Qualification and validation the metrology module located on CN machine tool -EMCO PC Mill 155 –

S. Merghache[1], A.Ghernaout[2]

[1]Department of Mechanics, Faculty of the Engineer's Sciences, University of Tlemcen, University Center of Tissemsilt, BP 119 Tlemcen, 13000 Algeria.
[2]Department of Mechanics, University of Tlemcen, BP 119 Tlemcen, 13000 Algeria.

Abstract. The contribution of machine tools in the blooming of several industrial domains is not to be demonstrated any more. However, during the last decade, the economic context imposed on this industry new standard of performance as regards the quality, the productivity, the costs and the delay of the production. The evolution of digitally operated modern machines drives integration of measurement and control in the cycle of manufacturing. The probe system brings an innovative solution to the improvement of CN machine tools efficiency and significantly expand its range of applications to improve the manufacturing process. The purpose of this article is to present our approach on the integration and the qualification of a metrology module associated with a software acquisition and analysis in relation to the digital control, a solution which we fulfilled and validated within our laboratory.

1. Introduction

The economic profitability of the automation of means of production requires a rigorous and automatic control of the manufactured products. Indeed, the quality of these products requires so far, means of automatic surveillance of tools and measuring the sides in the course of production. The evolution of the digitally operated modern machines drives to an integration of the measurement and the control directly in the cycle of manufacturing Figure 1. Probing on machine tools has greatly expanded its range of applications to improve manufacturing process by allowing [1, 3, 4, 6, 12]:

- To avoid pursuing an expensive manufacturing (complex parts, not corresponding),
- To measure before finishing and optimizing the last pass.
- To optimize the adjustment parameters of a part holder.
- To optimize the balance of manufactured surfaces in an acceptable gross.
- To optimize the corrections of tools and taking of the origins of a digital control.
- To correct the geometrical defects of the trajectories of a machine.
- To minimize the defect of the shape of a surface.
- To verify or measure a geometrical or the functional specification of a mechanical part.

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This list is not restrictive but it shows that such an organization is likely to make considerable gains in quality control, operating machinery, production and transit time of the parts in the workshop. The general problem so far is the geometrical identification of the real surfaces of a made part and the real trajectories of a machine. This identification has for objective to guarantee that the manufactured surfaces really coincide with the robust model defined by specifications. We present in our article the configuration which is materialized in our laboratory, the integration of a probe associated with a chain acquisitions data, software acquisition and analysis in relation to the control [2, 6].

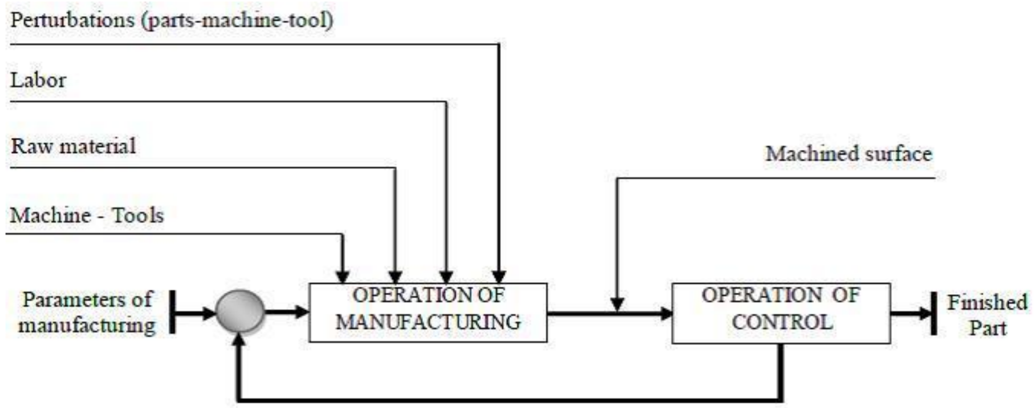

Figure 1. Buckle of integration of the measure and the control in the manufacturing. [12].

