Inspection-oriented Tolerancing
Size, Form, and Location

Summarized by

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If You Can't Measure It,
You Can't Manage It
(Peter F. Drucker, 1909-2005)

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Dr. Robert Roithmeier

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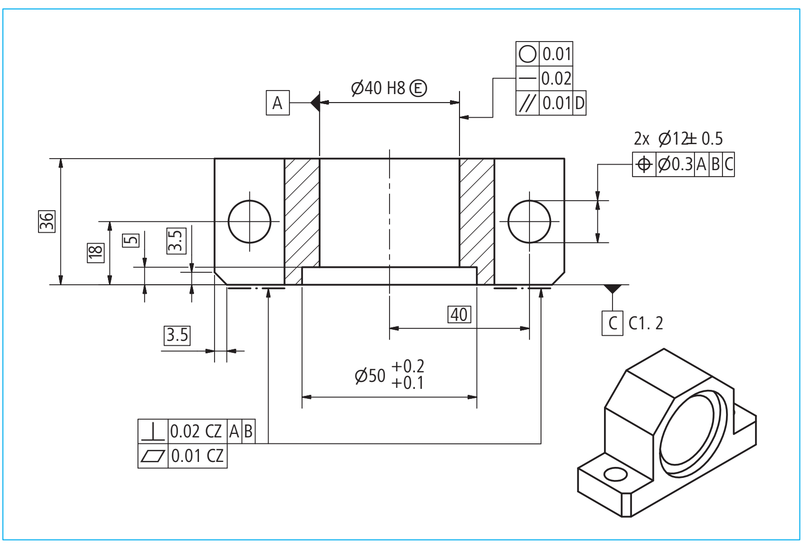
1 Introduction

1.1 Engineering in compliance with functional, manufacturing, and inspection requirements

In order to be competitive in international markets, the industry is forced to manufacture its products more efficiently and to become more productive. This is where engineering drawings of the workpieces to be produced come in, since they play a key role in this context. In industrial manufacturing, an engineering drawing is a core reference for a clear and complete product description. It is the most important means of communication between design, engineering, manufacturing, purchase, sales, and the customer – worldwide. No matter what format is used, this may be a traditional 2D engineering drawing on paper (see Illustration 1) or a digital data set [STEINBEIS 2014].

Illustration 1: Technical drawing of a bearing block (extract)



The drawing (or CAD data set) must include all specifications needed to guarantee functional safety, economical production, and reliable inspection of the workpiece in question. The technical drawing (or CAD description of the workpiece) must therefore be created with a view to meeting the requirements in terms of

- function
- production
- inspection.

This last point is often especially neglected, although it is one of the basic conditions for an economical production. That is why this book not only deals with the suitability of technical drawings and CAD descriptions for meeting functional and manufacturing requirements, but particularly focuses on their fitness for inspection purposes.

GPS standards

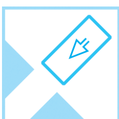
Thanks to the work of international standardization committees, a comprehensive descriptive language for geometrical product requirements has been created: the GPS standards[1]. Based on these standards, geometric requirements can be described completely, clearly, and unambiguously in technical drawings and CAD files. The GPS standards contain a symbolized language and rules, which are constantly evolving. Any information needed to meet the requirements with regard to function, manufacturing, and inspection can thus be included in the drawing. This guarantees the functional properties of a product and ensures its suitability for mounting and inspection once the drawing has been released [Gröger 2013].

1 GPS = Geometrical Product Specification; for details refer to [ISO 14638]

Furthermore, the GPS standards are supposed to promote communication between the different "worlds", which the [ISO 22432] standard describes as follows:

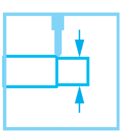
- product as conceived by the designer,
- manufactured product,
- measured product.

