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THREE-DIMENSIONAL MANUFACTURING TOLERANCING "THE WORST CASE SIMULATION WITH CATIA"

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Abstract:

This article proposes a 3D method of simulation of the defects generated by a manufacturing process, and the analysis of tolerance variation obtained compared to the functional requirements specifications.

The objective of this work is to collect the whole of the defects generated by the manufacturing process, these deviations result from two independents phenomena: the positioning of the part and the machining surfaces, which cause the random displacement of the machined surfaces. In this work we consider only the geometrical defects (position and orientation of surfaces) making the assumption that the form defects are negligible. This assumption is necessary for simulation to the worst cases.

Key Words: Manufacturing process, functional requirement, manufacturing tolerancing, dispersion, Worst case.

1. INTRODUCTION

A machining process is typically a discrete and multi-operational process with multivariate quality characteristics. Variation reduction and quality improvement is a very important and challenging topic, especially for complicated parts with tight tolerances, multiple operations and frequent changes of datum. Part variations can be attributed to process sequence, datum, fixtures, and machine tools. In addition, variations usually propagate from upstream to downstream operations. Since modelling variation stack-up facilitates design optimization, process control, and root cause diagnosis, it has been studied in many fields.

2. THE MACHINING SIMULATION

The geometrical machining simulation puts in situation, according to a given model, the whole of the geometrical defects which appear during the considered manufacturing process. It contributes to the manufacturing specifications by detailing the effects of the manufacturing defects on the requirements to be respected.

2.1. The unidirectional method of simulation

The unidirectional methods for geometrical simulation have as a common point to reduce the part to a number of directions which represents the directions of simulation. The handled sizes are not the specifications of the standard but the projections on the axis.

Based on this simplification, there are two families of methods:

- Methods based on the chains of dimensions
- Methods using the model of dispersion, developed by P. Bourdet [1]

2.1.1. The dimensions chain method

This method is used to calculate the manufacturing dimensions through a representation of the manufacturing process by graphs, called chains, in witch we represent all the actives surfaces "positioning surfaces, machined surfaces" in every considered set, by a vectorial representation.

It is based on the principle of the independence of the dimensions manufactured. If, for k surfaces active in the same phase, the methods that the engineer selects are supposedly "advantageous" dimensions according to (k-1) individual criteria, these dimensions are to be selected from k(k-1)/2 potential manufactured dimensions for this phase. It is also used to simulate the assemblability in the re-assembly phase.

2.1.2. Dispersions or Δl method

The method makes an inventory of dispersions intervening in obtaining a DD (Design Dept) condition. The validation of the process falls under the checking of inequations of the form:

$$\sum_{i=1}^{n} \Delta li \leq \text{ITBE}$$

Various operations make it possible to determine a manufacturing dimension of which each dimension has as a tolerance interval the sum of two dispersions, if two surfaces are machined in the same phase and the sum of several dispersions when two surfaces are not machined in the same phase.

ITCfij = Δli + Δlj (two surfaces machined in the same phase)

ITCfij: Tolerance interval of the dimension manufactured between surfaces i and j.

This method applies for as much direction as necessary, and it is adapted at parts having a simple morphology with orthogonal directions. As a result, displacements between directions are not taken into account.

2.2. Limits of the unidirectional machining simulation

The 1D manufacturing tolerancing has the simplicity of implementation and simplicity in the research and the calculation of the manufactured dimensions. However, it is limited by the taking into account of only one direction for each simulation, and does not take account of the orientation of part’s surfaces caused by the positioning and the type of contact between the elements of the CEU (Basic Cell of Machining).

This simplifying aspect of the 1D simulation methods was not appropriate for the treatment of the complex parts, and incites researcher to develop a three-dimensional models.

2.3. Three-dimensional machining simulation

The number of developments of the 3D geometrical simulation of machining is limited.

Among these developments:

F. Villeneuve [2], F. Vignat [3], S. Tichadou [4] S. Bhide [5] J-Ph. Petit [6] use with different methods the small displacement torsor to describe all intrinsic and extrinsic characteristics of parts and assembly.

