The Dimensional Dynamics Identification of Reconfigurable Machine Tools

CIPRIAN CUZMIN, VIRGIL TEODOR, NICOLAE OANCEA, VASILE MARINESCU, ALEXANDRU EPUREANU
Department of Manufacturing Engineering
"Dunărea de Jos" University of Galați
Galați, no. 111 Domnească Street., zip code 800201
ROMANIA
ciprian.cuzmin@ugal.ro

Abstract: - The paper presents a new method for online identification of the dimensional dynamics to be used for the dimensional control of reconfigurable machining systems. The dimensional control is designed as adaptive and predictive.

The dimensional control of the reconfigurable machining system is a key action in order to achieve the quality desired for the finite product. As a diminishing deviation presents the disadvantage that reducing deviations are accompanied by high costs, the deviation compensation implies a better control of the process.

The deviation compensation emerged during the working process requires knowledge of a model which describes the dimensional dynamics of the machine tool, which is the relation between the dimensional changing of the processed part and the parameters of the process. On the other hand the behavior of the machining system evolution changes significantly in time even during the processing of a small number of parts processed. This is the reason that dimensional dynamics must reveal the changing in time of the relation between dimensional variation of the parts and the process parameters.

Key-Words: - reconfigurable machine tools, online identification, dimensional dynamics, dimensional control

1 Introduction

The dimensional control of the processing is a key action to obtain the needed quality for the finite product. There are used two techniques for controlling the dimensional deviation:

a) the diminishing of the deviation by reducing the values of the process parameters and the use several consecutive processing;

b) the deviation compensation by modifying the programmed trajectory of the tool.

As reducing the deviation presents the main drawback that leads to the increase of the cost, the deviation compensation is a more suitable solution.

The deviation compensation emerged during the processing requires prediction based on a model that describes the dimensional dynamics of the machine tool ([1], [2], [4]), meaning the relation between the modifying dimension of the part processed and the processing parameters. On the other hand, the behavior of the machining system evolves significantly in time, even during the processing of a small part batch. This is the reason dimensional dynamics must comprise changing in time of the relation between dimensional part variation and the processing parameters.

In literature there are presented several compensation techniques as it follows:

a) all the parts are measured before and after the processing; the compensation is represented by the difference between the target surface and the obtained one [1];

b) the compensation of some of the components of the error [4], [5] is performed;

c) the processing parameters are kept constant in order to obtain a uniform deviation.

All the papers presented identify and compensate the components of the error and not the error itself [3], [7], [8].

The purpose of the paper is to develop a new method for online identification of the dimensional dynamics to be used in the dimensional control of the Reconfigurable Machining Tool (RMT). This dimensional control is designed as being adaptive and predictive.

The proposed method is experimentally tested in order to evaluate the performance when applying to an actual case; in chapter 2 it is described the identification algorithm of the dimensional dynamics; in chapter 3 it is shown the experimental research of dimensional dynamics; finally, chapter 4 comprises discussions and conclusions concerning the obtained results.

2 The Algorithm for online identification of the dimensional dynamics

We considere that a RMT has been configured and the tooling is changed to be able to process another part of the same product family. As a consequence of these changes the RMT behaviour has modified and the model that describes its behaviour is no longer valid [6]. It is neccessary that RMT should be re-identified, representing an important part of the ramp-up-time. We consider, that the RMT processes the part number **n** of the batch. We need to identify the relation between the dimensional deviation occurred during the processing of a part, and the data resulted from the monitoring of the RMT during the processing all of the previous **n-1** parts.

In order to describe the stationary state of the system coresponding to a certain bin of the tool trajectory the following variables will be used:

- variables that describe the mechanical field; these may represent components of the cutting force; $\mathbf{F^{(1)}}$, $\mathbf{F^{(2)}}$, $\mathbf{F^{(3)}}$ (average values of these in a bin width);
- variables that describe the thermical field; these may be average values $\mathbf{T^{(1)}}$, $\mathbf{T^{(2)}}$, $\mathbf{T^{(3)}}$ of the temperature from certain position of the RMT,
- variable **i** represents the count number of the bin corresponding to the tool trajectory,
- variable **j** representing the count number of the parts group processed that due to the shape and position error and wear can be considered unchanged.