2. Integration of probe system on CN machine tool «EMCO PC Mill 155»

2.1. The Description of EMCO PC Mill 155 machine

2.1.1. Generalities

For more than fifty years, EMCO develops and builds machines to manufacture metals, and since 1980, the company is also represented on the market with CN machine tools, in particular in the sector of training. The machine «EMCO PC Mill 155" is intended for the reaming and the drilling of machined metals and machined plastics [13].

Figure 2. CN Machine tool EMCO PC Mill 155. [13]

Our digitally operated machine tool represents 3, already possesses an articulated mechanical structure and a sensor of position on each of its axes. Thus she can become a machine to measure in or a CMM if she allows assuring all the following functions:

- To arrange a sensor.
- To allow the acquisition of coordinates of measurement.
- Allow the storage of the data.
- Assure the treatment of the result.

The set of these functions is not in priori assured but the current DCN authorizes them. The basic function which allows this use is "the stop on interruption". The machine which possesses this function and which can be endowed with a sensor of metrology can become a machine to measure. In the absence of resident sub programs assuring the storage of the information and their processing, it is always possible to the user to create files and necessary subroutines [5, 7].

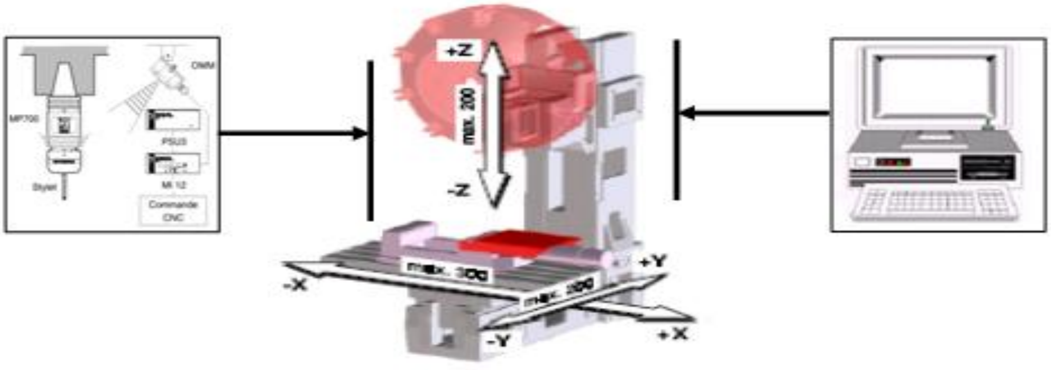

Figure 3. Transformation the CN machine tool of to the CMM.

2.2. Adopted Solution

2.2.1. The choice of the probe system

The choice of the system of probe depends naturally on its capacity to reach the point of measurement but also the shape and the requirements of the manufactures part as well as the nature of the machine which is used [8]. The probe system from Renishaw brings an innovative solution to the improvement of the efficiency on the machine tools:

- Saving of time.
- Reduction of rubbishes.
- Preservation of the competitiveness.

Thus we chose the system of probe MP700 of Renishaw Table.1, because it is an equipment of high precision designed specially to work in the environments the most hostile machine tools. This system was developed to supply:

- Repeatability improved in all the directions of probe.
- A low strength of release combined with a low variation of pre -race to supply a high precision, even during the use with long stilets.
- A decoupled life expectancy (10 million releases).
- A more precise and faster measure.
- An elimination of the defects of reset.
- A big immunity in the vibrations of machine tools.
- An impact resistance and in false release thanks to the use of a digital filtration, to the multiple ways. [8]

Table 1. Control probes for CN machine tool.

Machine	Compact	Small	Medium	Large
CN machine tool				
vertical	OMP40	OMP40	OMP60/RMP60	RMP60
horizontal	OMP40	OMP60	OMP60/RMP60	RMP60
high precision	OMP40	OMP400	OMP400/MP700	**MP700**
manual machines	Probe "job contact" (JCP)			

This system contains a probe MP700, the optical module machine, interface unit of probe MI12 and a power supply unit PSU3 [9].

