Sigma J Eng & Nat Sci 37 (2), 2019, 381-392

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

MODELING AND OPTIMIZATION OF THE ORIGINAL OFFSET ON THE NC MACHINE TOOL

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Received: 03.02.2019 Revised: 08.03.2019 Accepted: 20.03.2019

ABSTRACT

Currently the trajectories of the cutting tool play an important role in optimizing the manufacturing time and the machining quality (roughness, manufacturing tolerances, etc.).The purpose of this paper is to develop an approach for the manufacturing tolerances optimization under the effect of the cutting tool trajectory. This work is organized around two axes. In the first axis, an experimental study was conducted to determine the cutting tool path with less error. The second axis is devoted to modeling and real-time optimization of the cutting tool path defects. In this section the defects were modeled by the least square edit method.
Keywords: Optimization, modeling, manufacturing tolerances, cutting tool path.

1. INTRODUCTION

Precision plays a key role in the competition of modern companies. In the manufacture field, making parts with the same dimensions is impossible. This unavoidable inaccuracy is due to several factors such as the workpiece positioning, vibrations, tool wear, workpiece deformation. In this context, several studies have been presented; Chanda et al [1]; studied the influence of shape on tool path motion and developed a new methodology to characterize tool path motion that can be applied in any machine tool to enhance the efficiency and productivity of the manufacturing process. The characterization identifies the achievable set of kinematics for a tool path of a given shape without physical machining and knowledge of the motion control algorithms. I. del sol et al [2]; studied the effect of tool path on the geometric deviations. Different tool path were applied under the same machining parameters in dry milling. An evolution of Machining time, final thickness and roughness was presented. Lei Zhong et al [3]; proposed a novel S trajectory method to evaluate dynamic accuracy of five axis machine tools based on R-test measurements. The S trajectory was developed by scaling the machining path of the S-shaped test piece to the measuring stroke of the R-test. A simulation model was established to analyze the effect of several error factors on the S trajectory test and compared with the conical test. The results from the experience demonstrate that the S trajectory test is more sensitive to most geometric errors and dynamic errors than the conical kinematic test. Gaiyun He et al [4];

