

DEFAULTS SIMULATION OF A MEASUREMENT PROCESS

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Abstract: *During the measurement process of a mechanical workpiece, many factors affect the measurement uncertainty. Although a number of studies have been reported in evaluating measurement uncertainty, few have take into account the quality of the measured part to determine the influence of the real geometry on the calculation of the position of the datum coordinates system. This is the first aim of this article. The second one describes how we can use a Dimensioning and Tolerancing add-on (into simulation software) to predict the default of a real measurement process. This second part takes into account the defaults due to the manipulation of a measurement device. With these two points, we can simulate with more accuracy the global defaults of the measuring process.*

Keywords: *measurement, tolerance, simulation*

1. Introduction

The coordinate measuring machine (CMM) is the mostly used measuring device. It allows to carry out measurements and to inspect the quality of parts in all types of industry. This instrument is often preferred to others because it is a flexible device that can improve productivity of the measurement process of mechanical parts.

We are going to perform our research to focus on the influence of the geometrical defaults of the parts and on the methodology of measurement linked to the device used. The experiments are realized in the CAD environment (CATIA) with additional software of simulation (3DCS).

2. Problematic

2.1. Context of the study

During the measurement process, there are many parameters affecting the quality of the measurement results. Some of them are often studied: the influence of the probe system [3][5][7][10][15][17][20][25], the dynamic

and kinematic effects, the methodology of calculation used into the software [3][24], the thermal effects on the workpiece [14].

Abdelhak Nafia, J.R.R. Mayera, Adam Wozniakb [3] present a method for the separation of machine and reference sphere errors on one side and triggering probe and probe tip on the other side.

J. Sładek, A. Gąska [16] present an evaluation of coordinate measurement uncertainty with use of virtual machine model based on Monte Carlo method. This work simulates the CMM machine and the part in a virtual environment.

Jean-Pierre Kruth, Paul Vanherck, Christophe Van den Bergh and Benny Schacht [14] study the influence of the thermal effects. There is different gradient between the CMM and the parts. In this article, the part and the probe are considered deformable. This study focuses the interaction between workpiece and CMM during geometrical quality control.

Pinet Sriyotha, Kazuo Yamazaki, Xingquan Zhang and Masahiko [23] present a system to reduce residual vibrations in single-axis types of motion of the CMM in the high speed. The

dynamics of the CMM were considered and determined by experiment.

Adam Woźniak and Marek Dobosz [7] study the influence of the deformation between the probe and the parts in the process of metrology. They apply a Hertz law (elastic) in the area of contact.

2.2. Previous work

In recent articles [21][22], we have presented a method to optimize the metrology process. Instead of manufacturing a set of different parts with defaults (with a Gauss distribution), we prefer to simulate the defaults by using virtual parts. The use of virtual parts provides some advantages instead of using manufactured parts. In fact:

- It is impossible to produce a real part exactly the way we would like it to be (you can't manage the values of the defaults).
- It takes time to make parts.
- It costs to make parts.

2.2.1. Virtual parts concept

We have used a simple part with a drilled hole on a face. We have studied the influence of the part quality on the result of a measurement.

Because the software included in the CMM (coordinate measuring machine) has a lot of options, the operator has to make a choice between these options. For example, the software has different mathematical calculations and different ways to calculate the datum coordinate system. Unfortunately, the different methods give different results.

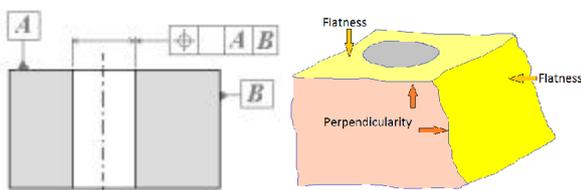


Figure 1 : Part for the study

On the studied part, we have considered three geometrical defaults being supposed to influence the quality of the measurement process and more precisely the position of a

calculated datum system. The flatness of the two surfaces and the perpendicularity between the faces are the parameters of the study (Figure 1). We use the DOE (design of experiment) [12][19] method to reduce the number of experiments to find the effect of each parameter. We have defined three levels for each geometrical default.

