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GD&T techniques application in coordinate measuring machines

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Abstract: The associated use of GD&T with coordinate measuring machines allows efficient and automatic analyzes of geometric tolerances, bringing not only economical but also technical benefits due to the standardization of inspection processes. This article aims to apply GD&T techniques in a CNC coordinate measuring machine through the geometric characterization of two aluminum parts produced in a machining center. The geometric tolerance analysis tools available in the machine software, which is called MCOMOS, were used to evaluate the position and circularity tolerance of parts elements.

Keywords: GD&T, tolerance, coordinate measuring machines

1. INTRODUCTION

With the development of computer-aided design tools and the high technology of production processes, there is a common effort towards reducing product disapproval in the inspection process. The need for well-crafted, clear and unambiguous designs, as well as the growing demand for products with not only dimensional but also geometric accuracy, and the questioning about the reprobation of functional parts, has brought to the Brazilian metrology scene a greater interest in the study of GD&T techniques, Acronym of Geometric Dimensioning and Tolerancing. [1]

GD&T was created in the mid-1940s, allegedly by Stanley Parker, Royal British Torpedo Factory engineer, and throughout the years this tool has been used worldwide. An important feature of GD&T, and the reason for its creation, is the format of the position tolerance zone, which in contrast to the square format of the Cartesian System is circular, allowing a 57% increase in the tolerance zone area. Stanley Parker came to this conclusion after realizing that products rejected by the Cartesian system were indeed functional. [2]

The GD&T techniques application in coordinate measuring machines (CMM) allows the analysis of geometric tolerances in an efficient and automatic way, provided that correct measurement strategies are defined. The current CMMs have truly mechatronic systems with capacity to automate complex operations, such as tolerance analysis. [3]

Coordinate measuring machines have become the primary resource of dimensional quality control for complex geometry parts in industry. The price lowering of computational resources and the development of more integrated manufacturing systems contribute for the expansion of these machines use for quality assurance of manufactured parts, and today the coordinate measuring machines represent a significant fraction of the measuring equipment used to define parts geometry. [4]

2. GD&T

Geometric tolerancing is a language that unequivocally communicates the specifications of engineering projects for quality assurance. As its name implies, it conveys the ideal geometry and tolerances of a part. Since GD&T is expressed using arabic drawings, symbols and figures, people everywhere can read, write, and understand it, regardless of their mother tongues. [5]

In contrast to traditional dimensioning and tolerancing methods, GD&T does not only question the quality of finished parts, but also the quality of the engineering drawings that were used to produce the part in question. Besides this difference, the GD&T differs from other methods, such as the Cartesian method, by the format of the position tolerance zone. [3]

Differences in the symbology of the GD&T and traditional systems are also important, GD&T has a more complex language than the traditional systems, encompassing not only dimensional tolerance, with variations in dimension sizes, but also tolerance of geometric characteristics. [3]

3. EXPERIMENTAL PROCEDURES

For this article development, measurements were made in two parts, here called part 1 and part 2, with identical nominal dimensions, made of aluminum and manufactured by using a CNC machining center, as can be seen in figure 1.

Figure 1 - Parts used in the experiment
Quirino (2017)

The measurements were carried out in the Laboratory of Precision Engineering of the Universidade Federal da Paraíba, using a Coordinate Measuring Machine, model Crysta Apex S 710.

For each element in both parts, twenty measures were taken. Position tolerance comparisons were performed under conditions of material independence and at maximum material condition, as well as circularity tolerance comparisons, in three holes, named A, B, C, of the parts, as can be seen in figure 2. The values were stored and exported to the .pdf format through the machine's MCOSMOS software.

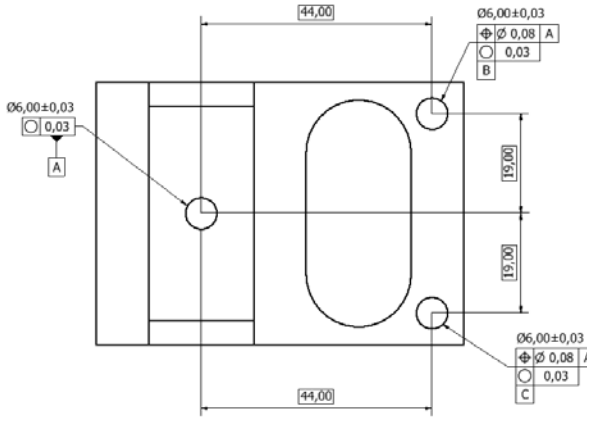

Figure 2 – Technical drawing of the tolerated elements
Quirino (2017)

4. RESULTS AND DISCUSSION

4.1. Position tolerance analyses

From the data of the nominal coordinates and measurements of the holes B and C, the position errors were determined in relation to the tolerance. Table 1 describes the tolerance determined in the design, regardless of the material condition, of 0,08 mm for the two holes and the position tolerance with the maximum material condition in the tolerated elements, 0,1327 mm for the hole B and 0,1318 mm for hole C, in addition to their respective errors in millimeters.

