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Analysis of Differences Between Perpendicularity Measurements Applying ISO 1101/2012 and ASME Y14.5-2009 and Its Impacts

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Abstract. The dimensional variations inherent in a manufacturing process are the reason for the existence of the acceptance tolerance concept on a product characteristic. The geometric quotation system has many advantages over the Cartesian system by avoiding ambiguity in the interpretation on form, orientation and location errors. The two main standards that define the geometric quotation on a mechanical design are ISO1101/2012 and ASME Y14.5-2009. However there are differences in interpretation even when the same symbols are mentioned by these standards. It is, therefore, important to know these differences to ensure the quality for companies that provide products to customers who apply different standards of geometric control. This article presents the results of perpendicularity control using each standard and their difference as an example of the impact when choosing one of them. In addition, the article shows preliminary results of a still on-going survey indicating that these differences between the standards are still little known among professionals in the areas involved in Brazil.

Keywords. Tolerances, Mechanical Design, GD&T, GPS, Metrology, Perpendicularity Measurement, ISO 1101/2012, ASME Y14.5-2009

Introduction

The inherent dimensional variations in a manufacturing process is the reason for the existence of the acceptance tolerance concept on a product characteristic in order not to compromise its function. The quotation on a mechanical drawings still uses the Cartesian system to define its dimensions and tolerances. An incorrect or ambiguous quote can cause major losses in product manufacturing [1]. Cartesian system quotation allows ambiguous interpretation and for such reason the geometric system quotation is gaining prominence in mechanical industries. Currently the automotive, aerospace and oil & gas industries has given much emphasis on philosophy of GD&T, ie, Geometric Dimensioning and Tolerances.

According to NADCA Product Specification Standards for Die Castings [2], the English engineer Stanley Parker was the creator of GD&T in the 30s. However the use of this metodology only gained momentum after World War II.

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Most of the dimensioning standards used in the industry are based on ASME (American Society of Mechanical Engineers) and ISO (International Organization for Standardization) [3]. These are the main standards applied as dimensioning methodology and there are also other global standards with lower expression. There is increasing pressure to migrate toward a common international standard, but we still need to keep them and understand their differences.

Also Krulikowski and DeRaad (1999) [3] devoted a chapter in the book Dimensioning and Tolerancing Handbook to compare ASME and ISO standards related to the design. They did their work primarily with ASME Y14.5M-1994 and ISO (various standards). In the case of ISO standards, updates used vary between 1982-1997.

ASME Y14.5 and ISO 1101 standards have some similarities, but many differences are important related to how some controls are performed that generate differences in results applying both standards. Usually standards have updates on their versions. Hence, this paper considers the ASME Y14.5-2009 and ISO 1101/2012 standards. This work focuses on the difference in how the feature of size (FOS) being controlled in position or orientation is defined by each of the standards, as well as its consequences.

1. Geometric Dimensioning Control - ISO 1101 x ASME

The two systems of geometric dimensioning most known and used in the world is the GPS (Geometric Product Specification) covered by ISO and GD&T standards (Geometric Dimensioning and Tolerancing) covered by ASME.

Usually a standard is updated to solve their own problems and to avoid ambiguity. Regarding ISO, TC213 committee works on GPS standards to solve the contradictions, gaps and lack of cohesion between them. It is also mentioned by B. Grant in 1997 that it was necessary to spread the practice of geometric dimensioning and tolerancing not only with examples, but standardizing rules that define the accepted practice widely applied in a common way around the world [4]. This will lead to:

- Reduce uncertainty in the design and product manufacturing;
- Increase the productivity of engineering and production efforts;
- Increase the use of computers and other advanced technologies in design and manufacturing.

The two tolerances systems - ISO and ASME - has much in common, but are not fully compatible [4].

James Salisbury, corporate metrologist at Mitutoyo (Aurora, IL), says the difference between ASME and ISO standards are huge and experts say that only 10% to 20% of the symbols have the same meaning [5]. Even when two symbols are equal in ASME and ISO standards, often use and interpretation are different [6].

One example where the symbols are the same but with different interpretation are the orientation (angularity, perpendicularity and parallelism) and location controls (position) on feature of size.