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presented a profile error estimation method for freeform surface using sweep scanning on Coordinate measuri ng machines. Wavelet decomposition was used for Key point's extraction from scanning data set. Then, Sequential Quadratic Programming algorithm was used to evaluate the extracted points. Zhen-yuan Jia et al [5]; proposed a tool path generation approach in order to enhance the processing quality in sub-regional processing with constraint of constant scallop-height at boundary for complex curved surface. A model was established for the distance between boundary and cutter contact (CC) point. Then, the curve of CC points for the boundary between sub-regions was created. The geodesics for the critical curve of CC points were determined. The analytical CC points on the geodesics were developed based on the estimated scallop-height and adjusted by the sensitivity analysis. The tool paths were generated by linking the analytical CC points. I. Lazoglu et al [6]; proposed a new method to engender optimized tool paths for freeform surfaces. Force-minimal tool path generation concept was presented and discussed. Tool paths generation method was established based on the combination of process mechanics with the optimization process, in order to determine new force-minimal tool paths precise for any given free form surface. Danijela Pezer [7] presented tool path optimization during the drilling process to improve productivity, time and cost saving. Genetic algorithm was used to transform the optimization problem to the Traveling Salesman problematic. An algorithm to solve salesman problem was introduced with objective to find the optimal tool path length. A mathematical model was established to determine the processing time. Jian-wei Ma et al [8]; proposed a new method for machining errors minimizing by tool path modifying and feed-speed optimization for rapidly varied geometric features. The feed speed was optimized take into account jerk and acceleration limitations of the feed shafts. The compensated cutter locations were determined by machining errors estimation. Based on the optimized feed speed and the compensated tool path, the NC codes were adapted. Xing Zhang et al [9]; presented a new optimization approach of tool orientation in roughing and finishing milling in 5-axis ball-end milling in order to obtain high efficiency and accuracy machining. Firstly, a new precise cutter/workpiece engaging model based on enhanced analytical approach using Taylor formula was developed, taken into account tool orientation and cutter run out. Then, using cutting force prediction model, the exact tooth trajectory was established. A. Yuen et al [10]; presented a new 9-axis micro-machine, which have three linear axis and a magnetically levitated rotary table with six degrees of freedom. The trajectory generation algorithm and control strategy which permit simultaneous motion on all the nine drives was explained. Jin Yi et al [11]; presented A new tool path planning method for 5-axis flank milling. The machined surface was geometrically divided into several segments; then the multi-population harmony search algorithm was used to optimize each sub-surfaces tool path individually. The Individual tool paths optimized were united together to form a complete one. Tunc [12]; presented a novel approach for automatic tool path modification in smart 5-axis sculptured surface machining. Process simulations was used in order to determine cutting forces variation and stability limit along the tool path; based on the simulation data analysis process parameters were improved by modifying the existing tool path. Keigo Takasugi et al [13]; presented a novel tool path generation algorithm in the parametric domain based on the parameter-based method, that can quickly determine an efficient tool path with a constant pitch in real space. The cutter contact path characterized as a parametric curve was established in the parametric domain and converted quickly into real space. Boundary representation implemented in the parametric domain was established to expend this method to surfaces composed of several patches. Shingo Tajima et al [14]; developed a new real time trajectory generation for machine tools and motion systems based on Finite Impulse Response (FIR) filters. Based on FIR filters, interpolation technique of linear and circular paths was established in order to generate continuously and accurately feed motion along multi-segmented machining tool-paths. Acceleration and jerk uninterrupted motion profiles were produced from velocity pulse commands. A segment interpolation timing technique was established to supervise the contour errors during continuous online interpolation of tool-paths. Sneha Tulsyan et al [15]; proposed a new method to enhance the accuracy at a djacent linear tool path segments for five axis machine tools. The tool path position and orientation were smoothed by using quintic and septic micro-splines, respectively between the adjacent linear toolpath segments. Optimal control points were determined for splines position to reach C3 geometric continuity between the splines and the linear segments, considering user-defined tolerance limits. Tunc et al [16]; proposed a new tool posture optimization approach for already generated 5-axis milling cycles. An already generated milling tool path was modified by a correction of the tool posture in order to reach a stable cutting depth, smooth machine tool motion and reduced cutting forces along the tool path. Jixiang Yang et al [17] ; presented an off line tool path generation and real time contour error evaluation approach for multi-axis machine tools with rotary axes, used to revolving parts manufacturing. The kinematics module was established; third order B-spline and third order polynomial spline was used respectively to characterize the tool tip position and the tool orientations. These splines were fitted to the curve length parameter of the tool tip positions. The contour error estimation method was done by the evaluation of the tool tip position contour inaccuracy, then the tool orientation contour error was determined and synchronized to the same pose at the desired trajectory with the tool tip position contour error. A. El Khalick and Naoki [18]; proposed a new method to evaluate tool orientation contour errors for five axis machine tools. A novel definition was established for the actual tool orientation contour error, taken into account synchronization between the tool tip and tool orientation contour errors; in order to overcome the problem of mismatch between the tool tip position and tool orientation. An estimation model for the tool orientation contour error was presented. Jian-wei Ma et al [19]; proposed a new tool path planning approach for curved surface parts machining using three axis machining with ball-end cutter, taken into account minimal cutting force fluctuation in order to improve machining quality. The constant scallop-height method was used to determine the cutter location points, then an optimization were carried out of cutting path interval and cutting step length. Tool path planning with minimal force fluctuation was determined by considering the nodes of the cutter location mesh units as the cutter location points. Abbas Shahzadeh et al [20]; proposed a novel path smoothing techniques for high speed CNC machines, in order to eliminate tool path discontinuities. Biclothoid fillets were used to transform any given path composed of lines and arcs to a curvature continuous path. The distance between the smoothed path and the original path was limited to the specified tolerance. In [21], a methodology of machined surface error compensation based on an inspection database by using an on-machine measurement system in profile milling has been developed. V.S. Rao [22], presented a compensation of surface error due to cutting force-induced tool deflections in a peripheral milling process. A new compensation method for geometry errors of five-axis machine tools has been developed [23].This method is based on a model that considers the tool orientation error only related to motion of machine rotation axes, and it further calculates the error compensations for rotation axes and linear axes separately. In [24, 25], a study and Modeling of Machining Errors on the NC Machine Tool has been presented.

