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COMPARISON OF A MACHINE OF MEASUREMENT WITHOUT CONTACT AND A CMM⁽¹⁾ : OPTIMIZATION OF THE PROCESS OF METROLOGY.

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Abstract: In the field of the control of manufactured products, the process of measurement usually proceeds on a type of machine (for example CMM) and the totality of measurement is then carried out. We propose here to study the capacities of 2 types of measuring machines in order to guide the operator towards an optimized choice of the process of measurement. The taking into account of the capability of the machine associated with the feasibility (facility of use) of measurement will be also supplemented by the taking into account the time necessary to realize measurement. A better knowledge of the limits of each machine will allow an optimization of the process of control.

Keywords: metrology, control, CMM, no-contact measuring system, industrial vision

1 Introduction

The three-dimensional metrology is one of the main problem for many industries for achieving dimensional and geometric product control. The control of technical parts for the plastic industry, automotive or electronics is more and more using the optical measuring systems without contact. The other way is to use a CMM (coordinate measuring machine) for a more classical control.

We have chosen to work with these two types of machine to develop our study. We try to define a methodology to optimize the use of these different types of measuring machines.

2 Problematic

There are three main steps during the realization of manufactured products: the stages of design, manufacture and control.

The designer defines the functional dimensioning of the parts by using the GPS standards.

The traditional method, for the control of the parts in metrology, consists in defining a measurement plan in adequacy with the measuring instruments available (We have to separate, for example, the measurement of the roughness of a surface, and the 3D control of geometrical specifications).

We can note that an operator usually prefers to use only one machine when it is possible. For example, in the case of the use of a CMM, the entirety of measurement will be carried out on the machine (dimension, form, and position specifications).

The idea we want to develop here, relates to the possibility of a distributed control: using different measuring instruments for different specification.

Is it preferable, in term of cost, to carry out the totality of a control on the same machine? Or is it better to carry out measurements on various machines?

This question is the base of the process planning in manufacturing activity. But, it is a non studied point for the control of the parts.

(1) CMM : coordinate measuring machine

3 Study

The context of the study is the industrial vision systems [2] and we are using the optical methods for dimensions measuring. In our study, the system is equipped with an optical device (camera) giving to the operator an image of the measured part. The optical machine is a TESA V300 (Figure 1). It is a manual machine with triple lighting: diasopic, episcopic and LED. Each axis (X/Y/Z) has a resolution of 0.05 μm .

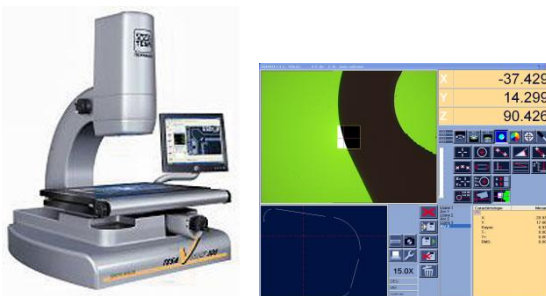


Figure 1 : Tesa Visio 300

3.1 Measurement method

For this study, we use a reference standard ring. So, we can compare the results of the measurement to the theoretical value. This is a standard datum ring with diameter accuracy less than 10^{-3} mm.

The TESA Visio provides 3 possibilities: manual selection of each point, automatic acquisition for each point, global acquisition of a profile (automatic sector detection).

The first step of the study was to measure diameter dispersion by using different ways to capture a geometrical element on a standard ring. The obtained results [8] show that the minimum diameter dispersion is given by the manual method (Figure 2).

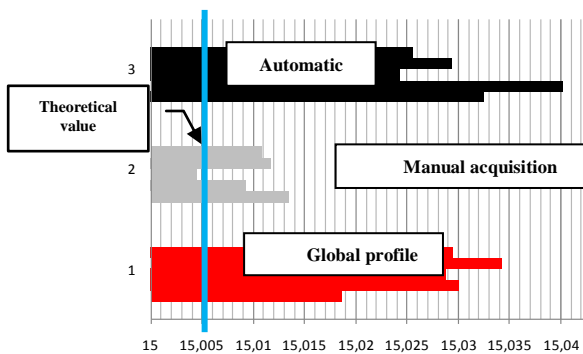


Figure 2 : accuracy of measurement methods

In this article, we have chosen the manual mode. It is the best way to get accurate results for our experiments.

By measuring the reference standard ring, we can obtain several values: the diameter, the XY position of the center and the circularity default (form). The figure 3 shows the definition of the circularity.

