

OPTIMIZATION COST AND QUALITY IN MANUFACTURING PROCESS USING TOLERANCE ANALYSIS

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Abstract: Time is the most important resource in modern manufacturing. Nowadays, it is very easy to calculate and build a technological process, tolerances and fit without resorting to real production. All simulations and calculations are performed long before the creation of technological lines, calculation of tolerances in assembly units. This leads to a significant reduction in funds and time at the stage of real production. All tolerances deviations [1] in the dimensional chain can be checked / calculated / corrected by simple simulation on a computer using modern programs. Tolerance Analysis is a CAD-embedded, Tolerance analysis software that helps you more clearly understand the impact of mechanical fit and performance based on the cumulative dimensional variation. The purpose of tolerance design is to consider the allowable variation in each part to determine if the engineering requirements are met when the parts are assembled. Tolerance Analysis can be made by appropriate analysis types: Worst Case, Root Sum Squares (RSS), Statistical (Cpk, Sigma, Yield, DPMO (Defects Per Million Opportunities)). The goal for optimizing tolerances is to create a cost-effective design for manufacturing.

Keywords: Tolerance Analysis, Worst Case, Root Sum Squares, DPMO

1. Introduction

Autodesk® Inventor® Tolerance Analysis is a CAD-embedded, 1D tolerance analysis software that helps you more clearly understand the impact of mechanical fit and performance based on the cumulative dimensional variation [1]. A 1D tolerance stackup means the distance being analyzed and all dimensions that contribute to the distance variation are acting in the same linear direction. Linear variation of the surfaces on either side of the stackup direction is considered; angular variation of the surfaces relative to each other is not considered. Sometimes the effects of angular variation are overlooked, so you should verify the analysis in 1D. The purpose of tolerance design is to consider the allowable variation in each part to determine if the engineering requirements are met when the parts are assembled [Autodesk,2021]. Tolerance Analysis helps you: Assure better fit by eliminating the need

for hand calculations and spreadsheets, Determine the optimum tolerances to keep your manufacturing costs down, Increase the quality and finish of your products.

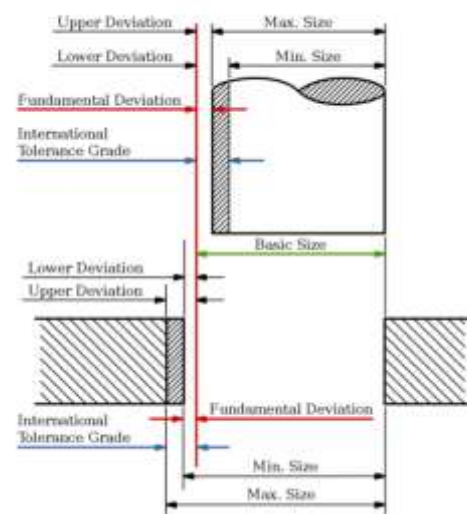


Figure 1: Tolerance Deviations and Sizes.

Tolerance Analysis supports Worst-case, general Statistical, and Root Sum of Squares (RSS) analysis methods. RSS is a special case of the Statistical analysis method and is described after the Statistical section.

Worst-case tolerance analysis is the traditional type of tolerance stackup calculation [Fischer,2011]. The individual variables are all placed at either the maximum or minimum limits to make the stackup distance as large or as small as possible [2].

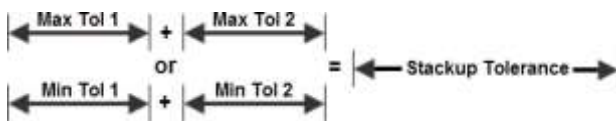


Figure 2: The individual variables are all placed at either the maximum or minimum limits.

The Worst-case method does not consider the distribution of the individual variables. Instead it assumes that all parts have been produced at the extreme limit of acceptability when they are assembled. This method predicts the absolute upper and lower limits of the stackup distance that can be achieved.

Designing to Worst-case tolerance requirements means that all parts produced to, but not beyond, their extreme limits assemble and function properly. The major drawback with the Worst-case method is that it often requires tight individual component tolerances. Worst-case can result in expensive manufacturing and inspection processes and high scrap rates.

Assigning tolerance that meet Worst-case analysis methods is often used for critical mechanical interfaces and spare part replacement interfaces. When Worst-case tolerancing is not a contract requirement, properly applied statistical tolerancing can ensure acceptable assembly yields with increased component tolerances and lower fabrication costs.

The Statistical analysis method takes advantage of the principles of statistics to relax the component tolerances without sacrificing quality. Each contributing dimension is assumed to have a statistical distribution. These distributions are combined to predict the distribution of the assembly stackup distance.

