The "Gauge model": A New Approach for Coordinate Measurement

Eric Pairel

HAL Id: hal-00778264

https://hal.archives-ouvertes.fr/hal-00778264

Submitted on 19 Jan 2013

THE «GAUGE MODEL»: A NEW APPROACH FOR COORDINATE MEASUREMENT

Eric Pairel

Laboratoire de mécanique appliquée (LMecA/CESALP)

Université de Savoie, Annecy, France

Abstract: A new approach for the metrology on Coordinate Measuring Machine (CMM) is presented. It is based on the utilization of virtual gauges. The originality of the presented virtual gauge model is the notion of «fitter gauge» which develops the traditional possibilities of gauges. This model allows the verification of functional specifications of the geometrical tolerancing. An example of inspection of a pattern of hole illustrates the method. The gauge model is based on the *TTRS model* [1] and its numerical implementation on the *small displacement method* [2].

Keywords: CMM, virtual gauge, tolerancing

1 INTRODUCTION

The principle of CMM software (Coordinate Measuring Machines) is to fit individually to each sampled surface, a theoretical elementary model (plane, cylinder,...). This approach leads to numerous difficulties to verify the standardized geometrical specifications on the CMM.

We present a new approach for the processing of the sampled points, based on the utilization of a virtual gauge model.

The geometrical specifications define theoretical boundary surfaces for the actual elements of the part. Different works have proposed to generalize this notion [3] [4].

Some have suggested to use boundary surfaces as virtual gauge for the inspection of the part on CMM [5], but no realisation has been presented.

The efficiency of the presented model is due to the concept of «fitter gauge».

2 GENERAL PRINCIPLE

The model of virtual gauge construction, that we present, has permitted the realisation of prototype software.

As usually, the surfaces of the part are individually sampled on a CMM. The prototype software computes the best fit of theoretically surface with sampled points. However, each sampled surface is represented by its sampled points. The theoretical surface which is fitted to the points, allows the verification of the surface (dimension and the form deviation). And it is useful for the next steps.

Thanks to dialogue boxes of the software, the user may have to define virtual gauges made by several simple shapes: plane, cylinder, cone, sphere, which are called «elementary gauges».

Then software computes if it is possible to assembly the virtual gauge with the sampled surfaces of the part.

3 PRESENTATION OF THE «GAUGE MODEL»

3.1 The elementary gauge

The fundamental element of this model is the **elementary gauge**.

An elementary gauge is a theoretical elementary surface (plane, cylinder, cone,...) compelled to stay outside the material by relationship to the sampled points of the inspected surface.

An elementary gauge can have two different kinds of «behaviour»: **fitter** or **limitter**.

An **elementary fitter gauge** «wants» to fit to the sampled surface that it concerns. For example, about a cylindrical gauge in a hole, its diameter will increase at the maximum.

The numerical criterion which is used for the fitting of gauge, is the minimal sum of positive deviations: minimize $(\Sigma\, e_i)$ with $\{e_i \geq 0\}$.

This criterion has got a very interesting interpretation. If the sampled points are regularly distributed on the surface, then it corresponds to the minimisation of volume of the space that is included between the actual surface and the gauge surface [6]. For a cylinder which is placed in a hole, this criterion is equivalent to the maximising of its diameter.

3.2 The composed gauge: association of elementary gauges

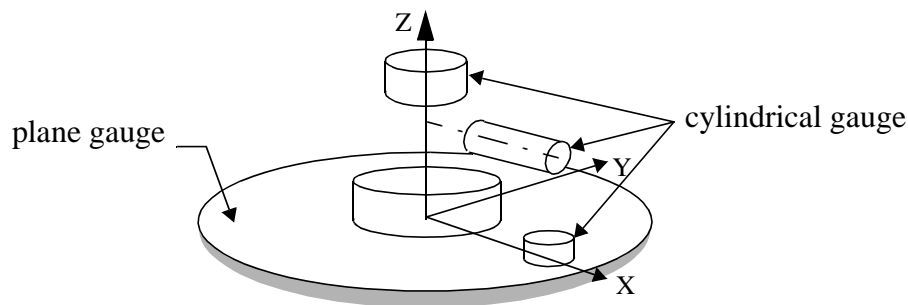By associating some elementary gauges, the user may build different **composed gauges**.

