PREDICTION OF THE DIMENSIONAL CHANGES DURING SINTERING OF PM PARTS

Dragoljub Drndarevic, Milovan Milivojevic
High Business Technical School, Uzice, Serbia, skola@vpts.edu.rs

Abstract - *A approach to modelling behaviour of PM parts dimensions at sintering process for the prediction of the dimensional changes is given. The model is developed on the basis of significant process factors by applying multilayer neural network architecture with backpropagation learning algorithm. Results of the simulation in the form of the diagrams and tables are presented. The presented model gives better results than the one based on statistical analysis of experimental data, i.e. less total mean approximation errors of the part dimensions for 11.4%. A practical result of the model is the determination of compact dimensions to compensate for dimensional changes during sintering.*

Keywords*: Process modelling, Powder metallurgy, Sintering, Dimensional changes, Neural networks*

1. INTRODUCTION

Modelling of the dimensional changes during sintering within the process of the production of the PM (powder metallurgy) 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 modelling was performed by means of artificial neural networks. A multilayer neural networks with backpropagation learning algorithm was used, which gave the best results in the process modelling.
Different methods of modelling sintering processes of metal powder parts are used (given in [1-4]).

2. MODEL

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 basic 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 dimension changes of the part during sintering is formed. As a model, a multilayer neural network is used [5], the architecture of which is shown in the Figure 1. The architecture of the model consists of the input layer, one (or more) "hidden" layers and output layer. Each layer consists of the processing elements, whereas the number of processing elements of input and output layers corresponds to the number of the chosen input factors and output characteristics of the part, respectively, while the number of the processing elements in the hidden layer is arbitrary.
The modelling consists of the learning and testing stages. Learning is an iterative process in which the coefficients (weights) of the model are determined. During testing with the obtained weights, for the corresponding input data, the requested characteristics are obtained. With the aim of determining accuracy, i. e. errors of the model, the values of the obtained characteristics can be compared to the corresponding experimental values.
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.
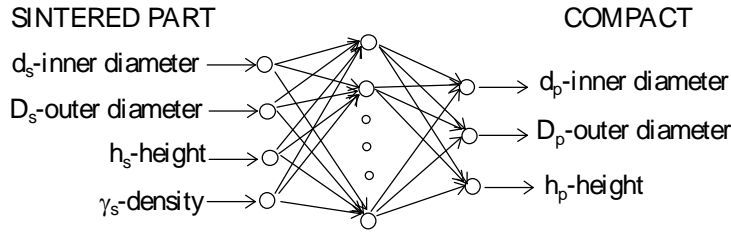
Figure 1. The architecture of the model of dimension changes during sintering

3. RESULTS

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:

$$Xds = \frac{dp - ds}{ds} \ ; \ XDs = \frac{Dp - Ds}{Ds} \ ; \ Xhs = \frac{hp - hs}{hs} \tag{1}$$

In the Figure 2., a relative change of the inner diameter Xds for the bearings with ds = 3-60mm is shown. Next to the real curve, its polynomial approximation is given. It is observed that the coefficient Xds decreases with diameter increasing. Coefficient XDs slowly increases, and Xhs behaves similarly as Xds (change of the coefficient XDs and Xhs is not shown). The mean values of the dimension changes during sintering amounts: Xds=2.26·10^{-3}, XDs= -1.45·10^{-4}, Xhs=-1.80·10^{-4}, where the sign gives direction of the change in relation to the supposed direction in the equation (1).
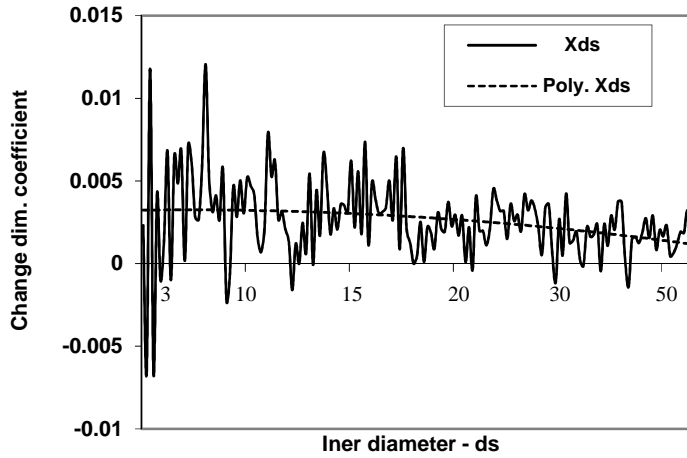

