GD&T

QUALITY

Tolerance Stack-up Analysis

OMNEX since 1985 BUILDING WORLDWIDE BUSINESS EXCELLENCE

OMNEX
WWW.OMNEX.COM

325 East Eisenhower Parkway, Suite 4
Ann Arbor, MI 48108
PH: (734) 761-4940
FAX: (734) 761-4966

Second Edition
May 2007

Omnex provides training, consulting and software solutions to the international market with offices in the USA, Canada, Mexico, China (PRC), Germany, India, the Middle East, and SE Asia. Omnex offers over 400 standard and customized training courses in business, quality, environmental, food safety, laboratory and health & safety management systems worldwide.

Email: info@omnex.com

Web: www.omnex.com

A BRIEF INTRODUCTION TO OMNEX

Omnex Introduction

- **International consulting, training and software development organization founded in 1985.**
- **Specialties:**
  - Integrated management system solutions.
  - Elevating the performance of client organizations.
  - Consulting and training services in:
    - Quality Management Systems, e.g. ISO 9001, IATF 16949, AS9100, QOS
    - Environmental Management Systems, e.g. ISO 14001
    - Health and Safety Management Systems, e.g. OHSAS 18001
- **Leader in Lean, Six Sigma and other breakthrough systems and performance enhancement.**
  - Provider of Lean Six Sigma services to Automotive Industry via AIAG alliance.

About Omnex

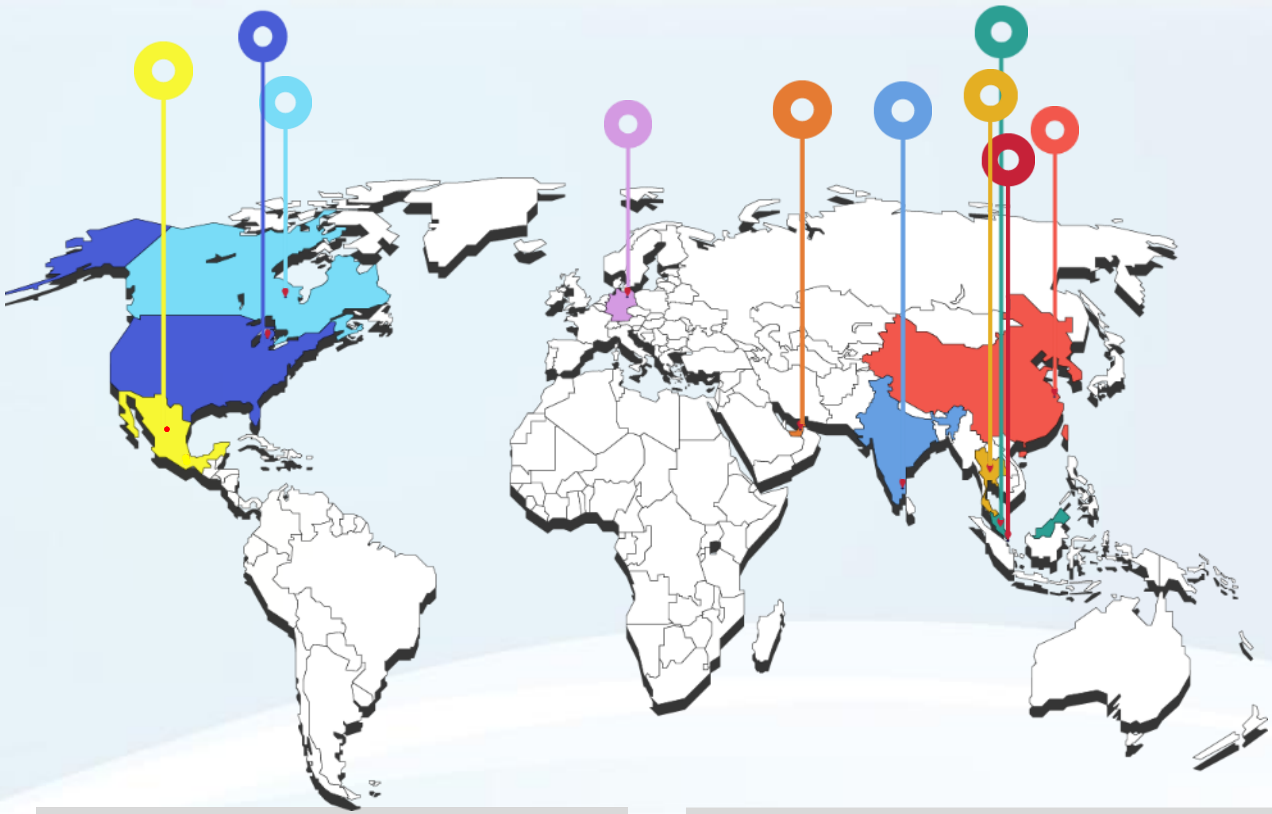
- Headquartered in Ann Arbor, Michigan with offices in major global markets.
- In 1995-97 provided global roll out supplier training and development for Ford Motor Company.
- Trained more than 100,000 individuals in over 30 countries.
- Workforce of over 400 professionals, speaking over a dozen languages.
- Former Delegation Leader of the International Automotive Task Force (IATF) responsible for ISO/TS 16949.
- Served on committees that wrote QOS, ISO 9001:2000, QS-9000, ISO/TS 16949 and its Semiconductor Supplement, and ISO IWA 1 (ISO 9000 for healthcare).
- Member of AIAG manual writing committees for FMEA, SPC, MSA, Sub-tier Supplier Development, Error Proofing, and Effective Problem Solving (EPS).

Omnex Worldwide Offices

Omnex is headquartered and operates from the United States through offices in Michigan.

The company maintains international operations in many countries to provide comprehensive services to clients throughout Western Europe, Latin America and the Pacific Rim.

www.omnex.com
info@omnex.com



- **Omnex Global Head Quarters** (Michigan, USA)
  West Coast Operations (San Jose, CA)
- **Asia Pacific HQ** (Chennai, Pune, Delhi, Bangalore)
- China (Shanghai, Guangzhou, Wuhan, Chengdu)
- Canada (Mississauga)
- Europe (Berlin, Germany)
- Middle East (Dubai, Saudi Arabia, Bahrain)
- Thailand (Bangkok)
- Mexico (Monterrey)
- Singapore
- Malaysia (Kuala Lumpur)

Rules of the Classroom

- ✓ Start and end on time
- ✓ Return from breaks and lunch on time
- ✓ All questions welcome
- ✓ Your input is valuable and is encouraged
- ✓ Don’t interrupt others
- ✓ One meeting at a time
- ✓ Listen – and respect others’ ideas
- ✓ No “buts” – keep an open mind
- ✓ Cell phones & pagers off or silent mode
- ✓ No e-mails, texting or tweeting during class
- ✓ If you must take a phone call or answer a text please leave the room for as short a period as possible

Icebreaker

- **Instructor Information:**
  - Name
  - Background
- **Student Introductions:**
  - Name
  - Position / Responsibilities
  - What is your involvement in the GDT?
  - What are your experiences with GDT?
  - Please share something unique and/or interesting about yourself.

OMNEX

Chapter #1

Tolerance Stack-up Introduction

What is Dimension and Tolerance

There are two components to the definition of part geometry:

1. nominal state: Nominal Dimension:
2. allowable variation: Tolerance :

Two dimensioning system: OMNEX

1. plus/minus dimensions and tolerances
2. GD&T Geometric Dimensioning and Tolerancing GD&T

Or combination of both systems.

the best way to tolerance features is by using GD&T. GD&T is the only way to ensure that everyone interprets the dimensioning and tolerancing specifications the same way.

Tolerance Stack up Questions

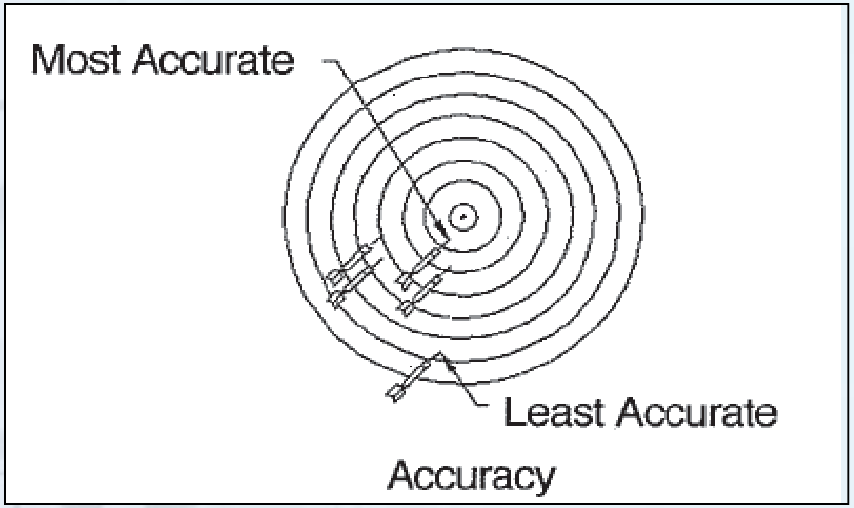
Tolerance Stack ups provide a numerical answer to a question. Typical questions include:

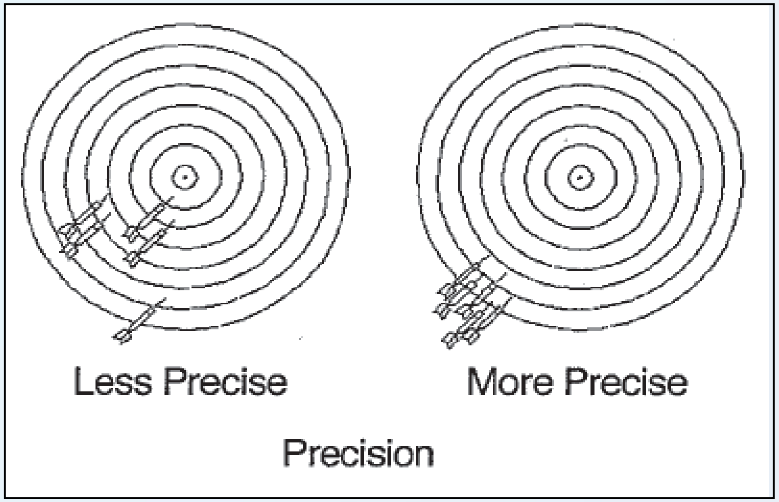
- **Will these two surfaces interfere?**
- **What is the minimum distance between the bolt head and the flange at 90° ?**
- **What is the maximum thickness of the two parts that must fit within this groove?**
- **Will the pin fit within the hole?**
- **How large can the body of the switch be and still assemble?**
- **What is the worst-case largest angle possible between these surfaces?**
- **How do I know if the worst-case assembly will satisfy its dimensional objectives?**
- **If we reduce the size of the clearance holes, will the parts still assemble?**
- **Will the dimensioning and tolerancing scheme used on the parts allow too much variation at assembly? Should the drawings be redimensioned and retoleranced to reduce the accumulation of tolerances?**
- **If we chuck the part using this diameter, how much tolerance is allowed for the smaller coaxial diameter?**

Tolerance Stack up Target

1. Optimize the tolerances of parts and assemblies in a new design.
2. Balance accuracy, precision, and cost with manufacturing process capability.
3. Determine the part tolerances required to satisfy a final assembly condition.
4. Determine the allowable part tolerances if the assembly tolerance is known.
5. Determine if the parts will work at their worst-case condition or with the maximum statistical variation.
6. Determine if the specified part tolerances yield an acceptable amount of variation between assembled components.
7. Troubleshoot malfunctioning existing parts or assemblies.
8. Determine the effect changing a tolerance value will have on assembly function.
9. Explore design alternatives using different or modified parts.

Accuracy vs Precision





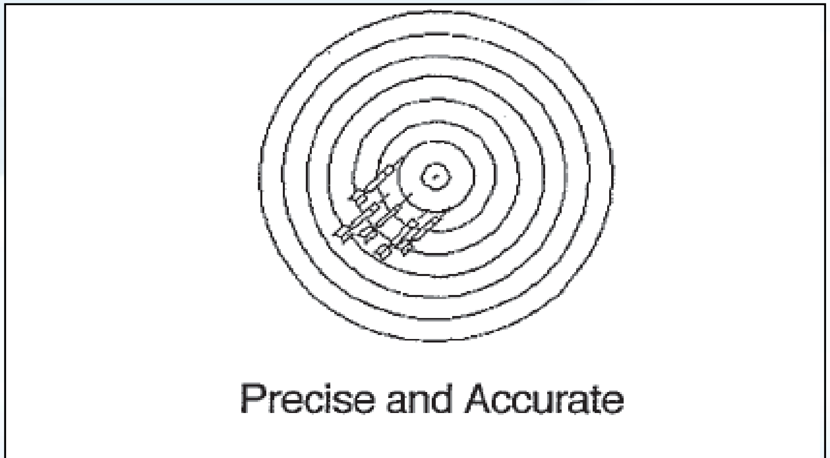
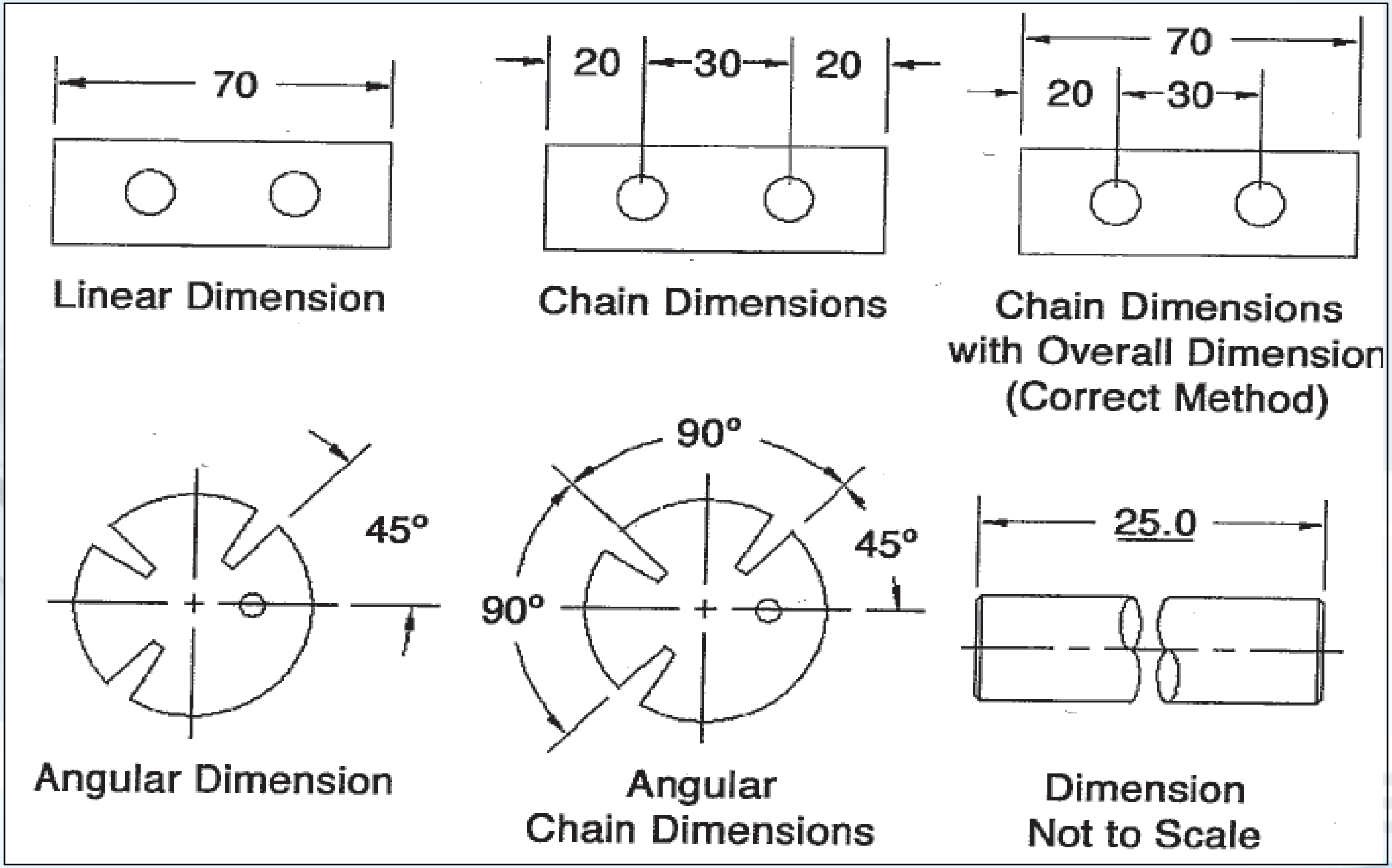


FIGURE 1.2 Accuracy vs. precision.

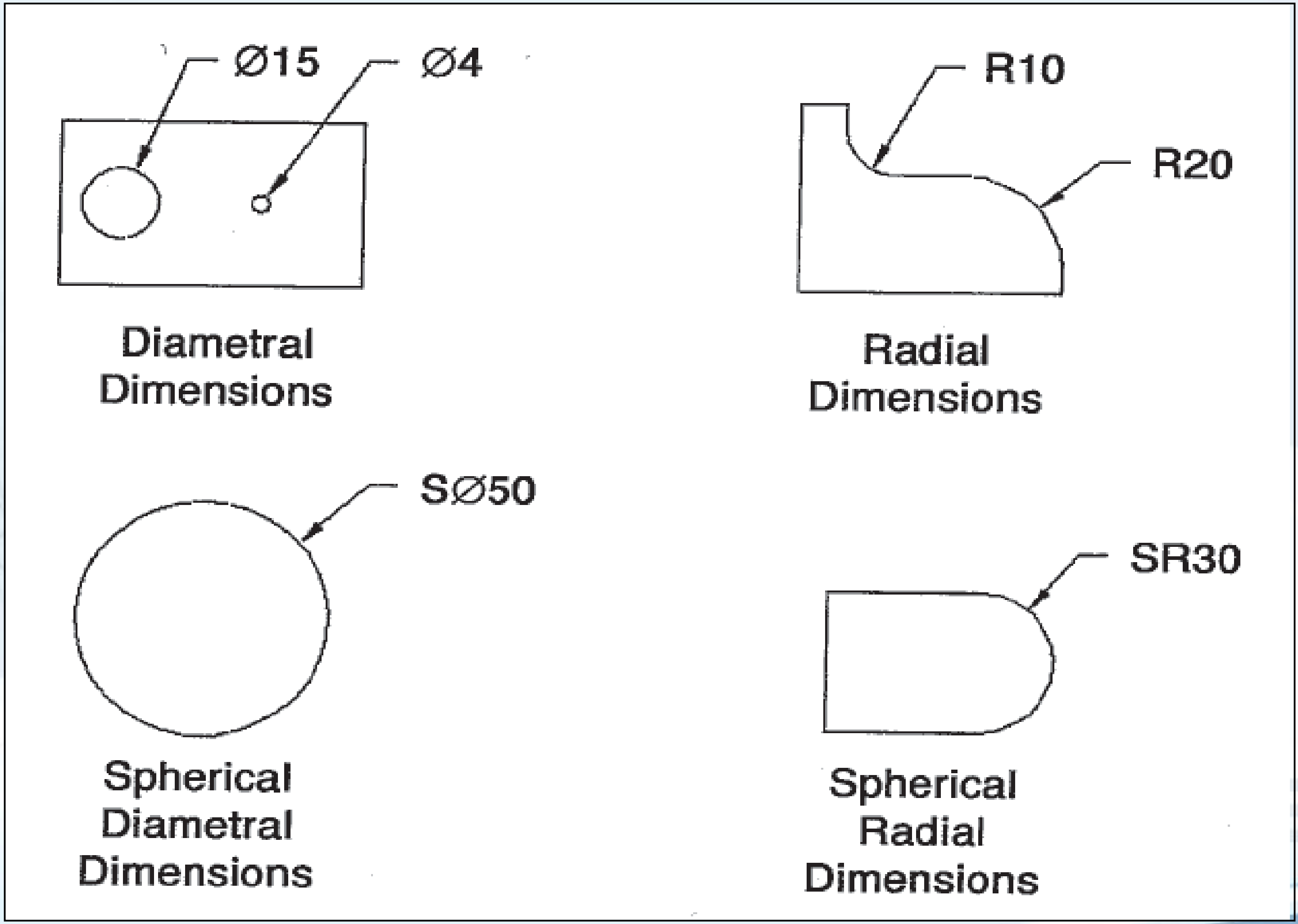
Chapter #2

Dimensioning and Tolerancing

Types Of Dimensions - Linear and angular dimensions



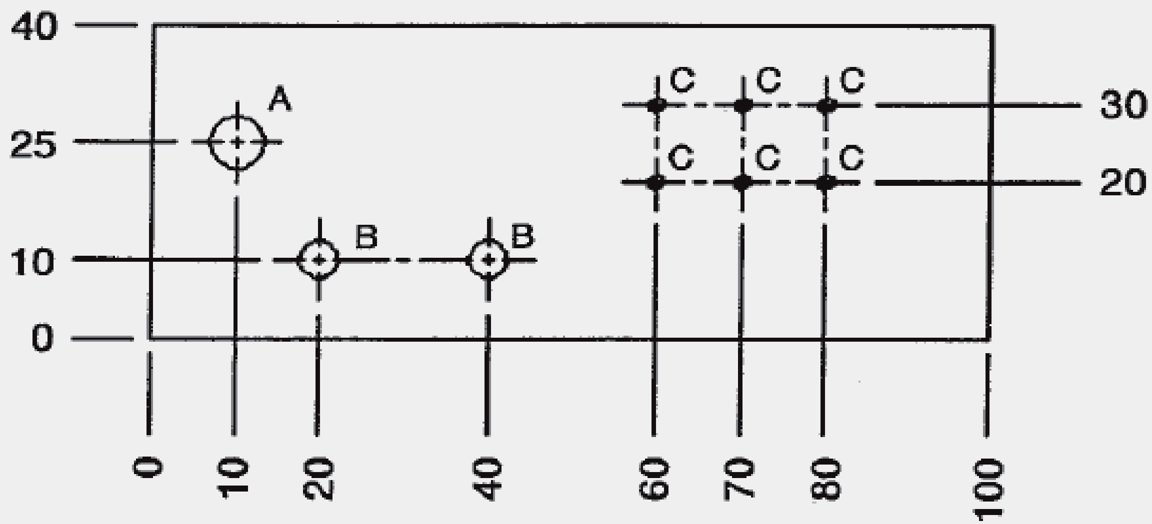
Types Of Dimensions - Linear and angular dimensions



OMNEX
WWW.OMNEX.COM

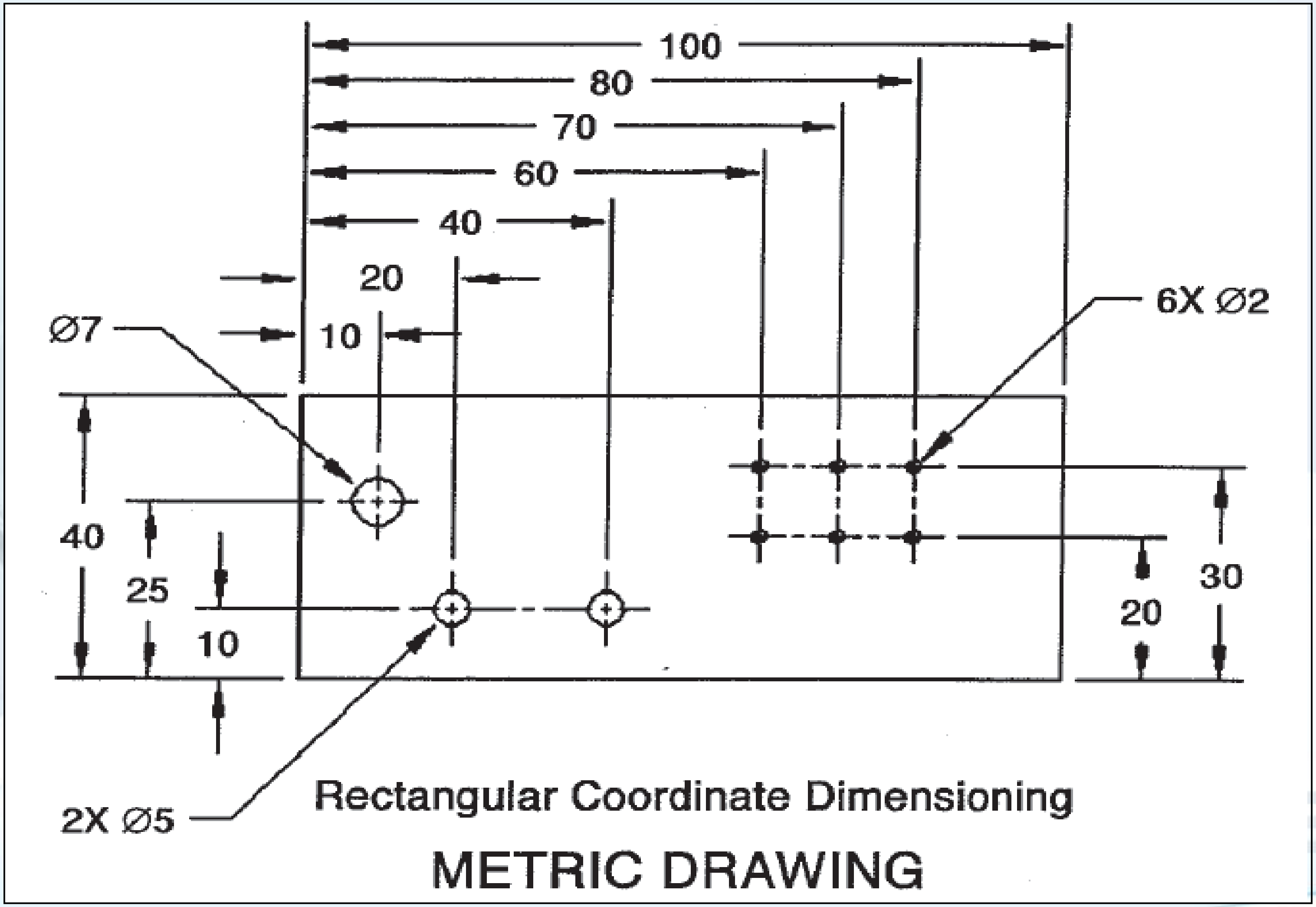
Types Of Dimensions - Rectangular’ coordinate dimensioning

Hole Label	Diameter
A	Ø7
B	Ø5
C	Ø2



Rectangular Coordinate Dimensioning
Without Dimension Lines
Hole Size Stated in Chart

Types Of Dimensions - Rectangular' coordinate dimensioning



How to Specify Tolerance

- **Tolerances may be stated specifically or generically as described below:**

  1. **Title Block or General Note Tolerances**
  2. **Local Plus/Minus Tolerances**
  3. **GD&T .o.m.n.ex**

Note: only linear units may be specified in a feature control frame

Dimensions must be arranged and related in such a way to minimize tolerance accumulation between related features.

GD&T Drawing

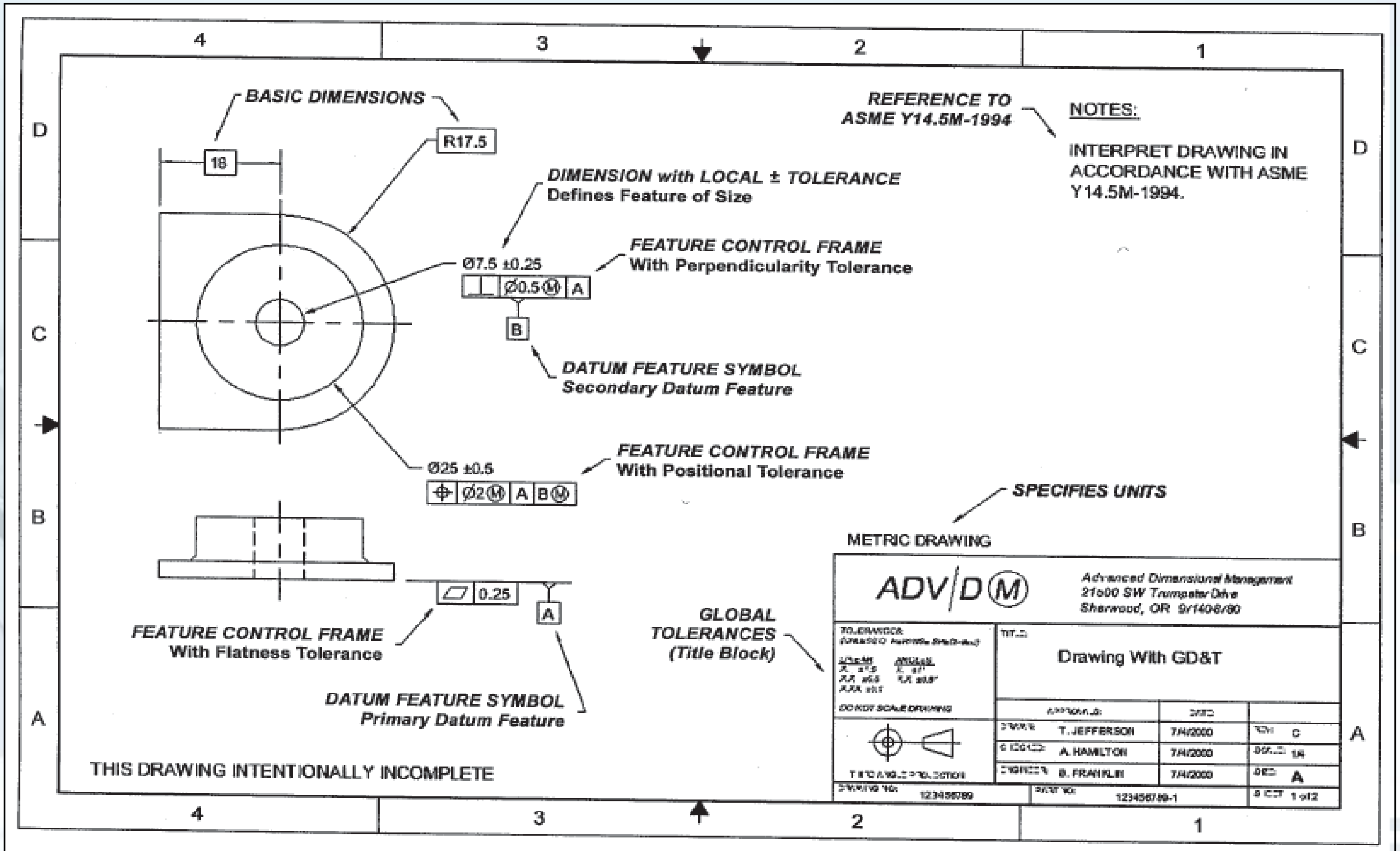


FIGURE 2.4 Drawing with GD&T.

Geometric Tolerance Symbol

Geometric Tolerances

	GEOMETRIC TOLERANCE AND SYMBOL	
FORM TOLERANCES	⏤	STRAIGHTNESS
	⏥	FLATNESS
	○	CIRCULARITY (ROUNDNESS)
	⌭	CYLINDRICITY
ORIENTATION TOLERANCES	∠	ANGULARITY
	⊥	PERPENDICULARITY
	∥	PARALLELISM
LOCATION TOLERANCES	⌖	POSITION
	◎	CONCENTRICITY
	⌯	SYMMETRY
PROFILE TOLERANCES	⌒	PROFILE OF A LINE
	⌓	PROFILE OF A SURFACE
RUNOUT TOLERANCES	↗	CIRCULAR RUNOUT
	⌰	TOTAL RUNOUT

FIGURE 2.5 GD&T symbology.

Feature Characteristics And Associated Tolerance Types

four types of tolerances:

- Size tolerances
- Form tolerances
- Orientation tolerances
- Location tolerances

Feature Characteristics And Associated Tolerance Types

- **Size:**

Only features of size have size as defined in the ASME Y14.5M-1994 standard. Therefore, only those features that are features of size require a size tolerance.

Some features, such as a single planar feature, do not have size characteristics and therefore do not require a size tolerance to be completely defined.

Feature Characteristics And Associated Tolerance Types

- **Form**

every feature must have a form tolerance, either directly or indirectly specified.

directly specified form tolerances include flatness, circularity, cylindricity, and straightness.

indirectly specified form tolerance comes with rule #1, a profile of a surface tolerance to a basically defined surface. profile of a surface may control form, orientation, location, and possibly even size

indirect methods of controlling form can be overridden by specifying a form tolerance with a smaller value.

Feature Characteristics And Associated Tolerance Types

- **Orientation**

can be considered as the angle between features, or more precisely, orientation is the amount a feature may tilt relative to a datum reference frame.

Aside from the primary datum feature, every feature on a part is oriented to other features. A primary datum feature is exempt because all other features are directly or indirectly oriented to it.

Feature Characteristics And Associated Tolerance Types

- Orientation may also be controlled directly or indirectly.
- Dimensions with ± tolerances for all features rely on the default angular ± tolerance in the title block to control the orientation of all features.
- Other methods of indirectly specifying an orientation tolerance occur where a profile of a surface tolerance is related to a datum reference frame and where a positional tolerance is related to a datum reference frame—both of these cases control orientation and may also control size, form, and location.

Feature Characteristics And Associated Tolerance Types

- Location tolerances must be directly specified, as they are not subsets of other tolerance types.

  For example, a positional tolerance related to a datum reference frame controls orientation as a subset of position, but only positional, run out, concentricity, symmetry and profile tolerances control location.

Chapter #3

Tolerancing Format and Decimal Places

Types of Tolerancing

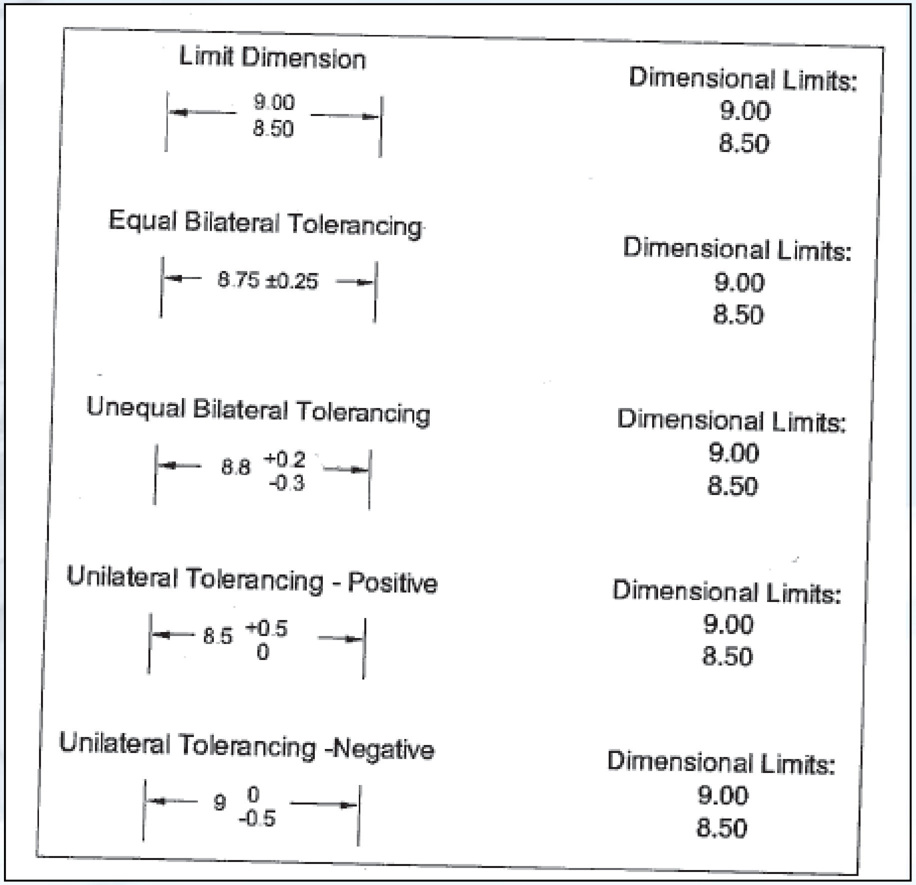
Tolerancing with SI Units: (millimeters)	Tolerancing with U.S. Customary Units: (inches)
Limit Dimension 8.75 8.25 *** Same number of decimal places in both limits.	Limit Dimension 8.75 8.25 Same number of decimal places in both limits.
Equal Bilateral Tolerancing 8.5 ±0.25 Number of decimal places may be different for dimension and tolerance.	Equal Bilateral Tolerancing 8.50 ±.25 Number of decimal places must be the same for dimension and tolerance.
Unequal Bilateral Tolerancing 8.5 +0.25 -0.40 *** Number of decimal places may be different for dimension and tolerances. Both tolerances must have the same number of decimal places.	Unequal Bilateral Tolerancing 8.50 +.25 -.40 Number of decimal places must be the same for dimension and both tolerances.