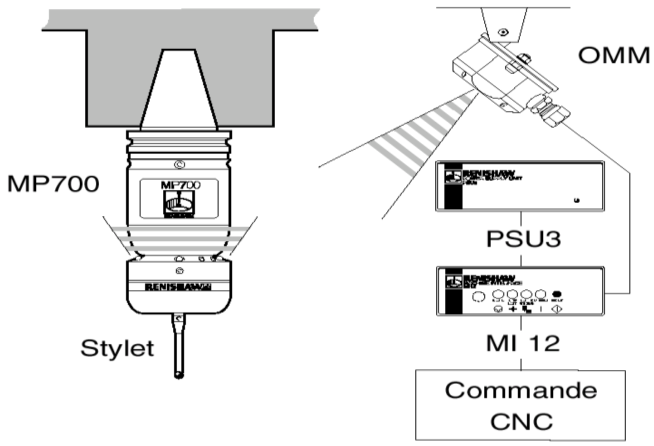

Figure 4. Probe system MP700 "variant OMM / MI 12".

2.2.2. Installation of the probe system MP700 on CN machine tool

For the good functioning of our system, the optical module machine (OMM), must have risen on the digitally operated machine tool so that the optical envelopes between the OMM and the sensing optical MP700 (OMP) module are positioned such as on the Figure 5. [9]

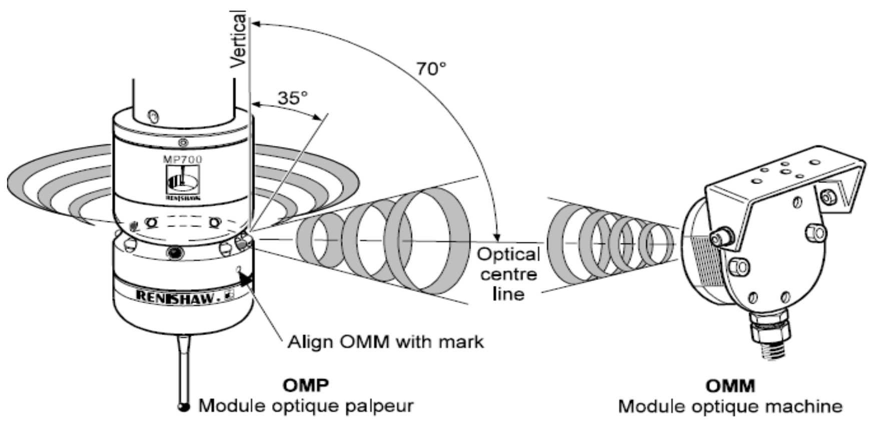

Figure 5. Requirements of working of the OMM.

3. Development of software for verification of the geometric specifications of the shape

For the purpose of controlled mechanical parts. We added a chain of acquisitions (MP700 probe system from Renishaw) and control software to our NC machine tool that exists in our atelier. Among all the functions of this software, we will limit ourselves in this article to those related to treatment of the measure, that is those who allow to determine the coordinates of points of contact between the probe and the surface to measure, and which allow, by a mathematical treatment of coordinates, To perform dimensional measurements and verify the characteristics of geometric tolerances of the parts. We expose an example of the righteousness, an example for the flatness and an example for the circularity.

3.1. General algorithm

A good definition of modules of the program and their interaction is one of the most important phases of the conception. The figure 6 illus trates, in generally the functional architecture of developed software. This figure represents all phases of our conception and our implementation [12].

