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Back propagation neural network based calculation model for predicting wear of fine-blanking die during its whole lifetime

Fei Yin [a,c], Huajie Mao [b,c,*], Lin Hua [a,c], Zhiqiang Gu [d]

[a] School of Automotive Engineering, Wuhan University of Technology, Wuhan 430070, China
[b] School of Materials Science and Engineering, Wuhan University of Technology, Wuhan 430070, China
[c] Hubei Key Laboratory of Advanced Technology of Automotive Parts, Wuhan 430070, China
[d] School of Mechanical and Electronic Engineering, Wuhan University of Technology, Wuhan 430070, China

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ABSTRACT

Die wear during fine-blanking process greatly influences the lifetime of die as well as the quality of products. It is a known fact that wear of die is nonlinearly related to blanking times during its whole service life. To illustrate this phenomenon effectively and precisely, a calculation model for predicting wear of fine-blanking die during its whole lifetime was established based on Back Propagation (BP) Neural Network, Finite Element Method (FEM) and experiments. The inherent law between wear of fine-blanking die and its working parameters was revealed by utilizing the BP neural network. Based on the obtained function and the variation of the working parameters, a calculation model was established to predict die wear at any blanking times during fine-blanking process. To verify the efficiency and validity of the proposed calculation model, a fine-blanked part was utilized in this paper. Tool wear of the bottom die was investigated. Pressure-pad force, ejector force, blanking speed, blanking clearance, fillet radius of bottom and hardness of bottom die were specified to be the key process parameters contributing to the wear condition of bottom die. The process parameters' coupled influence on die wear during fine-blanking process was obtained by a trained neural network. And the die–wear-curve predicted by the calculation model is in good agreement with the real manufacture, which confirms the validity of the proposed BP neural network based calculation model.

1. Introduction

As an advanced materials processing technology, Fine-blanking is a shearing process which produces very highly precise workpieces with completely smooth, tear-free sheared surface [1]. Comparing with the conventional blanking process, fine-blanking has the special characteristics of the application of V-ring indenter, high pressure on the blankholder and on the counterpunch as well as a smaller blanking clearance. These features would provide a high compressive stress in order to delay the generation of crack, resulting in a high surface quality of the blanked parts. Many researches have been performed to investigate the quality of the fine-blanked products and the mechanism of fine-blanking process.

Thipprakmas et al. analyzed the blanked surface during fine-blanking process by using Finite Element Method (FEM) and they stated that FEM could be used as an effective tool for predicting the fine-blanked surface and determining design and working parameters during fine-blanking process [2]. Then they investigated the mechanism and action of the V-ring indenter during fine-blanking process by using the FEM and they indicated the application of V-ring indenter can increase the burnish zone of the fine-blanked part [3].

Subsequently, Thipprakmas studied the degree of importance of the V-ring indenter parameters on fine-blanked surface features via FEM, Taguchi and the analysis of variance (ANOVA) techniques. By optimizing the geometry and position of V-ring indenter during fine-blanking process, the author improved the quality of the fine-blanked surface features [4].

Daeizadeh, et al. studied the effect of blank geometry and material properties on forming force in the fine blanking process by the theoretical formulation and an experimental approach, they concluded that forces in the Fineblanking process are increased by increasing the initial blanking thickness and tensile strength [5]. Then they investigated the effect of the shape of workpiece on forming force in fine blanking process and they stated that by increasing the shape of the workpiece, the forces in fine blanking process are increased [6].

Yiemchaiyaphum et al. studied the effects of back-up ring and the bridge width on die-roll of the fine-blanked parts via FEM

* Corresponding author at: School of Materials Science and Engineering, Wuhan University of Technology, Wuhan 430070, China. Tel.: +86 138 07171614; fax: +86 027 87168391.

E-mail address: maohj_whut@yahoo.cn (H. Mao).

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and experiments, respectively. They concluded that the application of back-up ring could reduce the amount of die-roll formation of the fine-blanked parts [7].

The researches cited above studied the mechanism of fine-blanking process and investigated the influential parameters on surface quality of fine-blanked products. Their conclusions have greatly advanced the development and application of the fine-blanking technique. While die wear that greatly influences the lifetime of dies, quality and cost of products during fine-blanking process was rarely investigated.

In 2011, Yin et al. investigated die wear during fine-blanking process of a kind of automobile synchronizer slipper via Finite Element Method (FEM) and experiments. They concluded that die wear is in proportion to the pressure pad force, ejector force, blanking speed and fillet radius of bottom die, while in inverse proportion to the blanking clearance and hardness of bottom die [8].

Although they calculated the die wear during fine-blanking process and revealed the relationships between wear of die and its working parameters during fine-blanking process, the research just calculated the wear of die during its first-time blanking. Wear theory suggests that wear of tool is changed along with the processing times. It mainly experiences the running-in stage, stable wear stage and rapid wear stage during its whole lifetime [9]. That means wear of fine-blanking die during each blanking time is different. Doing FE simulations and experiments repeatedly to gain the wear of die during each blanking time is obviously not an advisable choice because of the enormous resource consumption.