OMNEX
WWW.OMNEX.COM

Types of Tolerancing

Tolerancing with SI Units: (millimeters)	Tolerancing with U.S. Customary Units: (inches)
Unilateral Tolerancing 8.5 $^{+0.25}_{0}$ Number of decimal places may be different for dimension and tolerances. The zero tolerance has no decimal places and is not preceded by a + or - sign.	Unilateral Tolerancing 8.50 $^{+.25}_{-.00}$ Number of decimal places must be the same for dimensions and both tolerances.
Leading zeroes for dimensions and tolerances. Trailing zeroes only used in certain applications, (marked ***).	No leading zeroes for dimension values. Trailing zeroes used where needed.
Angular Dimensions and Tolerances Equal Bilateral: 23.5° ±1.0° Unequal Bilateral: 23.50° $^{+0.50°}_{-0.25°}$ Angles may be specified using decimal degrees or degrees, minutes and seconds. If decimal degrees are used, the number of decimal places must be the same for the dimension and both tolerances. Angular dimensions and tolerances follow the same rules on drawings prepared using either type of units.	

Tolerance Limit and Statistic Tolerancing



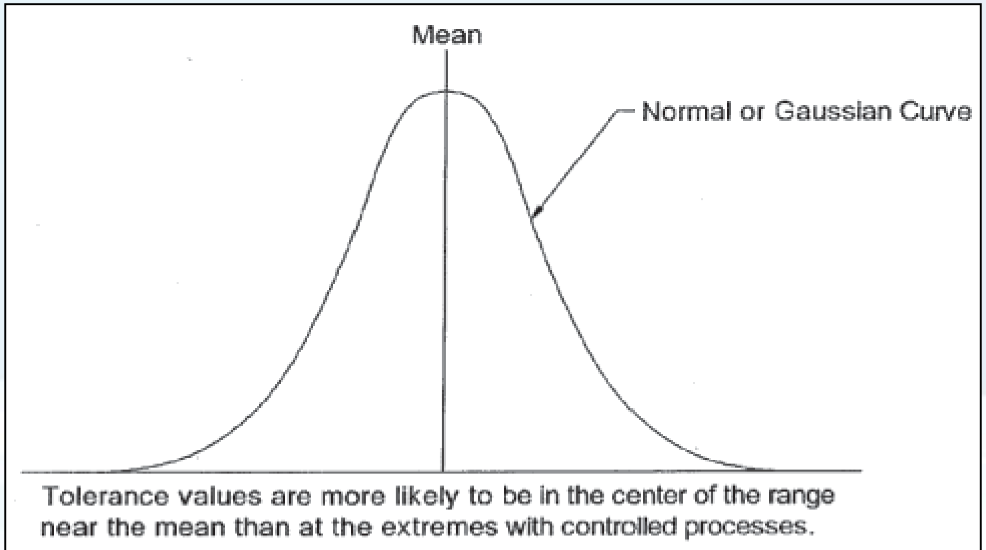


FIGURE 3.3 Gaussian distribution and the Central Limit Theorem.

Chapter #4

Tolerancing Converting

Converting Limit Dimensions to Equal Bilateral Format

Example #4.1

- Given a limit dimension,

  10.00 Upper limit (metric format)

  9.55 Lower limit (metric format)

$$\text{Total tolerance} = 10 - 9.55 = 0.45$$

$$\text{Equal bilateral tolerance value} = \frac{0.45}{2} = 0.225$$

$$\text{Adjusted nominal value} = 9.55 + 0.225 = 9.775$$

Conversion complete:

$$\text{Equal bilateral equivalent} = 9.775 \pm 0.225$$

Converting Limit Dimensions to Equal Bilateral Format

Example #4.2

$$8.50 \begin{array}{l} +.25 \\ -.10 \end{array}$$

$$\text{Upper limit} = 8.50 + .25 = 8.75$$
$$\text{Lower limit} = 8.50 - .10 = 8.40$$

Total tolerance derived from given tolerances

$$= .25 + .10 = .35$$

$$\text{Equal bilateral tolerance value} = \frac{.35}{2} = .175$$

$$8.40 + .175 = 8.575$$

Conversion complete :

$$\text{Equal bilateral equivalent} = 8.575 \pm .175$$

OMNEX

WWW.OMNEX.COM

Converting Limit Dimensions to Equal Bilateral Format

Example #4.3

$$8.50 \begin{array}{l} +.25 \\ -.00 \end{array}$$

Conversion complete :

Equal bilateral equivalent $= 8.625 \pm .125$

Example #4.4

$$8.5 \begin{array}{l} \ \ 0 \\ -0.25 \end{array}$$

Conversion complete:

Equal bilateral equivalent $= 8.375 \pm 0.125$

Mean Shift

- In converting unequal bilaterally and unilaterally toleranced dimensions to equal bilateral format, the dimension value changed to the midpoint or mean of the tolerance range.
- Where dimensions are included in the Tolerance Stack up, the mean shift is little more than a curiosity, as it has no effect on the outcome of the Tolerance Stack up.
- The mean shifts are accounted for in the Tolerance Stack up method. Using more advanced and streamlined methods where the dimensions are not included and only the tolerances are manipulated, the mean shift must be accounted for.

Mean Shift

Example #4.1a

No Mean Shift

Example 4.1a. Mean Shift Calculation for Limit Dimensions Converted into Equal Bilateral Format

- Given a limit dimension,

  10.00 Upper limit (metric format)

  9.55 Lower limit (metric format)

Example #4.2a

With Mean Shift

$8.50 \begin{array}{l} + .25 \\ - .10 \end{array}$

$8.575 \pm .175$

Converted dimension value (mean) – original dimension value (nominal) = mean shift

Mean shift = 8.575 – 8.50 = .075

OMNEX

WWW.OMNEX.COM

Mean Shift

Example #4.3a

$$8.50 \begin{array}{l} +.25 \\ -.00 \end{array}$$

$$8.625 \pm .125$$

$$\text{Mean shift} = 8.625 - 8.50 = .125$$

Example #4.4a

$$8.5 \begin{array}{l} 0 \\ -0.25 \end{array}$$

$$8.375 \pm 0.125$$

$$\text{Mean shift} = 8.375 - 8.50 = -0.125$$

Chapter #5

Source of Variation

Sources of Variation

1.Tolerances specified on the drawing
2. Variation encountered in the inspection process
3. Variation encountered in the assembly process . O-M-N-E-X

only specified tolerances, datum feature shift and assembly shift should be included in a Tolerance Stack up， the other sources of variation arc merely included here for descriptive purposes.

Sources of Variation

- Manufacturing Process Limitations (Process Capability)
- Tool Wear
- Operator Error and Operator Bias
- Variations in the material from the foundry, or material formed or cut by a 5. previous process contribute to possible variation.
- Ambient Conditions
- Difference in Processing Equipment
- Difference in Process
- Poor Maintenance
- Inspection Process Variation and Shortcuts
- Assembly Process Variation

Chapter #6

Tolerance Analysis

What Is Tolerance Analysis?

Tolerance Analysis is a global term that includes two subcategories:

1. To determine the meaning of individual tolerancing specifications;

2. To determine the cumulative variation possible between two or more features.

The second part of the definition is commonly called a Tolerance Stack up.

Typical questions of Tolerance Stack up

- Will these two surfaces touch in their worst case? If so, how much will they interfere?
- What is the minimum distance between the bolt head and the flange at 90° ?
- What is the maximum thickness of the two parts that must fit within this groove?
- Will the pin fit within the hole?
- How large can the body of the switch be and still assemble?
- What is the worst-case largest angle possible between these surfaces?
- How do I know if the worst-case assembly will satisfy its dimensional objectives?
- Why is there interference between these existing parts?
  is the interference allowed by the part tolerances and the assembly process?
- If we reduce the size of the clearance holes, will the parts still assemble?
- Will the dimensioning and tolerancing scheme used on the parts allow too much variation at assembly? Should the drawings be redimensioned and retoleranced to reduce the accumulation of tolerances?
- If we chuck the part using this diameter, how much tolerance is allowed for the smaller coaxial diameter?

Steps of Tolerance Stack up

1.The distance to be studied is identified and labeled.

2. The positive and negative directions of the Tolerance Stack up are identified.

3. A Tolerance Stack up sketch is created.

4. The dimensions in the positive direction are added together.

5. The dimensions in the negative direction are added together.

6. The negative direction total is subtracted from the positive direction total to find the "nominal" distance.

7. All applicable tolerances are added together. This is the to all possible variation.

8. Half of the total possible variation is added to the nominal distance to find the Upper Limit for the distance.

9. Half of the total possible variation is subtracted from the nominal distance to find the lower limit for the distance.

A Tolerance Stack up allows the designer to

1. To Optimize the tolerances of parts and assemblies in a new design.

2. Balance accuracy, precision, and cost with manufacturing process capability.

3. Determine the part tolerances required to satisfy a final assembly condition.

4. Determine the allowable part tolerances if the assembly tolerance is known.

5. Determine if the parts will work at their worst-case condition or with the maximum statistical variation.

6. Determine if the specified part tolerances yield an acceptable amount of variation between assembled components.

7. Troubleshoot malfunctioning existing parts or assemblies.

8. Determine the effect changing a tolerance value will have on assembly function.

9. Explore design alternatives using different or modified parts.

Four Main Factors That Determine Which Dimensions And Tolerances Are Included In A Tolerance Stack Up

- The geometry of parts and assemblies that contribute to the distance being studied in the Tolerance Stack up
- The dimensioning and tolerancing schemes on the drawings of the parts and assemblies in the Tolerance Stack up
- The assembly process, how the parts are assembled
- The direction of the Tolerance Stack up and the direction of the dimensions and tolerances

Methods And Types Of Tolerance Analysis

1.Manually modeled：

Manually modeled analyses are done by hand, using pen and paper, or spreadsheet programs. Manual analyses are limited to linear (one-dimensional) variation.

2. Computer modeled.

Three-dimensional analyses are best suited to computer-modeling tools. Computer modeled analyses are performed by computer statistical simulation programs. Programs are available for one-, two-, and three- dimensional analyses.

Tolerance Stack ups are performed to determine the variation of a single untoleranced dimension or distance.

The direction of a linear Tolerance Stackup

- The direction of a linear Tolerance Stack up is always along a straight line.
- Dimensions and tolerances on surfaces at an angle to the Tolerance Stack up direction may need to be projected into the direction of the Tolerance Stack up using trigonometry.
- Dimensions and tolerances that are perpendicular to the Tolerance Stack up direction typically have no effect on the Tolerance Stack up and are usually
  not included in the chain of Dimensions and Tolerances.

There are two major types of Tolerance Analysis

1. worst-case (arithmetic):

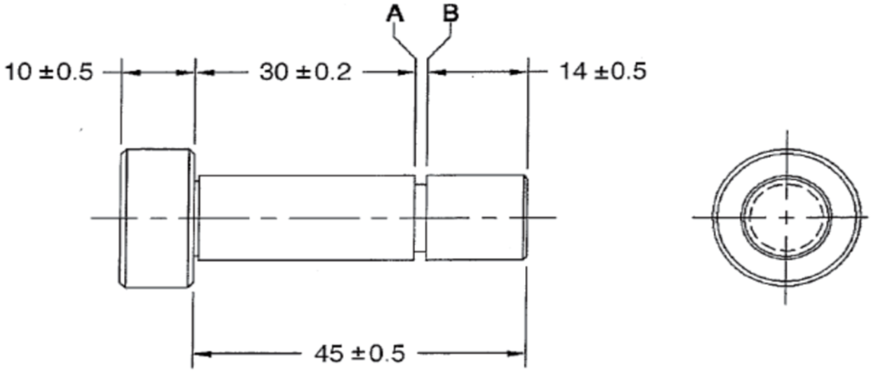
Worst-case tolerance analyses represent the largest (worst-case) possible variation.

2. statistical Tolerance Analysis:

For a Tolerance Stack up with many dimensions and tolerances, statistical tolerance analyses may be more appropriate.

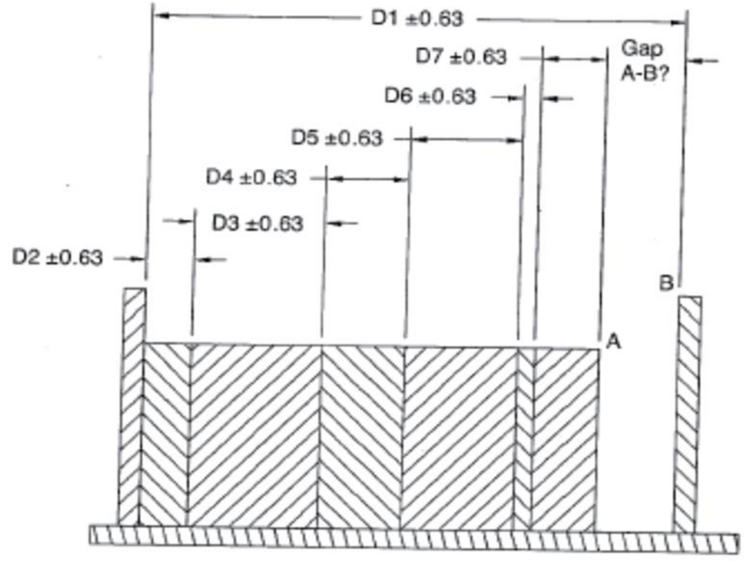
Examples of Tolerance Stackup

What are the Minimum and Maximum Distance for Gap A-B?



Pin with Groove

FIGURE 6.1 Single part with missing dimensions.



Simple Assembly with Missing Dimension

Examples of Tolerance Stack up

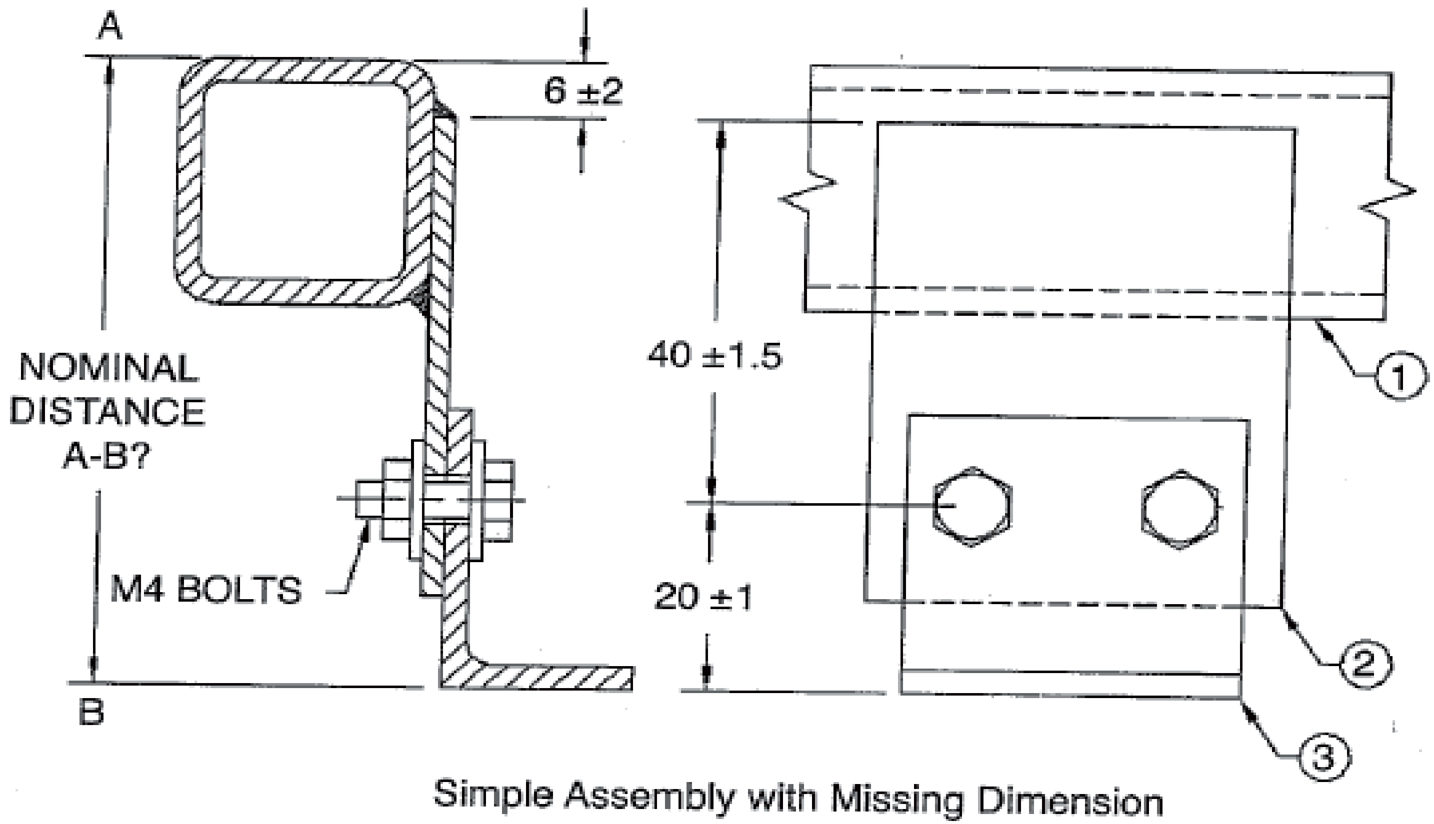


FIGURE 6.2 Assemblies with missing dimensions.

Chapter #7

Worst Case Tolerance Stack-up

Worst-case Tolerance Stack up

1. Select the distance (gap or interference) whose variation is to be determined Label one end of the distance A and the other end B (see Fig. 7.1).

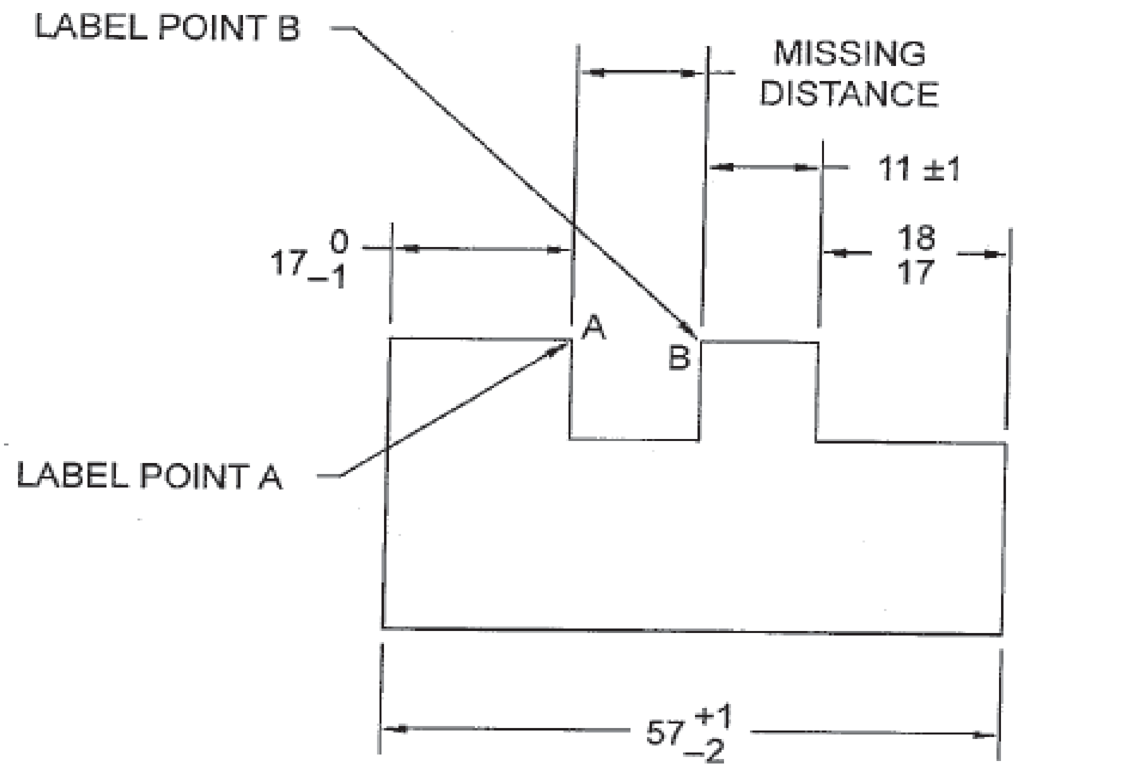


FIGURE 7.1 Worst-case chain of Dimensions and Tolerances #1.

Worst-case Tolerance Stack up

2. Determine if a one-, two-, or three-dimensional analysis is required.

   a. two-dimensional analysis: resolved into one dimension using trigonometry

   b. three-dimensional analysis: a linear Tolerance Stack up is probably not appropriate, and a computer program should be used

Worst-case Tolerance Stack up With Dimensions

3. Determine a positive direction and a negative direction.

   a. dimension that spans distance A—B: positive dimension “+“
   b. dimension that decrease distance A—B: negative dimension “-“

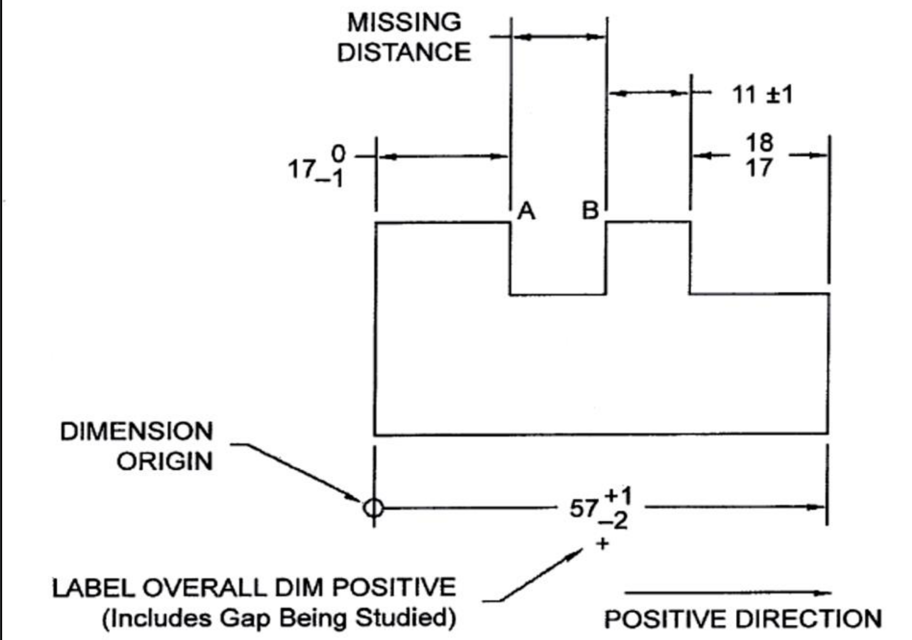


FIGURE 7.2 Worst-case chain of Dimensions and Tolerances #2.

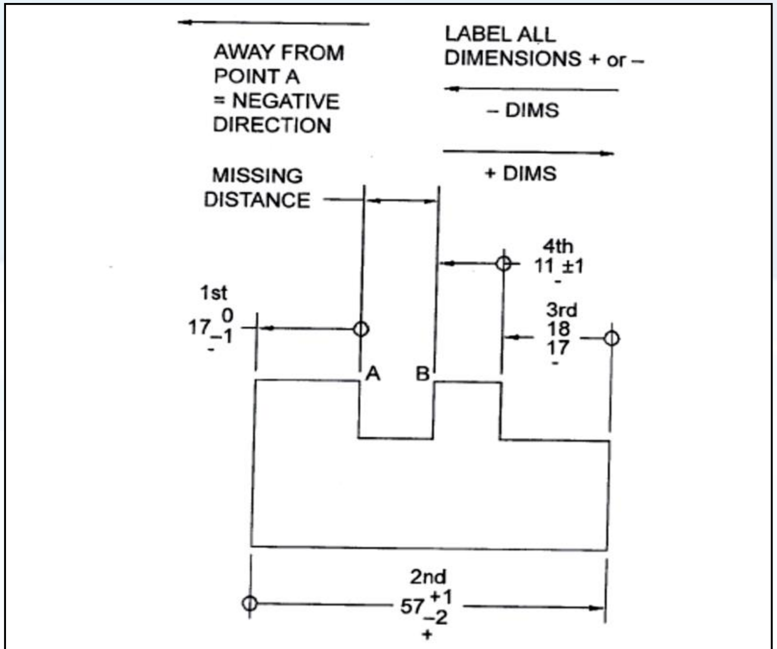


FIGURE 7.3 Worst-case chain of Dimensions and Tolerances #3.

Worst-case Tolerance Stack up With Dimensions

4. Determine a positive direction and a negative direction.

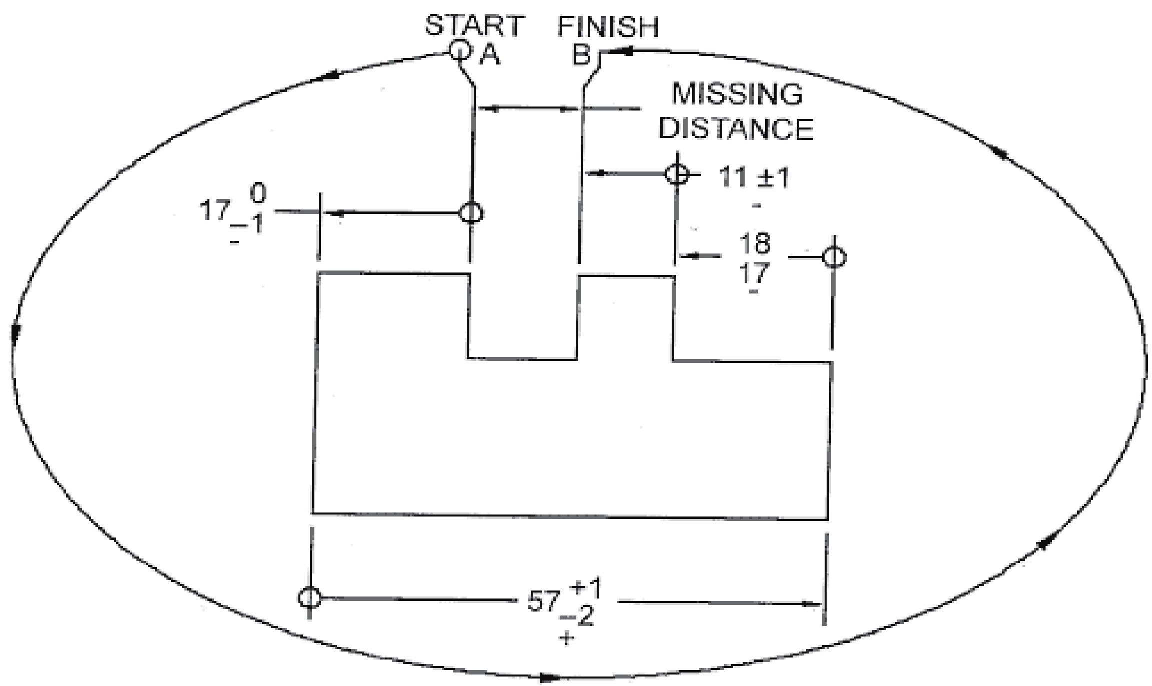


FIGURE 7.4 Worst-case chain of Dimensions and Tolerances #4. Follow the chain of dimensions and tolerances from point A to point B to make sure there are no breaks or discontinuities in the chain.

Worst-case Tolerance Stack up With Dimensions

5. Convert all dimensions and tolerances to equal bilateral format (See Fig. 7.5). Instructions for how to do this are included in Chapter 4

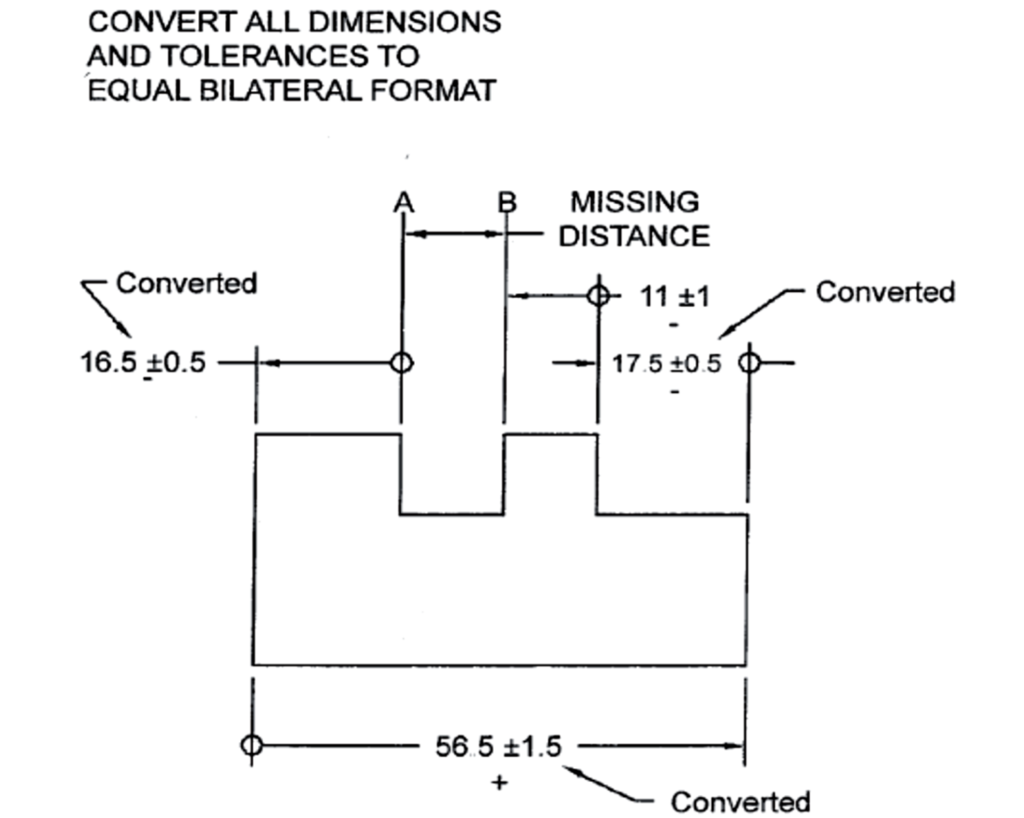
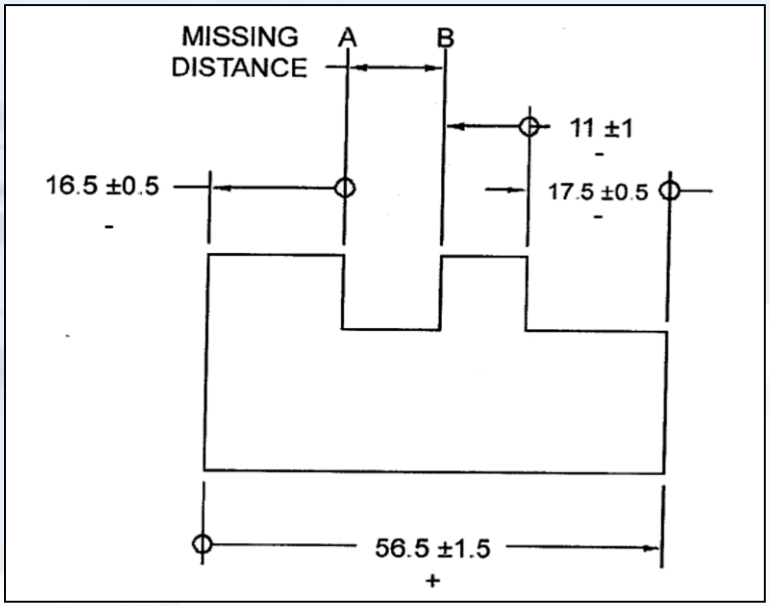


FIGURE 7.5 Worst-case chain of Dimensions and Tolerances #5.

Worst-case Tolerance Stack up With Dimensions

6. all the dimensions and tolerances put into a chart and totaled. Place each positive dimension value in the positive column on a separate line. Place each negative dimension value in the negative column on a separate line. (See Fig. 7.6.)



	+	–	Tolerances
		16.5	±0.5
	56.5		±1.5
		17.5	±0.5
		11	±1
TOTALS	56.5	45	±3.5

POSITIVE TOTAL

NEGATIVE TOTAL

TOTAL TOLERANCE VALUE

FIGURE 7.6 Worst-case chain of Dimensions and Tolerances #6.

Worst-case Tolerance Stack up With Dimensions

7. Place the tolerance value for each dimension in the tolerance column adjacent to each dimension. This value is half the total variation allowed by the tolerance

8. Add the entries in each column, entering the results at the bottom of the chart.

	+	–	Tolerances
		16.5	±0.5
	56.5		±1.5
		17.5	±0.5
		11	±1
TOTALS	56.5	45	±3.5

POSITIVE TOTAL

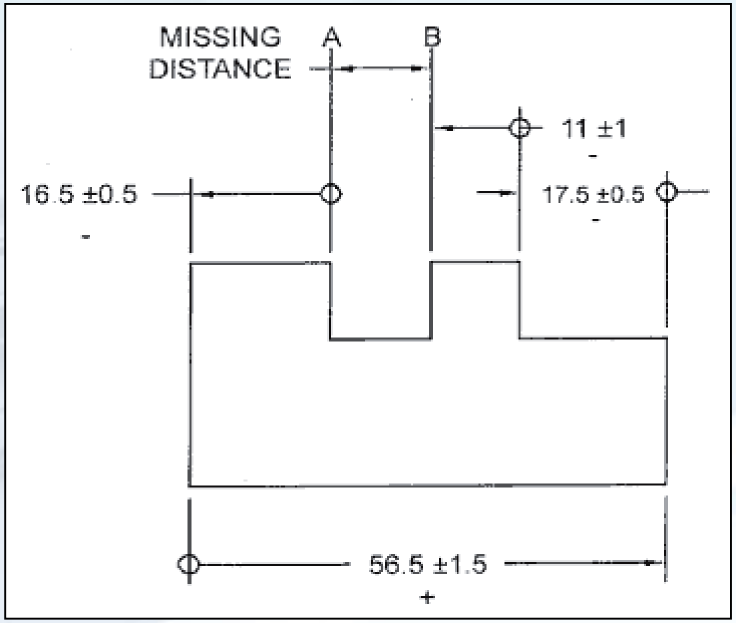
NEGATIVE TOTAL

TOTAL TOLERANCE VALUE

FIGURE 7.6 Worst-case chain of Dimensions and Tolerances #6.

