Forming Quality Forecasting for Inner Threads Copper Tubes Based on Neural Network

Chundi Jiang*

ABSTRACT
Aims at the defects such as folding and gaps, this paper analyze the relationship between the main processing parameters and inner thread forming quality. Using the fitness function of genetic algorithm to calculate individual fitness value, then the initial weights and thresholds of the Neural Network are assigned, BP Neural Network prediction model based on genetic algorithm is established. The results show that the Neural Networks model has high convergence speed and forecast accuracy, can realize the inner thread forming prediction accurately and improve effectively the forming quality of inner thread.

Key Words: Forming Quality, Neural Network, Forecasting, Inner Threads Copper Tube

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Introduction
These years later, the industry of air conditioning develops rapidly in china. China has become the first major producer of air conditioning in the global which accounts for approximately 60% of the total output and the maximum air conditioning consumption country which accounts for approximately 30% of the total demand. the data of 2015 national economic and social development statistical bulletin shows that air conditioning consumption is 142 million 4 thousand units, all trades consume about 7 million 962 thousand tons of copper in a year, and the balance between supply and demand shows an increasing trend.

According to the requirements of national sustainable development plan and 13th Five-Year planning outline, air conditioning manufacturing industry is developing towards energy saving, environmental protection and healthy. Two phosphorus deoxidized copper (TP2) has good thermal conductivity, corrosion resistance, diamagnetism and excellent processing performance, using widely in heat exchangers, fuel systems, air limiters, pump piping, other deep drawing and welding parts, etc. it is especially favoured in air conditioning industry. Before being processed inner thread copper pipe, the copper must be handled with double pull, the number of road reducing disc pull, thread forming, finishing and other processes. The copper will occur the phenomenon of work hardening, the internal stress is relatively large, and so the copper need to be annealed. The mechanical properties of annealed copper show as Table 1.

Table 1. Typical mechanical properties of tp2

<table>
<thead>
<tr>
<th>Kind</th>
<th>component</th>
<th>tensile strength (MPa)</th>
<th>Elongation (%)</th>
<th>Shrinkage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP2</td>
<td>99.9%Cu-0.02%P</td>
<td>233</td>
<td>53</td>
<td>70</td>
</tr>
</tbody>
</table>

The heat exchanger tubes in air conditioning have been replaced by the inner tube which has the high efficiency heat transfer performance.

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Compared with traditional light pipe, internal thread tube can increase the heating exchange area by 2~3 times, improve the heat exchange rate of 20%~30% because of the turbulent effect of the spiral internal thread, save energy about 15%. The processing technology of inner grooved copper is very high and the forming mechanism is very complex, the actual production process mainly depends on the workers experience to determine the processing parameters and the automation degree of processing equipment is relatively low in China, folding, gaps and the sawtooth of outer surface often appear during the forming stage, the forming quality of TP2 copper tube cannot be guaranteed. Therefore, it is particularly important to optimize the process parameters by the combined method of experiment and artificial Neural Network. All these works can provide some theoretical guidance for the actual production and satisfy the international development trend of internal thread with thin wall, small diameter and high gear teeth. It is significant to predict the quality of inner thread forming by calculating the fitness value of the individual with the fitness function and establishing BP Neural Network prediction model based on genetic algorithm.