2. EXPERIMENTAL STUDY

The purpose of this part is to study the influence of the original offset error on manufacturing tolerances. To achieve this goal, two steps have been developed.

2.1. First Stage

In this step we made tests on a paraxial displacement (in two sequences). The test conditions are:

- Lathe machine NC (X, Z, U, W) , DENFORD D13511 CYCLONE, FANUC language (Figure 1).

- Hours Number: 5 H / day.
- Tests Number: 55.
- Paraxial movement, in two sequences, over a distance of 100 mm between the tool tip (point A) and the workpiece (point B), Figure 2.
- Measuring device: numerical control director (0.001 mm).

The measurements are grouped in Figures 3 and 4.

Figure 1. Used machine

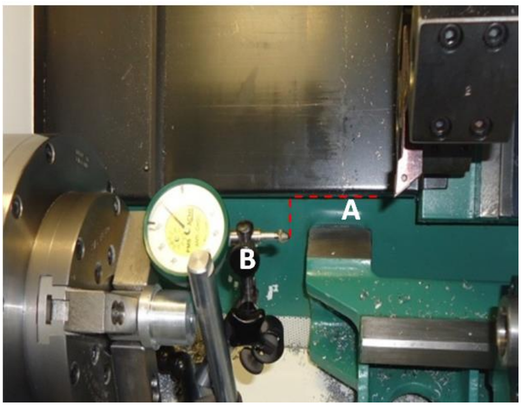

Figure 2. Offset in two sequences (X and Z)

The statistical results (max error, min error, average error, standard deviation and Δ MD), Table 1, are calculated from equations (1), (2), (3) and (4).

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} n_i \; x_i \tag{1}$$

$$v(x) = \sum_{i=1}^{N} \frac{n_i}{N}\left(x_i - \bar{x}\right)^2 \tag{2}$$

$$\sigma = \sqrt{v(x)} \tag{3}$$

$$\Delta MD_{ij} = 6\sigma_{ij} \tag{4}$$

Table 1. Statistical results of the 1st tests

	X	Z
MAX error	0,012	0,009
MIN error	-0,021	-0,01
Average error	-0,0056	-0,0013
Standard deviation	0,0060	0,0032
DELTA MD	0,0360	0,019

Figure 3 shows the original offset evolution following the X axis according to the test number.

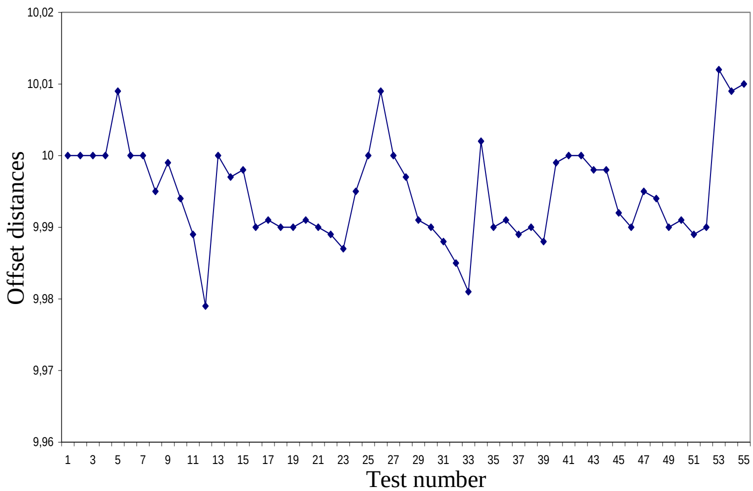

Figure 3. X axis Offsets according to the tests number

Figure 4 shows the original offset evolution following the Z axis according to the test number.