The methodology used to build the virtual parts (Figure 2) begin with a set of points into an excel file. This allows choosing the quality of the surface (flatness default). Then, we import the set of points into CATIA. We can rotate the set of points easily to obtain the virtual part with the perpendicularity default needed by the experiment. The last step is to export this model from CATIA to METROLOG XG software to realize all measurements.

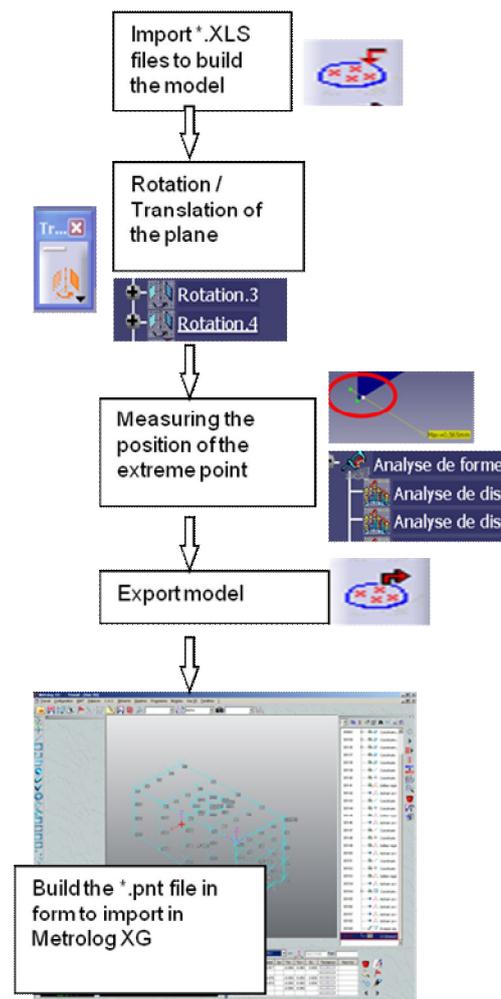


Figure 2 : Manual processing

2.2.2. The limit of this approach

This previous study [22] has permit to find the parameters which influence the result of the position of the hole. The limited number of parts is enough to determine if a parameter has an effect or not, but it is an insufficient number of values to obtain more information.

We don't know precisely the limit of the value for each parameter before it will influence the result of the metrology process.

To improve the results we need to change the way we consider the parameters. We will consider that the parameters are continuously variable. In this case, the DOE with the virtual parts method is not appropriate. The manual process to build all virtual parts will take too much time. Then, we choose to try another methodology for the simulation.

3. A new tool for simulation

3DCS is software associated to CAD system CATIA. Usually it is used to study mechanism functionality as gap and contacts. We have chosen to use it to simulate the metrologic process of a measurement.

3.1. Introduction to 3DCS

The Figure 3 shows an overview of the process of a 3DCS study in the case of a CATIA CAD model.

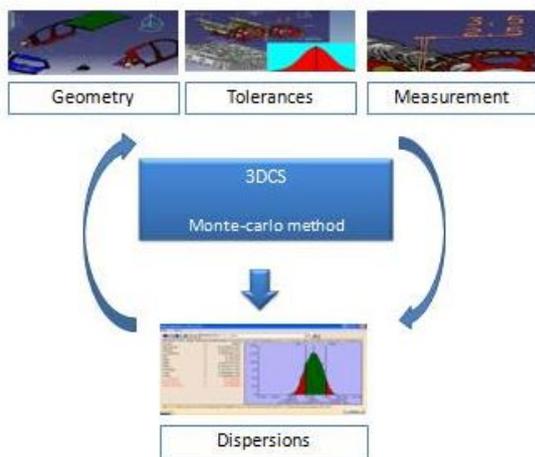


Figure 3 : 3DCS overview

It is possible to use geometry from CAD and to add information about the mechanism. The software is then able to study the

influence of each specification (tolerance, dimension, geometrical default ...) on the mechanical compartment. It is composed with different modules: FTA, Moves, Measurement, Statistical analysis ...

We will just present in next paragraphs the principles of the main modules: FTA (Functional Tolerancing and Annotation) and the statistical analysis method.

