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Error compensation in NC machine tools

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Abstract

This work contributes to the development of new approaches to tolerancing for machining using a machine tool with digital control. Our research is focused in two directions. First, it focuses on the manufacturing tolerances. The aim was to establish procedures for validating ranges of light manufacturing dispersions, manufacturing errors and machine tools with digital control, and cover various types of critical tolerances targeted. The second deals with design tolerances, for which we proposed a method for calculating functional tolerances.

Keywords: Errors, tolerance, manufacturing.

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1. Introduction

The tolerance of mechanical systems is one of the key steps in the creation of a product. The effects induced by tolerancing impact the quality and cost of a finished product. The control of dimensional and geometrical defects during the manufacture of mechanical parts ensures the final quality of the product. The aim is not to avoid dimensional and geometrical defects at all costs, but only to foresee them to take them into account and to verify that their effects will enable the product to meet the functional needs at the optimal cost.

Several studies have been devoted to tolerance problems in design and manufacturing. Jayaratnan and Srinivasan [1] developed virtual boundary requirements, an approach seeking to translate geometric tolerance into a mathematical form. Romulus *et al.* [2] proposed a calculation method for the three-dimensional analysis of tolerances by considering the main dispersions of the processes and errors due to the machine tool. Cheikh *et al.* [3] developed modelling of the optimisation of functional tolerances by the dispersion method. Wei and Lin [4] presented a study of the general analytical method for CNC machining of free-form surfaces. Mojtaba [5] proposed resolution methods associated with the model of the manufactured part model developed by Vignat and Villeneuve. The work in [6] studies the influence of systematic dispersion (SD) on manufacturing tolerances. Sebaa [7] proposed a mathematical model to calculate the distribution of fulcrums. Rahou [8] developed a modelling of machining errors on the NC machine tool.

2. Challenges of Traditional Data Centres

In general, manufacturing errors are classified into three categories. The first concerns machining errors such as tool wear and thermal dispersion. The second represents position errors such as clamping defects and positioning errors, while the third concerns geometrical errors such as the geometrical defects of the machine, parts, etc.

This work is devoted to the analysis of manufacturing defects concerning the positioning, trajectory and wear of the cutting tool.

2.1. Error of Cutting Tool

This section discusses quantification of the defects due to wear of the cutting tool. To achieve this objective, we used the results of Rahou *et al.* [9] on the influence of SD on manufacturing tolerances.

We used Eq. (1) [10] to calculate the values of the SD; these results are summarised in Table 1.

$$d_{ija} = d_{ijt} - \frac{\Delta CFs_{ij}}{N} i \tag{1}$$

Table 1. Systematic dispersion

Piece	Systematic dispersion	Piece	Systematic dispersion	Piece	Systematic dispersion
1	0	10	0.00934803	19	0.01869606
2	0.00103867	11	0.0103867	20	0.01973473
3	0.00207734	12	0.01142537	21	0.0207734
4	0.00311601	13	0.01246404	22	0.02181207
5	0.00415468	14	0.01350271	23	0.02285074
6	0.00519335	15	0.01454138	24	0.02388941
7	0.00623202	16	0.01558005	25	0.02492808
8	0.00727069	17	0.01661872		
9	0.00830936	18	0.01765739		

Figure 1 shows the evolution of SD as a function of the machined length. We note that this evolution is an increasing linear function.

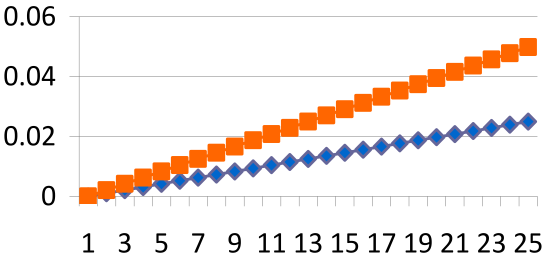

Figure 1. Evolution of the SD

2.2. Modelling of Systematic Dispersion

In this section, we used the Lagrange method for modelling. Model (2) is given in the following form:

$$IT = 9{,}8.10^{-4} + 3{,}36.10^{-5}\,x + 3{,}62.10^{-7}\,x^2 \tag{2}$$

2.3. Defects in the Trajectory of the Cutting Tool

The aim of this section is to quantify the defects due to the trajectory of the cutting tool. To achieve this objective, we carried out an experimental study.

