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Research Article

OPTIMIZATION AND MODELING OF THE WORKPIECE POSITION

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ABSTRACT

This paper presents an approach for the manufacturing tolerances optimization under the positioning effect.This work is organized around two axes. The first axis addresses the problem of manufacturing errors due to the free position of the part (without tightening). In this approach, we have modeled the positioning defects by using the small displacement torsor to determine the optimal distribution of the supports (plane support, linear support and point support). The second axis is dedicated to the modeling and positioning optimization under the tightening effect. In this section the defects have been modeled by the reaction torsors under the optimal position constraint. These models have been exploited to develop a tool for the optimal distribution, calculation of manufacturing dimensions, deviations and torsors of small displacements.
Keywords: Optimization, modeling, workpiece position, errors.

1. INTRODUCTION

Currently, the workpieces positioning plays an important role in the optimization of manufacturing time and the quality of machining such as roughness, geometric and dimensional tolerances...

Many research works were treated the errors problem with different approaches, T Adesta et al. [1]; studied the influence of tool path strategies on tool path throughout pocket milling process; by varying cutting speed, feed rate and depth of cut. New tool wear prediction model was developed based on this study. Li li et al. [2]; developed a multi objective model to optimize the tool path for high efficiency, taken into account energy saving and carbon emission in milling process. Alexander Yuen and Yusuf Altintas [3]; developed a new methodology to compensate the deviation of the tool tip caused by geometric error of 3-axis gantry type micro mill with rotary magnetic table of 6 degree of freedom. The geometric errors of each axis are measured and modeled with quintic polynomial functions. An ideal kinematic model was established, and modified to include the geometric errors; to get the tooltip position errors. The compensation of tooltip error in real time was done by changing the position of the rotary table using gradient descent algorithm. Gangwei Cui et al. [4]; developed a new software system for geometric error compensation of rapid positioning, linear interpolation, and circular interpolation movement by modifying NC code. Multi body system (MBS) theories were used for Geometric error modeling.