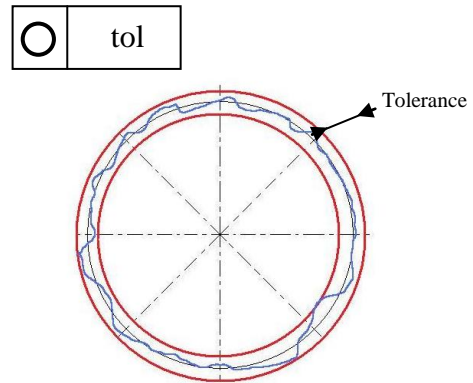


Figure 3 : circularity default

The real line (we can call it: “real circle”) must be included into an area: the Tolerance Zone. In the case of the circularity, the tolerance zone is defined by two circles with the same center, and with a radius difference lower than the value of the specification.

If we are using the Tesa Visio machine in a classical way, we can obtain each circle we measure with only three data: diameter, form and position.

But, for the form information, we have only a global result without any possibility to have a detailed measure. For example, we choose to acquire 20 points for a circle. We could expect to have 20 pairs of XY coordinates. In the Tesa Visio 300, the machine calculates a theoretical “best fit” circle associated to the 20 points and gives only the final result: the default of form (circularity).

Because we want to have a detailed study of the results of each measurement, we have chosen to measure all points independently. After that, we use an Excel Sheet to calculate the same information we could have obtained with the Tesa Visio. The method of calculation is presented into the next paragraph.

3.2 The calculation method

In the mechanical engineering field, the metrology often needs to calculate mathematical elements associated with real elements. In the GPS (geometrical product specification) concept, the term of skin model represents the real surfaces (figure 4).

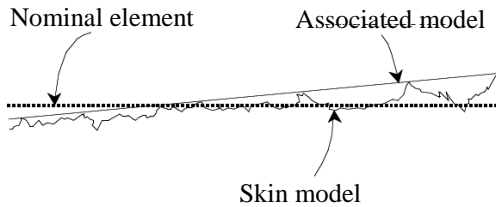


Figure 4 : skin model and mathematical association

The most common method used to associate a theoretical element to a skin model is the method of least squares [1]. This method allows estimating the numerical values of the form.

It exists with several variations: it's simpler version is called ordinary least squares (OLS), a more sophisticated version is called weighted least squares (WLS), which often performs better than OLS because it can modulate the importance of each point in the final solution. Recent variations of the least square method are alternating least squares (ALS) and partial least squares (PLS). [1]

The oldest (and still most frequent) use of OLS is linear regression, which corresponds to the problem of finding a line (or curve) that best fits a set of points. In the standard formulation, a set of N pairs of coordinates $\{x_i, y_i\}$ is used to find a pair of parameters α , and ω (figure 5)

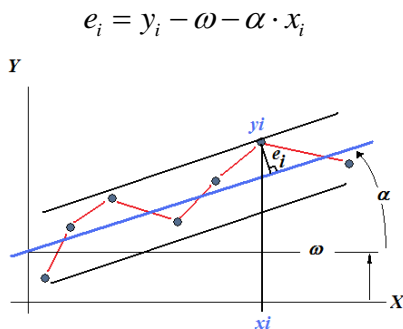


Figure 5 : least square method for a line

The least square method defines the parameters α and ω as the values which minimize the sum of the distances e_i^2 (hence the name least squares)

between the measurements and the model. What leads to minimize the function:

$$\varepsilon = \sum_i (e_i)^2 \quad (1)$$

This is achieved using standard techniques from calculus, namely the property that a quadratic (i.e., with a square) formula reaches its minimum value when its derivatives is equal to zero. This gives the following set of equations (called the normal equations):

$$\frac{\partial \varepsilon}{\partial \alpha} = 0 \text{ and } \frac{\partial \varepsilon}{\partial \omega} = 0 \quad (2)$$

Solving these 2 equations gives the least square estimates of α , and ω .

The OLS method can be extended to more than one independent variable (using matrix algebra) and to non-linear functions.

In this article, we are calculating the default of form of the datum ring. The result of the experiment (coordinates of points) to determine the circle requires to use the polar coordinates.