At home and abroad, many experts and scholars have researched deeply on the spinning forming process (Atia et al., 2016; Chauhan et al., 2011). Because of the complexity of the internal thread forming technology, the early research achievements derived from experiment and experience summary don’t form a complete theory. After the 90s, the research focuses on forming mechanism gradually. Rotarescu forms a certain theory by analysing the stress of contact region, nip Angle size and the influence of the steel ball number and size. By using the average contact pressure of the circular arc press into semi-infinite body under plane strain state, calculated indirectly the average contact pressure in the forming area, Mao-sheng Li discusses the average contact pressure of the steel ball press into semi-infinite body and obtains the relationship between the contact pressure of steel ball spinning and the circular arc punching into semi-infinite body under plane strain state. Using the method of finite element numerical simulation, Miao-Wang studies the forming law and the change rule of axial feed ratio under different speed, analyses the distribution of stress-strain, and gives the range of the feed ratio for the thin-walled ball. Using the ball spinning force of the light tube and the process parameters, many researches analyse the influence between the ball spinning process and the forming quality; rarely involve the forming mechanism and the stress distribution of internal thread forming. Shu-yong Jiang et al analyse the forming process of thin-walled tube in the longitudinal reinforcement, reveals the forming mechanism of spinning pieces, but the demoulding of forming longitudinal inner ribs is relatively simple (Jiang et al., 2007). Chundi Jiang has used digital signal processor control horizontal continuous casting traction motor three states of positive rotation, inversion rotation and stop, discusses the effect of the forming quality about the forming parameters (Jiang, 2012), Guang-liang Zhang has analyses the cause of fold in the forming process of TP2 internal thread, and results that the reason is the gap between tube and screw thread core head, but don’t associated this factor with the forming parameters. Zhaoze Zhang et al studies the forming mechanism of thread copper pipe, but rarely refer to the relation between forming parameter and forming quality, the analysis is still not deep enough, the analysis is still not deep enough (Zhang et al., 2005).

Spinning grooving stage is the key factor affecting the forming quality of inner thread copper pipe during inner thread forming process. Ball spinning has many characteristics such as local forming of spinning and rolling, metal filled in the tooth is a mechanical process, which is affected by complex mechanism, mold and lubrication condition and so on. Forming geometry, boundary conditions and contact conditions are nonlinear and belong to the category of nonlinear problem. Finite element simulation is a powerful analysis and optimization tool to solve non-linear problem, it can be used to analyse and predict the shape changes during forming period, obtain the ultimate stress and strain distribution and the process parameters influence on product quality and size, and so on (Poletti and Treville, 2016; Song et al., 2013; Wu et al., 2016). Therefore, it is suitable for the simulation and theory research on forming problem of inner grooved copper.

Process parameters, lubrication condition, the mechanical properties of the tube are constantly changing during actual production. Affected by the geometric model and the boundary conditions, the finite element simulation cannot meet the requirements of process parameters (Zeng and Chen, 2013; Zhou...
and Wang, 2011). Therefore, it is not enough to rely on the finite element simulation analysis. By training and learning from discrete data, BP neural network can transform forming quality forecast into solving the questions of network connection weights and threshold, it can establish system model between the inner thread forming process and forming quality through the neurons mutual connection and mathematical calculation (Lauret et al., 2015; Wang et al., 2015).

This paper predicts the forming quality of inner thread using BP Neural Network, through training from the experimental data of discrete learning, the complex mathematical modeling problem is transformed into solving the network connection weights and threshold value, system model is established to reflect the relationship between the main process parameters and inner thread forming quality, thus effective way is provided for the prediction of inner thread forming quality and defects.

**Optimization of forming process parameters**

Considering the requirements of tube surface finish and production efficiency during the thread forming process, the ratio of the motor speed and drawing speed cannot reflect the influence of various process parameters to the quality of internal thread forming, so this paper analysis the effect of every process parameter separately, then consider the influence about internal thread forming quality of all process parameters together.

**The influence of spinning position on forming quality**

Setting pinning speed to 17000r/min and drawing speed to 20m/min, five points along the forward direction of the tube are choices to dissect the influence of spinning position on the forming quality of internal thread.

It is shows that tooth height decreases with the spinning position gradually move forward in figure 1a, and the amplitude is about 5%. The reason is that metal resistance and surface friction in the teeth are greater near the core center of head position, so the stress is larger too, the metal can easily be embedded into the slot. The axial compressive stress is reduced with the spinning forward and the friction resistance decrease, then the tooth height decreases with the metal flow in the slot weakened.

