Springback simulation analysis of angle shape forming of springs based on orthogonal experiment method

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Abstract. The springback phenomenon in the angle shape forming process of spring affects the efficiency and accuracy of spring machine adjustment. In this paper, the angle shape forming process and springback process of SWOSC-V material are simulated by finite element analysis software ABAQUS, and orthogonal experiments are designed. According to the simulation results, the importance order and changing trend of each parameter are determined, and the parameters of minimum springback angle and springback law are obtained. It provides a reference for practical application. It is proved that the combination of finite element method and orthogonal experiment can improve the efficiency of finding the springback law.

1. Introduction
As a general purpose part, spring parts play a very important role in all walks of life. With the progress of spring forming technology in recent years, the processing of springs with various complex shapes has been gradually realized. Springs of any shape can be decomposed into three characteristics: linear, angular and spiral. Angle shape, as an important feature of spring parts, appears in various special-shaped springs and plays an important role in the use of springs. There are many ways to form the angle shape of special-shaped spring. Push-bending is a common way. The forming process is that the spring steel wire is fed out of the feeding wheel for a certain length, the bending tool moves in the direction of the steel wire to command location, and the end of the steel wire pushed by the bending knife bends. Then the bending tool moves back to the initial position in the opposite direction. At this time, the springback phenomenon of the bending steel wire happens. The springback phenomenon occurs in the forming process of spring angle shape makes the forming accuracy difficult to control. This kind of springback is due to the elastic recovery of the stress concentration in the bending part. At present, the main measure to control the springback is the over-bending method, that is, the tool feeds more, so that the angle after the elastic recovery meets the design requirements. In order to achieve the desired shape, the workers have to carry out repeated experimental processing, which is inefficient. Therefore, studying the springback law of angle shape forming process in springs has important sense to quickly and accurately adjust NC program and improve the pass rate of processing once.

Roger NWright [1] summarized the theoretical formula of bending radius change of wire formed by springback. LiZ B [2] with thin wall pipe bending as the research object, used the finite element simulation method for stainless steel pipe and aluminum alloy pipe bending forming and springback research, analyzed in detail the influence regular of different process parameters on the bending springback, developed NC tube bending springback compensation system based on the springback
database using VB language and SQL language. Liu J Y [3] measured the springback angle as the data sample, respectively used the least square method and BP neural network model to fit the data, obtained the functional relationship between the bending angle and the springback angle, and realized the prediction of the springback angle. Liu J W [4] carried out stress and strain analysis in two stages of theoretical elastic-plastic material bending resilience, and deduced a series of calculation formulas such as resilience curvature and resilience bending moment based on static equilibrium condition and deformation coordination condition. Using orthogonal experiment method and finite element analysis, Zhang X [5] concluded that the length of the bending moment arm is an important factor affecting the springback angle, and deduced the mathematical model of the springback angle based on the length of the bending moment arm this factor. Wang W Q [6] based on studying elastic-plastic theory of metal forming, through the spring space forming mechanism and movement process of steel wire mechanics analysis, using the finite element software ANSYS/ls-dyna simulated spring forming and springback processes, and spring springback regular were studied through test that verify the validity of the finite element analysis. Wang M M [7] using 45# steel wire as the research object conducted wire bending processing of finite element analysis and test, and the data obtained, and the multiple linear regression analysis based on simulation data set up the mathematical model of springback angle with two parameters including wire diameter and bending angle. NC compensation according to this mode makes the wire bending accuracy reached 1°.

ABAQUS finite element numerical simulation software has strong nonlinear mechanics analysis function. It is very suitable for elastic and plastic forming process simulation. Because it needs comprehensive data to determine the influence rule of these factors on springback, the common experimental method takes a lot of time. Orthogonal experiment method is a method that can get comprehensive experimental data with the least number of experiments. This experimental design method is to select appropriate representative points from a large number of experimental points and arrange them by using the established table-orthogonal table. Experiments and data analysis methods. Orthogonal table can sample equally in the range of factors, which makes each experiment more representative. Because the orthogonal table has the characteristics of balanced and dispersed, it guarantees some requirements of comprehensive experiment. These experiments can often achieve the purpose of experiment better, so the efficiency of analysis can be improved by using this method [8]. According to previous studies, the method of ABAQUS finite element simulation combined with orthogonal experiment can be more effective to analyze the influence of different factors on the bending and springback process of wire forming spring angle shape.

2. Finite element modelling of the forming process

2.1. Model and parameter setting

Using ABAQUS finite element software to simulate springback, the three-dimensional model of forming spring angle shape is established in SolidWorks three-dimensional modeling software, as shown in Figure 1. Then the three-dimensional model is imported into ABAQUS software. The density of wire material is 7.8e3 kg/m³, Young's modulus is 2.06e11 Pa, and Poisson's ratio is 0.28. The steel wire model is set to the hexahedron element type. The steel wire model with 1 mm, 1.5mm, 2mm and 2.5mm diameter are divided into 15036 elements, 15606 elements, 9553 elements and 10036 elements respectively as shown in the Figure 2.

