Tolerance Stack-Up Analysis

Presented By
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TECHNICAL TRAINING CONSULTANTS
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Course Outline

1. The Basics
   a. Identify factors pertinent to stack-up analysis
   b. Designate positive and negative routes
   c. Position each part for a worst-case analysis
   d. Calculate mean dimensions & equal bilateral tolerances
   e. Calculate virtual & resultant condition boundaries
   f. Calculate the tolerance of fixed and floating fasteners
2. **Box Assembly**
   a. Apply basic stack-up analysis to a box assembly
   b. Draw loop analysis diagram for the box assembly
   c. Designate positive and negative routes
   d. Calculate mean dimensions & equal bilateral tolerances
   e. Calculate MAX and MIN GAP

3. **Tolerance Stack-Up Analysis for Features of Size**
   a. Perform a loop analysis
   b. Determine the start and end points
   c. Graph values on a loop diagram
4. Tolerance Stack-Up Analysis for Assemblies with Plus and Minus Tolerancing
   a. Calculate airspaces and interferences
   b. Alternative method of Analysis

5. Tolerance Stack-Up Analysis for a Floating Fastener Assembly
   a. Calculate resultant and virtual conditions
   b. Convert all dimensions to equal bilateral tolerances
   c. Mix widths and diameters in a numbers chart
   d. Graph the numbers into a tolerance stack-up diagram
   e. Determine all unknown gaps in a five-part assembly
6. Tolerance Stack-Up Analysis for a Fixed Fastener Assembly
   a. Calculate overall housing requirements
   b. Calculate MIN and MAX GAPS within the assembly

7. Tolerance Stack-Up Analysis for a Five-Part Assembly
   a. Perform a tolerance analysis of a five-part rotating assembly with a variety of geometric tolerances.
   b. Practice simplifying a complex situation.
   c. Learn to calculate part-to-part analysis from two parts to an infinite number of parts.
   d. Determine assembly housing requirements.
   e. Calculate radial clearance and interference.
8. The Theory of Statistical Probability
   a. Convert an arithmetical to a statistical tolerance
   b. Use the Root Sum Squares (RSS) formula
   c. Determine the tolerance statistically likely to be consumed
   d. Compare statistical to arithmetical tolerance
   e. Calculate the percentage each tolerance may be increased
   f. Use a correction factor as a multiplier
   g. Reintegrate the Statistical Tolerance into the assembly
Chapter 1

The Basics

Lesson Objectives

You will be able to:

• **Identify** factors pertinent to stack-up analysis
• **Designate** positive and negative routes
• **Position** each part for a worst-case analysis
• **Calculate** mean dimensions and equal bilateral tolerances
• **Calculate** virtual and resultant condition boundaries
• **Calculate** the tolerance of fixed and floating fasteners
TOLERANCE STACK-UP ANALYSIS

Main Rules

1) Start at the bottom and work up or Start at the left and work to the right.

2) Stay on one part until it is exhausted.

3) Left and down are negative; right and up are positive.

4) Always take the shortest rout.
Step 1
Identify what requirement is under test.

Step 2
Identify all dimensions that contribute to the gap.

Step 3
Assign each dimension a positive or negative value:
- Left is negative    Right is positive
- Down is negative   Up is positive
Tolerance Stack-Up Analysis
Step 4
Only one set of mating features creates the worst-case gap.

Step 5
The analyst must deduce which geometric tolerance, location or orientation if either, contributes to the gap.

Step 6
If your assumptions are wrong, your answer is wrong.
Finding the mean:

Calculate the sum and the difference between the MMC and LMC and divide each by two

- **Maximum Material Condition (MMC):** The maximum material condition of a feature of size is the maximum amount of material within the stated limits of size. For example, the maximum shaft diameter or the minimum hole diameter.