Table 1. Tolerance and position error of holes B and C from part 1.

HOLE	MATERIAL CONDITION	TOLERANCE (mm)	POSITION ERROR (mm)
B	Regardless	0,0800	0,0617
	Maximum	0,1327	0,0617
C	Regardless	0,0800	0,0145
	Maximum	0,1318	0,0145

The tolerance at the maximum material condition considers the tolerance determined from the predicted tolerance in the design plus the portion of the maximum material condition, and the GEO PAK (MCOSMOS) application performs the calculations of the maximum condition portion automatically.

It is observed that the position error found in the two holes was lower than the tolerance in the condition of material independence. As the tolerance zone considering the Maximum Material Condition is larger, the deviation found in this condition also meets the design requirements.

The same measurement and tolerance procedure used in part 1 was used in part 2. As for part 1, the position errors of the holes and the deviation from the tolerance were determined from the coordinate values of the tolerated holes.

Table 2 describes the tolerance determined in the design, regardless of the material condition, of 0,08 mm for the two holes and the position tolerance with the maximum material condition, 0,1423 mm for the hole B and 0, 1631 mm for hole C, in the tolerated elements.

The position errors found in the two tolerated holes of part 2 were lower than the tolerance in both the material independence condition and the Maximum Material Condition, meeting the design requirements.

Table 2. Tolerance and position error of holes B and C from part 2.

HOLE	MATERIAL CONDITION	TOLERANCE (mm)	POSITION ERROR (mm)
B	Regardless	0,0800	0,0393
	Maximum	0,1423	0,0393
C	Regardless	0,0800	0,0413
	Maximum	0,1631	0,0413

The position errors found in both parts are compatible with the part manufacturing process, carried out in a CNC machining center. This type of manufacturing exhibits optimum accuracy and repeatability, resulting in parts with consistent elements that meet design specifications.

4.2. Circularity tolerance analyses

The circularity of holes A, B and C was also analyzed, and Table 3 shows the tolerance values and the circularity errors of each hole in part 1.

All holes in this part had circularity errors significantly smaller than the tolerance determined in the design. It is important to note that there might be a refinement of these circularity error values when considering more points in the analysis, for each hole four points were considered in the same depth.

Table 3. Tolerance and circularity error of holes A, B and C from part 1.

HOLE	TOLERANCE (mm)	CIRCULARITY ERROR (mm)
A	0,0300	0,0022
B	0,0300	0,0005
C	0,0300	0,0027

In the following step of the tolerancing, the circularity of holes A, B and C of part 2 was analyzed, and Table 4 shows the tolerance values and the circularity errors for each of these holes. Equally for part 1, all holes in this part had circularity errors significantly smaller than the tolerance determined in the design, with hole B having the largest deviation.

Table 4. Tolerance and circularity error of holes A, B and C from part 2.

HOLE	TOLERANCE (mm)	CIRCULARITY ERROR (mm)
A	0,0300	0,0038
B	0,0300	0,0053
C	0,0300	0,0039

4.2. Measurement uncertainty analyses

Based on the results and on the information collected in the CMM's calibration report, the expanded measurement uncertainty in millimeters for each element measure were evaluated according to the equations given by [6] and [7] and are presented in Table 5.

Table 5. Measurement uncertainties.

PART	ANALYZED ERROR	HOLE		
		A(mm)	B(mm)	C(mm)
1	Circularity	0,0008	0,0006	0,0007
	Position	-	0,0010	0,0008
2	Circularity	0,0006	0,0006	0,0007
	Position	-	0,0007	0,0007

5. CONCLUSIONS

This work aimed to study the GD&T techniques application to coordinate measuring machines. Experimental procedures were performed for evaluating the GD&T tools available in the software, which is called MCOMOS, of a coordinate measuring machine, in particular the position and circularity analysis tools. In this context, the main conclusions of this work can be described as follows:

• In general, part 2 presented larger geometry errors than part 1.

• The geometric position and circularity characteristics presented values of deviations within the design specifications for the two pieces.

• Although the circularity analysis was performed with few points, it presented satisfactory tolerance results in parts 1 and 2.

• The GEOPAK application of the MCOSMOS program package was effective in calculating and presenting geometric tolerance, and the creation an automatic inspection program led to a significant reduction in the parts inspection time.

• The use of CMMs along with GD&T techniques in industries as well as in academy provides many advantages such as: reduction of parts inspection time; standardization of the inspection and contributes for achieving high productivity and better quality of manufactured parts.

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