The SWOSC-V material has good strength limit and performance, and is widely used in springs. So take the springback characteristics of SWOSC-V material as the research object. According to the engineering curve of tension-displacement of steel wire obtained by universal tension testing machine, the true stress-strain data is obtained by calculating using the following formulas [9].

\[
\sigma = \sigma_{nom}(1+\varepsilon_{nom})/(1-\varepsilon_{nom})
\]

\[
\varepsilon = \ln(1+\varepsilon_{nom}) - \sigma / E
\]

(1)
In the formula above, $\sigma$ is the true stress, $\sigma_{\text{nom}}$ is the nominal stress, $\varepsilon$ is the true strain, $\varepsilon_{\text{nom}}$ is the nominal strain and $E$ is the elastic modulus of the material. According to the true stress-strain data, set true stress to true strain curve as shown in the Figure 3.

The material density of mandrel and tool is set to $7.8 \times 10^3 \text{ kg/m}^3$, Young's modulus is $2.10 \times 10^{11} \text{ Pa}$, Poisson's ratio is 0.3. The model adopts tetrahedral element type and is set as rigid body which can not be deformed. The number of mandrel and tool models’ elements is 800 as shown in the Figure 2. The friction coefficient is set to 0.15 [10].

![Figure 1](image1.png)  
**Figure 1.** Spring angle shape forming 3D model.  

![Figure 2](image2.png)  
**Figure 2.** Spring angle shape forming finite element mesh model.  

![Figure 3](image3.png)  
**Figure 3.** SWOSC-V material true stress-true strain curve.

2.2. Simulation algorithm selection

The springback simulation of steel wire bending is divided into two steps: forming simulation and springback simulation. Finite element plasticity algorithm is generally divided into dynamic display algorithm and static implicit algorithm. In the case of wrinkling and instability, the dynamic display algorithm of non-stiffness matrix will not cause difficulties in numerical calculation. Particularly suitable for solving large complex forming problems, dynamic display algorithm is used to simulate the forming process. But the explicit method of calculating springback is to get the balanced shape of the part through the attenuation of the stress field. Generally, it takes a long time and is not suitable for springback simulation [11]. In order to improve the simulation accuracy, static implicit algorithm is used to springback simulation.
3. Analysis of influencing factors of springback angle in bending

3.1. Orthogonal experiment design

According to the bending process of spring forming machine, the factors that can affect the bending springback are wire diameter \( d \) (mm), distance between tool and mandrel \( l \) (mm), feed \( h \) (mm), feed speed \( v \) (mm/s) and load time \( t \) (s). Wire diameter refers to the diameter of the cylindrical section of the processing object, and different diameters will cause different stress distribution. Different clearance distance between tool and mandrel leads to different forming angles. Tool feed refers to the amount of displacement experienced by the tool when it moves upward from contact wire to stop moving upward, and different forming angles are obtained with different displacement. Different speed of tool upward movement makes the bending stress of forming different (The strain rate of the material is not taken into account here, the feed speed is taken as a reference factor). If the tool stay for a period of time (loading time) in the end, it may cause stress changes in the bending part. These factors may cause different springback angles. The forming angle before tool unloading is \( \alpha \). The forming angle after tool unloading is \( \beta \). The springback angle is \( \gamma \). Figure 4 shows the Schematic diagram of spring angle shape forming factors.

In order to analyze the influencing factors of spring angle shape forming, a five-factor and four-level finite element simulation orthogonal test scheme was designed as shown in Table 1 [12]. A total of 16 simulation tests are required.

![Figure 4. Schematic diagram of spring angle shape forming factors.](image)

| Level factors | Wire diameter \( d \) (mm) | Distance between tool and mandrel \( l \) (mm) | Feed \( h \) (mm) | Feed speed \( v \) (mm/s) | Load time \( t \) (s) |
|---------------|--------------------------|-----------------------------------------------|-----------------|------------------------|-------------------|
| Level 1       | 1                        | 4                                             | 3               | 2                      | 0.5               |
| Level 2       | 1.5                      | 4.5                                           | 4               | 3                      | 1                 |
| Level 3       | 2                        | 5                                             | 5               | 4                      | 1.5               |
| Level 4       | 2.5                      | 5.5                                           | 6               | 5                      | 2                 |

Table 1. Five factors four level experiment table.
3.2. Orthogonal experiment results and analysis

The springback angle of bending under different bending simulation conditions was obtained by finite element simulation according to the orthogonal experimental scheme. In order to get the important order of each factor, the range of the experimental data is calculated. \( N = 1 \sim 4 \), \( K_n \) is the sum of the rebound values at the N level of each factor, \( k_n \) is the average rebound values at the N level of each factor, and \( R \) is the difference between the maximum value and the minimum value of \( k_n \) for each factor. The results are shown in the Table 2. Finally, the effect curve of each factor on the springback result is shown in the Figure 5.

