The ISO-GPS language, a proposed interpretation of ISO 1101: 2017

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Abstract. Geometrical Product Specifications (GPS) is the international symbolic language used to express geometrical technical functional requirements in technical drawings and unambiguously to define their meaning by relying on precise concepts and symbolic representations. Facing some ambiguities produced by certain "open" interpretations in the geometric specification of products (GPS) justifies a critical study and the indication a few guidelines for graphic interpretation of some concepts. On the other hand, EN ISO 1101: 2017 is a functional dimensioning tool defined on isolated, rigid, and immobile parts (except for run-out specifications) that should express unambiguously and completely all the specifications per zone for the geometry of a product on a sufficient nominal model support for the understanding of the standard and corresponding to the functional requirements of its assembly context, to which the part belongs. These difficulties in the interpretation of the norm persist at present, as reported by companies in our industrial environment. This document suggests guidelines for the interpretation of some concepts of the EN ISO 1101: 2017 standard (for non-expert engineering students) and aims to apply a systematic sequential procedure set in a series of steps to provide the precise determination of the tolerance zone to avoid ambiguity, misconceptions, and to enable definition and representation of geometric specifications in technical drawings.

Keywords: ISO-GPS language, Specification, GPS-Card, Functional dimensioning

1 Introduction

The aim of the ISO-GPS standardised graphical language in EN ISO 1101: 2017 [1] is to express geometrical technical functional requirements and to unambiguously define their meaning on the basis of precise concepts and graphical conceptual

representations [2]. The symbols, the terms and the rules of GPS language contained in this standard allow engineers to specify “the imperfect geometry of a component” [3]. We have to specify that EN ISO 1101: 2017 is the ratified standard of ISO 1101: 2017 by the Spanish Association for Standardization in April 2017.
Transition from ISO tolerance standards to ISO GPS tolerance standards shows the difficulty in the process of understanding them particularly the associated terms, the definitions in different languages regarding the interpretation of figures. We consider that it is necessary to highlight its diffusion for pedagogical purposes.
EN ISO 1101: 2017 should express all specifications per zone for the geometry of a product on a nominal 2D or 3D model, but this *ideal nominal model* is not a sufficient framework for its understanding. When standardised symbolic language is applied to a nominal (sketched or CAD specification in common area) model, it appears ambiguous and requires a precise conceptual “skin model” [4] that makes possible to construct an unambiguous meaning as the example shown in Fig. 1. It represents a nominal model *versus* the skin model (real part) in which all the elements necessary to define an ISO-GPS specification have been identified (in this case parallelism in common zone with respect to reference element A).

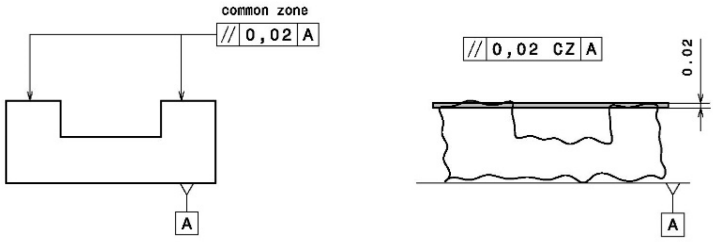


Fig. 1. Specification in common area (Nominal model) *versus* Skin model. Source: own elaboration.

In one of the annexes to the standard [1], tables with figures are provided with the aim of guiding the interpretation of the symbolic expression of these specifications, but without justifying how they have been arrived at. However, this standard redefines, harmonises and introduces new concepts which, although they represent an advance in terms of conceptual precision, do not help understanding by a non-expert user.
The main difficulties we hope to review and address in this paper are the fact that we do not have a protocol for interpretation nor equivalent terms in Spanish for the concepts of the EN ISO 1101: 2017 standard. A sequential procedure is given to facilitate the precise determination of the tolerance zone and we suggest completing a record card, including graphic content, to record all this information. Additionally, as an instance, some terms and concepts accepted in English and French [5] and we provide the equivalent terms and concepts in Spanish. Finally, conclusions and possible future prospects are highlighted.

2 Materials and Methods

Over the last few years, we have seen a persistent difficulty in understanding the ISO-GPS standards by industrial engineering students and some engineering professionals. They considered them cumbersome and not very practical at an academic level or even unnecessary for certain intermediate professional or industrial levels. The geometric specification standards have been affected by this consideration due to the incomplete understanding of basic concepts in the ISO-GPS standards causing their rejection as something cryptic and without much practical sense.