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G. S. Chen et al. [5]; proposed a new methodology for geometric error modeling of the translation axes and rotary axis of si x axes machine tools; the model was established by using the multi-body theory and the homogeneous coordinate transformation method. Real time error compensation system was developed based on the NUM numerical control system. En-Ming Miao et al. [6]; established different thermal error models by using multiple linear regression of least squares and least absolute estimation methods, distributed lag model, and support vector regression machine. Then a comparison was made between these models to verify their robustness. Gangwei Cui et al. [7]; proposed a new error compensation implementing strategy based on hand wheel offset function of CNC system. The function of redevelopment and differential resolver function (DRF) was used to establish the error compensation equipment which substitutes for electronic hand wheel of CNC system. Paolo Bosetti et al. [8]; presented different method for error compensation with real time system measurement of the displacement field. Reticular displacement measurement system (RDMS) was used to measure the deformation field of the machine components, where the structural deformations will be directly measured instead of being calculated by using analytical or numerical model. Shih-Ming Wang et al. [9]; proposed error measurement and compensation method that can on-machine examine the machining errors and automatically generate an NC program for error compensation; by using Canny edge detection algorithm and camera pixel calibration, the actual contour of the work piece was mapped to the theoretical contour to determine the machining errors and used to correct NC code. Ryan C et al. [10]; studied the stability of the modulated tool path (MTP) turning by a new periodic sampling approach, where the synchronicity of the sampled signal is evaluated numerically. The oscillation frequency of the spindle speed and the oscillation amplitude of the global feed per revolution was used to form discrete chips .M. Salehi et al. [11]; proposed a probabilistic sequential prediction of cutting forces. Bayesian inference was used to Merchant and Kienzle cutting force models, to inspect the cutting force prediction. Markov chain Monte Carlo was used to determine the model uncertainties. Jun Yang et al. [12]; used least square support vector machine for thermal error modeling of motorized spindle. Simultaneous measurements of axial and radial thermal drifts were applied by the five-point method. Thermal error compensation was proposed take into account cutting tool length and thermal tilt angles. Fuzzy cluster and correlation analysis was used to optimize temperature variables. Guoqiang Fu et al. [13]; proposed geometric error optimization and compensation of five axis machine tools. Optimal polynomials of error components of each axis are determined. Then a new mathematical geometric error model was proposed. The particle swarm optimization was used to optimize the NC code of error model and compensate the tool errors to find the optimal NC code program. Shuang Ding et al. [14]; proposed a new methodology for error compensation of five-axis orthogonal machine tool. The position-independent geometric error model was developed by using Error motion transformation according to homogeneous transformation matrix. Then the analytical numerical control code expression with error compensation was developed and used for NC code program generation. Zihan Li et al. [15]; proposed a new comprehensive method compensation method for geometric and thermal errors of machine tools. A synthesized volumetric model for the geometric and thermal errors was developed by using homogeneous transformation matrix method. then Chebyshev polynomial-based orthogonal least squares regression was used to improve the modeling precision of the geometric error components; and to improve the robustness of the thermal error models, the thermal errors caused by external and internal heat sources were modeled distinctly. Then an intelligent virtual compensation system was established .Qiang Cheng et al. [16]; proposed a novel analytical methodology to detect crucial geometric errors fora multi-axis machine tool based on multi body system (MBS) theory and global sensitivity analysis. MBS theory was used to determine the volumetric error model; Sobol global sensitivity analysis method was used to find crucial geometric errors of machine tool .Guoqiang Fu et al. [17]; used the product of exponential (POE) model for geometric errors integration of multi-axis machine tools. Three twists were established to represent the basic errors in x, y, and z directions; then POE model was applied to integrate the three twists, which improve the precision of the geometric error model. By applying POE method, squareness errors were considered. The topological structure of the machine tools was used to accuracy enhancement of the POE model and to get the order of all POE models, then the integrated POE model of geometric errors was established basing on the POE error model .Guoqiang Fu et al. [18]; presented accuracy improvement of five axis machine tool by using differential motion matrix. The integrated geometric error model with differential motion matrix was established by using the transforming differential change between coordinate frames, firstly geometric error components of each axis were transformed to the tool coordinate system with differential motion matrix. Then, geometric error components were summed and transformed for integrated error model in working table coordinate system. The integrated error components of tool compensation were accomplished by the constructed Jacobian. Finally, a methodology was established to determine error components of each rotary axis based on differential motion matrix .Junxu Ma et al. [19]; presented an assembly error model for linear axis of CNC machine tool that can analyze and predict the effect of component manufacturing inaccuracy and deformation based on the 3-2-1localization theory. The axes errors was determined taken into account component manufacturing error, structure effect and gravity deformation. Kuo Liu et al. [20];the comprehensive thermal error(CTE) of the servo axes of CNC machine tool was introduced and classified into the thermal expansion error (TEE) in the stroke range and the thermal drift error (TDE) of origin. Then, model for TEE was established basing on the heat production, conduction, and convection theory to real time prediction and compensation of thermal errors of servo axes. Also a model for TDE prediction and compensation was determined by applying multiple linear regression method.

2. EXPERIMENTAL STUDY

The purpose of this study is to determine the optimal Workpiece position. First, we performed 100 tests for free position to determine the optimal distribution. In the second step we quantified the optimal position errors under the tightening effect.

2.1. First step

On a prismatic Workpiece of 100mm x 40mm (figure 1), we have varied the distances between the normals, the results are given by graphs for each fulcrum, figures 2, 3, 4, 5, 6 and 7.