According to the obtained simulation data and range analysis results, the important order of the factors affecting the springback angle of SWOSC-V wire is as follows: wire diameter \( d > \) feed \( h > \) feed speed \( v > \) distance from tool to mandrel \( l > \) tool load time \( t \).

Table 2. Orthogonal simulation test results and range analysis.

| Wire diameter \( d \) (mm) | Distance between tool and mandrel \( l \) (mm) | Feed \( h \) (mm) | Feed speed \( v \) (mm/s) | Load time \( t \) (s) | Springback angle \( \gamma \)(°) |
|-------------------------|-----------------------------|-----------------|---------------------|-----------------|---------------------|
| test 1                  | 1                           | 4               | 3                   | 2               | 0.5                 | 8.666               |
| test 2                  | 1                           | 4.5             | 4                   | 3               | 1                   | 4.996               |
| test 3                  | 1                           | 5               | 5                   | 4               | 1.5                 | 9.015               |
| test 4                  | 1                           | 5.5             | 6                   | 5               | 2                   | 9.651               |
| test 5                  | 1.5                         | 4               | 4                   | 4               | 2                   | 5.696               |
| test 6                  | 1.5                         | 4.5             | 3                   | 5               | 1.5                 | 6.491               |
| test 7                  | 1.5                         | 5               | 6                   | 2               | 1                   | 7.753               |
| test 8                  | 1.5                         | 5.5             | 5                   | 3               | 0.5                 | 7.638               |
| test 9                  | 2                           | 4               | 5                   | 5               | 1                   | 6.214               |
| test 10                 | 2                           | 4.5             | 6                   | 4               | 0.5                 | 5.162               |
| test 11                 | 2                           | 5               | 3                   | 3               | 2                   | 5.087               |
| test 12                 | 2                           | 5.5             | 4                   | 2               | 1.5                 | 5.686               |
| test 13                 | 2.5                         | 4               | 6                   | 3               | 1.5                 | 4.638               |
| test 14                 | 2.5                         | 4.5             | 5                   | 2               | 2                   | 5.226               |
| test 15                 | 2.5                         | 5               | 4                   | 5               | 0.5                 | 5.370               |
| test 16                 | 2.5                         | 5.5             | 3                   | 4               | 1                   | 4.108               |
| K1                      | 32.327                      | 25.214          | 24.352              | 27.330          | 26.836              |
| K2                      | 27.579                      | 21.874          | 21.748              | 22.360          | 23.071              |
| K3                      | 22.149                      | 27.226          | 28.093              | 23.980          | 25.830              |
| K4                      | 19.342                      | 27.083          | 27.204              | 27.726          | 25.660              |
| k1                      | 8.082                       | 6.304           | 6.088               | 6.833           | 6.709               |
| k2                      | 6.895                       | 5.469           | 5.437               | 5.590           | 5.768               |
| k3                      | 5.537                       | 6.807           | 7.023               | 5.995           | 6.458               |
| k4                      | 4.836                       | 6.771           | 6.801               | 6.932           | 6.415               |
| R                       | 3.246                       | 1.338           | 1.586               | 1.342           | 0.941               |
Figure 5. The effect curve of each factor on springback.

From the effect curve, it can be seen that the springback angle decreases with the increase of wire diameter, first decreases and then increases with the increase of distance between tool and mandrel, tool feed, feed speed and loading time. According to the theory of orthogonal experiment, the combination of the corresponding level of the minimum kn value of each factor is the case of the smallest springback angle, and the combination of the corresponding level of the maximum kn value of each factor is the case of the largest springback angle. Therefore, when the diameter of steel wire is 2.5 mm, the distance between tool and mandrel is 4.5 mm, the feed rate of tool is 4 mm, the feed rate is 3 mm/s and the loading time is 1 second, the springback angle is the smallest. When the diameter of steel wire is 1 mm, the distance between tool and mandrel is 5 mm, the feed rate of tool is 5 mm, the feed rate is 5 mm/s and the loading time is 0.5 seconds, the springback angle is the largest.

According to the order of importance of these factors, the operator can quickly adjust the value of some factors to change the springback angle when forming the spring angle shape. By adopting this method, it is also possible to quickly obtain the order of importance of the factors affecting the springback angle and maximum and minimum springback conditions of other materials.

4. Conclusions

Based on the finite element simulation software, the orthogonal test of spring angle shape forming springback is carried out. The springback angle data, range analysis data and effect curve of SWOSC-V wire bending under different factors in the bending process are obtained. According to the simulation results, it is found that the order of importance of each factor on springback angle is \( d > h > v > l > t \), and the law of influence of each factor on springback angle is analyzed. The maximum springback conditions and the minimum springback conditions are obtained. It provides a reference for the rapid adjustment of the machine in the bending forming of spring angle shape.

Prospect: The next step is to fit regression formula to get the relationship between the bending springback angle of SWOSC-V material and the factors according to the test data. The springback angle of SWOSC-V material under different working conditions can be predicted by the formula. And they would be verified by the experiment on the actual equipment.

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