, approximately:

\[ T = Bt\sigma = \left( \frac{2}{\sqrt{3}} \right)^{n+1} KBT_0 \exp(-\varepsilon_x)\varepsilon_x^n \] (1)

\[ B = 2r_b \] (2)

\[ \sigma = K\varepsilon^n \] (3)

which \( r_b \) is radius of forming tool, \( t \) is thickness of under stretching sheet, \( K \) is strength coefficient, \( n \) is power of strain hardening, \( t_0 \) is initial thickness of sheet, \( \varepsilon_x \) is strain along x axis and \( \theta \) is tangential angle between sheet and tool. In attention to condition of imposed forces on the under stretching sheet, forces \( F_x, F_y, F_z \) will be acquired:

\[ F_x = T(1 - \cos\theta) \] (4)

\[ F_z = T\sin\theta \] (5)

**PRINCIPALS OF EXPERIMENTAL METHOD**

Experiments were carried out using a 3-axis CNC vertical milling machine. Mounted on it was a steel fixture in which the sheet metal could be clamped such that no material may flow into the forming area. Between this fixture and the milling machine work-surface a table type force sensor was mounted (Fig.3).

With these apparatuses the forces exerted upon the part by the tool were recorded on a computer based data acquisition system. Reported experiments are mainly based on the production of simple workpiece geometry, a cone (Fig.4).

The initial diameter of 180mm is maintained for each specimen, and most test parts were truncated at a 40mm depth. The tool travels along a path that traces the contour of the cone at a feed rate of 2000 mm/min. The standard process parameters applied are 0.5mm vertical step size, 10mm tool diameter and 50° wall angle and the standard material used is 1.2mm thick Al 3003. For the part geometry and tool paths, forces were measured in three directions corresponding to a Cartesian coordinate system. These three force components are: \( F_x, F_y, F_z \) and then combined into a total force vector. \( F_z \) is the maximum forming force applied in the vertical direction. \( F_x, F_y \) are the in-plane forces exerted on the sheet metal. A series of tests were carried out to ascertain the influence of the vertical step size, tool diameter, wall angle and the sheet thickness on the peak forming force (\( F_p \)) and the average force (\( F_a \)). Variation domains of effective parameters in this process have been presented in Table1.

<table>
<thead>
<tr>
<th>Table1: Effective parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>vertical step size (mm)</td>
</tr>
<tr>
<td>tool diameter (mm)</td>
</tr>
<tr>
<td>wall angle (°)</td>
</tr>
<tr>
<td>sheet thickness (mm)</td>
</tr>
</tbody>
</table>
In order to adjust and train neural network, 4 parameters as test parameters were surveyed (Table 2).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$F_p$ (N)</th>
<th>$F_s$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v=0.75mm$</td>
<td>586.85</td>
<td>548.14</td>
</tr>
<tr>
<td>$d=20mm$</td>
<td>702.11</td>
<td>672.96</td>
</tr>
<tr>
<td>$\alpha = 50^\circ$</td>
<td>553.42</td>
<td>531.51</td>
</tr>
<tr>
<td>$t_0=1.2mm$</td>
<td>554.53</td>
<td>486.29</td>
</tr>
</tbody>
</table>

Experimental results of force values $F_p, F_s$ for the 4 parameters have been presented in Table 3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$F_p$ (N)</th>
<th>$F_s$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v=0.75mm$</td>
<td>580.13</td>
<td>550.5</td>
</tr>
<tr>
<td>$d=20mm$</td>
<td>690.3</td>
<td>670.1</td>
</tr>
<tr>
<td>$\alpha = 50^\circ$</td>
<td>549.73</td>
<td>528.4</td>
</tr>
<tr>
<td>$t_0=1.2mm$</td>
<td>548.71</td>
<td>485.66</td>
</tr>
</tbody>
</table>

**DEFINITION AND TRAINING OF NEURAL NETWORK ALGORITHM**

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the network function is determined largely by the connections between elements. You can train a neural network to perform a particular function by adjusting the values of the connections (weights) between elements. Commonly neural networks are adjusted, or trained, so that a particular input leads to a specific target output. Such a situation is shown below (Fig. 5). There, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target.

According to obtained results, the trained neural network was able to predict the maximum and average values of force with high precision. Moreover, simulation process has been shown well accordance with experimental results. Figures 6 to 9 show convergence diagram of defined network for the test parameters. As has been shown, the desired purposes have been prepared by means of neural network.
Figures 10 to 13 show simulation results yield from neural network in comparison with experimental result for 4 parameters: vertical step size, tool diameter, wall angle and sheet thickness.
DISCUSSION
According to Fig. 10 to 13, we could yield a very good agreement between the predicting results of network simulation and experimental results for the test parameters: vertical step size 0.75mm, tool diameter 20mm, wall angle 50° and sheet thickness 1.2mm. Besides, error value of prediction of $F_p$ was in the range of (0.67-1.68) % and error value of prediction of $F_s$ was in the range of (0.13-0.58) %. So, with extremely low error and in a few second, we succeed to predict values of applied force in this process, based on the test parameters.

CONCLUSION
Optimal designing of tool and fixture because of suitable operation against imposed forces and also selection of desired machine-tool due to use of power and efficiency corresponding to condition of process, are significant factors during ISMF procedure. So, initial prediction of applied forces in the process, especially maximum force ($F_p$), will help designer to better select material and dimensions for tool and fixture. In such a condition, artificial neural network can be a great device to predict effective parameters, which is efficient both in cost and time. In this paper, by means of artificial neural network, prediction of applied force values in ISMF process was performed and the network results were in good agreement with experimental results.

REFERENCES