1.1. Feature of size

Feature of size (FOS) is not mentioned in VIM 2012 (International Vocabulary of Metrology) [7]. Feature of size are simple geometries such as spheres, cylinders (internal or external) and opposite planes that can be listed with a dimension and tolerance as shown in Figure 1.

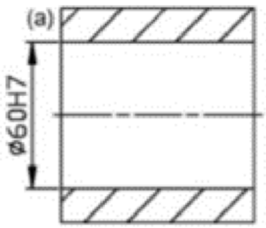

Figure 1. Example of a feature of size [4].

ISO 1101/2012 standard mention ISO 14405-1 that establish a feature of size as a geometrical shape defined by a linear or angular dimension which is a size. Size is an intrinsic characteristic of the feature of size which can be the diameter of a cylinder or the distance between two parallel planes.

In ASME Y14.5-2009 there are two types of feature of size [8]:

- Regular feature of size that is unique because:
    - Contains opposed points;
    - It may contain or be contained by an actual envelope as a sphere, cylinder or pair of parallel planes;
    - It has limits (it is not basic);
    - Follow rule number 1 of ASME Y14.5-2009.
- Irregular feature of size does not have all characteristics of a regular feature of size, so it is not under rule number 1 of ASME Y14.5-2009.

This paper only uses a regular feature of size that has similar concepts in both standards.

1.2. Orientation and location control

Feature of a part has errors inherently from manufacturing process that is not mathematically perfect. When measuring a feature we raised a cloud of points that approaches its real shape.

In ASME and ISO standards there are set criterias to find the feature of size. To perform orientation or location control, the center of the feature of size should be found.

1.2.1. ASME Y14.5-2009

Where the geometric tolerance of position, perpendicularity, parallelism or angularity is applied to a feature of size, geometric tolerance is controlling a mathing envelope of a central point, central plane or central axis of the feature by ASME Y14.5-2009 [8]. For cylinders, it must obtain the center of the largest inscribed cylinder (for holes) or the center of the smallest circumscribed cylinder (for pins). Figure 2 shows an actual cylindrical feature and the center of the smaller circumscribed cylinder of the actual feature. This center must be within the tolerance zone specified in the feature control frame to be approved.

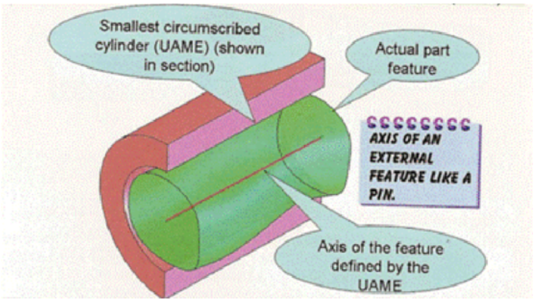

Figure 2. Obtaining the axis of a feature according to ASME Y14.5-2009 [8].

1.2.2. ISO 1101/2012

ISO 1101/2012 standard defines the extracted (actual) median line from the cylindrical feature center shall be within the specified tolerance zone. The standard specified on item 4.3 to obtaining such median line is described in the ISO 14660-1 and ISO/TS 17450-1 standards. Figure 3 shows details how this median line [9] is obtained.

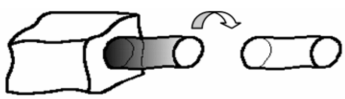

Fig. 15 Operations – partition 1.

Fig. 16 Operations – association 1.

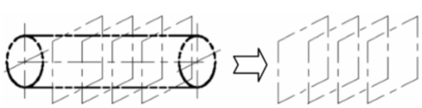

Fig. 17 Operations – construction.

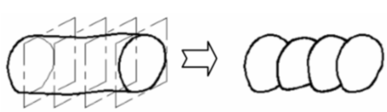

Fig. 18 Operations – partition 2.

Fig. 19 Operations – association 2.

Fig. 20 Operations – collection.

Figure 3. Obtaining the axis of a feature according to ISO 14660-1 and ISO/TS 17450-1 [9].