Bénéat [7] proposes a modeling based on a representation of the manufacturing defects by Jacobean matrix,

P. Le Pivert [8] uses a statistical approach to model the geometrical behaviour of the processes and to determine the variances during manufacturing.

3. DESCRIPTION OF THE METHOD

This paper proposes a 3D model of simulation of the defects generated by a manufacturing process and the analysis of the variation of the tolerances obtained compared to the functional requirements specified, by using CATIA V5 of Dassault System.

This method is based on the determination and the analysis of the part's surfaces deviations relative to their nominal position (nominal part). The method is developed in two steps:

- The first step determines the effect of the process in term of deviation of the part's surfaces. At the end of this step, a model of the manufactured part with deviation defects is generated.
- The second one consists in analyzing the Consequences of the process on the respect of the functional tolerances, using model of part developed at the end phase.

Six extreme cases (or six worst cases), possible for each surface, are given by (Figure 1).

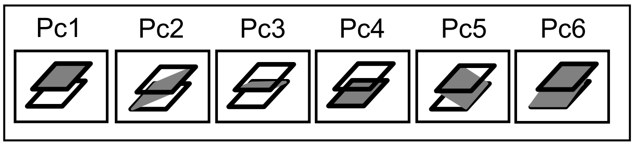

Figure 1: The six worst cases.

The surfaces deviations of the part are represented relative to their nominal surfaces "SN", in an extreme case among six possible extreme cases. The variation of each real surface "SR" remains included in an interval which represents the capability of the machine (given by sampling) to use for obtaining this part.

These deviations result from two independent phenomena: the position of the part and the machining which can generate geometrical defects of the manufactured surfaces "SF". Only the geometrical defects are taking into account (position and orientation of surfaces), the form defects are neglected.

For a given machining range, we begin with the first phase, we define positioning surfaces of the part i.e. primary surface, secondary surface and tertiary surface, and then we represent for each one of these surfaces an extreme state which represent real surface. After that, the machined surfaces are represented in an extreme case among the six possible worst cases. So we obtain the part with defects generated in the first phase.

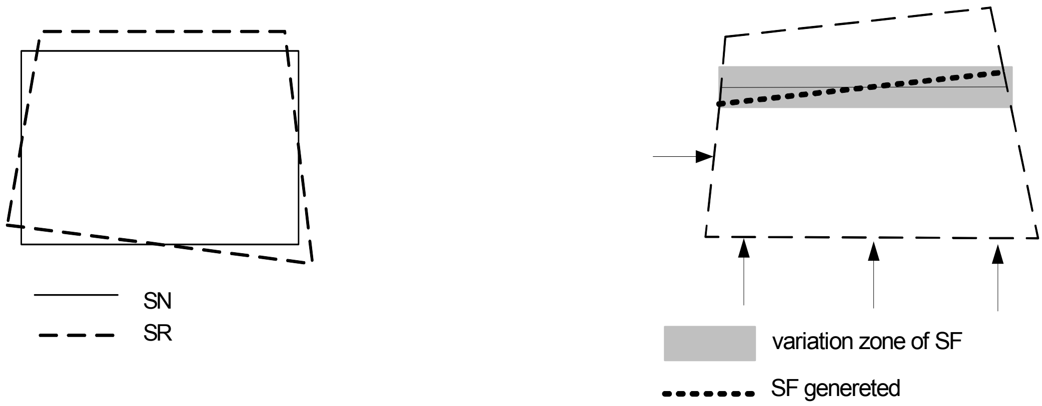

Figure 2: Stock and Phase 10.

In the following phase, the part is positioned by the real surfaces obtained in preceding phase then the machined surfaces are represented in an extreme case.

