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Research Article

OPTIMIZATION AND MODELING OF MANUFACTURING TOLERANCES UNDER THE CONSTRAINT OF GEOMETRIC ERRORS

Mohamed RAHOU*[1], Fethi SEBAA[2]

[1]*Higher School of Applied Sciences of Tlemcen, Dept. of Technology, 13000, Tlemcen-ALGÉRIA;* ORCID:0000-0003-2253-4460
[2]*University of Tlemcen, Dept. of Mechanical, 13000, Tlemcen-ALGÉRIA;* ORCID:0000-0001-5630-7819

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ABSTRACT

This paper presents a new method of optimizing manufacturing tolerances. On the principle of kinematics of the rigid body, we used transport matrices with polynomial functions. First, we did 1500 tests on a CNC machine to quantify the EBS deviations. By integrating the two matrices, force matrix and small displacement matrix, to determine manufacturing errors. An example of machining has been processed to validate the results.
Keywords: Optimization, modeling, manufacturing tolerances, errors.

1. INTRODUCTION

The tools, methods or approaches developed cover the entire life cycle of a product (Product Life Cycle) while respecting the notion of price quality.

Research and development in universities and industries, need a proper tolerance propagation system that can handle three-dimensional geometric tolerances and analyze how these geometric tolerances are propagated in three-dimensional space.

The development of a 3D tolerance propagation system requires two things closely related to each other, the representation of tolerance zones and a mechanism for propagation of tolerance. In the 1990s, much progress was made in this area, mainly in the theoretical aspects of the kinetic formulation of tolerances, small displacement torsor (TPD) or more commonly used in English (SDT), matrix representation, vector tolerancing.

The preliminary work, which motivated the development of 3D techniques for the propagation of tolerance, by Russian researchers, introduced in Portman and Shuster [1] and Portman [2] the technique of the spatial dimension chain. Although geometric tolerances are not explicitly taken into account, they model the propagation of position errors ε in terms of an open kinematic chain where errors are represented in a matrix comprising linear position errors and angular position errors.

Fleming [3] presents a work that constitutes a fundamental basis for 3D propagation methods of tolerance. It shows how a toleranced part can be represented as a network of zones and

* Corresponding Author: e-mail: rahoumohamed3@gmail.com, tel: +00213779545990

reference points connected by arcs. The main step in research on the propagation of 3D tolerance usually begins with how to model tolerance zones.

Laperriere and Lafond [4], Lafond and Laperriere [5], Laperriere and El Maraghy [6] Laperriere and Kabore [7] have explicitly modeled the propagation of small dispersions along the tolerance chain using the Jacobian transformation.

Bourdet et al. [8] proposes a set of 3D models of tolerance propagation based on the concept of a small displacement torsor (TPD). TPD is a mathematical representation of the displacement of a rigid body in which three rotations and three translations are involved. Based on the assumption that the displacements are small, linearization is used to derive the final shape of a torsor.

Villeneuve [9] proposes as part of a specification process integrating the functional constraints and those related to the manufacture of a mechanism, a three-dimensional formalization of manufacturing tolerancing by associating the concept of small displacements and the machining entities.

Wolf [10] proposes a model of quotation of the pieces of revolution. This is a 2D extension of the uniaxial "Delta L" method initially proposed by P. Bourdet. Villeneuve [11] presents a 3D manufacturing tolerancing model for mechanical parts. The concept of small displacement torsor (TPD) is used to model the manufacturing process. The main originality is the modeling of the machining assembly as amechanism. Anselmetti [12] developed the CLIC method (Location Quotation with Influence of Contacts). It includes algorithms of choice of specifications, an original and complete method of 3D computation of the resultant called "lines of analysis", at the worst case and in statistics, and a method of synthesis of tolerances. Villeneuve [13] proposes a three-dimensional model of defective parts called MMP (Model of Manufactured Part) allowing the 3D simulation of a manufacturing process and the analysis of compliance with functional specifications. This model is used for the simulation of production lines. Dantan [14] proposes a GeoSpelling model allowing a complete and coherent process of tolerancing. This model, proposed to ISO for the reconstruction of standards in the areas of tolerancing and metrology, allows a unified description of the geometric specification. This model takes into account, not only the specifications of the insulated parts, but also the assemblies. Sebaa [15] has developed a 3DmaTol module (3D Manufacturing Tolerancing) contributing to the three-dimensional tolerancing of manufacturing tolerances. Rahou [16] developed a Modeling of Machining Errors on the NC Machine Tool.

