Study on springback behavior of carbon steel during single-point dieless forming based on neural network method

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Abstract. Springback phenomenon is one of the most important factors affecting the machining accuracy in dieless forming processes and it has been studied by many scholars. Because of its highly nonlinear influence, there is no good numerical or analytical method to solve the springback problem. In this paper, according to the stamping experiments of strip sheet based on single point dieless forming machine tool, the effect of the stamping increment step and the stamping position on springback and the springback prediction method are studied. The experimental results show that the stamping increment step has little effect on springback, and when the stamping point is closer to the support position, the springback of the plate is smaller. Moreover, a neural network model (ANFIS model) based on experimental data is established to predict the springback and the effectiveness of this method is verified by testing.

1. Introduction
In order to meet the development of modern industry, plate bending technology should meet the following requirements: high efficiency, high flexibility and high precision. Because of its advantages of high flexibility, high efficiency and low cost, dieless forming technology has become a hot research topic in metal sheet forming industry. Single point dieless incremental forming is a kind of forming method, which controls the movement of the individual forming tool step by step through the numerical control system. However, this kind of dieless incremental forming also has the problem of springback, which affects the forming precision of the sheet metal.

Springback, which is a complex non-linear problem influenced by many factors, is difficult to be described by precise mathematical model. Due to good ability to approximate any nonlinear system, many researchers have used neural network method to study springback problem, control process parameters and predict springback effect in recent years. Cao and Kinsey [2] put forward the use of online recognition of punch stroke-punch pressure curve parameters as the only input of neural network to identify process parameters, output to control the edge force to reduce springback and prevent rupture. Inamdar and Date et al. [3] studied the application of an ANN to the problem of controlling springback in air-vee bending. Abbassi and Belhadj et al. [4] used the GTN model to evaluate the toughness damage and fracture phenomenon, then they determined the material parameters of damage based on the artificial neural network identification method. Jamli et al. [5] combined the finite element method and neural network to analyze the nonlinear unloading modulus and springback in sheet metal forming process. Sharad et al. [6] used neural network to map the springback obtained from finite element analysis and the results obtained by FE simulations were in
good agreement with that based on simple neural network. Viswanathan et al. [7] used neural network system along with a stepped binder force trajectory to control the springback angle in the steel channel forming process.

Fuzzy neural network, as a combination of fuzzy technology and neural network, has strong capability in understanding the fuzzy inference and learning neural network. As the data based modeling method, and the fuzzy membership function and fuzzy rules in this system are obtained by a large amount of learning rather than the expert experience. It is particularly important for systems whose characteristics are not yet understood or are highly complex. In this paper, the effect of stamping increment step and different stamping positions on springback is studied by stamping experiments with strip plate. Meanwhile, a fuzzy neural network is proposed to predict springback and the correctness of this method is proved by testing.

2. Experimental Arrangements
As shown in Fig.1, the experimental machine is composed of a stamping system, a flexible support system, a control system and a set of 3D scanning system. During the experiments, the PC executes the CNC code to control the machine and make the sheet deform to reach the target shape. The feed speed of the stamping tool is 100 mm/min. After the operation is completed, the 3D scanner is used to scan and measure the shape of the specimen after each bending process and after each springback process, and the measurement accuracy can reach 0.05mm. The metal sheet material used in this study is carbon steel Q235 and its size is 440 mm*36 mm*3 mm.

Figure 1. Bending machine

Figure 2. Experiment model

Here in this study, several bending experiments were carried out to investigate the influence of stamping positions and stamping incremental steps on the springback behavior of this carbon steel.
The experimental arrangement is shown in Table 1, where “location” means the distance from the stamping position to the center and “depth” means the stamping depth as shown in Fig.2. It should be noted that stamping depth of “30/60” in the table means the first stamping depth is 30 mm and the second stamping depth is 60 mm. The stamping process is shown in Fig.3.

