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Recent developments in International Organization for Standardization geometrical product specification standards and strategic plans for future work

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Henrik S Nielsen

Abstract

Over the last 2 years, ISO TC 213, the committee that publishes the ISO geometrical product specification (GPS) standards, has published about 35 standards, more than double the number of the preceding 4 years. This rapid development has brought many significant changes to the ISO-GPS system. The author is the chairman of that committee and gives an overview of the more important ones in this article. The work is now at a crossroad, where items that have been on the TC 213 work program for many years have been completed. This has allowed TC 213 to start new strategic initiatives that will guide the development of ISO-GPS standards over the next 8–10 years. This article will outline the two stages of the strategic plan, the changes to the ISO-GPS standards complex that is envisioned, and how it will impact the users of these standards; whether they are part of the specification community or the verification community.

Keywords

Dimensioning, tolerancing, standards, geometry, product specifications, ISO, geometrical product specifications (GPS), TC 213

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Introduction

The author started participating in International Organization for Standardization's (ISO) standardization work in 1988 at a meeting of ISO TC 57 "Metrology and properties of surfaces" in Bad Dürrheim, Germany. One of the major items of discussion at the time was the implementation of digital measuring instruments. The discussion was centered around the necessary data density and trying to balance the "trueness" of the measured values with the abilities of the computers of the day.

In the end, the committee made a number of decisions that are still driving the way ISO geometrical product specifications (GPS) standards are written today. One decision was that the committee wanted the definition of surface texture to be measurable. Up until that point, the measurand for surface texture was what an infinitely thin and sharp stylus would see. Apart from the mechanical difficulties in designing such a stylus and in making it last, it also meant that a detector and an amplifier with a flat frequency response to infinite frequency and an infinite number of data points in the data set were necessary, if one wanted to digitize the measurement and use computers for filtering and parameter calculations.

The nature of surface texture is such that for surfaces that really matter, for example, surfaces that participate in sliding or rolling contact or to which paint or glue has to adhere, one cannot get to the right roughness parameter values through theoretical calculations. One has to measure surfaces and test them to see which ones work to find the proper parameter values for the specification.

This realization was the driver behind making surface texture measurable as defined. Otherwise, it would be impossible to convert the data from the research and

HN Metrology Consulting, Inc., Indianapolis, IN, USA

Corresponding author:
Henrik S Nielsen, HN Metrology Consulting, Inc., 10219 Coral Reef Way, Indianapolis, IN 46256, USA.
Email: hsnielsen@hn-metrology.com

development (R&D) experiments to specifications on technical drawings. As a consequence, the committee defined the primary profile, that is, the profile on which the surface texture is defined, as the profile that a stylus of defined radius would see. It further defined a λs filter that removed the short-wave components of the surface in a controlled manner, such that minor differences in stylus radii would not result in appreciable differences in measured values, because it is very hard to make a stylus tip with a uniform radius of nominal value. This is codified in ISO 3274.[1] This way of thinking of specifications as definitions of measurands is carried through today in the work of ISO TC 213, as it writes the ISO-GPS standards.

ISO TC 213 and the GPS Master Plan

ISO TC 213 was set up in 1996 by combining ISO TC 3 "Limits and Fits", ISO TC 10/SC5 "Technical drawings, product definition and related documentation — Dimensioning and tolerancing" and ISO TC 57. The idea was that it was necessary to consolidate specification and verification standards in the same technical committee, so there could be a dialogue between those who specify geometry and those who measure it.

One of the first documents resulting from what was to become ISO TC 213 was ISO/TR 14638,[2] the GPS Master Plan. This document defined fundamental, global, general, and complementary GPS standards as shown in Table 1. It also fits the general GPS standards into a matrix that contained what is known as the chains of standards and defined the six chain links that were necessary in order for a specification to be unambiguous and the measuring result used to verify it traceable as shown in Table 2. Since then, all GPS standards have contained an annex that indicates where the particular standard fits into the GPS matrix.

ISO 17450 "General concepts"

ISO/TS 17450-2[3] was published in 2002. It built on the ideas of the Master Plan and the early work performed in TC 57 defining surface texture in terms of ideal measuring instruments. As the work matured, the committee realized that it was really defining measurands, not measuring instruments.