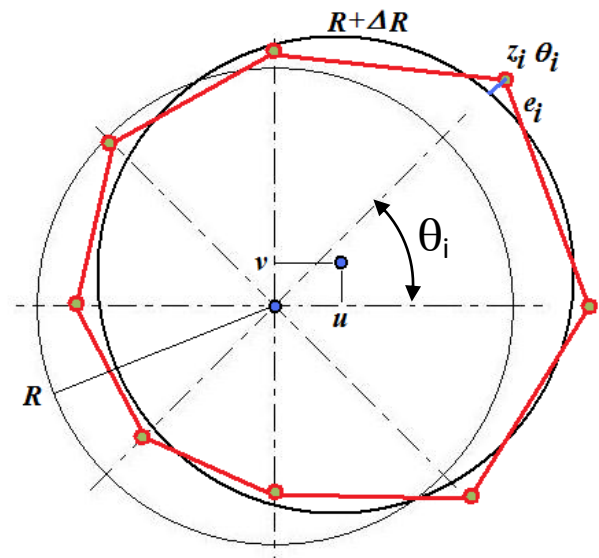


Figure 6 : least square method for a circle

The figure 6 shows the parameters we use to determine a theoretical circle associated to a real set of points.

- Z_i : distance is measured from the nominal circle
- e_i : error after calculation

- ΔR : radius variation of the experimental circle compare with the nominal circle
- u, v: distance between the two centers (small displacement)

Based on the figure 6, e_i is calculated as follows:

$$e_i = z_i - u \times \cos \theta_i - v \times \sin \theta_i - \Delta R \quad (3)$$

After calculation, we replace u, v and ΔR into the equation (3). The values ($e_{max} - e_{min}$), determine the default of form of the circle.

3.3 The design of experiment

In the aim to compare the two machines we have, the experimentation was carried out in a similar way on the Tesa Visio 300 and the trimasure CMM.

We used the manual mode for TESA Visio 300 with the setup parameters as follows: down light, zoom at 50%, and manual acquisition of the points. The CMM allows to measure circles and to export all points after the measurement operation.

We measured the datum ring several times. For each machine, we get the points from five measures. Each measure, is composed of twenty points with X_i, Y_i coordinates.

The figure 7, shows the position of the centre of a measured circle obtained by the calculation of the two parameters u and v. If we want to compare (with a graph) our results on the circularity default, we need to have all of the points x_i, y_i expressed into the same datum coordinate system.

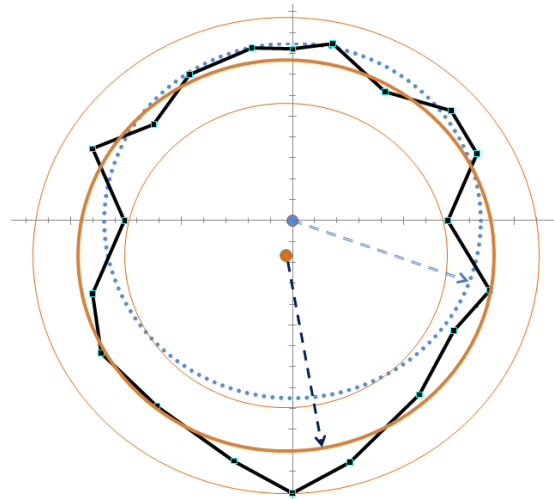


Figure 7 : nominal (dot) and optimized (red line) circles

On the CMM machine, it's easy to obtain all coordinates with a defined origin. The software allows defining an origin before to save all the coordinates (x_i, y_i). In this case, each circle is used as the origin of the system. The calculation of the least square method gives $u = v = 0$ (table 1). The only one parameter is ΔR .

For TESA V300 machine, we measured 8 points on the circle to determine the center of the circle. This center is then defined as the origin of the system. This is necessary before to obtain 20 points by second measurement operation. In this case we can have small displacement: u and v have small values (Table 1). This is one of the assumptions of the least square method.

After performing the experiments, we calculate with an excel sheet the parameters of each circle composed of 20 points.

3.4 The statistical approach

We made five measurements for each type of machine. For more accurate results during the analysis, we took the average value with two methods (Figure 8).

The first approach: Each set of 20 points measurement determine a circle by using the least squares method. Each measurement allows obtaining a circularity default. We will then calculate the average value of the circularity parameter.

X	Y	u	0,00
8,504	-0,038	v	0,00
8,128	2,512	dr	0,002
...	...	eimin	0,010
...	...	eimax	0,005
8,066	-2,678		
CMM			
X	Y	u	0,001
8,504	0,137	v	0,001
8,126	2,503	dr	0,002
...	...	eimin	0,010
...	...	eimax	0,005
8,068	-2,685		
Visio 300			

Table 1 : CMM and Visio300 datum system

The second approach: After performing the experiment, we calculate the average (x_i, y_i) coordinate for each point of each measurement. The least square method is used only after this step. We determine the parameters of a circle calculated with the average set of points.