Function



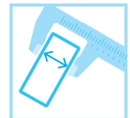
The product conceived by the designer is a purely functional one. All geometric properties are chosen for the purpose of fulfilling the desired function. Geometric tolerances (size, form, position, and surface tolerances) are defined to guarantee that function. This means that the "imprecise" workpiece must be able to fulfill its intended function throughout the entire service life if its deviations are within the defined tolerance limits. It must be either unconditionally suitable for assembly (i.e., same parts can be exchanged at will) or conditionally suitable (i.e., same parts are combined or can only be exchanged together) [Klein 2014]. These are the function-related requirements to be met by the engineering drawing.

Production



The manufactured product is subject to typical deviations resulting from the production process. In practice, it is impossible to manufacture parts without deviations. Such deviations are caused by the effects of material properties and production conditions (e.g. tool type, shear force, production speed, clamping, residual stress of the workpiece, ...). Nevertheless, it must be possible to manufacture the workpiece within the defined tolerances, while ensuring cost-efficiency and process capability [Klein 2014]. According to this, a manufacturing-oriented drawing needs to meet other requirements than a function-oriented one: it must, for example, specify the points for clamping and include the allowances required for the various machining steps.

Inspection



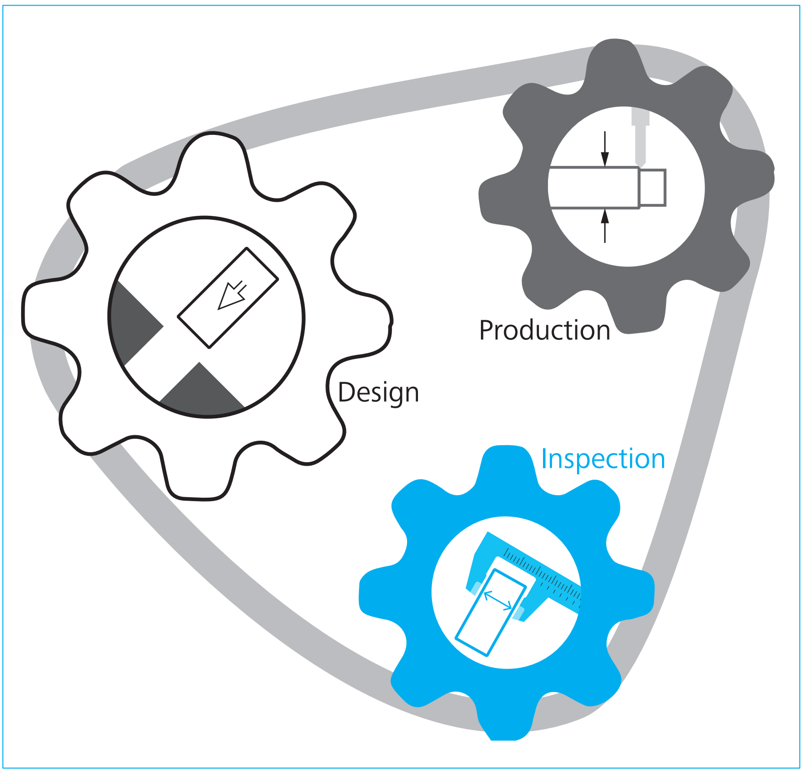
With regard to the measurement of a product in turn, additional criteria need to be met. It should be possible to inspect or measure the product reliably and as easily as possible. The drawing must include the essential features of a product to ensure its function and suitability for assembly [Klein 2014]. The drawing is supposed to allow clear and unambiguous interpretation of all tolerances in order to avoid different or incomparable measurement results and, consequently, unnecessary discussions with suppliers and other departments due to incompleteness, contradictions, and ambiguities. Reliable inspection is a precondition for reliable manufacturing. Therefore, both the function-oriented drawing and the manufacturing-oriented drawing (if available) need to be created with a view to meeting inspection requirements. However, two particular problem areas will have to be faced in this context, and this book aims to help you handle these difficulties:

- The first issue to face is the large number of standards existing in the field of geometrical product specification (GPS). They cover far more than 2000 text pages, which have not all been read and understood by all those involved in the product manufacturing process. Consequently, only few quality professionals fully understand the information provided by a drawing [NPL 79] and the meaning of the symbols (e.g. 20h7 (GN) ACS 0.2 (SR)), or know how to perform the corresponding measurements.
- The second problem is that the symbols used in a technical drawing (e.g. ⌖ or ◎) may apply to different tolerances and measurement methods, depending on the country, the drawing's date of creation, and the standard on which it is based.

