Study and Modeling of Machining Errors on the NC Machine Tool

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Abstract—**The precision exploits a central role the competition of the modern companies. In the field of manufacture, the realization of the parts is unit or in series with same precision i.e. with same dimensions is impossible. This inevitable inaccuracy is due to several factors such as the error of setting in position, the vibrations, the wear of the tool during machining, positioning of the stops. In the technical literature, these factors called dispersions of machinings and which are division in two dispersions, random dispersion and systematic dispersion. In this paper, we have done, as a first step, an experimental study to determine the influence of machining errors on the manufacturing tolerances. In the second step, we used the Lagrange method for modeling manufacturing errors, and finally we have proposed solutions for the optimization of these errors.**

Index Terms—**errors, tolerance, manufacturing**

I. Introduction

Tolerancing has a significant influence on the performance of mechanical products and especially on their production costs.

Many research works were treated the tolerancing problem with different approaches, Rong and Bai "Ref. [1]" analyzed a dependent relationship of operational dimensions to estimate machining errors in terms of linear and angular dimensions of a workpiece. Cai *et al* "Ref. [2]" proposed a method to conduct a robust fixture design to minimize workpiece positional errors as a result of workpiece surface and fixture setup errors. Djurdjanovic and Ni "Ref. [3]" developed procedures for determining the influence of errors in fixtures, locating datum features and measurement datum features on dimensional errors in machining. These studies were conducted when a static case was assumed.

Kim and Kim "Ref. [4]" have developed a volumetric error model based on 4x4 homogenous transformation for generalized geometric error. Eman and Wu Ref. [5]" have developed error model accounts for error due to inaccuracies in the geometry and mutual relationships of the machine structural elements as well as error resulting from the relative motion between these elements. Kakino *et al* "Ref. [6]" have measured positioning errors of multi-axis machine tools in a volumetric sense by Double Ball Bar (DBB) device. Takeuchi and Watanabe "Ref. [7]" have shown five-axis control collision free tool path and post processing for NC-data.

Jun "Ref. [8]" developed real-time error compensation methods to reduce both geometric and thermally induced quasistatic machine tool errors. Rahou "Ref. [9]" proposed a method for the modeling and error compensation of machine tool. Wang et al "Ref. [10]" proposed an error prediction method that can determine the position errors of the cutter for compensation without computing a complex error model on-line. Lei and Hsu "Ref. [11]" proposed a real-time error compensation method for five-axis CNC machine tools, which integrated the geometric error model in the interpolator, and compensation values for the servo controlled axis were generated based on the inverse Jacobian matrix.

Rahou "Ref. [12], [13]", has developed a method for compensating manufacturing errors in real time.

II. Systematic Dispersion

Systematic dispersion is due primarily to the wear of the cutting tool between the realization of the first part and the last part of a given series. In other words, after an adjustment, the first parts will have a dimension D which gradually increases to arrive as the tool wears with a dimension D+Δs.

It is difficult, if not impossible; to obtain manufacturing tolerances while being limited only to systematic dispersions. For this reason, it is necessary to take into account all dispersions. In order to achieve this goal, there are three stages.

A. First Phase

We have machined 40 parts, C35 matter, on lathe with numerical control using a facing tool with standard brought back pastille "J11ER".

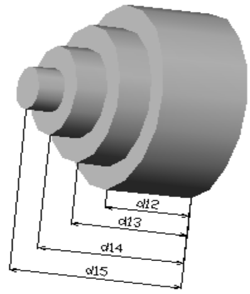

Figure 1. Drawing the workpiece

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The Fig. 2 represents the averages of 5 surfaces.

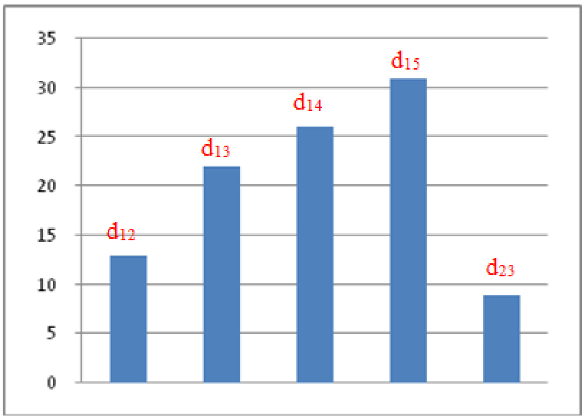

Figure 2. Averages of 5 surfaces

The Fig. 3 shows the standard deviations of 5 surfaces.