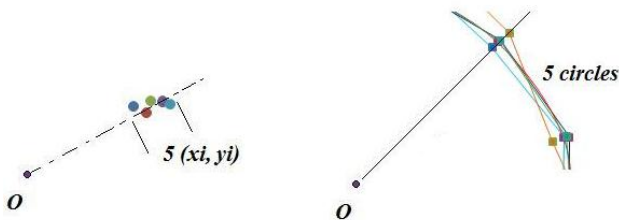


Figure 8 : statistical method

The aim of these two approaches was to determine the best methodology (in term of time of measurement and calculation).

4 Results and analysis

The quality of the measured circle (circularity default) has the same average value for the two machines we used (0,007 mm on the CMM and 0,010 mm on the Visio300).

The repeatability of the measure between each set of 5 measurements allows us to say that the result can be studied (figure 9).

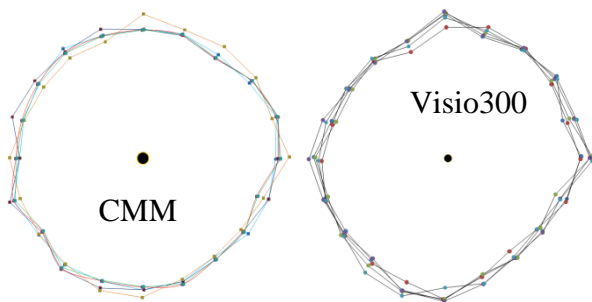


Figure 9 : graphical results

The most important result we have noticed relates to the graphics on figure 10 (case of the Visio300).

The graphical observation shows that the area where we can obtain the outer and the inner point of each measure is at a different place. For the CMM machine, the results are good at the positions: 0, 90, 180, 270° and for the TESA Visio300 machine, the best results are at points 45, 135, 225, and 315°.

This can be explained by the way we acquire the points.

On the CMM machine, the move of the sensor is controlled by a numerical system with two X and Y axis. The direction of the move gives more reliability if we use only one movement at the same time: X only or Y only. The combination of the two axis for a simultaneous move involve a different dispersion due to the detection of the measured surface by the sensor.

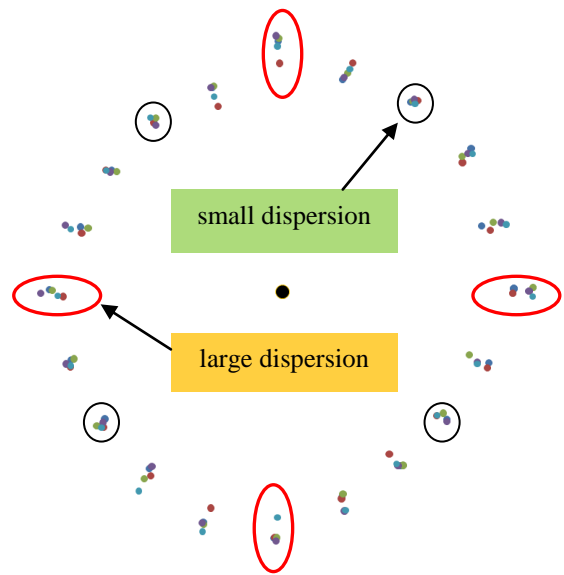


Figure 10 : best result area for the Visio300

In the case of the Visio300 machine, it is more difficult for the operator to be precise when he try to measure a point with the tangent position than with a clear intersection of the cursor and the circle (Figure 11).

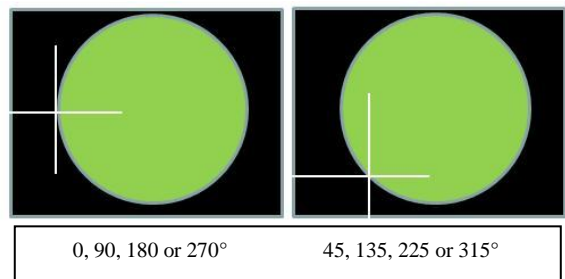


Figure 11 : visio300 acquisition

5 Conclusion

This article is a first step for a more global study. It shows that the choice of the machine we want to use is maybe linked to the capability of the

measurement machine (average value of the circularity in our case), but also linked to the time we want to spend for the measurement operation.

The choice of the points (number and position), and the way to acquire each point is a subject that will be experimented in a next study.

We will also extend the study by taking into account the velocity of the machine (in particular for the CMM machine).

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