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Research Paper

# Influence of form deviations on the tolerance analysis

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**Abstract**

The objective of this paper is to present the influence of form deviations on the tolerance analysis of an assembly. For this we will study initially the tolerance analysis using the deviations and clearances domains method, a second time we will integrate the influence of form tolerances on the allowable deviation domain. To illustrate this analysis we used a classical assembly with position and form tolerances (coaxiality and cylindricity). Finally a comparative study between the two cases was illustrated.

***Keywords***:*Tolerance Analysis, CAD/CAM, Assembly Systems, Engineering Drawings.*

## 1. Introduction

The tolerance analysis is an estimate process of the accumulation of manufacturing tolerances and assemblability variations in a mechanism, due to dimensional and geometric variations in manufacture, orientation and position deviations of the various parts of the mechanism. A preliminary analysis of tolerances is essential to estimate the accumulation of the tolerances and avoid failures due to the propagation of the tolerances and infeasibility of assemblies.

We discuss in this paper the influence of form deviations on the tolerance analysis using the deviations and clearances domains method.

The analysis of geometric tolerances without consideration of form variations (cylindricity in our example) considers the cylindrical surface is represented by the least square cylinder. When we considered the cylindricity, the assembly is limited by the maximum material boundary. In this case the cylindrical surface is modeled by two cylinders (a maximum material cylinder and least material cylinder).

## 2. The deviations and clearance domains method

The deviations and clearances domains method allows the analysis of geometric tolerances of mechanical systems. Dimensional and geometric tolerances of the parts being fixed, the method used to define the relationship between functional tolerances and specific tolerances of the functional surfaces. This method has been developed and applied to mechanisms with links in series and in parallel [1], [2].

This approach is based on the small displacement torsors to specify the clearance and the deviation domains [3], [4].

### 2.1. The deviation domain

Any surface has six deviations: 3 translations and 3 rotations. These deviations are low amplitude relative to the positions of the surfaces, it is possible to characterize with a small displacements torsor, where $\overrightarrow{\delta\theta}$ is the rotation vector and $\overrightarrow{\delta(M)}$ is the translation vector [5].

$$\begin{Bmatrix} \overrightarrow{\delta\theta} \\ \overrightarrow{\delta(M)} \end{Bmatrix}_M = \begin{pmatrix} r_x & t_x \\ r_y & t_y \\ r_z & t_z \end{pmatrix} \quad (1)$$

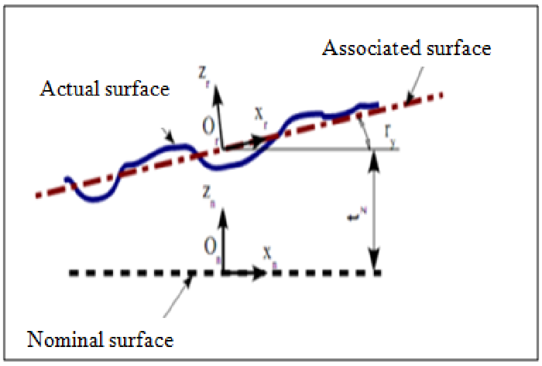


**Fig. 1:** Plan deviations

## 2.2. The clearance domain

We considered a link between two parts; this connection is made by two contact surfaces. The clearance torsor of the link expresses the possible degrees of freedom between the two parts. The clearance torsor depends on the nature of the contacting surfaces.

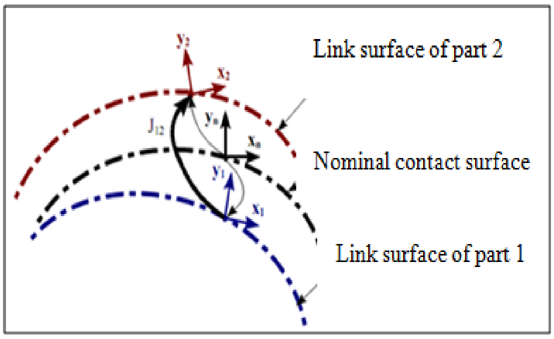


**Fig. 2:** Clearance between two parts

The clearance torsor of this link is noted J1A2:

$$J_{1A2} = \begin{Bmatrix} r_x & t_x \\ r_y & t_y \\ r_z & t_z \end{Bmatrix} \quad (2)$$

# 3. Tolerancing using the deviations and clearance domains method

Several studies have been made using the influence of form variations in assemblies, especially in the case of plane surfaces [6].In our case we considered an assembly of two cylindrical parts with a perfect cylindrical surface [7,8,9,10,11].