In this paper, a BP neural network based calculation model was established to calculate the wear of fine-blanking die during its whole lifetime. By analyzing the experimental data from FE simulations, a designed BP neural network revealed the inherent law between wear of fine-blanking die and its working parameters. Based on the obtained law and the variation of working parameters during fine-blanking process, the instant die wear at any blanking times and the total die wear after any blanking times can be obtained accurately and quickly from the calculation model. A fine-blanked part was utilized in this paper to verify the efficiency and validity of the proposed calculation model. Tool wear of the bottom die was investigated. And pressure-pad force, ejector force, blanking speed, blanking clearance, fillet radius of bottom die and hardness of bottom die were specified to be the key process parameters contributing to the wear condition of bottom die. Experiments were performed on the fine-blanking machine and the die–wear-curve predicted by the calculation model shows a very good agreement with the real manufacture, which confirms the validity of the proposed calculation model.

2. BP neural network based calculation model

2.1. Thoughts and algorithm

During fine-blanking process, there exists an inherent law between die wear and working conditions of fine-blanking die. The inherent law is the constant and natural property between the related objects and it will not change along with the blanking times. It is the change of the working conditions such as the setting of the process parameters, the status of fine-blanking machine and dies that lead to different die wear during each blanking. Based on the analysis above, die wear during each blanking can be calculated by: (1) revealing the inherent law between wear of die and its working conditions during fine-blanking process and (2) formulating the variation of the working parameters during fine-blanking process. The calculation thoughts and algorithm can be stated as follows:

Initial working parameters: $x_{1,1}, x_{2,1}, \ldots, x_{n,1}$

Step 1: Calculate die wear during the 1st blanking:

$$w_1 = F(x_{1,1}, x_{2,1}, \ldots x_{n,1});$$

Update the working parameters for the 2nd blanking:

$$x_{1,2} = f_1(x_{1,1}), x_{2,2} = f_2(x_{2,1}), \ldots, x_{n,2} = f_n(x_{n,1});$$

Step 2: Calculate die wear during the 2nd blanking:

$$w_2 = F(x_{1,2}, x_{2,2}, \cdots x_{n,2})$$

Update the working parameters for the 3rd blanking:

$$x_{1,3} = f_1(x_{1,2}), x_{2,3} = f_2(x_{2,2}), \ldots, x_{n,3} = f_n(x_{n,2});$$

Step p: Calculate die wear during the *p*th blanking:

$$w_p = F(x_{1,p}, x_{2,p}, \ldots x_{n,p})$$

Total wear: $sum(w_1, w_2, \ldots, w_p)$where $x_{i,j}$ represents the *i*th working parameter's value during the *j*th blanking; w_j is the die wear during the *j*th blanking; *F* is the inherent relationship between die wear and working parameters during fine-blanking process; f_i denotes the variation of the *i*th process parameter; $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, p$.

2.2. Establishment of the calculation model

To fulfill the thoughts and algorithm demonstrated above, BP neural network was utilized in this paper to reveal the inherent relationship between the die wear and process parameters during fine-blanking process.

Developed based on the working principle of the nervous system of organism, BP neural network has the powerful ability of nonlinear interpolation. It can acquire the relationship between research objectives by training and learning process and has been widely used in engineering application [10,11].

Younesi et al. predicted the wear behaviors of nickel free stainless steel-hydroxyapatite bio-composites by using the BP neural network. They concluded that artificial neural network is an effective tool in the prediction of produced composites properties and quite useful rather than using time-consuming experimental processes [12].

Yin et al. developed a BP neural network to predict the warpage value of a plastic injection part and then they proposed a hybrid of BP neural network and genetic algorithm method for process parameters optimization during plastic injection molding. The research results indicate that BP neural network can be used as an efficient tool for prediction and optimization during plastic injection molding [13,14].

In this paper, a multilayer BP neural network model was designed on the Matlab platform to acquire the functional relationship between die wear and process parameters during fine-blanking process. After training process of the designed network with experimental data from the FE simulations, the mathematical function was saved as a database, which can be read and calculated. The whole structure of the BP neural network based calculation model for predicting wear of fine-blanking die during its whole lifetime can be seen in Fig. 1:

Where w_j is the die wear during the *j*th blanking; X_j is the matrix consists of the working parameters of the *j*th blanking: $x_{1,j}, x_{2,j}, \ldots, x_{n,j}$; F_{net} represents the functional relationship between die wear and process parameters obtained by the trained neural network; *f* is the variation of the working parameters during fine-blanking process; δ denotes the maximum predictive error of the trained network and *N* is the specified calculating number.