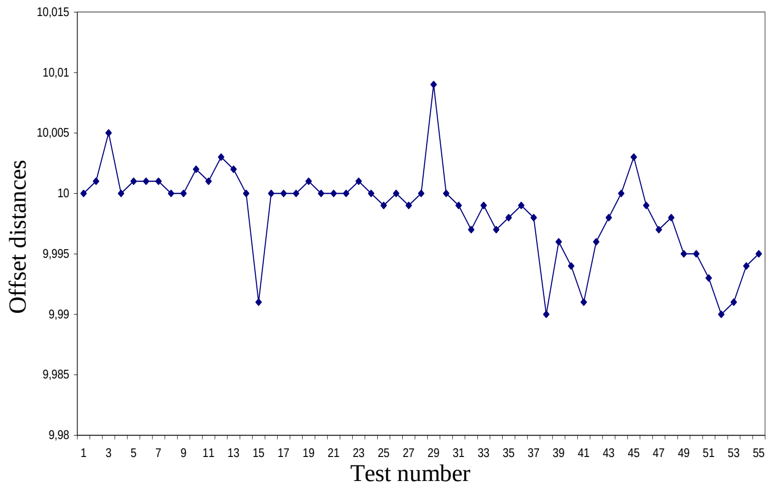

Figure 4. Z axis Offsets according to the tests number

Figure 5 shows the offset evolution following the resultant of the X and Z axes according to the tests number.

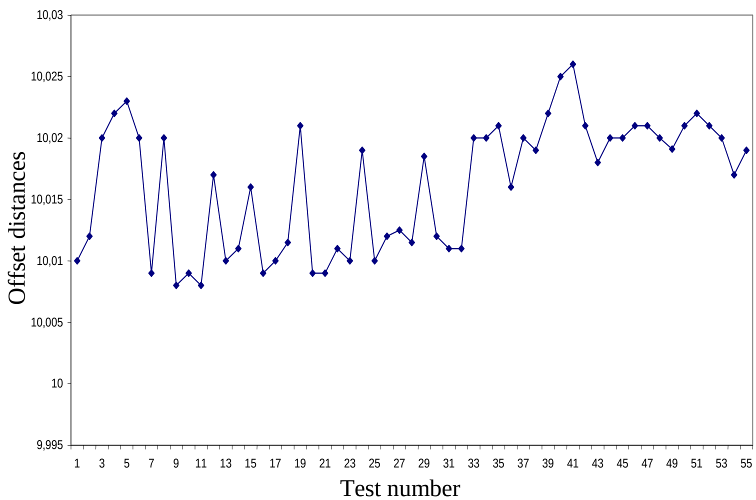

Figure 5. Offsets of the X and Z axis resultant according to the tests number

The statistical results of the resultant (max error, min error, mean error, standard deviation and) are grouped in table 2.

$$Re = \sqrt{X^2 + Z^2} \tag{5}$$

Table 2. Statistical results of the resultant

	XZ Resultant
MAX error	0,021
MIN error	0
Average error	0.008
Standard deviation	0.0048
DELTA MD	0.028

2.2. Second step

The test conditions of the second stage are:

- Lathe machine NC (X, Z, U, W) , DENFORD D13511 CYCLONE, Fanuc language (figure 1).
- Hours Number: 5 H / day.
- Tests Number: 55.
- Measuring device: numerical control director (0.001 mm).
- Displacement :linear interpolation of the axes (X Z) in a single sequence, Figure 6.

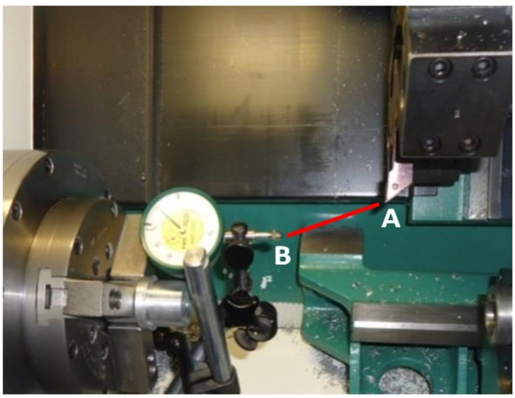

Figure 6. Offset by the interpolation of (X Z)

The measurements of this test are grouped in a graph (Figure 7). This study shows the evolution of original offset along the X axis and the Z axis according to the tests number. Note that the curve of this step is increasing, contrariwise the curve of the first step is variable.