## 3.1. Tolerance analysis without form deviations

### 3.1.1. Example study

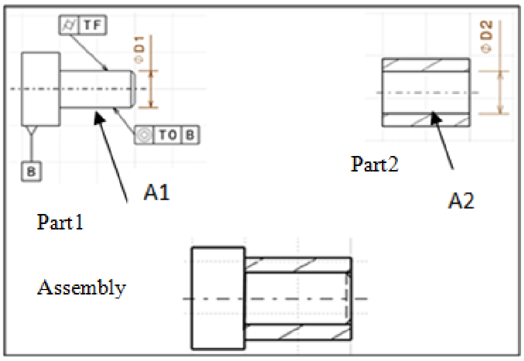


**Fig. 3:** Example Study

### 3.1.2. Hypothesis

- The part (2) (hole) is considered without form deviation;
- The tolerances assigned to the part (1) are position tolerance (coaxiality of the shaft) and the form tolerance (cylindricity of the shaft).
- Functional condition is the assemblability of the two parts.
- The study of parts concerns functional surfaces (surfaces that influence the functional condition).

### 3.1.3. Study of the deviations domains

- deviation domain of the part (2)

The hole of the work piece (2) (surface A2) is considered as a perfect reference then: the deviation domain is E2A = 0.

- deviation domain of the part (1)

The cylindrical surface (A1) is the Z-axis, so that the deviation torsor surface is of the following form:

$$E1A = \begin{Bmatrix} r_x & t_x \\ r_y & t_y \\ 0 & 0 \end{Bmatrix}_{(O,x_o,y_o,z_o)} \quad (3)$$

To respect the coaxiality tolerance of the cylindrical surface (A1) requires that the displacement of the points O1 and O2 along the two axes X and Y does not exceed the tolerance interval divided by 2 (to / 2) [12].

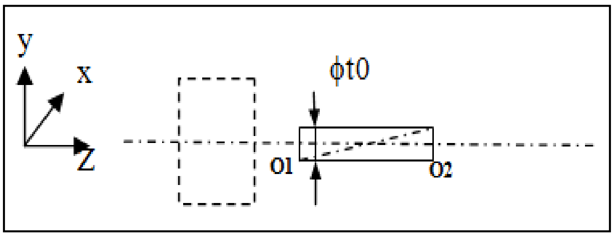


**Fig. 4:** Presentation of the Coaxiality tolerance Zone

$$\begin{cases} -\frac{t_0}{2} \le \overrightarrow{\delta O1}.\vec{x} \le \frac{t_0}{2} \\ -\frac{t_0}{2} \le \overrightarrow{\delta O1}.\vec{y} \le \frac{t_0}{2} \\ -\frac{t_0}{2} \le \overrightarrow{\delta O2}.\vec{x} \le \frac{t_0}{2} \\ -\frac{t_0}{2} \le \overrightarrow{\delta O2}.\vec{y} \le \frac{t_0}{2} \end{cases} \quad (4)$$

The deviation domain of the surface related to the center of the cylindrical link is:

$$(E1A) = \begin{Bmatrix} -t_0/2 \le t_x + \frac{h}{2} r_y \le t_0/2 \\ -t_0/2 \le t_x - \frac{h}{2} r_y \le t_0/2 \end{Bmatrix} \quad (5)$$

The graphical representation is the following form:

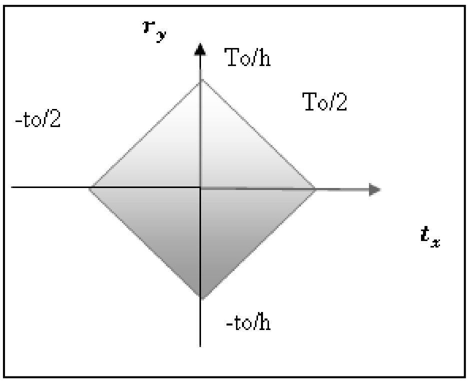


**Fig. 5:** Representation of the Deviations Domain of Coaxiality

#### 3.1.4. Study of the clearance domains

- clearance domain of the link (1-2).