- **Least Material Condition (LMC):** The least material condition of a feature of size is the least amount of material within the stated limits of size. For example, the minimum shaft diameter or the maximum hole diameter.
Example – Limit dimension

Ø20 – 22

<table>
<thead>
<tr>
<th>MMC/LMC</th>
<th>22</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMC/MMC</td>
<td>+ 20</td>
<td>– 20</td>
</tr>
<tr>
<td>Equal Bilateral Tolerance (±) of part</td>
<td>21 ± 1</td>
<td></td>
</tr>
</tbody>
</table>
**Example – Unequal bilateral tolerance**

\[
\begin{align*}
\varnothing50 & \\
+1 & -3
\end{align*}
\]

<table>
<thead>
<tr>
<th>MMC/LMC</th>
<th>51</th>
<th>51</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMC/MMC</td>
<td>+47</td>
<td>-47</td>
</tr>
<tr>
<td>2 ( \frac{98}{2} )</td>
<td>49</td>
<td>2</td>
</tr>
</tbody>
</table>

**Equal Bilateral**

Tolerance \((\pm)\) of part \(49 \pm 2\)
Boundaries

• Virtual Condition

The virtual condition of a feature specified at MMC is a constant boundary generated by the collective effects of the MMC limit of size of a feature and the specified geometric tolerance.

Virtual condition calculations:

External Features (Pin) Internal Features (Hole)

MMC

Plus Geo. Tol. @ MMC
Equals Virtual Condition

MMC

Minus Geo. Tol. @ MM
Equals Virtual Condition
**Resultant Condition**

The resultant condition of a feature specified at MMC is a variable boundary generated by the collective effects of the LMC limit of size of a feature, the specified geometric tolerance, and any applicable bonus tolerance.

Extreme resultant condition calculations:

<table>
<thead>
<tr>
<th>External Features (Pin)</th>
<th>Internal Features (Hole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMC</td>
<td>LMC</td>
</tr>
<tr>
<td>Minus Geo. Tol. @ MMC</td>
<td>Plus Geo. Tol. @ MMC</td>
</tr>
<tr>
<td>Minus Bonus Tolerance</td>
<td>Plus Bonus Tolerance</td>
</tr>
<tr>
<td>Equals Result. Condition</td>
<td>Equals Result. Condition</td>
</tr>
</tbody>
</table>
Worst Case Boundaries of a Hole

FIGURE 1-1

Virtual Condition  Resultant Condition
VC = MMC – GT   RC = LMC + GT + Bonus
VC = 49 – 1 = 48   RC = 51 + 1 + 2 = 54
### Virtual and Resultant Conditions, Hole

<table>
<thead>
<tr>
<th>VC/RC</th>
<th>54</th>
<th>54</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC/VC</td>
<td>+ 48</td>
<td>– 48</td>
</tr>
<tr>
<td></td>
<td>(\frac{102}{2})</td>
<td>(\frac{6}{2})</td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>3</td>
</tr>
</tbody>
</table>

**Equal Bilateral**

**Tolerance (±) of part** 51 ± 3
Worst Case Boundaries of a Pin

FIGURE 1-5

<table>
<thead>
<tr>
<th>Virtual Condition</th>
<th>Resultant Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC = MMC + GT</td>
<td>RC = LMC – GT – Bonus</td>
</tr>
<tr>
<td>VC = 47 + 1 = 48</td>
<td>RC = 45 − 1 − 2 = 42</td>
</tr>
</tbody>
</table>

Tolerance Stack-Up Analysis
### Virtual and Resultant Conditions, Pin

<table>
<thead>
<tr>
<th>VC/RC</th>
<th>48</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC/VC</td>
<td>+ 42</td>
<td>– 42</td>
</tr>
<tr>
<td></td>
<td>2) [90]</td>
<td>2) [6]</td>
</tr>
<tr>
<td></td>
<td>[45]</td>
<td>[3]</td>
</tr>
</tbody>
</table>

**Equal Bilateral**

Tolerance (±) of part  \[45 \pm 3\]
Floating Fasteners

The floating fastener formula is:

\[ T = H - F \quad \text{or} \quad H = F + T \]

\( T \) is the clearance hole MMC Location Tolerance
\( H \) is the Clearance Hole MMC diameter
\( F \) is the Fastener’s MMC diameter, the nominal size

The floating fastener tolerance applies to each hole in each part.

\[ H = F + T = .250 + .020 = .270 \]
Fixed Fasteners

\[ t_1 + t_2 = H - F \quad \text{or} \quad H = F + t_1 + t_2 \]

- \( t_1 \) is the threaded hole Location Tolerance at MMC
- \( t_2 \) is the clearance hole Location Tolerance at MMC
- \( H \) is the Clearance Hole MMC diameter
- \( F \) is the Fastener’s MMC diameter, the nominal size

\[ H = 0.250 + 0.024 + 0.000 = 0.274 \]