Figure 1. Example of composed gauge.

Each elementary gauge concerns one particular surface of the inspected part. It is characterized by the fitter or limitter behaviour.

The construction of a composed gauge consists in defining the situation of each elementary gauge in a unique frame which is the **composed gauge frame**. For that, the elementary gauges have got their own local frame.

3.3 Priorities between elementary gauges

The user can define a chronological order for the fitting of the elementary gauges. For example, he can specify that the plane must fit itself before the other gauges (figure 2). Thus he gives to it the **priority of level 1**. We will designate its behaviour **fitter 1**.

When the plane is fitted to the sampled surface, the composed gauge has got only three degrees of freedom of displacement with regard to the part: two translations and one rotation in the plane. The fitting of others gauge is then constrained by these degrees of freedom.
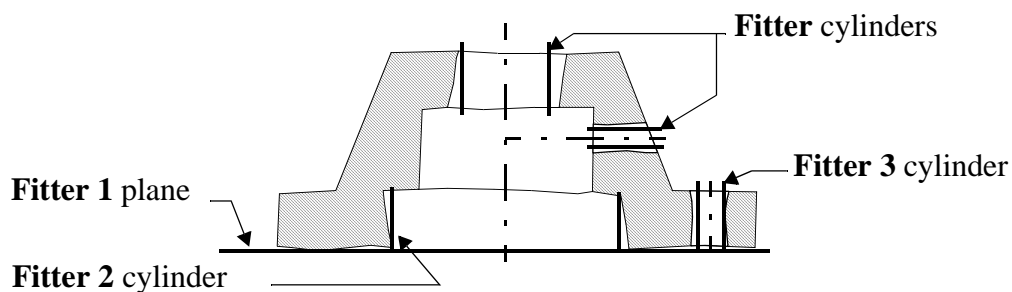

Figure 2. Level of priority between elementary gauge.

Giving the level 2 to the central cylindrical gauge (**fitter 2** cylinder), the composed gauge moves of manner to let the maximal «inflation» of this cylinder inside the sampled hole. Then the composed gauge has got only one degree of freedom: the rotation along the fitter 2 cylinder axis.

The rotation can be eliminated by giving the level 3 to the peripheral cylindrical gauge (fitter 3 cylinder).

Then it is useless to define an order between the two last cylindrical gauges because the composed gauge has not got any degree of freedom. Consequently, we will give to them the behaviour fitter without priority, just wrote **fitter**. They are simultaneously fitted after gauges of level 1, 2 and 3.

This result is general: it is useless to define a priority to a gauge of which the fitting does not eliminate any degree of freedom. For instance, the software forbids to give the level 3 to the cylinder which is coaxial to the fitter 2 cylinder because it does not eliminate any degree of freedom.

The *classification table for TTRS* [7] allows to demonstrate that the previous three levels of priority are sufficient [8].

The gauges of level 1, 2 and 3 generalize and formalise the concept of datum systems of the standardized geometrical tolerancing.

3.4 Degrees of freedom for the situation of an elementary gauge

The user can give to an elementary gauge, one or several degrees of freedom of displacement with respect to the composed gauge frame. For example, he may authorize the fitter 3 cylinder to translate itself along the X axis.

This possibility lets measure the distance between two parallel axis for example.

3.5 The limitter behaviour of elementary gauges

The second behaviour that we may give to an elementary gauge is the **limitter** behaviour.

An elementary limitter gauge behaves like a material gauge: either it comes into or it does not come into the surface that it concerns. Its dimension is fixed.

They permit the direct verification of assembly requirement.