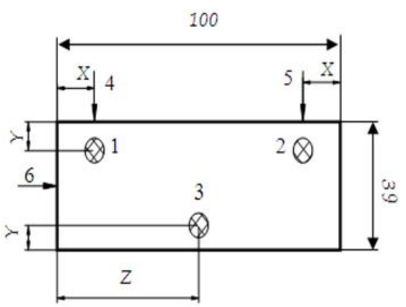

Figure.1a Fulcrums Variation

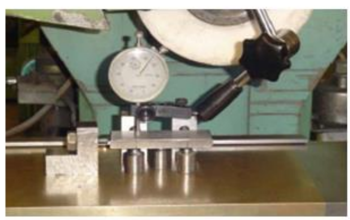

Figure.1b Example of measurement

Figure.1 Workpiece in manufacturing position

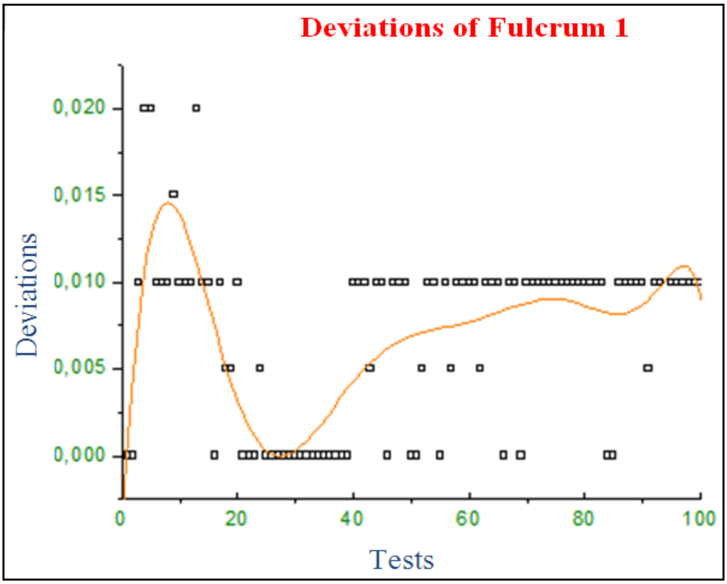

Figure 2. Deviation of Fulcrum 1 according to the tests number

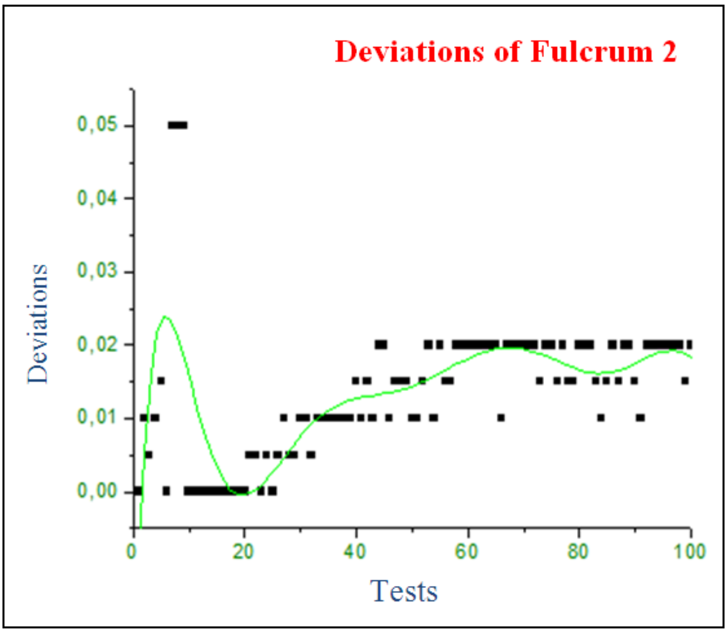

Figure 3. Deviation of Fulcrum 2 according to the tests number

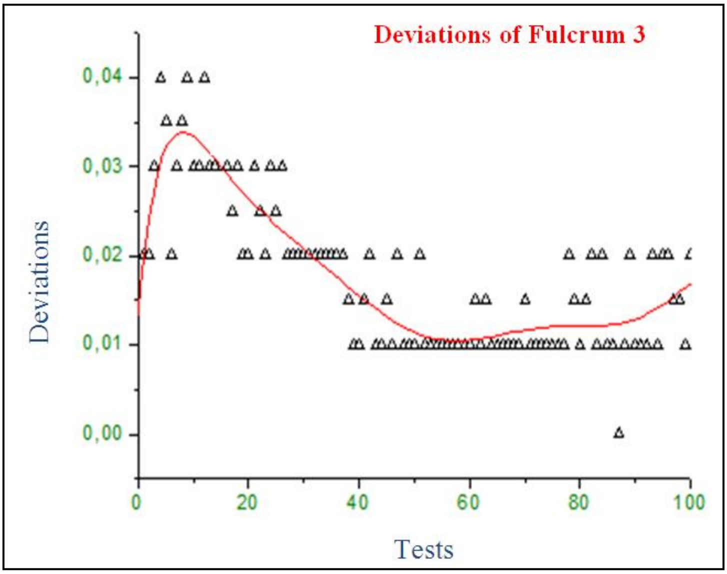

Figure 4. Deviation of Fulcrum 3 according to the tests number

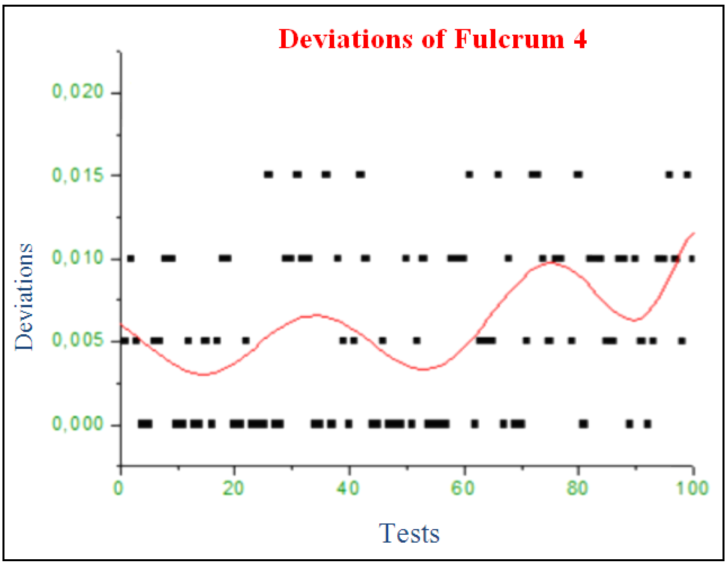

Figure 5. Deviation of Fulcrum 4 according to the tests number

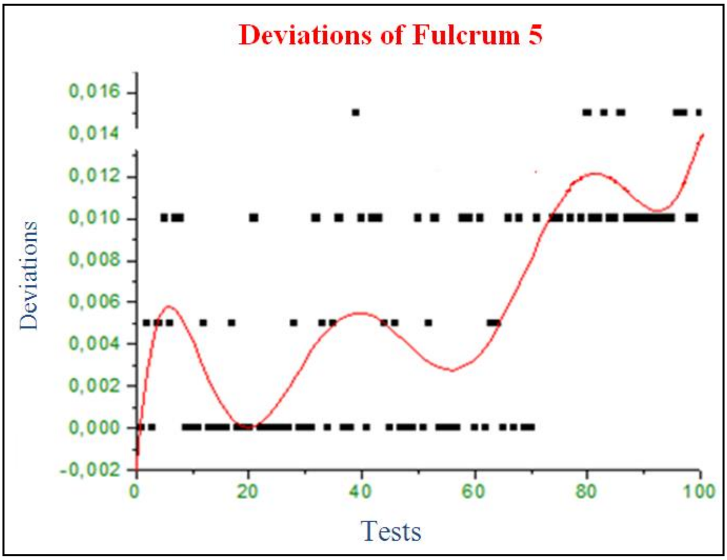

Figure 6. Deviation of Fulcrum 5 according to the tests number

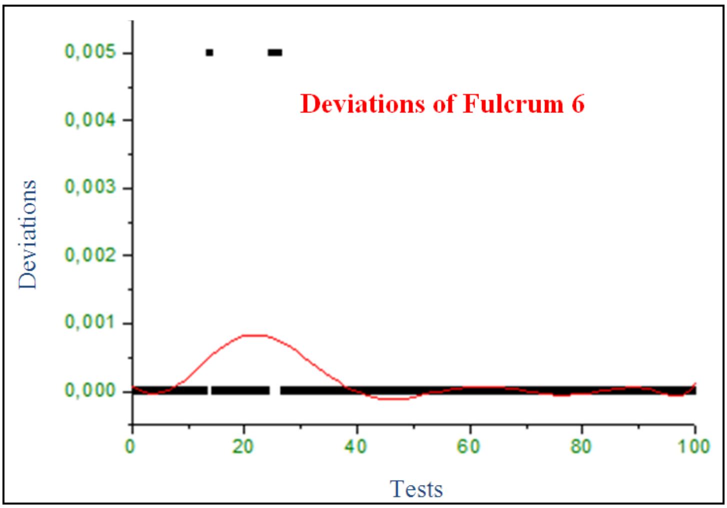