Figure 1b shows that the folding depth will decrease first and then increase with spinning position forward. The reason is that the contact surface of the core head position is not equal the area of alveolar near the middle and the front tube, this will lead to stress in the thread cross section cannot satisfy the requirement of balance and rotary motion of the screw thread instability. The internal thread will move away alveolar in the subsequent spinning process, the extending direction of internal thread cannot consistent with the slot, the fold will appear during the next filling. If the spinning position near thread core about 1/4 front, the unbalance will be improved through change the roughness of the thread core and the slot. The reasonable fluctuation of spinning position is allowed to avoid or reduce the occurrence of folding. When the spinning position is too close to the front, it is not conducive to the axial balance, even cause the thread to crack.

![The influence of spinning position on the height of inner thread](image)

![The influence of spinning position on the depth of folding defects](image)

**Figure 1.** The influence of spinning position on the forming quality

**The influence of motor speed on forming quality**

The drawing speed is 20m/min, spinning position is about 2mm from the thread core, the motor speed is selected 21000r/min, 23000r/min, 25000r/min, 27000r/min and 30000r/min, the influence of motor speed is analyzed on internal thread forming quality.

Figure 2 shows that tooth height decreases with motor speed increase, and the
change rate is about 2.7%, while the depth of folding increased as the motor speed decreased and then increased. The reason is motor speed cannot meet the requirements of release track under 20m/min drawing speed. The influence of the internal thread on the spinning position during demoulding leads the relative rotation of tube cannot keep up the speed of internal thread core, thereby the folding is forming.

After motor speed achieves a reasonable state, if motor speed continues to increase, the metal flow in the circumferential direction will increase, prone to cause certain metal accumulation ahead of spinning area, this will lead to the required spinning force increase, and even make the ball from rolling to sliding. The force on metal circumference increases which makes the relative motion between the tube and the screw thread core higher, and the folding phenomenon appears. Figure 2b shows that the increase of motor speed will lead the folding depth increasing; the tooth height decreases with the motor speed increasing, the reason is each ball spins repeatedly during the forming process of internal thread. The axial feed of each ball satisfies the following equation:

\[
\Delta L = V \Delta t = \frac{4 \pi V (r_1 + t_1)(R - r)}{n w_2 R}
\]

(a) The influence of motor speed on height of inner thread tube

(b) The influence of motor speed on depth of folding defects

Figure 2. The influence of motor speed on the forming quality

We can see from figure 3 tooth height gradually increases with the increase of drawing speed, and the change rate is about 1.9%, the folding depth decreased first and then increased. The reason is that the axial feed increases with the drawing speed increases, that is equal to add to each ball increased, the amount of metal available for filling increases under the same motor speed, and the tooth height increases; on the contrary, the pressure of each ball is relatively

\[
\Delta L: \text{The length of the thread in the axial direction between two steel balls, mm; } \\
\Delta t: \text{The time between the two steel balls; } \\
t_1: \text{Thickness of tube after spinning; } \\
R: \text{Ball radius; } \\
w_2: \text{Motor speed; } \\
n: \text{Ball number.}
\]

According to the Eq (1), the axial feed reduces with the increase of motor speed, which is means the rotation pressure of each ball decrease, the amount of filling metal reduces under the same drawing speed, the forming of tooth height is insufficient.

The influence of drawing speed to forming quality

Setting the spinning speed is 17000r/min, the spinning position is about 2mm away screw thread core, drawing speed is selected 25m/min, 30m/min, 35m/min, 40m/min and 45m/min, this paper analyses the influence of forming quality under different drawing speed.

(a) The influence of drawing speed on height of inner thread tube

(b) The influence of drawing speed on depth of folding defects

Figure 3. The influence of drawing speed to the forming quality
small when the drawing speed is slower, the amount of metal available for filling is less, the tooth height is relatively short (Gonçalves, 2017).