2. EXPERIMENTAL STUDY

During its machining, a part is put in position and maintained in the reference system of the machine tool using an apparatus. A poorly adapted part is one of the main causes of non-quality mechanical parts obtained by machining. The main causes of rejection due to coin take-off come either from a bad adjustment of the setting in position of the part, or deformations of the part or dispersions on the position of the part in the reference system of the machine.

Several experimental studies have been conducted to identify these errors for the measurement of geometrical defects using a gauge block. A similar experimental study was established with a test surface of a raw bearing surface and ground surface for the measurement.

2.1. Test Procedure

The problems, due to a bad choice of part take, appear during the production. To avoid this, it is essential to control the choice of part taking for machining.

The procedure is based on the measurement of geometrical defects due to the movements of the table using a standard shim fixed on the table. The distances between the normals were chosen according to the experi mental study of positioning on a rough prismatic piece; the latter being fixed on the table [17].

Test conditions:

- Rigid piece dimensionally stable;
- Piece dimensions: 50 * 90 * 10 mm;
- Contact surfaces: rectified (super finish);
- Measuring surfaces: standard gauge;
- Measuring equipment: electronic truss, precision comparator 0.001;
- Number of tests: 100 for each of the normals;
- Thermal equilibrium achieved;
- Support: magnetic vise, marble and non-deformable test fixture;
- Mounting: normal machined;

Figure 1 illustrates the six normals used.

Figure 1. Six normal

Figure 2 gives the best pace and represents the optimal isostatic position.

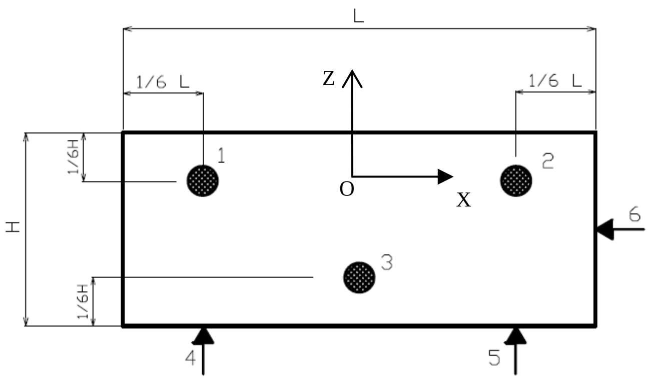

Figure 2. Optimal isostatic position

The use of a gauge block for determining geometrical defects or a blank to quantify positioning defects has resulted in the same optimal position.

All representations or models attempt to approximate the standardized representation of the rating in accordance with ISO 1101 and ASME Standard Y14.5M.

Defining the actual geometry of the parts requires the use of a:

- Design model of the nominal geometry;
- Tolerancing model for calculating tolerances;

The main models in tolerancing used for the description of the geometry of the parts constituting the system conceived are:

- Torsor model;
- Model by zone of tolerance;
- Model by play area;
- Models based on offsets;
- Requirement on virtual borders;
- Model SATT (Clement, ..)

3. MODELING ERRORS

In this study, we use the small displacement torsors for the modeling of deviations of the part without clamping and we use the reactions torsors for the modelization of the deviations of the part with clamping.