The numbering of the part processed, considered with the wear unchanged, has its origin in the current part, e.g. during processing the second part wear can be considered unchanged, then **n**, **n-1** parts represent such a group with numbering **k**=1, and the parts **n-2**, **n-3** form a second group for **k**=2 and so on. This variable characterises the tool wear and the RMT behaviour corresponding to the processing period of time for the current part,

- deviation **δ** corresponding to the bin order i number.

Variables **F**, **T** and **δ** values will be scaled on their own variation in such a way that all the variables can be represented by integer values. For instance in fig.1 these variables have been scaled using 6 levels.

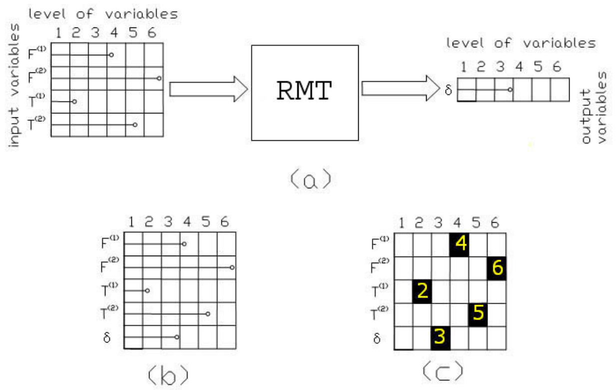
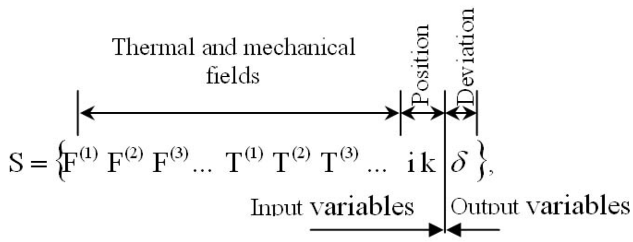


Fig. 1. Three representation ways of the steady state of the system coresponding to the one tool path bin

We define RMT state using an interger number set representing the thermical and mechanical fields, position and deviation.

The RMT state in a certain step will be represented as it follows:



where $\mathbf{F^{(1)}}$, $\mathbf{F^{(2)}}$, $\mathbf{F^{(3)}}$, representing the obtained values by signal processing of the data read by different sensors in different points of the system, $\mathbf{T^{(1)}}$, $\mathbf{T^{(2)}}$, $\mathbf{T^{(3)}}$, representing the temperatures measured in different points of the system, **i** is the order bin number from the tool trajectory corresponding to the processing of a part, and **k** is the current number of the parts group processed with shape and position error, can be considered unchanged.

For the sake of simplicity let us consider that the mechanical field is evaluated in a single point on the machine. In this case four states can considered $S_1 = \{F_1\ T_1\ i_1\ k_1\ \ \delta_1\}$, $S_2 = \{F_2\ T_2\ i_2\ k_2\ \ \delta_2\}$, $S_3 = \{F_3\ T_3\ i_3\ k_3\ \ \delta_3\}$, $S_4 = \{F_4\ T_4\ i_4\ k_4\ \ \delta_4\}$.

In the state field we define the following metrics. The difference between S_1 si S_2 states is:

$$S_1 - S_2 = \{(F_1 - F_2), (T_1 - T_2), (i_1 - i_2), (k_1 - k_2), (\delta_1 - \delta_2)\} \quad (1)$$

The distance between the states is:

$$d(S_1, S_2) = |F_1 - F_2| + |T_1 - T_2| + |i_1 - i_2| + |k_1 - k_2| \quad (2)$$

Several states are considered as part of the same equivalence class if the input variables meet a certain condition. For instance, we consider the classification of states depending on their distance with an indicated state. States that have the distance

a relative to the indicated state form an equivalence class of **a** order. peculiarly, if **a**=0, then the states are identical.