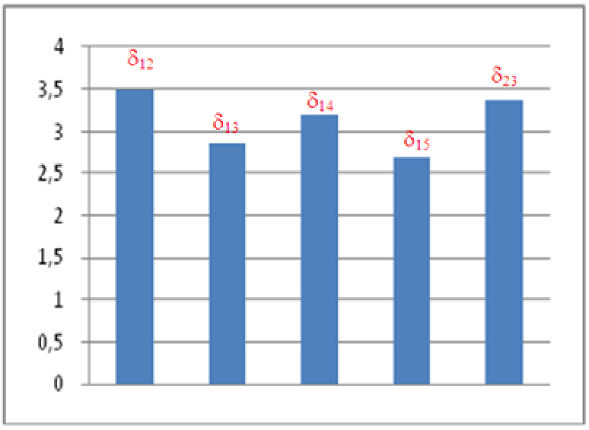

Figure 3. Standard deviations of 5 surfaces

B. *Second Phase*

In this section, we used the formula (1) to filter random dispersion.

$$da_{ij} = dt_{ij} - \frac{\Delta CFs_{ij}}{N} i \qquad (1)$$

The Fig. 4 shows the filtered averages.

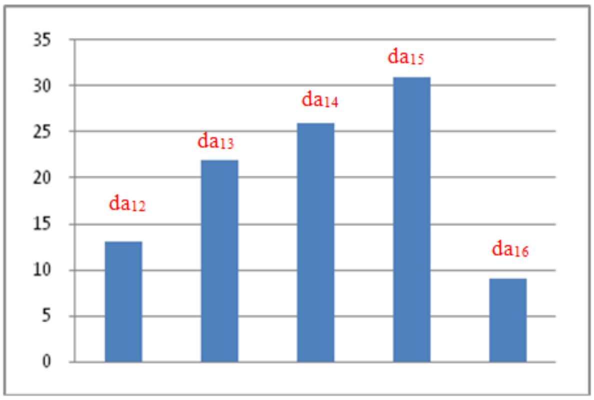

Figure 4. Filtered averages

The Fig. 5 shows the filtered standard deviations.

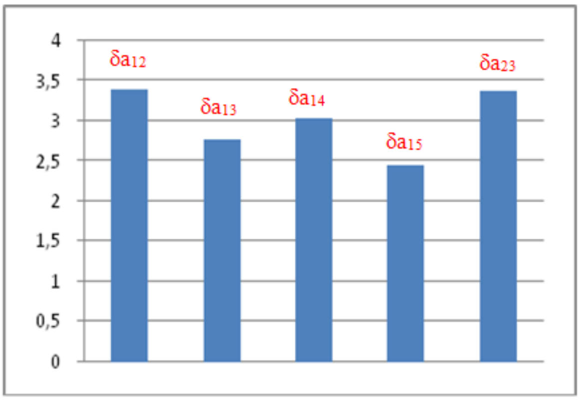

Figure 5. Filtered standard deviations

C. *Third phase*

Based on the two previous stages, we can calculate the systematic dispersion.

The Fig. 6 shows the ΔCFsij.

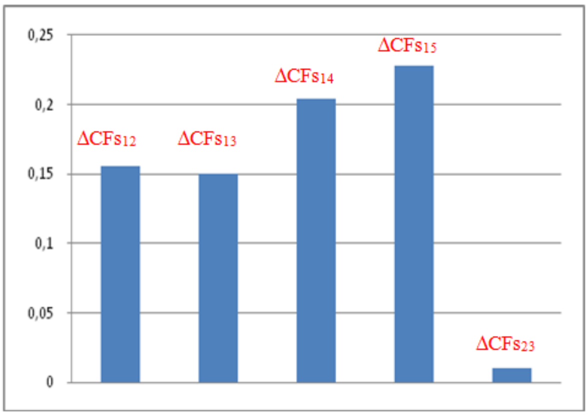

Figure 6. ΔCFsij

III. Errors Modeling

In this section, we model the systematic dispersion by the Lagrange method and positioning of the workpiece by small displacement torsor.

A. *Modling of Systematic Dispersion*

The general form is given by the following expression

$$\varphi_k(t) = \frac{(t-t_0)(t-t_1)\ldots(t-t_{k-1})(t-t_{k+1})\ldots(t-t_n)}{(t_k-t_0)(t_k-t_1)\ldots(t_k-t_{k-1})(t_k-t_{k+1})\ldots(t_k-t_n)}$$

$$\begin{cases} \varphi k(tj) = 0 \text{ si } j \neq k,\ 0 \leq j \leq n \\ \varphi k(tk) = 1 \end{cases}$$

$$p(t) = \sum_{j=0}^{n} p_j \varphi_j(t)$$

The interpolation equations are given by the relations (2), (3) and (4).

