Analysis and impact of different ambiguities in industrial technical product drawings

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Abstract. The declaration of conformity of a workpiece to the technical product drawing is absolutely essential in modern industrial product development. Today, the dimensioning of the technical product drawing features many ambiguities, which are indicated unconsciously by the construction and development departments. Not least, the reason for this can be found within the steady changes of the international standards, which are controlled by the system of Geometrical Product Specification (GPS). As soon as the planning, concept and development stage within classical industries is largely completed and a no longer modifiable drawing status has been attained, suitable tools have to be built on the basis of the technical product drawing in order to start production. Once the tools are available, the results of the pilot series can be assessed via initial sample analysis. During this stage, the assessment via measurement technology equipment ensues in order to ascertain the requirements of the technical product drawing. The assessment of the negative measurement values ensues within the project team, which is difficult since it can yield many divergent assertions. This paper analytically shows the impact of ambiguities resulting from technical product drawings and contributes to the solution of a precise geometrical quality assurance through its clarity.

1. Introduction
In the industrial sector, it is the customers who decides on the success or failure of a company, because they either buy a product or they don’t. The parameters of purchase price, quality and availability of a product are usually decisive for their satisfaction, with the customer matching the product to his requirements. Accordingly, it has a negative effect on the purchase decision if a product is inexpensive but does not meet the pre-defined requirements of the technical drawing. As soon as the planning, concept and design phase in the technical area is largely completed and a drawing status that can no longer be changed has been reached, the appropriate tools must be built in order to be able to start production. When the tools are available, the result can be evaluated in a pilot series. If the result is positive, the finished parts are sent in for an initial sample analysis. The measurement is carried out either externally or internally in a measurement laboratory, whereby ideal ambient conditions should prevail, and higher-quality measuring instruments than in series production should be used. The objective is to evaluate the decisive test specifications and, if necessary, take corrective action based on the measured values. In this case, either the tools or the technical drawing must be changed, or the pilot series must be rejected. If the manufacturing process is classified as sufficiently safe based on the pilot series, production release can finally take place and the product can be transferred to series production.
2. Standard specifications in technical product drawings

In the product development, the international Geometrical Product Specification (GPS) standards are regarded as indispensable. The principle of independence [1] is an essential component. It stipulates that every GPS requirement for a geometric element or a relationship between geometric elements must be fulfilled by default independent of other requirements. An exception is made if it is identified as part of the current specification in a marked standard or by a special indication such as modification symbols. In accordance with the principle of independence, it becomes clear that, depending on the order of magnitude used and documented, different measured values can occur during the measuring process. Finally, figure 1 shows that different two-point measurements (which are valid as a default rule unless otherwise specified in the technical drawing) can be output.

![Figure 1. Independence principle, determination of different two-point size dimensions [2].](image)

However, the challenge and conductive factor for the process deviations is also that there is no GPS-standard specification in which it is stated how often the two-point size measurements must be recorded and documented, so that the test of the intended specification is also proven [3].

2.1. Ambiguities due to distance measures

However, serious deviations also occur during the verification of distance measurements as they are also known under classical step dimensioning. These are dealt with in an own international standard [4] and are regarded as ambiguity and as a non-reproducible requirement. The following figure 2 shows theoretically and practically possible distances to be measured for a single specification.

![Figure 2. Ambiguity with possibility to determine various measured values [5].](image)

Ambiguities can be marked for uniqueness using geometric specifications such as form- and position tolerances [6]. However, further challenges such as different understanding, training and technical equipment are required, which must be purchased involving high costs.

2.2. Alternative specification to optimise the process chain

Due to tighter tolerances and increasing quality requirements, the importance of simple specification in technical drawings is becoming more and more relevant. According to the guideline guide to the
expression of uncertainty in measurement (GUM), it is repeatedly assumed that the measured value must also be the best estimate of a measurand [7]. However, this prerequisite is rather fulfilled by the mean value, more rarely by an extreme or random value. Recommended GPS-standard specifications, which can also be specified in any technical drawing, would thus be covered by the least square’s method (Gaussian strategy) as also shown in figure 3.

Figure 3. Visualization of a size measure of the smallest deviation squares according to Gauss [2].

This evaluation by gaussian method, presupposes that a means value covers the requirement according to GUM [7] most closely. The surfaces will be recorded and arithmetically evaluated. Finally, empirical measured values output.

