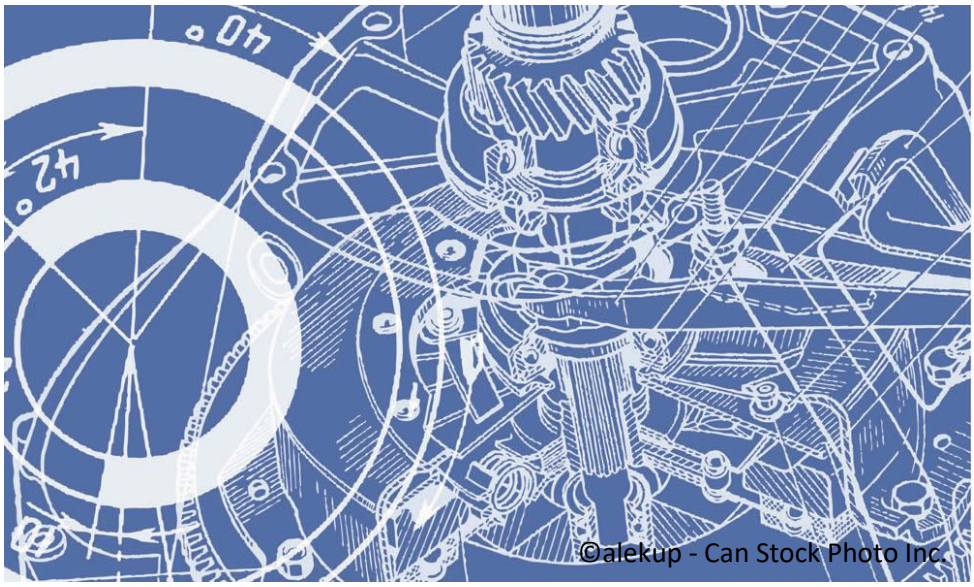


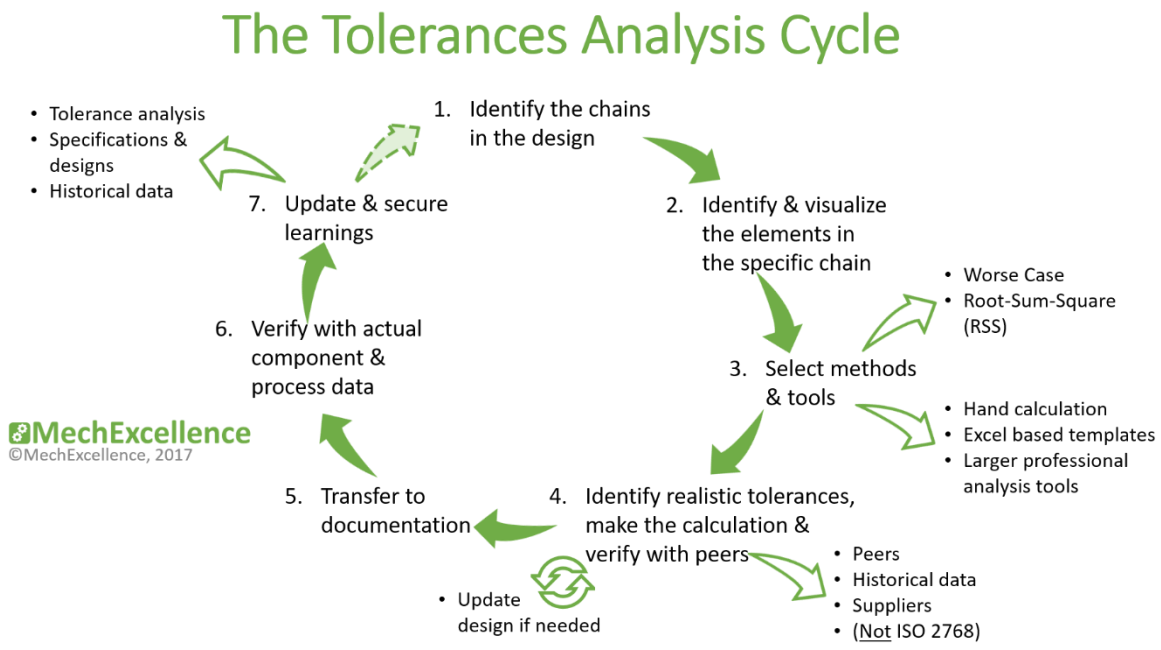
The Tolerance Analysis Cycle

Often, I see that the mechanical engineer stops the work with the tolerance calculations just after these are done, forgetting the work that needs to be done later in the pipeline of the product creation process.