Figure 7. Deviation of Fulcrum 6 according to the tests number

Figures 2, 3,4,5,6 and 7 represent the evolution of the supports errors according to the tests number. Note that the highest errors are at the level of the support 2 (plane support) and 4 (linear support). The least error is at the level of support 6. According to these errors, the optimal position of the positioning is given in the relation (1).

$$\begin{cases} X = 0.16\,L \\ Y = 0.16\,H \\ Z = 0.5\,E \end{cases} \tag{1}$$

2.2. Second step

In this step, we measure the defects of the optimal positioning under the tightening effect (figure 8) and we calculate the standard deviations of each support. The results are given by graphs.

Figure 8. Example of measurement

Figure 9 shows the evolution of the standard deviation of the plane support according to the test number.

According to the graphs (Figure 9), we notice that in the majority of the positions, Fulcrum 2 and Fulcrum 3 carry important errors.

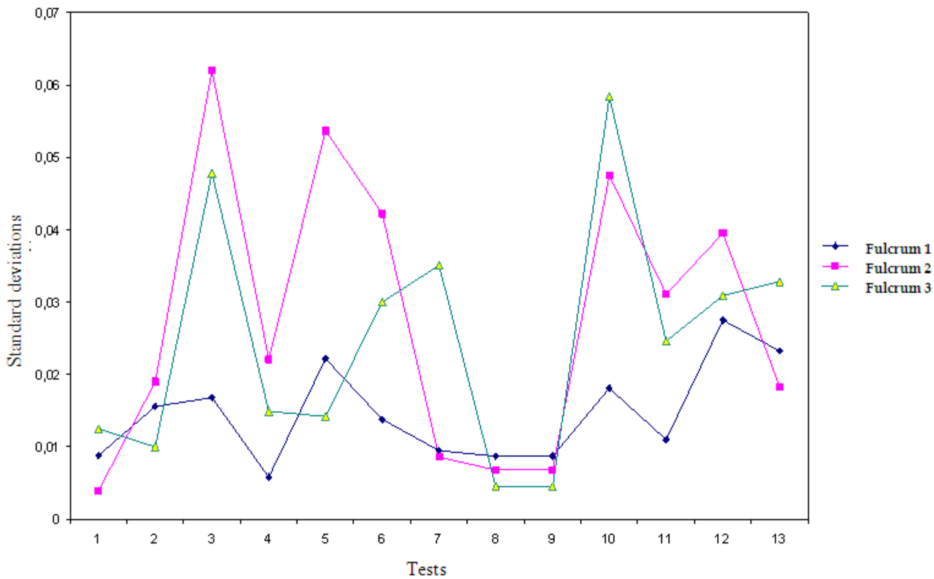

Figure 9. Standard deviations of the Fulcrum plan under the tightening impact

Figure 10 shows the evolution of the standard deviation for the linear support according to the test number. We notice that the two graphs are confused. This phenomenon demonstrates that the two supports 4 and 5 are parallel.

Figure 11 shows the evolution of the standard deviation for the Fulcrum 6 according to the test number. We notice that the graph of the support 6 is always zero; this phenomenon is due to the punctual contact of the support.

