

Tolerance design in assembly processes: a faster, more robust production start-up

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With complicated automated assembly processes it is often difficult to oversee just how the combination of component tolerances and placement inaccuracies will result in a fit... or misfit. As a result, the start-up phase tends to suffer from problems that have not been anticipated. A structured approach, based on statistical tolerance design using Monte Carlo simulations, can provide a good insight into capabilities and any necessary improvements to the assembly process. And most important of all, let you take proactive steps to address critical issues even before the equipment and parts have been ordered.

To know the risks...

As with the introduction or modification of production processes, complicated assembly processes often involve significant risks. Following a long, sometimes tedious development process, the real test comes with production start-up: real parts, real assembly equipment and with real deviations occurring on a real shop floor. Raising the questions, is the new/modified process robust enough to cope with such deviations, and what will the capability of the assembly process be in a real application?

...requires insight

It is often difficult to oversee exactly how the combination of component tolerances and placement inaccuracies will result in a fit... or misfit. Yet to get an insight into critical aspects of the assembly process, and opportunities to make improvements to it where necessary, requires insight and a thorough analysis of that process. And making changes and modifications after the assembly equipment has been acquired and installed, and the first pilot runs completed, is generally speaking extremely costly.

But avoiding expensive problems later...

The start-up phase of complex assembly processes tends to suffer from problems that have not been anticipated, leading to unnecessarily long cycle times. And this in a phase with hard deadlines for market introduction. Often resulting in persistent problems in production, or worse still quality issues in the market.

...is possible

So how can engineers manage risks during the assembly process and proactively check in an early phase for potential problems on the basis of the information available at that point?

Learn from suppliers

To begin with, a good collaboration and co-development with your parts suppliers will give you helpful insights into tolerances, variation and the suppliers' capabilities.

What can you expect in terms of variation in dimensions of the components or parts? Information will be available, for example, on tolerances and properties of variations for formed metal parts and moulded plastic parts. And for the assembly process, the relevant equipment suppliers can provide the placement inaccuracies of carriers and robots. These are provided for different movements/rotations and tend to be amazingly accurate. Tolerance design based on such information is an important tool when modelling the relevant variations and determining the outcomes of this total chain of variations and thus the probability of a misfit.

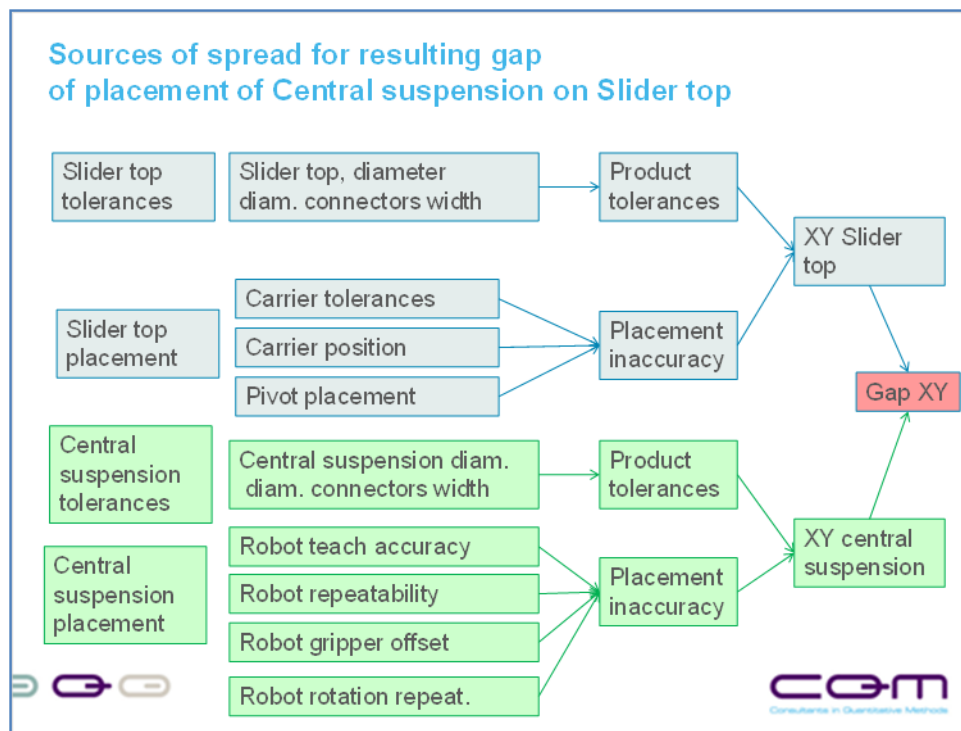
Take a structured approach

The engineer's challenge is to work with the information that's available and use his technical insight to proactively focus on critical process steps and parts.