The (pre-2004) ISO standards on tolerances involved an intuitive, quick and practical use of geometrical and technical concepts. They have limitations in terms of specifying of tolerances, which can lead to variations in product quality and functionality. In contrast, ISO-GPS standards involve the use of new, very precise terms and concepts. This transition from ISO standards to ISO-GPS standards for tolerances implies the adoption of new standard symbols and definitions, as well as understanding and implementing of the new tolerance specification and verification methods that requires additional training as certain explanations or descriptions are cumbersome and do not help their understanding. Charpentier and Prenel [6] point out that this evolution from ISO tolerance standards to ISO-GPS tolerance standards leads to a fracture in the learning process which they understand as the shift from "interpretation" to "meaning".

The former ISO standards on tolerances, both dimensional and geometric, and the ISO TC10 basic standards on TDP (Technical product documentation) relied on the interpretation of symbols whereas the ISO-GPS standards aim to avoid the possibility of “open” interpretation by seeking a disambiguation, a unique geometrical significance of the dimensions. In ISO-GPS, the term 'dimension' is changed to 'specification'. This implies a loss of expressiveness, but is much more precise in its meaning. In this context we understand "specify" as precisely defining a geometrical element on a real part.

Another difficulty in understanding the ISO-GPS standards is that a code must be mastered in order to decode them. Moreover, the representation is based on a nominal or theoretical model (2D or 3D) when this decoding must be based on a different model, a model that is closer to the real thing and more difficult to reproduce, the *Skin Model*. The term *Skin Model* [7, 8] refers to a geometric model that describes the external shape of an object and is used to specify the surface geometry of an object.

In summary, we have detected a problem of understanding a geometric message based on an insufficient understanding and mastery of geometric, metrological and functional terms and concepts. We intend to minimise this difficulty in understanding the significant practical consequences by selecting a few examples that facilitate the identification of problems and proposing a method to overcome them.

Our proposal addresses measurement specifications and specifications by tolerance zone. We do not include specifications by pattern because these types of standards

and specifications respond more to practical, productive and assembly needs than to the geometric or functional definition of parts.
Given the complexity of the ISO GPS tolerance standards, an alternative approach is proposed, in an academic context, to facilitate the precise understanding and their effective use of an ISO-GPS specification based on tolerance zones and identification of each intervening element of this type of ISO-GPS specification. Finally, we propose an orderly record of the identification process (GPS record) that will allow its subsequent “capitalisation” [9].

3 Guidelines for graphic interpretation

The best way to start the studying ISO-GPS tolerance standards is through the precise reading of ISO specifications on part definition drawings. Of the three types of ISO-GPS specifications, ISO zone specifications are the most intuitive and well-known, so it would be advisable to begin the study with them. In this case, the conformity criterion goes from establishing a limit with the numerical value of a quantity to the inclusion of the "real" surface of the part within a tolerance zone.
The accurate understanding of an ISO zone specification requires the use of a number of non-explicit geometric elements, as well as the use and understanding of the different properties of integral, derived, extracted, etc. elements. These types of elements may have very different geometric natures, from each other, but with a very direct link. These particular properties and the links of geometric association between them are rigorously defined in ISO standards, but these are neither adequate nor useful texts for an initiation study. Geometric tolerances do not require a detailed understanding or knowledge of metrological operations, although some notions of dimensional metrology are recommended.
An inattentive reading of an ISO specification can seem geometrically very intuitive and apparently easy to understand. A low-level reading could imply: not considering the precision in defining the geometry of a part, not understanding how the specifications have been generated, what is the functional utility of these "geometric tolerances", why certain "geometric tolerances" are necessary and others are not, and why it is necessary to introduce metrological considerations in the definition of an ISO-GPS specification.
When reading a part definition drawing, many geometric constraints are implicit (parallelism, coaxiality, symmetry, etc.) and its definition is apparently resolved with a few dimensions and ISO dimensional tolerances. When we perceive the part as a component of an assembly with parts linked geometrically, that is when we can appreciate the need to identify the functional geometric requirements in which the component is involved to be able to precisely define its geometry.
An ISO specification on a drawing is the communication of a technical functional requirement of a geometrical type that must have been previously wrote down in the technical functional load booklet or card and that in practice has contractual value. A "geometric tolerance" must be the result of a process of technical-

geometric functional specification and analysis. This representation on the drawing constitutes the "final product" of the geometry definition. All this work prior to the dimensioning of the drawing is very valuable and must be recorded so that it can be capitalised on, that is, it can be used and verified later.

