

SIMULATION OF THE MANUFACTURING PROCESS, GENERATION OF A MODEL OF THE MANUFACTURED PARTS

Frédéric Vignat, François Villeneuve
University of Grenoble, Laboratory 3S, France
frederic.vignat@inpg.fr, francois.villeneuve@inpg.fr

Designing a new product in an industrial context supposes to be certain to be able to produce it according to a level of quality and controlled cost. To achieve this goal, it is necessary to simultaneously design the product and the process of production and to be able to simulate the envisaged process in order to predict the productivity and the quality that can be obtained. The proposed method is based on the generation of a virtual model of the manufactured parts (model MMP). The deviations of the manufactured surfaces of the MMP are expressed compared to the nominal part. These deviations are collected by simulation of the suggested manufacturing process. The range of variation of these deviations represents the 3d capabilities of the manufacturing means.

1. INTRODUCTION

To answer to an identified need, the designer creates a product. The use of CAD softwares has been generalized and the widely used concept of digital mock-up give to the CAD model a central position. The CAD model a nominal model of the designed products and all the forecast simulations are made with this model. The manufacturing step of the product generates deviations and the consequences of these deviations have to be managed. It is necessary give limits to the deviations so that its influence on the product functionality is limited the requirements range. Several models to estimate the deviations generated by the manufacturing process and to evaluate its consequences on the cinematic functionality of the product have been proposed.

(Dantan and Al, 2000a) (Dantan and Al, 2000b) proposes to model the manufacturing process by gauges with internal mobilites. They define three spaces g_s , g_i and g_g for gauge situation, gauge intrinsic and gauge gap representing the variations due to the manufacturing process. The envisaged variations of these parameters determine a field of variation DM of the parameters of situation S and intrinsic I of the part. If this field DM is included in the D_{specif} field representing the field in which the functional specification is respected, it is possible to conclude that, for this phase, the selected process makes it possible to carry out suitable parts. The defined gauge can also be used like a manufacturing specification.

(Zhou and Al, 2003) use a vectorial model to describe the defects relative to a nominal model and gathers them in a state vector $x(k)$. They then write that each manufacturing set-up generates defects which it classifies in three categories (see figure X): positioning defects which correspond to the positioning defects of a perfect part in an imperfect part-holder, machining defects corresponding to the defects of the machined surfaces relative to the machine and reference defects corresponding to the positioning defects of an imperfect part in a perfect part-holder. They then use matrices operators to combine the defects and to determine the state vector at the end of the set-up $x(k+1)$.

(Tichadou and Al, 2004) propose a graph representation of the manufacturing process. This graph model the successive set-up and for each set-up the positioning surface and their hierarchy and the machined surfaces. This graph makes it possible to highlight the influential paths. They propose then 2 analysis methods. The first one uses a small displacements torsor model. The second one is based on the use of a CAD software in which they model a manufacturing process with defect. They then virtually measure the realized part and check its conformity.

The common simulation and transfer tools assume that the form and orientation defects are negligible in front of dimensional defects. A vector can thus model each dimension. The projection of the vectors on the specified direction gives algebraic relations that can be used for the simulation or transfer purpose. The Δl method (Bourdet, 1973) and the tolerance chain are the main used methods using this model.

Usually, the designer indicates limits to the deviation by defining tolerances. (Zangh, 1996) describe the tolerances as a link between the product functional needs and the manufacturing cost. Specifications influence both the product and the process and the tolerancing activity has to be considered as a transverse one. Zangh proposes an integrated design approach where intermediate (functional) specifications are not used. He proposes to calculate directly the consequences of the manufacturing defects on the respect of the functional needs.

The model proposed in this paper can be used, in a classical way, to verify that the defects generated by the process are within the indicated tolerances. It can also be used, forgetting the tolerance intermediate step, to simulate directly the consequences of the defects on the utilization life cycle step of the product.

The MMP is constructed around the nominal model of the part. This nominal model can be positioned by a set of surfaces. The surfaces of the MMP are ideal surfaces associated to real surfaces by a criterion like least square. The deviations of these surfaces are described by a small displacement torsor. The parameters of these torsors depend on positioning and machining deviations and the limits on these parameters are expressed by constraints.

Containing defects parameters representing the main causes of process inaccuracy and constraints limiting the variation of these parameters, the MMP can be presented like the model of the manufactured parts.

