

AN APPLICATION OF NEURAL NETWORKS IN MODELLING

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Summary: An approach to modelling behaviour of powder metallurgy parts dimensions at sintering process for the prediction of the dimensional changes is given. The model is developed on the base of significant process factors applying multilayer neural network architecture with backpropagation learning algorithm. Results of the simulation in the form of the diagrams and tables are presented. Obtained model gives better results than the one of statistical procedure of the experimental data, i.e. less total mean approximation errors of the part dimensions for 11.4%. Practical effects of the modelling is in determination of compact dimensions in accordance with dimensional changes during sintering.

Keywords: Modelling, Sintering process, Dimensional changes, Neural network, Model error.

1. INTRODUCTION

Prediction of the dimensional changes during sintering within the process of the production of the powder metallurgy (PM) parts with cold compaction in a closed die is presented. During sintering a great number of the process factors appear, which influence change of dimensions and by that, on a final accuracy of a part (temperature, sintering time, type of the protection atmosphere, regimes of pre-heating and cooling, kind of transport). In this paper the objective was to examine the influence of geometry and dimensions of a part to the change of these dimensions during sintering.

The prediction was performed by means of the model based on artificial neural networks (NNs). A multilayer NN with backpropagation learning algorithm was used, which gave the best results in the process modelling.

Modelling by NNs is used in most fields of production. The concepts involved in NN modelling and its application to various aspects in powder metallurgy manufacturing is given in [1,2]. Our investigations in application of NNs in powder metallurgy are given in [3-5].

2. BACKPROPAGATION ALGORITHM

Backpropagation algorithm, also known as a “Generalized Delta rule” [6] is used for learning of multilayer NN. Multilayer NN (Figure 1) has a feedforward signals flow and fully interconnected corresponding layers through processing elements. The general architecture consists of the input layer with N processing elements, H “hidden” layers with N_1, N_2, \dots, N_H elements, respectively, and the output layer with M elements.

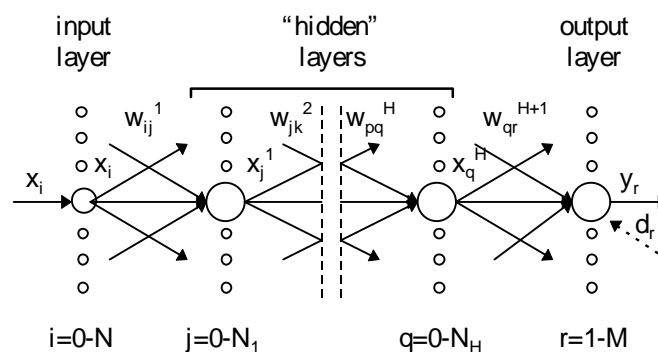


Figure 1: A general architecture of multilayer neural network

The learning process is performed in iterative cycles. Each cycle consists of two passes: a forward pass and a backward pass.

In the forward pass, the outputs of processing elements in all layers from input to output are determined. The input layer does not process input signals x_1, x_2, \dots, x_N , it only performs fanout of signals to the elements of second layer. The inputs x_j^l in the first “hidden” layer are obtained as the sum of products weights w_{ij}^l of interconnections of elements i and j and the input x_i , to which the corresponding transfer function is applied. With this kind of NN the transfer function is more often sigmoid. In the same way, the inputs in other layers are obtained, and at the end the outputs of NN y_1, y_2, \dots, y_M are obtained.

In the backward pass, by the application of the gradient descent method on the mean square output error, which is difference between the desired outputs d_1, d_2, \dots, d_M and outputs of the NN y_1, y_2, \dots, y_M , the correction of weights is done. The correction of weights is performed by the outputs error backpropagation from output to input layer. The iterations are performed for corresponding input/output pairs and thereby the output error is decreased, until it reaches a set value in accordance with chosen criterion. As the criterion, besides the mean square error, the maximal error, the mean error, etc. can be taken.

3. DEVELOPMENT OF MODEL FOR PREDICTION

The model is formed for the certain kinds of PM parts - self-lubrication bearings, material of which is bronze P4013Z. The regimes of the sintering process for the given material during obtaining of the experimental data were constant. The process is observed inversely. As input factors, dimensions and density of the sintered parts are taken, and output characteristics are dimensions of the compacts, on the basis of which, dimensions of the compaction tool can be determined, i. e. the elements necessary for projecting manufacture process. Based on the experimental data, a model of dimensional changes of the part during sintering is formed. As a model, a multilayer neural network is used, the architecture of which is shown in the Figure 2.

The standard backpropagation algorithm with correction of weights after every iteration and with the moment term is applied, based on which a programme for simulation is formed. Within the simulation programme, the preparation of inputs, i.e. experimental data, has been performed (randomization of order, division of the entire input set into training data set and test data set, parameterization and normalization of data), generation of the initial weight values and defining of the accuracy criterion.