ISO/TS 17450-2 defines the basic terminology of operations, operators, and uncertainties. The committee began viewing specifications in terms of operators that consist of a number of operations in a defined order. Some operations are mechanical, such as the tactile sensing of the surface, whereas others are mathematical. These operators define characteristics, and specifications put constraints on these characteristics. By defining specifications in these terms, it is possible to map the verification (the measurement) to these operations. This allows comparison of the verification operator (i.e. what happens in the measurement) to the specification operator (i.e. the definition of the measurand).

This comparison in turn allows a move away from the binary thinking that there are correct ways and incorrect ways of measuring a particular specification. Instead, the differences between the specification operator and the verification operator are quantified in terms of uncertainties. This allows users of the ISO-GPS system to decide on a case-by-case basis whether a given measuring process is good enough to be used to verify a particular specification, or whether the uncertainty is too high.

ISO/TS 17450-1,[4] which was published in 2005, formally introduced the duality principle (Figure 1) as the way to view the verification as ideally being a mirror image of the specification, thus complementing the idea that the two should mirror each other, but not necessarily be the same.

Table 1. The GPS matrix model.

Fundamental GPS standards	**Global GPS standards** GPS or related standards that covers or have influence on several or all GPS chains of standards	
	General GPS matrix (chains of standards) 1. Linear size 2. Linear distance 3. Radial distance 4. Arc length 5. Angular size 6. Angular distance 7. Form of a line (unrelated) 8. Form of a line (related) 9. Form of a surface (unrelated) 10. Form of a surface (related)	11. Orientation 12. Location 13. Circular runout 14. Total runout 15. Datums 16. Roughness 17. Waviness 18. Primary profile 19. Surface imperfections 20. Edges
	Complementary GPS matrix Process-specific chains of standards Machine element-specific chains of standards	

GPS: geometrical product specifications.

Table 2. The general GPS matrix.

Chain link					
1	2	3	4	5	6
Drawing indication–code	Tolerance definition–theoretical definition of the characteristic	Definition of the characteristic on the real workpiece Specification operator	Measured value of the characteristic for the real workpiece Verification operator	Definition of metrological characteristics for measuring equipment	Calibration and verification of metrological characteristics for measuring equipment
Specification of GPS characteristics			**Verification of GPS characteristics**		

GPS: geometrical product specifications.

