Dimensional Management in Vehicle Development

A preventive quality assurance method

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____ In vehicle development, dimensional management is used as a preventive quality assurance method to ensure fulfillment of visual and functional requirements. This makes it possible to avoid potential problems before they occur. The overriding objective of dimensional management is to achieve high product quality without rework.

At Porsche Engineering, the dimensional management method is assigned to the Production Engineering department, which deals with process issues for vehicle and industrial projects on a cross-project basis.

Why dimensional management?

The ever more demanding requirements on products in terms of design, appearance, and function led to the development of dimensional management, a preventive quality assurance method that ensures the functionality and producibility of designs at an early stage. Dimensional management makes it possible to avoid potential problems before they occur. It enables engineers to fulfill required quality characteristics (joint scheme) and safeguard points of constriction and critical functions.

The three central components

Dimensional management is primarily comprised of three central components: "specifications—functional dimensions and joint scheme," the "reference point system," and "statistical tolerance analysis." In detail:

Specifications—functional dimensions and joint scheme

Components and modules are to be dimensioned in consultation according to overarching quality and functional characteristics. The values thus determined are called functional dimensions. The relevant characteristics for the product are summarized in a requirement catalog—for instance in a joint diagram or functional dimensions catalog. This is used in production for statistical process control (SPC) and error analysis.

Functional dimensions for individual parts or assemblies are documented in the respective drawings. In defining the functional dimensions, the dimensional management principle of *"As precise as necessary, as imprecise as possible"* should be observed. The proper balance between restriction and room for maneuver is necessary to produce a flawless product at an acceptable cost. It is also important to ensure the testability of functional dimensions, as what is technically feasible in practice often places limits on the theoretical ideal.

If, for example, a curved surface or a hard-to-reach edge is involved, it may be difficult or even impossible to measure the functional dimension reproducibly in reality. The result is high scrap rates, which in turn leads to a search for the error, intervention in ongoing processes, and other measures that—particularly in manufacturing—cause high costs. This can be avoided through intelligent definition of functional dimensions.

Reference point system (RPS)

The comprehensive reference point system (RPS) for the individual parts and assemblies up to completion of the product is the foundation for dimensional management. It is the basis for creating tolerance concepts and measurement planning as well as for the assembly concept.

The task of RPS is the precise positioning of a component/assembly in free space and the limitation of the six degrees of freedom (three translational and rotary directions of motion each) using the 3-2-1 rule. This applies to all fixed systems. For kinematic systems, the degree of freedom for the component that causes a motion must remain unrestricted. The RPS points should be in stable areas and ideally parallel to the component coordinate system in their alignment. An adroitly positioned RPS can enable tolerance effects in places that are neither of a functional nor customer-specific character.

Statistical tolerance analysis

Statistical tolerance analysis makes it possible to determine the influence of particular characteristics such as geometric dimensioning and tolerancing or assembly factors in the overall context. By analyzing this calculated data in combination with the required quality characteristics, it is possible to determine first pass yields and scrap rates. 1D tolerance calculation or 3D tolerance simulation is used for this.

The statistical calculation of quality and functional characteristics primarily shows whether the target parameters will be achieved with the present assembly concepts and the available quality of components or whether optimizations will be required to reach the targets. The task then is to develop solutions with the relevant departments.

Advantages

This analytical approach makes it possible to secure the required quality characteristics (e.g. joints and transitions) and functional requirements for components (e.g. points ›

There are various approaches to influencing a result:

- > Optimization of the assembly concept, thus reduction of contributors
- > Optimization of the mounting concepts for individual parts
- > Construction changes
- > Adjustment/restriction of individual tolerances (caution: rising production costs)
- > Optimization of the production process and thus improvement of the quality capability indicators of individual contributors (process capability cp or process capability indicator cpk—caution: rising production costs)
- > Expansion of quality specifications (tolerance specification)
- > Styling adjustments (modify critical joint designs, etc.)

of constriction and mountability). Weaknesses in the styling, design flaws, and process risks also become visible and can be remedied as necessary. This enables significant reductions in the times and costs for development, production, and reworking.

Interface in the product creation process

Successful dimensional management spans the entire development process and requires continuous and close consultation with all involved departments (development, production, ›

1D tolerance calculation

- > Mathematical calculation of tolerances using statistics
- > From simple calculation (Root Sum Square method) to complex calculation using convolution of different distributions
- > The latter in special tolerance calculation programs
- > Suitable for preliminary concept calculations and simple relationships
- > Also applicable with larger or more complex scopes

3D tolerance simulation

- > Results from three-dimensional simulations of assemblies with randomly varying tolerances
- > Result of over thousands of simulated production runs with statistical evaluation
- > Suitable for large, complex contexts with a strong three-dimensional impact
- > Advantages:
  - – Summarization of multiple measurements in one simulation
  - – Accounts for three-dimensional geometry and effects
  - – Simpler variant evaluation
  - – Evaluation of kinematic systems
  - – Evaluation of flexible, overdetermined components
- > Disadvantages:
  - – Potentially complex setup
  - – Higher software costs