This is a cylindrical link of Z-axis; the clearance domain related to the center of the link is shown by the following inequalities:

$$\mathrm{J1A2}=\begin{cases}-\mathrm{J01}/2 \leq t_x+\frac{h}{2} r_y \leq \mathrm{J01}/2 \\ -\mathrm{J01}/2 \leq t_x-\frac{h}{2} r_y \leq \mathrm{J01}/2\end{cases} \quad (6)$$

The graphical representation of the clearance domain is:

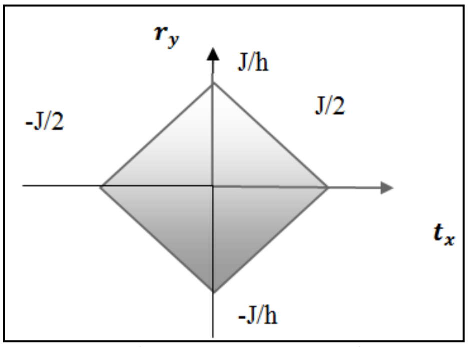


**Fig. 6:** Representation of the Clearance Domain of the Cylindrical Link

#### 3.1.5. Verifying the functional condition (assembly of the parts)

For the mechanism functionality, clearance domain must contain the deviation domain (E1A≤ J1A2).
In the limit, we have: $t_0$ = j.

### 3.2. Tolerance analysis with form deviations

The analysis of the geometrical Tolerancing without consideration of form deviations (cylindricity) considers that the cylindrical surface is represented by the Gaussian cylinder (the least square cylinder), or assembly is limited by the largest diameter of the part (1) as shown in the following schema:

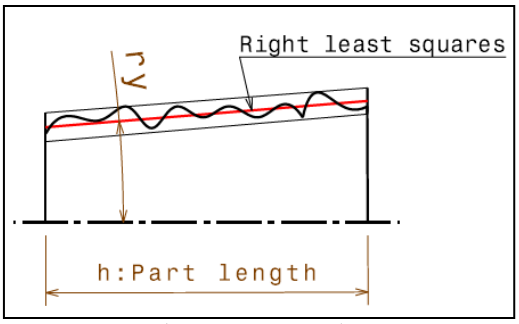


**Fig. 7:** Representation of the Cylindrical Surface with Form Deviations

The worst case analysis taking into account cylindricity deviations considers that the cylindrical surface is modeled by two cylinders (the maximum material and least material cylinders), with our analysis we shift the control line (line of least squares) to the outside for the correction of the deviation domain of the assembly.
Note in the admissible deviation domain graph:

- If the coaxiality deviations is minimal (toward the center of the graph), the cylindricity deviation does not affect the analysis (the part is still within the admissible deviation domain whatever the cylindricity deviation).
- If the coaxiality deviations is maximal (ry away from zero), the cylindricity deviation which is not considered will influence the analysis, otherwise the part is acceptable but the assembly is impossible.

To illustrate the method and calculate the correction value of the admissible deviation domain we will use the following hypothesis.

- $\frac{t_f}{t_0} = \mathrm{c}$
- $r_{ymod}$: is the modified value for respect the coaxiality and cylindricity deviations

- $r_{yc}$ : is the value of cut down of $r_y$

The objective is to calculate $r_{ymod}$ function of the c and $r_y$ .