3.2. FTA module

This module is used to define the tolerances and geometrical defaults of each part. Annotations are added to the 3D model. Figure 4 is an example of 3D annotation with a datum plane as reference and a geometrical specification to qualify the spherical surface.

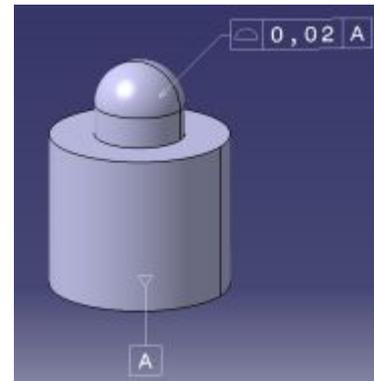


Figure 4 : FTA Annotation

3DCS software uses this information to define the area of displacement for the real surface. During the study, we have to create points (called 3DCS points) associated to a surface (feature points). These points have then the possibility to move into 3D space, according to the tolerances added to the surface in FTA module. In the case of the example (Figure 4) any point we will study on the top surface is able to move +/- 0,01 mm away from the CAD theoretical surface.

3.3. Statistical approach

3DCS use the method of Monte Carlo to generate parts with defects according to tolerances added in the FTA model. A tolerance distribution (Figure 5) is assigned to

each dimension or specification of the model. Then, the software generates a set of parts with different sizes (included into the distribution) and calculates a set of assembly.

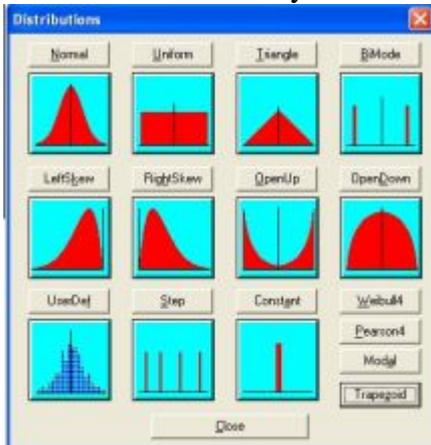


Figure 5 : Statistical distributions

The system provides for example 1000 values for a measure on the assembly. We can so obtain the mean, the standard deviation and the capability of the mechanism to be functional (dispersion is less than the defined tolerance).

3.4. Application

We have used this new methodology for a simulation of a measurement process into two different ways. The first case is the build of a biggest set of parts to improve the DOE method. The second case is the simulation of the manipulation of the measurement device.

4. Simulation of a calculation method

4.1. 3DCS method for Coordinate System

The ISO standard defines a unique method to calculate a coordinate system in the case of our application part (Figure 1). The “good” one is defined with a tangency and a perpendicularity constraint at the same time for the second plane (Ref B) [2]. The metrologic software associated to each CMM provides different options to calculate a coordinate datum system. Our first study [22] was limited by the number of virtual parts we could obtain in a reasonable time. By using

this new method, we only need to change the FTA annotation value to obtain a new part.

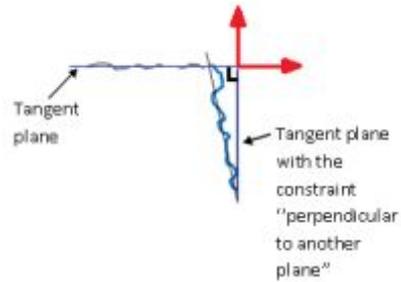


Figure 6 : Coordinate System

Instead of calculate (Figure 6) the position of the datum coordinate system, we define a geometrical constraint between a part that represent the perfect geometry of the datum system. The assembly (Figure 7) of the virtual gauge (perfect part) with the real part (part with flatness and perpendicularity defaults in FTA model) is a simulation of the metrologic methodology to associate a coordinate system AB to a real geometry.

