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ANALYSIS OF DIFFERENCES BETWEEN MEASUREMENTS APPLYING ISO 1101/2012 AND ASME Y14.5-2009 AND ITS IMPACTS ON AUTOMOTIVE INDUSTRY

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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. In the automotive sector 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 of interpretation even when the same symbols are mentioned in these standards. When a company supplies parts to OEM (Original Equipment Manufacturer/Manufacturing) that apply different geometric control standards, it is important to know these differences to ensure product quality. 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. Data from a still ongoing survey show how these differences between the standards are still little known among professionals, mainly within the automotive industry in Brazil.*

Keywords: *GD&T, GPS, Mechanical Design, Metrology, Quality*

1. 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 drawing still uses the Cartesian system to define its dimensions and tolerances in many mechanical industries. Silva (2012) comment that an incorrect or ambiguous quotation can cause major losses in product manufacturing. Cartesian system quotation allows ambiguous interpretation and for such reason the geometric system quotation is gaining prominence in many industries. Automotive is one sector that has given much emphasis on philosophy of GD&T, i.e., Geometric Dimensioning and Tolerancing.

The engineer Stanley Parker was the creator of GD&T in the 30s according to NADCA Product Specification Standards for Die Castings (2009). However, the use of this methodology only gained momentum after World War II.

Most of the dimensioning standards used in the industry are based on ASME (American Society of Mechanical Engineers) and ISO (International Organization for Standardization) according to Krulikowski and DeRaad (1999). 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 it still need to keep them and understand their differences.

Krulikowski and DeRaad (1999) 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. Also Henzold (2006) wrote a chapter comparing ASME, ISO and other standards in such subject.

ASME Y14.5-2009 and ISO 1101/2012 standards have some similarities, but many differences are importantly 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.

2. OEM REQUIREMENTS

Nowadays many OEM (Original Equipment Manufacturer/Manufacturing) apply GD&T on their drawings and some of them establish as a requirement.

Generally American OEM apply ASME Y14.5-2009 and European ISO 1101/2012. Then GM, Ford, Chrysler and Fiat apply ASME Y14.5-2009. Volvo, MAN, Iveco, Renault and PSA apply ISO 1101/2012. It does not have information about other OEM.

GM has a specific requirement for suppliers about fixture that they need to understand the GD&T concepts. The GM Fixture Standards (GM1925/2008) summarize the minimum requirements that apply to all GM suppliers PPAP checking fixtures worldwide. All fixture should be built to math data and GD&T. GM drawing specify ASME Y14.5 as a standard to be applied.

Ford establish on the Statement of Requirements ASME Y14.5-2009 as the standard to be applied on their drawings.

According to standard IATF 16949/2016 the design output has a requirement about knowledge of the GD&T.

3. GEOMETRIC DIMENSIONING CONTROL - ISO1101/2012 X ASME Y14.5-2009

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. On automotive sector also these are que most applied standards.

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, comment Humienny (2009). 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 according to Humienny (2009).

Looking beyond symbol shape, ISO and ASME standards contain numerous differences in the use and interpretation. Some of them are significant and affect the acceptance criteria. Krulikowski (2012) mention even when two symbols are equal in ASME and ISO standards, often use and interpretation are different. If someone knowledgeable in ASME interpret a mechanical drawing prepared to the ISO it is possible to encounter problems.

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.

3.1 Feature of size

Feature of size (FOS) is not mentioned in VIM 2012 (International Vocabulary of Metrology). 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 some examples in Figure 1.

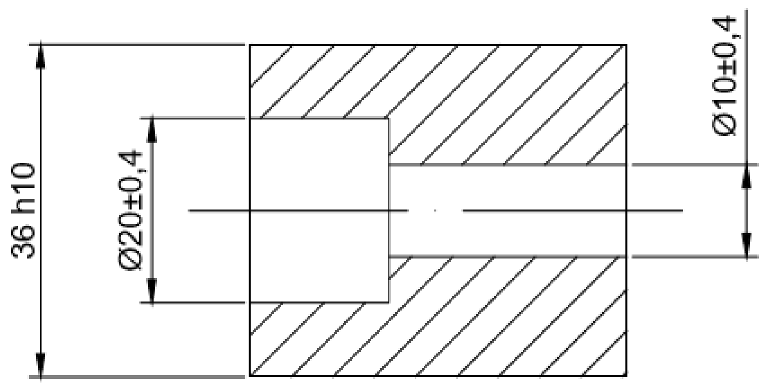

Figure 1. Examples of a feature of size

ISO 1101/2012 standard mention ISO 14405-1:2016 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:

- 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.

