TOLERANCING MINI-SERIES

Tolerances are a fundamental part of modern product design and manufacturing. They affect not only the quality and performance of a product, but also its cost, manufacturability and time-to-market. Poorly defined tolerances, inadequate reference patterns, or inefficient assembly sequences can lead to high production costs, higher rework and scrap rates, and delays in product launch. It is therefore critical for engineering organizations to have a clear understanding of the impact of tolerance decisions throughout the product development process (PDP).

In today's increasingly complex and multi-functional design environments, tolerances must be precisely defined, managed, and communicated. This ensures that critical dimensional information flows seamlessly from design to production to quality control, and back to engineering. Whether documented in 2D engineering drawings or incorporated into 3D CAD master files, tolerances and reference structures are the backbone of design intent and product quality assurance.

This series of articles explores four key aspects of modern tolerance:

1. Dimensional Management (DM)
2. ISO GPS – Geometrical Product Specifications
3. Statistical Simulation of 3D Tolerance
4. QIF format for model-based definition (MBD) and digital continuity

Each article aims to provide insights into how tolerance can be systematically implemented in PDP, using simulation, standards, and digital tools to improve product quality and reduce manufacturing costs.

Definition of Geometric Dimensioning and Tolerancing in ISO GPS

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The definition of tolerances according to the ISO GPS standard is central to modern dimensional management. Building on the principles of deriving tolerances and references from product and assembly requirements, as presented in the first part of this article, this section focuses on the practical implementation of ISO GPS – the international series of standards for geometric product specification.

Basics: the functional definition of datum reference frames (DRFs)

Component tolerances are fundamentally defined based on the assigned functional reference system. DRFs are specified in ISO 5459 and are based on how the component functions within the overall product. They are defined by the six degrees of freedom (translation and rotation axes of the component). The following principle applies: DRFs are derived from the geometric assembly elements of the component as well as the sequence in which they are aligned during the assembly process.

Typical functional geometries include planar surfaces, holes, pins and spherical surfaces i.e. geometries that are suitable for achieving stable and reproducible alignment of components. These "standard geometries" are documented on the drawing as DRFs in accordance with ISO GPS and form the binding basis for production, assembly, testing, and quality control.

Defining the degrees of freedom (DOFs)

When determining the DRFs, the role of each geometric element in limiting certain DOFs must be considered. For example, a reference plane defines three DOFs (translations in the normal direction, and rotations around the two main axes of the plane).

Conversely, a borehole or shaft with predominantly axial alignment defines four DOFs (two x translations and two x rotations perpendicular to the main axis).

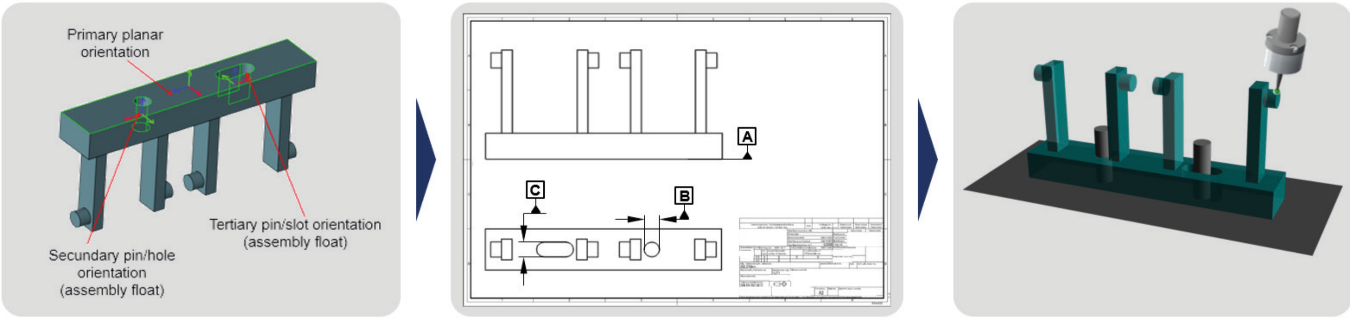


Fig. 1. Derivation of part and measurement DRF from assembly orientation.

The sequence of these constraints is not arbitrary: in the so-called "primary-secondary-tertiary" principle, the most important surface or axis is defined first (primary datum), followed by additional references to fully constrain all six DOFs.

Top-down approach: consistency of DRFs

A fundamental principle of the ISO GPS approach is to ensure consistency of DRFs at all assembly levels, from the final product to its individual components. This top-down approach ensures that the DRFs of the components align with the reference system of the final product.

However, "DRF flaws" can arise when new or different DRFs are defined in subassemblies or individual components. This can lead to unwanted variation accumulations, assembly problems, or quality deviations. The solution: DRF elements are derived from the top-level assembly and inherited across all sub-levels.

Geometric tolerances in relation to DRFs

Once the DRFs have been clearly defined, the tolerance definitions will be established in accordance with the ISO GPS series of standards, including ISO 8015, ISO 17450 (Basic standards), ISO 5459 (DRF), ISO 1101 (form, location, orientation and runout) and ISO 5458 (pattern tolerancing). The following distinctions are made:

- Position tolerances define the position of an element in relation to a DRF
- Profile tolerances regulate permissible deviations of surfaces or planes (e.g. surface profile, or line)
- Orientation tolerances limit rotational deviations (e.g. perpendicularity, angularity, and parallelism)
- Form tolerances describe a single geometric element (e.g. straightness, flatness, roundness, cylindricity, or a profile without datums)

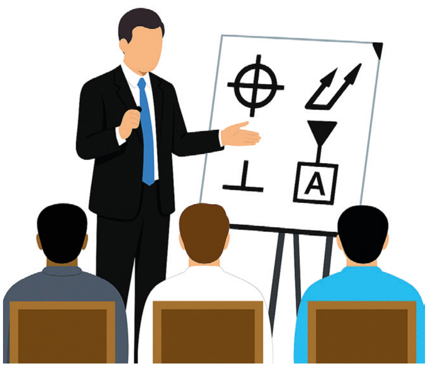
In this context, position and profile tolerances warrant particular attention, as they cover form, position and orientation. These tolerances serve as "master tolerances" for numerous function-critical elements.

The specific tolerance values depend on the function of the element within the product, the material used, the manufacturing process, and environmental factors such as temperature and humidity.

Training and qualification of ISO GPS standards

Implementing the ISO GPS standard in practice requires a solid knowledge base. Therefore, it is critical to the success of the project that all the developers, designers, quality, and production experts involved receive training.

EnginSoft's basic ISO GPS training courses typically last two days and cover the methodology for defining DRFs, as well as how to interpret and apply tolerance symbols. Advanced training courses and customer-specific workshops are also available. During these courses, components in technical drawings are analysed according to their function and specific tolerances are derived.



The ISO GPS CBT (computer-based training) course from Sigmetrix provides flexible, location- and time-independent training. Spanning 13 chapters and approximately eight hours, this course provides all areas of a company with the necessary basic knowledge. An added benefit of the CBT is that it is permanently available as a digital knowledge base that can be revisited as required.

Conclusion

Rather than being an isolated step at the end of the design process prior to releasing technical drawings, defining geometrical dimensions and tolerances is an integral part of systematic tolerance management. Functional definition of references, use of consistent DRFs throughout the product, and targeted training of those involved ensure cost-optimized components, product quality that meets ISO GPS standards, and reproducible, high performance production processes.

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With the ISO GPS CBT from Sigmetrix, we ensure our associates worldwide stay up to date with the latest ISO GPS standards.

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Simon Schmitt
Senior Product Manager Corporate Learning
at Bosch Training Center