3.1. Small Displacements Torsor

The concept of small displacement torsor (TPD) was developed in the 1970s by Pierre Bourdet and André Clément [18]. The displacements of a solid can be characterized at a point O by a translation vector and a rotation matrix, equation (1).

$$\overrightarrow{D_M} = \vec{t_o} + \overrightarrow{MO} \wedge \vec{\omega} \quad (1)$$

With:

$\overrightarrow{t_o}(u,v,w)$ translational vector at the point O around the x, y, z axes, and $\vec{\omega}(\alpha,\beta,\gamma)$ vector of rotation around the x, y, z axes.

$$\begin{vmatrix} \dot{x} \\ \acute{y} \\ \acute{z} \end{vmatrix} = \begin{vmatrix} u \\ v \\ w \end{vmatrix} + \begin{vmatrix} \cos\alpha\cos\beta\cos\gamma - \sin\alpha\sin\gamma & -\cos\alpha\cos\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\alpha\sin\beta \\ \sin\alpha\cos\beta\cos\gamma + \cos\alpha\sin\gamma & -\sin\alpha\cos\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\alpha\sin\beta \\ -\sin\beta\cos\gamma & \sin\beta\sin\gamma & \cos\beta \end{vmatrix} \begin{vmatrix} x \\ y \\ z \end{vmatrix} \quad (2)$$

The couple of vectors $\vec{\tau}\left(\vec{t},\vec{\omega}\right)$,equation (2), constitutes a torsor called torsor of small displacements. In this work, this torsor of small displacements characterizes the deviations (ε_i) of the piece on the supports after displacement of the table. The measurements of the defects generated by these movements are taken at the level of the positioning norms.

3.2. Reactions Torsors

We model the reaction of each type of support (fulcrum) by a torsor. This torsor is composed of six components, three reactions noted Rx, Ry, Rz and three moments Mx, My, Mz.

- For plane support, figure 2, the torsor at the point O is given by the system (3).

$$\begin{aligned}
&R_x = 0\\
&R_y = 0\\
&R_z = R_1 + R_2 + R_3\\
&M_x = \frac{L(R_2 - R_3)}{3}\\
&M_y = \frac{H.(R_1 - (R_2 + R_3))}{3}\\
&M_z = 0
\end{aligned} \tag{3}$$

• For the linear support, figure 2, the support torsor is given by the expression (4)

$$\begin{aligned}
&R_x = 0\\
&R_y = 0\\
&R_z = R_4 + R_5\\
&M_x = 0\\
&M_y = \frac{H(R_4 - R_5)}{2}\\
&M_z = \frac{H(R_4 + R_5)}{2}
\end{aligned} \tag{4}$$

• For punctual support, figure 2, the support torsor is given by the following system (5):

$$\begin{aligned}
&R_x = 0\\
&R_y = 0\\
&R_z = R_6\\
&M_x = 0\\
&M_y = 0\\
&M_z = 0
\end{aligned} \tag{5}$$

4. APPLICATION

Figure 3 shows a workpiece with drilling counters or a lack of concentricity must be respected. This case could be adapted to the case of coaxiality.

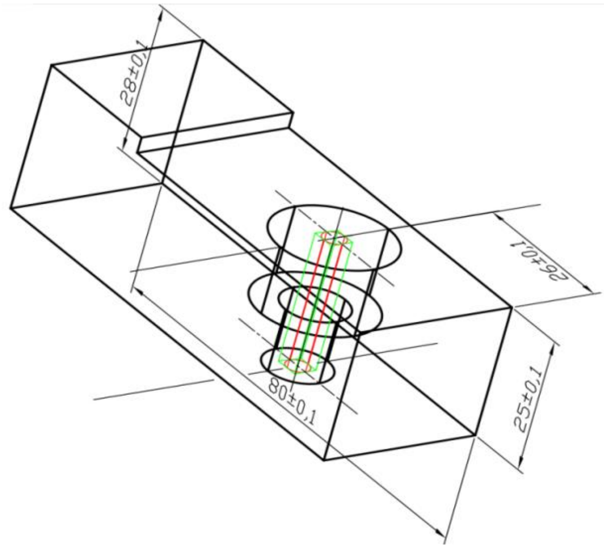

Figure 3. Drawing of the workpiece

Figure 4 shows the optimal distribution of normals.