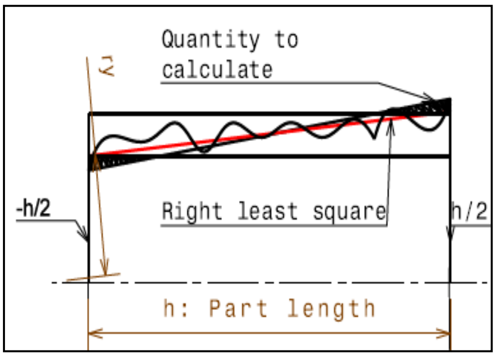


**Fig. 8:** Illustration of the Influence of the Cylindricity Deviations on the Tolerance Analysis

Considering the following diagram:

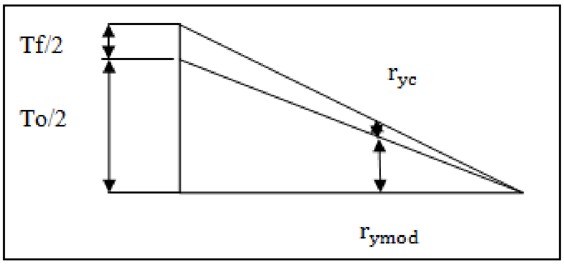


**Fig. 9:** Schema to Calculate $R_{ymod}$

- We have, without consideration of cylindricity deviations:

$$t_x + \frac{h}{2} r_y = t_0/2$$

When: $t_x = 0$ , $r_y = t_0/h$

- Considering the cylindricity deviation, we have:

$$t_x + \frac{h}{2}(r_y + r_{yc}) = t_0/2 + t_f/2$$

Therefore: $r_{yc} = t_f/h$

Where: $\frac{t_f}{t_o} = c$

Then: $r_{ymod} = \frac{t_o}{h} - \frac{ct_o}{h}$

In another way:

$$r_{ymod} = r_y - c.r_y \quad (7)$$

Finally we have the graphical representation of domain taking into account the cylindricity deviations.

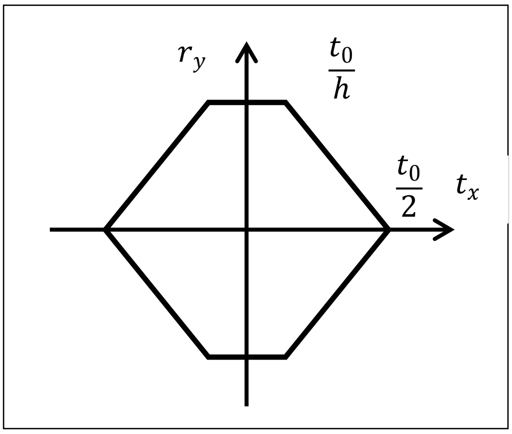


**Fig. 10:** Graphical representation domain by integrating cylindricity deviations

### 3.3. Calculation of the non-conformity of assemblies

To calculate this rate must calculate the ratio between the two surfaces (S1) and (S2) shown in the following diagram:

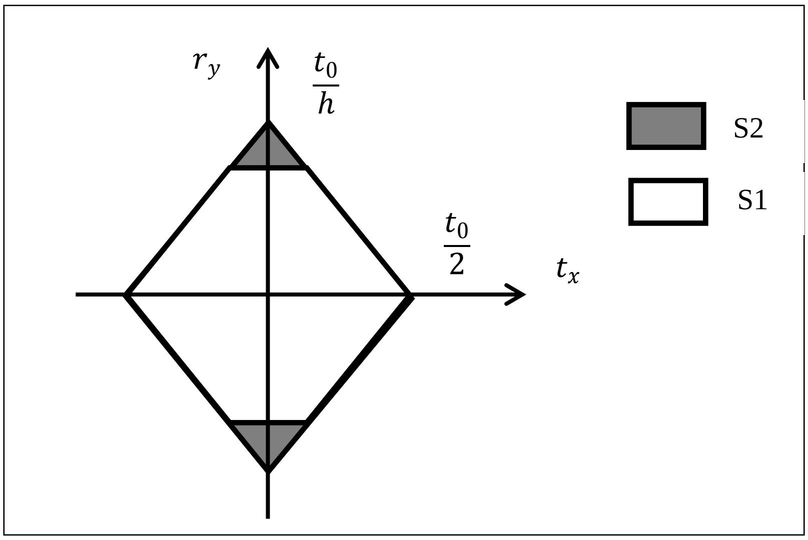


**Fig. 11:** Representation of (S1) and (S2) Areas

- $S1 = t_0 \times \frac{t_0}{h} = \frac{{t_0}^2}{h}$
- $S2 = t_f \times \frac{t_f}{h} = \frac{{t_f}^2}{h}$