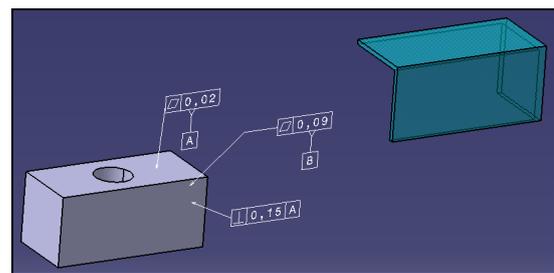
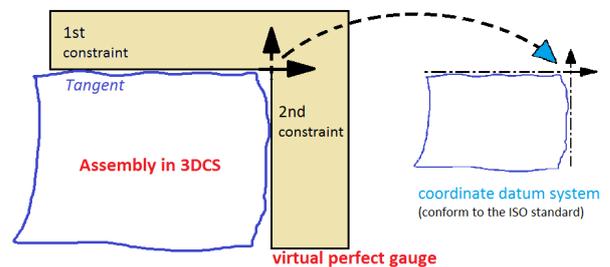


Figure 7 : 3DCS method for a coordinate system association

4.2. Results of the DOE

By using the 3DCS software, we obtain a set of parts with geometrical defaults. The parameter with the biggest influence (on the position of the coordinate system) change with the values of the geometrical defaults. At the beginning (Figure 8), the perpendicularity of

the top plane is more influent than the flatness. A larger flatness value becomes the most influent parameter on the result.

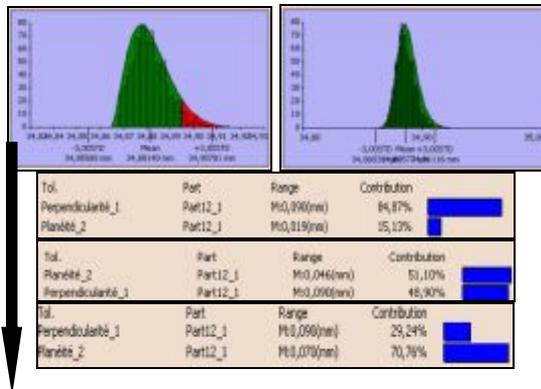


Figure 8 : Evolution of default influence

We have obtained a graphical surface (Figure 9) that represents the influence of two parameters on the global result for the position of the coordinate system.

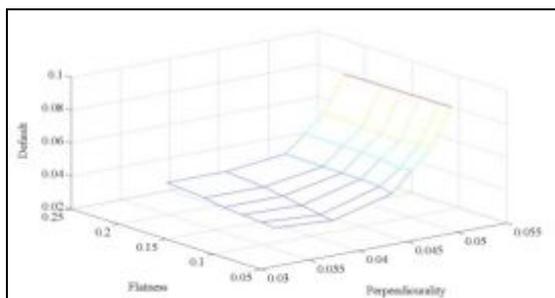


Figure 9 : Results of DOE

With a manual building of the virtual parts, the effect was observed, but with a continuous variation of the parameters values, it is possible to obtain a direct link between the 3 parameters and the default on the position of a datum coordinate system.

5. Simulation of a measurement device

As presented in the introduction paragraph, we have also use this new tool for simulation to evaluate the uncertainty of a measurement process linked to the quality of the manipulation of the device.

5.1. Flatness device measurement

The example is the measurement of the flatness of a plane. Usually, the simplest way

to obtain the result, and the less expensive because of the device, is to do a manual measurement with a simple datum reference plane and a dial gauge. The difficulty for the manipulation is to obtain the right orientation of the part before to perform the flatness measurement. Because we want to measure the form default, we need to erase the orientation default (Figure 10).

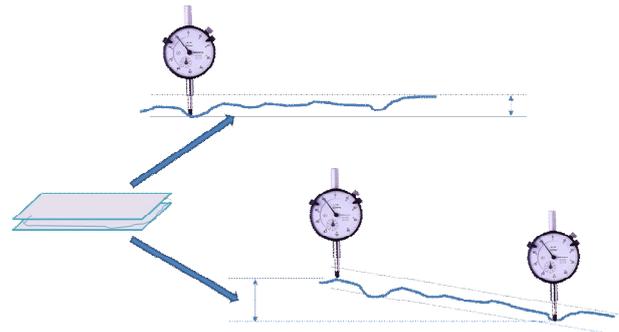


Figure 10 : practical flatness measurement

The tool for simulation is used in this case to evaluate the effect of a bad orientation due to the manipulation. We have practice several real manipulation to quantify the best result we could obtain.

5.2. Virtual measurement

The FTA annotation module is used to translate the default of the manipulation into a tolerance value (Figure 11).