**Optimizing parameters of forming process**

From the analysis of internal thread forming regularity and defects, the forming quality of internal thread is affected by steel ball size, lubrication condition and many other factors, but mainly affected by the three factors, that are motor speed, drawing speed and spinning position. These parameters affected and connected to each other, so according to the interaction of three parameters, this paper design orthogonal experiment to optimize, the factors of level values are shown in table 2.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Motor speed (W)</th>
<th>Drawing velocity (V)</th>
<th>Spinning position (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td></td>
<td>21000</td>
<td>25</td>
<td>-1</td>
</tr>
<tr>
<td>Level 2</td>
<td></td>
<td>23000</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Level 3</td>
<td></td>
<td>25000</td>
<td>35</td>
<td>3</td>
</tr>
<tr>
<td>Level 4</td>
<td></td>
<td>27000</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>Level 5</td>
<td></td>
<td>30000</td>
<td>45</td>
<td>7</td>
</tr>
</tbody>
</table>

According to the level-value of each factor in table 1, this paper design the orthogonal test table for 3 factors 3 levels, after the completion of forming experiment, the sample label is measured to obtain the condition of internal thread depth and folding forming conditions under the different process parameters, using comprehensive evaluation method and according to the importance to 4:1 weighted way, total score is calculate about the tooth depth and folding condition, then statistical analysis of experimental results are obtained.

From the experimental results, we can see that the influence degree of the three parameters to internal thread forming quality: spinning position>motor speed>drawing speed. Based on results of average calculation, we can also obtain the optimal scheme forφ7.00×0.24+0.15 tube, the motor speed is 23000 r/min, drawing speed is 30 m/min, spinning position is greater than 1 mm from the center of the screw thread core position, and these are most optimal parameters to avoid or reduce the folding. Then the optimal scheme is test by experiment, the results show that the optimal scheme can effectively increase the tooth depth and reduce the folding, shown in table 3.

**Forming prediction based on BP Neural Network**

In order to solve the hidden layer unit of continuous power problem in multi-layer Neural Network, BP Neural Network is put forward by Rumelhart etc in 1986, which is an algorithm for multilayer feed forward network Error back Propagation, BP algorithm for short. It is widely used in function approximation, pattern recognition, classification and compression and other fields (Ghritlahre and Prasad, 2018).

**BP Neural network**

BP Neural Network usually consists of input layer, hidden layer and output layer. In network training process, a set of learning samples from all the nodes of input layer through the hidden layer to the output nodes, the output of the nodes in each layer affect only the next layer nodes output, output layer neuron obtain the input response, according to the correction principle of error reduction, layer connection weights of BP Neural Network are modified step by step, the reverse error propagation is modified unceasingly, until BP Neural Network reach the required learning goals.

**BP neural network computational procedure**

BP algorithm belongs to 6 algorithm. It is a kind of supervised learning algorithm, which consists of information forward transmission and error back propagation. The main computational procedures as follows:

(1) Given Input/output Sample Data for Normalization

The input and output data are normalized according to mapminmax function, show as Eq (2).

\[ y_i = \frac{y_{max} - y_{min}}{x_{max} - x_{min}}(x_i - x_{min}) + y_{min} \]  

(2) 

\[ x_i \] is the data to be normalized, \( x_{max}, x_{min} \) are maximum and minimum values in the column, \( y_i \) is the normalized data, \( y_{max}, y_{min} \) are maximum and minimum values in the column, defaults to 1 and -1, respectively.
(2) Output of Hidden Layer Node
A row vector is used to represent the network weights of the input layer and the hidden layer, and then the output of hidden layer node is

\[ y_i = \sum_j w_{ij} x_j + \theta_j = f(\text{net}_i) \]  

(3) \( \theta_j \) is threshold value, generally connected to the fixed bias +1.

(3) Output of Output Layer Node
\( T_{hi} \) is the network weight of output layer and hidden layer, then output of output layer node is

\[ O_i = \sum_{j} T_{hi} y_j + \theta_i = f(\text{net}_i) \]  

(4) \( \text{net}_i = \sum_{j} T_{hi} y_j + \theta_i \)

(4) Calculate Error
If \( t_i \) is the expect output of output node, then error of output node is

\[ E = \frac{1}{2} \sum_i (t_i - T_i)^2 \]  

(5) The error of output layer and hidden layer node are

\[ \delta_i = (t_i - O_i) f'(\text{net}_i) \]
\[ \delta = f'(\text{net}_i) \sum_{j} \delta_j T_{hi} \]  

(6) \( \delta_i \) is the error of output layer, \( \delta \) is the error of hidden layer, \( f(\cdot) \) is transfer function.

