



Research Paper

Three-dimensional functional tolerancing automated by MT2M and Qualitative Tol

Automatisation du tolérancement fonctionnel tridimensionnel par la MT2M et Tol Qualitatif

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ABSTRACT

This paper deals with automatic three-dimensional (3D) functional tolerancing. A combination between the Minimum Transfer Modified Method (MT-2M) and qualitative tolerancing method for prismatic parts is developed. The MT-2M is used for the recognition of functional surfaces. This technique lies in integrating the projections of surfaces of the parts under consideration along the three axes (X, Y and Z) and the contacts between these same surfaces in one table of matrix representation of the assembly. Then, the adequate qualitative tolerancing of the part under study is determined according to the number of functional conditions (CF), their types, and by using an ISO (International Organization for Standardization) analysis. Finally, a 3D functional tolerancing (dimensioning and tolerancing) is then obtained in localization and orientation, to be installed on the drawings of different parts of the assembly. A manual application of this method to a simple example of assembly, and the software developed in this study are presented.

RÉSUMÉ

Cet article présente l'automatisation du tolérancement fonctionnel tridimensionnel (3D). Une combinaison entre la méthode du transfert minimum modifiée (MT-2M) et la méthode du tolérancement qualitatif des pièces prismatiques sera développée. La méthode du transfert minimum modifiée est utilisée pour la reconnaissance des surfaces fonctionnelles. Puis, suivant le nombre de conditions fonctionnelles (CF), leurs types et en utilisant une analyse ISO, on trouve le tolérancement qualitatif adéquat de la pièce étudiée. Enfin, on obtient une cotation fonctionnelle (dimensionnement et tolérancement) 3D en localisation et en orientation à installer sur les dessins de définitions des différentes pièces constituant l'assemblage. Une application manuelle de cette méthode à un exemple simple d'assemblage, ainsi que le logiciel mis au point seront présentés.

1 Introduction

It has been shown experimentally that the decisions made during the design process induce about 75% of the total cost of product realization [1]. During the design operation of the product, the designer defines a target geometry which

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guarantees its good functioning. However, it is impossible to make perfect parts. It is then necessary to find a compromise between the needs of the engineering and design department and the equipment of production [2]. Nowadays, this compromise can be balanced by tolerancing. Tolerancing defines the limits of acceptance of products in order to guarantee the customer's satisfaction, which depends on the quality of the mechanism. This quality appears at the moment of assembling the different component of the assembly (existence of the mechanism). Quality is also confirmed by the good performance of the mechanism throughout its lifetime (service rendered to the customer) [3]. Two approaches are possible, i.e. unidirectional (1D) tolerancing and 3D tolerancing. Tolerancing can be approached in two different ways: worst-case tolerancing and statistical tolerancing [4], [5], [6], [7], [8]. Worst-case tolerancing guarantees a good functioning if all the parts are within their respective tolerances. Statistical tolerancing supposes that the probability of finding a worst-case configuration is small. This means that the tolerances on each part can be increased, but the nonconformity rate of the functional conditions must be evaluated. The 1D tolerancing is achieved by neglecting the orientation and shape defects, with respect to the position defects, and is therefore not appropriate for multi directional treatment (3D). Problems related to the geometric specifications and complex assemblies are processed by means of the three-dimensional tolerancing [9]. The analysis and synthesis [10] of 3D functional tolerances remain unsolved. The solution is not completely satisfactory for the industry. The three-dimensional functional tolerancing is intended to predict the variations of an assembly [11]. It allows defining the functional geometry of the part which guarantees its correct operation, with an optimum precision. Currently, the geometric and dimensional constraints are inserted manually during the design process [11], [12]. Three-dimensional tolerancing methods aim is to make good quality products. Within this scope, the present work presents the automatic 3D functional tolerancing using a combination of the MT-2M [9] and the method of qualitative tolerancing for prismatic parts.