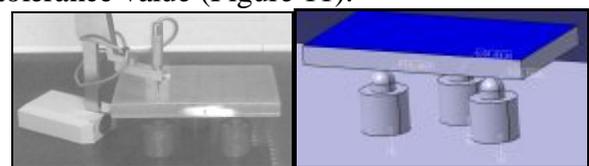


Figure 11 : Device and model

The parameter we have chosen for the position of the part during the manipulation for the measurement is a form default of the contact surface (Figure 4). It allows each contact point of the bottom plane of the simulation part to “move” with a small displacement linked to a tolerance value. With a set of more than 20 measurements, we could define the value of the manipulation best default to +/- 0,01 mm.

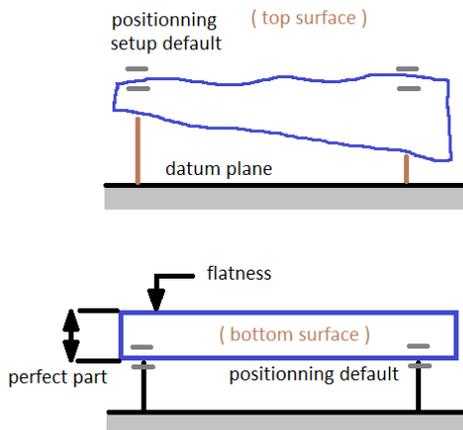


Figure 12 : Model for simulation

The default is applied to the contact point on the bottom surface by considering a perfect geometrical part and a default linked to the support. In the real manipulation, the default is at the top of the real part (the 3 points the operator has to setup as a horizontal plane) (Figure 12).

5.2.1. Flatness 0,1– Position 0

The first case of simulation was a flatness default of 0,1 (applied to the top surface of the part = studied surface) with a positioning default equal to 0. In this case, the simulation tool confirms dispersion equal to 0,102 mm. The difference is the statistical approach that means a 99,73% distribution [1]. So the maximum value of the Monte-Carlo method can be a bit more than 0,1 mm (but near to the 0,1 value).

5.2.1. Flatness 0,1 – Position 0,02

In this second case, the value for the simulation of the measurement is at the maximum 0,098 mm. The value is the same as for the first case. The error of the operator during the manipulation has a very few effect on the measurement.

5.2.3. Flatness 0,03– Position 0,02

This third case is the most important of our study. When the value of the flatness we need to simulate is near to the value of the positioning default, the global result is 0,039 mm. Without positioning default, we have only 0,0308 mm for the worst case.

5.3. Analysis of the results

The simulation of the measurement process shows us that the value of the positioning default can have an effect on the result of the flatness measurement.

6. Conclusion

In this article, we have tried to use a new method of simulation applied to the measurement process.

The defaults we have taken into account are on the first side, the quality of the part that we measure, and on the second side, the error due to the manipulation of a device.

For the first study, the aim was to prove that it was possible to improve the results of our previous work [22] with a most efficient methodology.

For the second study, the aim was to demonstrate the possibility to evaluate the influence of the device on the result. But, only by taking into account the error of manipulation.

Our future studies will be developed with the same tools, by adding the possibility to observe the part deformation due to clamping system. It will be in the case of flexible parts. The 3DCS module provides tool to be able to include FEM (finite elements method) calculation.

References

- [1] AFNOR X06-080. Application de la statistique, plans d'expériences, vocabulaire et indications générales. 1989.
- [2] Anselmetti B., « Langage des normes ISO de cotation », Collection Hermes Sciences, 2003.
- [3] Abdelhak Nafia, J.R.R. Mayera, Adam Wozniakb, Novel CMM-based implementation of the multi-step method for the separation of machine and probe errors, Precision Engineering, 35(1), 2011, 318–328.
- [4] Antonio Piratelli-Filho, Glauber Roberto Lesnau, Virtual spheres gauge for coordinate measuring arms performance test, Measurement, 43(2), 2010, 236-244.
- [5] A. Weckenmann , T. Estler , G. Peggs, D. McMurtry, Probing Systems in Dimensional Metrology, CIRP Annals - Manufacturing Technology, 53(2), 2004, 657-684.