A clear instance of the inaccuracy and ambiguity in traditional dimensioning is the application of ISO 8015:1985 which does not provide a precise definition of the direction of measurement. The use of the envelope requirement ensures the assembly of parts, but it is still not possible to apply it to flat surfaces in opposition or to cylindrical surfaces. By introducing the envelope requirement, an additional non-dimensional, pattern or template requirement is being introduced. When the envelope requirement is applied to a non-connected surface, indeterminacy occurs as two independent envelope requirements are defined, which does not ensure the conformity of the part as it does not control the orientation and position of each of the enveloping surfaces. Figure 2 shows an example of a dimension according to ISO 8015:1985. Two parts are shown at the bottom, which must fit together the assembly forces a common area requirement that the envelope condition does not allow to express, therefore it does not allow to ensure the assembly of both parts, which is what the envelope condition apparently guaranteed. We draw attention to the fact that this is an ISO, not an ISO-GPS, dimensioning.

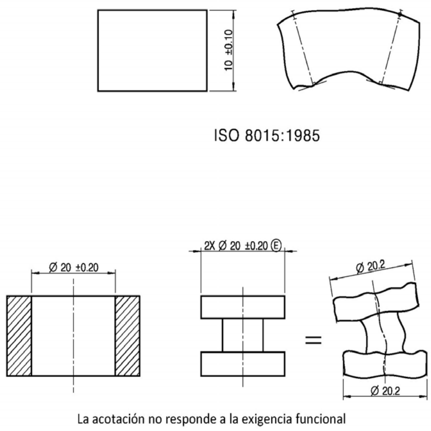


Fig. 2. Example of dimensioning which does not correspond to the functional requirement, ISO 8015:2011[10]. Source: own elaboration.

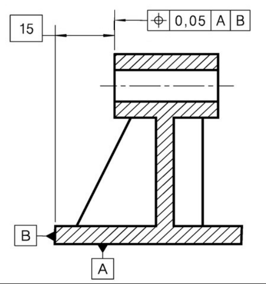
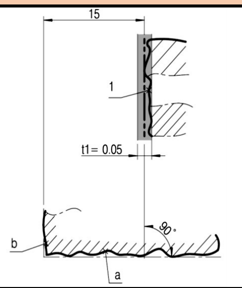
3.1 Proposal description

A practical format for collecting all information linked to an ISO-GPS specification is a card with graphic, numerical, text and operational fields. This card can be susceptible to computer processing. Each ISO functional dimension (geometric tolerance) found in a functional definition drawing must have its corresponding GPS card and be integrated into an ISO-GPS dimensioning dossier. In this way the information will be complete and “capitalizable”. This ISO dimensioning dossier will be integrated in the specifications or Technical Functional Loads Booklet of the project. This ISO-GPS card is the adaptation of a proposal published by Mathieu and Ballu [9] as an ISO-GPS table model and is widely disseminated professionally and academically. Developing an ISO-GPS dimensioning dossier table involves adopting the current industrial practice of definition drawings.

The differences with the card described [9] are that the latter highlights the intention of the operation and the current proposed in this paper does not, in other words, it is a record adjusted to the definition and identification of operations and results. We propose a non-explanatory but expository card in which elements and operations of the ISO-GPS specification are identified.

Four fields are identifiable in the card: Identification and graphical presentation of the specification under consideration; Description of non-ideal elements; Description of ideal elements and Description of characteristic and condition.

Table 1. GPS specification card (Spanish context)

<table>
<tr><td>Ficha GPS nº:</td><td>1</td><td>Elementos no ideales</td><td>Elementos ideales</td></tr>
<tr><td>Especificación</td><td>Zona GPS</td><td rowspan="5">Elementos de Referencia.
Sa, Superficie nominalmente plana.
Sb, Superficie nominalmente plana</td><td rowspan="5">Referencias especificadas.
Primaria:
Pla, Plano asociado a Sa.
• Chebichev.
• Tangente exterior.
Secundaria:
PLb, Plano asociado.
• Perpendicular a Sb Chebichev.
• Tangente exterior.</td></tr>
<tr><td>Tipo</td><td>localización</td></tr>
<tr><td>Autor</td><td>A.V.</td></tr>
<tr><td>Revisión</td><td>M.E.</td></tr>
<tr><td colspan="2">Modelo nominal</td></tr>
<tr><td colspan="2">
</td><td rowspan="2">Elemento de Tolerados.
S1 Superficie nominalmente plana.</td><td rowspan="2">Elemento Nominal.
PL1 Plano asociado.
• Paralelo a PLb
• Distante PLb: 15mm</td></tr>
<tr><td colspan="2">Skin Model</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td>Característica</td><td>Condición</td></tr>
<tr><td>Zona de Tolerancia
Espacio entre:
• Planos paralelos a PL1
• Separados t1=0,05mm
• Simétricos respecto a PL1.</td><td>Condición de Conformidad:
Distancia de punto extraído de S1 a PL1: d1
$\frac{t1}{2} \leq d1$</td></tr>
</table>