- Partition 1 – from the non-ideal surface model, of the non-ideal cylindrical surface
- Association 1 – of ideal feature (cylindrical)
- Construction – of planes perpendicular to the axis of the associated cylinder
- Partition 2 – of non-ideal circular lines
- Association 2 – of ideal feature of type circle
- Collection - of the centres of the ideal circles

In ISO 22432 are described various types of feature [10]. One of them is called substitute feature. It is a unique ideal feature associated with a non-ideal feature, e.g. as used in CMM techniques.

Despite the fact that ISO 1101 defines an extracted (actual) median line from a non-ideal feature, CMM apply an ideal feature associated with a non-ideal feature.

2. Methodology

2.1. Orientation and location control

In order to simplify the test, this paper shows the perpendicularity control of a round pin. However, the understanding of a perpendicularity control on a feature of size is similar to position and orientation control (perpendicularity, parallelism and angularity).

Usually the control of this type of feature is by checking its actual center in relation to the reference defined by the technical drawing.

Two parts were used with cylindrical features (pins) containing deviations of form on them. The design of the prototype is shown in Figure 4. One of the samples was made with an important deviation (~2mm) and another one with a small deviation (~0,2mm).

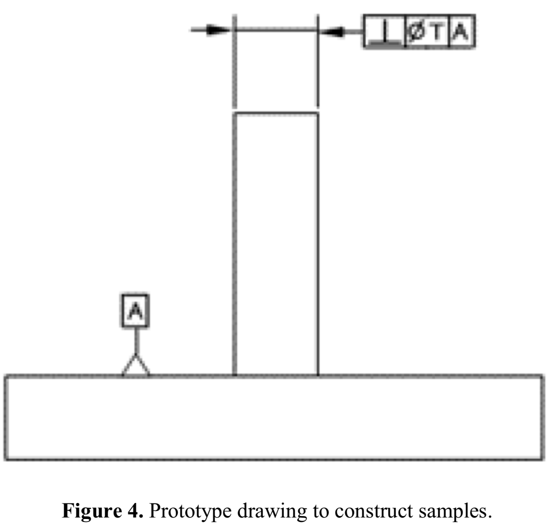

Figure 4. Prototype drawing to construct samples.

2.2. Equipments applied on tests

Four coordinate measuring machines (CMM) were applied, one at UFMG campus and the remaining at two other laboratories.

The CMM at UFMG is a TESA MH 3D 4.5.4. Last calibration was performed on 08.04.13 and presented a maximum error of (3.0 + 1,0L / 250) µm (length L in mm).

The second CMM is a Mitutoyo M Bright with valid calibration until May 2016.

The third CMM is a Coord 3 Ares, last calibration on November 23rd 2015.

The forth CMM is a Dea Scirocco. Calibration was not available.

2.3. Metodology applied on tests

XYZ points from a pin were obtained in the space that comprise the point cloud of the cylindrical feature in analysis. This cloud of points obey the following criteria:

- The cylindrical feature is divided into 5 sections and for each section are collected 6 points.
- These points are used to calculate the perpendicularity according both standards under review. The calculation was performed by the CMM´s software.

2.4. Survey related to professional knowledge differences on standards

A survey was prepared in order to know about the knowledge of professionals from development, manufacturing, metrology and education areas about the differences between ISO 1101 and ASME Y14.5 standards.

The following questions were proposed to respondents.

- What is the economic sector that you work?
- Which department do you work?
- Experience time.
- Do you apply GD&T concepts in your work activities?
- Which standard related to GD&T do you apply in your work?
- If you use both standards mentioned above, do you know the main differences between them?
- To control the orientation feature of size (FOS), do you know how each standards establish to found the feature center?

3. Results

3.1. Results on orientation control

Measurements at UFMG were performed at a temperature of (20 ± 1)°C. The equipment software does not provide a way to choose the feature of size by least squares (ISO) or the minimum circumscribed cylinder (ASME). Therefore, it's not possible to find the difference between measurements following ISO 1101 or following ASME Y14.5.

Nonetheless, the manufacturer of the CMM TESA MH 3D (at UFMG) clarifies that its software complies with ISO requirements. To measure according to ASME requirements an additional software is needed. Following contacts with the manufacturer, softwares used by their CMM´s in Brazil usually have ISO as default standard.