The statistical results of the resultant (max error, min error, mean error, standard deviation and) are grouped in table 3.

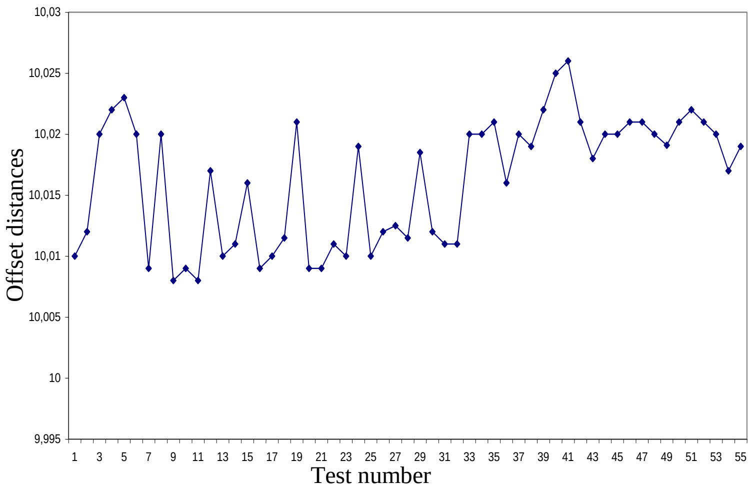

Figure 7. X and Z axis Offsets according to the tests number

Table 3. Statistical results of the 2nd stage

	XZ
MAX error	0,026
MIN error	0,008
Average error	0,0162
Standard deviation	0,0057
DELTA MD	0,034

2.3. Results interpretation

We note that the smallest value of ΔCF is in the first step. So moving with less error is the paraxial displacement. In the first step, we have acceleration and deceleration. By cons in the second stage, there are several accelerations and decelerations. The speed variation has a very important influence on the manufacturing tolerances.

3. TRAJECTORY MODELING

In this section, we used the least squares method for modeling the cutting tool path. The principle of this method is based on the search for a polynomial P (x) of degree K, Equation (6).

$$P(x) = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \cdots \alpha_K x^K = \sum_{i=0}^{K} \alpha_i . x^i \quad (6)$$

We pose:

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

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

We obtain Equation (7).

$$a_{ij}\alpha_j = b_i \quad (7)$$

The calculus of the coefficients α_j is done by the resolution of a linear equation system (8).

$$[a]\{\alpha\} = \{b\} \quad (8)$$

With [a] a known matrix and {b} a known vector.

In our work IT represents P (x) and x represents the length of the tool path.

A program was developed under FORTRAN 90 language to determine offset modeling (Figure 8).