3.2 Reading sequence

The ISO-GPS card we propose allows us to collect all data and elements used when executing the sequence of the precise reading of the ISO specification that consists of the following steps:

Table 2. sequence of the precise reading of the ISO specification (also in Spanish)

English	*Spanish*
1- Nominal model	1- Modelo nominal
2- Skin-Model	2-Skin-Model
3- Tolerance type per zone	3-Tipo de tolerancia por zona
4- Integral and/or derived features affected by tolerance	4- Elemento integral y/o derivado afectado de tolerancia
5- Elements of the references system	5- Elementos del sistema de referencias
6- Specified elements of the references system	6- Elementos especificados del Sistema de referencias
7- Nominal element	7- Elemento nominal
8- Width of the tolerance zone	8- Anchura de la zona de tolerancia
9- Tolerance zone	9- Zona de tolerancia
10- Position of the tolerance zone relative to the nominal element	10- Posición de la zona de tolerancia respecto al elemento nominal
11- Conformity condition of the specification	11- Condición de conformidad de la especificación

The first step is to draw the ISO dimension. In its representation, only the part views and the components of the ISO dimension should appear: tolerance box, reference system, TED (theoretically exact dimension), etc. It will occupy a graphic field of the ISO form.
Next, the Skin-Model of the part must be traced with a thin continuous line in another graphic field of the form. On this skin-model every geometrical element that participates in the specification must be determined, so it must be large enough to appreciate all the geometry without difficulty.
The third step is to identify the type of tolerance by zone and the class to which it belongs (form, orientation, location or run-out).
The next step is to identify and highlight on the skin-model the geometric element affected by the tolerance. All geometry that must be within the tolerance zone to be defined must be identified. For this purpose, a thick dashed line should be drawn over the initial skin-model. If the elements affected by the tolerance are derived or extracted elements, additional traces may be drawn.
The following step is to identify the elements that make up the reference system. This step has to be repeated for each element of the reference system. It shall be

drawn on the skin-model with a dashed line of medium thickness and superimposed on the element. In form tolerances, the following two steps are not necessary.

Associated with each reference element, the specified reference element, i.e. the metrological or effective reference element must be identified. In addition, the type of association between the specified element and the integral (Gaussian, Chevichev,...) must be established. It shall be drawn with a thin (dashed and dot line) only in the areas where this element is associated. There may be non-connected lines for the case of partial references.

Identification of the nominal element. With the specified reference system and the TED we can determine the nature and position of the ideal-nominal element. We will have to draw it on the skin-model with thin dashed and two points lines and also represent the nominal dimensions with respect to each specified element of the reference system.

The next step is to determine and identify the tolerance width using a code that allows to appreciate to which part it belongs to and the position it occupies in the list of all tolerances of that part. The numerical value of quality IT must be taken from the nominal drawing and placed in a field on the ISO form.

Next, we must define and drawn the tolerance zone using the boundary surfaces. It is most frequent that the surfaces delimiting the tolerance zone are of the same geometrical nature as the nominal element, but in all cases, they must be able to contain within them the element affected by the tolerance. They must be traced with thin continuous lines.

Once the tolerance zone has been identified, we must determine its position relative to the nominal element. Most often the boundary surfaces of the tolerance zones are symmetrical with respect to the nominal element.

Finally, we must express the metrological condition of conformity of the specification. The discrete and discontinuous character of an extracted element, both integral and derived, must be considered, even other metrological conditions, such as differences between the captured or effective point.

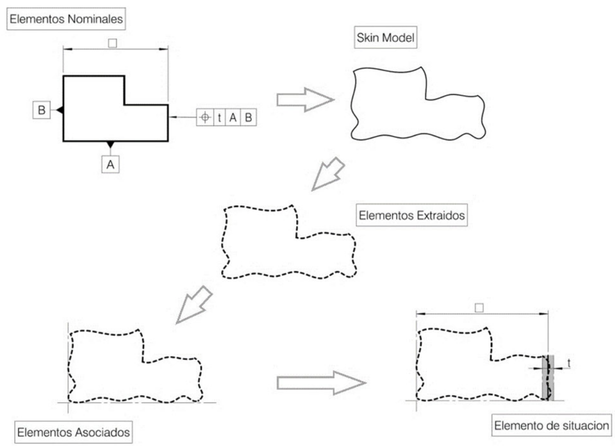


Fig. 3. Reading process for Spanish students. Source: own production.