**Table 1. Experimental arrangement**

| No. | Stamping location(mm) | Stamping depth (mm) | No. | Stamping location(mm) | Stamping depth (mm) |
|-----|-----------------------|---------------------|-----|-----------------------|---------------------|
| 1   | 0                     | 60                  | 7   | 60                    | 60                  |
| 2   | 0                     | 30/60               | 8   | 60                    | 30/60               |
| 3   | 0                     | 15/30/45/60         | 9   | 60                    | 15/30/45/60         |
| 4   | 30                    | 60                  | 10  | 90                    | 30                  |
| 5   | 30                    | 30/60               | 11  | 90                    | 15/30               |
| 6   | 30                    | 15/30/45/60         |     |                       |                     |

**Figure 3. Stamping process**

3. Results and Discussion

3.1. Experimental Results

3.1.1 Influence of Incremental Steps on Springback Behavior. Here in this section, the stamping points are in the middle position, and move 30mm and 60mm to the support side, respectively. For each case, the final stamping depths are the same (60mm) while the incremental steps are different as shown in Fig.4.a. Taking the case that stamps in the middle position as an example, the plate can be bented once (No.1), twice (No.2) or four times (No.3) to the final depth of 60 mm. The final shapes of the plates were compared and shown in Fig.4. Results show that the difference of bending angle under different stamping increments is very small, that is, the effect of incremental step on springback behavior of the carbon steel is very small when the stamping points are the same.

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3.1.2 Influence of Stamping Position on Springback Behavior. Here in this study, the stamping depths are the same (30mm) while the stamping points are different from each other (as shown in Fig. 5). The shapes of the plates after bending process and after springback process are compared in Fig. 6. (both the forming and springback shapes are the first stamping of the marked group) It can be seen that the springback angle is smaller when the stamping position is closer to the support position.

Figure 4. Impact of incremental step on springback

Figure 5. Stamping position diagram

Figure 6. Springback of different stamping positions
3.2. Springback Prediction

ANFIS adopts the Takagi-Sugeno model inference method, which has the advantage of fuzzy logic to express human knowledge and the learning ability of neural network. It provides an effective tool for modeling and controlling complex systems. Fuzzy neural network is generally composed of input layer, fuzzy layer, fuzzy inference layer, fuzzy layer and output layer [8] (As shown in Fig.7).

\[ \alpha_j = \mu_{A1}(x_1)\mu_{A2}(x_2) \cdots \mu_{An}(x_n) \]  \hspace{1cm} (1)

The output of the fuzzy system is the weighted average of the output of each rule.

\[ y = \frac{\sum_{j=1}^{m} \alpha_j y_j}{\sum_{j=1}^{m} \alpha_j} = \sum_{j=1}^{m} \bar{\alpha}_j y_j \quad \bar{\alpha}_j = \frac{\alpha_j}{\sum_{i=1}^{m} \alpha_i} \]  \hspace{1cm} (2)

Matlab is used to write the fuzzy neural network program. The network structure consists of two inputs and one output. The input variables are the stamping position and the stamping depth, and the output variable is the springback volume as shown in Fig.8.

Using mesh segmentation method to generate FIS, membership function is gbellmf (bell type), each input takes 15 membership functions, the grid partitioning leads to 225 rules and the training step is 100. The comparison of training data and test data is shown in Fig.9.a, the membership function images before and after training are shown in Fig.9.b and Fig.9.c.
To verify the accuracy of the model, we select 45 test samples to test the model. The root mean-squared error (RMSE) is 0.2769 (as shown in Fig. 9d), which indicates that the predicted results of the ANFIS model are in good agreement with the experimental results.

4. Summary
Here in this study, the influence of incremental steps and stamping positions on the springback behavior of carbon steel Q235 are experimentally studied and analyzed and the ANFIS model was used to predict the springback behavior of this material during the bending process. The key conclusions can be obtained as follows:

1. The incremental step has little effect on the springback behavior if the final depths and the stamping positions are the same.
2. The springback angle is smaller when the stamping position is closer to the support position.
3. ANFIS has a good approximation ability to the highly nonlinear problem of springback. When more geometric features of the plate and more process parameters are added to the ANFIS input space, with enough training samples, the prediction accuracy of the ANFIS model can be increased. It also lays the foundation for springback prediction of the square plate forming experiment in the future.

Acknowledgement
This research was financially supported by the Key Cooperative Program of the Bureau of International Cooperation, Chinese Academy of Sciences (172644KYSB20160024) and Chinese Postdoctoral Science Foundation (2017M612779).

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