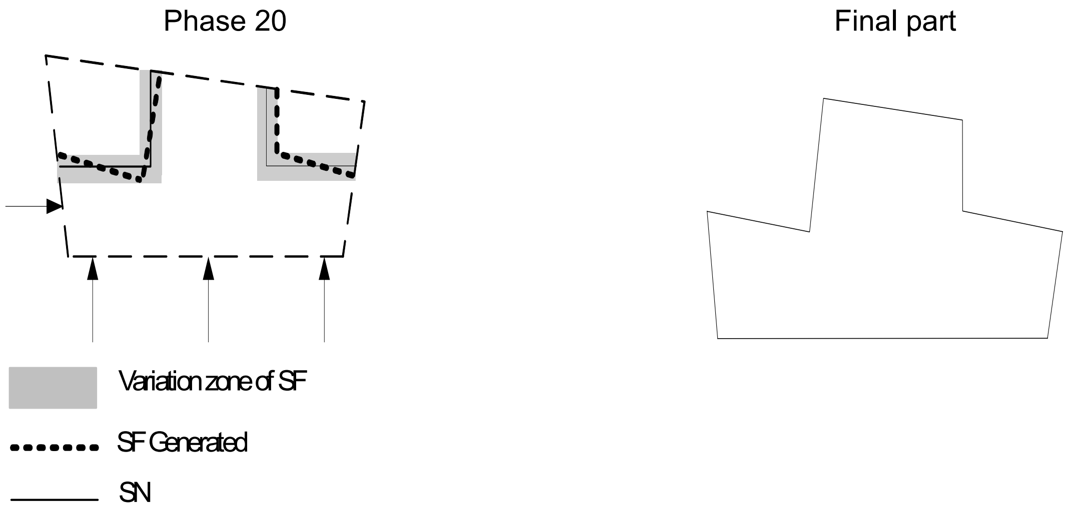

Figure 3: Phase 20 and Final part.

The same thing will be repeated until the last phase, so we obtain the final part with all its real surfaces presenting the defects accumulated during the manufacturing process.

The definition of the various dimensions and specifications of the machined part is represented by parameters that connect the various constraints which exist between part's surfaces. This parameterization makes it possible to test the validity of the range adopted on various machines whose capabilities are also variable.

To highlight the possible deviations at worst cases using the parameterization the following method was used:

Each surface is shifted compared to its nominal position of a distance d equal to the interval of tolerance which represents capability machine divided by 2 as (Figure 4.(a)) indicates it.

$$d = \left(\frac{IT}{2}\right) \tag{1}$$

The following stage consists in inclining the generated surface of an angle α as (Fig2.(b)) shows it . The value of this angle is given by the formula (2):

$$\alpha = \mathrm{tg}^{-1}\left(\frac{IT}{l}\right) \tag{2}$$

l: represents the length of the nominal surface.

With this parameterization it is enough to change the value of IT corresponding to the machine which we will use so that all parameterized surfaces take account of this modification.

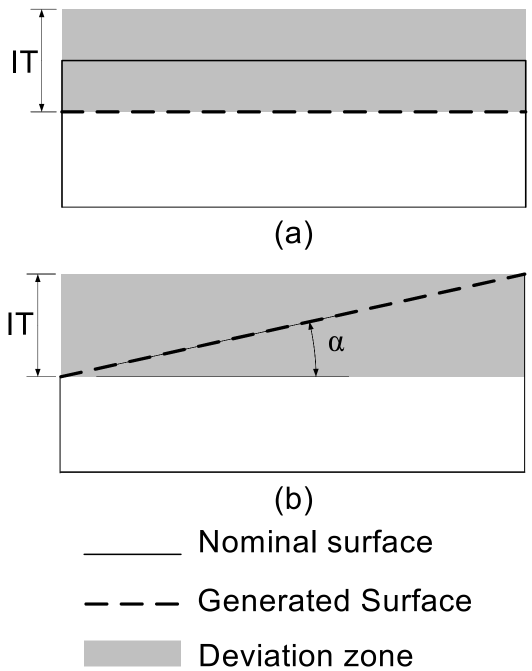

Figure 4. Representation method of the worst case.

Using model of part developed at the end set up, we will be able to define the consequences of the process on the respect of the functional tolerances.

If the part, with these surfaces in their limits of tolerance, is in conformity; we can judge that with such a capability machine, all the parts will be in conformity with the Design Dept (DD) requirements.