- [6] Antonio Piratelli-Filho, Benedito Di Giacomo, CMM uncertainty analysis with factorial design, *Precision Engineering*, 27(3), 2003, 283-288.
- [7] Adam Woźniak, Marek Dobosz, Influence of measured objects parameters on CMM touch trigger probe accuracy of probing, *Precision Engineering*, 29 (3), 2005, 290-297.
- [8] B. Bourgeay, « Estimation des incertitudes de mesure sur MMT », *L'accréditation Cofrac des mesures tridimensionnelles*, INSA Lyon, 2008.
- [9] Chang-Xue Jack Feng, Anthony L. Saal, James G. Salsbury, Arnold R. Ness, Gary C.S. Lin, Design and analysis of experiments in CMM measurement uncertainty study, *Precision Engineering*, 31(2), 2007, 94 – 101.
- [10] Chang-Xue (Jack) Feng, Xianfeng Wang, Subset Selection in Predictive Modeling of the CMM Digitization Uncertainty, *Journal of Manufacturing Systems*, 21(6), 2002, 419-439.
- [11] Emanuele Modesto Barini, Guido Tosello, Leonardo De Chiffre, Uncertainty analysis of point-by-point sampling complex surfaces using touch probe CMMs DOE for complex surfaces verification with CMM, *Precision Engineering*, 34 (1), 2010,16-21.
- [12] George J. Besseris, Profiling effects in industrial data mining by non - parametric DOE methods: An application on screening checkweighing systems in packaging operations, *European Journal of Operational Research*, 220(1), 2012, 147-161.
- [13] Herve Abdi, "Least Squares", The University of Texas at Dallas, Richardson, TX 75083-0688, USA
- [14] Jean-Pierre Kruth, Paul Vanherck, Christophe Van den Bergh, Benny Schacht, Interaction between workpiece and CMM during geometrical quality control in non-standard thermal conditions, *Precision Engineering*, 26(1), 2002, 93-98.
- [15] J.B. Liao, M.H. Wu, R.W. Baines, A coordinate measuring machine vision system, *Computers in Industry* 38 (1), 1999, 239-248.
- [16] J. Sładek, A. Gąska, Evaluation of coordinate measurement uncertainty use of virtual machine model based on Monte Carlo method, *Measurement*, In Press, Corrected Proof, Available online 2 March 2012.
- [17] Marek Dobosz, Adam Woźniak, CMM touch trigger probes testing using a reference axis, *Precision Engineering*, 2005, 281-289.
- [18] M. Dobosz, A. Woźniak, Metrological feasibilities of CMM touch trigger probes Part II: Experimental verification of the 3D theoretical model of probe pretravel, *Measurement*, 34 (4), 2003, 287-299.
- [19] M. Pillet, *Les plans d'expériences par la méthode Taguchi*, Les Editions d'organisation, Paris 1997.
- [20] Marcus Petz, Rainer Tutsch, Ralf Christoph, Matthias Andraes, Benjamin Hopp, Tactile - optical probes for three-dimensional microparts, *Measurement*, In Press, Corrected Proof, 2011.
- [21] Valery WOLFF, Dinh-Tin TRAN, Comparison of a machine of measurement without contact and a CMM : Optimization of the process of metrology, *TEHNOMUS Journal*, 2011, 9-14.
- [22] Valery WOLFF, Dinh - Tin TRAN, Stéphane RAYNAUD, influence of the part quality on the method of calculation, proceeding of the conference CAFMET, 2011.
- [23] Pinet Sriyotha, Kazuo Yamazaki, Xingquan Zhang and Masahiko, An Experimental Study on the Vibration - Free, High - Speed Operation of a Three - Dimensional Coordinate Measuring Machine, *Journal of Manufacturing Systems*, 2004, 173-181.
- [24] Yin Zhongwei, Zhang Yuping, Jiang Shouwei, Methodology of NURBS surface fitting based on off – line software compensation for errors of a CMM, *Precision* 27 [1], 2003, 299-303.
- [25] Z. Meng, R.S. Che, Q.C. Huang, Z.J. Yu , The direct - error - compensation method of measuring the error of a six-freedom-degree parallel mechanism CMM, *Journal of Materials Processing Technology*, 129 (1-3), 2002, 574-578.