Tolerance Stack-Up Analysis

Presented By

Gene Cogorno

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

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.

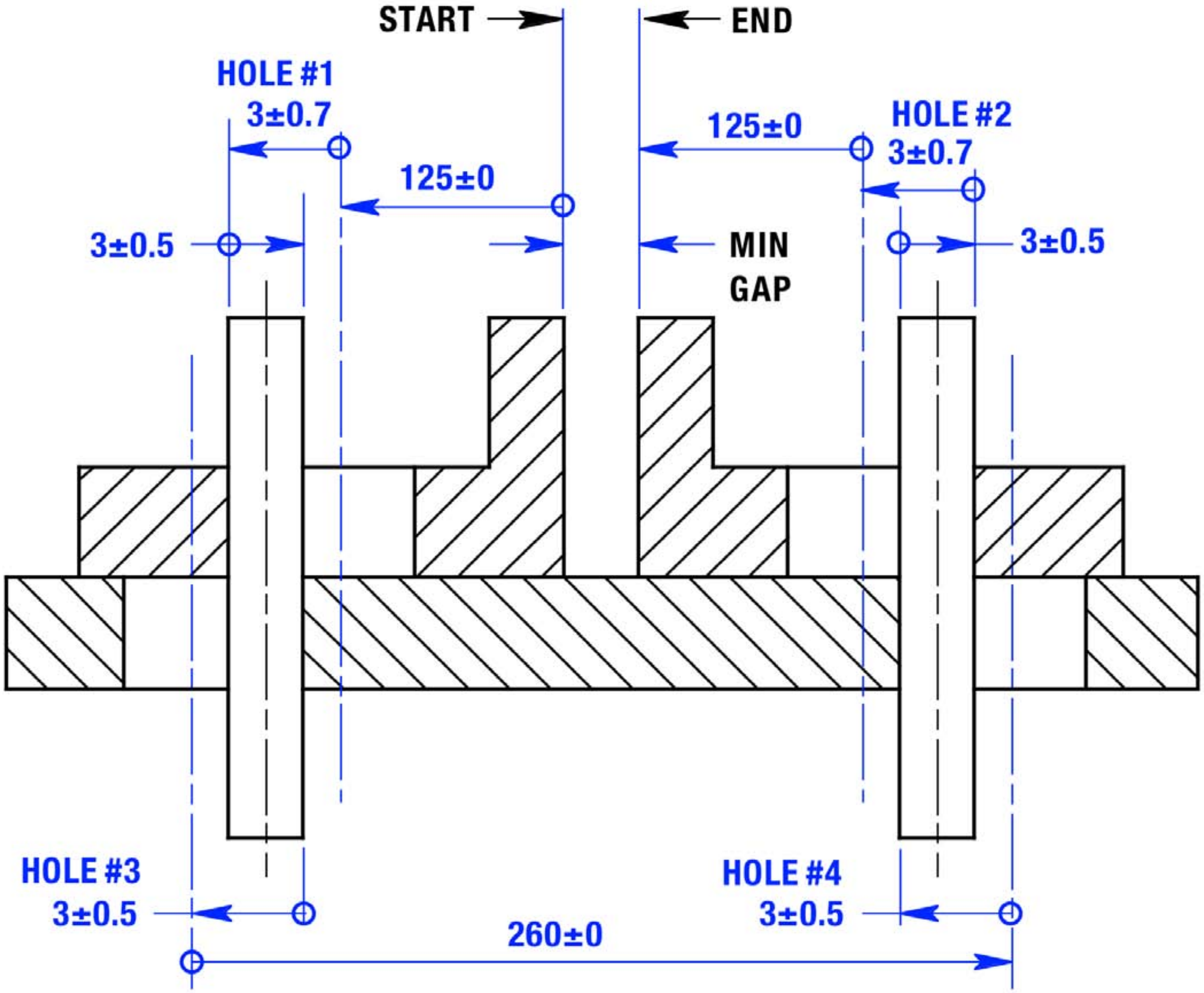
Step 2

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**


START
END
HOLE #1
3±0.7
125±0
125±0
HOLE #2
3±0.7
3±0.5
MIN
GAP
3±0.5
HOLE #3
3±0.5
260±0
HOLE #4
3±0.5

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

MMC/LMC	**22**	**22**
LMC/MMC	**+ 20**	**– 20**
	$2\overline{)\,\mathbf{42}}$	$2\overline{)\,\mathbf{2}}$
	21	**1**

Equal Bilateral

Tolerance (±) of part **21 ± 1**

Example – Unequal bilateral tolerance

$$\varnothing 50^{+1}_{-3}$$

MMC/LMC	**51**	**51**
LMC/MMC	**+ 47**	**– 47**
	$2\overline{)\,\mathbf{98}}$	$2\overline{)\,\mathbf{4}}$
	49	**2**