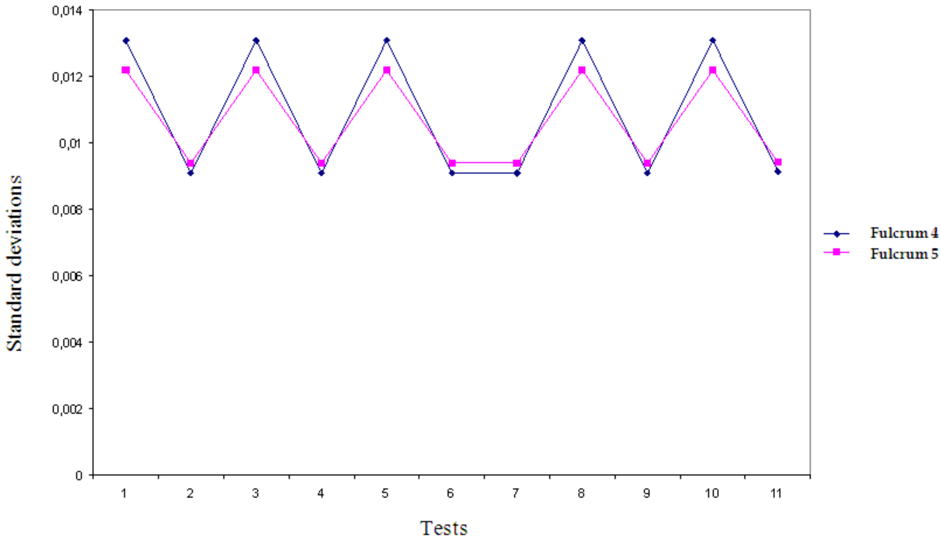

Figure 10. Standard deviations of the linear Fulcrum under the tightening impact

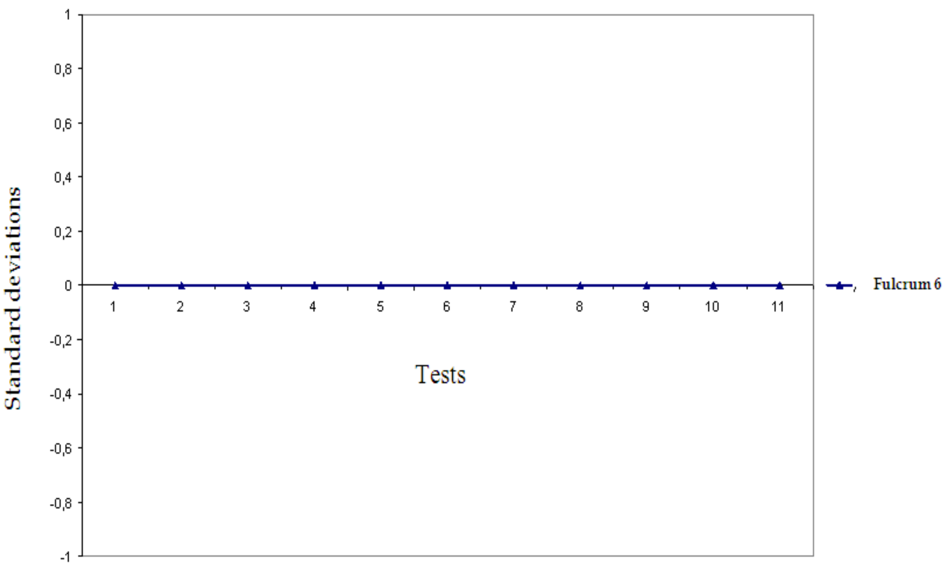

Figure 11. Standard deviations of the punctual fulcrum under the tightening impact

3. DEVIATIONS MODELING

In this section, we used a new approach for modeling positional deviations. This approach is based on the principle of the modified least squares method. The purpose of this approach is to optimize the errors convergence.