Then the rate of nonconformity of assemblies without consideration of form deviations (cylindricity in our case) is:
$\Gamma(\%) = \frac{tf^2}{to^2} \times 100(\%) = \ c^2\ 100(\%)(8)$

### 3.4. Calculation of the non-conformity of the assembly with Monte Carlo simulation

The purpose is to calculate the rate of the non-Conformity using the Monte Carlo simulation and data shown in the following table was used:

**Table 1:** Simulation Data

| | |
|---|---|
| Position tolerance | 0,2 mm |
| Form tolerance | 0,04 mm |
| Ratio C | 0,20 |
| Length h | 10 mm |

To calculate the rate of non-conformity, we use a Monte Carlo simulation that generates in first time 1000 random points within the permissible tolerance domain (the position tolerance domain) (Figure 12).

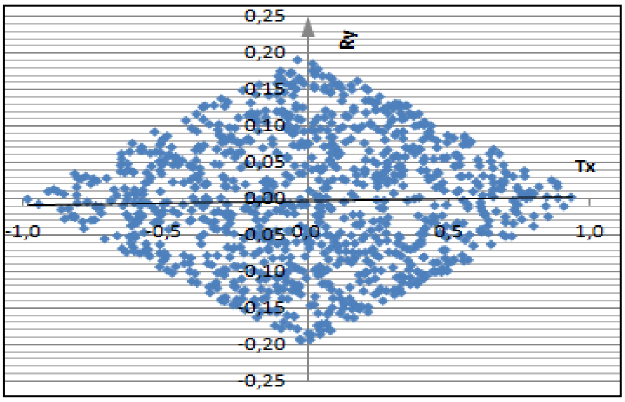


**Fig. 12:** Deviation domain without form deviations

Then we calculated the set of points that are within thefieldmodifiedby the influence of form deviation (zone of tolerance taking into account the form deviations) (Figure 13).
Finally, the rate of conformity of the parts is the ratio of the number of points of the domain in (Figure 13) divided on the number of points of the domain in (Figure 12).

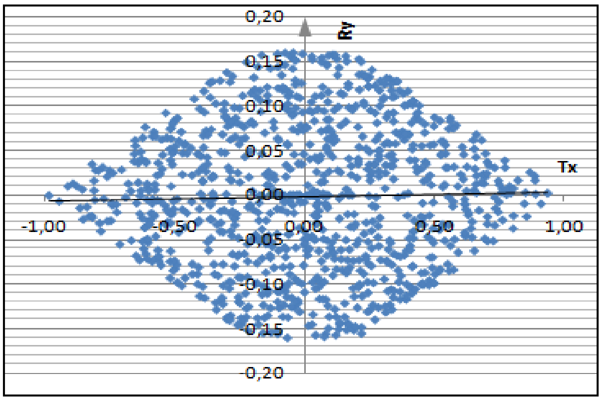


**Fig. 13:** Deviation domain with form deviations

With the simulation data shown in the table 1, the rate of non-conformity is: 3.92%.
Using the formula (8) is, the rate of non-conformity is:$\Gamma(\%) = 4\%$

The difference between the two results is due to the sample size, then when the size increases the precision of the result increases.

## 4. Conclusion

In this paper we presented a study of tolerance analysis with the deviation and clearance domains method. We introduced a position tolerance (coaxiality) in order to study the influence of form tolerance (cylindricity) in analysis tolerance using deviation and clearance domains method.
The introduction of form deviations generates a different deviation domain. This allows us to have a different functional requirement of the assembly.
Finally, this difference is illustrated by the definition of a rate of non-conformity of the assembly that is calculated using two methods and their results was compared.
The application of this approach to a complex industrial mechanism is provided in a future work.

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