4 EXAMPLE

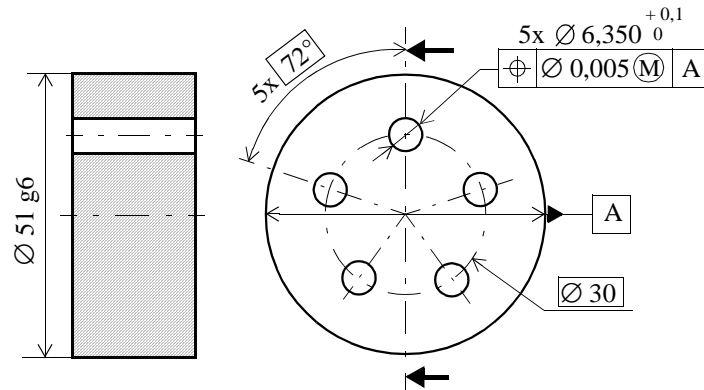A partial detail drawing of a machining made part is represented as follow.

Figure 3. Detail drawing of the inspected part.

We present the numerical results obtained from the inspection for one part.

The objective lies in the verification of the positional tolerance of the five holes.

Each actual surface is sampled with a CMM.

4.1 Identification of the sampled surface

The surface identification is made by fitting a cylinder on each sampled surface. We obtain the envelope diameter for each of them:

- External surface: $\varnothing$ 50.979 mm; Form deviation: 4 μm

- Internal holes: diameters between 6.355 and 6.358 mm. Form deviation between 3 and 10 μm.

4.2 Verification of the positional tolerance

The virtual gauge which corresponds to the positional tolerance is composed by a fitter 1 external cylinder (reference on the external surface) and five limitter internal cylinders $\varnothing$ 6,345 mm ($\varnothing$ 6,345 is the virtual diameter which is defined by the maximum material principle = 6,350 - 0,005):
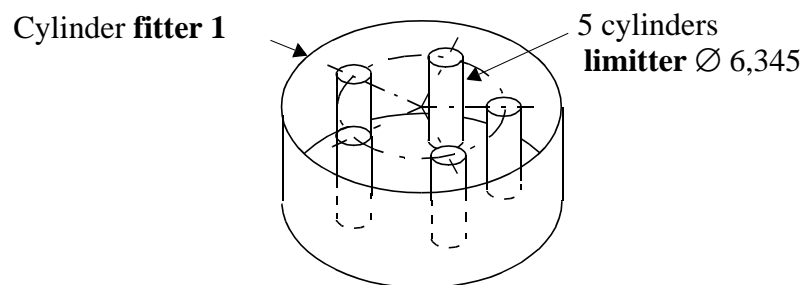

Figure 4. Composed gauge which correspond to the positional tolerance.

First, the fitter 1 cylinder is fitted. Then the composed gauge has got only two degrees of freedom for the assembling of the five limitter gauges. The software shows us that the matting of this gauge is impossible. As a consequence, the specification is not respected.

4.3 Maximum diameter incoming in the holes with regards to the reference

The previous composed gauge is modified and we attribute the fitter behaviour to the five internal cylinders.

First, the external cylinder is fitted. Then the five internal cylinders will be «inflate» inside the sampled holes. They keep the same diameter each other.

Thus we obtain a 6.319 mm diameter. It is 26 µm less than the $\varnothing$ 6.345 mm one.

4.4 Position of the holes each other

Now we define another gauge composed of the five fitter internal cylinders for the holes. The five cylinders will «inflate» in the holes.

Thus we obtain a 6,347 mm diameter. It is 2 µm more than the $\varnothing$ 6.345 mm one

Therefore, five limitter internal cylinders $\varnothing$ 6,345 should be assemble with the holes.

4.5 Conclusion

For the inspected part, holes are well positioned each other, but it is the pattern of holes which is wrongly positioned with regard to the reference surface.

5 NUMERICAL IMPLEMENTATION

We use the *small displacement method* [9] to calculate the assembled fitted position of the composed gauge. The first stage consists in defining an initial position of the composed gauge close to the assembled position.

5.1 Calculation of an initial position of the composed gauge

Each surface of the part is represented by a set of sampled points and by a theoretical surface that is fitted to the points.

Each elementary gauge of the composed gauge is linked with one surface of a part.

The objective is to defined an initial position of the composed gauge nearby the assembling position.