The algorithm of this method is given by the relation (2).

$$E(\alpha_i)\ is\ min \Rightarrow \frac{\partial E}{\alpha_i} = 0 \quad ,i = 0\ldots.k$$

$$\frac{\partial E}{\alpha_i} = \sum_{r=0}^{n}(-2x_r^i)[\,f(x_r) - \sum_{j=0}^{k}\alpha_j.x_r^j\,] = 0$$

$$\sum_{r=0}^{n}(x_r^i.f(x_r)) = \sum_{r=0}^{n}x_r^i\ \sum_{j=0}^{k}(\alpha_j.x_r^j)$$

$$\sum_{r=0}^{n}(x_r^i.f(x_r)) = \sum_{j=0}^{k}\alpha_j.\sum_{r=0}^{n}\ x_r^{i+j})$$

we put (2)

$$b_i = \sum_{r=0}^{n}(x_r^i.f(x_r))$$

$$a_{ij=}\sum_{r=0}^{n}\ x_r^{i+j})$$

$$a_{ij}\ \alpha_j = b_i$$

Equations (3), (4), (5), (6), (7) and (8) represent the deviations modeling for each support.

$$\varepsilon_1 = -3{,}810\,.\,10^{-2} + 5{,}39\ 10^{-3}\ X - 4{,}706\,.\,10^{-4}X^2 + 7{,}762\,.\,10^{-5}X^3 \quad (3)$$

$$\varepsilon_2 = -2{,}675\,.\,10^{-2} + 2{,}281.\,10^{-2}\ X - 3{,}601\,.\,10^{-3}X^2 + 2{,}497\,.\,10^{-4}X^3 \quad (4)$$

$$\varepsilon_3 = 1{,}391\,.\,10^{-2} + 6{,}751\ 10^{-3}\ X - 8{,}292\,.\,10^{-4}X^2 + 4{,}789\,.\,10^{-5}X^3 \quad (5)$$

$$\varepsilon_4 = 0{,}601\,.\,10^{-2} -\ 0{,}256\ 10^{-3}\ X + 0{,}689\,.\,10^{-5}X^2 - 0{,}296\,.\,10^{-5}X^3 \quad (6)$$

$$\varepsilon_5 = -1{,}981\ \ .\,10^{-2} +\ 3{,}221\ 10^{-2}\ X - 4{,}327\,.\,10^{-4}X^2 + 2{,}057\,.\,10^{-5}X^3 \quad (7)$$

$$\varepsilon_6 = 6{,}652\ \ .\,10^{-5} -\ 4{,}1683\ 10^{-5}\ X + 7{,}640\,.\,10^{-8}X^2 + 1{,}381\,.\,10^{-6}X^3 \quad (8)$$

4. APPLICATION

We have developed a tool for the positioning defects optimization, Figure 13, under the equations (3), (4), (5), (6), (7) and (8). This tool fulfills several functions such as the optimal distribution, the calculation of small displacement torsors, and deviations calculation …….

The figure 12 shows an example of a workpiece.