2 Unidirectional model

The unidirectional tolerancing of parts is performed by using the dimensional chain. To apply this approach, it is required to assume that shape and orientation defects are negligible relative to position defects. Indeed, in this configuration, all the positions of surfaces are characterized by a point (substitution point located outside the material) projected orthogonally on the study direction. This substitution point is supposed to represent the real geometry of parts [13], [14]. Take the example of a plane that is perpendicular to the study direction. The position defect can vary between two boundaries (e_0 and e_1) which depend on the shape defect and the orientation defect (Fig. 1). The fluctuation between the two bounds is of the order of:

$$e_1 - e_0 = h \tan(\alpha) + \frac{DF}{\cos(\alpha)} \quad (1)$$

According to this relation, it is clearly understood that in order to minimize the error on the position, the angle α , as well as the form defect DF, should not be too large. In the 1D model, localization defects are the only ones that are taken into consideration.

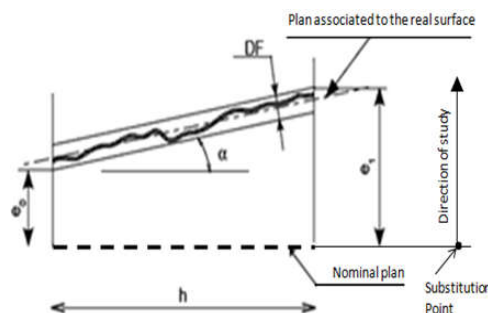


Fig. 1 – Representation of the perceptible defects on a real part.

3 Application

As a practice example, an assembly of three parts (1, 2 and 3), comprising three functional conditions, with one condition along each axis, is considered, as shown in fig. 2.

Fig.3 displays the example of the assembly (Fig. 2), with the projections of the surfaces and contacts of parts along the three axes X, Y and Z.

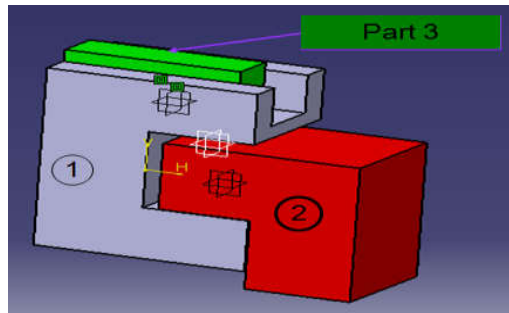


Fig. 2 – Assembly of three pieces (1, 2 and 3).