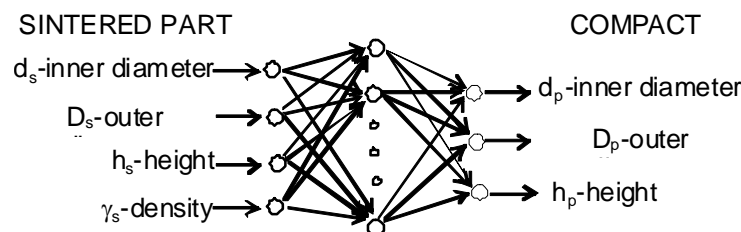
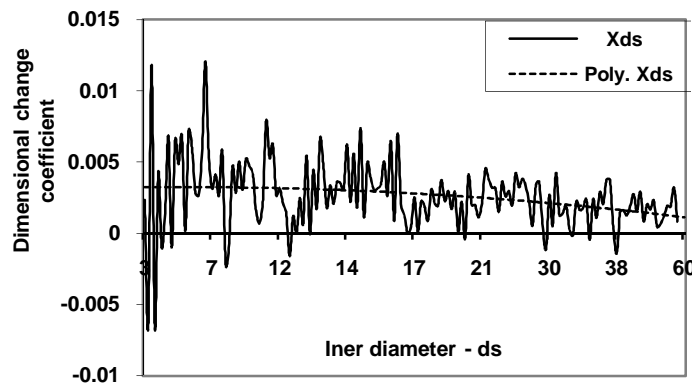


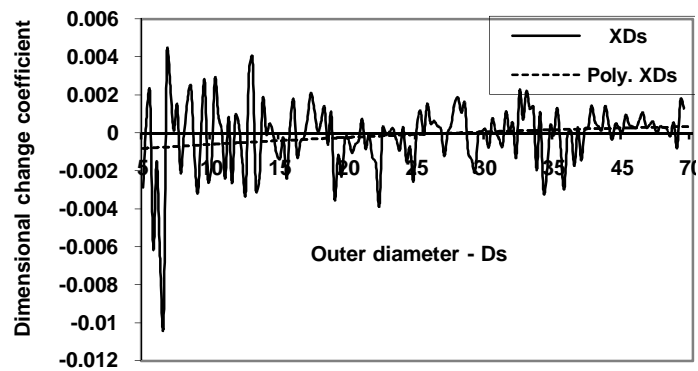
Figure 2: The architecture of the model of dimensional changes during sintering

The set of input, i. e. experimental data is divided in the way that approximately 3/4 of the accidentally chosen data are used for learning and 1/4 for testing. By optimization as per the criterion of the minimum error of testing and minimum number of learning cycles, the parameters of the model are obtained as follows: learning rate term 0.9, momentum term 0.4, the interval of the initial weights ± 0.3 and the number of processing elements in the hidden layer 4.

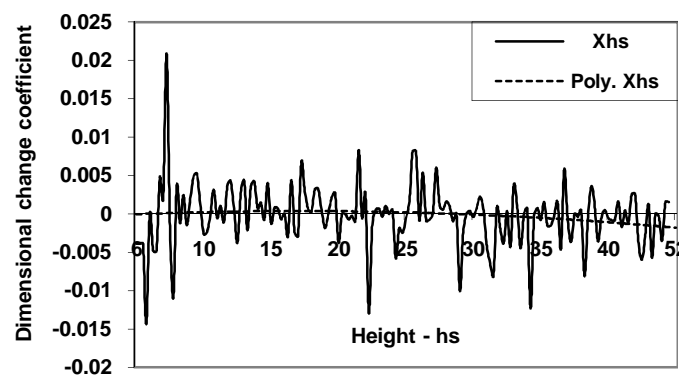
4. PREDICTION RESULTS



a)



b)



c)

Figure 3: Dimensional change coefficients

By the simulation of the model with the optimal parameters in the set of the experimental data for testing, the outputs are obtained, i. e. dimensions of the part after compaction, for the given dimensions of the sintered part. Based on the

input experimental data and the obtained outputs, the coefficients which represent relative change of the corresponding dimensions during sintering are obtained as follows:

$$Xds = \frac{dp - ds}{ds}; XDs = \frac{Dp - Ds}{Ds}; Xhs = \frac{hp - hs}{hs}$$

In the Figure 3, dimensional change coefficients are shown. A relative change of the inner diameter Xds for the bearings with $ds = 3-60\text{mm}$ is shown in the Figure 3a. Next to the real curve, its polynomial approximation is given. It is observed that the coefficient Xds decreases with diameter increasing. Coefficient of the outer diameter XDs slowly increases with increasing Ds (Figure 3b), and coefficient of the height Xhs behaves similarly as Xds (Figure 3c). The mean values of the dimensional changes during sintering is given in the Table 1, where the sign gives direction of the change in relation to the supposed direction in the equation given above.