2. THE GEOMETRICAL MODEL

The geometrical model used to describe the MMP is based on the definition described in (Bourdet et al, 1995) (Thiebaut, 2001) for the assembly analysis and extended by (Villeneuve et al, 2001) for the manufacturing process analysis. This

model is based on an ideal part is a part made up of perfect form surfaces deviated relative to their perfect position. The surfaces of the ideal part are associated to the real one by a measurement and an association process. The geometrical description of the MMP is based on the nominal model of the part than can be issued of a CAD model. This nominal model is composed of:

- a global frame which can be constructed on associated surfaces
- nominal surfaces with for each surface:
 - type of surface
 - local frame
 - boundaries (edges and vertexes)

The associated part is described relative to the nominal one by the deviation of each surface. Real surfaces are associated to ideal surfaces using a usual criterion like least square. In the MMP is described the deviation of these real surfaces relative to the nominal one by a small displacement torsor which structure depend on the surface type. For example for the plane 6 of the part, in a local frame (with Z local axis normal to the plane), the torsor is described figure 1. The 3 non-null values represent the potential defects of the surface and the 3 null values represent the invariant degrees of the surface.

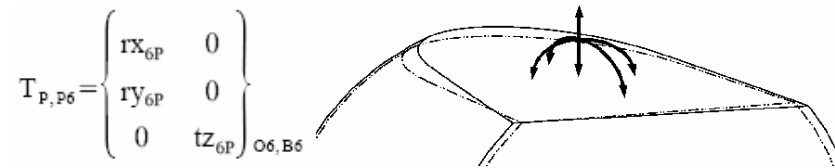


Figure 1 –Plane 6 displacement

This model is also used to describe the process: the associated part-holder, the part positioning and the machining operations.

3. THE MODEL OF MANUFACTURED PARTS

The model of manufactured parts (see figure 3) is a representation of the set of produced parts including description of the process in term of geometrical deviations. It particularly describes the defects generated by the process, classify these defects and indicate the limits on these one. To illustrate the concepts presented in this paper, an example of realised part represented figure 2 will be used.

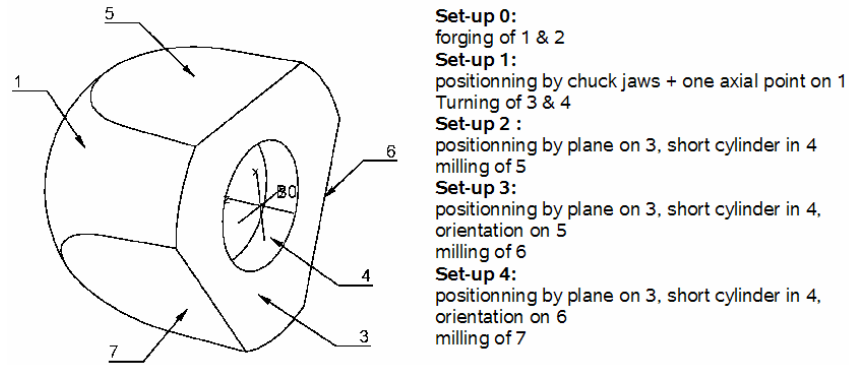


Figure 2 – Example of part and process planning

The defects generated by a machining process are considered to be the result of 2 independent phenomenons: the positioning one and the machining one; accumulated over the successive set-ups. The combination of these two phenomenons can be made by summation; the result is the deviation of a realized surface relative to the part.

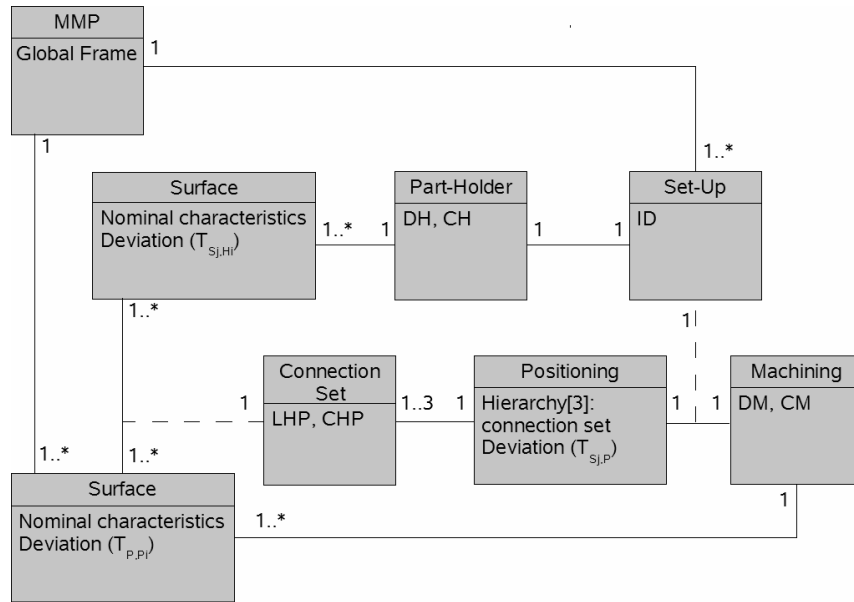


Figure 3 – Structure of the MMP

The positioning deviation is the deviation of the nominal part relative to the nominal machine. The part positioning operation on the part-holder is realized by a