4. CASE STUDY

The part which we will study is a "Vé" for modular assembly of metrology that its design drawing is given by (Figure 5).

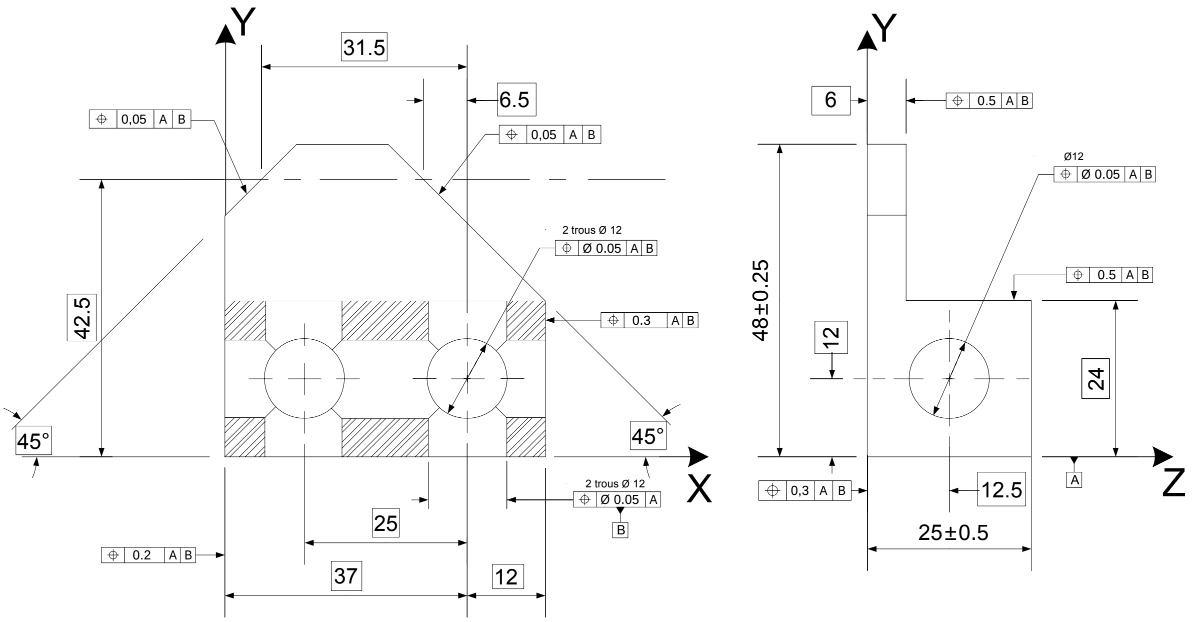

Figure 5. Design drawing [8].