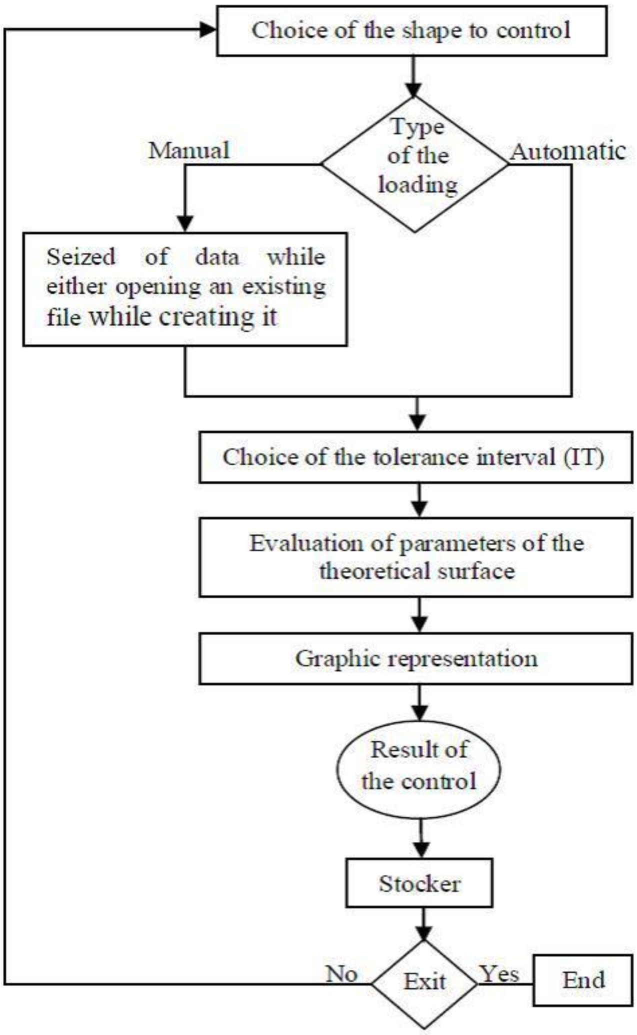

Figure 6. General Algorithm of surface control.

3.2. Calculation of the parameters

The done measures are some submissive sizes to the difficult disruptions to synthesize and information that they contain is with difficulty usable. We try to show to get the different parameters of the theoretical shapes how here. All calculations are based on the principle of optimization by the method of least squares.

3.2.1. Straightness

In this case, the application of the method of least square allows obtaining from a cloud of point, the coefficients A and B of the characteristic equation of a straight line [10]. This last is gotten so that the distance that separates it of every experimental point is minimal. To see Figure 7.

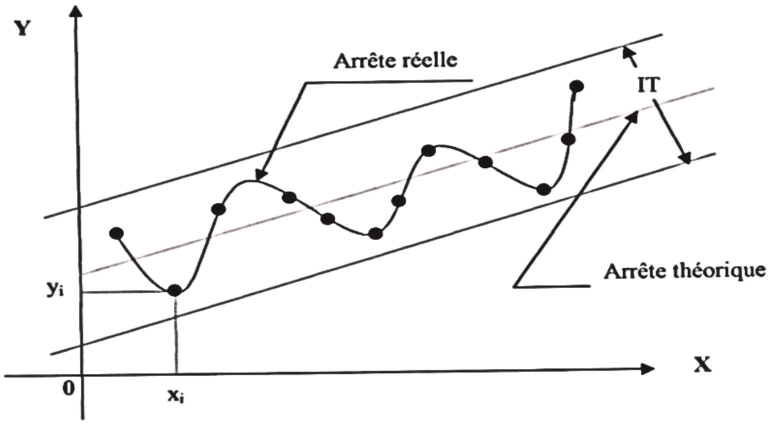

Figure 7. Reference theoretical for the Straightness.

x, *y* are the coordinates of the experimental statements that form the cloud of points and n represents their number

$$y = Ax + B \tag{1}$$

With

$$A = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left[\sum_{i=1}^{n} x_i\right]^2} \tag{2}$$

And

$$B = \frac{\sum_{i=1}^{n} y_i \sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{n\sum_{i=1}^{n} x_i^2 - \left[\sum_{i=1}^{n} x_i\right]^2} \tag{3}$$

3.2.2. Flatness

For flatness we move from one dimensional to two-dimensional plane at the right in Figure 8.For this we must calculate the coefficients of the optimal characteristics, knowing that his equation in space is written as follows [11].