Statistical analysis predicts a distribution of the stackup distance instead of the extreme limits that the Worst-case method determines. Statistical analysis provides increased design flexibility to design to any quality level, not just 100 percent. Statistical analysis differs from the RSS method because it does not assume that the assembly quality level must be the same as the part quality level [Tynes,2012].

The standard deviation calculated for the normal distribution of each dimension is calculated from the following equation (1).

$$C_p = \frac{UTL-LTL}{6\sigma} \quad (1)$$

where:

UTL – Upper Tolerance Limit

LTL – Lower Tolerance Limit

σ – distribution standard deviation

Solving for the standard deviation yields (2)

$$\sigma = \frac{UTL-LTL}{6C_p} \quad (2)$$

The most common assumption of $C_p=1.0$ stems from the assumption of a manufacturing process that places the defined tolerances at +/- 3 standard deviations from center of the tolerance zone, assumed to be the mean, so that the probability of a part complying to the required tolerances is 99.7%. For all statistical analyses, Tolerance Analysis assumes that manufacturing targets the midpoint of the tolerance range, therefore the mean is assumed to be the midpoint of the tolerance range.

Root Sum of Squares, or RSS, analysis leverages the principals of the general statistical analysis method described in the previous section but with some simplifying assumptions to enable calculations with tolerances instead of standard deviations. One of the primary assumptions is that the ratios of each of the tolerances to their associated standard deviations on the dimensions and the stackup result are the same. For an RSS analysis, Tolerance Analysis assumes a C_p of 1.0 for all dimensions and the resulting stackup limits.

2. Simulation Real Example. Tolerance optimization and Optimal Results

Tolerance Analysis is a 1-Dimensional tolerance analysis tool that reports the tolerance stackup of parts in a single linear direction such as X. The analysis lets you determine if the parts in an assembly meet mechanical fit and performance requirements based on the cumulative part tolerances.

A 1D analysis is typically captured in a spreadsheet, but the spreadsheet method is difficult to set up and maintain because it must:

- Manage all product requirements simultaneously.
- Use common dimensions and tolerances for each part involved in multiple stackups.
- Accurately calculate the effects of geometric tolerances.
- Automatically include the effects of the clearances around fasteners and pins which results in assembly shift and variation in locating one part relative to another.
- Accurately calculate the statistical results.

Consider a real example, a dimensional chain of 9 components: Main shaft (yellow), Clip Ring 1 (green), Bearing 1 (blue), Compensation ring 1 (red), Compensation ring 2 (red), Conical gear (grey), Compensation ring 3 (red), bearing 2 (blue), Clip Ring 2 (green) [3].

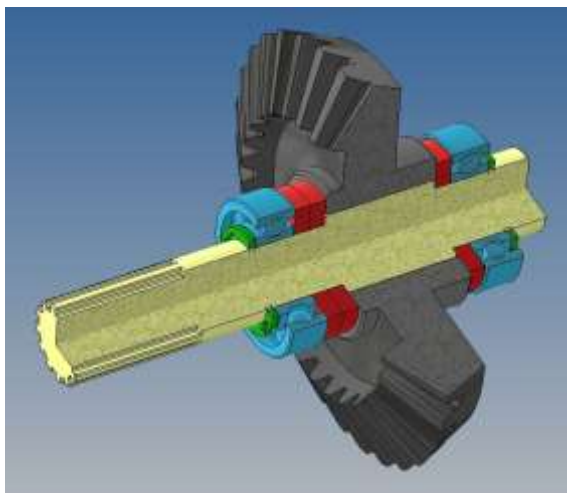


Figure 3: Main Assembly Components.

The main end dimension loop will be located between the Clip Rings. We will set tolerances for all elements by default (+/- 0.1), and for the Bearing (+0/-0.12) standard for this size [4]. And a gap of 0.25 as build.

Name	Sens	Nominal	Tolerance
CONICAL_GEAR_DF032:1 (mm)			
Face26			
Dimension15	-1	35.0 ±	0.1
Face29			
Compensation Ring1 (mm)			
Face26			
Dimension14	-1	1.0 ±	0.1
Face27			
50° BALL BEARING 6005 25x47x12			
Face30			
Dimension16	-1	12.00 ±	0.00
Face25			
Radial Clip:2 (mm)			
Face24			
Dimension17	-1	2.0 ±	0.1
Face21			
Main Ax:1 (mm)			
Face32			
Dimension18	+1	78.3 ±	0.1
Face33			
Radial Clip:1 (mm)			
Face21			
Dimension17	-1	2.0 ±	0.1
Face24			
TEHNOMUS2021			
Objectives (mm)		0.250 ≥	0.071
		0.250 ≥	0.000

Figure 4: Component tolerance values.