The transition is defined as a pair of states, one is considered the initial state and the second is the final state and they are represented as it follows:

$$\tau_{(1,2)} = \begin{Bmatrix} F_1 & T_1 & i_1 & k_1 & \delta_1 \\ F_2 & T_2 & i_2 & k_2 & \delta_2 \end{Bmatrix} \begin{matrix} \downarrow \text{Initial state} \\ \uparrow \text{Final state} \end{matrix} \quad (3)$$

$$\tau_{(3,4)} = \begin{Bmatrix} F_3 & T_3 & i_3 & k_3 & \delta_3 \\ F_4 & T_4 & i_4 & k_4 & \delta_4 \end{Bmatrix}.$$

For given transitions we define the difference between two transitions:

$$\tau_{(1,2)} - \tau_{(3,4)} = \begin{Bmatrix} F_1 - F_3 & T_1 - T_3 & i_1 - i_3 & k_1 - k_3 & \delta_1 - \delta_3 \\ F_2 - F_4 & T_2 - T_4 & i_2 - i_4 & k_2 - k_4 & \delta_2 - \delta_4 \end{Bmatrix}. \quad (4)$$

We consider that two transitions are equivalent if the difference is:

$$\tau_{(p,q)} - \tau_{(r,s)} = \begin{Bmatrix} 0 & 0 & a & b & \delta_p - \delta_r \\ 0 & 0 & a & b & \delta_q - \delta_s \end{Bmatrix}, \quad (5)$$

where $\begin{matrix} a = i_p - i_r = i_q - i_s \\ b = k_p - k_r = k_q - k_s \end{matrix}$.

Two equivalent transitions have the same variation of input values (mechanical field (**F**), thermical field (**T**) and position (**i**, **k**)). This is the reason that the same output variation will occur, represented by:

$$(\delta_p - \delta_r) = (\delta_q - \delta_s). \quad (6)$$

The identification algorithm is represented in figure 2:

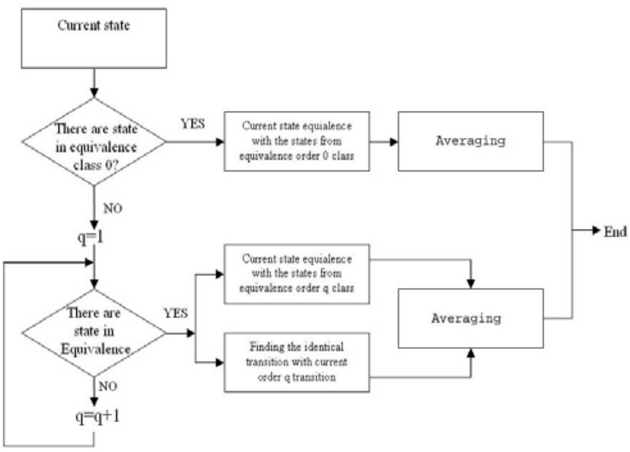


Fig.2. Data processing algorithm

3 Experimental researches

It has been processed a 70 parts batch (fig.3). The linear trajectory of the tool was divided in 5 regions. The dimensional control algorithm was operated separatly in each of the zones. During the processing the cutting force was measured. The average value of the corresponding cutting force was used for the dimensional control of a certain zone from the tool path.

Using the proposed algorithm and taking into account the recent event emerged concerning the processing system evolution, we simulated the dimensional compensation and we obtained the following results:

-the average value of the deviation decreased from 0.837014 mm to 0.0103 mm, meaning a 81 times improvement;

- standard deviation decreased from 0.249 mm to 0.23 mm, that is a 1.1 time improvement.