Table 1: Mean values of the dimensional change coefficients

Xds	XDs	Xhs
$2.616 \cdot 10^{-3}$	$-1.453 \cdot 10^{-4}$	$-1.796 \cdot 10^{-4}$

The results of the model simulation in the form of the output errors are given in the Figure 4. The errors represent mean values of the absolute deviations of the model outputs from the desired ones, i. e. experimental values of the outputs. The diagrams in the Figure 4. display the change of learning and testing errors as per dimensions for 3000 cycles of training, since during increase the number of cycles, the convergence is very slow. The change of the learning errors with increasing cycles of training is given in the diagram in the Figure 4a. The learning errors, after relatively rapid decrease in the beginning of the training, and varying in the next stage, after approximately 600 cycles enter into the convergence area. The testing errors behave in a similar way (Figure 4b). It is observed that the error of modelling of the compact height is considerably bigger from the error of inner and outer diameters. Apart from that, the learning error at the compact height is bigger than the testing error, which refers that the noise of the process is bigger at this dimension.

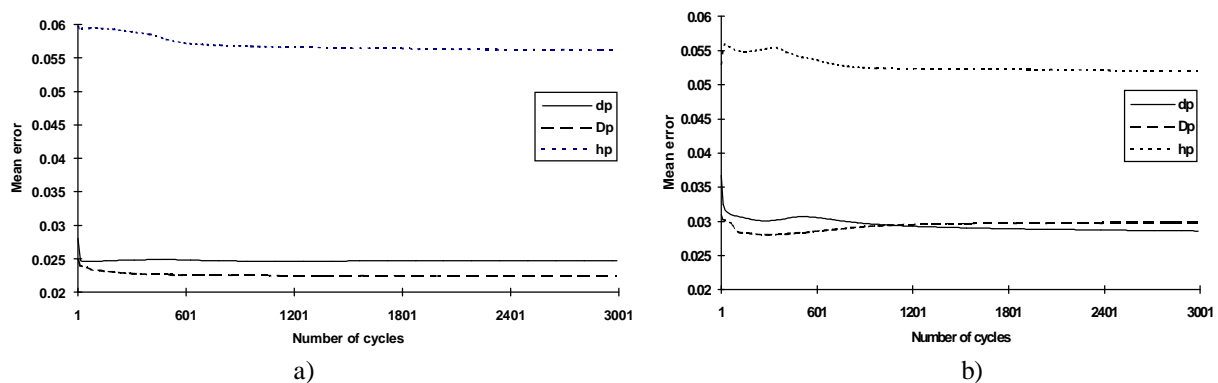


Figure 4: The learning errors (a) and testing errors (b) of the part dimensions model

5. COMPARISON OF MODEL RESULTS WITH STATISTICAL PROCEDURE

The results of model simulation, given in this paper, were compared with the standard procedure based on statistical processing of experimental data. This procedure is carried out by backward movement, from the sintered part dimensions to compaction, taking into consideration dimensional changes in sintering. Dimensional change coefficients, based on learning data set used with NN, were determined. Compact dimensions were determined for testing data set using obtained coefficients. The same form of the mean error as the one of the NN was used for comparison.

The comparison results are given in the Table 2. The results show that NN based model gives lower mean error of every output, and lower total mean error for 11.4% than obtained by statistical procedure. This was achieved by including a greater number of significant factors and their interdependence, as well as by having more common functional forms and iterative approach to solution.

Table 2: The mean errors of the prediction for statistical procedure and for NN model

Model	d_p	D_p	h_p	Σ
With statistical procedure	0.02858	0.02977	0.05198	0.11033
With NN	0.03315	0.03271	0.05867	0.12453

6. CONCLUSIONS

A procedure and results are presented of the dimensional changes modelling during sintering with usage of multilayer neural networks and backpropagation learning algorithm.

In developing of the model, the advantages of the neural networks are used for identification of the unknown behaviour of the process with great number of the influential factors (the tolerance of error, robustness to the noise and incomplete data and approximation ability of high nonlinearity systems). With parallel processing structure a required interdependence of the inputs and simultaneous forming of a greater number of outputs are achieved.

A practical significance of the dimensional changes prediction during sintering is in determination of the dimensions of the compact for the required dimensions of the sintered part and a kind of a material, for the in advance set regimes of the process. By means of the dimensions of the compact, dimensions of the compaction tool can be determined, in order to get a final part of the necessary dimensions as a result.

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