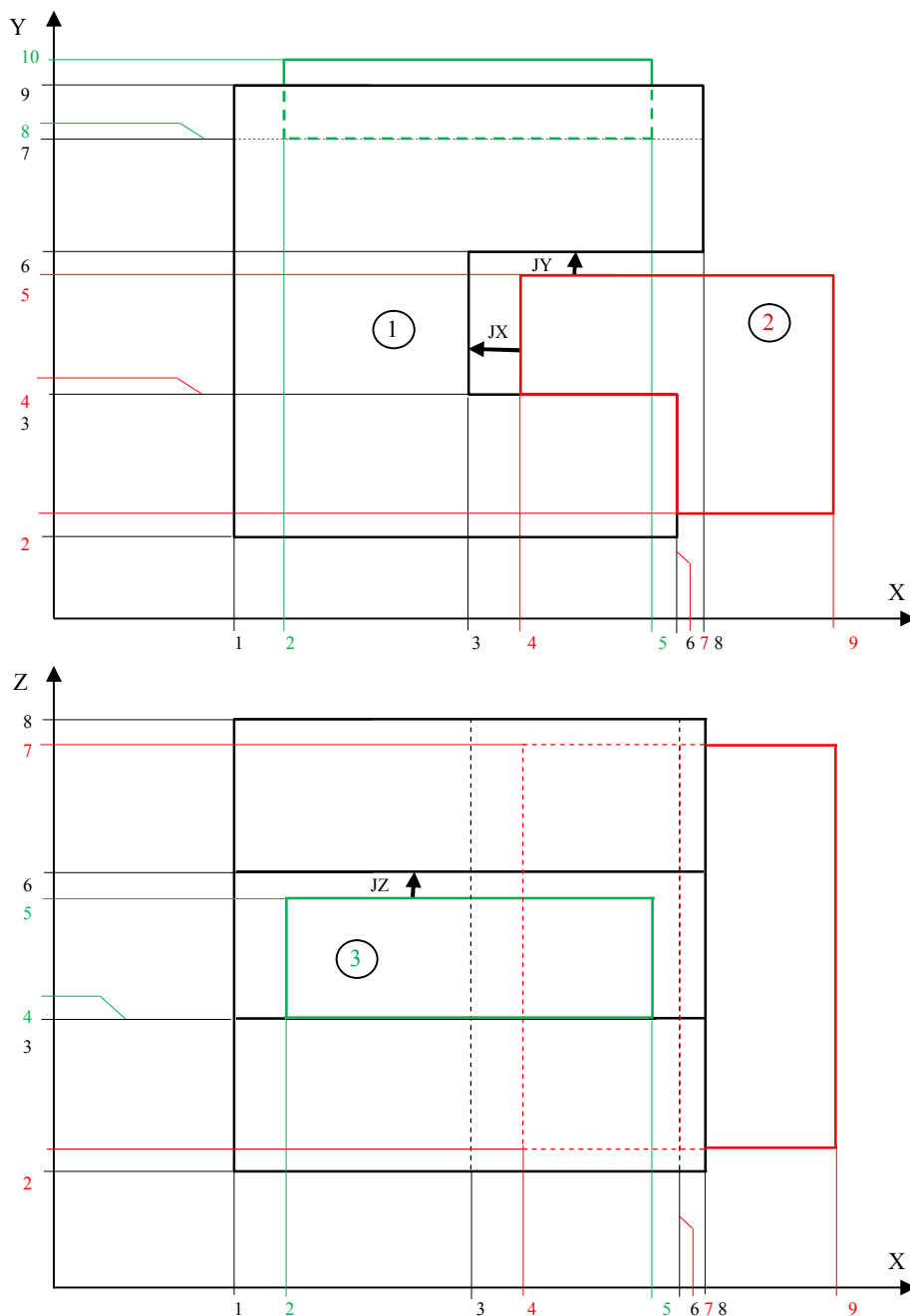


Fig. 3 – Assembly example (Fig.2), with projections of surfaces and contacts along the three axes X, Y and Z.

3.1 Matrix representation of the assembly

The assembly is represented as a matrix (Table 3) with I_s columns and I_p rows. I_p represents the index of parts along the X, Y and Z axes. I_s represents the index of the surfaces along the X, Y and Z axes and the surfaces of contact. The element A_{I_s, I_p} of the matrix contains a value (element 1) only when the surface I_s belongs to part I_p , or when there is contact. Otherwise it is null.

- *Table for the localization of surfaces*

Table 1 is a table for the localization of the surfaces of the assembly example (Fig.3) along the X, Y and Z axes.

- *Table for the localization of contacts*

Table 2 shows the table for the contacts localization of the assembly example (Fig.3), along the X, Y and Z axes.

Table 1 Table for the localization of surfaces of the assembly example along the X, Y and Z axes.

	X									Y										Z							
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8
1X	X																										
1Y										X	X			X	X												
1Z																				X	X		X	X			
2X																											
2Y																				X	X		X	X			
2Z																											
3X																											
3Y																											
3Z																											

Cross X (1-1X) in Table 1 means that surface 1 belongs to part 1 along the axis X.

Table 2 Table for the contacts localization of the following assembly example along the X, Y and Z axes.

	X									Y										Z							
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8
C1X						X	X																				
C1Y										X	X					X	X										
C1Z																											

Cross X-X (6.7 - C1X) in Table 2 denote that there is contact between the surfaces 6 and 7 that belong to parts 1 and 2, respectively, along the axis X.

- *Matrix representation of the assembly example*

The combination of the two tables 1 and 2 allows forming the assembly matrix. Table 3 represents the matrix of the assembly example (Fig. 3) along X, Y and Z axes.

Table 3 Matrix of the assembly example, along X, Y and Z axes.

	X									Y										Z							
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8
1X	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1Y	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1
2X	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2Y	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
3X	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
3Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
C1X	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C1Y	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
C1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0

3.2 Minimum transfer modified method (MT-2M)

Medjadi [15] adapted the minimum transfer method, developed by Duret [16], to one-dimensional functional tolerancing. In the present study, an attempt is made to modify and adapt this method to 3D functional tolerancing; it is

now called the Minimum Transfer Modified Method (MT-2M) [9]. The principle of MT-2M is to recognize the surfaces that delineate a functional condition (Fig.4); they are noted p and q . The unique elements which are present in all the columns of the matrix are all cancelled (Table 3), except those positioned on columns p and q . The same procedure is repeated for rows (without exception). These operations are repeated until a logical result is achieved (0 or 2 elements per column, counting even the contacts, except for columns p and q). Once a logical result is obtained, it becomes possible to say that the functional dimensions (with their position and orientation constraints), which participate in the realization of the conditions, are those delimited by the surfaces which hold the elements (1) that are present on the rows of the matrix. The surfaces that do not participate are null (0). The various steps of this method are illustrated in the flowchart of fig.4.