Worst-case Tolerance Stack up With Dimensions

9. Subtract the negative total from the positive total.



	+	–	Tolerances
		16.5	±0.5
	56.5		±1.5
		17.5	±0.5
		11	±1
TOTALS	56.5	45	±3.5

POSITIVE TOTAL 56.5
– NEGATIVE TOTAL – 45
= NOMINAL DISTANCE 11.5 ±3.5 → MAX DIST. = 15; MIN DIST. = 8

TOTAL TOLERANCE VALUE (±3.5)

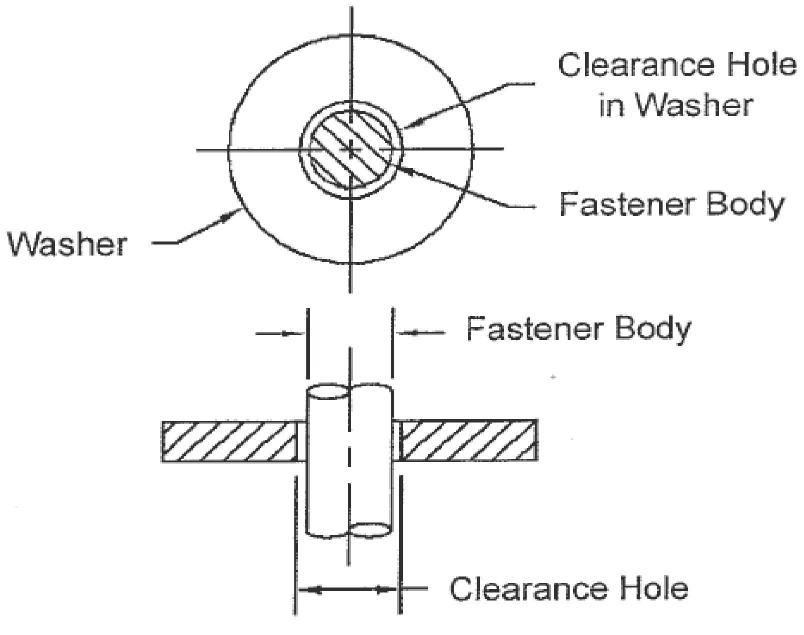
FIGURE 7.7 Worst-case chain of Dimensions and Tolerances #7.

Assembly Shift

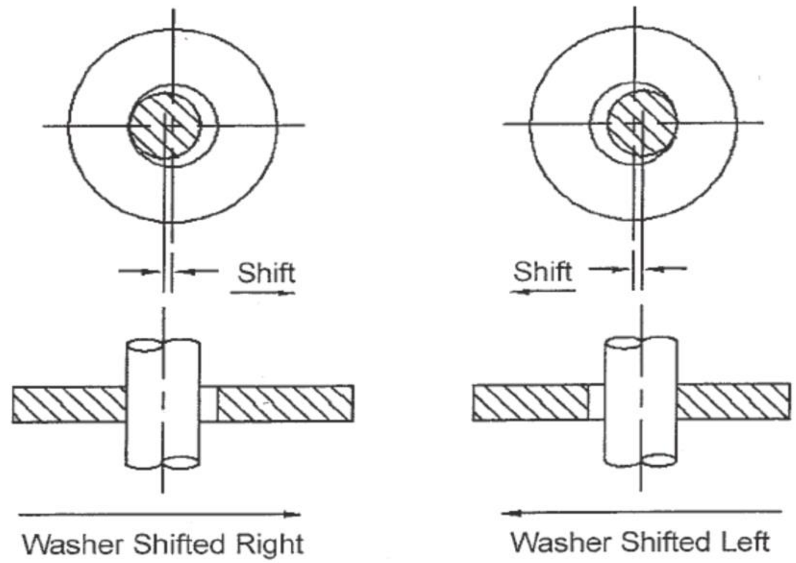
- Assembly shift represents the amount that parts can move during assembly due to the clearance between a hole and a fastener, a hole and a shaft, a width and a slot (like a key and keyway) or between any external feature within an internal feature.
- Assembly shift accounts for the freedom parts have to move from their nominal locations due to the clearance between mating internal and external features at assembly.
- Parts are routinely subjected to forces during assembly: such as gravity

Assembly Shift

Assembly shift is often overlooked until there is a problem at assembly or until a Tolerance Stack up is performed.



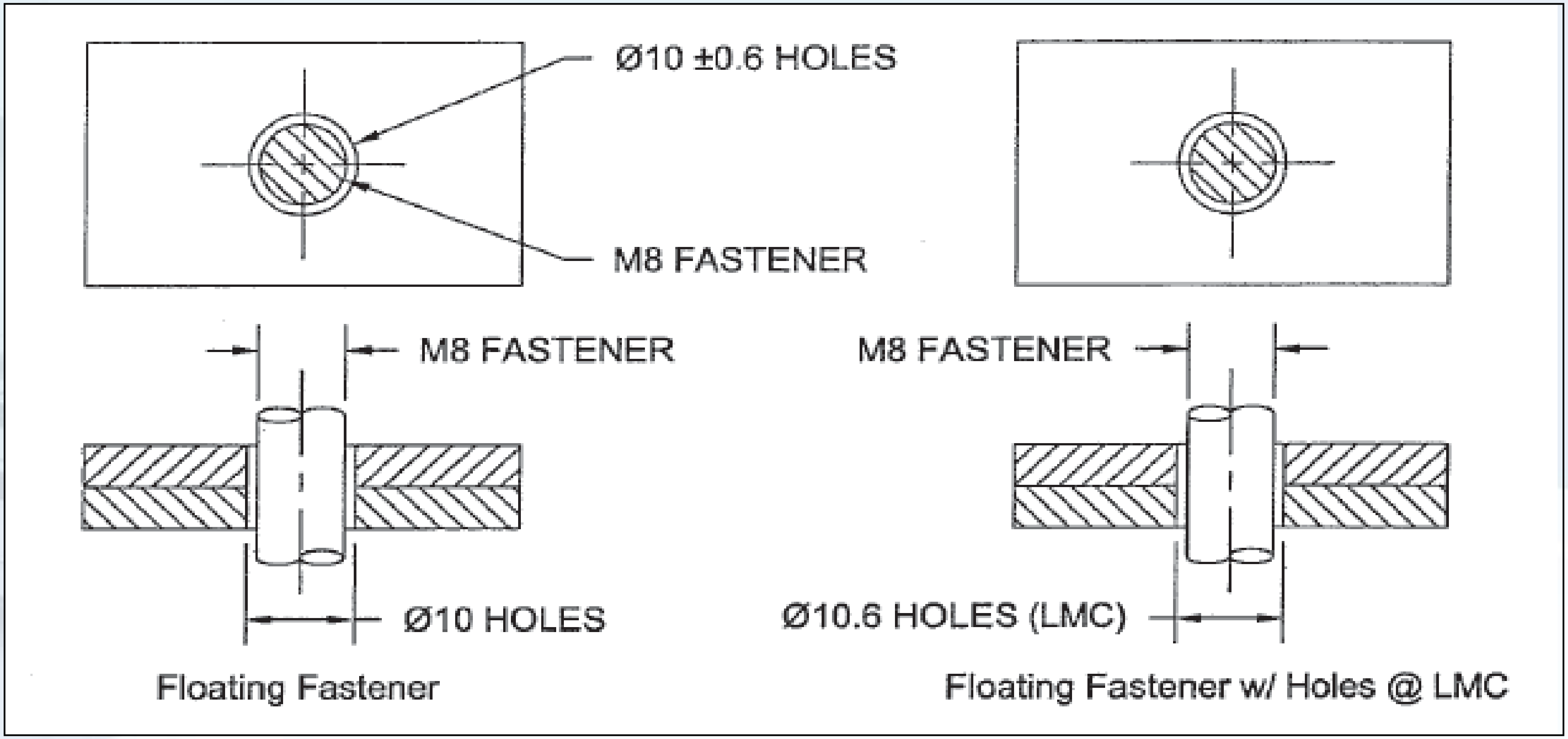
Nominal Washer & Fastener



Washer Shifted about Fastener

FIGURE 7.8 Shift about a fastener.

Assembly Shift – Floating Fastener



major diameter of the fastener must he used in the Tolerance Stack up. A common shortcut: use the nominal size, exp. 8mm for M8.

Assembly Shift – Floating Fastener

NOMINAL HOLE Ø	10
+ SIZE TOLERANCE	+0.6
LMC (LARGEST) HOLE Ø	10.6
LMC (LARGEST) HOLE Ø	10.6
- FASTENER Ø	-8
WORST-CASE ASSEMBLY SHIFT	2.6

Convert to ±: 2.6 / 2 = ±1.3

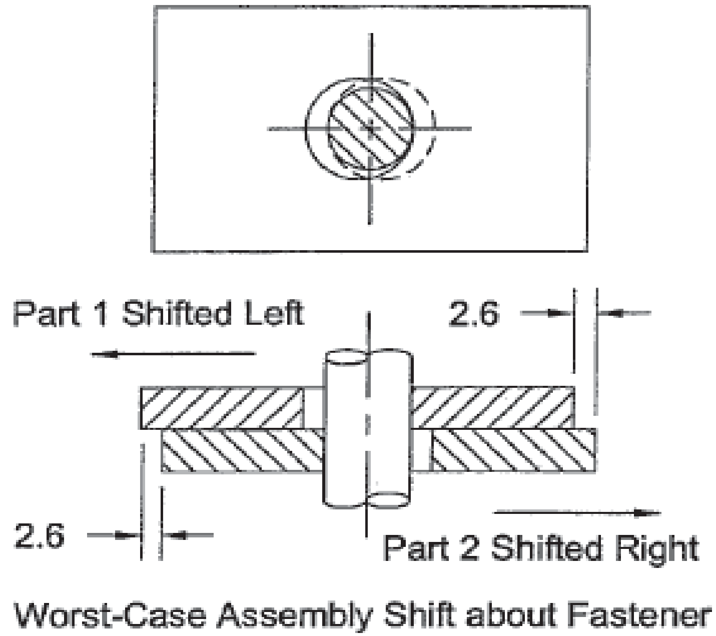


FIGURE 7.9 Worst-case assembly shift. The Worst-Case Assembly Shift applies to each part. Each part may shift +/-1.3mm relative to the fastener, leading to Total Assembly Shift of 2 *±1.3 = ±2.6.

Assembly shift is greatest when the hole and the fastener are at their least material conditions (LMC), which are the largest hole and the smallest fastener.

Rules for Assembly Shift

- In fixed-fastener cases assembly shift is added to the Tolerance Stack up once, representing the amount the clearance holes can shift about the fastener.

- In floating-fastener cases assembly shift is added to the Tolerance Stack up twice, each line representing the amount the clearance holes in each part can shift about the fastener.

  The amount each part may shift about the fastener is independent of the mating parts and must be calculated separately.

Rules for Assembly Shift

- Assembly shift is typically not calculated for fasteners within a threaded hole because fasteners are commonly assumed to self- center within the threaded holes.

  there is always some clearance between internal and external threads, and assembly forces do bias the threads at assembly. A simplified approach could be to compare the difference between the pitch diameters of mating male and female threads, which is sometimes called the allowance, and use that value for the assembly shift.

Rules for Assembly Shift

- In cases where the results of the Tolerance Stack up are very critical and the tolerances are tight, it may be necessary to calculate or estimate the amount that a threaded fastener may move within a threaded hole.

- In cases where oversized holes or slots are used to allow for adjustment at assembly, the assembly shift may be eliminated or even subtracted from the total tolerance. The assembly process will allow time for adjustment, that the assemblers understand the purpose of this extra adjustment, and the parts can be adjusted at assembly, i.e., they are not too heavy or awkward to properly be adjusted to an optimal position.

Rules for Assembly Shift

- **Adjustment at assembly:**

  The parts must be able to be adjusted at assembly if the assembly shift is to be eliminated or subtracted from the total tolerance.

  Some parts may be too heavy, too large, too small, too awkward, or difficult to access or see the critical dimension to allow for proper . adjustment at assembly. In these cases the assembly shift should be included in the Tolerance Stack up. O$M$$NEX

  This text assumes that there is no adjustment at assembly and that any and all possible assembly shift will show up at final assembly.

  Given that premise, each occurrence of assembly shift must be included in the Tolerance Stack up.

The Role Of Assumptions In Tolerance Stack ups

What's the coaxial relationship? - Not toleranced!

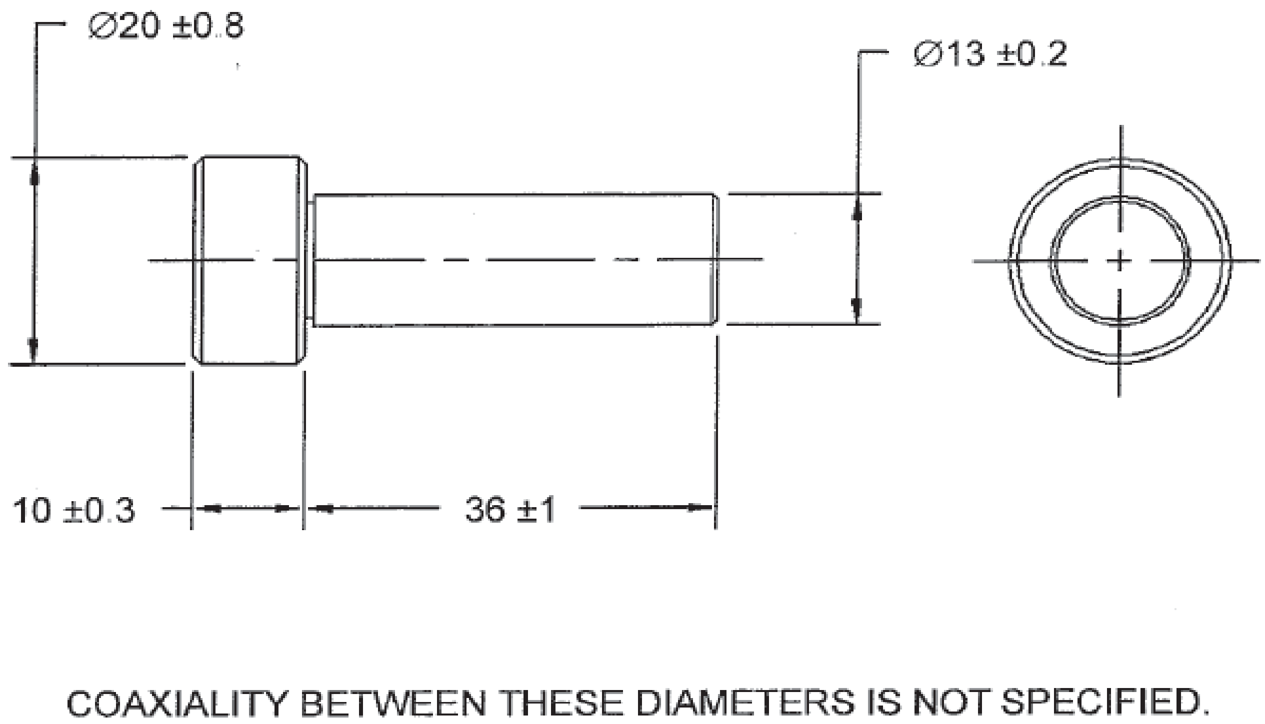


FIGURE 7.10 Coaxial pin without GD&T.

The Role Of Assumptions In Tolerance Stack ups

- **Framing the problem requires assumptions: idealization**

  The Tolerance Analysis techniques presented in this text are for solving one- dimensional, linear Tolerance Stack ups.

  All parts are considered in a static state.

  The Tolerance Stack up allows parts to shift or rotate relative to one another during assembly, but the study is performed in a static condition.

  Typically a worst-case static condition, reflecting worst- case misalignment, minimum clearance, or maximum interference. If desired, statistics may be used to reduce the predicted worst- case total variation.

The Role Of Assumptions In Tolerance Stack ups

- **Tolerance Stack ups are performed with these considerations:**

  If more than one position or orientation of a part must be studied, then a Tolerance Stack up should be done for the considered feature at each important position or orientation.

  Tolerance Stack ups are performed at a specified temperature. Unless specified otherwise, Tolerance Stack ups are performed at ambient temperature, the temperature at which the parts are assembled and! or inspected.

  If a study is needed to account for differential thermal expansion, then the study should be done at the operating temperature. It may be common in some industries to perform Tolerance Stack ups at a number of temperatures to account for various stages of cooling or heating during operation.

The Role Of Assumptions In Tolerance Stack ups

- Here parts are assembled at one temperature and operate at a different temperature, it is important to study both conditions, as the parts must be assembled before they can operate.

- Tolerance Stack ups are most accurate when done on parts and assemblies at the temperature at which they were inspected

- Many more assumptions are required for Tolerance Stack ups done at reduced or elevated temperatures

- Catalog parts: it is very common to have no tolerances available on a catalog data sheet. More commonly a detail is included showing the required mating part geometry, typically inadequate from a Tolerance Analysis, such as bearing, bolt, bushing, etc.

Worst-case Tolerance Stack up Examples #7.1

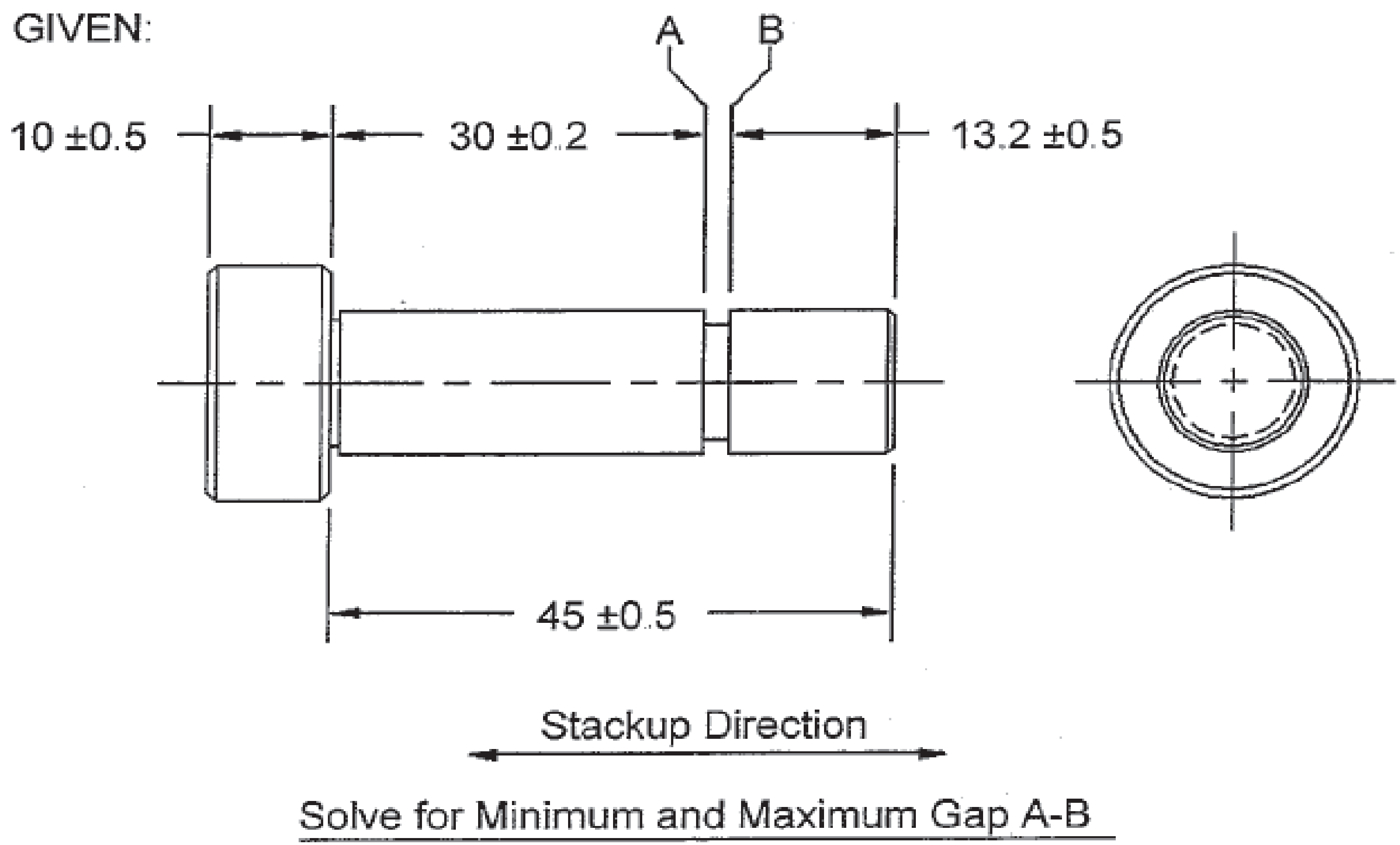
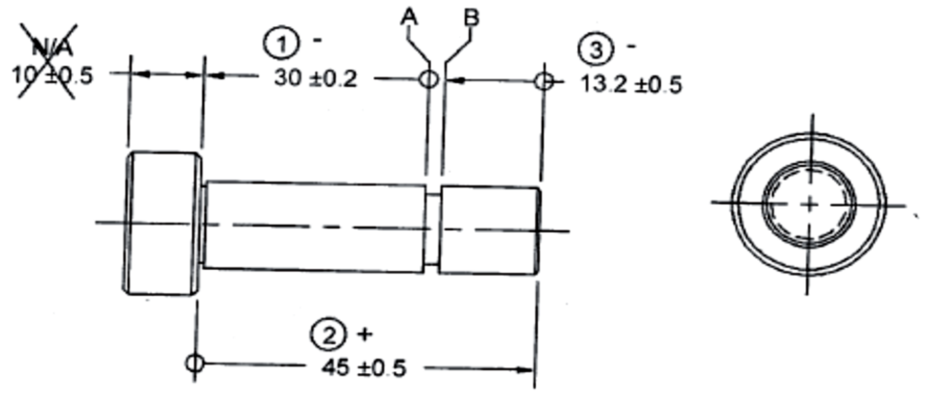


Figure 7.11 Pin with groove.

OMNEX
WWW.OMNEX.COM

Worst-case Tolerance Stack up Examples #7.1



Tolerance Stackup Sketch

+	–	Tolerances	Description
	30	±0.2	GROOVE - HEAD
45		±0.5	OVERALL LENGTH
	13.2	±0.5	TIP - GROOVE
45	43.2	±1.2	Totals

Positive Total 45
– Negative Total – 43.2
= Nominal Gap 1.8 +/– 1.2

MAX GAP = 3
MIN GAP = 0.6

Tolerance Value

Stackup Direction

Solve for Minimum and Maximum Gap A-B

FIGURE 7.12 Pin with groove solved.

Worst-case Tolerance Stack up Examples #7.2

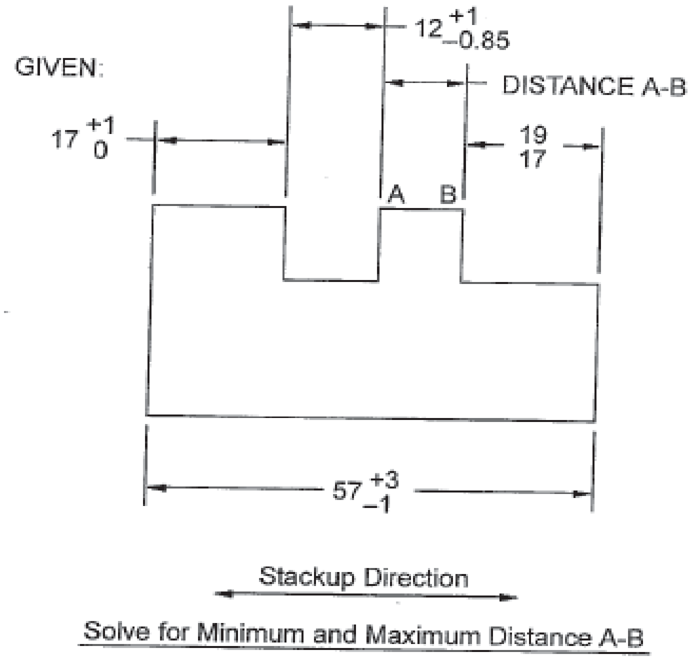
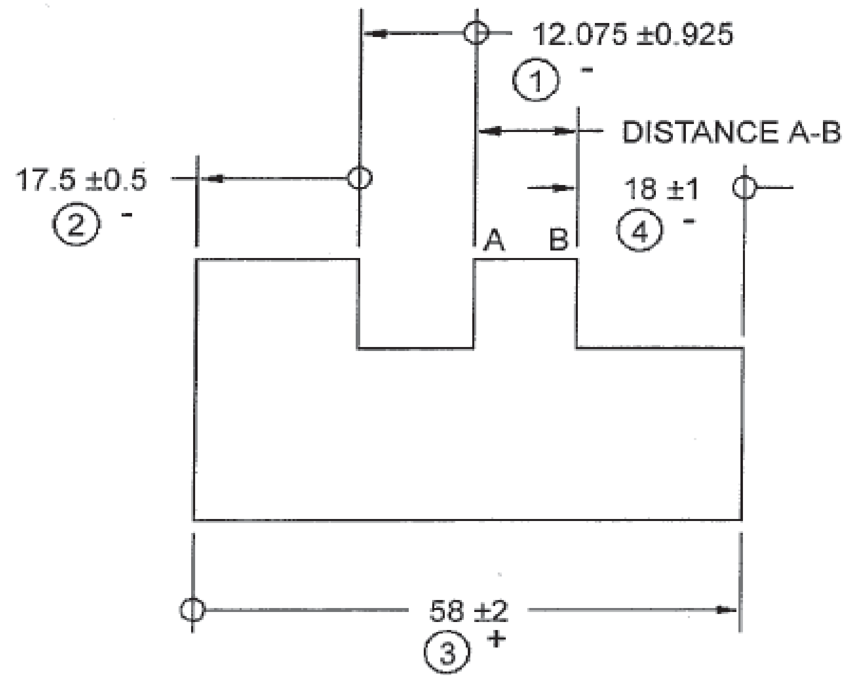


FIGURE 7.13 Simple part.



Tolerance Stackup Sketch

Worst-case Tolerance Stack up Examples #7.2

+	–	Tolerances	Description
	12.075	±0.925	DIM 1
	17.5	±0.5	DIM 2
58		±2	DIM 3
	18	±1	DIM 4
58	47.575	±4.425	Totals

	Positive Total	58
–	Negative Total	–47.575
=	Nominal Distance	10.425

+/– 4.425

MAX DISTANCE = 14.85

MIN DISTANCE = 6

Tolerance Value

Stackup Direction

Solve for Minimum and Maximum Distance A-B

FIGURE 7.14 Simple part solved.

Worst-case Tolerance Stack up Examples #7.3

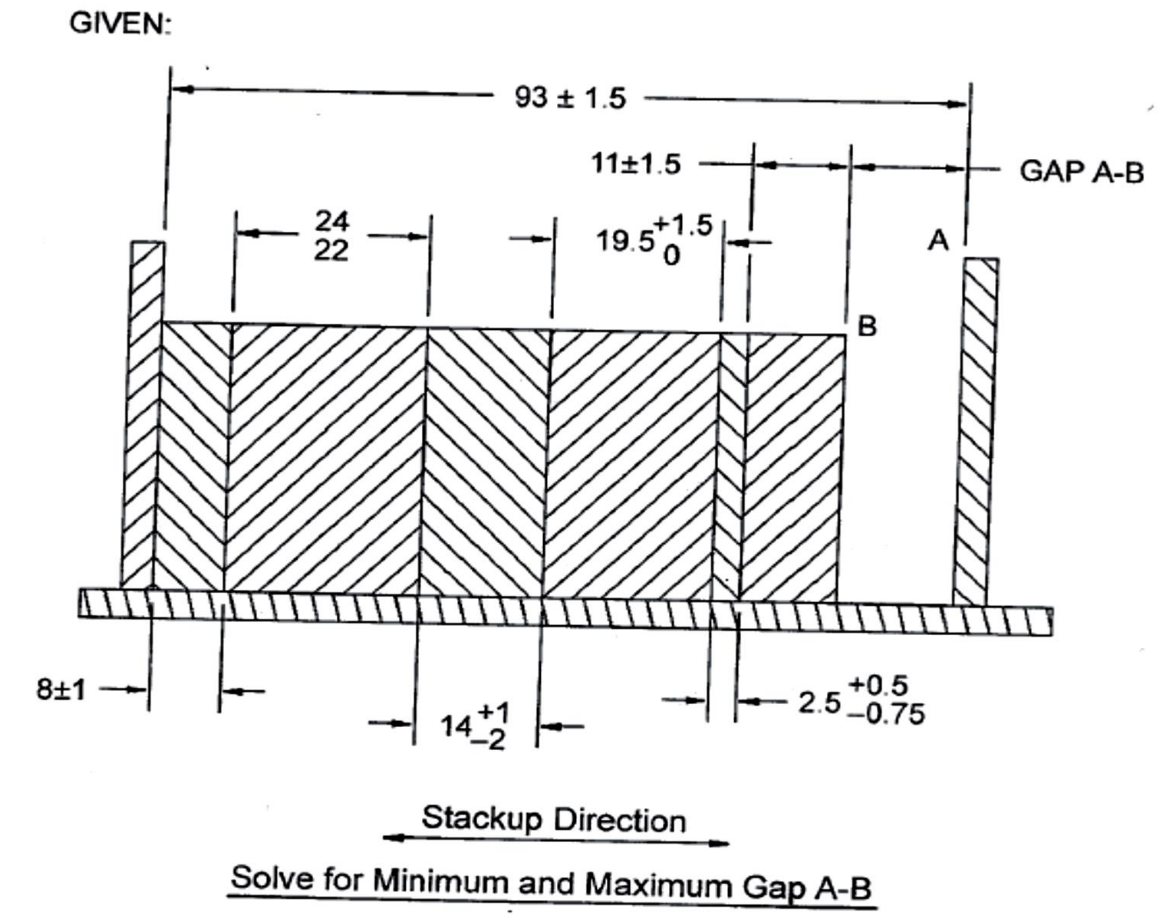
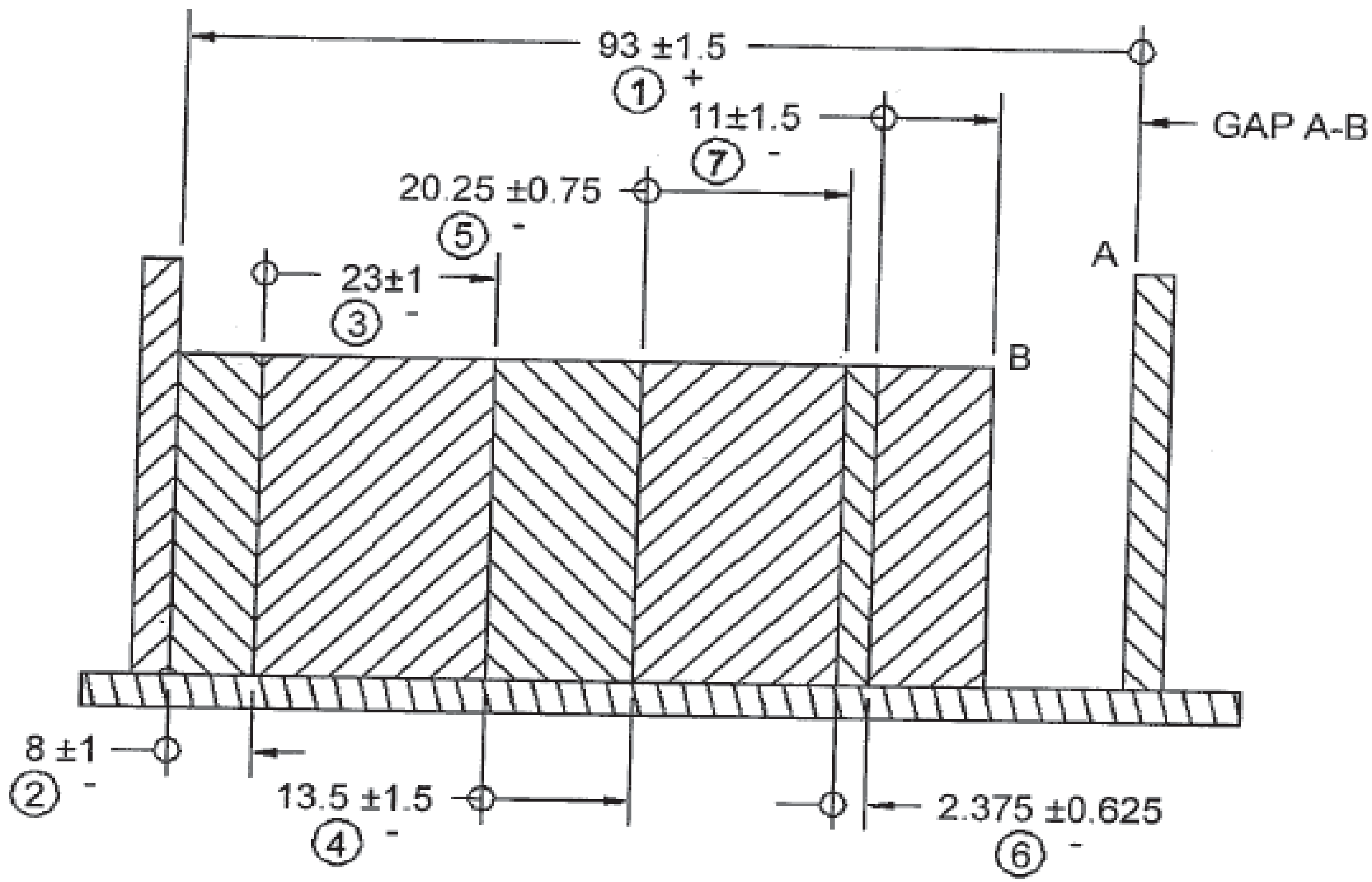


FIGURE 7.15 Simple assembly.

OMNEX
WWW.OMNEX.COM

Worst-case Tolerance Stack up Examples #7.3



Tolerance Stackup Sketch

Worst-case Tolerance Stack up Examples #7.3

+	–	Tolerances	Description
93		±1.5	DIM 1
	8	±1	DIM 2
	23	±1	DIM 3
	13.5	±1.5	DIM 4
	20.25	±0.75	DIM 5
	2.375	±0.625	DIM 6
	11	±1.5	DIM 7
93	78.125	±7.875	Totals

	Positive Total	93
–	Negative Total	–78.125
=	Nominal Gap	14.875

+/– 7.875 (Tolerance Value)

MAX GAP = 22.75

MIN GAP = 7

Stackup Direction

Solve for Minimum and Maximum Gap A-B

FIGURE 7.16 Simple assembly solved.