3.2 Orientation and Location Control

Feature of a part has errors inherently from manufacturing process that is not mathematically perfect. When measuring a feature, it raised a collected feature points (point cloud) that approaches its real shape.

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

Where the geometric tolerance of position, perpendicularity, parallelism or angularity is applied to a feature of size, geometric tolerance is controlling a matching envelope of a central point, central plane or central axis of the feature by ASME Y14.5-2009 according to Day (2009). 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.

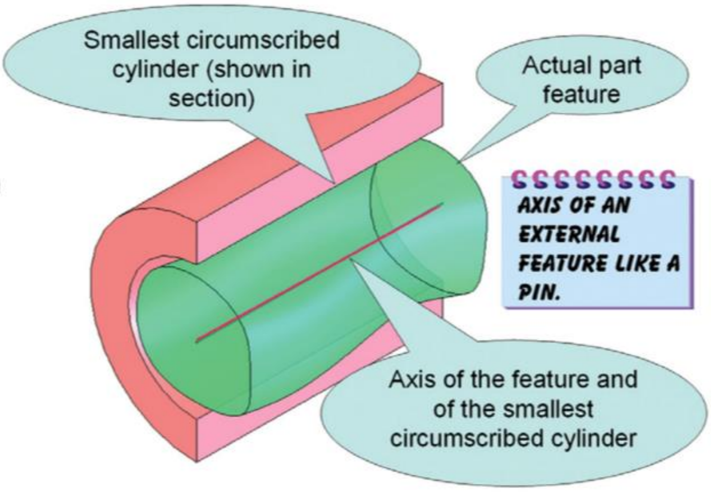

Figure 2. Obtaining the axis of a feature according to ASME Y14.5-2009 (Day 2009)

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 14660-1/1999 and ISO/TS 17450-1/2011 standards. Figure 3 shows details how this median line is obtained.

Despite the fact that ISO 1101/2012 defines an extracted (actual) median line from a non-ideal feature, CMM (Coordinate Measuring Machine) apply an ideal feature associated with a non-ideal feature.

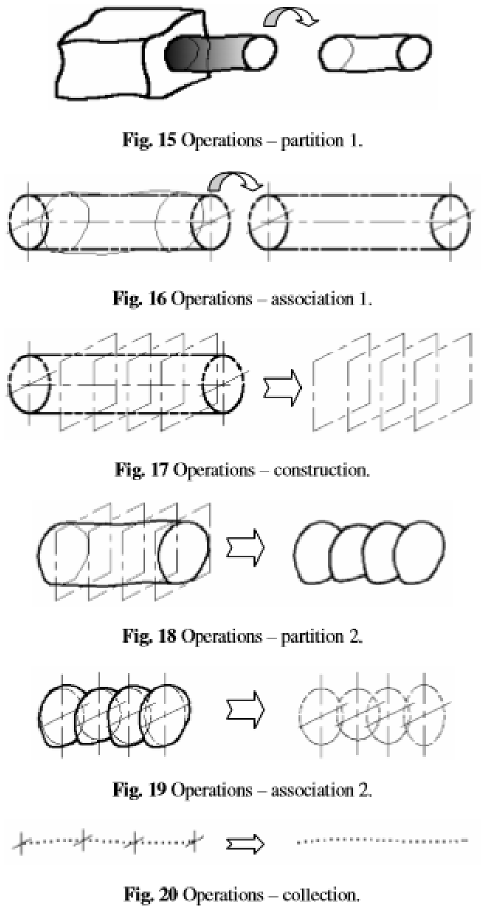

Figure 3. Obtaining the axis of a feature according to ISO 14660-1 and ISO/TS 17450-1 (Humienny 2009)

4. METHODOLOGY

4.1 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 a great deviation (~2 mm) and another one with a small deviation (~0,2 mm).