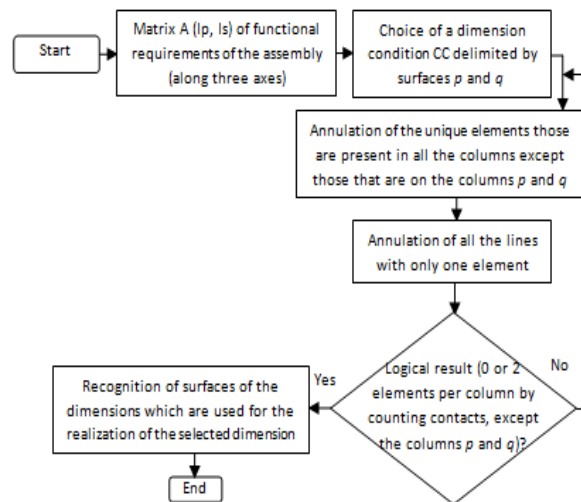


Fig. 4 – Flowchart of the Minimum Transfer Modified Method (MT-2M) [9].

The Minimum Transfer Modified Method (MT-2M) is applied to the functional condition 5Z-6Z (clearance JZ), with $p = 5Z$ and $q = 6Z$. Table 4 illustrates the matrix representation in the modified minimum transfer state for condition (5Z-6Z).

Table 4 Matrix in modified minimum transfer state, for condition (5Z-6Z).

	X									Y										Z							
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8
1X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
2X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
C1X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C1Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0

The dimensions found, for Part 1 and Part 3, are 3Z-6Z and 4Z-5Z, respectively.

3.3 Qualitative tolerancing for prismatic parts

The method used in qualitative tolerancing for prismatic parts was performed using an ISO (International Organization for Standardization) analysis [9]. The specifications to be installed on the different parts making up the assembly are obtained, depending on the number of functional dimensions and their types (stacking, groove, etc.). The flowchart for automation is given in fig.5. Symbols used in flowchart of qualitative tolerancing are shown in Table 5.

Table 5 Different symbols used in the flowchart of qualitative tolerancing.

Symbol	Designation
SD	Surface of Departure
SA	Surface of Arrival
$SPer$	Surface perpendicular to SD and SA
tp	Tolerance of position
to	Tolerance of orientation
tf	Tolerance of form

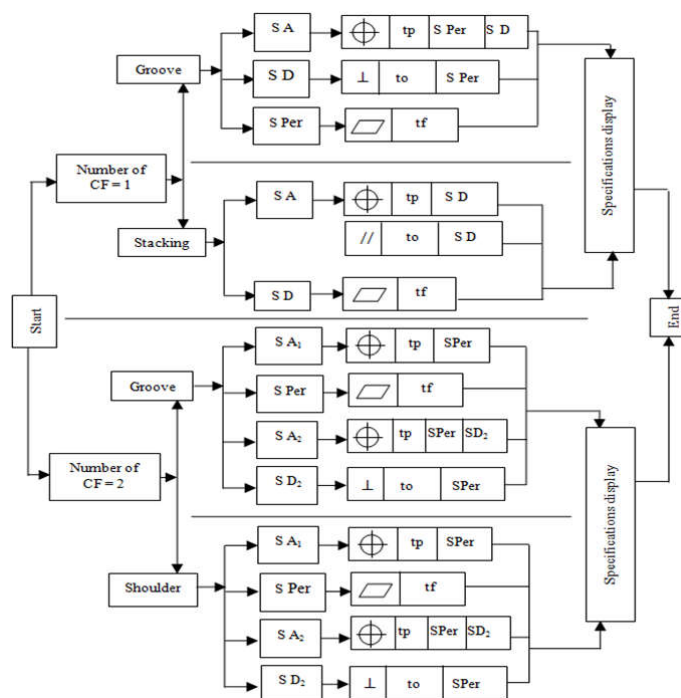


Fig. 5 – Flowchart of qualitative tolerancing [9].