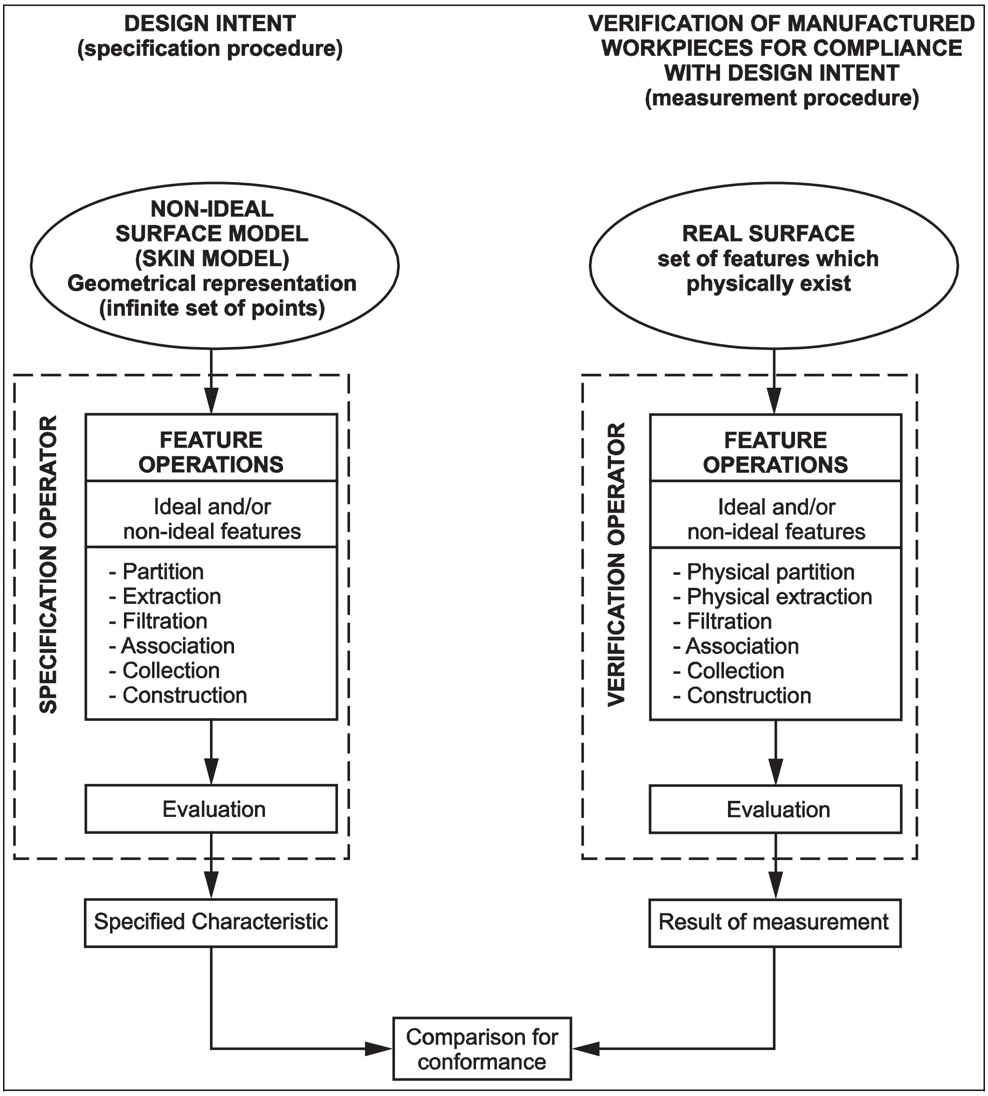

Figure 1. The duality principle.

ISO 14253 "Inspection by measurement of workpieces and measuring equipment"

ISO 14253[5–7] is a series of standards that have to do with uncertainty and how it applies to GPS. ISO 14253-1[5] of 1998 defines the fundamental rules for proving conformance and nonconformance with a specification. In essence, it requires the party making the proof to count the uncertainty against itself; so components have to be measured to be inside the specification limits by more than the uncertainty in order for it to be proven to conform and outside the specification limits by more than the uncertainty in order for it to be proven to not conform.

Only product that can be proven to conform shall be shipped to the customer, and only product that can be proven to not conform shall be rejected and returned to the supplier. If both parties adhere to these rules, there should never be a situation where a delivered product does not conform to specifications, nor a situation where a conforming product is rejected and returned.

These rules mean that it makes a difference whether a customer requires the supplier to provide proof of conformance or relies on incoming inspection. They also mean that there is a gray area where neither conformance nor nonconformance can be proven.

ISO/TS 14253-2[6] of 1999 is a guide to estimating uncertainty for GPS measurement that introduces the novel idea of a target uncertainty and the Procedure for Uncertainty Management (PUMA) method that aims at proving that the actual uncertainty is less than the target uncertainty with minimum effort, rather than estimating the actual uncertainty as accurately as possible.

ISO 8015 fundamentals—concepts, principles and rules

Last amongst these fundamental standards is ISO 8015,[8] which was published in a new and significantly updated version in 2011. It formally states 13 basic principles for GPS that up until then had been taken for granted, but not been available in a standard that could be referenced, or at least not in a form that provided traceability between the principles and GPS specifications.

Recent developments

The standards discussed above all aimed at developing the structure behind the ISO-GPS system without providing much in terms of indications that would be visible on technical drawings. However, with this foundation in place, ISO TC 213 has started issuing standards that dramatically increases the vocabulary of the GPS language and allows designers to express much more precisely what their requirements are to the components they design.

ISO 14405-1:2010 ("Geometrical product specifications (GPS) — Dimensional tolerancing — Part 1: Linear sizes")[9] gives a number of modifiers that allow the designer to express requirements to linear sizes that go far beyond the old-fashioned and expensive envelope requirement that only is appropriate for fits. Srinivasan[10] discusses this in more detail.

ISO 5459:2011 ("Geometrical product specifications (GPS) — Geometrical tolerancing — Datums and datum systems")[11] updates the concept of datums for the first time in 30 years. To put this in perspective, the previous version of this standard was issued in the same year when IBM introduced the personal computer.

Finally, ISO 1101:2012 ("Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out"),[12] which was published recently, adds some new possibilities to geometrical tolerancing. However, the primary aim is to make tolerances independent of the view plane, so they are unambiguous when used on a three-dimensional (3D) model in a computer-aided design (CAD) system.

ISO TC 213 has also developed a number of tools that will be available for specifications in the next generation of specification standards. In particular, the ISO 16610 "Filtration" series[13] defines a number of new filtering tools, which allow the separation of different kinds of surface features. One can think of it as separating short-wave and long-wave surface components from each other, but in reality, it is much more complicated than that.

