TECHNOLOGY TRANSFER

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.

Dimensional Management (DM)

by Florian Weidenhiller
EnginSoft

What is dimensional management?

Dimensional management (DM) is a simulation-based engineering methodology that analyses and ensures dimensional quality throughout the product lifecycle. It aims to minimize variation in parts and assemblies through robust design, manufacturing, and inspection processes. By controlling variation early in the product development process (PDP), DM supports the creation of products that meet quality requirements while reducing costly rework, scrap, and delays in production and/or time-to-market.

More than just a quality control tool DM is an integrated framework that links design, manufacturing, and quality teams, within a company and with suppliers/customers, promoting collaboration and data-driven decision-making. It acts as a vital interface between the PDP and the production planning process (PPP), ensuring that product and process designs are compatible, feasible, and verifiable.

The role of dimensional management in the product development process

Dimensional management plays a central role in the entire PDP, serving as a common thread linking all disciplines involved from initial concept to full-scale production. Rather than treating dimensional quality as an afterthought, DM brings it into the initial stages of development, allowing teams to anticipate challenges and control variation before physical prototypes are built.

At each phase of the PDP, DM allows dimensional requirements to be clearly defined and evaluated. This includes setting quality limits, planning assembly sequences and analysing how design choices affect overall build precision. With this insight, teams can make informed decisions that balance functionality, manufacturability, and cost.

One of the main functions of DM is to create robust reference diagrams and tolerance definitions that are both technically valid and achievable. These definitions are created with an understanding of how parts will be assembled and inspected, ensuring alignment between digital models and real-world production. Critical characteristics, those that have a direct impact on performance or assembly, are identified early on, enabling the development of targeted inspection and verification strategies.

DM also guides the creation of measurement plans, ensuring that dimensional checks focus on what really matters. This includes identifying not only where to measure, but also how to measure, with what equipment, and under what conditions. By considering inspection requirements alongside design and manufacturing, DM ensures that quality assurance is not an afterthought but an integral part of the product lifecycle.

Most importantly, DM facilitates smooth communication between functions. It creates a common language for dimensional quality, enabling design, manufacturing, and quality teams to work in a coordinated way. This alignment reduces ambiguity, avoids costly iterations, and ensures that the product performs its intended function with a high degree of confidence, on time and within budget.

Systematic approach to dimensional management

The implementation of dimensional management follows a structured, step-by-step methodology that is aligned with the key stages of the product development process: concept, design, prototyping, and production. Rather than relying on disconnected quality control at a late stage in the process, this approach integrates dimensional thinking from the very beginning.

The concept phase focuses on defining and documenting the dimensional requirements of the product. Initial considerations include the evaluation of possible assembly and design alternatives, with the goal of minimizing complexity and variation. A key part of this phase is establishing clear parts and assembly location diagrams, which form the basis for downstream production and quality assurance processes.

As the project matures, more detailed activities will be undertaken. These will include the definition of ISO GPS-compliant reference structures and feature controls to communicate tolerance information. Design optimization will be conducted using 3D tolerance simulations to predict and control variation between assemblies. Critical functional characteristics and relevant measurement points are identified to guide both production control and inspection planning. An optimized measurement strategy is also developed at this stage to ensure that subsequent inspection can be carried out efficiently. In the prototyping phase, the focus shifts to the validation of processes and physical tools. Measurement devices and equipment are assessed and verified for suitability in both design and production contexts. Statistical techniques such as gauge repeatability and reproducibility (Gauge R&R) studies are used to ensure that measurement systems are consistent and reliable. In addition, capability studies are used to assess the dimensional stability of parts and assemblies under real-world conditions.

Finally, during the production phase, dimensional management supports the implementation of statistical process control and continuous quality monitoring. This includes not only the detection of variation, but also the active management of improvement initiatives. Root cause analysis is conducted to resolve any dimensional issues that arise during assembly. Information from production is fed back into the design and manufacturing processes, enabling continuous optimization throughout the product lifecycle.

This holistic and iterative approach to dimensional management ensures that tolerances and reference schemes are not only theoretically valid, but also practically viable, traceable, and measurable throughout the product's journey from concept to reality.

Key principles and emphases

The successful application of dimensional management depends on a set of foundational principles that guide its implementation across all disciplines. At its core, DM is a collaborative process that requires the active involvement of design, manufacturing and quality experts. All decisions regarding tolerances, reference structures and measurement strategies must be discussed, validated, and agreed upon by the relevant stakeholders to ensure alignment and consistency.

A critical starting point for DM is the geometry of the product itself, which serves as the basis for defining both functional requirements and quality criteria. The orientation and sequence of assembly steps are logically derived from this geometry. These assembly considerations are not developed in isolation but are deeply connected to the dimensional stability and inspection feasibility of the product. Reference patterns and tolerances are determined based on part orientation and functional features. Specifically, the orientation of parts in an assembly is guided by principles such as degrees of freedom and the function of mating surfaces or critical elements. This structured derivation ensures that references are both logically chosen and meaningful, supporting robust assembly and inspection.

To optimize these definitions, DM relies heavily on 3D statistical tolerance simulations. These simulations allow teams to evaluate different scenarios, identify variation risks, and make informed decisions on where to tighten or loosen tolerances. This not only supports better product quality but also reduces overengineering and unnecessary manufacturing costs.

Finally, it is essential that all optimized tolerance and reference information is accurately documented and communicated. This is typically done through 2D engineering drawings or embedded directly into 3D CAD master models, ensuring that design intent is preserved and accessible throughout the product lifecycle, from design to manufacturing, and even into inspection and quality feedback loops.

Why DM matters

DM is not an optional add-on, but a fundamental element of modern engineering workflows. In a world of shrinking development cycles, complex supply chains and increasing quality demands. DM enables companies to deliver the right products first time. It reduces ambiguity in design intent, aligns teams across disciplines and minimizes surprises in production and assembly.

Integrating simulation, standards and measurement, dimensional management is the backbone of digital product quality, from the first conceptual sketches to full-scale production.

For more information:
Enrico Boesso – EnginSoft
e.boesso@enginsoft.com