Equal Bilateral

Tolerance (±) of part **49 ± 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		MMC
Plus	Geo. Tol. @ MMC	***Minus***	Geo. Tol. @ MM
Equals	Virtual Condition	***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:

External Features (Pin)		**Internal Features (Hole)**	
	LMC		LMC
Minus	Geo. Tol. @ MMC	***Plus***	Geo. Tol. @ MMC
Minus	Bonus Tolerance	***Plus***	Bonus Tolerance
Equals	Result. Condition	***Equals***	Result. Condition

Worst Case Boundaries of a Hole

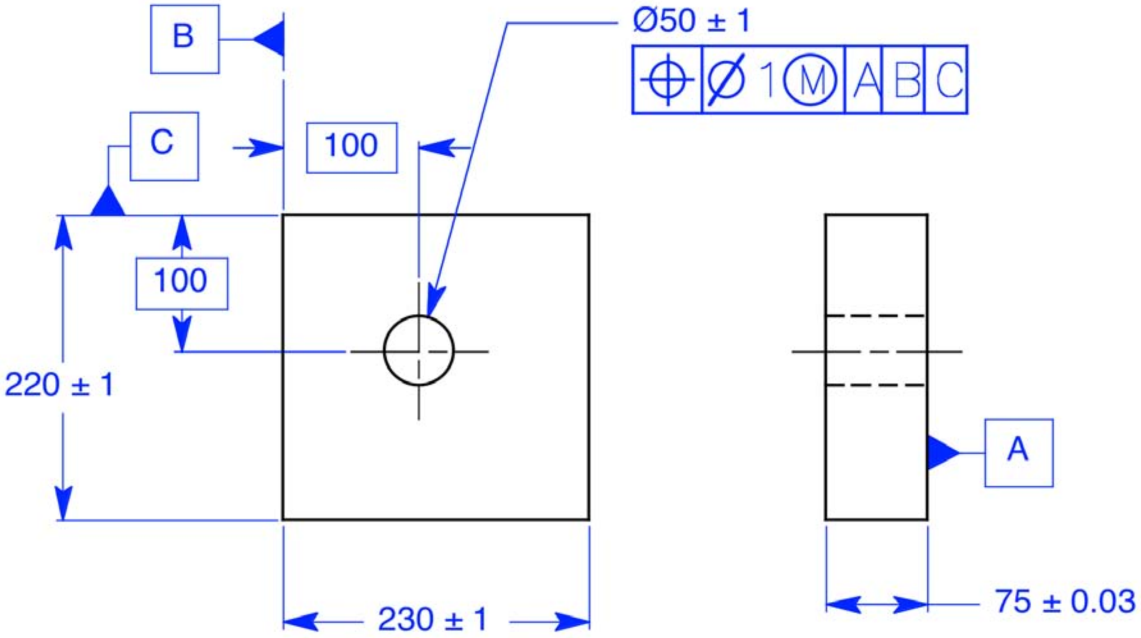


FIGURE 1-1

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

VC/RC	**54**	**54**
RC/VC	**+ 48**	**– 48**
	$2\overline{)\mathbf{102}}$	$2\overline{)\quad\mathbf{6}}$
	51	**3**