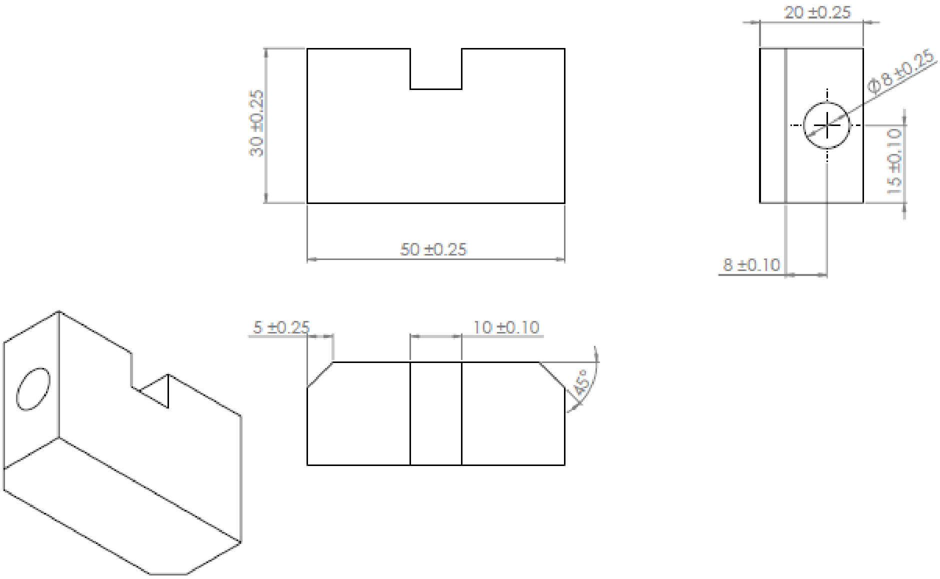

Figure 12. Example of a workpiece

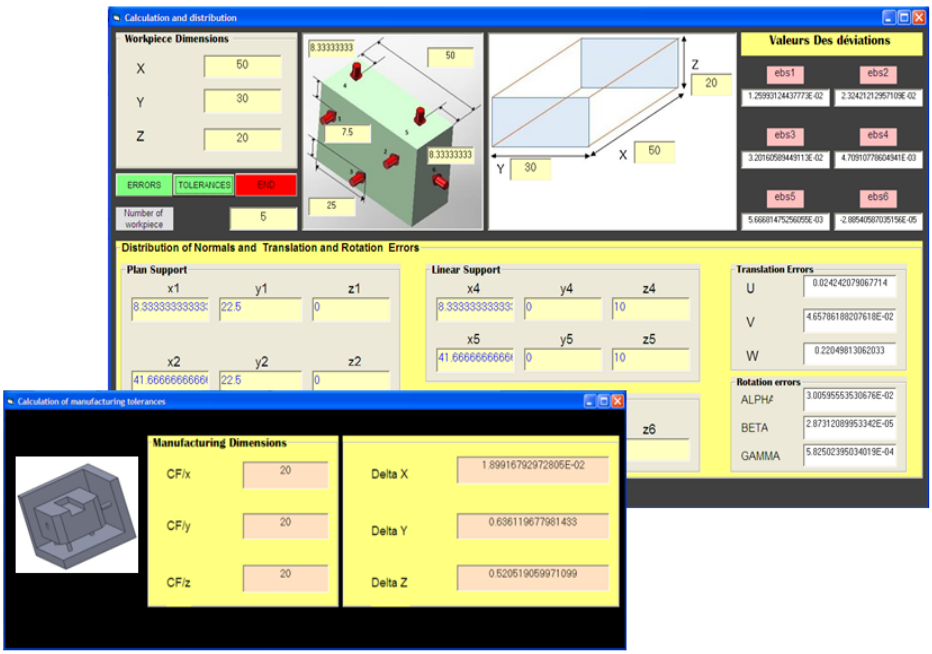

Figure 13. Application

In this example, we have introduced dimensions of a prismatic part to calculate manufacturing tolerances along the three axes under the positioning effect.
The results are grouped in Tables 1 and 2.

Table 1. Results

Fulcrums	Normals distribution			Values of deviations	Traslations errors	Rotations errors
	X	Y	Z			
1	8.33	22.5	0	0.013841915614	0.02453653060805	0.0209106032006
2	41.66	22.5	0	0.015292362004	0.04789719003255	0.000019584418011
3	25	22.5	0	0.0333020724246	0.153195267403775	5.83804704317999E-04
4	8.33	0	10	0.0034710531173		
5	41.66	0	10	0.004123867051		
6	0	15	10	0.0002113345948		

Table 2. Results of manufacturing tolerances

	Workpiece dimensions	Manufacturing dimensions	Delta (ERRORS)
X	50	20	0.0161711484035
Y	30	20	0.45443315995819
Z	20	20	0.466462627052555

5. CONCLUSION

In this paper, the impact of positioning defects on manufacturing tolerances has been studied. This study shows that positioning errors play a very important role in relation to the overall defects of the machining; they represent 35% of the total dispersion. This percentage is a very important factor in the parts manufacturing. For this reason we have developed a tool for the determination of optimal distributions, calculation of small displacement torsors, angular deviations and manufacturing tolerances in 3D. These results have been validated by a real example. We found in this paper that the manufacturing tolerances were optimized by 40% under the optimization effect of the positioning defects.

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