Worst-case Tolerance Stack up Examples #7.4

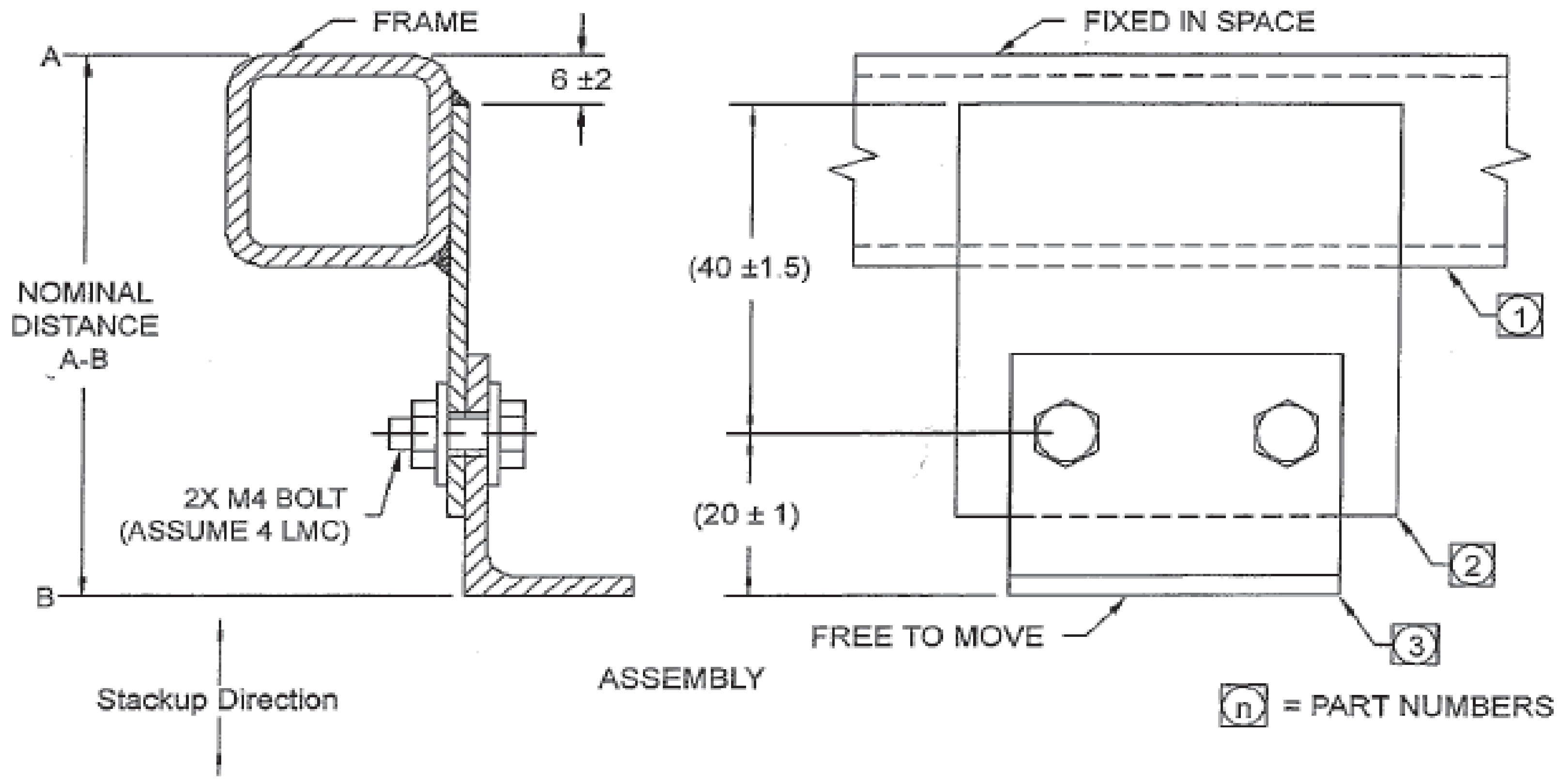


FIGURE 7.17 Hanger assembly (with gravity and assembly shift).

Worst-case Tolerance Stack Up Examples #7.4

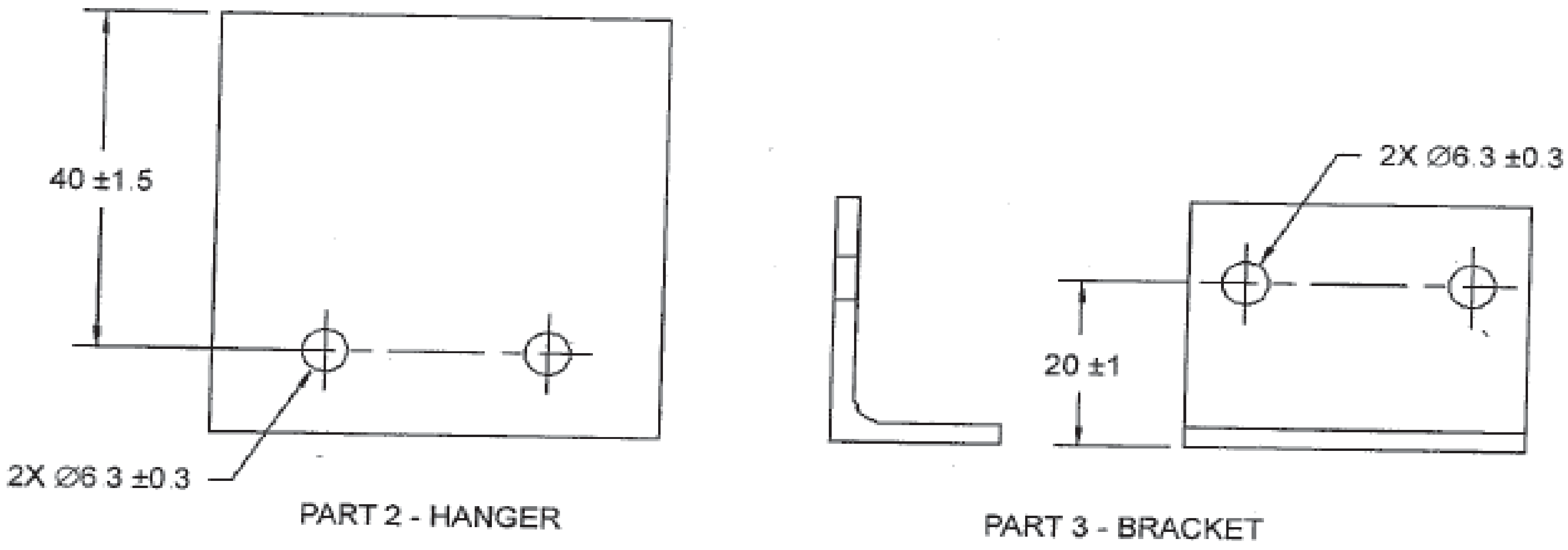


FIGURE 7.18 Parts for hanger assembly.

Worst-case Tolerance Stack up Examples #7.4

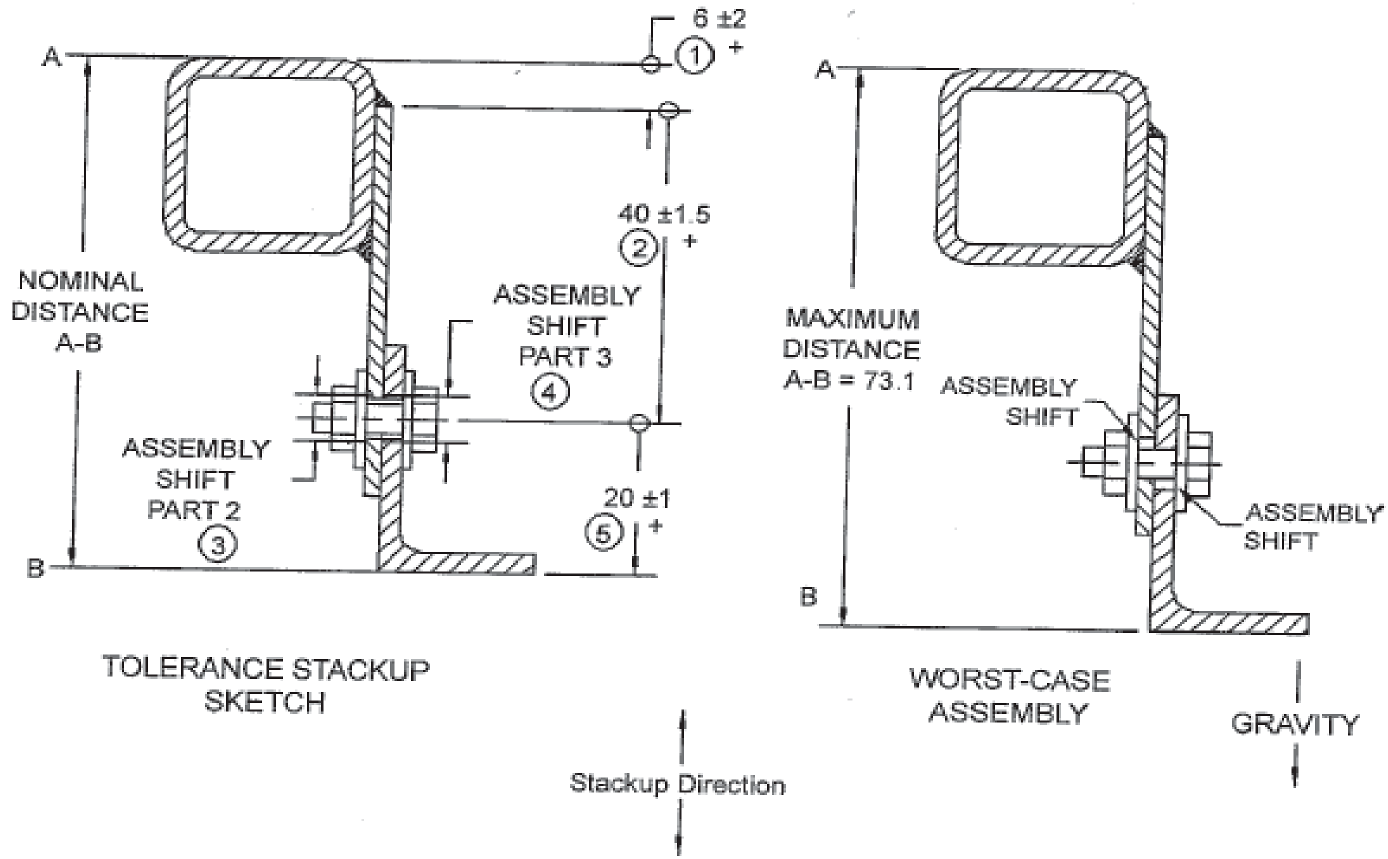


FIGURE 7.19 Worst-case hanger assembly and Tolerance Stackup sketch.

Worst-case Tolerance Stack up Examples #7.4

+	–	Tolerances	Description
6		±2	DIM 1: PART 1 - PART 2
40		±1.5	DIM 2: PART 2 EDGE - HOLES
		±1.3	DIM 3: ASSY SHIFT PART 2: 6.3(H) + 0.3(ST) – 4(F) = 2.6 / 2 = ±1.3
		±1.3	DIM 4: ASSY SHIFT PART 3: 6.3(H) + 0.3(ST) – 4(F) = 2.6 / 2 = ±1.3
20		±1	DIM 5: PART 3 HOLES - FLANGE
66	0	±7.1	Totals

Positive Total 66

– Negative Total –0

= Nominal Distance 66 +/– 7.1

MAX DISTANCE = 73.1

MIN DISTANCE =

Tolerance Value

Solve for Maximum Distance A-B

FIGURE 7.20 Tolerance Stackup report solved.

Worst-case Tolerance Stack up Examples #7.5

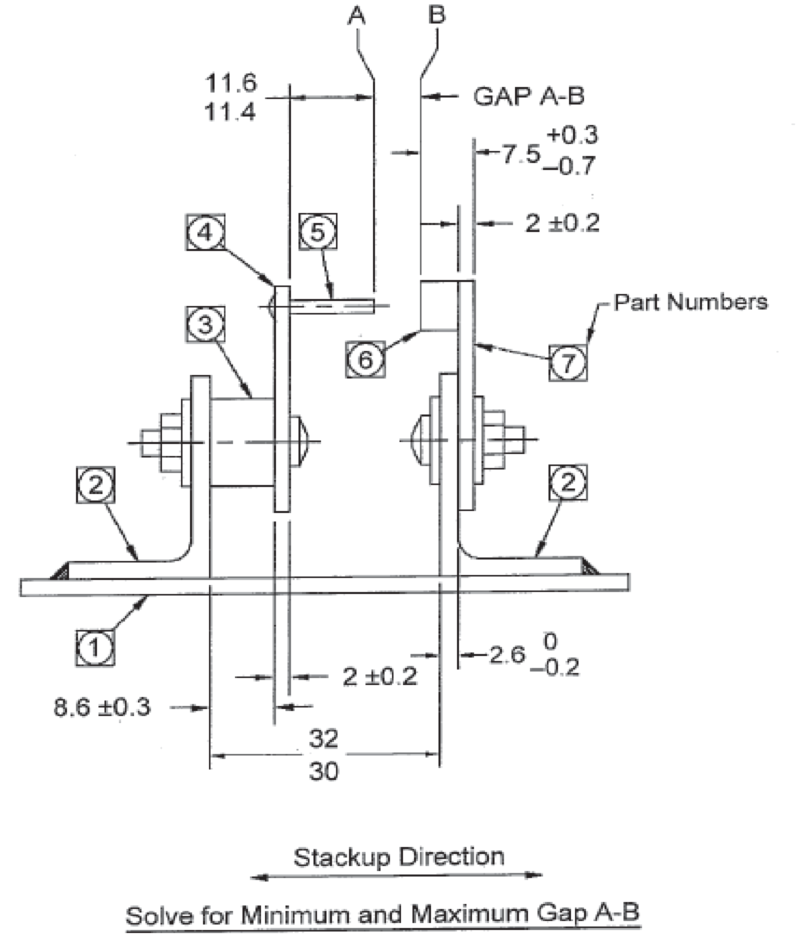


FIGURE 7.21 Complex welded assembly.

Worst-case Tolerance Stack up Examples #7.5

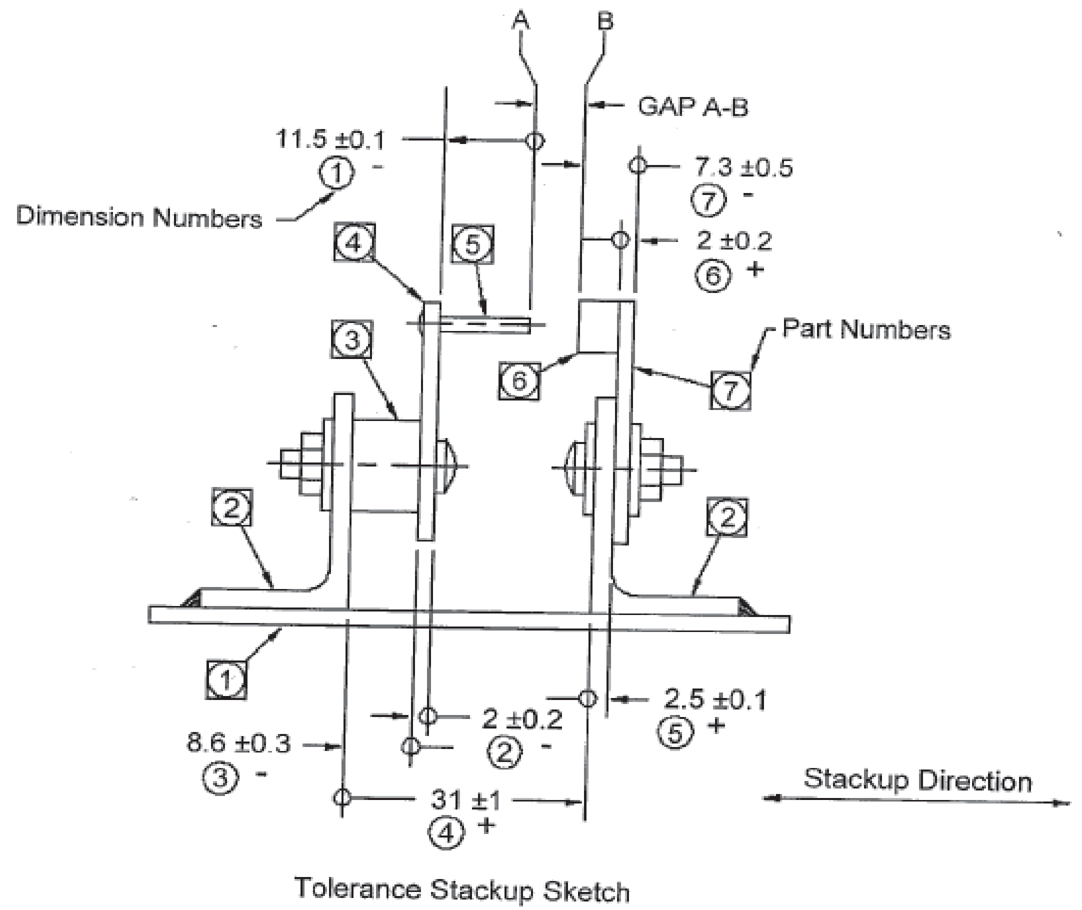


FIGURE 7.22 Complex welded assembly (Tolerance Stackup sketch).

Worst-case Tolerance Stack up Examples #7.5

Worst-Case Tolerance Stackup

Dim No	Part No	+	–	+/–	Description
1	5		11.5	+/– 0.1	Pin Length
2	4		2	+/– 0.2	LH Plate Thickness
3	3		8.6	+/– 0.3	Standoff Thickness
4	2	31		+/– 1	Flange to Flange Dist Between LH & RH Item 2
5	2	2.5		+/– 0.1	RH Angle Brkt Web Thickness
6	7	2		+/– 0.2	RH Plate Thickness
7	6 & 7		7.3	+/– 0.5	Thickness of RH Plate and Boss
		35.5	29.4	+/– 2.4	Totals

Positive Total	35.5	
– Negative Total	- 29.4	
= Nominal Gap	6.1 +/– 2.4	Tolerance

Max Gap	8.5	
Min Gap	3.7	Clearance

FIGURE 7.23 Tolerance Stackup report solved.

Worst-case Tolerance Stack up Examples #7.6

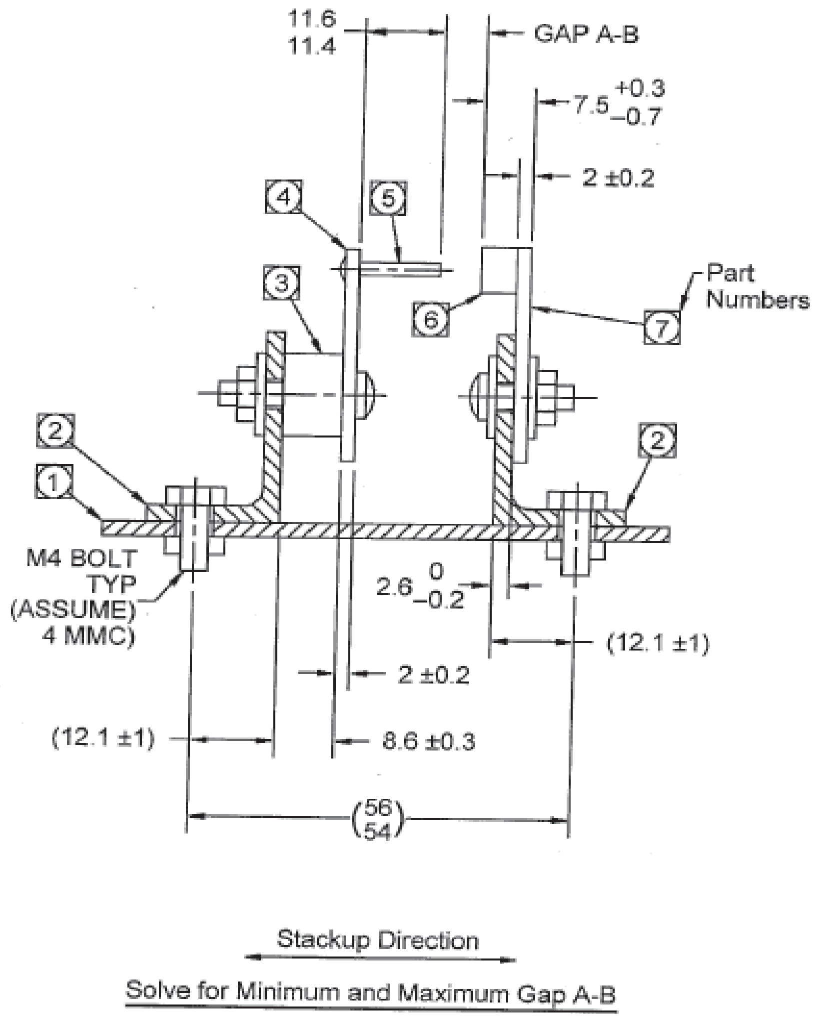
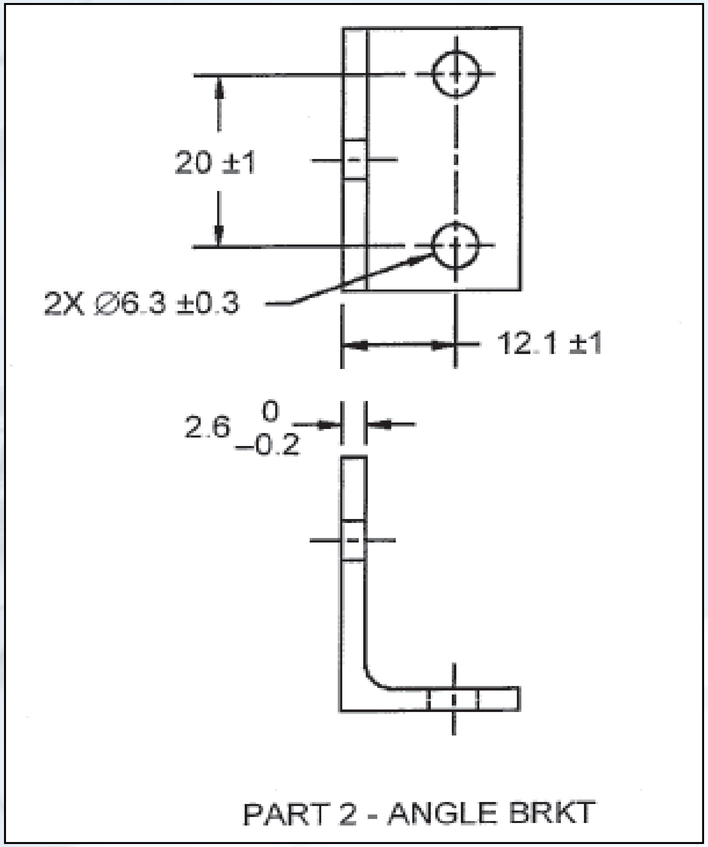


FIGURE 7.24 Complex bolted assembly.

Worst-case Tolerance Stack up Examples #7.6



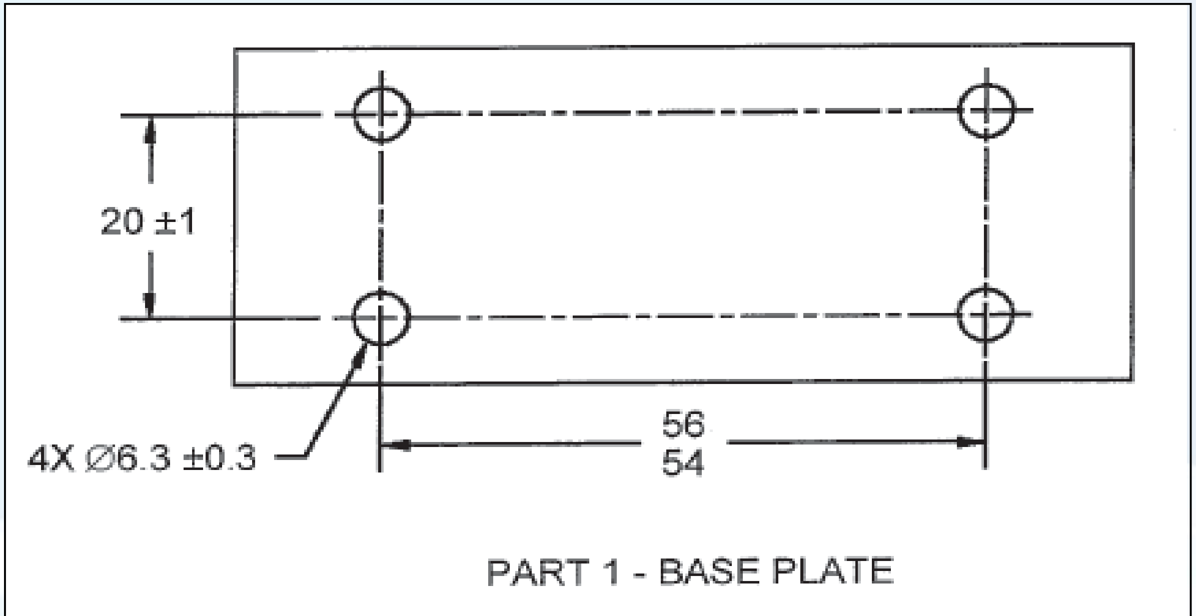


FIGURE 7.25 Parts for complex bolted assembly.

Worst-case Tolerance Stack up Examples #7.6

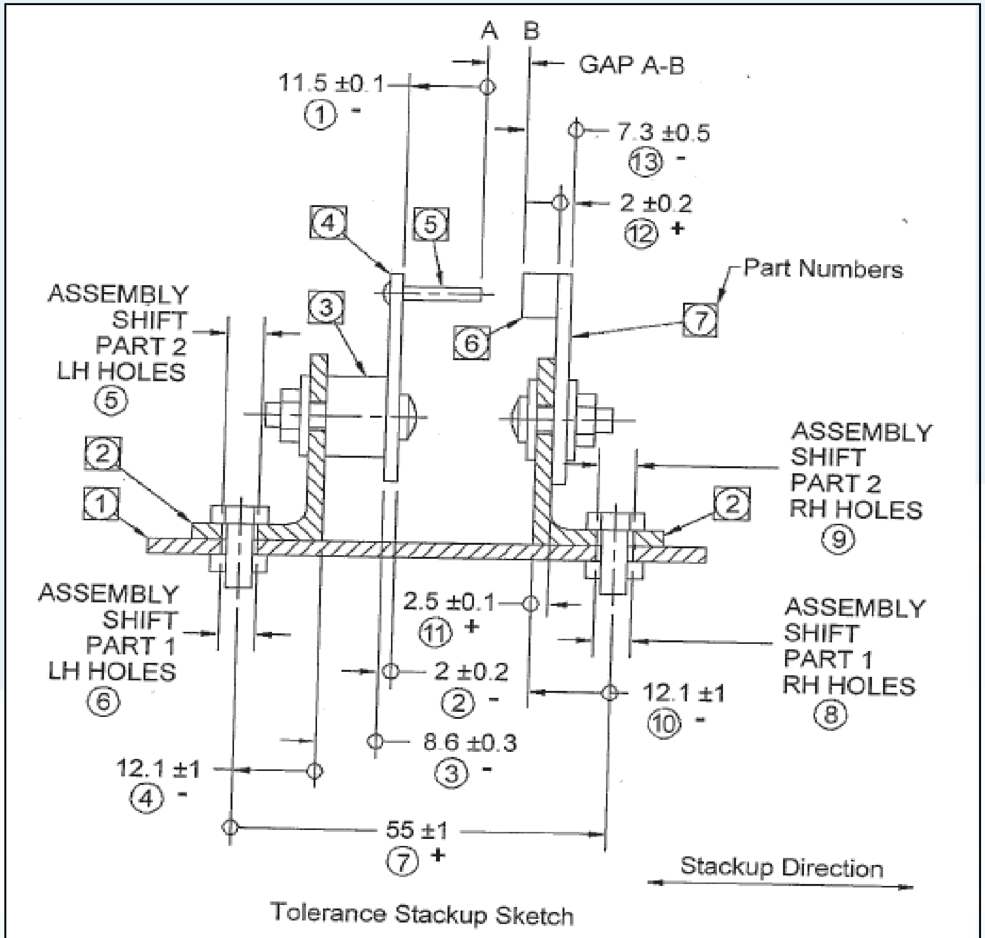


FIGURE 7.26 Complex bolted assembly Tolerance Stackup sketch.

OMNEX
WWW.OMNEX.COM

Worst-case Tolerance Stack up Examples #7.6

Worst-Case Tolerance Stackup

Dim No	Part No	+	–	+/–	Description
1	5		11.5	+/–0.1	Pin Length
2	4		2	+/–0.2	LH Plate Thickness
3	3		8.6	+/–0.3	Standoff Thickness
4	2		12.1	+/–1	CL Hole - Edge on LH Angle Brkt
5	2			+/–1.3	Assy Shift in LH Angle Brkt Holes @ LMC: 6.6–4 = 2.6 / 2 = +/–1.3
6	1			+/–1.3	Assy Shift in Base Plate LH Holes @ LMC: 6.6–4 = 2.6 / 2 = +/–1.3
7	1	55		+/–1	CL - CL Holes Dim on Base Plate
8	1			+/–1.3	Assy Shift in Base Plate RH Holes @ LMC: 6.6–4 = 2.6 / 2 = +/–1.3
9	2			+/–1.3	Assy Shift in RH Angle Brkt Holes @ LMC: 6.6–4 = 2.6 / 2 = +/–1.3
10	2		12.1	+/–1	CL Hole - Edge on RH Angle Brkt
11	2	2.5		+/–0.1	RH Angle Brkt Flange Thickness
12	7	2		+/–0.2	RH Plate Thickness
13	6 & 7		7.3	+/–0.5	Thickness of RH Plate & Boss
Totals		59.5	53.6	+/–9.6	Worst Case Tolerance

Positive Total	59.5
Negative Total	–53.6
Nominal Gap	5.9 +/– 9.6

Max Gap	15.5	Clearance
Min Gap	–3.7	Inteference!!!

FIGURE 7.27 Complex bolted assembly - spreadsheet with solution.

Worst-case Tolerance Stack up Examples #7.6

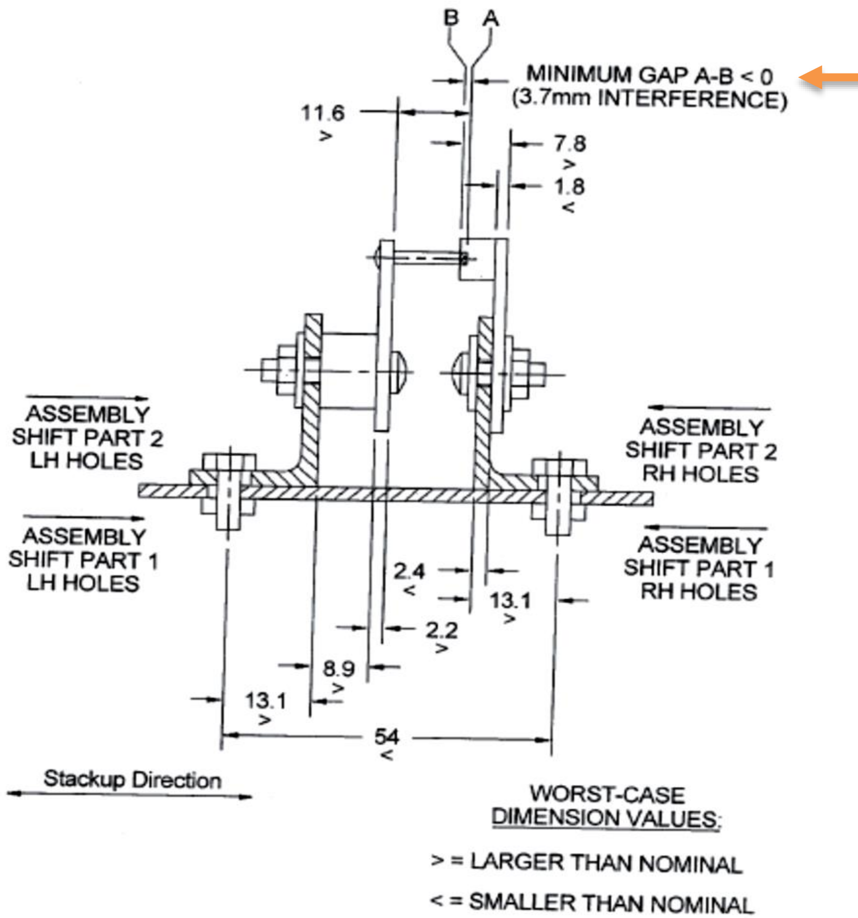


Figure 7.28 Complex bolted assembly solved (interference).

assembly by bolting: More variation than welding assembly

-3.7

Tolerance Stack ups And Assemblies

Moving Across an Interface from One Part to the Other in a Tolerance Stack up

Two common types of interfaces encountered in Tolerance Stack ups:

1. **Mating planar surfaces:**

   traversing a planar interface (two nominally flat mating surfaces)

2. **clearance holes in mating parts or clearance holes and tapped holes that share common fasteners**

   a. traversing a feature-of-size interface, such as coaxial clearance holes in mating parts, or coaxial clearance and threaded holes, with common fasteners

   The fixed- and floating-fastener situations described in Chapter 18 are examples of a feature-of-size interface.

Tolerance Stack ups And Assemblies

- **The guidelines are based on the following assumptions:**

  the mating features in the interface are part of the Tolerance Stack up

  the dimensions and tolerances contribute to the Tolerance Stack up

  they are not directly part of the distance being studied.

  the dimension and tolerance values are in the same direction as the Tolerance Stack up direction.

  the dimensions and tolerances arc in equal bilateral format. If they are not, they must be converted to equal bilateral format.

Tolerance Stack ups And Assemblies

- **Planar Interface:** Traversing a Planar Interface from One Part to Another in the Tolerance Stack up

For ± dimensions and tolerances:

The dimension to the interfacial surface on the first part is included in the Tolerance Stack up.

The ± location tolerance associated with the dimension is included in the Tolerance Stack up.

Now the Tolerance Stack up moves from the interfacial surface on the first part to the mating surface on the second part.

Steps 1.a and 1.b are repeated in reverse order for the second part.

Tolerance Stack ups And Assemblies

- **For GD&T: GD&T**

  a. If the planar feature is a referenced datum feature:

  b. The basic dimension to the datum feature is included in the Tolerance Stack up.

  c. If there is a profile tolerance specified for the datum feature, lines for profile tolerance and datum feature shift are added to the Tolerance Stack up report.

Tolerance Stack ups And Assemblies

- The values for profile and datum feature shift are entered if the location of the datum feature contributes to the Tolerance Stack up. (The value for datum feature shift may be zero.)

- The values for profile and datum feature shift are set to zero and the lines are marked “N/A” if the location of the datum feature does not contribute to the Tolerance Stack up.

- If the location of the surface does not affect the Tolerance Stack up, but the profile tolerance controls the form of the feature, the profile tolerance may be included in the Tolerance Stack up as described in Chapter 20.

Tolerance Stack ups And Assemblies

- If the datum feature has a form tolerance, the form tolerance is typically not included in the chain of Dimensions and Tolerances. However, the form tolerance may be included in the Tolerance Stack up per the guidance in Chapter 20 if desired.
- Special cases may require using an orientation tolerance or a lower segment composite profile tolerance in the Tolerance Stack up. These are uncommon applications and must be carefully addressed on a case-by-case basis. For more information see Chapter 9.
- Now the Tolerance Stack up moves from the interfacial surface on the first part to the mating surface on the second part.
- Steps 2.a.i—2.a.iv are repeated in reverse order for the second part.

Tolerance Stack ups And Assemblies

- **If the planar feature is not a datum feature:**

  The basic dimension from the datum reference frame related to the feature is included in the Tolerance Stack up.

  Lines for profile and datum feature shift are added to the Tolerance Stack up report. The values for profile and datum feature shift are entered. (The value for datum feature shift may be zero.) (See Chapters 9, 13, and 14.)

Tolerance Stack ups And Assemblies

- Special cases may require using an orientation tolerance or a lower segment composite profile tolerance in the Tolerance Stack up. These are uncommon applications and must be carefully addressed on a case-by-case basis. For more information see Chapter 9.

- Now the Tolerance Stack up moves from the interfacial surface on the first part to the mating surface on the second part.

- Steps 2.b.i--2.b.iii are repeated in reverse order for the second part.

Tolerance Stack ups And Assemblies

- **Feature-of-Size Interface:**

Traversing a Feature-of-Size Interface (Mating Clearance and/or Threaded Holes with Common Fasteners) from One Part to Another in the Tolerance Stack up

For ± dimensions and tolerances:

The dimension to the Feature of Size on the first part is included in the chain of Dimensions and Tolerances. (This is the dimension in the direction of the Tolerance Stack up where rectangular or polar coordinate dimensioning is used.)