set of hierarchically organized elementary connections. Each set determine part of the 6 degrees of freedom of the MMP in the 3D space. The positioning deviation is expressed by a small displacement torsor $T_{S_j,P}$ for set-up j . This deviation is function of the MMP surfaces deviation generated by the previous set-ups, the part-holder surfaces deviations and the link part-holder/part surfaces.

The part-holder surfaces deviations are described by small displacement torsors $T_{S_j,Hk}$ for surface k of the part-holder in set-up j . The parameters of these torsors (DH) are saved in the part-holder object of the MMP (table 1) and limited by constraints (CH) representative of the part-holder quality. These constraints are limiting one or a set of parameters together.

Table 1 – Part-holder description

Set Up 3 : Part-Holder		
Surface	Deviation DH	Constraints CH
Plane 3S3	$rx_{3S3}, ry_{3S3}, tz_{3S3}$	$-0,0001 \leq rx_{3S3} \leq 0,0001$ $-0,0001 \leq ry_{3S3} \leq 0,0001$ $-0,01 \leq tz_{3S3} \leq 0,01$
Cylinder 4S3	$ra_{4S3}, rx_{4S3}, ry_{4S3}, tx_{4S3}, ty_{4S3}$	$-0,01 \leq ra_{4S3} \leq 0,01$ $\sqrt{tx_{4S3} - 2,5 ry_{4S3}}^2 + (ty_{4S3} + 2,5 rx_{4S3})^2 \leq 0,01$ $\sqrt{tx_{4S3} + 2,5 ry_{4S3}}^2 + (ty_{4S3} - 2,5 rx_{4S3})^2 \leq 0,01$
Line 5S3	ry_{5S3}, tz_{5S3}	$-0,01 \leq tz_{5S3} \pm 20 ry_{5S3} \leq 0,01$

An elementary connection joins an associated surface of the part-holder and an associated surface of the MMP. The relative position of these 2 surfaces is described by a small displacement torsor $T_{Hk,Pi}$, called link torsor. The 6 parameters of this torsor are the link parameters (LHP). The LHP values depend on connected surfaces contact condition and can be calculated for each part/part-holder pair using positioning rules expressed by constraints (CHP). Two type of contact are distinguished: the floating and the slipping one. For floating contacts, the only constraint is non-penetration of the part in the part-holder and is determined on the boundary edge and vertex. For slipping contact the part is pushed on the part holder by a clamping strength. The constraint associated to this type of contact is a positioning function to maximise combined to non-penetration condition. The connection data are saved in the connection sets objects of the set-up (table 2).

Table 2 – Positioning description of the primary connection in set-up 3

Set Up 3 : Positioning				Hierarchical set : 1		
Part-Holder surface	LHP	Type of contact	Positioning function	Non Penetration condition	Solution	MMP surface
Plane 3S3	lr_{3S3} lry_{3S3} ltz_{3S3}	slipping	$-ltz_{3S3}$	$24,92lr_{3S3} + 30lry_{3S3} + ltz_{3S3} \geq 0$ $38,44lr_{3S3} + 6,58lry_{3S3} + ltz_{3S3} \geq 0$ $13,52lr_{3S3} - 36,58lry_{3S3} + ltz_{3S3} \geq 0$ $-24,92lr_{3S3} + 30lry_{3S3} + ltz_{3S3} \geq 0$ $-38,44lr_{3S3} + 6,58lry_{3S3} + ltz_{3S3} \geq 0$ $-13,52lr_{3S3} - 36,58lry_{3S3} + ltz_{3S3} \geq 0$	0 0 0	Plane 3

The deviation of the surface machining operation is described relative to the nominal machine by a small displacement torsor T_{S_i, P_i} for the surface i realised in set-up j . This torsor is grouping deviation of the surface swept by the tool and cutting local deformations. The parameters of this torsor represent machining deviations (DM). They are limited by constraints (CM) representing the machines and tools capabilities. These data are stored in the machining object of the MMP (table 3).