The test conditions are:

- CNC turning machine (X, Z, U, W);
- Number of tests: 25;
- Measuring equipment: Calculator of the CNC;
- First test: displacement over a distance of 20 mm as illustrated in Figure 2;
- Second test: displacement over a distance of 100 mm;

Figure 2. Work mode

– First test 'displacement of 20 mm.'

Figure 3 shows the evolution of the trajectory defects of the cutting tool according to the test number. We note that this evolution is a random function.

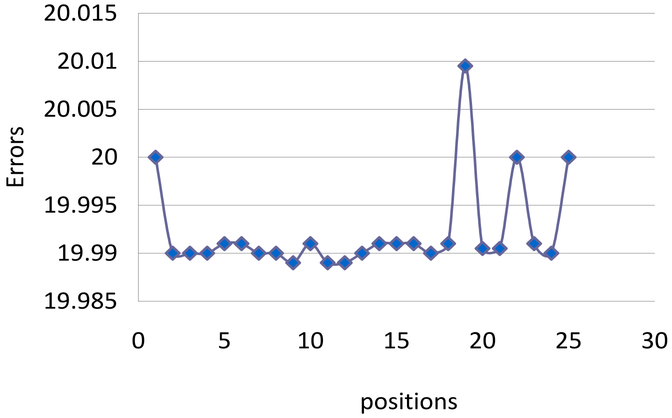

Figure 3. Evolution of the trajectory defects 'displacement of 20 mm'

Second test 'displacement of 100 mm'

Figure 4 shows the evolution of the defects of the trajectory of the cutting tool according to the test number. We note that this evolution is a random function.

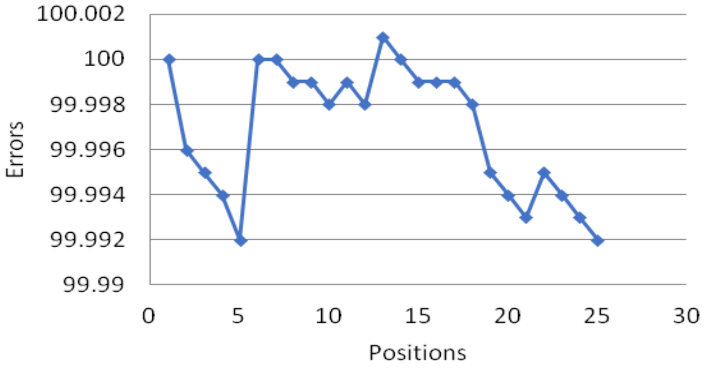

Figure 4. Evolution of the trajectory defects 'displacement of 100 mm'

According to the two tests, it is noted that the errors or defects of the trajectory of the cutting tool increase when working with small displacements.

2.4. Modelling of the Trajectory

In this section, we have modelled the error of the cutting tool trajectory.

$$IT = -1{,}3551953\,X + 7{,}076302.10^{-2}\,X^{2} + 2{,}041475.10^{-3}\,X^{3} - 962{,}662000\,X^{4} \tag{3}$$

Eq. (3) represents the modelling for a displacement of 20 mm

$$IT = -3{,}275554\,X + 1{,}7145.10^{-1}\,X^{2} + 4{,}944582.10^{-3}\,X^{3} - 2331{,}235\,X^{4} \tag{4}$$

Eq. (4) represents the modelling for a displacement of 100 mm

2.5. Defects the Workpiece Position

The purpose of this section is to quantify the defects due to positioning. To achieve this objective, we used the results of Sebaa *et al.* [11].