The ± location tolerance associated with the dimension is included in the Tolerance Stack up.

Tolerance Stack ups And Assemblies

- If the features are clearance holes, assembly shift is calculated and added to the chain of Dimensions and Tolerances for the holes in the first part. If the features are threaded or press-fit holes assembly shift is not added.
- Now the Tolerance Stack up moves from the interfacial feature on the first part to the mating feature on the second part.
- Steps 1.a—1.c are repeated in reverse order for the second part.

Tolerance Stack ups And Assemblies

- **Feature-of-Size Interface:**

GD&T: GD&T

If the feature of size (hole, pin, etc.) is a referenced datum feature

The basic dimension to the datum feature is included in the Tolerance Stack up.

If a positional or orientation tolerance is specified for the datum feature, lines for the positional/orientation tolerance, bonus tolerance, and datum feature shift are added to the Tolerance Stack up report.

Tolerance Stack ups And Assemblies

- **Feature-of-Size Interface:**

GD&T:

The values for position/orientation, bonus tolerance, and datum feature shift are entered if the location of the datum feature contributes to the Tolerance Stack up. (The values for bonus tolerance and datum feature shift may be zero.) (See Chapter 9.)

The values for position/orientation, bonus tolerance, and datum feature shift are set to zero and the lines are marked "N/A" if the location of the datum feature does not contribute to the Tolerance Stack up. (This is common where the datum feature of size is the primary or secondary datum feature in a referenced feature control frame.) (See Chapters 9, 13, and 14.)

Tolerance Stack ups And Assemblies

- **Feature-of-Size Interface:**

GD&T:

Assembly shift is calculated and added to the chain of Dimensions and Tolerances for the datum feature of size in the first part. Assembly shift is typically not added if the datum features of size arc threaded holes.

Now the Tolerance Stack up moves from the datum feature on the first part to the datum feature on the second part.

Steps 2.a.i—2.a.iii arc repeated in reverse order for the second part.

Tolerance Stack ups And Assemblies

- **Feature-of-Size Interface:**

GD&T:

If the feature of size (hole, pin, etc.) is a not a datum feature:

The basic dimension from the datum reference frame related to the feature is included in the Tolerance Stack up.

Lines for positional tolerance, bonus tolerance, and datum feature shift are added to the Tolerance Stack up report. The values for position, bonus tolerance, and datum feature shift are entered. (The values for bonus tolerance and datum feature shift may be zero.) (See Chapters 9, 13, and 14.)

Tolerance Stack ups And Assemblies

- **Feature-of-Size Interface:**

GD&T:

If the feature of size (hole, pin, etc.) is a not a datum feature:

Assembly shift is calculated and added to the chain of Dimensions and Tolerances for the holes in the first part. Assembly shift is typically not added if the features of size are threaded holes.

Now the Tolerance Stack up moves from the interfacial feature on the first part to the mating feature on the second part.

Steps 2.b. 1—2..b.iii are repeated in reverse order for the second part.

Chapter #8

Statistic Tolerance Stack-up

Statistical Tolerance Stack ups

- Statistical Tolerance Stack ups determine the probable or likely maximum variation possible for a selected dimension.

- realistically assumes that it is highly improbable that all the dimensions in the Tolerance Stack up will be at their worst-case low limit or high limit at the same time.

- The sum of the dimensions and tolerances will likely approximate a normal distribution.

- Most or all of the dimensions will likely be closer to their nominal value than either extreme. Also, some of the dimensions that the worst-case model required to be at their upper limit may actually be closer to their lower limit, and vice versa. The combination of these factors leads to the idea of a statistical Tolerance Stack up.

Statistical Tolerance Stack ups

- when it is appropriate to use a statistical versus a worst-case Tolerance Stack up.
- depends on a number of factors, including the number of tolerances in the Tolerance Stack up, the quantity of parts to be manufactured, manufacturing process controls, design sensitivity, past company practices, and willingness to accept risk, to name a few.
- A simple rule of thumb is as the number of tolerances in a Tolerance Stack up increases, the benefits and validity of using a statistical analysis increases.

Statistical Tolerance Stack ups Assumption

- **Statistical tolerance analyses are based on several conditions being in place. These include::**

  The manufacturing processes for the parts must be controlled processes. This requires, among other things, that manufacturing nominal is the same as design nominal.

  Processes must be centered and output normal or gaussian distributions (see Fig. 8.1). This presents a problem where unequal bilateral or unilateral tolerances have been specified.

  Parts must be randomly selected for assembly.

Statistical Tolerance Stack ups Assumption

- The design must be able to tolerate the possibility that some small percentage of the as-produced parts or assemblies exceed the calculated statistical result.

- The enterprise must be willing to tolerate the possibility that some parts or assemblies will be rejected due to exceeding the calculated statistical result.

Statistical Tolerance Analyses

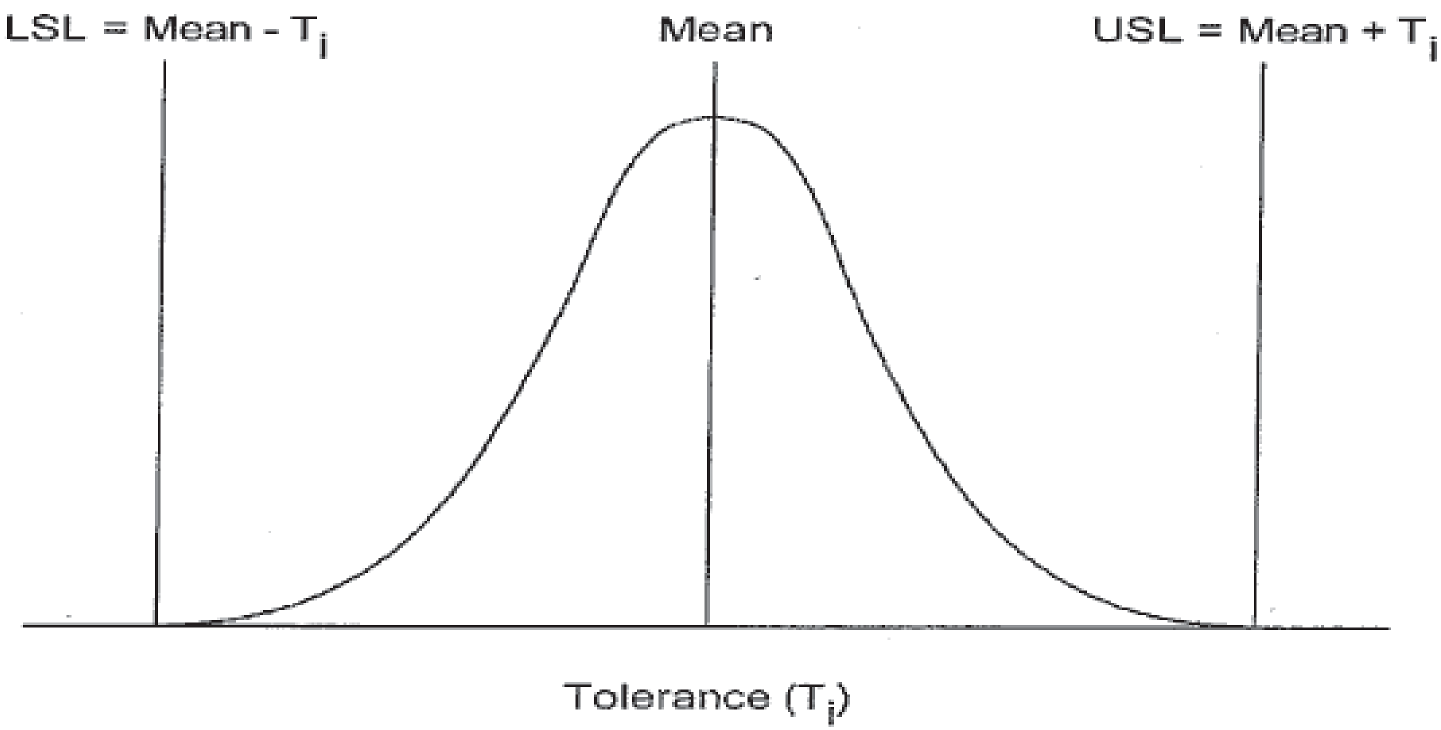
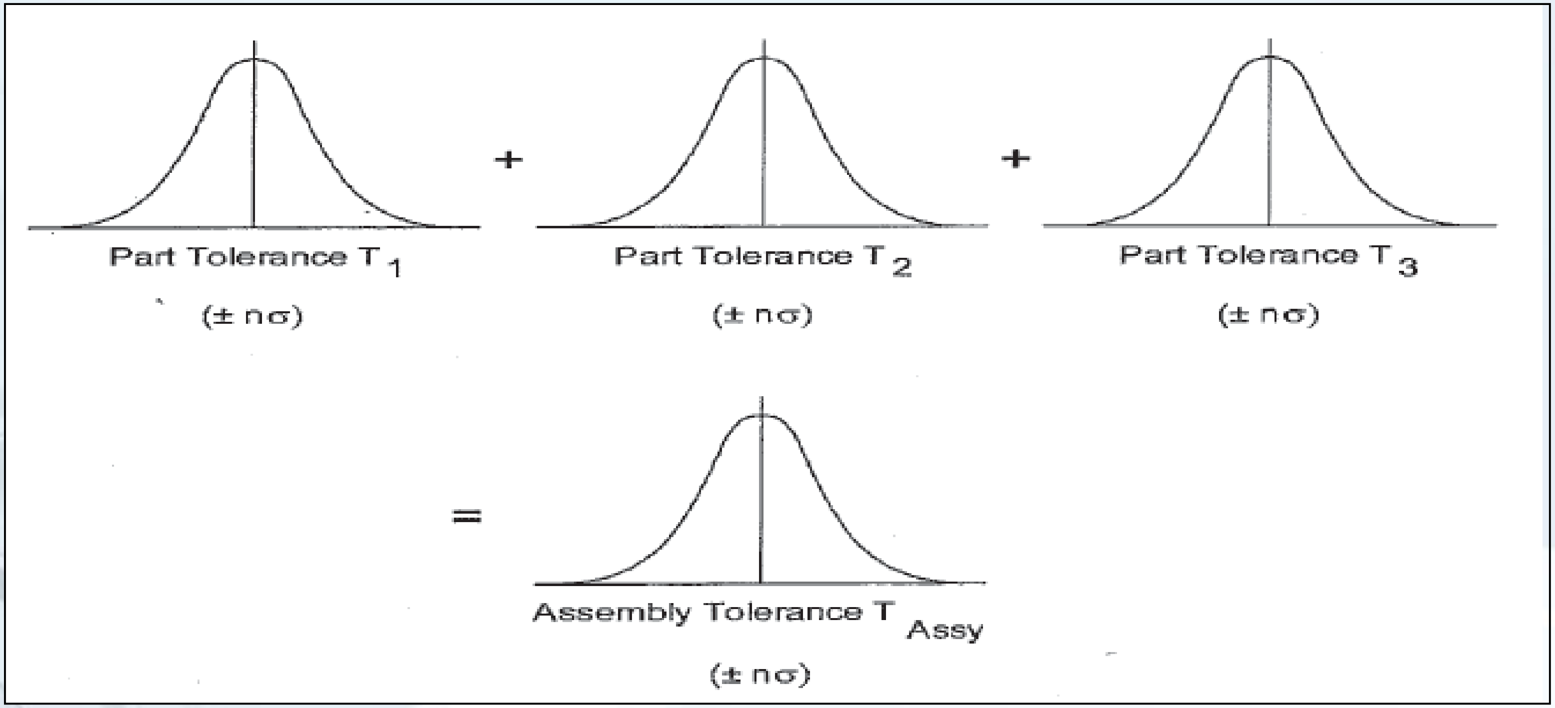


FIGURE 8.1 Gaussian distribution.

Statistical Tolerance Analyses



$$\text{RSS Tolerance} = \sqrt{T_1^2 + T_2^2 + T_3^2 \ldots + T_n^2}$$

FIGURE 8.2 Root sum formula for statistical Tolerancing. Where: T_n = Tolerances in the Tolerance Stackup.

Statistical Tolerance Analyses

- **Two statistical methods for Tolerance Analysis:**

- **Root-sum-square (RSS)**
  Root-sum-square is commonly used on manually modeled and spreadsheet-based statistical Tolerance Stack ups.

- **Monte Carlo simulations**
  Monte Carlo simulation is typically used with computer-based Tolerance Analysis simulation software. Simply put, Monte Carlo simulations take all the variables in a Tolerance Stack up, give them a random value within their range, derive a result, iterate this process thousands of times, and average the result.

Statistical Tolerance Analyses Case

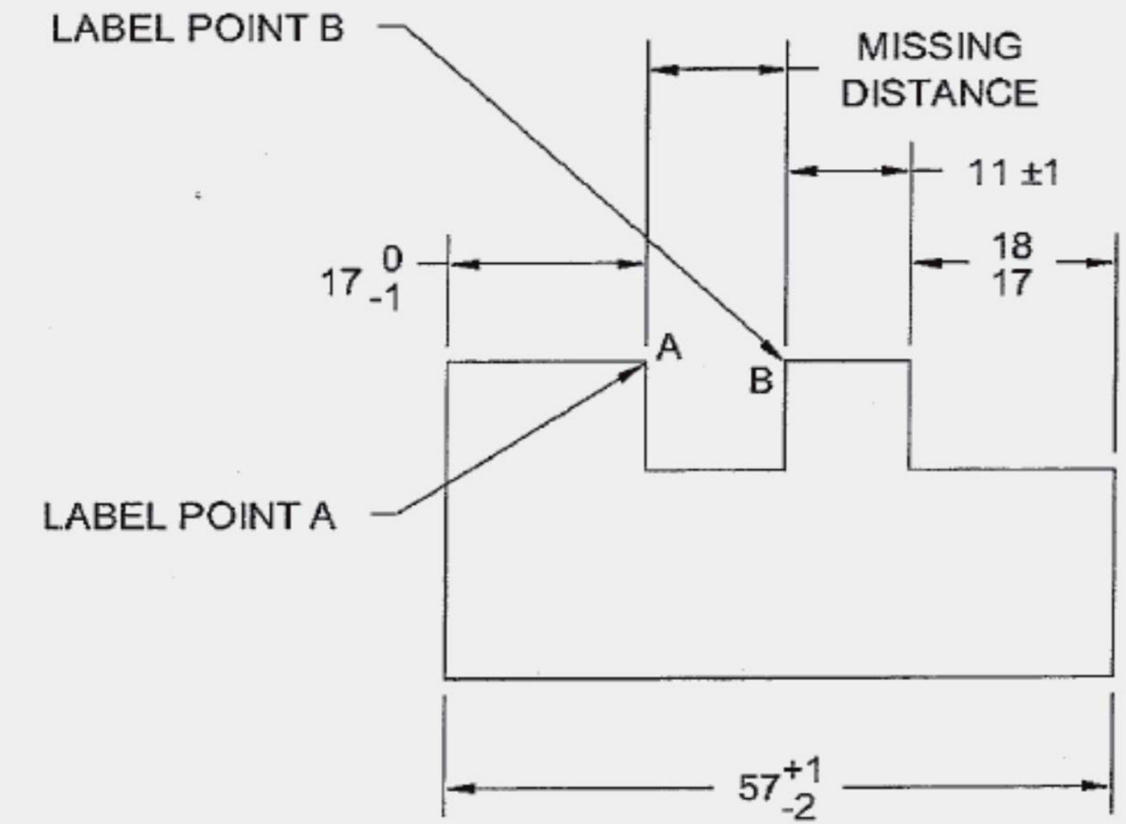


FIGURE 8.4 Statistical chain of Dimensions and Tolerances #1.

Statistical Tolerance Analyses Case

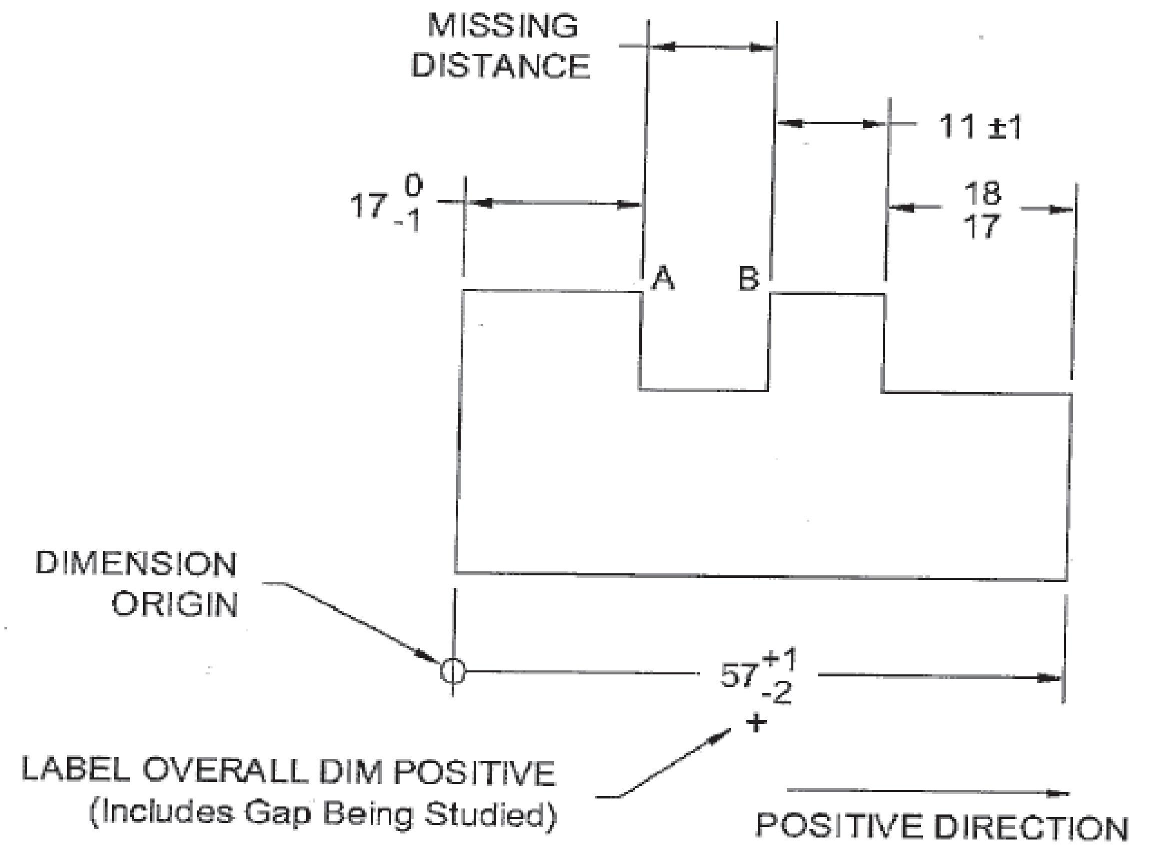
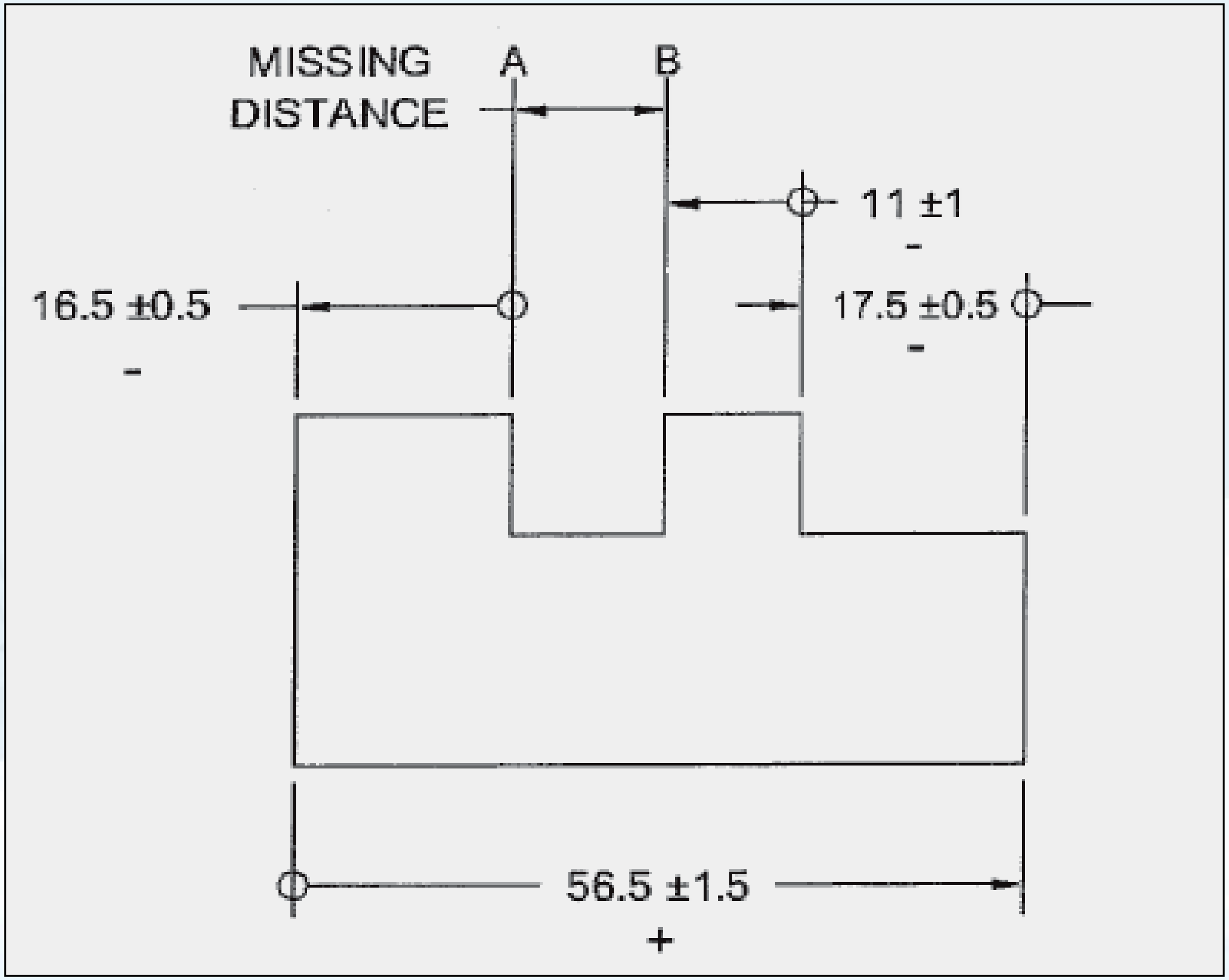


FIGURE 8.5 Statistical chain of Dimensions and Tolerances #2.

Statistical Tolerance Analyses Case



Statistical Tolerance Analyses Case

+	-	Tolerances	Squared Tolerances	
	16.5	±0.5	±0.25	
56.5		±1.5	±2.25	
	17.5	±0.5	±0.25	
	11	±1	±1	
56.5	45	±3.5	$\sqrt{\pm 3.75}$	TOTALS

RSS = ±1.94

ADJUSTED RSS: 1.5 * ±1.94 = +/-2.91

POSITIVE TOTAL 56.5
NEGATIVE TOTAL -45
NOMINAL DISTANCE 11.5 ±2.91

MAX DIST. = 14.41
MIN DIST. = 8.59

ADJUSTED RSS TOLERANCE VALUE

FIGURE 8.14 Statistical chain of Dimensions and Tolerances #11.

Statistical Tolerance Analyses Case

Program:	Electronics Packaging Program AV-11	Stack Information:	
Product:	Part Number 12345678-001, Rev A, Description: Ground Plate Enclosure Assembly: Option 1 w 8 Holes as Datum Feature B	Stack No:	AV-11-010a
		Date:	07/04/02
		Revision	A
Problem:	Edges of Ground Plate must not Touch Walls of Enclousre	Direction:	Along Plane of Ground Plate (Y Axis)
Objective:	Option 1: Determine if Ground Plate Contacts Enclosure Walls	Author:	BR Fischer

Description of Component / Assy	Part Number	Rev	Item	Description	+ Dims	- Dims	Tol	Percent Contrib	Dim / Tol Source & Calcs
Enclosure	12345678-002	A	1	Profile: Edge Along Pt A			+/- 0.5000	19%	Profile 1, A, Bm
			2	Datum Feature Shift: $(DF_{B@LMC} - DFS_B)/2$			+/- 0.2900	11%	= (3.422 - (3.242 - 0.4)) / 2 (Shift within Minor Dia)
			3	Dim: Edge of Enclosure - Datum B	8.5000		+/- 0.0000	0%	8.5 Basic on Dwg
			4	Position: DF_B M4 Holes			+/- 0.2000	8%	Position dia 0.4 @ MMC A
			5	Bonus Tolerance			+/- 0.0000	0%	N/A - Threads
			6	Datum Feature Shift: $(DF_{B@LMC} - DFS_B)/2$			+/- 0.0000	0%	N/A - DF_A not a Feature of Size
			7	Assembly Shift: (Mounting $Holes_{LMC} - F_{LMC}$) / 2			+/- 0.6650	25%	= ((5 + 0.15) - 3.82) / 2
Ground Plate	12345678-004	A	8	Position: DF_B Dia 5+/-0.1 Holes			+/- 0.2250	9%	Position dia 0.45 @ MMC A
			9	Bonus Tolerance			+/- 0.1000	4%	= (0.1 + 0.1) / 2
			10	Datum Feature Shift: $(DF_{B@LMC} - DFS_B)/2$			+/- 0.0000	0%	N/A - DF_A not a Feature of Size
			11	Dim: Datum B - Edge of Ground Plate		6.0000	+/- 0.0000	0%	6 Basic on Dwg
			12	Profile: Edge Along Pt B			+/- 0.5000	19%	Profile 1, A, Bm
			13	Datum Feature Shift: $(DF_{B@LMC} - DFS_B)/2$			+/- 0.1500	6%	= ((5 + 0.15) - (5 - 0.15)) / 2
				Dimension Totals	8.5000	6.0000			
				Nominal Distance: Pos Dims - Neg Dims =		2.5000			

RESULTS:

	Nom	Tol	Min	Max
Arithmetic Stack (Worst Case)	2.5000	+/- 2.6300	-0.1300	5.1300
Statistical Stack (RSS)	2.5000	+/- 1.0721	1.4279	3.5721
Adjusted Statistical: 1.5*RSS	2.5000	+/- 1.6082	0.8918	4.1082

Notes:

- M4 Screw Dimensions: Major Dia: 4 / 3.82 - M4 Tapped Hole Dimensions: Minor Dia: 3.422 / 3.242
- Used min and max screw thread minor dia in Datum Feature Shift Calculations on line 2.
- Used smallest screw major dia in Assembly Shift Calculations on line 7.

Assumptions:

- Assume threads are self centering. Do not include bonus tolerance on line 5.

Suggested Action:

- May want to use two holes as locators instead of all eight. See Stack Opt - 2.

FIGURE 8.15 Sample Tolerance Stackup report form.

Statistical Tolerance Analyses

Example #8.1

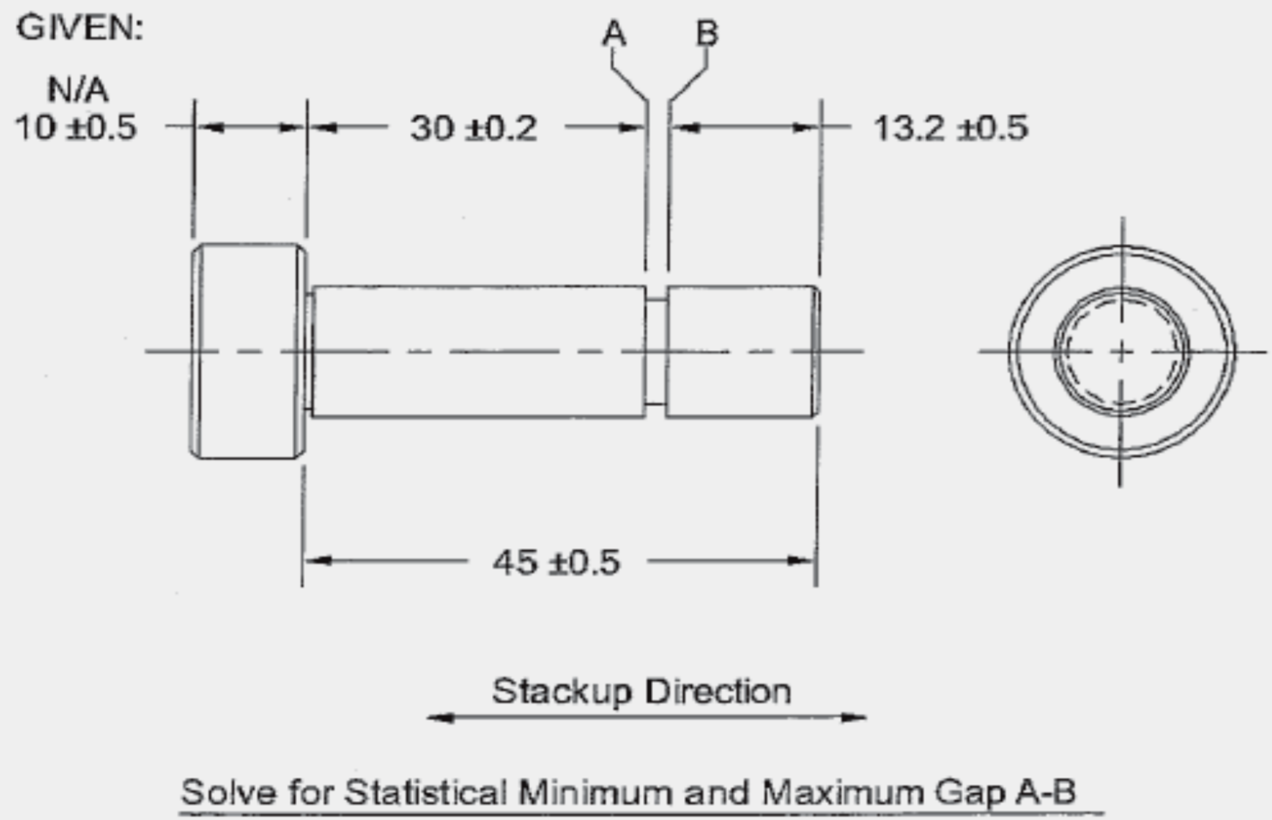
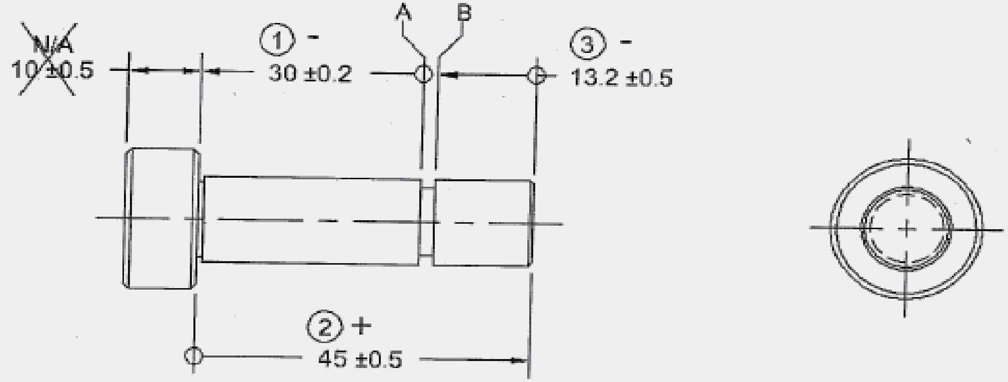


FIGURE 8.16 Pin with groove.

Statistical Tolerance Analyses

Example #8.1



Tolerance Stackup Sketch

+	-	Tolerances	Squared Tolerances	Description
	30	±0.2	±0.04	GROOVE - HEAD
45		±0.5	±0.25	OVERALL LENGTH
	13.2	±0.5	±0.25	TIP - GROOVE
45	43.2	±1.2	√±0.54	Totals

±0.74	RSS Tolerance Value
*1.5	
±1.1	Adjusted RSS Tolerance Value

Positive Total	45
- Negative Total	-43.2
= Nominal Gap	1.8

+/- 1.1 → MAX GAP = 2.9; MIN GAP = 0.7

Adjusted RSS Tolerance Value

Statistical Tolerance Analyses

Example #8.2

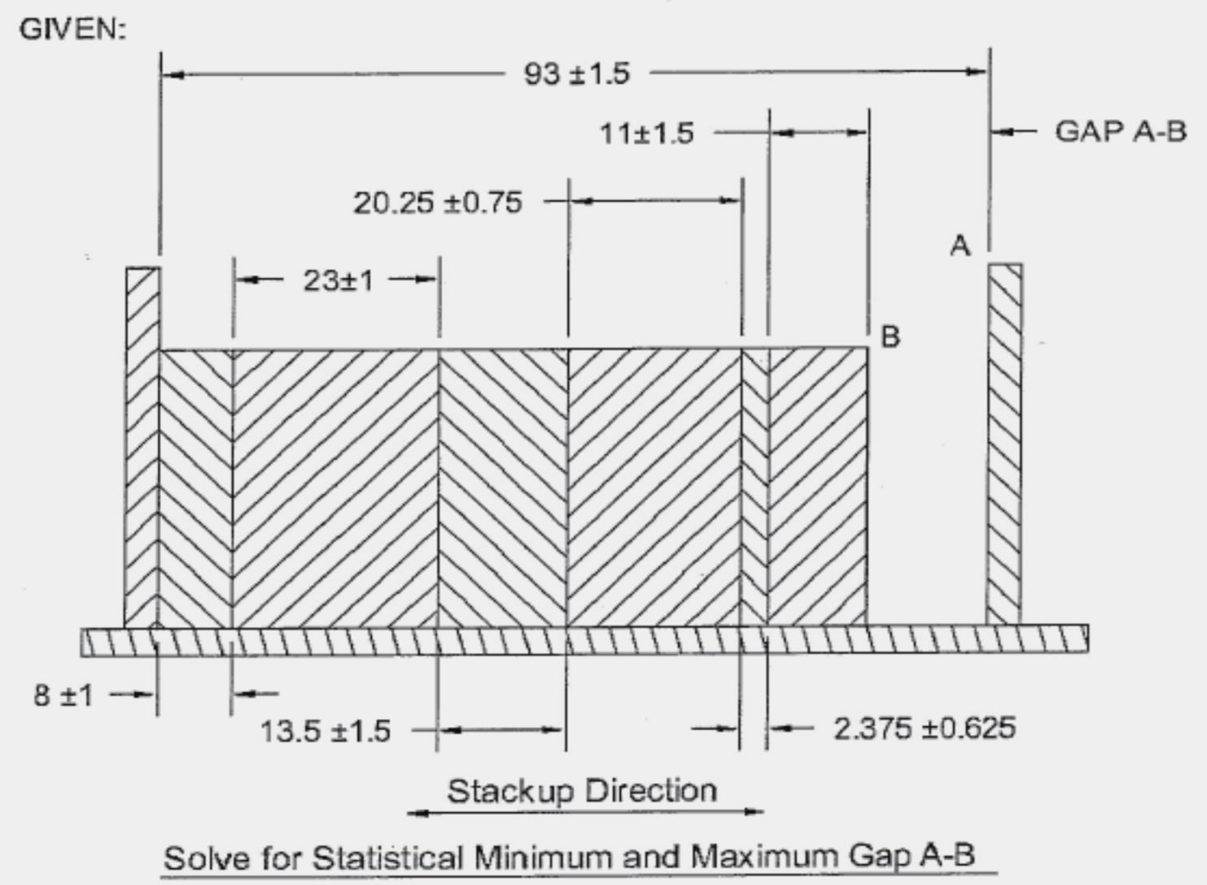


FIGURE 8.20 Simple assembly.