The first equation is for the systematic dispersion.

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$$p(t) = 7.2 \quad 10^{-4} t^2 + 0.8 \quad 10^{-5} t + 2.4 \quad 10^{-4} \qquad (2)$$

The second equation is for the random dispersion.

$$p(t) = 6.2 \quad 10^{-2} t^2 + 0.4 \quad 10^{-3} t + 0.2 \quad 10^{-2} \qquad (3)$$

The third equation is for the total dispersion.

$$p(t) = 0.2 \quad 10^{-1} t^2 + 0.3 \quad 10^{-1} t + \quad 10^{-2} \qquad (4)$$

B. *Modling of Workpiece Positioning*

The concept of small displacement torsor (SDT) has been developed in the 70s by Pierre Bourdet and Andrew Clement.

The displacement of a solid can be characterized by a point O by a translation vector and rotation matrix, equation (5).

$$\overrightarrow{D_M} = \vec{t} + \overrightarrow{MO} \wedge \vec{\omega} \qquad (5)$$

With

t (u,v,w) translation vector

w (α,β,γ) rotation vector

The translation vector and rotation are given according to ε, equations (6), (7), (8), (9), (10) and (11).

The Fig. 4 shows the small displacements.

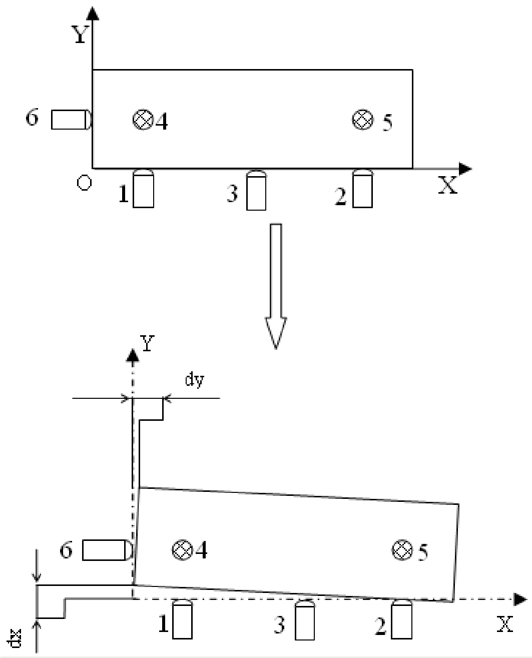

Figure 7. Part deviations

$$\varepsilon_1 = \left[\begin{matrix} u \\ v \\ w \end{matrix} + \left|\begin{matrix} \alpha \\ \beta \\ \gamma \end{matrix}\right. \quad \Lambda \quad \begin{matrix} x_1 \\ y_1 \\ z_1 \end{matrix}\right] \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \qquad (6)$$

$$\varepsilon_1 = v - (\alpha . z_1 - \gamma . x_1)$$

$$\varepsilon_2 = \left[\begin{matrix} u \\ v \\ w \end{matrix} + \left|\begin{matrix} \alpha \\ \beta \\ \delta \end{matrix}\right. \quad \Lambda \quad \begin{matrix} x_2 \\ y_2 \\ z_2 \end{matrix}\right] \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \qquad (7)$$

$$\varepsilon_2 = v - (\alpha . z_2 - \delta . x_2)$$

$$\varepsilon_3 = \left[\begin{matrix} u \\ v \\ w \end{matrix} + \left|\begin{matrix} \alpha \\ \beta \\ \delta \end{matrix}\right. \quad \Lambda \quad \begin{matrix} x_3 \\ y_3 \\ z_3 \end{matrix}\right] \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \qquad (8)$$

$$\varepsilon_3 = v - (\alpha . z_3 - \delta . x_3)$$

$$\varepsilon_4 = \left[\begin{matrix} u \\ v \\ w \end{matrix} + \left|\begin{matrix} \alpha \\ \beta \\ \delta \end{matrix}\right. \quad \Lambda \quad \begin{matrix} x_4 \\ y_4 \\ z_4 \end{matrix}\right] \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \qquad (9)$$

$$\varepsilon_4 = w + (\alpha . y_4 - \beta . x_4)$$

$$\varepsilon_5 = \left[\begin{matrix} u \\ v \\ w \end{matrix} + \left|\begin{matrix} \alpha \\ \beta \\ \delta \end{matrix}\right. \quad \Lambda \quad \begin{matrix} x_5 \\ y_5 \\ z_5 \end{matrix}\right] \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \qquad (10)$$

$$\varepsilon_5 = w + (\alpha . y_5 - \beta . x_5)$$

$$\varepsilon_6 = \left[\begin{matrix} u \\ v \\ w \end{matrix} + \left|\begin{matrix} \alpha \\ \beta \\ \delta \end{matrix}\right. \quad \Lambda \quad \begin{matrix} x_6 \\ y_6 \\ z_6 \end{matrix}\right] \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \qquad (11)$$

$$\varepsilon_6 = u + (\beta . z_6 - \delta . y_6)$$

The relations (6), (7), (8), (9), (10) and (11) are applied to find the small displacements, translations *u,v,w*, equations (15), (16), (17) and rotations α, β, γ (12), (13) and (14).