Equal Bilateral

Tolerance (±) of part **51 ± 3**

Worst Case Boundaries of a Pin

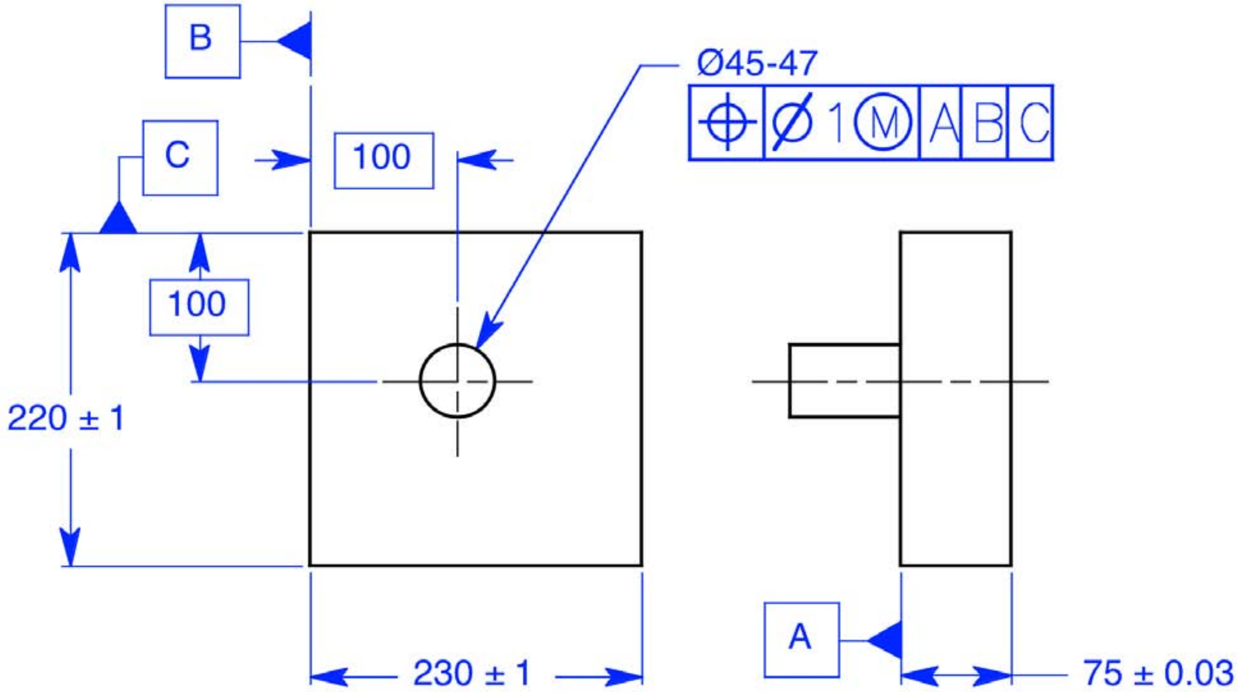


FIGURE 1-5

Virtual Condition

$VC = MMC + GT$

$VC = 47 + 1 = 48$

Resultant Condition

$RC = LMC - GT - Bonus$

$RC = 45 - 1 - 2 = 42$

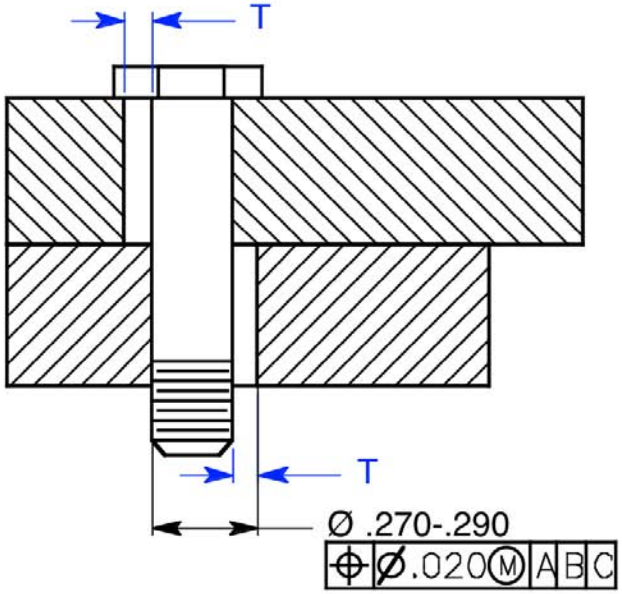
Virtual and Resultant Conditions, Pin

VC/RC	**48**	**48**
RC/VC	**+ 42**	**– 42**
	2) **90**	2) **6**
	45	**3**

Equal Bilateral

Tolerance (±) of part **45 ± 3**

Floating Fasteners



The floating fastener formula is:

T = H – F   or   H = F + T

T is the clearance hole **MMC Location Tolerance**

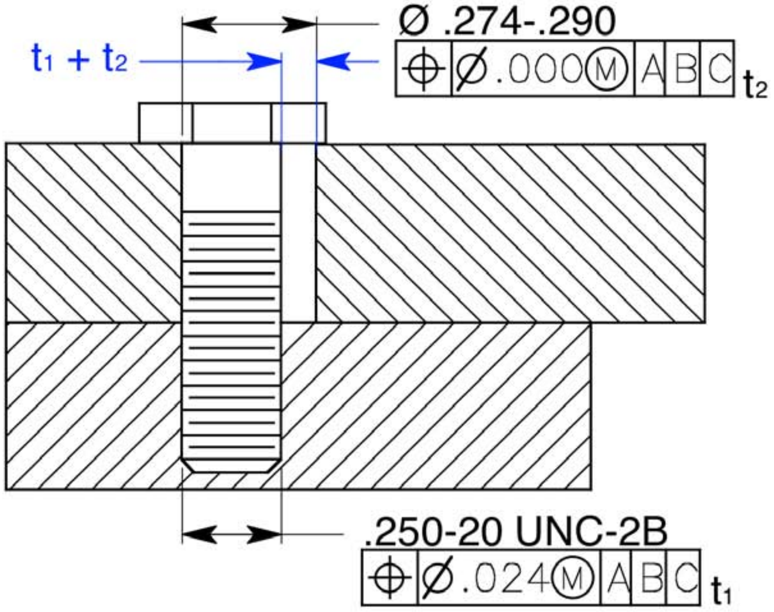
H is the **Clearance Hole MMC** diameter

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



The fixed fastener formula is:

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

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

$$H = .250 + .024 + .000 = .274$$