For that, two frames are built, one onto the composed gauge and the other onto the sampled surfaces.

The frame on the composed gauge is constructed from two or three elementary gauge owing to a classification procedure of their association. We use the *classification table of TTRS*.

The frame on the part is constructed in the same way, from sampled surfaces which are linked to the previous elementary gauges.

Those two frames permit to define the initial position of the composed gauge.

5.2 Calculation of the assembling of the composed gauge

The computing of the composed gauge displacements is based on the *small displacement method*.

If the composed gauge contains one, two or three fitter gauge having priority, the successive displacements allowing to fit them are first computed. The next displacement is computed for the fitting or for assembly of the fitter or limitter gauges.

Lets call e_i the algebraic deviation between a sampled P_i point and a elementary gauge surface. The assembly requirement of the composed gauge is expressed by a linear inequalities system: $\{e_i \geq 0\}$

The fitting of gauges is expressed by a linear *objective function*: minimize (Σe_i) [6]. The obtained optimization problems are called *linear program*. A simplex algorithm is used for their resolution.

It gives the composed gauge displacement as well as the variation of the fitter gauge dimensions.

6 CONCLUSION

The gauge model is a simple coherent model which allows the direct verification of complex functional specifications. It generalizes and formalizes different concepts of the standardized geometrical tolerancing (maximum material condition, datum systems).

The developed prototype software has permitted to validate the used numerical methods. The accuracy of numerical results is completely acceptable in comparison with the CMM accuracy.

Our research is now oriented to the utilisation of the gauge model for the specification of parts. We think that it is more simple for the designer to directly describe the functional gauge of the part rather than express it as a location tolerance with the maximum material principle which can be wrongly understood. The gauge model is mainly a geometrical model. So it should allow to integrate the tolerancing in CAD system.

REFERENCES

[1] B. Charles, A. Clement, A. Desrochers, P. Pelissou, A. Riviere, Controlling a mechanical part designed with a feature based system, *Computer Integrated Quality System in CIM*, IFIP Conference (Yugoslavia, June 89).

[2] P. Bourdet, Contribution à la mesure tridimensionnelle: Modèle d'identification géométrique des surfaces; Métrologie fonctionnelle des pièces mécaniques; Correction géométrique des machines à mesurer tridimensionnelles, *Thèse d'état de l'Université de Nancy I*, 1987.

[3] R. Jayaraman, V. Srinivasan, Geometric tolerancing: 1. Virtual boundary requirements, *IBM Journal of Research and Development*, Vol 33, N° 2, March 89.

[4] S.D. Nigam, J.D Guilford, J.U. Turner, Derivation of generalized datum frames for geometric tolerance analysis, ASME Design Automation Conference (Albuquerque, Sep.1993).

[5] B. Charles, A. Clement, A. Desrochers, P. Pelissou, A. Riviere, Toward a computer aided functional tolerancing model, *Proceedings of the International Conference on CAD/CAM and AMT* (Jerusalem, dec. 89)

[6] E. Pairel, Definition of a new tolerancing principle and of the method of its verification on Coordinate Measuring Machine, *7ème Congrès International de Métrologie* (Nîmes, France, Oct. 95).

[7] M. Briard, B. Charles, A. Clement, P. Pelissou, A. Riviere, The mating function in CAD/CAM systems, *Design Automation Conference*, ASME Meeting (Canada, Sept 89).

[8] E. Pairel, Métrologie fonctionnelle par calibre virtuel sur Machine à Mesurer Tridimensionnelle, *Thèse de Doctorat de l'Université de Savoie*, Dec. 1995.

[9] P. Bourdet, A. Clement, A study of optimal-criteria identification based on the small-displacement screw model; *Annals of the CIRP*, Vol. 37/1/1988.

Contact point: Eric Pairel, LMeca/CESALP, Université de Savoie, 41 avenue de la plaine, B.P. 806, 74016 ANNECY Cedex, FRANCE, Tel. +33 4 50 66 60 00, Fax. +33 4 50 66 60 20, E-mail: pairel@esia.univ-savoie.fr