> *Until it has been verified by process data, the tolerance calculation is merely an assumption*

After the calculation is done, there are still activities, however often forgotten, related to the tolerance calculations. When the first dimensional data arrives from the first article inspection, and later the first process data from either the process capability study or the production introduction, it needs to be linked back to the tolerance calculations. Both to ensure a robust design, as well as to ensure lessons learnt for future products.

I have illustrated this in what I have called “The Tolerance Analysis Cycle” in the below figure.



Step 1-5 should be well known, but I will tie a few comments to each of them.

Step 1 “Identify the chains in the design”

Create a list of all the interfaces in your design and identify the tolerance chains. It might be a good idea also to put them in priority. The list will support you during the product development and verification to have focus on the tolerance chains and their status.

Step 2 “Identify & visualize the elements in the specific chain”

My own experience is, that using hand sketches works better than print outs or pictures from CAD systems. Simply because you can better focus on the elements and exaggerate areas to show air gaps and details, leaving out unnecessary elements/lines from other features etc.

Step 3 “Select method & tools”

Selecting the right method can be tricky. For an unexperienced engineer, it is crucial to get support from peers or tolerance specialists. For larger more complex tolerance chains, you often need to use both Root-Sum-Square (RSS) and worse case considerations, within the same chain. Here, I just want to highlight the importance of making the right considerations and I believe there are experts much better suited to elaborate on this than myself.

For tools, my own experience is, that it is often enough with a well thought through excel based tolerance calculation sheet to handle even complex chains. Sometimes a hand calculation is enough. On the market, there are also various more advanced excel sheets and advanced standalone tools and CAD System integrated tools.

Step 4 “Identify realistic tolerances, make the calculation & verify with peers”

A common pitfall here is to just “lower” the tolerance until the desired result appears, hoping that it all will be ok in the end. In most cases, it won’t. When I started as mechanical engineer, it was also quite common just to use the ISO 2768 tolerance tables to determine the tolerances, with no regard to the intentions and conditions in the standard. My own experience is, that it is like taking a shortcut, just to find out later, that you did not gain anything. I strongly discourage it. Instead each dimension tolerance should be evaluated based on the material and production process it is produced by. It can be a good thing to make company tolerance standards based on historical data, utilizing peers and experts when deciding the tolerance to use.

There is a loop between the product design and the tolerance calculation that the engineer must keep going until the tolerance calculation and the product design are supporting each other.

Step 5 “Transfer to documentation”

This should be well known and normal practice. Still I think that many designers forget to revisit their tolerance calculations when creating the drawing. The tolerance calculation is a done deal, it is “archived”, and the focus is creating the drawing in a rush. However, there must be a thread from the 3D CAD via the tolerance calculation to the drawing, to verify the assumptions made in the product design. Dimensions with critical tolerances identified in the tolerance calculations must be visible in the drawings, ensuring that they are verified in the product verification process.

> *Use of historical data to determine the tolerance is best practice*

Even though step 5 is often forgotten, I think that the step 6 & 7 are very seldom done, but it is equally important to understand the robustness of the design and improve the conditions for development of future product. Remember, until now, the tolerance calculation is just an assumption.

Step 6 “Verify with actual component data” & Step 7 “Update & secure learnings”

Making the link between the actually achieved tolerances, based on the manufacturing of tools and the component production and its process spread, and the assumptions done in the tolerance calculations is a crucial part in understanding your design robustness. When having dimensions near to, or outside the limits, the tolerance calculations must be revisited before accepting this. Is this always done?? I don’t think so. Accepting tolerances outside specification needs a revisiting of the tolerance re-calculation and in most cases, drawings must be updated and even sometimes the product design itself.

Utilizing the data gained in the verification process to create company tolerance standards based on historical data will lead to better understanding of the tolerances that can be achieved. Which again can lead to more realistic tolerances, increased robustness, ease of verification and lower field failures. It might also show that smaller tolerances, than expected, can be gained with the materials and production methods used within the company.

> *Use your dimensional verification data to build a company tolerance standard – based on the materials and process used for the company products*

The last step is closing the tolerance analysis cycle from one product to the next.

Following the cycle all the way through will support you later in error and problem solving where tolerance issues have occurred, as well as in your new product development.

Gert Plenge

Project & Team Manager

Founder of MechExcellence

www.mechexcellence.com

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