Each step in this orderly sequence of defining the specification requires a type of geometric elements according to its purpose: representation of the real part, the geometry that is possible to capture and work with, geometry to associate in order to build references and finally geometry to locate each tolerance zone. The ISO-GPS card shall be completed with identifying data of the assembly, the part and the dimension that allow locating quickly to which device and component corresponds and all relevant data. It must include the information of who has made the specification and who has reviewed it.
Traditionally, the ISO-GPS record incorporates nominal models and skin-models in 2D, which is simpler, but there is the possibility of incorporating 3D models in accordance with UNE-EN ISO 16792:2021. This type of registration requires CAD tools with Functional Tolerancing and Annotations (FTA) modules, that are becoming increasingly common and accessible and have the advantage of linking the ISO-GPS specification to the 3D model.

4 Conclusions

Careful analysis and understanding are necessary when using mathematical models of reality. It is reasonable that the representation of nominal models should be simplified as ideal and perfect, but they are not complete. The models of reality and the definitions of the geometrical functional requirements to be fulfilled by the real parts cannot be simplified. The ISO-GPS language allows these geometric requirements to be expressed and understood precisely and unambiguously, but the multiplicity of elements and mathematical operations involved requires a methodology and a register adjusted to the functional importance of the requirements they define, since their fulfilment always guarantees the operation of the part to which they belong.
In our experience, we have found that there is a certain reluctance to change models of understanding related to the interpretation of standards. This undesirable circumstance can be minimised by setting up:

- the proposed protocol showing the accuracy of the ISO-GPS language;
- a complete GPS card that ensures the presence of all the elements involved in the specification;
- the analysis card of the functional ISO dimensions on the skin model must be accompanied by the nominal model;
- each functional dimension must have its own GPS card and all of them must make up the ISO dimensioning dossier of the part and this must be integrated into the Product Specification.

As a future perspective, we believe that complete, precise and rigorous translations of the ISO-GPS standards into Spanish are necessary.

References

1. EN ISO 1101: 2017, Geometrical Product Specifications (GPS) – Geometrical tolerancing – Tolerances of form, orientation, location and run-out (ISO 1101:2017). (2017)
2. Esandi Baztán, María Ángeles. La teoría funcional de la lexicografía y su aplicación a la construcción de diccionarios especializados. Una propuesta de diccionario de expresión gráfica en la ingeniería. Diss. Universidad de Valladolid, (2020).
3. Tornincasa, S. Technical Drawing for Product Design; Cham, Switzerland: Springer Tracts in Mechanical Engineering (STME) (2021); ISBN: 978-3-030-60853-8.
4. Anwer, N., Alex Ballu A., and Mathieu L. "The skin model, a comprehensive geometric model for engineering design." CIRP Annals 62.1 (2013): 143-146.
5. Charpentier, F.: Mémento de spécification géométrique des produits: les normes ISO-GPS. Dunod (2021); ISBN 978-2-10-083117-3
6. Charpentier, F., Prenel, J. M.: Les normes ISO de tolérancement GPS, une fracture dans le processus d'apprentissage (2009). http://cfc-technic.eu/iDisk/Divers/article-cfc.pdf, last accessed 2023/04/12
7. Aublin, M, *et al.* "Exploitation du concept GPS et de la normalisation pour la Spécification Géométrique des Produits." Ministère de l'Education National, de la Recherche et de la Technologie, CERPET (1999).
8. Dantan, Jean-Yves, et al. "Tolerance synthesis: quantifier notion and virtual boundary." Computer-Aided Design 37.2, pp. 231-240, ISSN 0010-4485 (2005). https://doi.org/10.1016/j.cad.2004.06.008
9. Mathieu, L., and Ballu A. "La «Fiche GPS», outil d'expression univoque des spécifications géométriques." Actes AIP-PRIMECA de la journée thématique» le tolérancement le long du cycle de vie du produit, Paris (2005).
10. ISO 8015:2011 - Geometrical product ISO 8015:2011 - Geometrical product specifications (GPS) - Fundamentals - Concepts, principles and rules, (2011).