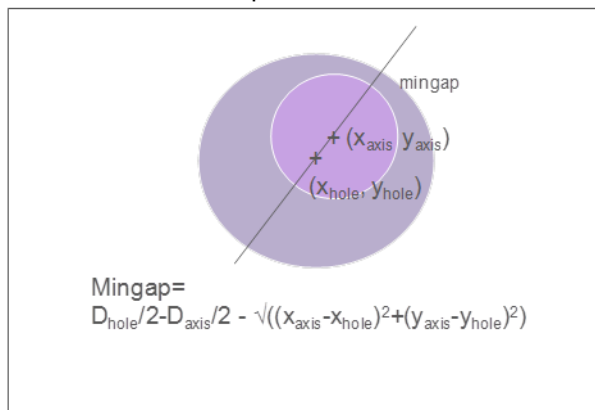
Assembly processes are all about connecting different components and sub-assemblies. So the assembly of products is actually like a stacking of building blocks each with their own variations in dimensions, using assembly tools each with their own variations in placing accuracies. Making it difficult to foresee the effect of all these variations in parts and placements, and whether the total assembly will fit and fulfil your requirements. We therefore recommend a structured approach to modelling the assembly process and its variations, following these steps:

Modelling the assembly process: the key steps

- What are the critical steps and fits of parts in the process? A process risk assessment (e.g. a process FMEA) gives you insight into the priorities for issues you need proactively to address.
- Address the priority issues found during the risk assessment using focused actions:
 - How is the assembly sub-process organized (process map) in successive process steps? What components are involved? What is the critical metric determining how much this process step contributes to the total fit/misfit?
 - Capture the variation build-up during the assembly process. Look at carrier variation, robot placement accuracies, part tolerances, calibration deviations for robot positions, etc (see graph).



This variation build-up can be written down in a mathematical model or 'transfer function'.



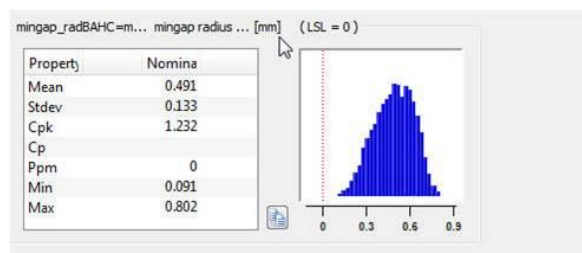
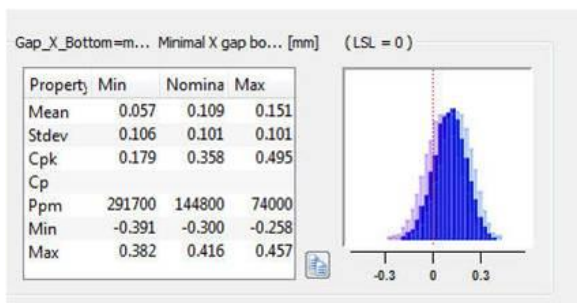
Example to illustrate use of a transfer function:

Calculation of minimal gap between an axis and a hole

D_{hole} and D_{axis} vary as result of component dimension variations

$x_{\text{axis}}, y_{\text{axis}}, x_{\text{hole}}, y_{\text{hole}}$ all vary as result of their specific placement inaccuracies and carrier/position variations

- Use a Monte Carlo simulation of the mathematical model to simulate the process and variances involved, and thus determine the distribution of the resulting critical metric. See as an illustration next two simulated results, showing the resulting gaps for the critical metric in two situations. The first result shows a prediction of a poor performance with a large probability of misfits. The second result predicts a capable assembly process.



Monte Carlo simulations can also provide information on the level of impact that specific parts and variations will have on the end result. The CQM Tolerance Designer software offers an easy-to-use dedicated tool for this purpose.

- Run the simulation model for scenario calculations and sensitivity analyses: what will be the outcome in specific situations? Examples of relevant scenarios could include deviating quality of components or an improved robot calibration procedure.
- Based on the simulation results, determine whether the assembly sub-process is sufficiently capable and robust: are additional actions required to improve the process? What are the dominant contributors to the variation build-up? Are there opportunities for cost reduction: re-evaluate supplies and/or equipment that are beneficial but not critical.

Shorter cycles, less risk

Clearly the main benefits of this approach are that it lets you take proactive steps to address critical issues, before equipment and parts are ordered, when any changes will still only incur limited additional costs. And preparation for the assembly process ramp-up will be fact-based, drawing on all available experience and knowledge. Thereby helping avoid last-minute issues and reduce the throughput time for the introduction of the assembly process: in other words, shorter cycle times and less risk.

Long-term benefits

The approach also has long-term benefits. It lets you involve product developers, suppliers and production engineers in addressing critical issues. Linking up their experience and technical knowhow as needed to involve all parties who can contribute to the ultimate success of your production start-up and production control.

Involving everybody in this way doesn't have to be particularly very time-consuming. Though it obviously requires exchange of information, assessing the prioritization of critical issues, and sharing results. And the lead should be taken by the engineers responsible for the introduction of the process and equipment.

Another benefit is that both the insights and the assembly process simulation model remain available to inform other work you may do around assembly processes, such as:

- Introducing similar products/assembly lines with different characteristics, parts or equipment;
- Determining whether potential new suppliers have sufficient capabilities to ensure robust production;
- Using the simulation model in scenario calculations to support root cause analyses and help identify the main effects of production problems.

CQM: your perfect partner for a smarter approach

All in all, this approach to tolerance design has many benefits. It brings all the stakeholders together. It makes the discussion fact-based. And engineers appreciate the chance it gives them to gather insights at an early stage and proactively prepare the set-up and installation of any new or modified assembly process.

CQM can help you introduce this way of working and the processes involved. Supporting you throughout the start-up phase, while ensuring your specific assembly processes meet your immediate and wider business requirements. And with the CQM Tolerance Designer you have an easy-to-use tool designed specifically to carry out Monte Carlo simulation for tolerance analyses.

For more information, please contact CQM

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