3. Reproducibility analysis of different evaluation strategies

In order to investigate the influence of different evaluation strategies, a meaningful analysis is presented with the help of sampling tests, which among other things can prove reproducibility. In order to evaluate the measuring strategies properly, the influence of different sensors on different workpieces is optimally prevented [8]. First, at different locations (DE=Germany and RO=subsidiary in Romania) at least five saturated and air-conditioned plastic samples are taken from the same tool and are checked based on an ambiguous specification. The requirement is 70.70mm ±0.05mm. Furthermore, two different operators, different measuring equipment (calibrated computer tomography and -multisensor technology, with a maximum permissible error of 6.5µm) and different evaluation strategies (two-point measurement and Gaussian strategy) are available for the experiment. First, in the following figure 4, a representation of all experiments that have been determined in this context is shown.

Figure 4. Demonstration of process deviations on industrial workpieces.

If the evaluation is filtered according to the two-point measurement and the Gaussian strategy, a clear trend can be highlighted as shown in figure 5 (evaluations according to the Gaussian strategy) and as shown in figure 6 (evaluations according to the two-point measurement).
Figure 5. Evaluation by means of the Gauss strategy on five plastic samples with different operators and different measuring systems.

Figure 6. Evaluation by means of the two-point measurement on five plastic samples with different operators and different measuring systems.

Subsequently, as already noted in the GUM guideline (best estimate is only fulfilled by the mean value) [7], a new test of the two-point measurement was initiated. Each individual sample should be measured at least five times without the operator knowing that the same sample is being measured repeatedly. Finally, the mean value from five individual measurements of the identical sample was output, the course of which is shown in figure 7.

Finally, a comparison to the Gaussian strategy becomes clear. The more measurements are carried out, the more likely it is that the measured value of the before presented position from the Gaussian
strategy (figure 5) will be reached. This also corresponds to the theory of normal distribution/Gaussian distribution.

![Graph showing tolerance zone](image)

**Figure 7.** Evaluation by means of the two-point measurement with five repetitions each.

4. Systematic measurement error, forced by ambiguous specifications

Prospectively, it will be somewhat more difficult to integrate processes and research into the everyday environment of industrial product development. The challenge lies in identifying systematic errors at an early stage, before they are merely evaluated incorrectly and lead to costly interventions in the tool or the entire process chain. Figure 8 shows a single detailed view of a technical drawing, which at first appears to be self-evident and unambiguous.

![Detailed view of technical drawing](image)

**Figure 8.** Detailed view of a reconstructed technical drawing from a medium-sized company.

Already the acquisition of the radii will not be reproducible, because there is a little circular segment available and so a random error will be occurring with also no reproducible centre point to be expected [9]. If dimension position number four is considered here solely, it quickly becomes clear that the requirement is measured by means of the intersection point (as can also be seen in detail Z 10/1). To visualize this measuring problem, the workpiece was scanned using computer tomography and presented as an stereolithography (STL) -file for preview in Figure 9.
Consequently, two projected planes were generated on the surfaces so that they intersected. In order to see the trend of the intersection point, the created planes were enlarged simulatively. It becomes apparent that various intersection points can be determined, if a bigger view is shown here. It quickly becomes clear that an offset of 0.032mm can already be expected at a simple geometry. Finally, incorrect or omitted measuring would eventually lead to an incorrect assessment and cause high costs [10].

5. Conclusion
In the productive industrial sector, measurement tasks are still solved in many ways. These divergent procedures do not make measurement values comparable to each other. In order to obtain reliable and reproducible measured values, it is advisable to document the measuring strategy for measuring tasks with similar workpiece geometries. From the realization that the operator has the greatest influence on reproducible and reliable measurement results, it can be concluded that special care must be taken in this respect. Not only because the operator error can never be ruled out, but also because in most cases the operator himself is responsible for defining the measuring strategy in a company. A global guideline and clearly documented explanations in technical product drawings are regarded as indispensable during the consequent globalization. The specifications from technical drawings must be clear and complete so that reproducibility and comparability can be carried out in the process. Ambiguities do not allow for comparison. Thus, it remains a prospective research matter to master various ambiguities and changes in the technical product documentation in the coming years. Ultimately, the new "Industry 4.0" revolution also requires precise testing of product quality as a basic prerequisite, so that subsequent processes can harmonize with each other in general.

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