Measurements at the second laboratory were performed at a temperature of (22.8 ± 0.5)°C. It was observed that this CMM, as well, does not allow the measurement of orientation errors following ISO 1101 or even ASME Y14.5. The CMM´s software does not provide ways to choose the feature of size by least squares (ISO) or the minimum circumscribed cylinder (ASME). Therefore, no tests could be arranged in order to detect differences between measurement results, neither following ISO 1101 nor following ASME Y14.5.

The manufacturer Mitutoyo explains that the software used in their CMM´s complies with ISO requirements and the software version available at that particular laboratory is a version (V2.0 R3) that does not yet have the possibility to choose a feature according to ISO or ASME. The version on the CMM in question can only choose the least square average from a circunferency. To choose the cylinder by least squares averages of minimum circumscribed circles, a version 3.0 or higher is required .

Other manufacturers of CMM´s have confirmed that their machines, as well, apply ISO as default and, usually, do not provide detailed information on how to differentiate the control of orientation or location following both standards.

The two remaining CMM´s able to measure by both standarts gave the following results:

Table 1. Results on two equipments (values in mm).

		Results	
Equipment	**Calculation condition**	**Part 1 (Perp. ~0,2)**	**Part 2 (Perp. ~2,0)**
CMM Coord 3 Ares	ISO	0,2064 / 0,2111 / 0,2121	2,7711 / 2,7639 / 2,7626
	ASME	0,2044 / 0,2051 / 0,2074	2,7702 / 2,7679 / 2,7670
CMM Dea Scirocco	ISO	0,162	1,979
	ASME	0,162	1,982

Three results were obtained from Coord 3. Their mean and standard deviation are shown on table 2.

Table 2. Mean and standard deviation.

Calculation condition		**Part 1 (Perp. ~0,2)**	**Part 2 (Perp. ~2,0)**
ISO	Mean	0,2099 mm	2,7659 mm
	Standard deviation	3,0 μm	4,6 μm
ASME	Mean	0,2056 mm	2,7684 mm
	Standard deviation	1,6 μm	1,2 μm
	Difference of mean (90% confidence)	(4,2 ± 4,1) μm	(2,5 ± 5,8) μm

In this experiment the probe contacted all around the pin. However, it was impossible to calculate the orientation errors following both standards from the same collected feature points (point cloud). Hence, it was performed six times, three times for each standard, certainly inflating their respective standard deviations. Nontheless, results from Coord 3 already demonstrate significant differences between ISO and ASME, as can be verified through a single sided test of sample means (t-test with 95% [11]).

The advantage of Dea´s CMM is its ability to calculate orientation errors for both standards from the same collected feature points (point cloud). Theoretically, this allows for the best direct comparison of results. However, in the experiment with this particular CMM, only a one-sided contact of the cylinder (semi cylinder) was feasible, thus, loosing the possiblity of direct comparison of results with Coord 3 CMM.

3.2. Results on survey about knowledge on differences between standards

This survey involved a sample of 121 professionals with greater participation from the automotive sector (64%) and from the product development department (42%) as shown on Figure 5 and 6. Distribution of experience was well-balanced as shown on Figure 7.

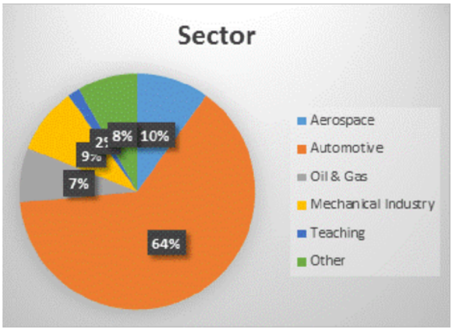

Figure 5. Sector distribution.

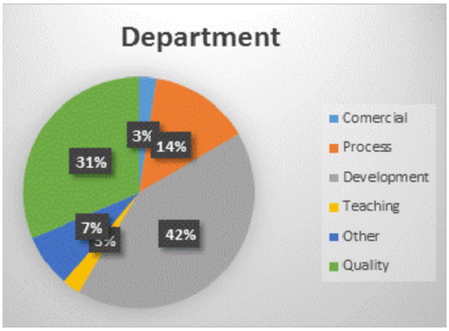

Figure 6. Department distribution.