1.2 Cooperation between the areas

Such challenges related to a function-, manufacturing-, and inspection-oriented geometrical product specification can only be tackled jointly. Even though the designer is always responsible for the product specification, it is only if design, manufacturing, and metrology staff act together that cost-efficiency, high quality, and operational reliability (also in terms of product liability) can be guaranteed.

Illustration 2: Cooperation in industrial production



Need for communication

Communication between the various stages is of fundamental importance in the course of a production process. Good metrology, in particular, should be a part of this process. It is not restricted to measurements on the final product. According to the GPS system, tolerancing and measurement capability criteria should be considered for all stages of design, manufacturing, and inspection. It is usually much costlier to modify an engineering drawing later, for example when noticing that a specific functional feature cannot be measured as planned [NPL 79] or does not provide the desired information.

The following chapters will present various aspects of geometric dimensioning and tolerancing ("GD&T") for design, manufacturing and inspection of workpieces. Furthermore, you will find an outline of the international system of ISO GPS standards, and the book will deal with advanced options for defining the measurement strategy in the technical drawing.

14 rules of analysis capability

Fourteen rules of inspection-oriented GD&T are summarized below. Each rule will be dealt with in detail in the course of the book:

- Rule R1: inspection-oriented tolerancing of form
  Form must be controlled for any geometric element that is relevant to function or will be used as a datum for other features. Furthermore, tolerances of size and position can be adhered only if the form of a feature is also controlled. (Page 25 et seqq.)
- Rule R2: inspection-oriented dimensional tolerancing
  Modifiers are to be used for task-specific dimensional tolerancing. Such unambiguous metrological specifications allow better comparison of measurement results and target-oriented tolerancing in compliance with functional, manufacturing, and inspection requirements. (Page 47et seqq.)
- Rule R3: inspection-oriented independency and envelope requirement
  The separate verification of size and form tolerances is useful for

the manufacturing process (independency principle). The dimensional tolerance needs to be marked by Ⓔ only in cases where the function requires adherence to the envelope condition. This is always preferable to a reduction of the individual size and form tolerances. Requesting the envelope requirement for all sizes would not be economical and defeat the purpose. If, instead of using the Ⓔ symbol, you reduce the individual size and form tolerance ranges just to "be on the safe side", you would unnecessarily increase the expenditure for production and inspection. (Page 53 et seqq.)

→ Rule R4: inspection-oriented datums

In order for a datum to be stable and suitable for analysis, its form deviation must be significantly smaller than that of the feature to be toleranced. Furthermore, when establishing datums, make sure that they are distinctive and accessible for measurement, and that the datum feature and the toleranced feature are not too far apart. (Page 61 et seqq.)

→ Rule R5: inspection-oriented tolerancing of orientation

Check whether it is possible to use angularity tolerances instead of angular dimension tolerances. They are usually easier to measure, especially in the area near the vertex. Moreover, the angularity tolerance provides separate results for the datum feature and the toleranced feature. (Page 75 et seqq.)

→ Rule R6: inspection-oriented tolerancing of location

Tolerancing is always preferable to dimensional distance tolerancing. It is easier to define positions than dimensions, and this reduces specification uncertainties significantly. The use of cylindrical or circular tolerance zones generally provides a larger tolerance surface while the functional requirements remain the same. This ensures optimized usage of the desired tolerance and better suitability for inspection purposes. (Page 87 et seqq.)

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