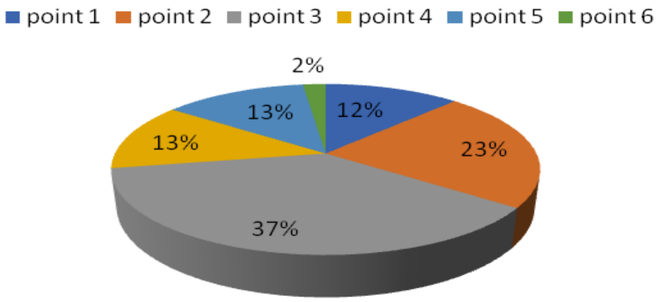

Figure 5. Defects of each fulcrum

Figure 5 shows the defects of each support. We note that the most important error is at the level of Fulcrum 3.

2.6. Modelling of Positioning Defects

In this section, we used the small displacement torsors for modelling the positioning errors. The concept of the torsor of small displacements was developed in the 1970s by Bourdet [12], Bourdet *et al.* [13] and André Clément. It makes it possible to define at every point M a rigid body with a small displacement. The displacements of a solid can be characterised at a point O by a translation vector and a rotation matrix as

$$\overrightarrow{D_M} = \overrightarrow{t_o} + \overrightarrow{MO} \wedge \overrightarrow{\omega} \tag{5}$$

We apply Eq. (5) to find the deviations *dx*, *dy* and *dz* (Eqs. (6)–(8)).

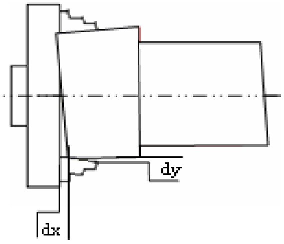

Figure 6. Positioning defects

$$dz = \begin{bmatrix} du \\ dv \\ dw \end{bmatrix} + \begin{vmatrix} d\alpha \\ d\beta \\ d\delta \end{vmatrix} \Lambda \begin{bmatrix} x \\ y \\ z \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{6}$$

$$dz = dw + (d\alpha.y - d\beta.x)$$

$$dy = \left[\begin{array}{ll|lcr} du & & d\alpha & & x \\ dv & + & d\beta & \Lambda & y \\ dw & & d\delta & & z \end{array}\right] \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \tag{7}$$

$$dy = dv - (d\alpha.z - d\delta.x)$$

$$dx = \left[\begin{array}{ll|lcr} du & & d\alpha & & x \\ dv & + & d\beta & \Lambda & y \\ dw & & d\delta & & z \end{array}\right] \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \tag{8}$$

$$dx = du + (d\beta.z - d\delta.y)$$

3. Compensation for Manufacturing Errors

We have three possibilities for the compensation of manufacturing errors.

- *First possibility*

Inject the models into the D function of the tool offset. The screen in Figure 7 shows a window for entering data such as tool number, tool offset, coordinates, etc.

État action de référence

Chariots avec positions d'axe valables

Chariot 1: X Y Z
Chariot 2: Z

Figure 7. Example of correction of the cutting tool

-Second possibility

Program the models developed in the machining program. The following example reflects the correction of the tool T01 by compensating for the error calculated by the program in a sequence N according to the machined length:

```
N01     G21 G99 G28 U0 W0 ;
N02     M6 T01 D1 ;
N03     M3 S707 ;
N04     G00 X36 Z33 ;
```

```
N05  G01 Z13 F0.05 ;
N06  X42 ;
N07  G00 Z33 ;
N08  X32 ;
N09  M3 S796 ;
N..   ………… ;
```

– *Third possibility*
  Develop an interface (software) between the control unit and the operative part.

In this case, we integrate the models developed in the same way as a preparatory function G, such that the function G06 for the FANUC control allows the machining of complex shapes defined by polynomial functions or spline functions

4. Conclusion

In this work, a three-step approach was presented for the calculation of SDs, dispersions due to the trajectory of the cutting tool and dispersions of positioning. The results show that SDs account for 20%, and defects due to positioning represent a very important percentage of the order of 63%, relative to the trajectory and wear defects.

The manufacturing tolerances are optimised in real time by injection of the SD and the error due to the offset of origin to the function of correction of the cutting tool.

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