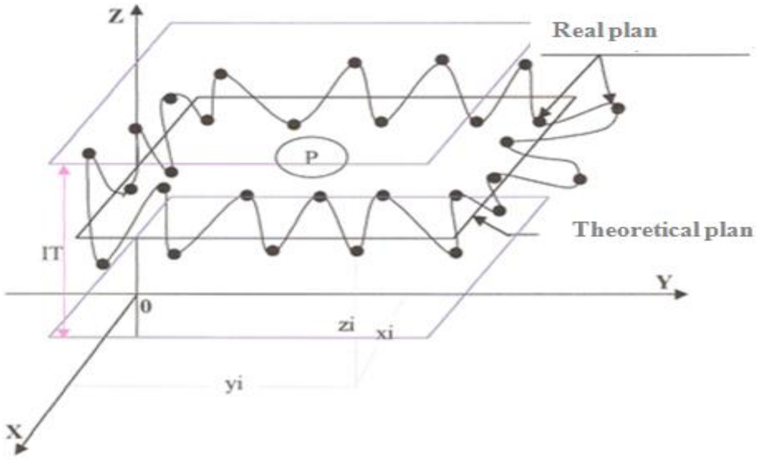

Figure 8. Reference theoretical for the flatness.

$$Z = Ax + By + C \tag{4}$$

It is therefore about determining coefficients A, B, and C according to relations:

$$A = \frac{[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i] - B[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i]}{\left[n\sum_{i=1}^{n} y_i^2 - \left[\sum_{i=1}^{n} y_i\right]^2\right] - \left[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right]^2} \tag{5}$$

$$\mathrm{B} = \frac{b_1 - b_2}{\left[n\sum_{i=1}^{n} y_i^2 - \left[\sum_{i=1}^{n} y_i\right]^2\right] - \left[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right]^2} \tag{6}$$

$$C = \frac{\sum_{i=1}^{n} z_i}{n} - A\frac{\sum_{i=1}^{n} x_i}{n} - B\frac{\sum_{i=1}^{n} y_i}{n} \tag{7}$$

with

$$b_1 = \left[n\sum_{i=1}^{n} x_i^2 - \left[\sum_{i=1}^{n} x_i\right]^2\right]\left[n\sum_{i=1}^{n} y_i z_i - \sum_{i=1}^{n} y_i \sum_{i=1}^{n} z_i\right]$$

and

$$b_2 = \left[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right]\left[n\sum_{i=1}^{n} x_i z_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} z_i\right]$$

3.2.3. Circularity

As regards the circular shape she defined in a Cartesian mark by an equation of the shape [3,4]:

$$(x-a)^2 + (y-b)^2 = r^2 \tag{8}$$

Where, r represents the radius of the circle. We calculate the optimal radius of circle r_{opt}, of the way that difference par rapport to every radius raised by the measure laughed r_i is minimal, Figure 9.

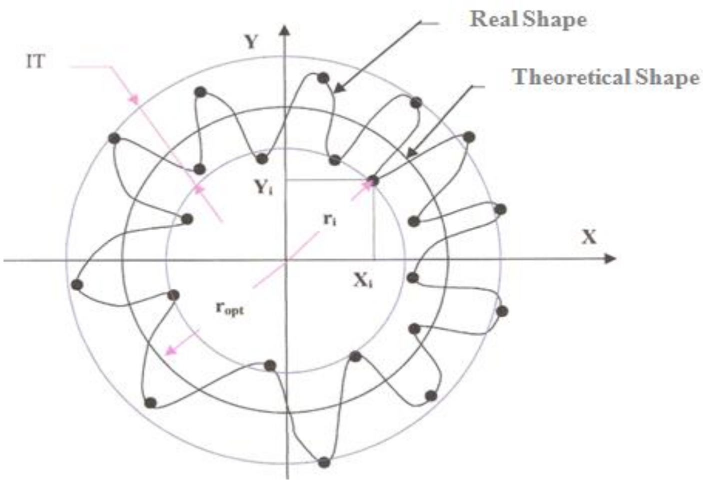

Figure 9. Reference theoretical for the circularity.

We know that a and b are the coordinates of the center of the circle, and n the number of points

$$b = \frac{b_1 - b_2}{2\left[n\sum_{i=1}^{n} y_i^2 - \left[\sum_{i=1}^{n} y_i\right]^2\right] - 2\left[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right]^2} \tag{9}$$

$$a = \frac{\left[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n}(x_i^2 + y_i^2)\right] - 2b\left[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right]}{2\left[n\sum_{i=1}^{n} y_i^2 - \left[\sum_{i=1}^{n} y_i\right]^2\right] - 2\left[n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right]^2} \tag{10}$$

with

$$b_1 = \left[\sum_{i=1}^{n} x_i^2 - \left[\sum_{i=1}^{n} x_i\right]^2\right]\left[n\sum_{i=1}^{n} y_i(x_i^2 + y_i^2) - \sum_{i=1}^{n} y_i \sum_{i=1}^{n}(x_i^2 + y_i^2)\right]$$

$$b_2 = \left[\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right]\left[n\sum_{i=1}^{n} x_i(x_i^2 + y_i^2) - \sum_{i=1}^{n} x_i \sum_{i=1}^{n}(x_i^2 + y_i^2)\right]$$