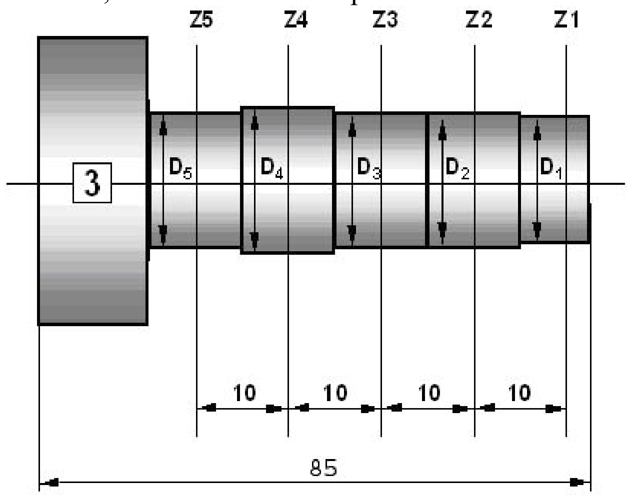


Fig.3 Blank work piece

It is noted that the performance of the method is very good as the dimensional dynamics of the system is described sufficiently accurate.

Applying this method is quite simple, with a small number of operations to complete the prediction, meaning that the speed of the prediction calculus is very high. The dimensional compensation is performed online from this deriving a low production cost.

The precision can be improved by increasing the number of zones of the tool path, as well as the decreasing of width of the intervals of scaling for process variables.

4 Conclusions

We can state that the proposed method is able to improve the RMT behavior for mechanical cutting processing, improving the processing precision by compensating the errors.

The novelty of the proposed method is that considering the whole error as an entity, it successfully achieves to differentiate deviation compensation in the process.

Using this method the time needed for the identification of the RMT is reduced. Taking into account the evolution in time of the RMT, the model is changing continuously, describing a real evolution of the system.

References:

[1] Choudhury S. K., V. K. Jain, S. Rama Krishna, *On-Line Monitoring of Tool Wear and Control of Dimensional Inaccuracy*, In: Turning, Journal of Manufacturing Science and Engineering, February 2001, Volume 123, Issue 1, pp. 10-12

[2] Dong, C., Zhang, C., Wang, B., Zhang, G., *Prediction and Compensation of Dynamic Errors for Coordinate Measuring Machines*, Journal of Manufacturing Science and Engineering, August 2002, Volume 124, Issue 3, pp. 509-514.

[3] Hong Yang, Jun Ni, *Dynamic Modeling for Machine Tool Thermal Error Compensation*, Journal of Manufacturing Science and Engineering, May 2003, Volume 125, Issue 2, pp. 245-254

[4] Kim, S., Landers, R.G., Ulsoy, A., *Robust Machining Force Control With Process Compensation*, Journal of Manufacturing Science and Engineering, August 2003, Volume 125, Issue 3, pp. 423-430.

[5] Lian, R.J., Lin, B.F., Huang, J.H., *A grey prediction fuzzy controller for constant cutting force in turning*, International Journal of Machine Tools and Manufacture, Volume 45, Issue 9, July 2005, pp. 1047-1056.

[6] Mehrabi M.G., A.G. Ulsoy, Y. Koren, and P. Heytler, *Trends and Perspectives in Flexible and Reconfigurable Manufacturing Systems*, Journal of Intelligent Manufacturing, Vol. 13, No.2, April 2002, pp 135-146.

[7] Steven Y. Liang, Rogelio L. Hecker, Robert G. Landers, *Machining Process Monitoring and Control: The State-of-the-Art*, Journal of Manufacturing Science and Engineering, May 2004, Volume 126, Issue 2, pp. 297-310

[8] Tseng, P.C., Ho, J.L., *A Study of High-Precision CNC Lathe Thermal Errors and Compensation*, The International Journal of Advanced Manufacturing Technology, Springer London, June 2002, Volume 19, Number 11, pp. 850 – 858.

Acknowledgement

This paper was developed under the research programs CEEX, grants 22 and 23, funded by the Romanian Ministry of Education and Research