4 Programming and validation tests

Based on the previously cited algorithms, a simulation module, called 3D-QT_PP (Three-dimensional Qualitative Tolerancing for Prismatic Parts) was developed. It was programmed in Visual Basic language. The program includes the MT-2M part and the qualitative tolerancing component (Qualitative Tol).

4.1 Application of MT-2M

First, the Minimum Transfer Modified Method is applied to the assembly example (Fig. 3). Fig. 6 shows the data file.

	Ase "X"												Ase "Y"										Ase "Z"	
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	1	2
1X	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1Y	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0
1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
2X	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2Y	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
2Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3X	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
3Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
C1X	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C1Y	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C2Y	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
C1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0

Fig. 6 – Data file of the assembly example.

Now, the MT-2M is applied to the functional condition (5Z-6Z) of the assembly example (Fig. 3). Fig.7 shows an intermediate step, which is the choice of a functional condition to be checked (condition 5Z-6Z).

Fig. 7 – Selecting the functional condition (5Z-6Z).

An automatic reading of the data sheet in fig.6 is initiated. Fig.8 illustrates the file of simulation results (application of MT-2M).

	Ase "X"												Ase "Y"										Ase "Z"	
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	1	2
1X	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
2X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
C1X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C1Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C1Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0

Fig.8 – File of simulation results for the condition (5Z-6Z).

The quotation (dimensions) found, for Part 1 and Part 3, are 3Z-6Z and 4Z-5Z, respectively.

It is well noted that the results of automatic treatment are found to be consistent with those of manual treatment (Table 4).

4.2 Application of Qualitative Tol

Based on the results obtained with the MT-2M (Fig.8), the parts are treated one by one in order to find the appropriate qualitative tolerancing. The number of the component under study, the number of the CF and the numbers of the functional surfaces are all introduced into the Qualitative Tol. Fig.9 shows the data file of the application of Qualitative Tol to part 3, in the assembly example of fig.3.

Fig. 9 – Data file of the application of Qualitative Tol to part 3.

After processing, the specifications to be installed on the surfaces of the part under consideration are obtained. Fig.10 shows the data file of the application of Qualitative Tol to part 3.

Fig. 10 – Result file of the application of Qualitative Tol to part 3.

The qualitative tolerancing of part 3 is carried out from fig.10, with surface 8Y=A and surface 4Z=B. We have just to copy the specifications (Fig. 10) and install them on the functional surfaces (Fig. 11).

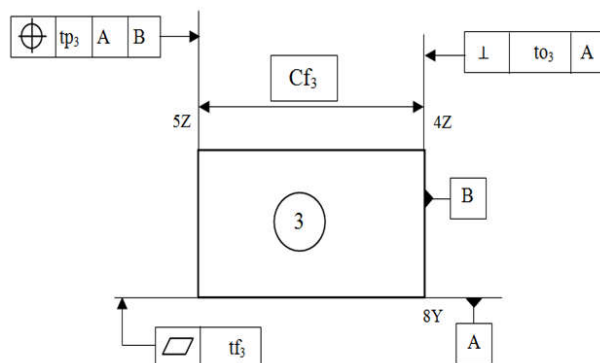


Fig. 11 – Qualitative tolerancing of part 3.

5 Conclusion

The objective of the present work is to contribute to the development of a tool that helps automating the three-dimensional functional tolerancing. A combination of the Minimum Transfer Modified Method (MT-2M) and the method of qualitative tolerancing for prismatic parts have been developed. The minimum transfer modified method is used for the recognition of functional surfaces. Then, depending on the number of functional conditions (CF), their types and using an ISO analysis, the adequate qualitative tolerancing of the part under study is determined. Finally, a 3D functional tolerancing is obtained in localization and orientation. Moreover, manual application of this method to a simple assembly example and the developed software, are presented. Our future research is intended to enrich the Qualitative Tol database in order to be able to treat any type of morphology, integrate it into a CAD/CAM system and to have a simple and complete tool for three-dimensional functional tolerancing.

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