And the optimal radius of circle r_{opt}:

$$r_i = \sqrt{(x_i - a)^2 + (y_i - b)^2} \tag{11}$$

And

$$r_{opt} = \frac{\sum_{i=1}^{n} r_i}{n} \tag{12}$$

4. Experimentation

The tests are divided in to three phases:
The first tests to the level of manufacture laboratory by the system of probe MP700 from Renishaw that is installed on CN machine tool. For it as must do the following stages:

1. Choose the shape to control.
2. Grid the surface according to measurements of parts.
3. Put the piece on the marble of the machine.
4. Probing the part.
5. Raise coordinates of points probed entered into tables.
6. Validate the treatment of control.

The second test is done on our software with the same coordinates of points probed by the CN machine tool.
The third test is of compared results of measure of CN machine tool with results of measure of CMM.

5. Results and discussions

5.1. Results of measure

Numerous data essay have been reassembled in this article. Figure 10, Figure 11, And Figure 12 represents coordinates of points probing by our probe MP700, for the verification of the Straightness, the Flatness and circularity on our CN machine-tool.

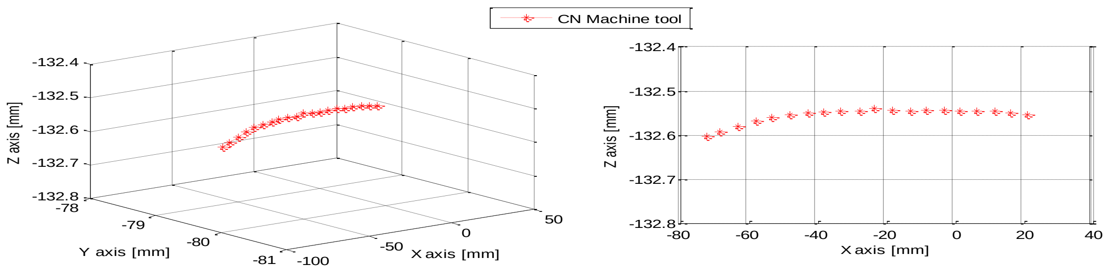

Figure 10. Cloud points « case of the Straightness ».

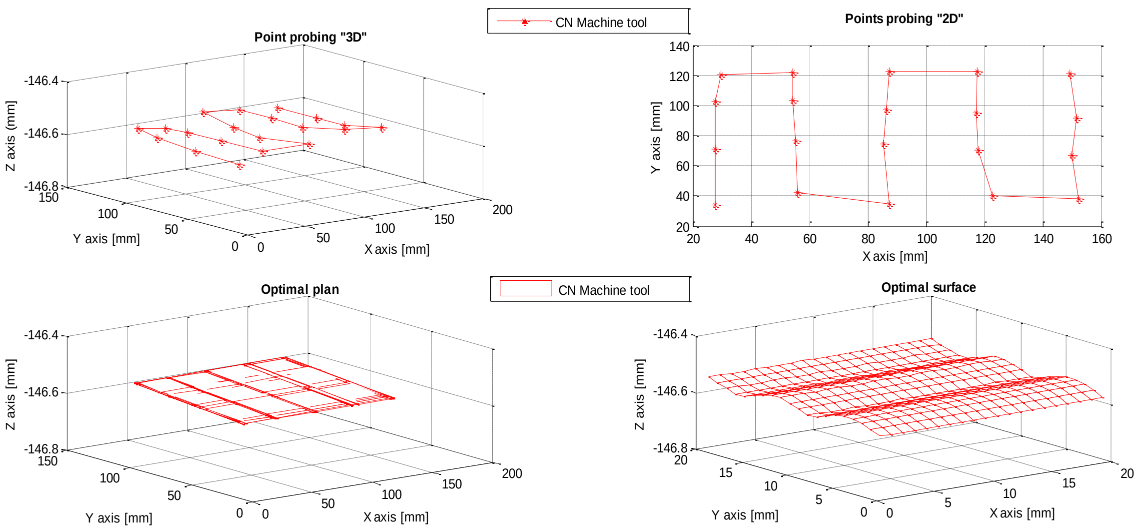

Figure 11. Cloud points « case of the flatness ».