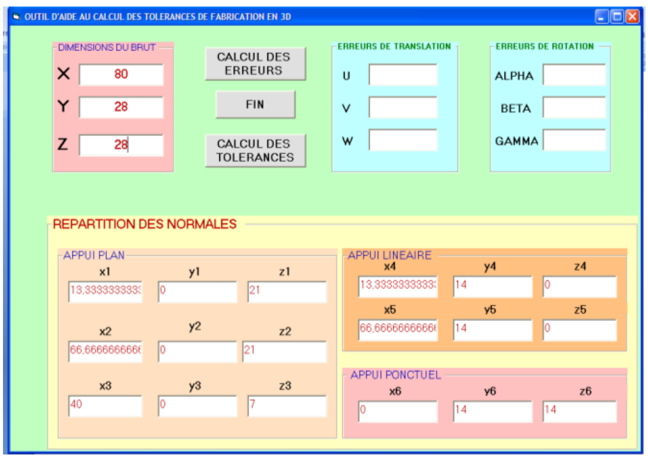

Figure 4. Positioning of normals

Figure 5 shows the calculation of the deviations.

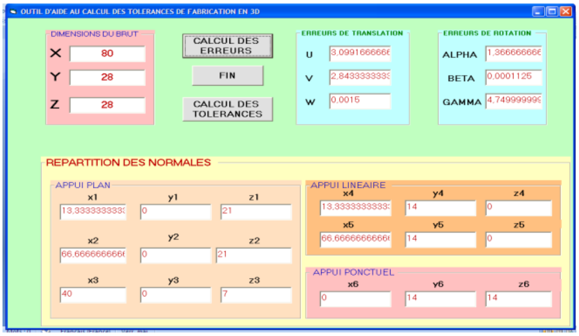

Figure 5. Calculation of deviations

Figure 6 shows the calculation of the concentricity tolerances of the counterbore.

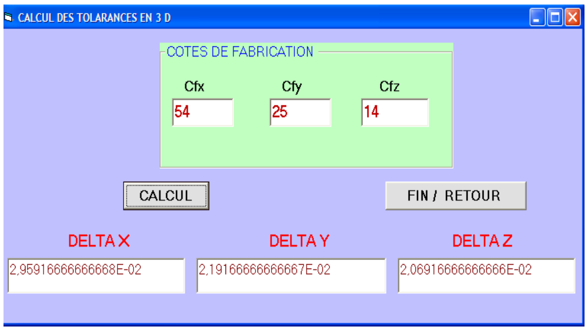

Figure 6. Calculation of concentricity tolerance

5. CONCLUSION

Nowadays, producing at the lowest cost, optimizing and modeling systems or functions with a view to simulating them is a very important objective for the industrial sector. Any technical study must consider the life cycle of a product, from design to recycling [ISO 9000].

This modeling is an approach or a model of three-dimensional tolerancing of the geometrical constraints while taking into account geometrical defects of the table failing to eliminate them. This approach is based on the concept of the torsor of small displacements which takes into account the extent of the surface. Since this model is limited to tolerancing the tolerance zone, it can become a true geometric model of specification based on the intrinsic declaration of geometry. The development of a tool to help calculate manufacturing tolerances in 3D is very useful for manufacturers and a source of guidance for designers lacking information on machining.

This contribution will help to establish a spirit of simultaneous engineering by pooling skills upstream, thus facilitating technical or technological decision-making, avoiding interference between the different OS / OM / MM departments through good coordination. New 3D tolerancing approaches focused mainly on the analysis and synthesis of tolerances will be at the origin of the development of powerful tools that can be integrated into powerful commercial software.

We propose to browse the perspectives of research still open as a result of this work:

- Thermal dispersions;
- Deformation of the piece (influence of materials);

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