$$\alpha = \frac{(\varepsilon_1 - \varepsilon_2) + \dfrac{[(\varepsilon_3 - \varepsilon_2).(1 - Z_1) - (\varepsilon_1 - \varepsilon_3).(1 - Z_3)]}{(1 - Z_2)}}{(1 - Z_1)} \qquad (12)$$

$$\beta = \left[\frac{(\varepsilon_1 - \varepsilon_2) + \dfrac{[(\varepsilon_3 - \varepsilon_2).(1 - Z_1) - (\varepsilon_1 - \varepsilon_3).(1 - Z_3)]}{(1 - Z_2)}}{(1 - Z_1)(X_4 - X_5)}\right] \qquad (13)$$

$$\left[\frac{(Y_4 - Y_5)}{(1 - Z_1)}\right] + \frac{(\varepsilon_4 - \varepsilon_5)}{(X_4 - X_5)}$$

$$\gamma = \frac{[(\varepsilon_3 - \varepsilon_2).(1 - Z_1) - (\varepsilon_1 - \varepsilon_3).(1 - Z_3)]}{(X_1 - X_2).(1 - Z_2)} \qquad (14)$$

$$u =$$

$$\varepsilon_6 + \left[\frac{[(\varepsilon_3 - \varepsilon_2).(1 - Z_1) - (\varepsilon_1 - \varepsilon_3).(1 - Z_3)]}{(1 - Z_2)(X_1 - X_2)}\right]$$

$$- \left[\frac{\dfrac{\left((\varepsilon_1 - \varepsilon_2) + \dfrac{[(\varepsilon_3 - \varepsilon_2).(1 - Z_1) - (\varepsilon_1 - \varepsilon_3).(1 - Z_3)]}{(1 - Z_2)}\right)}{(1 - Z_1)}}{(X_4 - X_5)} \atop .(Y_4 - Y_5) + \frac{(\varepsilon_4 - \varepsilon_5)}{(X_4 - X_5)}\right] \qquad (15)$$

$$Y_5$$

$$v = \varepsilon_3 - \left[\frac{(\varepsilon_1 - \varepsilon_2) + \dfrac{[(\varepsilon_3 - \varepsilon_2).(1-Z_1) - (\varepsilon_1 - \varepsilon_3).(1-Z_3)]}{(1-Z_2)}}{(1-Z_1)} \right] .Z_3 + \left[\frac{[(\varepsilon_3 - \varepsilon_2).(1-Z_1) - (\varepsilon_1 - \varepsilon_3).(1-Z_3)]}{(1-Z_2)(X_1 - X_2)} \right] .X_3 \quad (16)$$

$$w = \varepsilon_4 + \frac{(\varepsilon_3 - \varepsilon_2)}{(1-Z_1)} Y_3 + \left[\frac{[(\varepsilon_3 - \varepsilon_2).(1-Z_1) - (\varepsilon_1 - \varepsilon_3).(1-Z_3)]}{(1-Z_2)(1-Z_1)} \right] Y_3 - \left[\frac{\dfrac{\left((\varepsilon_1 - \varepsilon_2) + \dfrac{[(\varepsilon_3 - \varepsilon_2).(1-Z_1) - (\varepsilon_1 - \varepsilon_3).(1-Z_3)]}{(1-Z_2)} \right)}{(1-Z_1)}}{(X_4 - X_5)} .(Y_4 - Y_5) + \frac{(\varepsilon_4 - \varepsilon_5)}{(X_4 - X_5)} \right] Y_5 \quad (17)$$

IV. Conclusion

In this work, a step centered on three stages, was presented to calculate dispersions of machining and their influence on the intervals of tolerances. The influence of systematic dispersion accounts for 10% of the total discrepancies under the conditions normal and between 25% and 35%, if the parameters of cut or the cutting tool are badly selected.

The relative value of 10% of the tolerance is very important especially in work in series; because the wear of the tool influences the dimensions of adjustment. An error about the micron influences the overall costs of the end product and risk to guarantee the competitiveness of the product on the market.

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