Finally, on the surface texture front, a lot of work has gone into developing the ISO 25178 "Surface texture: areal" series that expands the surface texture area from two-dimensional (2D) profile-based evaluations to 3D areal-based evaluations.

Overall, ISO TC 213 has approved 35 standards and other documents over the last 2 years. This compares to the nine completed between 2006 and 2009 (Figure 2). While many of these were conversions of Technical Reports (TR documents) and Technical Specifications (TS documents) into International Standards, it does indicate a significant improvement in productivity and a desire to reach compromises to allow work to progress for the committee.

This means that many of the work items that have been active for many years have been concluded. The revision of ISO 5459[11] has been on the work programme for 15 years and the new ISO 1101[12] has been on the programme for the better part of a decade. It also means that there are several tools available in terms of filtering and association that are not available to designers, because the drawing indications to invoke these tools have not been standardized yet. This cleanup in the work program has caused ISO TC 213 to develop a strategic plan. This plan has two phases and is discussed in the next clauses.

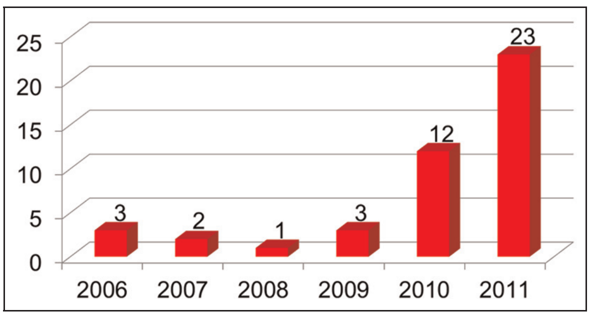

Figure 2. ISO TC 213 standards approvals 2006–2011.

Strategic plan initiatives

The strategic plan for ISO TC 213 has six broad initiatives as described in the following sections.

Initiative 1: rules-based standards

Many of the ISO-GPS standards are based on examples rather than rules. ISO 1101[12] is the most prominent example of this standardization approach. The example-based standards are enticing because they look simple and easy to understand at first glance. The problem is that the examples given are often too simple and do not cover the complexities one is likely to encounter on real components. The example-based standards force the user to interpolate between examples and extrapolate when actual usage goes outside what the examples cover.

Rule-based standards, however, often seem complicated at first glance. Typically, many rules are needed and most of them focus on exceptions and special cases; so it appears that the standard is more concerned with those than with what the average user needs every day. However, the clear advantage of rules-based standards is that there is much less guesswork and they are much less open to interpretation; so the common understanding of what the standards mean will be much broader among practitioners, and the implementation of the standards in, for example, CAD/computer-aided manufacturing (CAM) systems and coordinate measuring systems will be much more uniform.

ISO TC 213 has converted some standards to rules-based standards, in particular ISO 2692 (Geometrical product specifications (GPS) — Geometrical tolerancing — Maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR))[14] and ISO 5459.[11] It is the intent under this initiative to convert ISO 1660 ("Technical drawings — Dimensioning and tolerancing of profiles")[15] ISO 5458 ("Geometrical product specifications (GPS) — Geometrical tolerancing — Positional tolerancing"),[16] and ultimately, ISO 1101 ("Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out")[12] to rules-based standards.

Initiative 2: characteristics

For geometrical tolerancing, only tolerance zones are defined. This means that, strictly speaking, geometrical tolerances as defined in ISO 1101[12] cannot be measured in a way that reports a value, but can only be measured in a way that has an yes/no answer to check whether a feature or a set of features fit within their tolerance zones. Coordinate-measuring machines make this type of measurements anyway, by interpreting the zone definition and (usually) reporting the size of the smallest zone that would allow the feature to pass the tolerance.

The aim of this initiative is to define characteristics and actual values for geometric specifications and to define a signed and global characteristic (actual value) for each workpiece. This, in turn, will form the basis of another initiative that is aimed at providing tools to specify population characteristics.

Initiative 3: form standards

ISO TC 213 has recently converted ISO 12180,[17,18] ISO 12181,[19,20] ISO 12780,[21,22] and ISO 12781[23,24] from TS to International Standards. These standards cover cylindricity, roundness, straightness, and flatness. While these standards cover all the necessary concepts, they are written from a measurement perspective rather than from a specification and measurand definition perspective. In addition, due to lack of consensus, many defaults are missing (e.g. filter values); therefore, unless the designer specifies values for these parameters, the specification is incomplete.