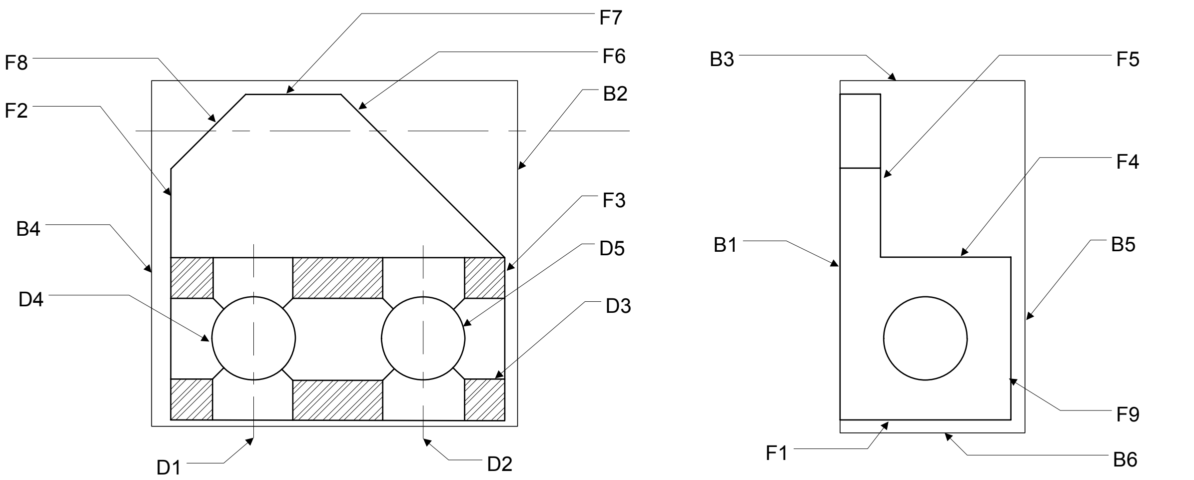

Figure 6. Location of surfaces.

Several rang of machining are possible but this one was retained because the positioning in phase 20 uses, like phase 10, a raw surface. This positioning on raw surfaces leads to dispersions larger than a positioning on a machined surface .on the other hand the positioning is done on surfaces of great dimension which is a favorable point.

The machining range of this part is presented in the form of a graph which is called SPIDER GRAPH [9] made up of:

- an external ring which definite existing surfaces with the state of reception of the part before the stages of machining,
- a ring for each phase , where only active surfaces are presented : the positioning surfaces are represented in hexagons with features which indicate the type of connection (Figure 7), and the machined surfaces are represented in circles (Figure 8).

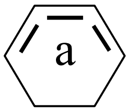

Figure 7. Hexagon representing a positioning surface (Plane connection).

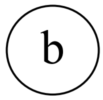

Figure 8. Circle representing a machined surface (b).

The Figure 9 presents the SPIDER GRAPH which summarizes the machining range of the part to be studied

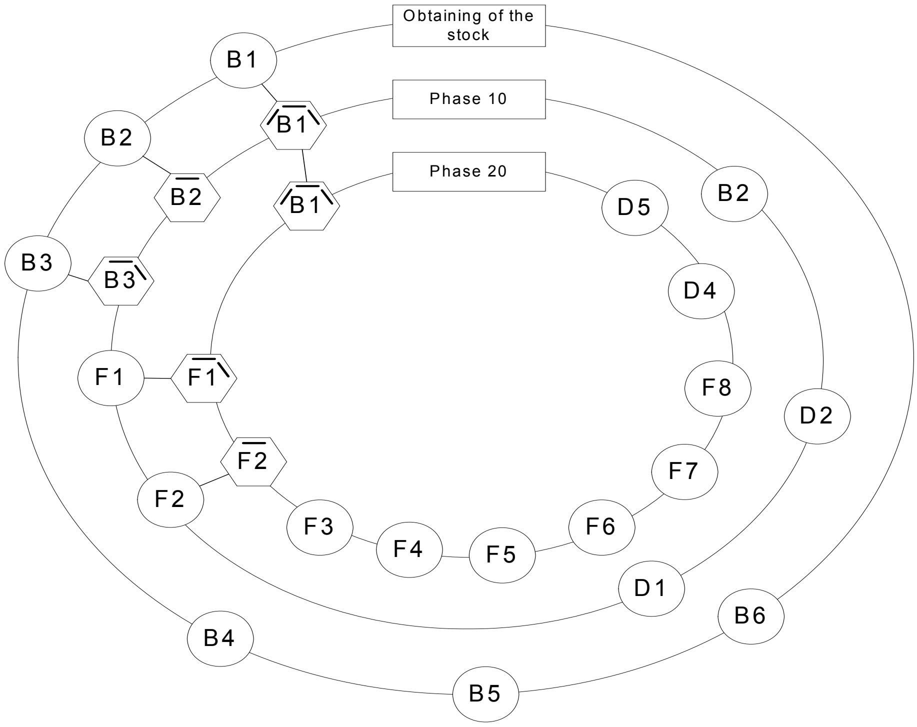

Figure 9: The Machining range with the SPIDER GRAPH.

The part is positioned on an assembly by these raw connected surfaces B1, B2 and B3, each machined surface is represented by a plan located between two plans which present the lower limit "LI" and the higher limit "LS" of the tolerance interval. All machined surfaces are generated by the same method shown by (Figure 10).