Statistical Tolerance Analyses

Example #8.2

Tolerance Stackup Sketch

+	-	Tolerances	Squared Tolerances	Description
93		±1.5	±2.25	DIM 1
	8	±1	±1	DIM 2
	23	±1	±1	DIM 3
	13.5	±1.5	±2.25	DIM 4
	20.25	±0.75	±0.5625	DIM 5
	2.375	±0.625	±0.391	DIM 6
	11	±1.5	±2.25	DIM 7
93	78.125	±7.875	$\sqrt{\pm 9.70}$	Totals

±3.115 RSS Tolerance Value

*1.5

±4.67 Adjusted RSS Tolerance Value

Positive Total	93
- Negative Total	-78.125
= Nominal Gap	14.875

+/- 4.67 (Adjusted RSS Tolerance Value)

MAX GAP = 19.545

MIN GAP = 10.205

Stackup Direction

Solve for Statistical Minimum and Maximum Gap A-B

FIGURE 8.21 Simple assembly solved statistically.

OMNEX

WWW.OMNEX.COM

Statistical Tolerance Analyses

Example #8.3

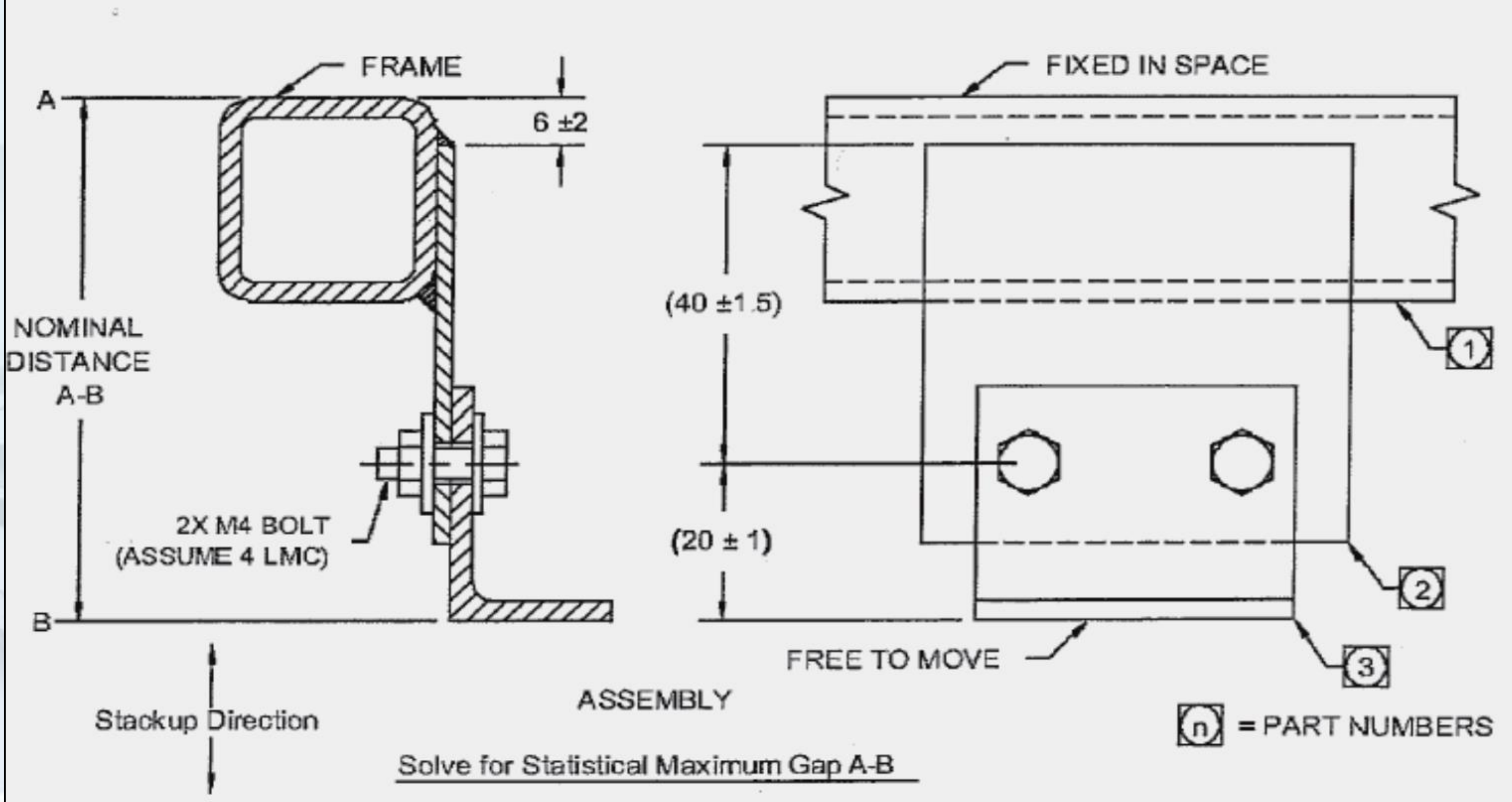


FIGURE 8.22 Hanger assembly (with gravity and assembly shift).

Statistical Tolerance Analyses

Example #8.3

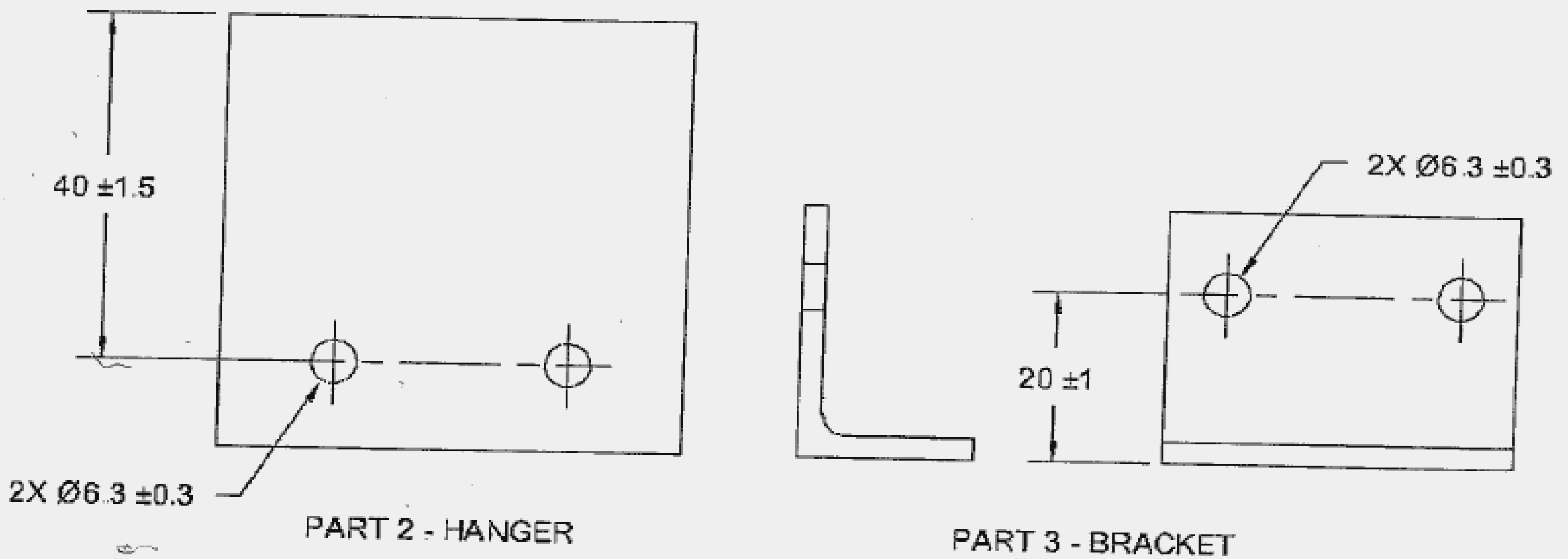


FIGURE 8.23 Parts for hanger assembly.

Statistical Tolerance Analyses Example #8.3

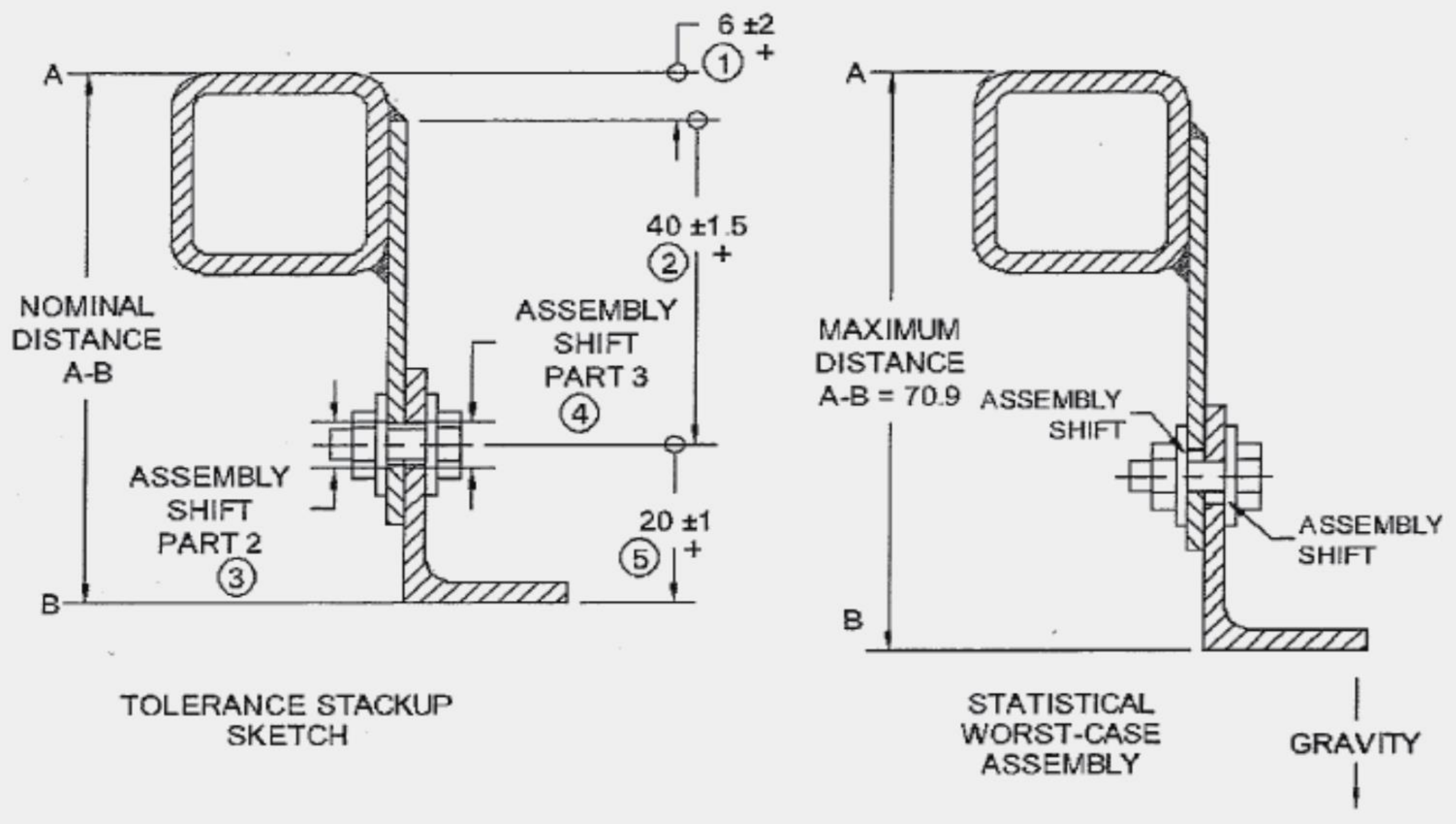


FIGURE 8.24 Statistical worst-case hanger assembly and Tolerance Stackup sketch.

Statistical Tolerance Analyses Example #8.3

+	-	Tolerances	Squared Tolerances	Description
6		±2	±4	DIM 1: PART 1 - PART 2
40		±1.5	±2.25	DIM 2: PART 2 EDGE - HOLES
		±1.3	±1.69	DIM 3: ASSY SHIFT PART 2: 6.3(H) + 0.3(ST) - 4(F) = 2.6 / 2 = ±1.3
		±1.3	±1.69	DIM 4: ASSY SHIFT PART 3: 6.3(H) + 0.3(ST) - 4(F) = 2.6 / 2 = ±1.3
20		±1	±1	DIM 5: PART 3 HOLES - FLANGE
66	0	±7.1	$\sqrt{\pm 10.63}$	Totals

±3.26 RSS Tolerance Value

*1.5

±4.89 Adjusted RSS Tolerance Value

Positive Total 66

\- Negative Total -0

= Nominal Distance 66 +/- 4.89

MAX DISTANCE = 70.89

MIN DISTANCE =

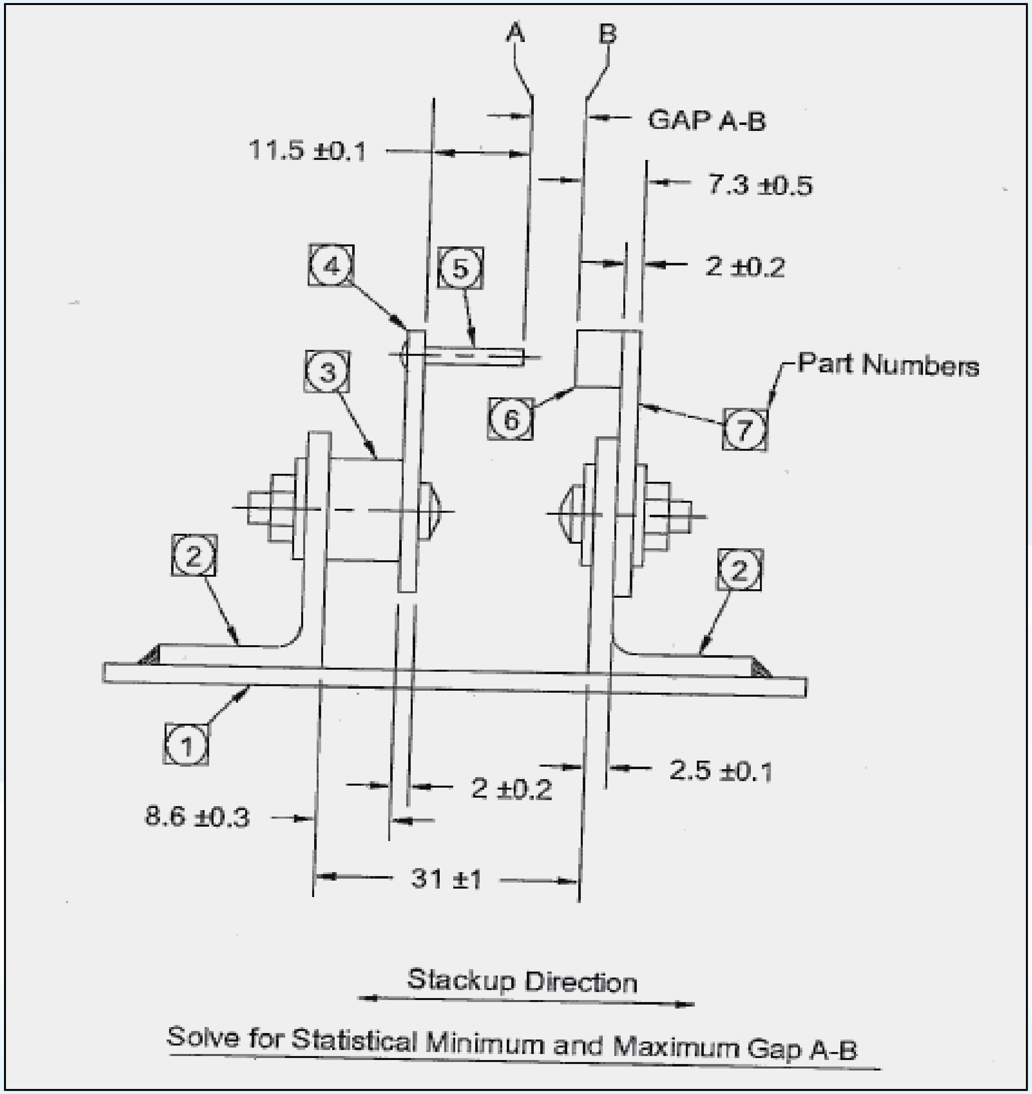
Stackup Direction

Adjusted RSS Tolerance Value

Solve for Statistical Maximum Gap A-B

FIGURE 8.25 Tolerance Stackup report solved statistically.

Statistical Tolerance Analyses Example #8.4



Statistical Tolerance Analyses Example #8.4

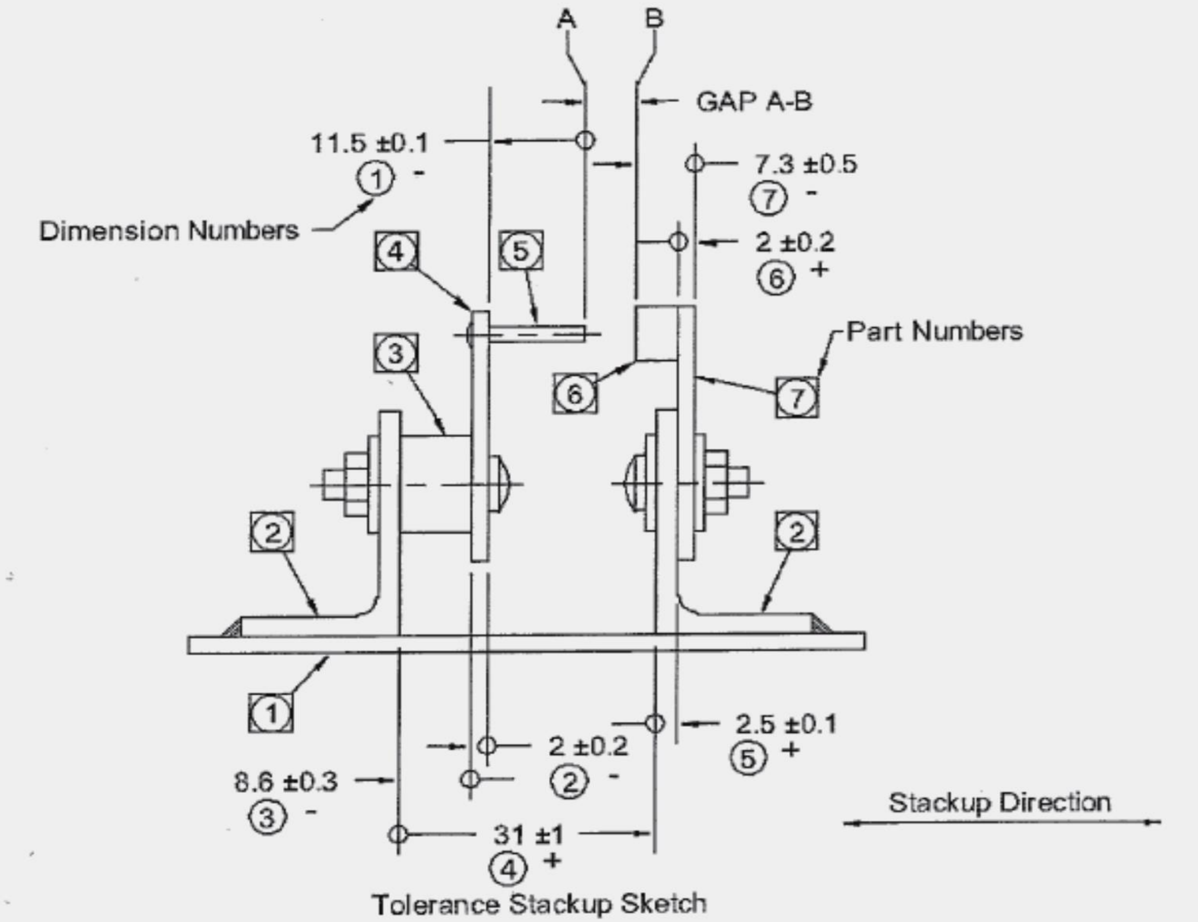


FIGURE 8.27 Complex welded assembly (Tolerance Stackup sketch).

Statistical Tolerance Analyses Example #8.4

Statistical Tolerance Stackup

Dim No	Part No	+	-	+/-	Squared Tolerances	Description
1	5		11.5	± 0.1	± 0.01	Pin Length
2	4		2	± 0.2	± 0.04	LH Plate Thickness
3	3		8.6	± 0.3	± 0.09	Standoff Thickness
4	2	31		± 1	± 1	Flange to Flange Dist Between LH & RH Item 2
5	2	2.5		± 0.1	± 0.01	RH Angle Brkt Web Thickness
6	7	2		± 0.2	± 0.04	RH Plate Thickness
7	6 & 7		7.3	± 0.5	± 0.25	Thickness of RH Plate and Boss
Totals		35.5	29.4	± 2.4	√ ± 1.44	Totals
					+/- 1.20	RSS Tolerance
					+/- 1.8	Adjusted RSS Tolerance (RSS * 1.5)

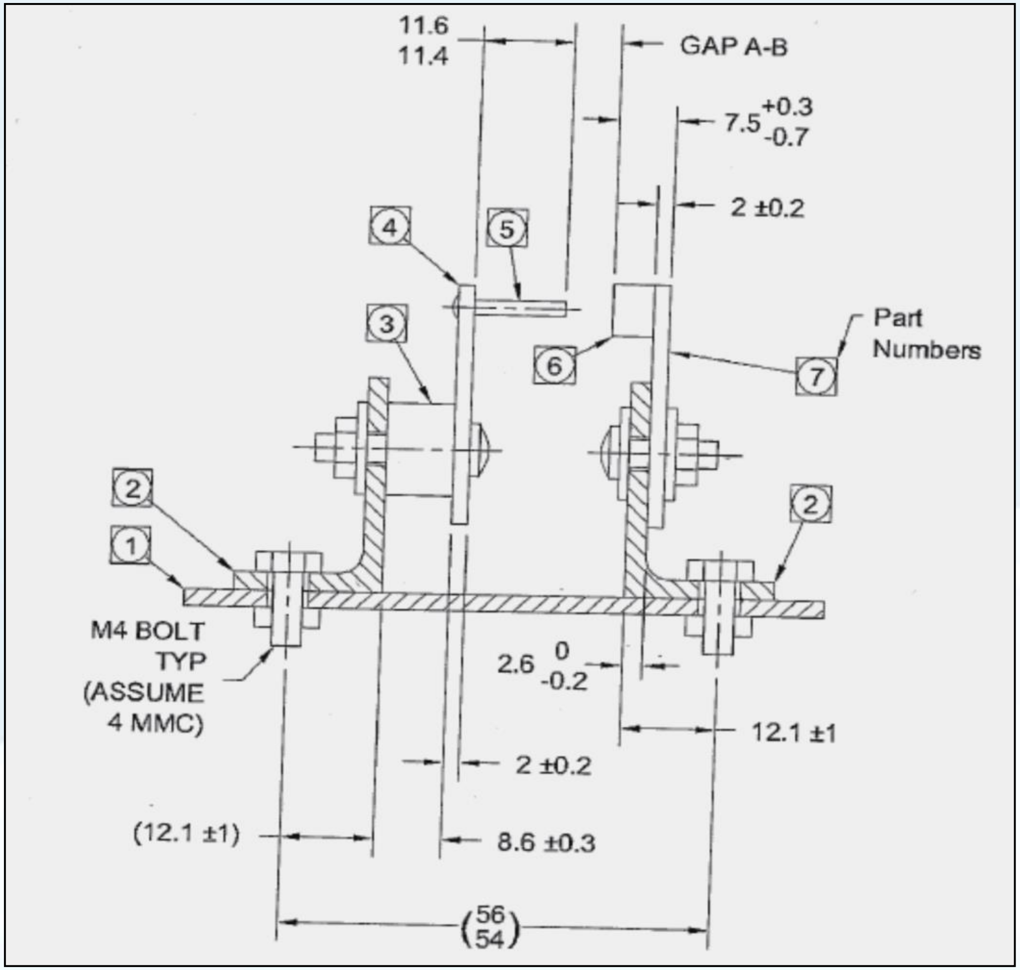
Positive Total	35.5	
- Negative Total	- 29.4	
= Nominal Gap	6.1 ± 1.8	Adjusted RSS Tolerance

Max Gap	7.9
Min Gap	4.3

Solve for Statistical Minimum and Maximum Gap A-B

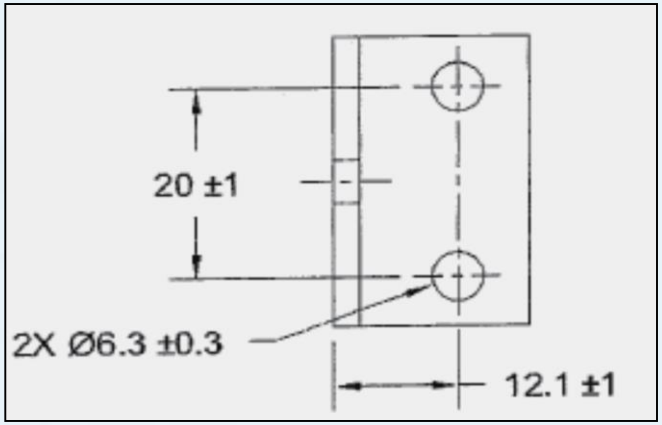
FIGURE 8.28 Tolerance Stackup report solved statistically.

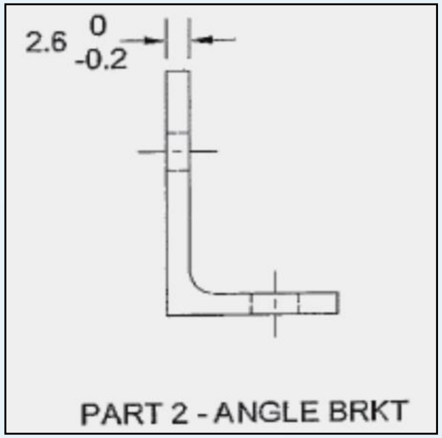
Statistical Tolerance Analyses Example #8.5

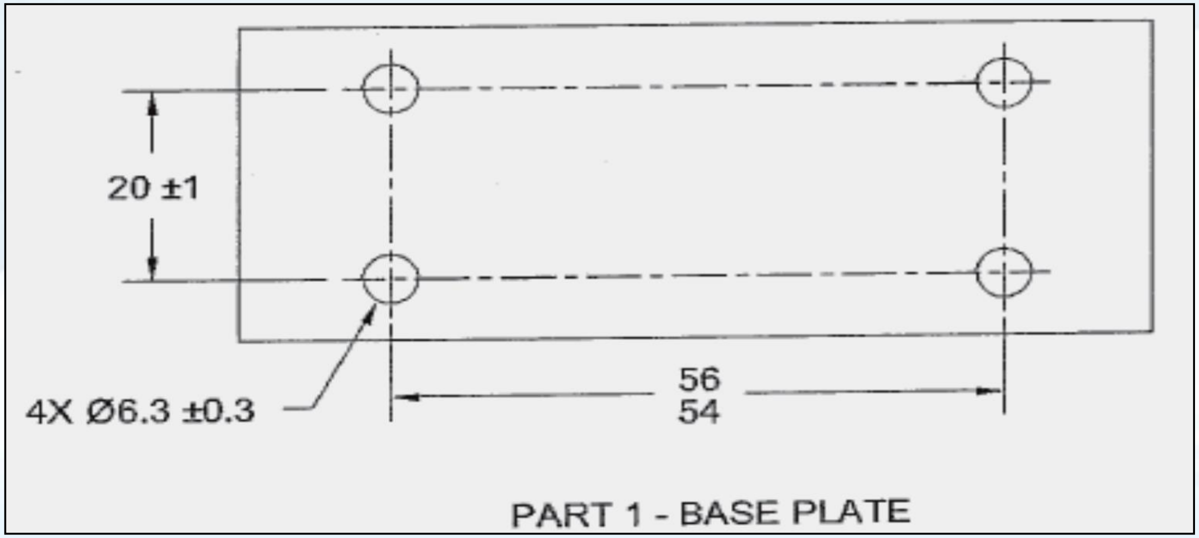


Solve for Minimum and Maximum Gap A-B

Statistical Tolerance Analyses Example #8.5







Chapter #9

Geometric Dimensioning and Tolerancing

WWW.OMNEX.COM

GD&T Advantage

- GD&T creates coordinate systems based on datum reference frames all features on a part are unambiguously related to these coordinate systems

- Tolerance Stack ups done on parts and assemblies that have been properly dimensioned and toleranced with GD&T are easier and more straightforward than with parts defined by $\pm$ dimensions and tolerances.

- Tolerance Stack ups performed on parts with GD&T require far fewer assumptions regarding how to interpret the tolerance specifications.

Converting GD&T Into Equal Bilateral Tolerances

- parts and assemblies dimensioned with GD&T must also be converted to equal bilateral ± tolerances before a Tolerance Analysis can be completed.
- Plus/minus dimensions and tolerances are still used with drawings based on GD&T, but their use should be limited to defining features of size and the depth or length of features such as holes and pins.
- For many reasons, ± dimensions and tolerances should not be used to locate features.

Profile Tolerances

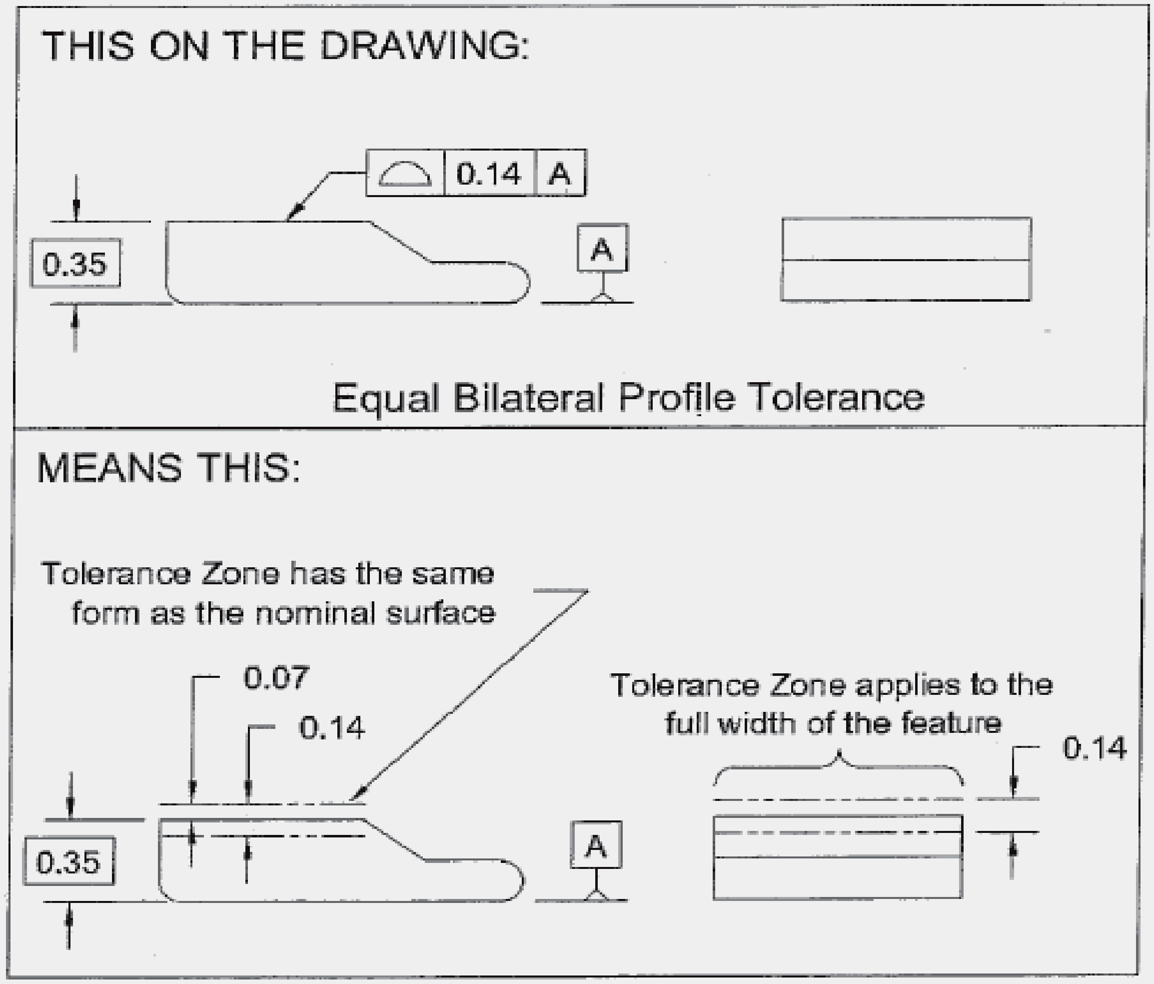


FIGURE 9.2 Equal bilateral profile.

Profile Tolerances

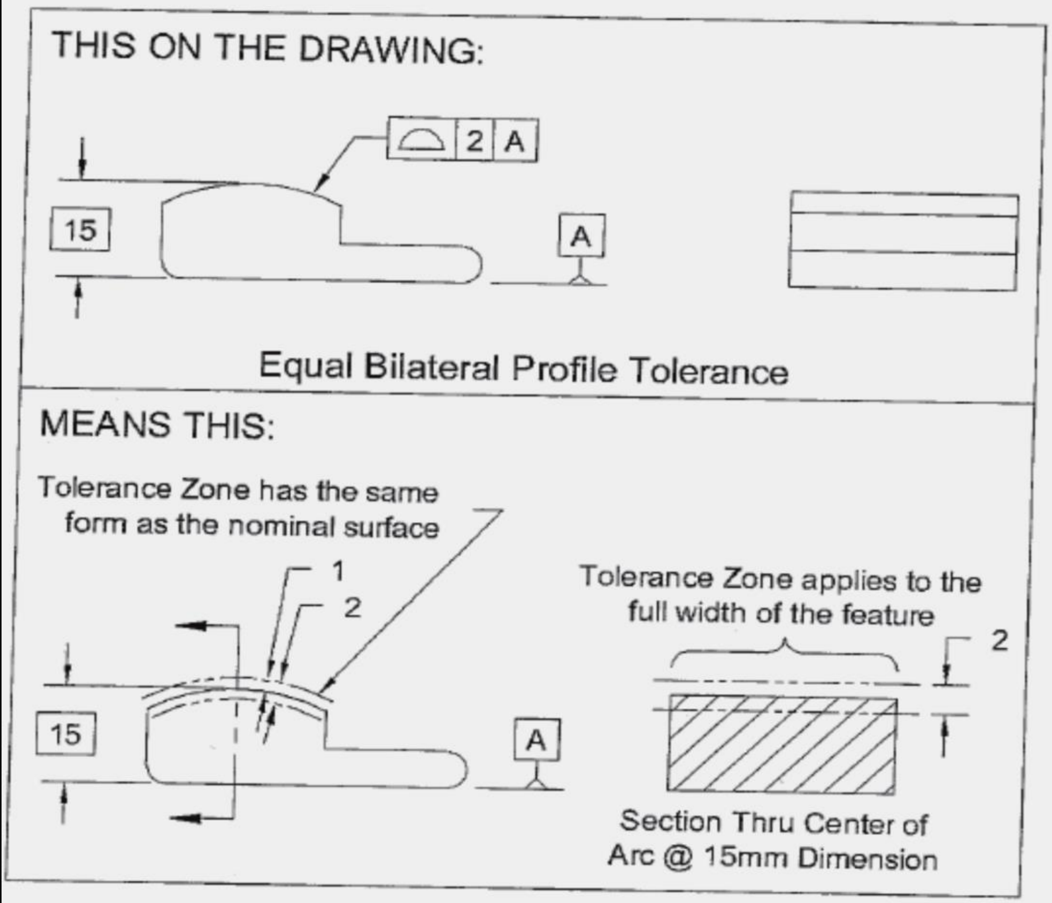


FIGURE 9.3 Equal bilateral profile curved surface.