Figure 2. Relative change of the inner diameter during sintering

The results of the simulation model in the form of the output errors are given in the Figure 3. 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 Table in the Figure 3. gives the errors of learning and testing as per dimensions for 3000 cycles of learning, since during increase the number of cycles, the convergence is very slow. The change of the testing errors with increasing cycles of learning is given in the diagram in the Figure 3. The testing errors, after relatively rapid decrease in the beginning of the learning, and varying in the next stage, after approximately 600 cycles enter into the convergence area. 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.
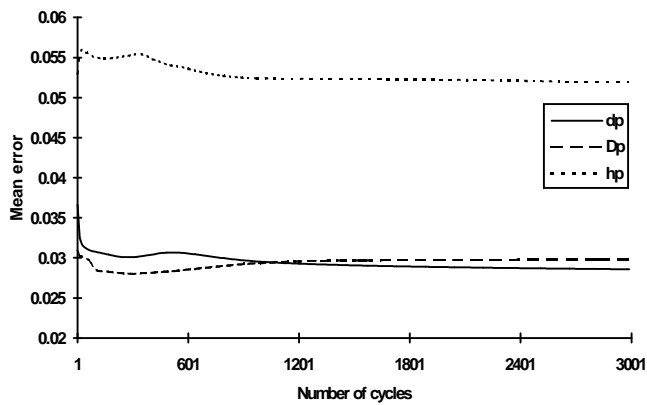
Dimensions	dp	Dp	hp
Learning	0.0247	0.0224	0.0561
Testing	0.0286	0.0298	0.0520

Figure 3. Errors of the sintering model

Detailed information of possible approximation with the model based on NN is shown in Table 1. Network output values, obtained from testing corresponding data sets and, for the purpose of comparison the experimental output values from the same set, are given (k is ordinal number of experiment).

Table 1. Model testing outputs and experimental outputs

k	Model outputs			Desired (exp.) outputs		
	d_p	D_p	h_p	d_p	D_p	h_p
1	7.033	9.061	7.643	7.033	9.055	7.640
2	30.162	35.166	25.879	30.088	35.164	25.920
3	11.590	14.108	13.648	11.624	14.121	13.640
	....					
38	20.053	30.139	20.658	20.008	30.092	20.670
39	60.135	70.081	51.692	60.128	70.158	51.840

The comparison results are given in 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 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	0.03315	0.03271	0.05867	0.12453
With NN	0.02858	0.02977	0.05198	0.11033

4. CONCLUSIONS

A procedure and results are presented of the dimensions change 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 dimensions change modelling 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.

REFERENCES

[1] German R.M., Computer modeling of sintering processes, Int. Journal of Powder Metallurgy, 38 (2), 2002: 48-66.
[2] Drndarevic D., Djuricic M., Modelling of the Dimensional Changes during Sintering, Science of Sintering, SANU, Belgrade, Vol. 37, No. 3, 2005: 181-187.

[3] Rojek J. et al., Modeling of a sintering process at various scales, XXI Int. Polish-Slovak Conf. Machine modeling and Simulations, 2016., Science Direct, Procedia Eng. 177, 2017: 263-270.

[4] Wawrzyk K. et al., A constitutive model and Numerical Simulations of Sintering Processes of Macroscopic Level, AIP Conf. Proceedings 1922 030011, 2018: 030011(1-7).

[5] Rumelhart D. E., Hinton G. E., Williams R. J., Learning representation by back-propagating errors, Nature, Vol. 323, 1986: 533-536.