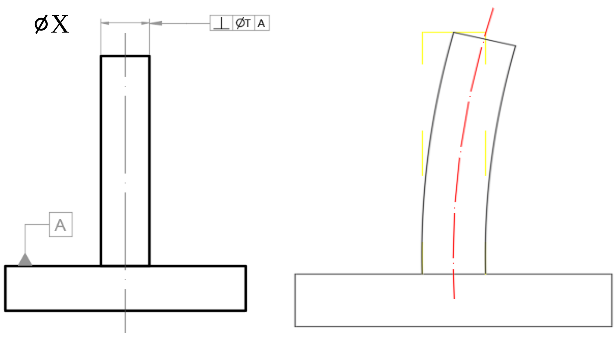

Figure 4. Prototype drawing to construct samples

4.2 Methodology 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 software.
- Perpendicularity calculation follow standard definition described on item 3.1.

4.3 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 1101/2012 and ASME Y14.5-2009 standards.

Some questions were proposed to respondents about their knowledge on GD&T.

5. RESULTS

5.1 Orientation Control

Manufacturers of CMM 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.

Three CMM able to measure by both standards gave the following results:

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

Equipment	Probe	Calculation condition	Part 1 (Perp. ~0,2)	Part 2 (Perp. ~2,0)
CMM Coord 3 Ares (calibration 11/23/15 Resolution – 0,1 μm)	Fix probe	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 (calibration not available Resolution – 1,0 μm)	Mobile probe	ISO	0,162	1,979
		ASME	0,162	1,982
CMM Zeiss Duramax (Calibration 07/23/16 U_{95} = 2,4+(L/300) μm Resolution – 0,1 μm)	Scanning probe	ISO	0,1374	1,8700
		ASME	0,1171	1,7756

Three results were obtained from Coord 3 Ares. 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. Nonetheless, results from Coord 3 Ares already demonstrate significant differences between ISO and ASME, as can be verified through a single sided test of sample means (t-test with 95 %) according to Montgomery (2017).

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, losing the possibility of direct comparison of results with Coord 3 Ares CMM.

The advantage of Zeiss Duramax is the ability to calculate orientation errors from the same points measurements and applying scan system. On this measurement it is able to found differences between both standards as presented on table 3.

Table 3. Differences between ISO and ASME with CMM Zeiss Duramax.

Equipment	Calculation condition	Part 1 (Perp. ~0,2)	Part 2 (Perp. ~2,0)
CMM Zeiss Duramax (Calibration 07/23/16 U_{95} = 2,4+(L/300) µm)	ISO	0,1374	1,8700
	ASME	0,1171	1,7756
Calculation difference		0,0203	0,0944
Uncertainty		± 0,0026	

5.2 Results on survey about knowledge on differences between standards

This survey involved a sample of 85 professionals with important participation from the development and quality department (41 % and 37 % respectively) and distribution of experience was well-balanced.

The survey showed that 84 % of respondent professionals use GD&T in their activities. From these respondents, 47 % apply ASME Y14.5-2009 and 44 % apply ISO1101/2012. Only 11 % of the professionals who apply GD&T know the major differences between these standards.

6. SUMMARY AND CONCLUSIONS

Albertazzi and Sousa (2015) wrote the measurements reliability is an important factor so that business transactions are made in a just and peaceful manner. In addition to the uncertainties that are inherent to each measurement process, there are criteria 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 1101/2012 and ASME Y14.5-2009. Most CMM apply ISO as default, however ASME Y14.5-2009 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 software is 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 may often be questionable when it comes to the control of orientation or position.

In addition, a question arises regarding all CMM that apply an associated feature instead of the extracted feature when using ISO 1101/2012 for the calculation of orientation errors. ISO should be updating its description of definitions or, otherwise, calculation on CMM should be revised.

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