15 ± 1

Profile Tolerances

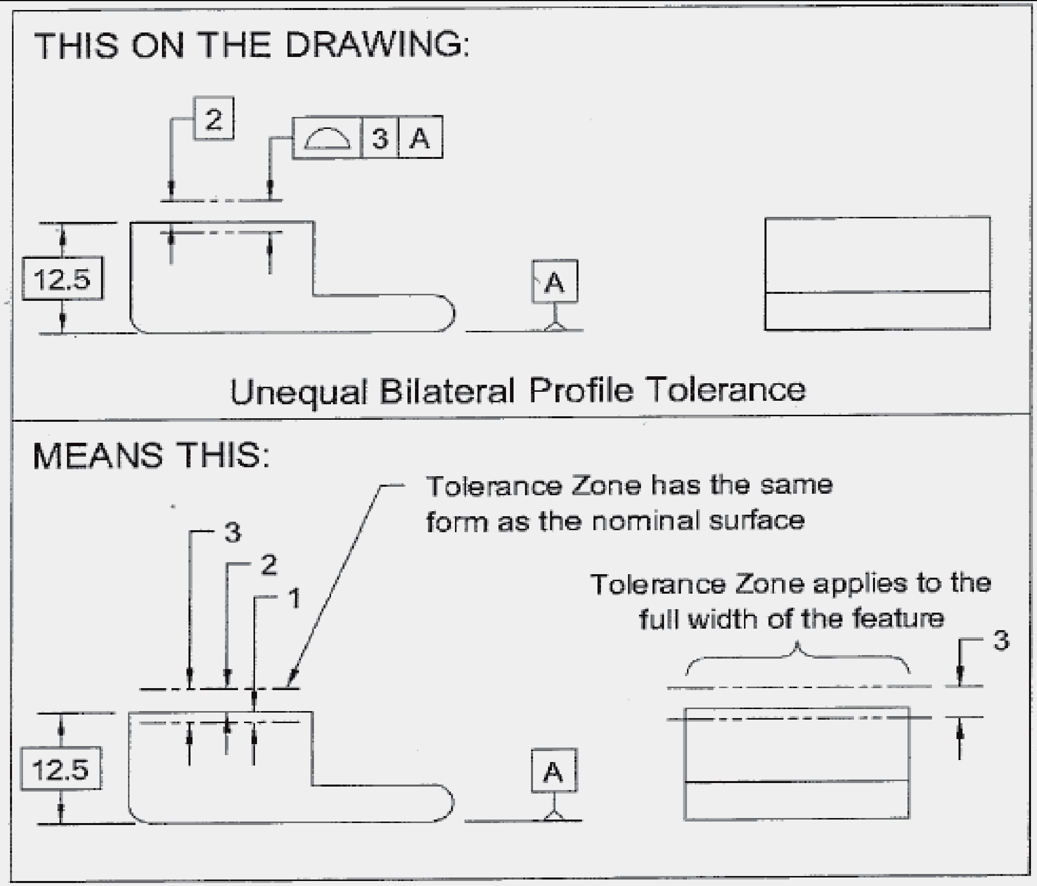


FIGURE 9.4 Unequal bilateral profile.

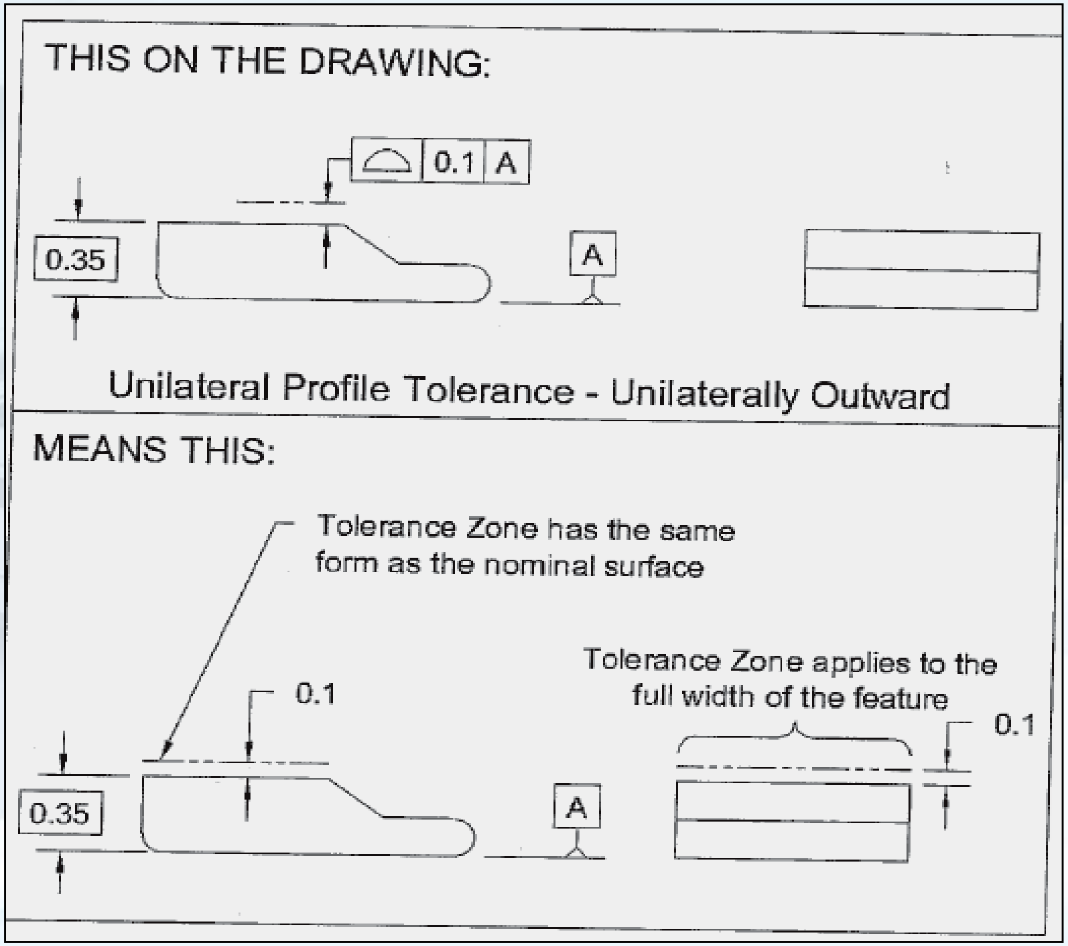
$$\text{Upper limit} = 12.5 + 2 = 14.5$$
$$\text{Lower limit} = 12.5 - 1 = 11.5$$

$$3 = \pm 1.5$$

$$11.5 + 1.5 = 13$$

$$13 \pm 1.5$$

Profile Tolerances



$$\text{Upper limit} = 0.35 + 0.1 = 0.45$$

$$\text{Lower limit} = 0.35 - 0 = 0.35$$

$$0.1 = \pm 0.05$$

$$0.35 + 0.05 = 0.4$$

$$0.4 \pm 0.05$$

OMNEX

WWW.OMNEX.COM

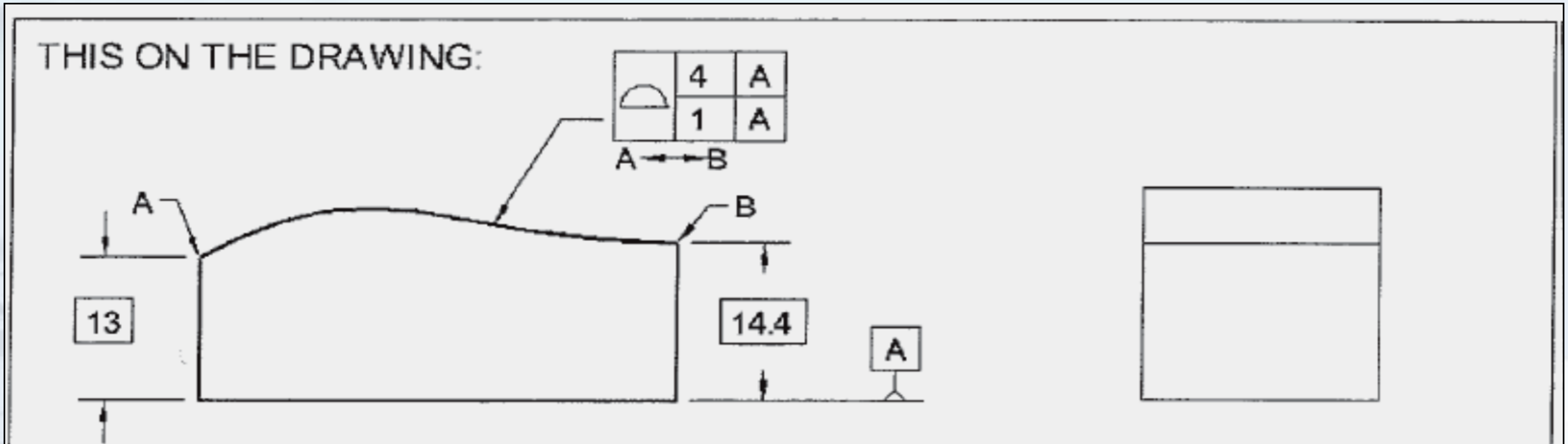
Converting GD&T Into Equal Bilateral Tolerances

- **Composite profile tolerances**

  The profile tolerance specified in the uppermost segment of the feature control frame represents the total allowable variation in location of the feature to a datum reference frame.

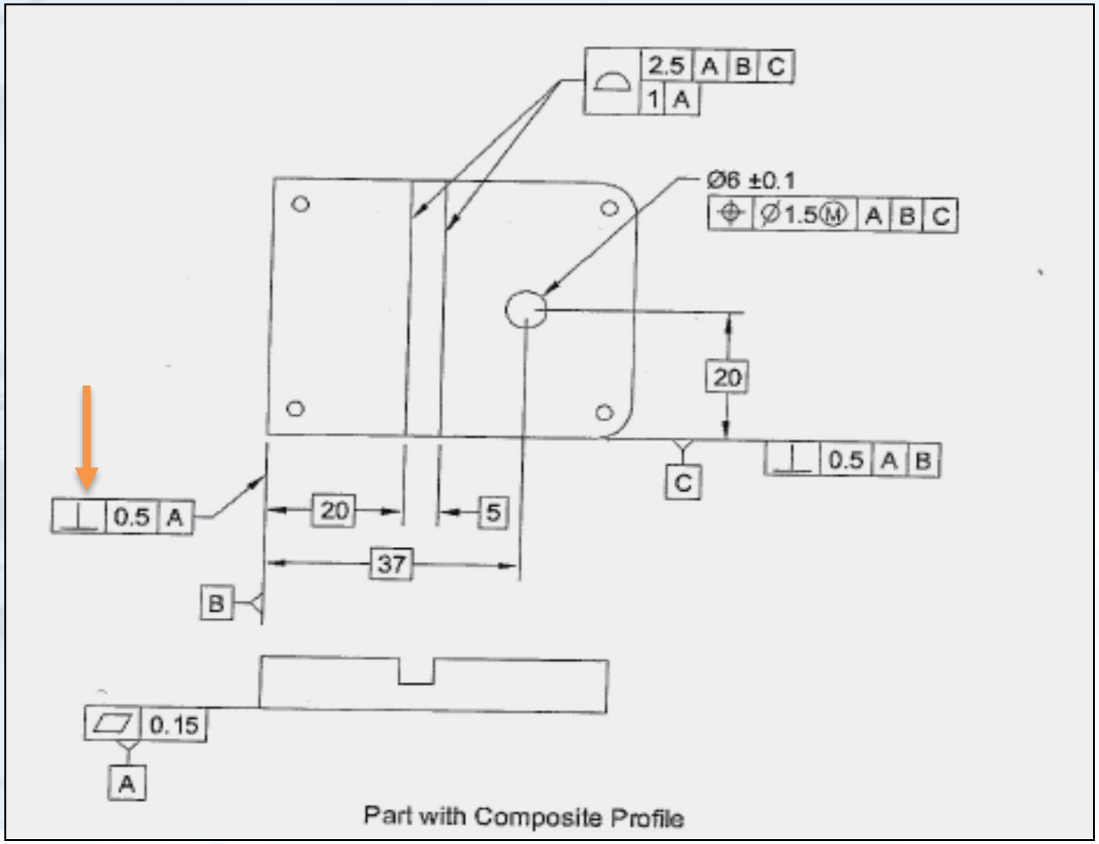
  Typically the tolerance defined in the uppermost segment is used, in Tolerance Stack ups.

Composite Profile Tolerances

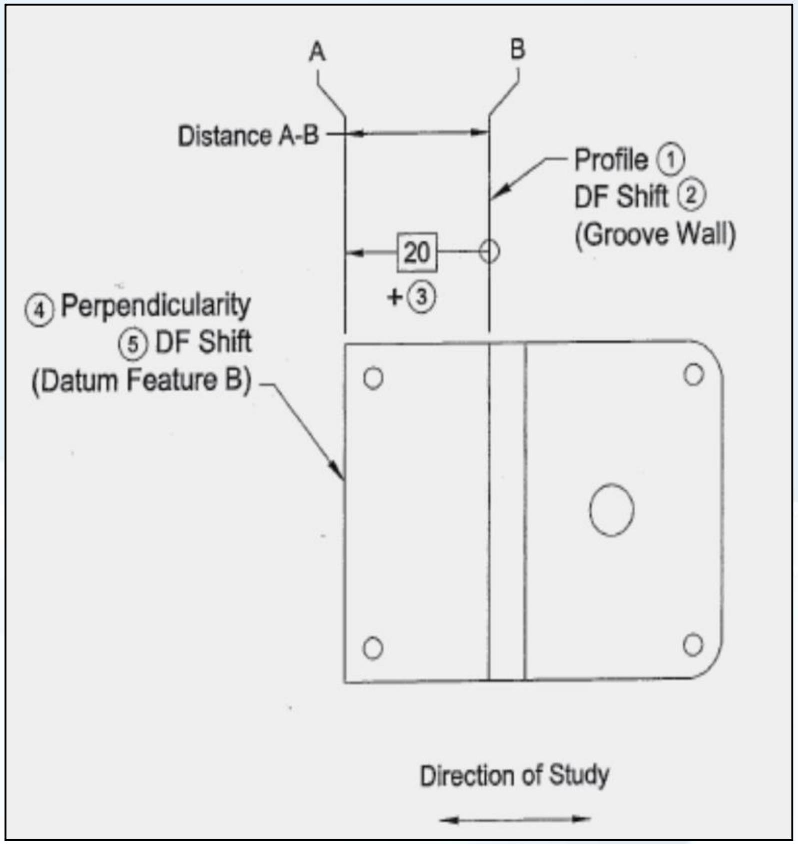


Composite Profile of a Surface

Composite Profile Tolerances Example #9.1



Part with Composite Profile



Composite Profile Tolerances Example #9.1

Tolerance Stack

Release 1.2a

Program: Tolerance Analysis and Stackup Manual

Product:

Part Number	Rev	Description
-	A	Part with Groove

Problem: It is Important to Know the Minimum Distance Between the Groove Wall and the Left Edge of the Part

Objective: Determine the Minimum Distance Between the Groove Wall and the Left Edge of the Part

Stack Information:

Stack No: Figure 9-9
Date: 07/04/02
Revision A

Direction: Horizontal
Author: BR Fischer

Description of Component / Assy	Part Number	Rev	Item	Description	+ Dims	- Dims	Tol	Percent Contrib	Dim / Tol Source & Calcs
Part with Groove	123-002	A	1	Profile: Edge Along Pt A			+/- 1.2500	83%	Profile 2.5, A, B, C (Upper Segment)
			2	Datum Feature Shift			+/- 0.0000	0%	N/A
			3	Dim: Groove Wall - Datum B	20.0000		+/- 0.0000	0%	20 Basic on Dwg
			4	Perpendicularity: (Datum Feature B)		0.2500	+/- 0.2500	17%	Perpendicularity 0.5, A on Dwg - See Notes
			5	Datum Feature Shift:			+/- 0.0000	0%	N/A
				Dimension Totals	20.0000	0.2500			
				Nominal Distance: Pos Dims - Neg Dims =		19.7500			

RESULTS:

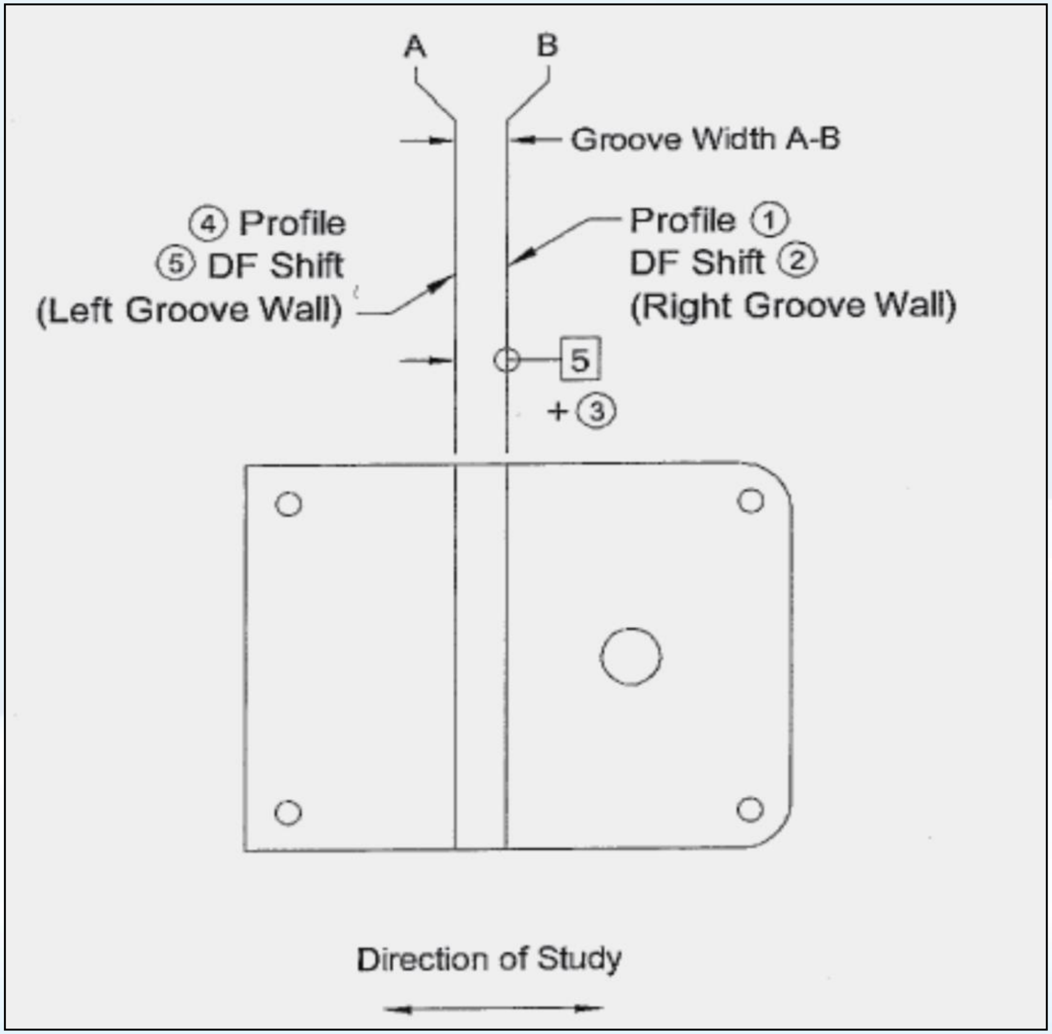
	Nom	Tol	Min	Max
Arithmetic Stack (Worst Case)	19.7500	+/- 1.5000	18.2500	21.2500
Statistical Stack (RSS)	19.7500	+/- 1.2748	18.4752	21.0248
Adjusted Statistical: 1.5*RSS	19.7500	+/- 1.9121	17.8379	21.6621

Notes:
- The Upper Segment Profile Tolerance is used in this Tolerance Stackup.
- It must be understood that the Perpendicularity tolerance applied to Datum Feature B allows portions of the Datum Feature to tilt and / or have form error relative to Datum B, which is perfectly perpendicular to Datum A. Therefore the Perpendicularity tolerance should be included in the Tolerance Stackup. The Perpendicularity tolerance only allows the distance between Datum Feature B and the Groove to decrease, so it must be accompanied by a negative Mean Shift. The Perpendicularity tolerance is added as an equal-bilateral tolerance of +/-0.25, with a Mean Shift of 0.25, which is half the Perpendicularity tolerance value. The Mean Shift is indicated by placing the 0.25 value in the "- Dims" column on the same line as the Perpendicularity tolerance. See Chapter 20 for more information.

Assumptions:

Suggested Action:

Composite Profile Tolerances Example #9.2



Composite Profile Tolerances Example #9.2

Tolerance Stack

Program: Tolerance Analysis and Stackup Manual

Product:

Part Number	Rev	Description
-	A	Part with Groove

Problem: It is Important to Know the Minimum and Maximum Groove Width

Objective: Determine the Minimum and Maximum Groove Width

Stack Information:

Stack No: Figure 9-11
Date: 07/04/02
Revision: A

Direction: Horizontal
Author: BR Fischer

Description of Component / Assy	Part Number	Rev	Item	Description	+ Dims	- Dims	Tol	Percent Contrib	Dim / Tol Source & Calcs
Part with Groove	123-002	A	1	Profile: Edge Along Pt A			+/- 0.5000	50%	Profile 1, A (Lower Segment)
			2	Datum Feature Shift			+/- 0.0000	0%	N/A
			3	Dim: Right Groove Wall - Left Groove Wall	5.0000		+/- 0.0000	0%	5 Basic on Dwg
			4	Profile: Edge Along Pt A			+/- 0.5000	50%	Profile 1, A (Lower Segment)
			5	Datum Feature Shift			+/- 0.0000	0%	N/A
				Dimension Totals	5.0000	0.0000			
				Nominal Distance: Pos Dims - Neg Dims =		5.0000			

RESULTS:

	Nom	Tol	Min	Max
Arithmetic Stack (Worst Case)	5.0000	+/- 1.0000	4.0000	6.0000
Statistical Stack (RSS)	5.0000	+/- 0.7071	4.2929	5.7071
Adjusted Statistical: 1.5*RSS	5.0000	+/- 1.0607	3.9393	6.0607

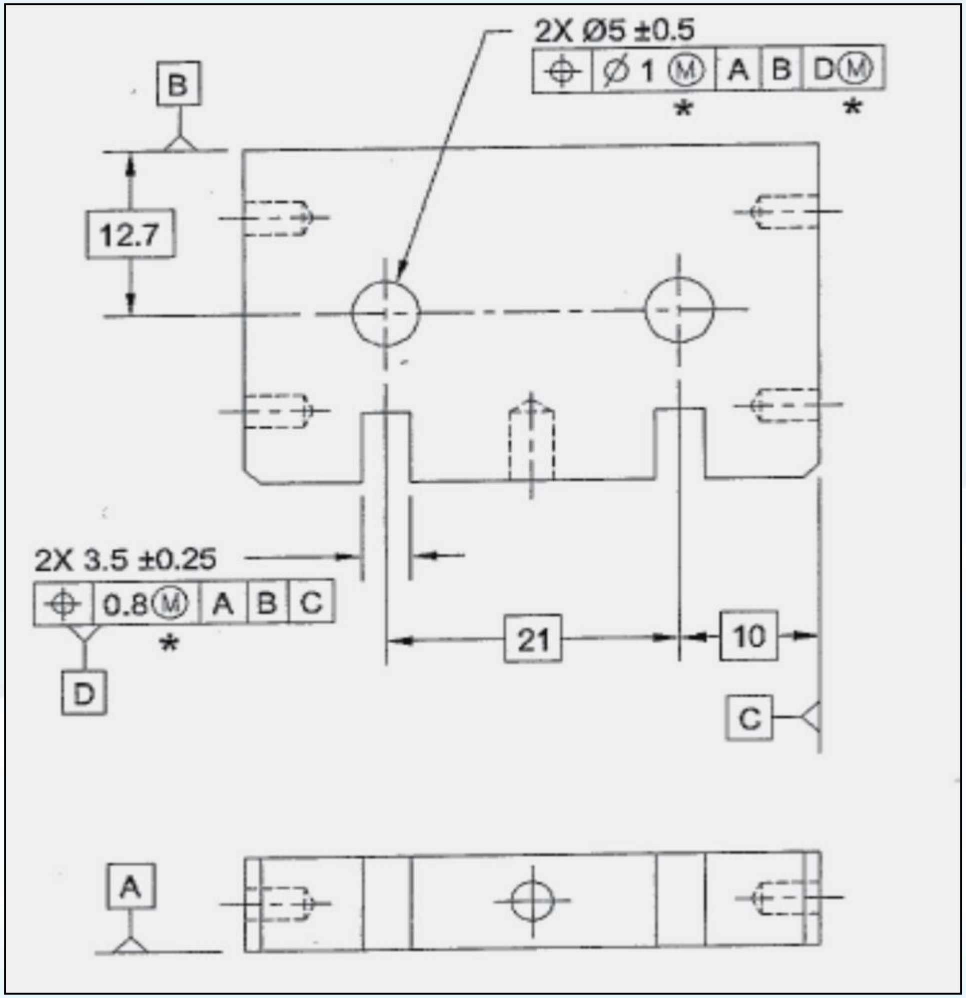
Notes:

WWW.OMNEX.COM

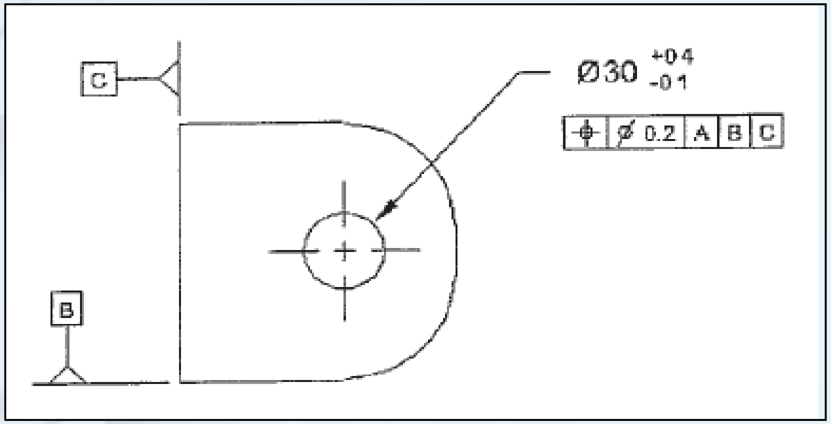
Positional Tolerances

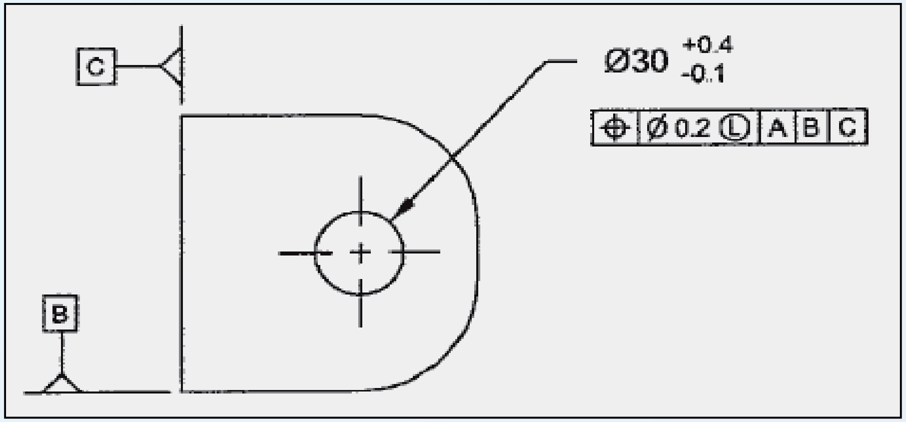
- Positional tolerances can also be translated into ± tolerances: MMC, LMC, RFS
- Positional tolerances specify a cylindrical or total width tolerance zone for features of size (FOS)

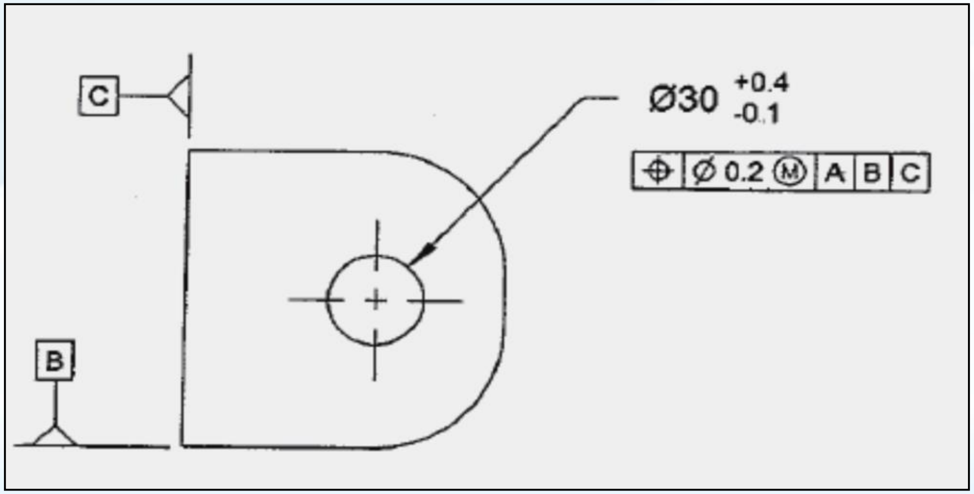
Positional Tolerances: MMC



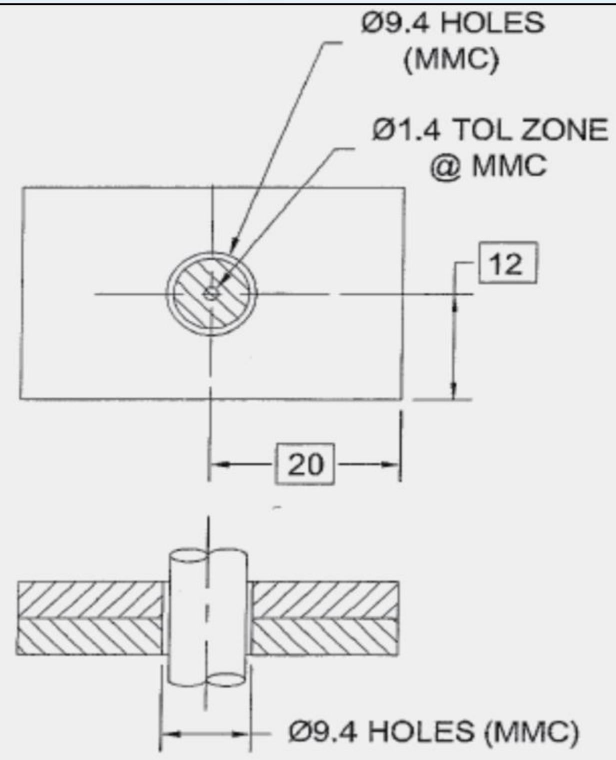
Positional Tolerances: RFS, MMC, LMC



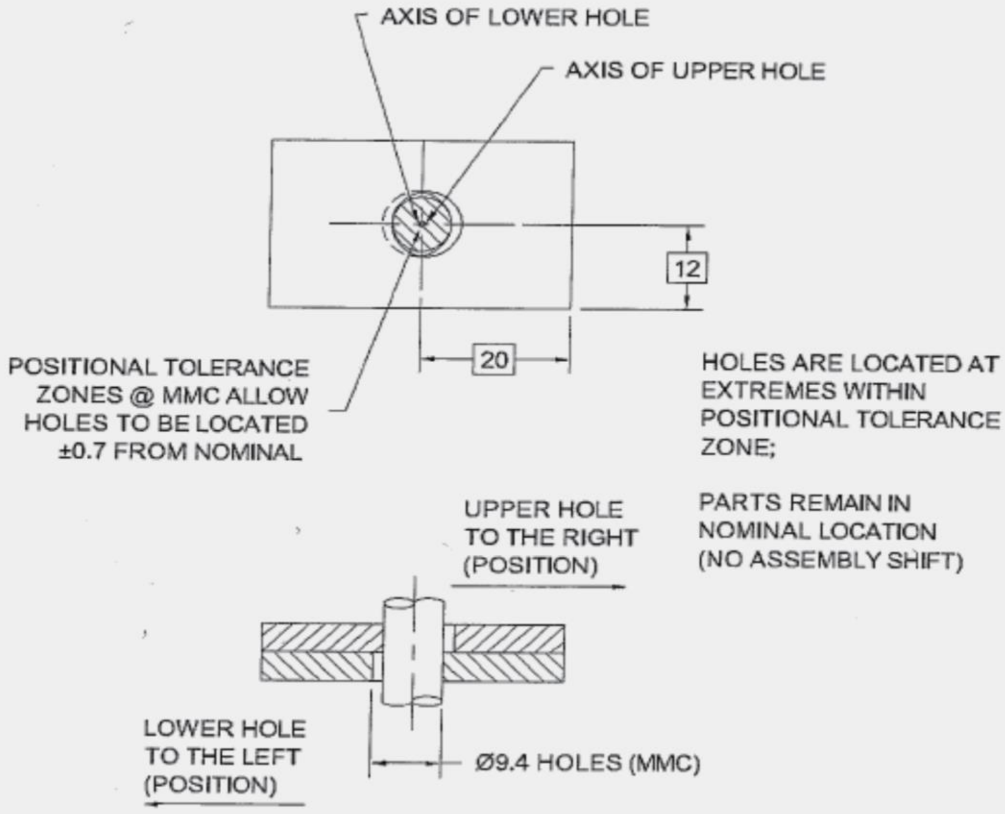




Positional Tolerance, Assembly Shift, And Misalignment

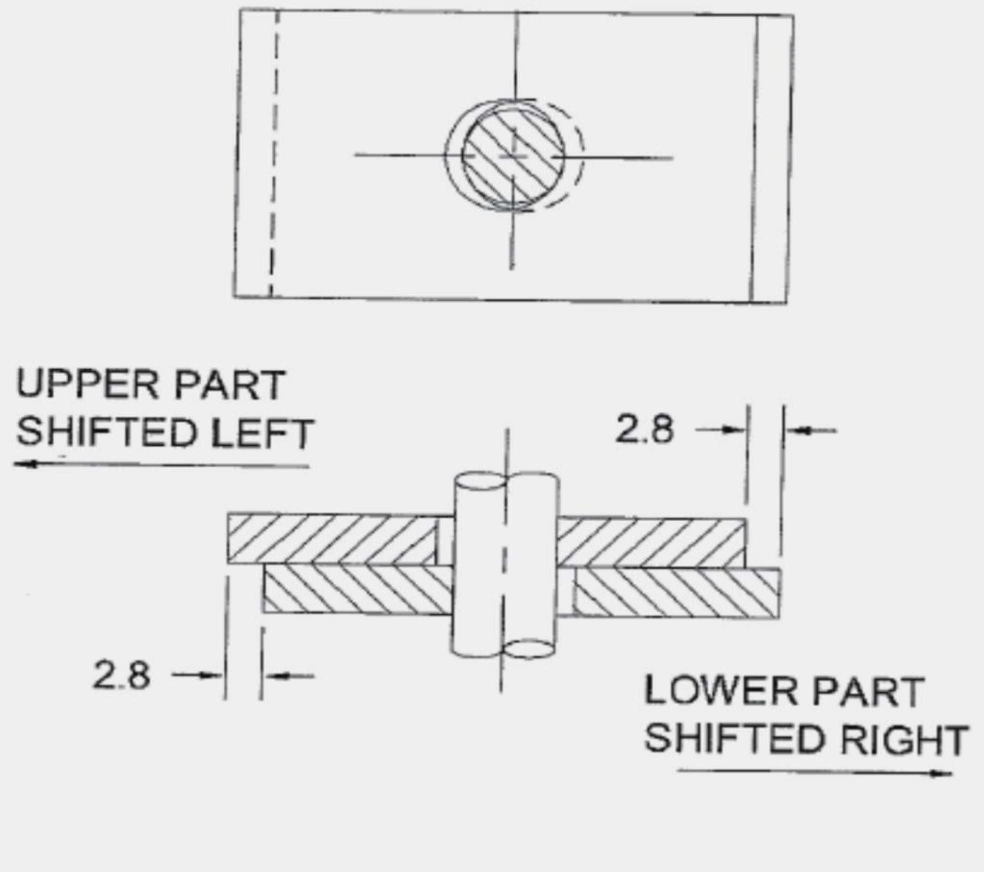


Misalignment with Holes @ MMC:
MMC Holes @ Nominal Position



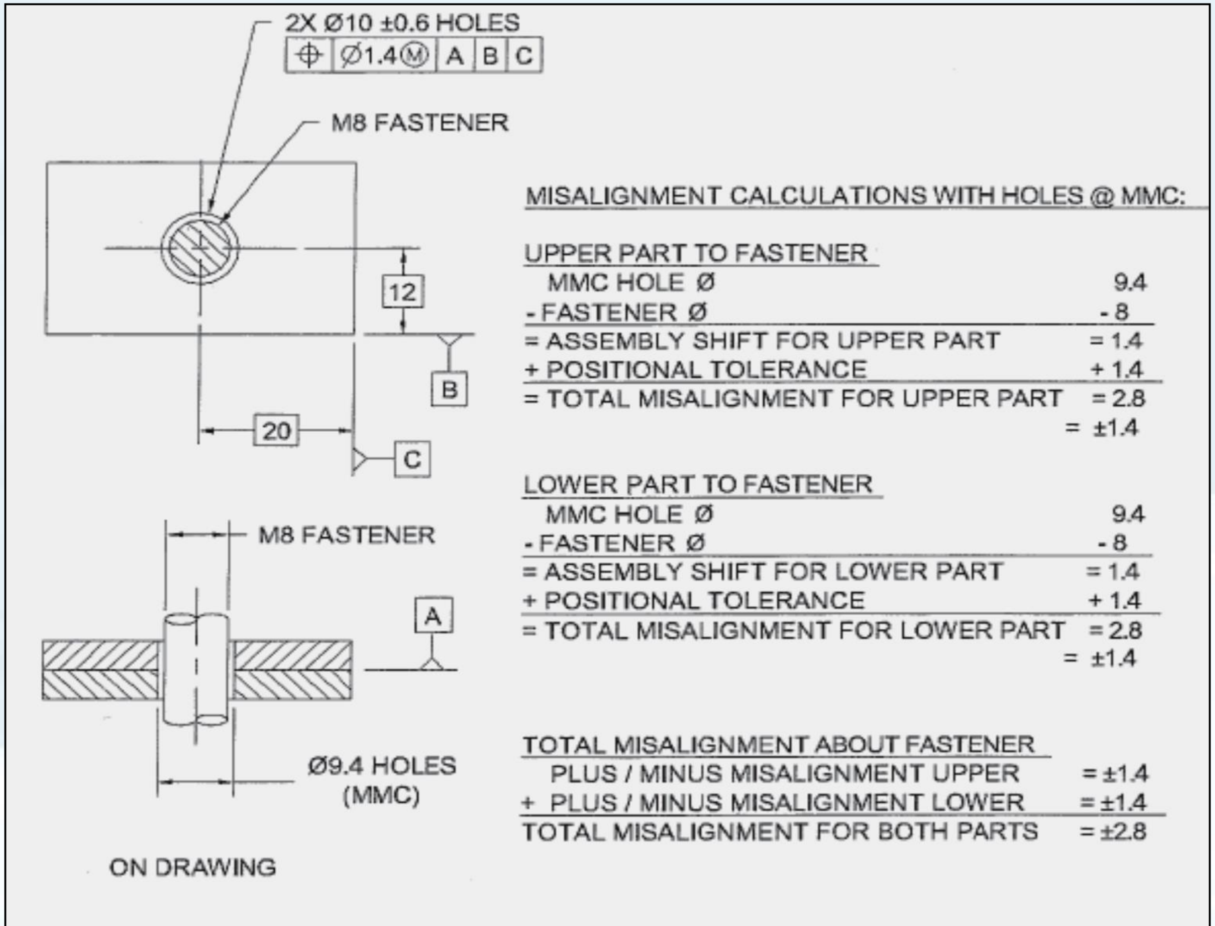
Misalignment with Holes @ MMC: Holes with Positional Error - No Assembly Shift