As part of the review during the conversion, it was decided that the concepts covered in these standards should be covered for all geometrical characteristics, that is, all the 14 symbols given in ISO 1101.[12] It was further decided that consensus should be sought for defaults on more, if not all, parameters. Currently, preliminary work is going on to define the features to which the specifications apply, that is, the details of extraction, filtering, data density and so on, as well as the characteristics that can be specified.

Initiative 4: new specifications

This initiative includes population characteristics, or what is commonly referred to as statistical tolerancing. The aim is to define all the relevant and necessary characteristics, not just a "statistical-tolerancing" modifier. It also includes the ability to specify contacting features, specifications that apply under the application of specified forces and specifications on assemblies including moveable assemblies such as rolling bearings.

Initiative 5: general tolerancing update

Many disputes between suppliers and customers come down to general tolerances as defined in ISO 2768-1[25] for dimensional tolerances and ISO 2768-2[26] for geometrical tolerances. Both these standards were published in 1989 and do not reflect the needs of modern manufacturing.

General tolerances are popular among designers because they provide a pleasant feeling of having completed the drawing and having a safety net, even if some tolerances have been forgotten. They are equally unpopular among suppliers because they add hidden tolerances to the drawings. Work on this initiative is yet to be initiated, but the aim is to significantly update these standards, so that they become less of a focal point for disputes.

Initiative 6: edges

Edges play a significant role in the function of workpieces, both in assembly and in making sure the intended features interface with each other. The tools for specifying edges are currently quite rudimentary, unless geometrical tolerances are used and those are often seen as being too cumbersome to use for defining edges. Work on this initiative is yet to be initiated, but the vision is to provide a more convenient and complete set of tools for specifying edges.

Strategic plan phase 1

The strategic plan is divided into two phases, each of which is expected to last for 3–5 years. The first phase has deliverables for each of the six initiatives as discussed earlier. In addition, an update to ISO 1101:2012[12] that primarily adds modifiers to enable the designer to specify filtering and association for the toleranced feature as well as the datum features is in the works. It is also intended to provide more precise tools to indicate requirements to groups of features and locking patterns of tolerance zones together. This update is a major expansion of the tolerancing language and enables much more precise control over toleranced features using geometrical tolerances than what is possible today. It is expected to be the most significant update to ISO 1101 ever. However, it is not converting ISO 1101 into a pure rules-based standard.

Strategic plan phase 2

The aim for phase 2 is to convert ISO 1101 into a multipart standard to strengthen the ISO 1101 brand. The new standard is intended to encompass ISO 1101,[12] ISO 1660,[15] ISO 2692,[14] ISO 5458,[16] ISO 5459,[11] ISO 10579 (“Geometrical product specifications (GPS) — Dimensioning and tolerancing — Non-rigid parts”),[27] the deliverables for initiative 3, and other geometrical-tolerancing deliverables from phase 1.

Collecting all these standards under one standard number is intended to provide awareness among users that this information belongs together and that these standards cannot be read in isolation. It is also expected that the conversion will reduce the perceived need for repeated information in different standards, which is a significant problem. Every time information is repeated, it is usually phrased differently, increasing the possibility for differing interpretations that can all be supported by reference to standards. By eliminating repeated information, the standard becomes less ambiguous. It also becomes more modular, making it easier to maintain, because we can update one part of the standard, without creating contradictions with other parts of the standards.

Summary

This article summarizes the work and developments that have taken place since the formation of ISO TC 213, the work that is going on right now, and the work that is planned for the next 10 years. Much of the 16 years since the formation of ISO TC 213 has been spent on building a sound theoretical foundation for the GPS system. A comparatively large part of the deliverables over this period has focused on the behind the scenes parts of GPS: the fundamental rules, the concepts of operators and uncertainties, rigorous definitions of features, operations and characteristics, and tools for extraction and filtering. Much of this material has had little impact on and created little interest from the end users of GPS standards.

This is now about to change. The new ISO 5459[11] and ISO 14405-1[9] have been the first standards to have direct impact on what can be expressed on a technical drawing. There are more tools available for expressing functional needs for datums, datum targets, and datum systems precisely. Size is no longer just size; there is a series of modifiers that allows the designer to indicate precisely what is meant by a size tolerance. Next comes ISO 1101:2012,[12] which adds some new possibilities, but the major update of geometrical tolerancing will be in the next update of ISO 1101, which is expected in 2015. It will have as profound an impact on geometrical tolerancing, as ISO 14405-1[9] has had on the concept of size.

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