(5) Update of the Weight and Threshold Value
The error of output layer and hidden layer can be used to modify the weights and thresholds of the network (Fichera and Pagano, 2017).

The weights of output layer:

\[ T_{hi}(k+1) = T_{hi}(k) + \eta \delta_i y_i \]  

(7)

The error of output layer:

\[ \delta_i(k+1) = \delta_i(k) + \eta \delta_i \]  

(8)

The weights of hidden layer:

\[ w_{ij}(k+1) = w_{ij}(k) + \eta' \delta_i' \]  

(9)

The threshold of output layer:

\[ \theta_i(k+1) = \theta_i(k) + \eta' \delta_i' \]  

(10)

\( \delta_i' \) is the error of output node 1, \( \delta_i \) is the error propagated by weight \( T_{hi} \) to hidden nodes \( i \).

Using train function trainlm of Levenberg-Marquardt and BP learning rule of learngd, this paper shows the results with the performance analysis function mse.

(6) Error Control
When the training error is satisfied as Eq (11), the training is over.

\[ E = \sum_{k=1}^{p} (t_i^{(k)} - o_i^{(k)}) < \varepsilon \]  

(11)

\( p \) is the number of sample data, \( \varepsilon \) is the limit of error.

(7) Prediction
The flow chart of predicting system is showing as figure 4.

The optimization of BP neural network

Figure 4. Flow chart of predicting system
Although BP Neural Network is very useful in solving nonlinear relationship between input and output, but it is often multidimensional complex surface as solving the actual problem, BP Neural Network can converge to the local minimum point. In order to solve the problem, This paper calculate the fitness value of individuals by the genetic algorithm and find most fitness value of individual through selection, crossover and mutation operation, then the initial weights and threshold of BP Neural Network are gained, the process is shown in figure 5.

**Based on genetic algorithm of BP neural network prediction model**

The determination of Neural Network prediction model refers to the determination of network layer and the number of neurons in each layer. This paper mainly studies the three independent variables (motor speed, drawing speed and spinning position) and a dependent variable (inner thread depth), so here chooses the network structure of 3-7-1.

In Neural Network model, the training sample tends to have an order of magnitude difference among different dimensional data, easy cause training speed slowly and affect the convergence property of the network, in order to avoid larger prediction error between the input and output, all data must be converted into number within a certain range. Considering Matlab Neural Network toolbox has high processing accuracy to [0, 1] interval data, using the linear function of Mapminmax, the training samples and test samples are mapped to the range of [0, 1]. But near 0 and 1, the curve is flat and the convergence speed is slow, in order to reduce the learning time of network, this paper map the input and output data in [0.1, 0.9], that is:

$$x_i = \frac{0.8(x - x_{\min}) + 0.1}{x_{\max} - x_{\min}}$$  \hspace{1cm} (12)

$X$ is the normalized data; $x_{\max}, x_{\min}$ is the maximum and minimum value of the column; $x_i$ is the data of normalization.

The sample date is used to train the Neural Network model and test, the mean square error is smaller after 13 cycles and the accuracy requirement is satisfying, shown in figure 6. In order to verify the prediction accuracy of network model, based on other sample data, the prediction results are analyzed, shown in figure 7, the results show that the minimum relative error is 0.076% between the predicted values and the absolute value, the maximum relative error is 0.8%, the average relative error is 0.418% and the precision is high.
Conclusions
This paper establishes the input and output relationship between motor speed, drawing speed, spinning position and inner thread depth based on genetic algorithm, establishes the structure of network model, determines some parameters such as genetic factors, learning rate, the threshold and weighting value, then the required accuracy is obtained and the prediction results are reliable. Results show that the network model has high convergence speed and high accuracy, the quality of inner thread forming can be predicted accurately, a new way is provided for the prediction of inner thread forming quality.

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