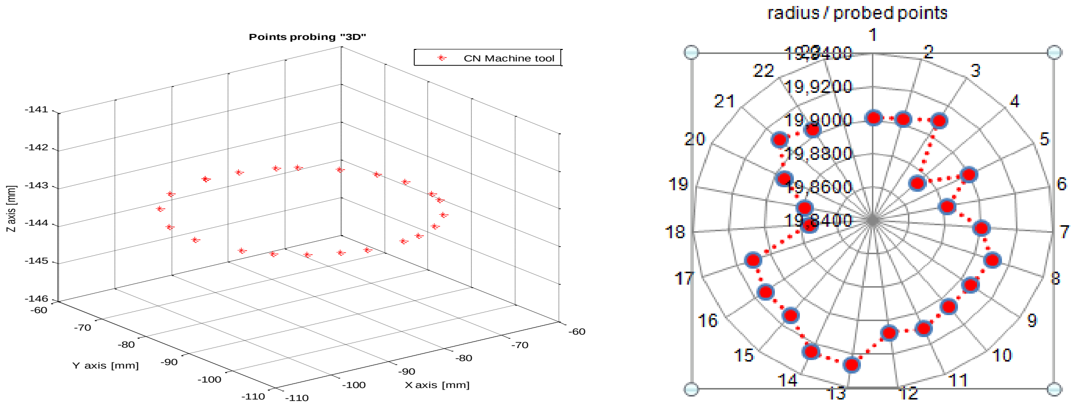

Figure 12. Cloud points « case of the Circularity ».

5.2. Comparison of the measure between CN machine tool and CMM

Figure 13, Figure 14 and Figure 15 represent the comparison of measure of the Straightness, the flatness and the circularity between CN machine tool and CMM that is the precision of the two machines, in 2D and 3D.

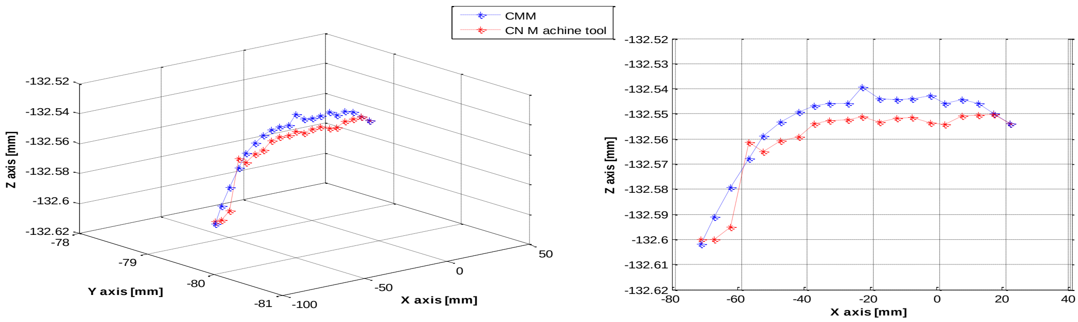

Figure 13. Comparison of the measure of the straightness between CMM and CN Machine tool.