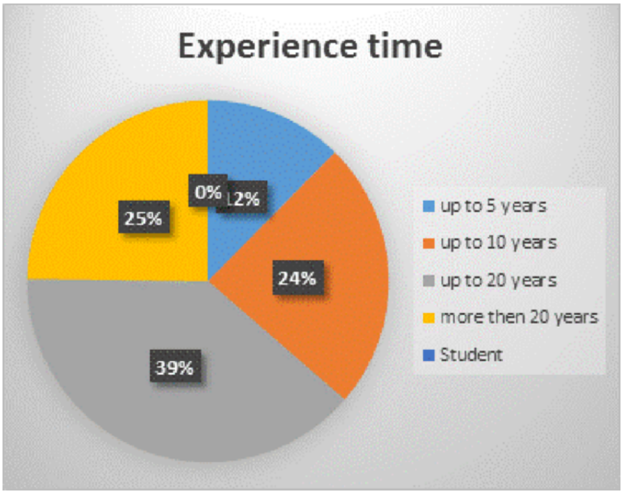

Figure 7. Experience distribution.

The survey showed that 77% of respondent professionals use GD&T in their activities. From these respondents 56% apply ASME Y14.5 and 35% apply ISO1101 as shown on Figure 8. Only 18% of the professionals who apply GD&T know the major differences between these standards as shown on Figure 9.

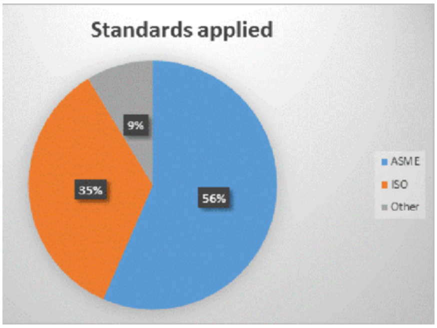

Figure 8. Standards applied.

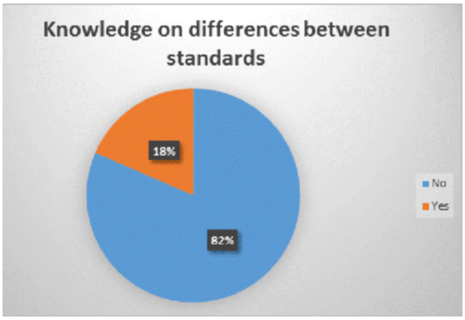

Figure 9. Knowledge on differences between ASME and ISO.

4. Conclusion

The measurements reliability is an important factor so that business transactions are made in a just and peaceful manner [12]. In addition to the uncertainties that are inherent to each measurement process, there are criterias defined by ASME and ISO standards on how to control a feature, that may add a significant contribution to the overall uncertainty. If these influences are not properly understood and, hence, not recognized, they may inflate the risk of disapproval of good parts and/or approval of bad parts.

Among the rules of geometric control, the most applied standards are ISO 1101 and ASME Y14.5. Most CMM´s apply ISO as default, however ASME Y14.5 standard is more widely applied by professionals who use GD&T.

Ignorance of the rules and their differences may generate product designs not suited to its needs. Who produces a part may misinterpret what the designer expects and quality control may disapprove good parts or approve bad parts. The precision in communication must be reassured in all departments that use a mechanical drawing within an organization and in relations between customer and supplier.

Many industry companies have a similar CMM to those applied in this experiment, i.e., small and compact. Sometimes, additional softwares are needed but often have a high cost that usually, is due to the complexity of algorithms for extracting elements as set by both standards. So what is measured today by CMM´s may often be questionable when it comes to the control of orientation or position.

In addition, a question arises regarding all CMM´s that apply an associated feature instead of the extracted feature when using ISO 1101 for the calculation of orientation errors. ISO should be updating its description of definitions or, otherwise, calculation on CMM´s should be revised.

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