Let's make a dimensional chain [5].

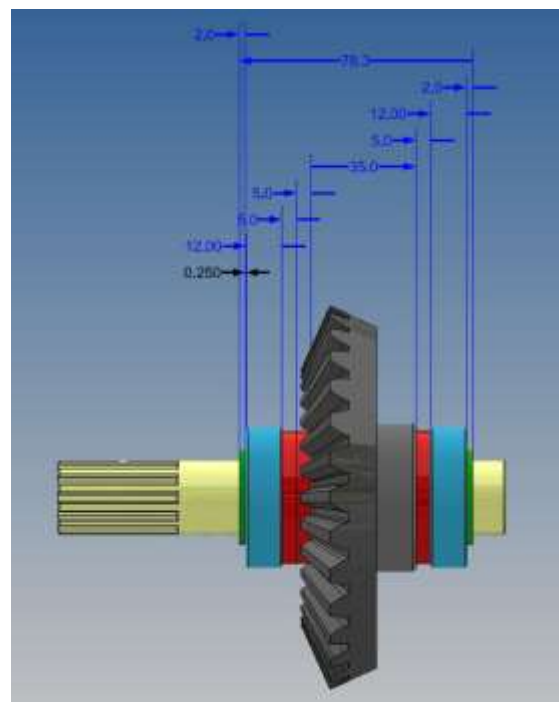


Figure 5: Dimensional chain.

Consider the results, study the component most contribution on the tolerance and gradually correct it, if it's necessary [6]. The value position is the Compensation Rings.

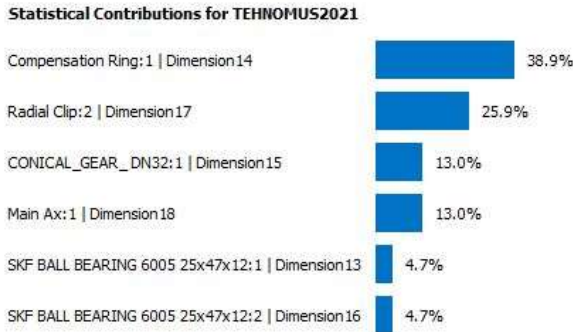


Figure 6: Most contribution component.

Despite a not very positive result on the Worst Case [7], there is no need to tighten the tolerances of some elements.

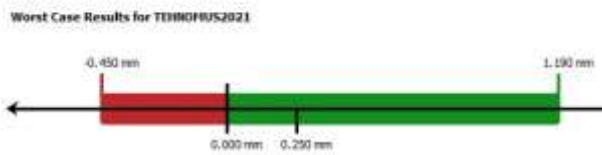


Figure 7: Worst Case Results.

According to the results of the RSS we are in the permissible values [7].

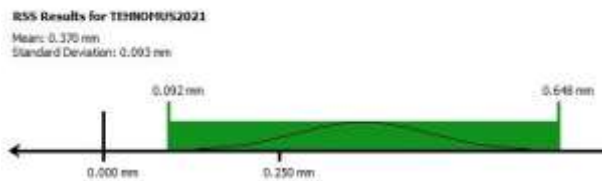


Figure 7: RSS Results.

The DPMO values show us the number of defective parts 32 per million, which is 0.0032% of the total number of products [8].

Tightening the tolerances of one or more parts will entail significantly higher costs than losses for the calculated minimum percentage of defective products.

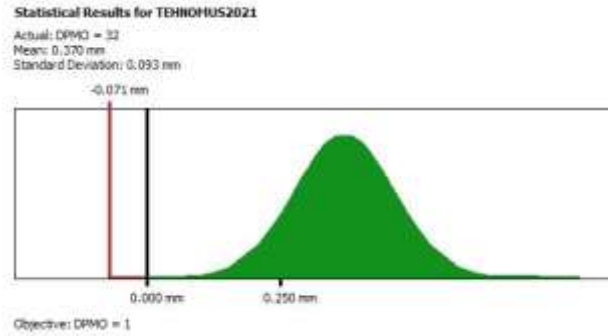


Figure 8: DPMO Results.

3. Conclusions

The goal for optimizing tolerances is to create a cost-effective design for manufacturing.

Tolerance Analysis helps you identify potential manufacturing issues. Use the bidirectional associativity between your model tolerances and tolerance analysis to refine your tolerances and perform multiple iterations of the analysis to maintain the required quality and reduce cost.

References

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