Table 3 – Machining parameters description

Set Up 3 : Machining		
Surface	Deviation DM	Constraints CM
Plane 6	rx_6	$-0.0001 \leq rx_6 \leq 0.0001$
	ry_6	$-0.0001 \leq ry_6 \leq 0.0001$
	tz_6	$-0.01 \leq tz_6 \leq 0.01$

For each surface, the positioning and machining effects are added and its deviation relative to the nominal part is determined and expressed by a small displacement torsor T_{P, P_i} for surface i of the part like in figure 4 for surface 6 of the example figure 2. This deviation is stored in the surface object of the MMP.

$$T_{P, p6} = \begin{pmatrix} Urz_{3S2} + ry_{3S3} + lry_{3S3} + rx_5 + rx_6 & 0 \\ 0,86 lrx_{10S1} - 0,86 lrx_{3S3} + 0,5 lry_{10S1} + 0,5 lry_{3S3} & 0 \\ -0,86 rx_1 + 0,86 rx_{10S1} - 0,86 rx_3 - 0,86 rx_{3S3} & \\ -0,5 ry_1 + 0,5 ry_{10S1} - 0,5 ry_3 + 0,5 ry_{3S3} + ry_6 & \\ & -1,73 lrx_{10S1} - 6,49 lrx_{3S3} - lry_{10S1} + 3,75 lry_{3S3} \\ & + 0,5 ltx_{10S1} + 0,5 ltx_{4S3} - 0,86 lty_{10S1} - 0,86 lty_{4S3} \\ & -8,66 rx_1 - 1,73 rx_{10S1} - 6,49 rx_3 - 6,49 rx_{3S3} \\ & + 2,16 rx_4 - 5ry_1 - 1ry_{10S1} - 3,75ry_3 \\ & + 3,75ry_{3S3} + 1,25ry_4 - 0,5tx_1 + 0,5tx_{10S1} \\ & - 0,5tx_4 + 0,5tx_{4S3} + 0,86ty_1 - 0,86ty_{10S1} \\ & + 0,86ty_4 - 0,86ty_{4S3} + tz_6 \end{pmatrix}$$

Figure 4 – Deviation of a surface of the MMP

4. THE PROCESS SIMULATION

The MMP construction is done through a simulation. The simulation is performed in two steps determining the effects of the 2 phenomenons. First, the MWP (Model of WorkPiece or intermediate MMP at the end of a set-up) from the previous set-up is positioned on the part holder. Then, the surfaces realised during the current step are machined.

The positioning is the result of the combination of parallel and hierarchically organised elementary connections between surfaces of a part-holder and surfaces of

a part. A pair of surfaces, a connection type, a contact type and a potential contact zone defines a connection. The contacts are of two types, floating one and slipping one.

Each connection contributes to part of the 6 positioning degrees of the MMP and the links parameters describing this contribution are named determined. The connection also lives some degrees free and the a links parameters associated to these degrees are named undetermined. The position of the MMP fixed by a connection n can be calculated by equation (1)

$$\text{Pos}[n] = T_{S_j, P} = T_{S_j, H_k} + T_{H_k, P_i} - T_{P, P_i} \quad (1)$$

A rigid part position being unique in the 3D space, it is possible to express that expression coming from each connection is equal (2).

$$\forall n, m < \text{number of connections: Pos}[n] = \text{Pos}[m] \quad (2)$$

This process called unification gives a system of $6 \times (\text{number of connections} - 1)$ equations that is solved to eliminate undetermined and over constrained links. The resolution of this problem (Villeneuve et al, 2005) gives the position of the MMP function of 6 piloting links. The values of these links depend on contact condition and part and part-holder surfaces deviation. This dependency is expressed by constraints function of the contact type like presented in chapter 3. The part position is being determined the surfaces can now be realised. The determination of the deviation of a realised surface relative to its nominal position is done by addition of positioning and machining deviation using (3).

$$T_{P, P_i} = -T_{S_j, P} + T_{S_j, P_i} \quad (3)$$

This operation is repeated for the successive set-ups and leads to the construction of the MMP.

5. CONCLUSION

Verifying that nominal model of the product is a good answer to the expressed or implied needs is not sufficient. To be delivered, the products have to be manufactured and assembled. The manufacturing process generates deviation that have to be managed in order to be certain that the whole products are functional.

To approach this goal, a model of the manufactured parts with deviations is proposed. This model is a representation of the set of produced parts. It is generated by a simulation stage with the manufacturing means capabilities as input parameters.

This model can be used in an analysis stage to verify that the produced parts fit with the functional tolerances. It can also be used to perform assembly and mechanism simulation with deviated parts in a product life cycle engineering practice.

6. REFERENCES

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