Dimensional management – procedure in vehicle development

1	Definition of the scopes/quality characteristics (joint diagram, function dimension catalog)
2	Identification of relationships and contributors (assembly sequence, RPS design, tolerance concept)
3	Identification of factors and production process parameters (component, equipment, assembly tolerances and their distributions)
4	Execution of tolerance analysis (1D tolerance calculation/3D tolerance simulation)
5	Evaluation of results (Monte Carlo simulation) and estimation of contributors (Pareto analysis), determination of first pass yields (rework) with regard to required quality and joint specifications (from joint diagram/functional dimension catalog)
6	Documentation of tolerance analysis (including graphic representation)
7	Communication of analysis results to development teams
8	Definition of measures and development of concept alternatives in the development teams in case of “not-OK” results
9	Feed measured values into tolerance analysis and update

The dimensional management system

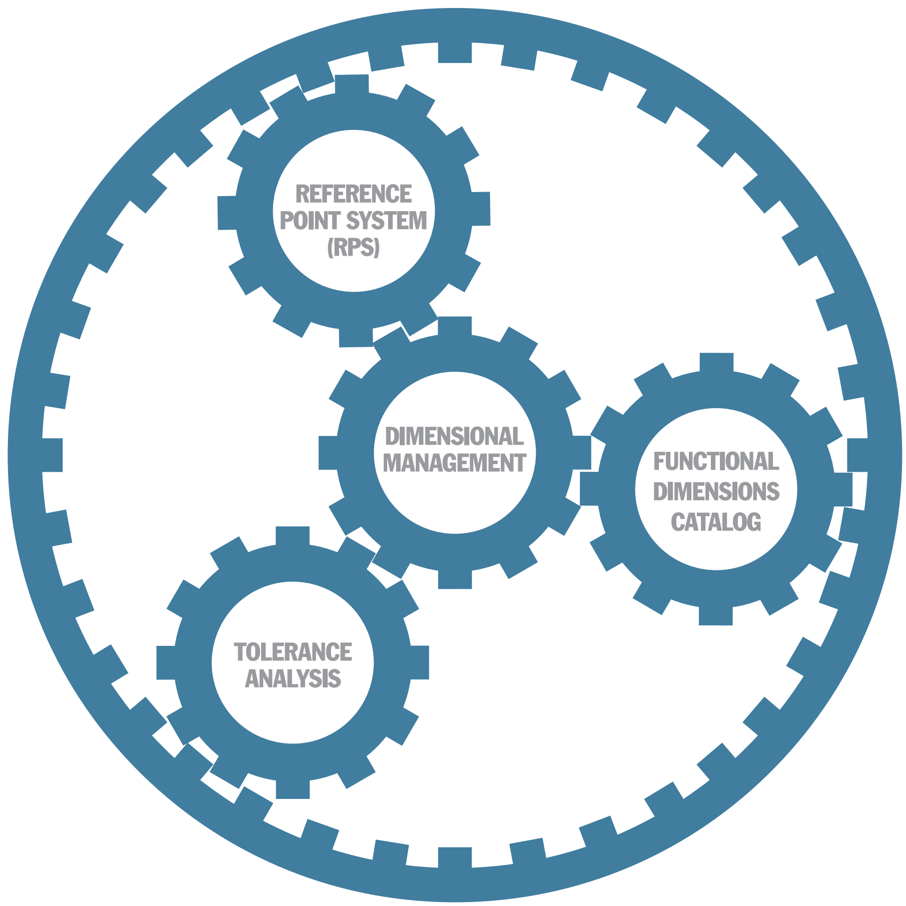
Quality characteristics
Tolerance specification

Design
RPS, tolerance values

Assembly
Tolerance values, assembly concepts

Quality/measurement technology
Measurement data/practical results

Supplier
Tolerance values



Statistical and arithmetical **calculation results**

Determination of the **first pass rate**

Identification of **main contributors**

Design decision, variant calculation

Every joint is in the right place—design and function in perfect harmony.

quality, and suppliers). This involves gathering required information, implementing it in dimensional management, and communicating the results back to the interfaces.

Dimensional management interfaces

- Design
- Development
- Assembly planning
- Quality of purchased parts
- Suppliers
- Production
- Measurement technology

To ensure the greatest possible positive impact of dimensional management, it must be brought into the development process at an early stage. Employees with dimensional management experience should ideally be involved from the concept phase onwards and provide consulting support with regard to RPS and assembly concepts. In the run-up to production, i.e. when initial measurement data already exists, the data can be fed back into the tolerance analysis to validate assumptions.

And its usefulness is not limited to the scopes of OEM-internal production. Suppliers of individual parts and assemblies can also benefit from utilizing the full spectrum of dimensional management.

Expanding and communicating knowledge

To prepare the next generation for dimensional management, guest lectures and papers are presented at the University of Stuttgart and the Karlsruhe Institute for Technology (KIT). Academic papers on the subject of dimensional management at Porsche Engineering have also led to collaborations with the Institute for Product Development (IPEK) and the Institute for Production Technology (wbk) at KIT. In addition to promoting education, Porsche Engineering also ensures that it is able to maintain and continuously raise its already high standard with regard to dimensional management.

Conclusion

Fulfillment of required visual and functional quality characteristics while reducing rework and process costs is the engine for the early application of dimensional management as a preventive quality assurance method in the product creation process. Thanks to the introduction of 3D tolerance simulation, it will be possible to handle complex problems more efficiently and in greater detail in the future. ■

911 (TYPE 991) Fuel consumption (combined): 12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km