



TenStep Supplemental Paper

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Manufacturing Tolerances

Every manufacturer wants to product a perfect product each time. However, that is normally not possible. First of all, there is a human factor built into many manufacturing processes, and humans cannot be perfect on every iteration. Second, the machinery and tools used to build the products are themselves not perfect, and are subject to some level of variation, including normal wear-and-tear. However, as processes become more automated, and the machinery used to build the products become more precise, a greater percentage of products approach the perfect state as originally designed.

Care must be taken when assembling a product because of the tolerance levels of the underlying parts. It is easy to produce parts that conform to specified tolerances, but these parts do not always work together when assembled. This can cause problems in a final assembly, even though all of the parts fall within allowable tolerances. For instance, three parts may have a common hole that needs to be in alignment. The three holes may all be within .001 meters of the perfect location. However, one part has the hole slightly lower, one is slightly higher and one is slightly to the right. In all cases, the hole is within .0009 of specification, so they all are within tolerance. However, when they are lined up, a precise pin cannot be inserted in the hole because of the combination of the imprecision. In this case, the overall effects of the tolerances on the final assembly were not fully analyzed.

Tolerances should not be limited to part design. Manufacturing companies need to manage tolerances all the way from the design phase to the manufacturing phase to the final assembly. Often, when engineers design parts, they assign individual tolerance values without considering their impact on the final assembly.

The involvement of different departments throughout the manufacturing process further complicates matters. For instance, design engineers sometimes assign tolerances for the end product without checking to see if these tolerances can be achieved in the manufacturing process. In many companies, there is hardly any communication between designers and manufacturers during the product development process. It is only after the manufacturing process starts that people realize that the tolerances cannot be achieved efficiently.

A sizable percentage of rework and material waste is related to tolerances. In high-volume industries, such as consumer electronics and automobiles, rework and material waste are not only caused by tolerance values that are too high, but also by process variations. In addition, precision dies and fixtures wear away, causing changes in the process. When less than perfect processes are involved in producing parts with tolerances, the tolerances are magnified, eventually leading to greater problems in assembly. Therefore, processes must be monitored closely using statistical process control. Using tools to measure and compare the final product with the initially designed product helps identify differences, as well as degradations over time.

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Resources are scarce in all companies. However, in many cases, manufacturing companies spend significant sums on warranty costs dealing with quality problems after the product is sold. In many cases, the back end warranty costs can be reduced, and customer satisfaction can be increased, if more time is spent in the initial phases to improve the design and manufacturing processes.

By continuing to do things the way they have always been done, companies remain unaware of problems caused by poor tolerances. The manufacturing process needs to strictly follow the assembly plan defined during the design stage. If changes during manufacturing are required, they must be referred back to the design team and re-analyzed. This helps to identify potential out-of-tolerance and assembly problems early.

Companies need to understand their manufacturing capability and provide adequate feedback to the design team so that they will be aware of these capabilities. The design team can use this information to design appropriate tolerances. A systematic approach to specifying tolerances includes:

- **Define the design objectives:** What has to be produced?
- **Understand the sensitivity of the underlying machinery and tools:** Can the product be built given the cost and capabilities of the available machinery and tools? Will new tools and processes need to be built or bought? Can your company afford to build the product at the designed level of quality?
- **Determine how the tolerances of each part will impact the final assembly.** Can the final product still be assembled and be of high quality if you look at the worst case of all underlying tolerances in combination with each other?
- **Understand process capability:** Is manufacturing capable of building such a product? Can all the parts be seamlessly integrated?
- **Simulate the process:** Evaluate the manufacturing process by emulating the design and running it through a virtual plant. Often, companies find that it is only after the product is assembled and ready to ship that they realize the final product does not meet the specifications.
- **Specify critical dimensions:** Measure critical dimensions after the product has been built to ensure everything meets final tolerances.
- **Monitor continuously:** Measure and monitor continuously to ensure that manufacturing processes are capable of meeting the design objectives.
- **Document at every design stage:** This helps to review, track, and account for problems encountered in the later stages.

It is crucial for manufacturers to systematically apply and manage tolerances from the pre-design and design phases all the way through the manufacturing phase to the final assembly. The cost of making changes at the design phase is low and grows exponentially in the field phase. So, catch problems as early as possible, control your



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tolerances, or else the imprecision will end up controlling you, as you will end up spending too much of your time on rework and process corrections.