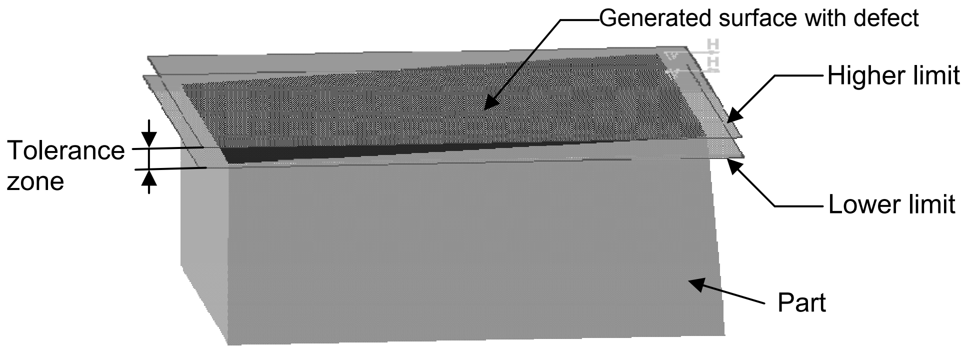

Figure 10: Generation of the machined surfaces at worst case.

It should be noted that the defects are exaggerated to be visible.

The machined surfaces in phase 10 are generated with defects. These surfaces can be used as connected surfaces in the following phase.

In the end the final part is created with cumulates deviations of surfaces relative to their nominal positions, generated during the manufacturing process.

The following stage consists of the analysis of the results;

According to standard NF EN ISO the 1101 [10] the definition of tolerance's zone of localization of a plane surface or a median plane is as follows:

⌖	t	A	B

"The zone of tolerance is limited by two parallel plans distant of t and laid out symmetrically compared to the exact theoretical position determined by exact theoretical dimensions compared to specified references A and B".

Thus for each surface it is necessary to determine the position of theoretical surface and to measure the real surface variations compared to its theoretical position.

For several values of capability machine, we took measurements for each surface of the part to check if the geometrical conditions are checked or not. For example F8 surface has a geometrical condition of localization of 0,05 mm relative to A and B, thus real surface must be located between two parallel plans (represented in figure 6 by (a) and (b) line) distant of 0,05mm and laid out symmetrically on both sides of the exact theoretical position of surface.

The (Figure 11) represents the deviation zones measured for various values of capability machine.

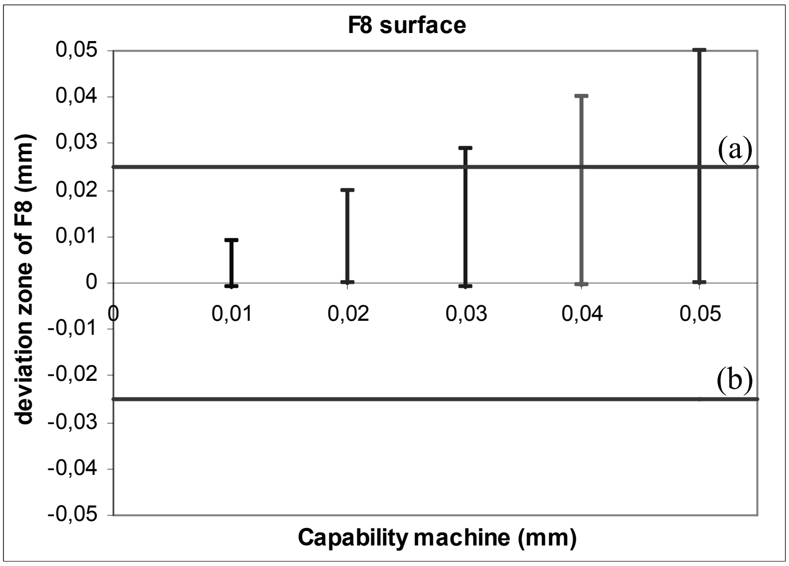

Figure 11: Deviations zones of F8 surface according to the capability machine.