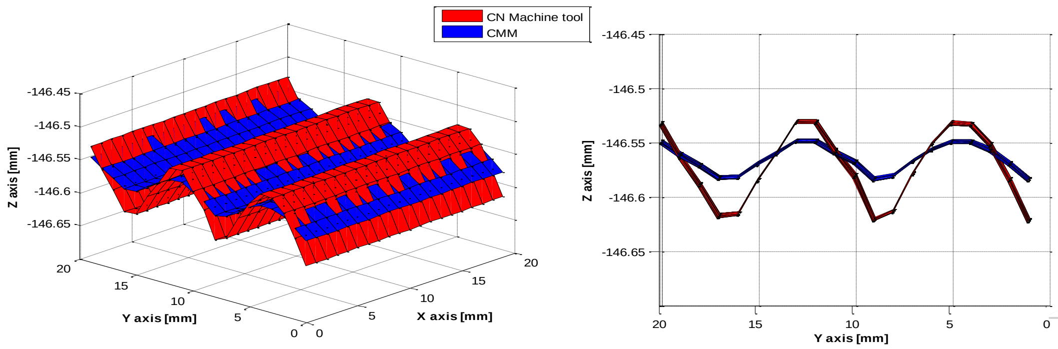

Figure 14. Comparison of the measure of the flatness between CMM and CN Machine tool.

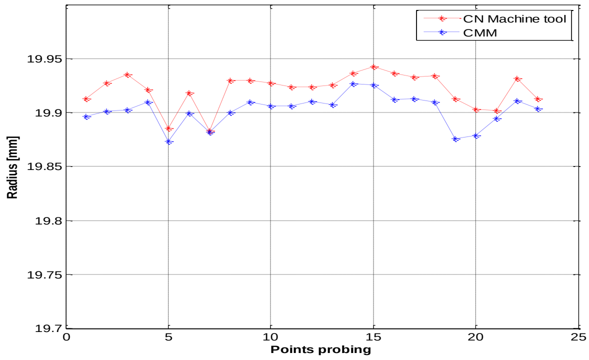

Figure 15. Cloud points « case of the flatness ».

5.3. Discussed results

One observes that the acceptance of the measure of the part is directly dregs with the interval of tolerance, that is to say when one changes the value of the tolerance interval, the nature of measure of the piece changes. One also notes that the different geometric specification measure gives the following shape shortcomings:

Table 2. form errors of the geometric specifications

	CMM			CN Machine Tool		
	Form errors min [mm]	Form errors max [mm]	Interval [mm]	Form errors min [mm]	Form errors max [mm]	Interval [mm]
Straightne	0.0004	0.0390	0.0386	0.0007	0.0471	0.0464
Flatness	0.0007	0.0486	0.0479	0.0005	0.0826	0.0821
Circularity	0.0004	0.0291	0.0287	0.0003	0.0381	0.0378

If one compares results of measure of the flatness between CN Machine tool and CMM, one gets a reduction of 41.66% of form errors respectively. On the other hand one can affirm that the form errors in the case of the measure of the circularity, is decreased of 24.07% between CN Machine tool and CMM. So in the case of the measure of the straightness by CN Machine tool and CMM gives a reduction form errors of 16.81%.
One also notices that the precision of the measure of a mechanical parts decreases for the two machines when the number of axes of the diplacement of the probe augment, is that owed to the quasi -static errors of axes Table 3. Therefore the measure of a geometric specification by CMM is more precise than the measure by the CN machine-tool.

Table 3. the variation of the errors forms with regard to axes of displacement.

Geometric specification	The variation of from errors between CMM and CN Machine tool [%]	Number of axis of the probe displacement
Straightness	16.81	1 axe [X]
Flatness	41.66	3 axes [X, Y, Z]
Circularity	24.07	2 axes [X, Y]

6. Conclusion

One conclusion the presence of a probe MP700 from renishaw on our CN machine tool “EMCO PC Mill 155” permits to do real operations of metrology, analogous to the one of machines to measure (CMM). However one can also achieve operations of measure that are very useful to improve the fruitfulness. So this system costs 20 less dear times that a CMM.
One also observes in all cases of measures to study a meaningful grain of the defect of shape between the measure by the two CN machine tool machine and CMM that to be-to-say the measure by CMM is more precise than the measure by CN machine tool is that owed to the almost-static mistakes. These mistakes of behavior are owed to the structure of the profile geometric-kinematics of the machine, combined to the mechanical, thermal solicitations and inertielleses developed during the operation of machining. If they are known, they can be made up for by the mediator of a command module interns external either that one can integrate to the CN machine tool.

4. References

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