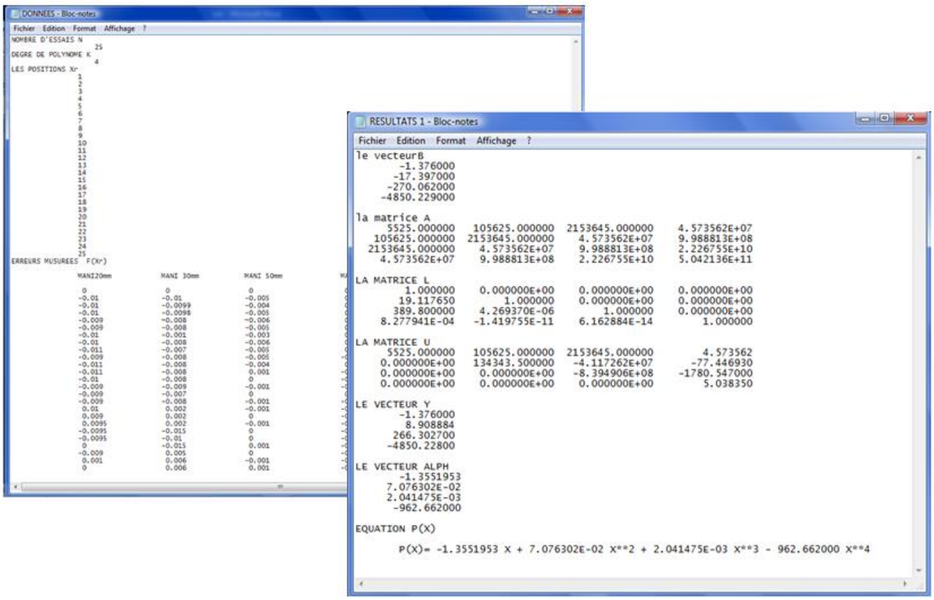

Figure 8. Results

4. COMPENSATION FOR MANUFACTURING ERRORS

For the optimization of manufacturing tolerances under the effect of cutting tool trajectory, we have proposed, under the base of this study, two methods. In the first method, we inject the model developed in tool offset option D (Figure 9). In the second method we insert the model developed in the machining program (Figure 10).

4.1. First possibility

Inject the models developed in the function of the tool offset T represented by the numerical address D (Figure 9).

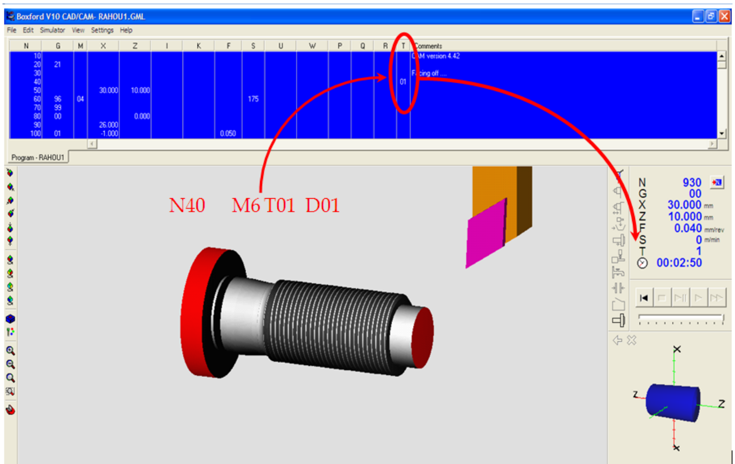

Figure 9. Example of an interface

4.2. Second possibility

Program the models developed in the machining program (Figure 10). 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.

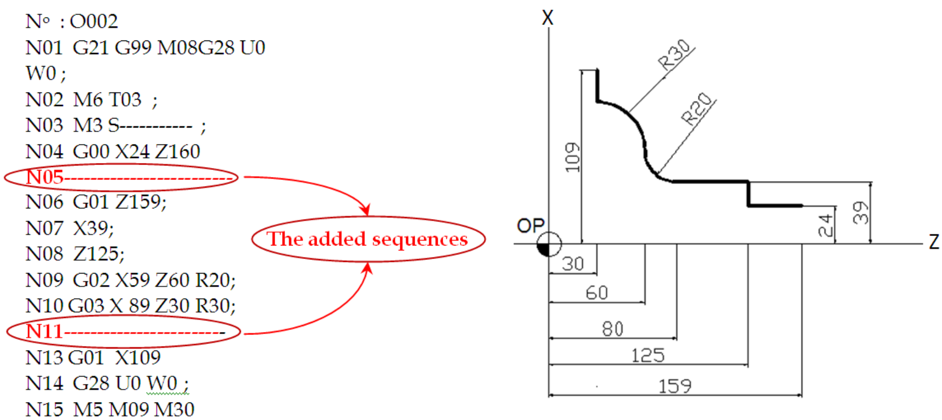

Figure 10. Example of a machining program

5. CONCLUSION

In this paper, we presented two approaches for calculating toolpath defects and their influence on tolerance intervals. It is found that the axial offset causes a displacement with less error compared to the sequential displacement. In the same context, it has been found that the speed variation effect has a significant influence on the manufacturing tolerance interval.

In this study, we proposed two approaches for manufacturing tolerances optimizing. The first approach is based on the integration of the model developed in the source program of the machine into D code. the second method is devoted directly to the machining program (the operator).

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