This result shows that for a capability machine 0,01mm and 0,02mm, the deviation zones of F8 surface don't exceed the limits of the tolerance interval required by the DD. Thus the condition of localization is satisfied. But for a value of capability machine higher than 0,03mm, the deviation zone exceeds the limits, by consequence the condition of localization associated to this surface is not checked and the part is not in conformity with the functional requirements.

In this paper we analyze also the influence of the variation of the locator position against the functional conditions for a fixed value of capability machine (Figure 12).

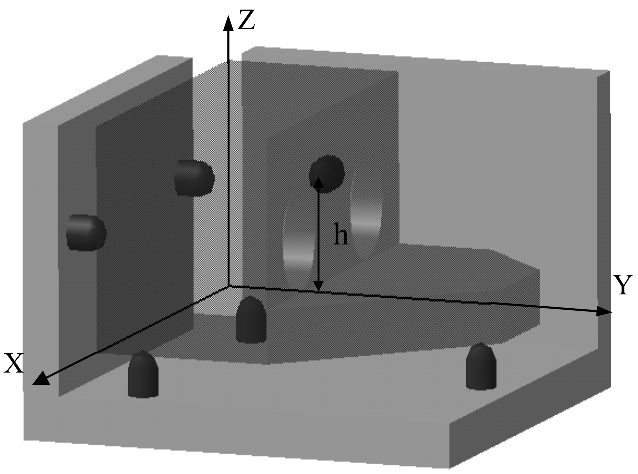

Figure 12. Variation of the locator position according to the direction Z.

The (Figure 13) represents the deviation zones of F8 surface measured for various position of the locator and for a capability machine equal to 0,03mm.

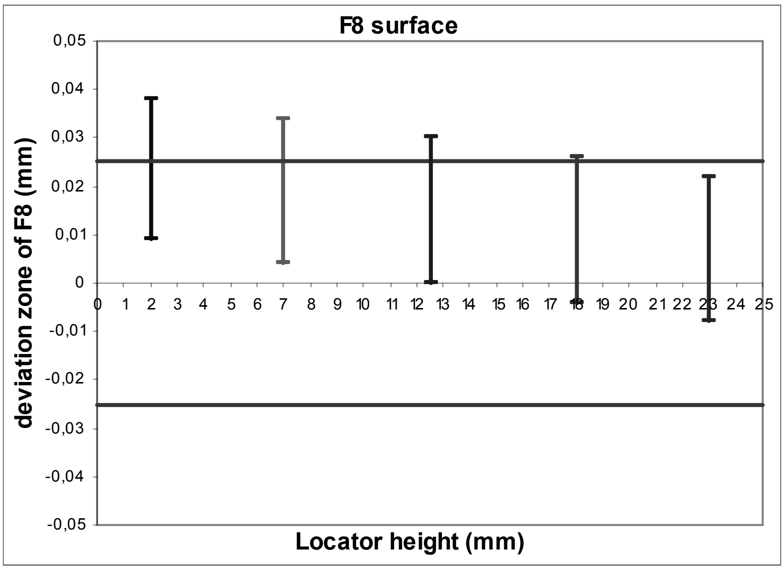

Figure 13. Deviation zones of F8 surface according to the locator height for C=0,03mm.

The change of the locator position generates a variation of the position of the deviation zone relative to the exact theoretical position of this surface.

We already found that for a capability machine 0,03mm the deviation zone of F8 surface exceeds the limits of the functional tolerance interval. With the change of the locator position according to the direction Z, the position of the deviation zone changes. For a locator position of 23 mm the deviation zone becomes inside the tolerance zone. Then the condition of localization is checked. This result shows that the choice of the machine is dependent on the locator position.

5. CONCLUSION

This paper deals with problem which plays a significant role in the success of the production schedules: the tolerancing, essence to define the geometry of a machine element ensuring its functionality in an assembly with a good precision.

We developed a method of three-dimensional simulation at worst cases using the software CATIA. This method could be considered in the long term for the development of a tool of computer-assisted tolerancing, if we manage to treat in an automatic way all the combinations of the worst case possible, and that we develop an interface with modelers CAD.

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