Positional Tolerance, Assembly Shift, And Misalignment



Maximum Misalignment with Holes @ MMC

Positional Tolerance, Assembly Shift, And Misalignment



Misalignment with Holes @ MMC: Drawing and Calculations

Positional Tolerance, Assembly Shift, And Misalignment

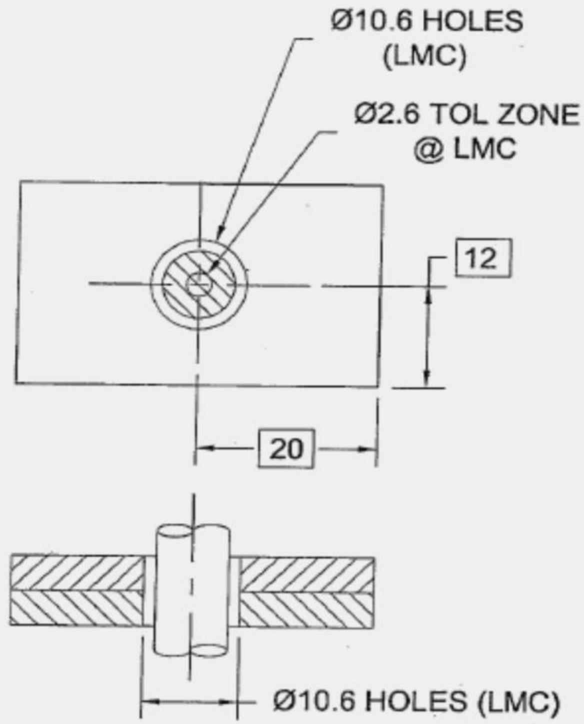
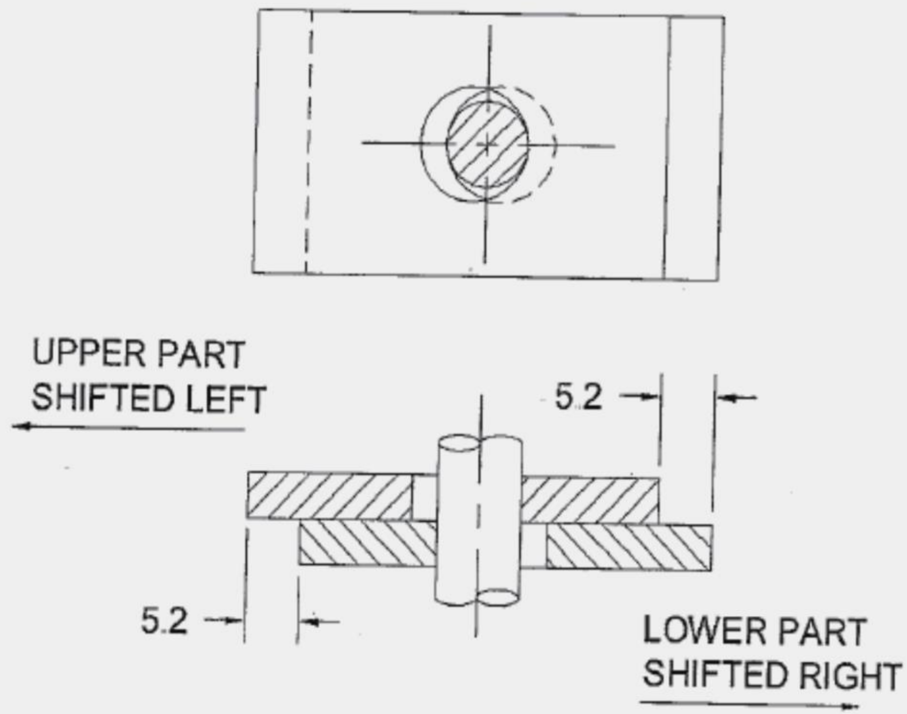
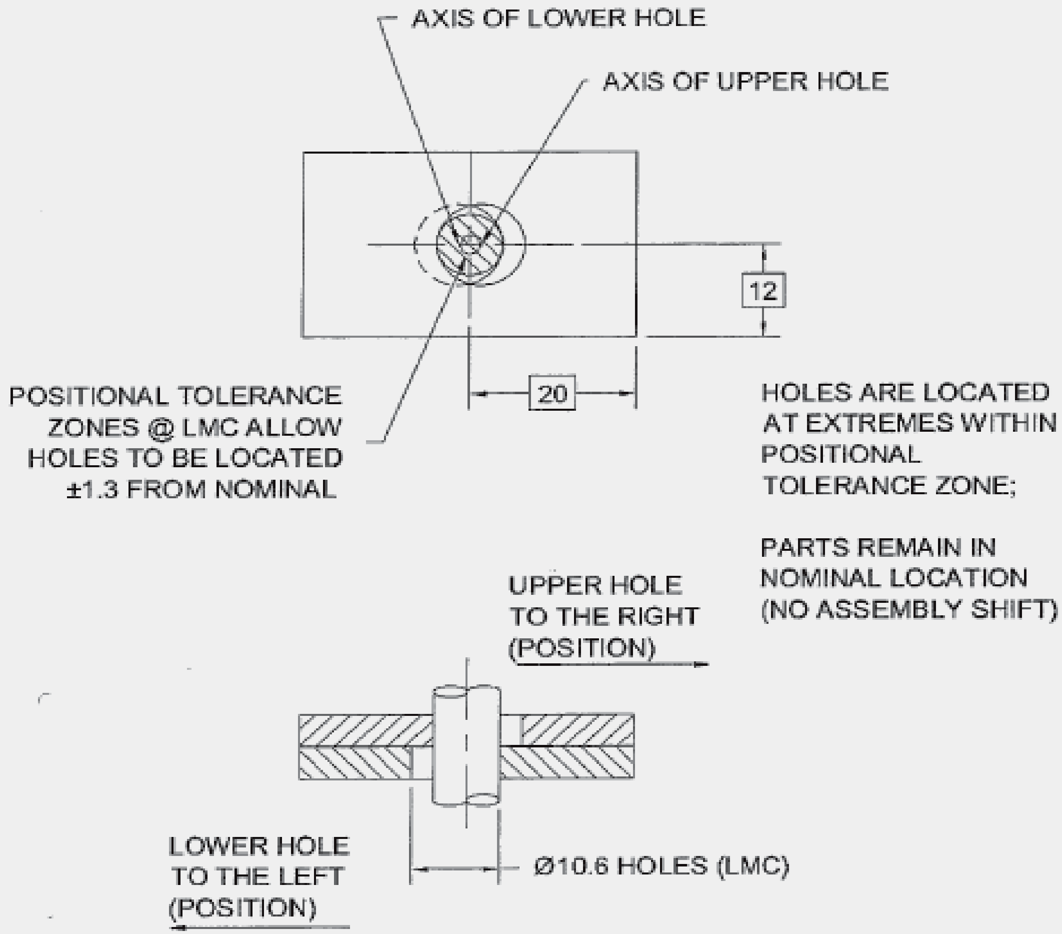


FIGURE 9.21 Misalignment with holes at LMC #1, nominal.



Maximum Misalignment with Holes @ LMC

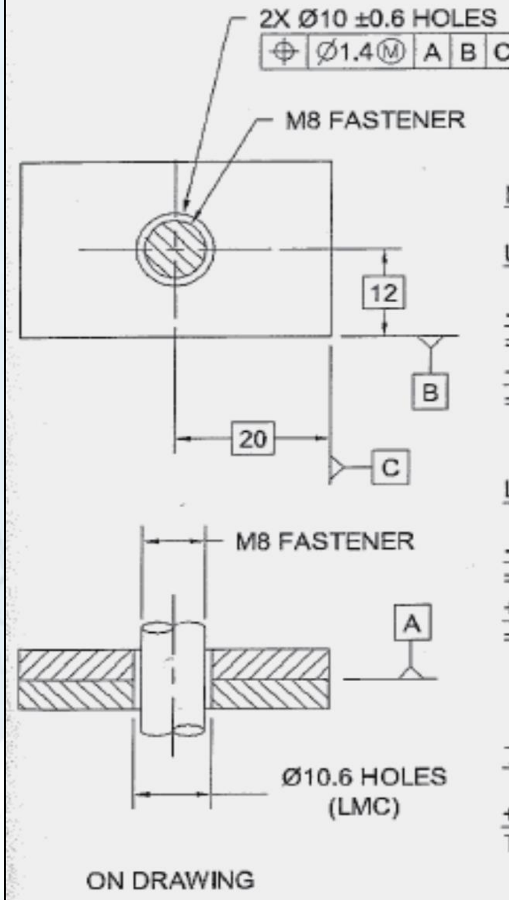
Positional Tolerance, Assembly Shift, And Misalignment



Misalignment with Holes @ MMC: Holes with Positional Error - No Assembly Shift

FIGURE 9.22 Misalignment with holes at LMC #2, with positional error.

Positional Tolerance, Assembly Shift, And Misalignment



MISALIGNMENT CALCULATIONS WITH HOLES @ LMC:

UPPER PART TO FASTENER

LMC HOLE Ø	10.6
- FASTENER Ø	- 8
= ASSEMBLY SHIFT FOR UPPER PART	= 2.6
+ POSITIONAL TOLERANCE @ LMC	+ 2.6
= TOTAL MISALIGNMENT FOR UPPER PART	= 5.2
	= ±2.6

LOWER PART TO FASTENER

LMC HOLE Ø	10.6
- FASTENER Ø	- 8
= ASSEMBLY SHIFT FOR LOWER PART	= 2.6
+ POSITIONAL TOLERANCE @ LMC	+ 2.6
= TOTAL MISALIGNMENT FOR LOWER PART	= 5.2
	= ±2.6

TOTAL MISALIGNMENT ABOUT FASTENER

PLUS / MINUS MISALIGNMENT UPPER	= ±2.6
+ PLUS / MINUS MISALIGNMENT LOWER	= ±2.6
TOTAL MISALIGNMENT FOR BOTH PARTS	= ±5.2

WORST-CASE MISALIGNMENT!

Misalignment Error with Holes @ LMC: Drawing and Calculations

OMNEX

WWW.OMNEX.COM

Positional Tolerance Example #9.1

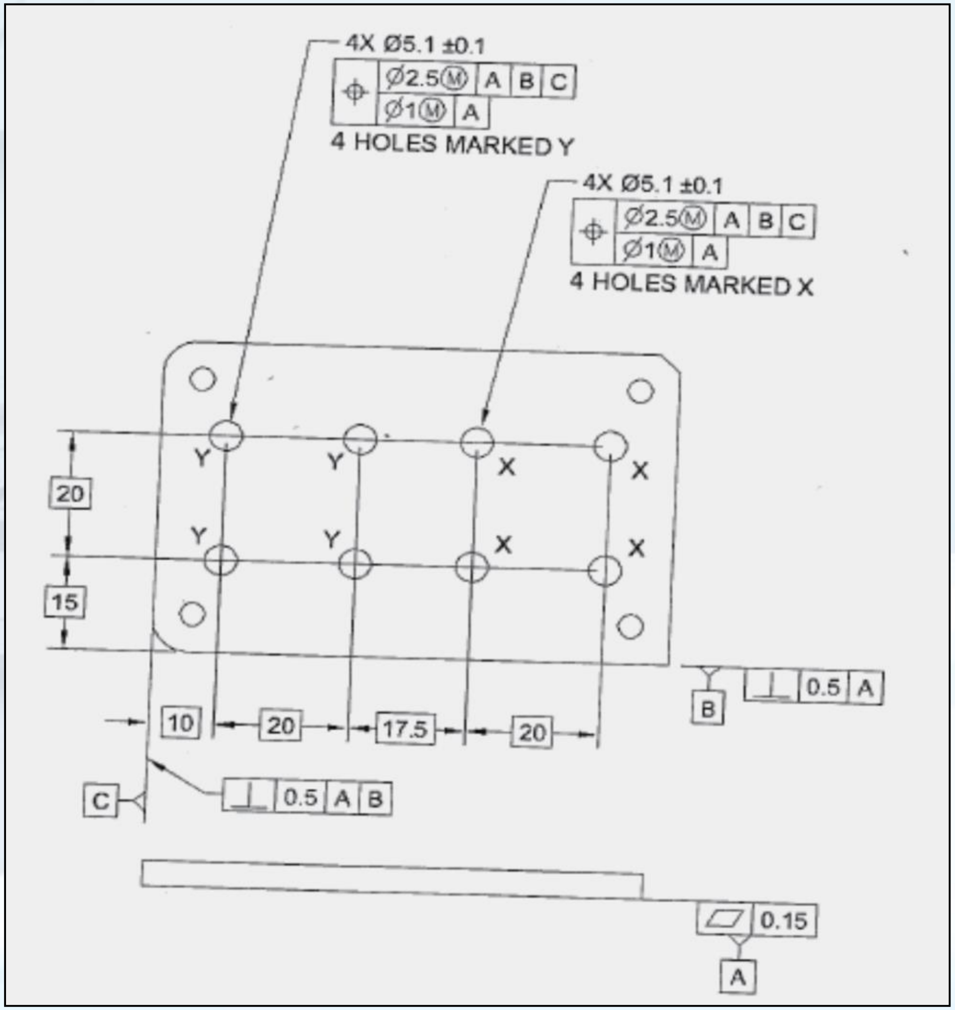


FIGURE 9.25 Composite position back panel detail: Option 1. In this example, each four hole pattern has its own composite position feature control frame. Using this method makes the two patterns distinct.

Positional Tolerance Example #9.1

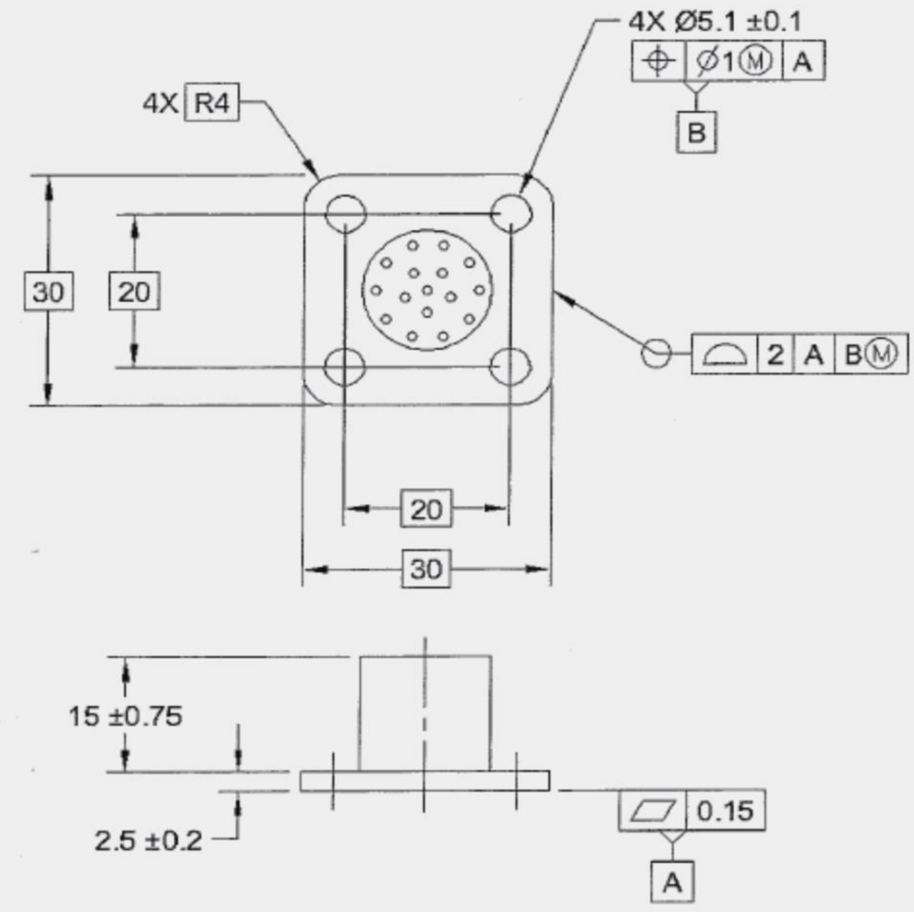


FIGURE 9.26 Composite position, connector detail.

Positional Tolerance Example #9.1

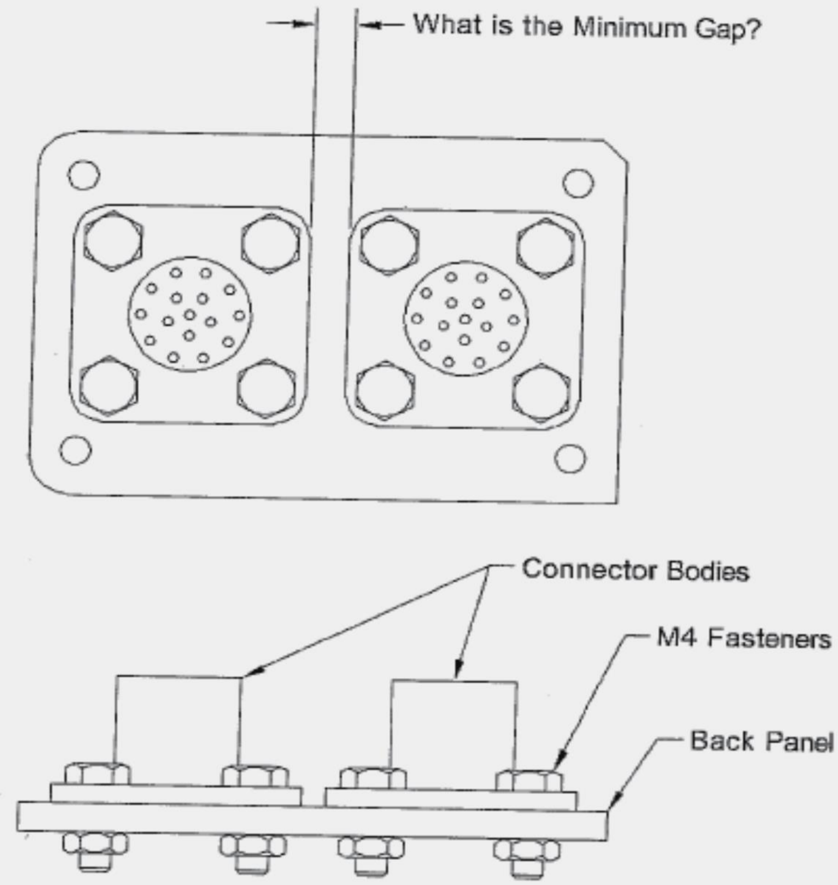
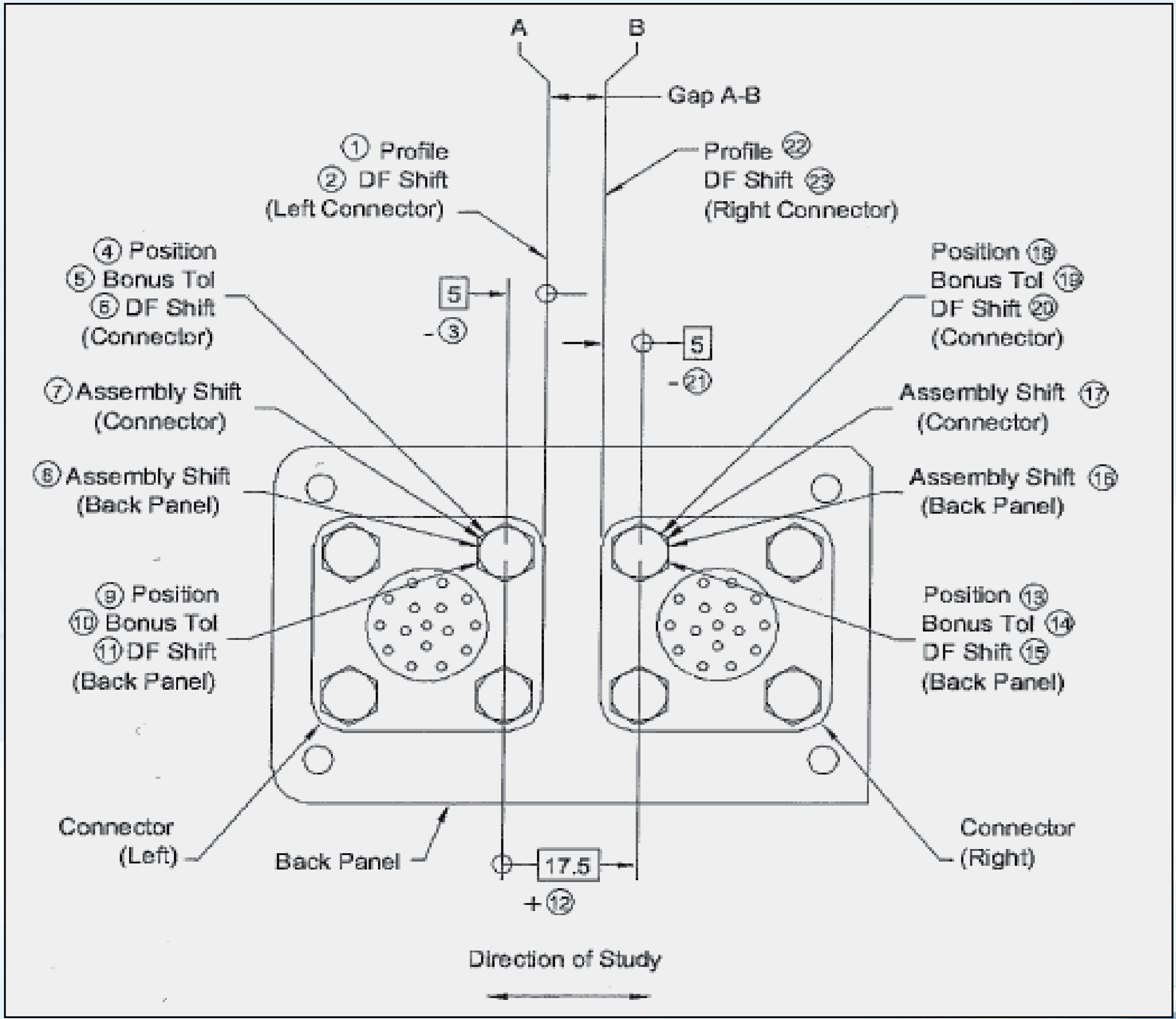


FIGURE 9.27 Composite position, connector module assembly: Option 1.

Positional Tolerance Example #9.1



Positional Tolerance Example #9.1

Program: Tolerance Analysis and Stackup Manual

Release 1.2a

Product:

Part Number	Rev	Description
Opt-1	A	Connector Module Assembly: Option 1

Problem: The Connectors Must not Contact Each Other at Assembly

Objective: Determine if Connectors Make Contact at Assembly

Stack Information:

Stack No: Figure 9-29
Date: 07/04/02
Revision: A

Direction: Horizontal
Author: BR Fischer

Description of Component / Assy	Part Number	Rev	Item	Description	+ Dims	- Dims	Tol	Percent Contrib	Dim / Tol Source & Calcs
Connector	123-002	A	1	Profile: Edge Along Pt A			+/- 1.0000	12.0%	Profile 2, A, Bm
(Left)			2	Datum Feature Shift: $(DF_{B@LMC} - DFS_B)/2$			+/- 0.6000	7.2%	= (5.1 + 0.1 - (5.1 - 0.1 - 1)) / 2
			3	Dim: Edge of Connector - Datum B		5.0000	+/- 0.0000	0%	= (30 Basic - 20 Basic) / 2 on Dwg
			4	Position: DF_B Holes			+/- 0.0000	0%	N/A - (See Note 3)
			5	Bonus Tolerance			+/- 0.0000	0%	N/A - (See Note 3)
			6	Datum Feature Shift			+/- 0.0000	0%	N/A - DF_A not a Feature of Size
			7	Assembly Shift: (Mounting $Holes_{LMC}$ - F) / 2			+/- 0.6000	7.2%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
Back Panel	123-001	A	8	Assembly Shift: (Mounting $Holes_{LMC}$ - F) / 2			+/- 0.6000	7.2%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
			9	Position (Holes on Left)			+/- 1.2500	15.1%	Position dia 2.5 @ MMC A, B, C (Upper Segment)
			10	Bonus Tolerance			+/- 0.1000	1.2%	= (0.1 + 0.1) / 2
			11	Datum Feature Shift			+/- 0.0000	0.0%	N/A - (See Note 1)
			12	Dim: CL Left Holes - CL Right Holes	17.5000		+/- 0.0000	0%	17.5 Basic on Dwg
			13	Position (Holes on Right)			+/- 1.2500	15.1%	Position dia 2.5 @ MMC A, B, C (Upper Segment)
			14	Bonus Tolerance			+/- 0.1000	1.2%	= (0.1 + 0.1) / 2
			15	Datum Feature Shift			+/- 0.0000	0.0%	N/A - (See Note 1)
			16	Assembly Shift: (Mounting $Holes_{LMC}$ - F) / 2			+/- 0.6000	7.2%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
Connector	123-002	A	17	Assembly Shift: (Mounting $Holes_{LMC}$ - F) / 2			+/- 0.6000	7.2%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
(Right)			18	Position: DF_B Holes			+/- 0.0000	0%	N/A - (See Note 3)
			19	Bonus Tolerance			+/- 0.0000	0%	N/A - (See Note 3)
			20	Datum Feature Shift			+/- 0.0000	0%	N/A - DF_A not a Feature of Size
			21	Dim: Datum B - Edge of Connector		5.0000	+/- 0.0000	0%	= (30 Basic - 20 Basic) / 2 on Dwg
			22	Profile: Edge Along Pt B			+/- 1.0000	12.0%	Profile 2, A, Bm
			23	Datum Feature Shift: $(DF_{B@LMC} - DFS_B)/2$			+/- 0.6000	7.2%	= (5.1 + 0.1 - (5.1 - 0.1 - 1)) / 2
				Dimension Totals	17.5000	10.0000			
				Nominal Distance: Pos Dims - Neg Dims =		7.5000			

RESULTS:

	Nom	Tol	Min	Max
Arithmetic Stack (Worst Case)	7.5000	+/- 8.3000	-0.8000	15.8000
Statistical Stack (RSS)	7.5000	+/- 2.7028	4.7972	10.2028
Adjusted Statistical: 1.5*RSS	7.5000	+/- 4.0542	3.4458	11.5542

Notes:

1 - Datum Feature Shift is not included for the Back Panel in this Tolerance Stackup because Datum Features A, B & C are not Features of Size.
2 - M4 Screw Dimensions: Used 4mm as Major Diameter of Threads
3 - The Positional Tolerance on the Connector's Datum Feature B Holes does not contribute to the Stackup. Because the holes are the secondary Datum Feature, they are the basis from which all other features on the part are located in the direction of the Stackup.

Assumptions:

Suggested Action:

- Using the tolerance in the Upper Segment on Lines 9 & 13, the worst-case Tolerance Stackup result is 0.8 interference.

Positional Tolerance Example #9.2

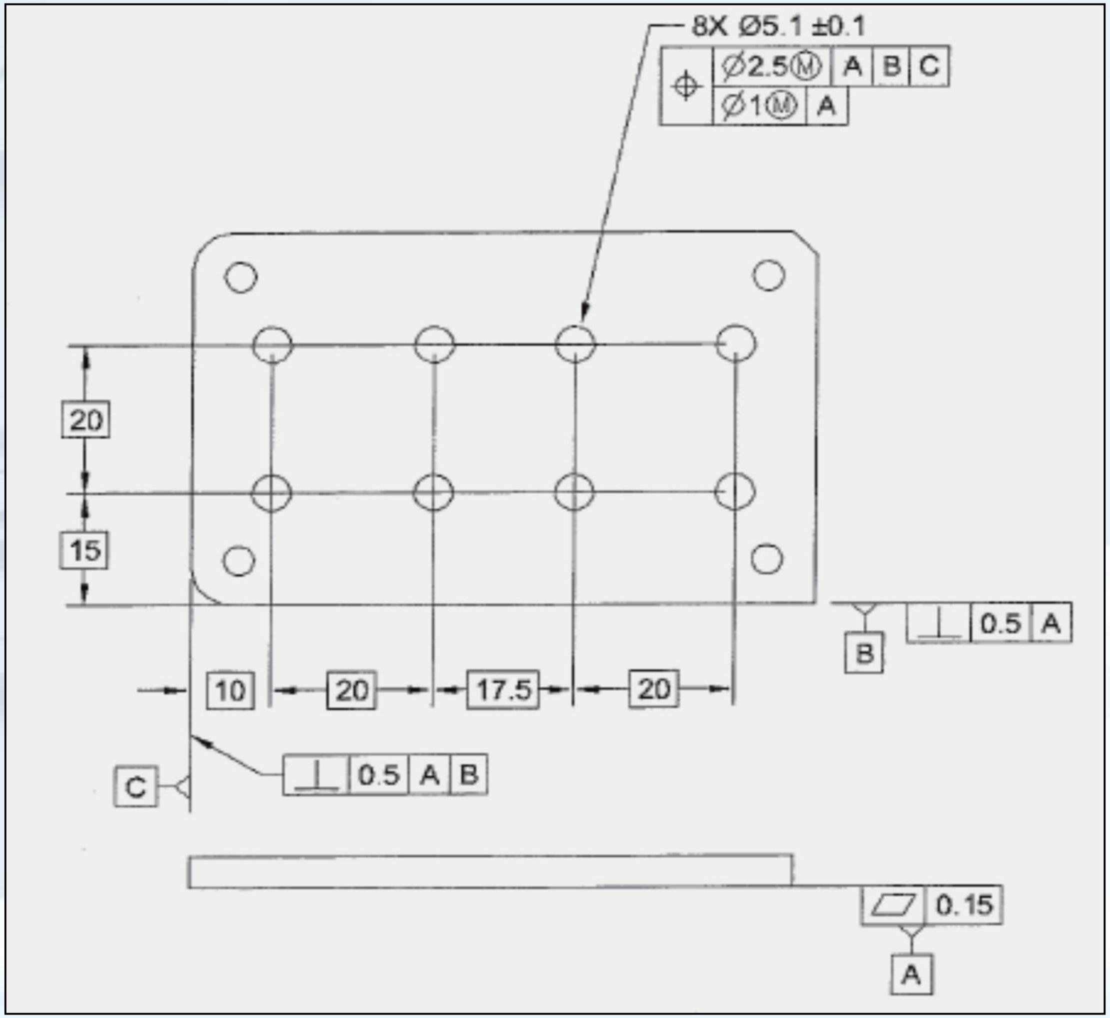


FIGURE 9.30 Composite Position, back panel detail: Option 2. In this example, all eight holes are toleranced with a single Composite Position Feature Control Frame. Using this method treats the two patterns as a single pattern.

OMNEX
WWW.OMNEX.COM

Positional Tolerance Example #9.2

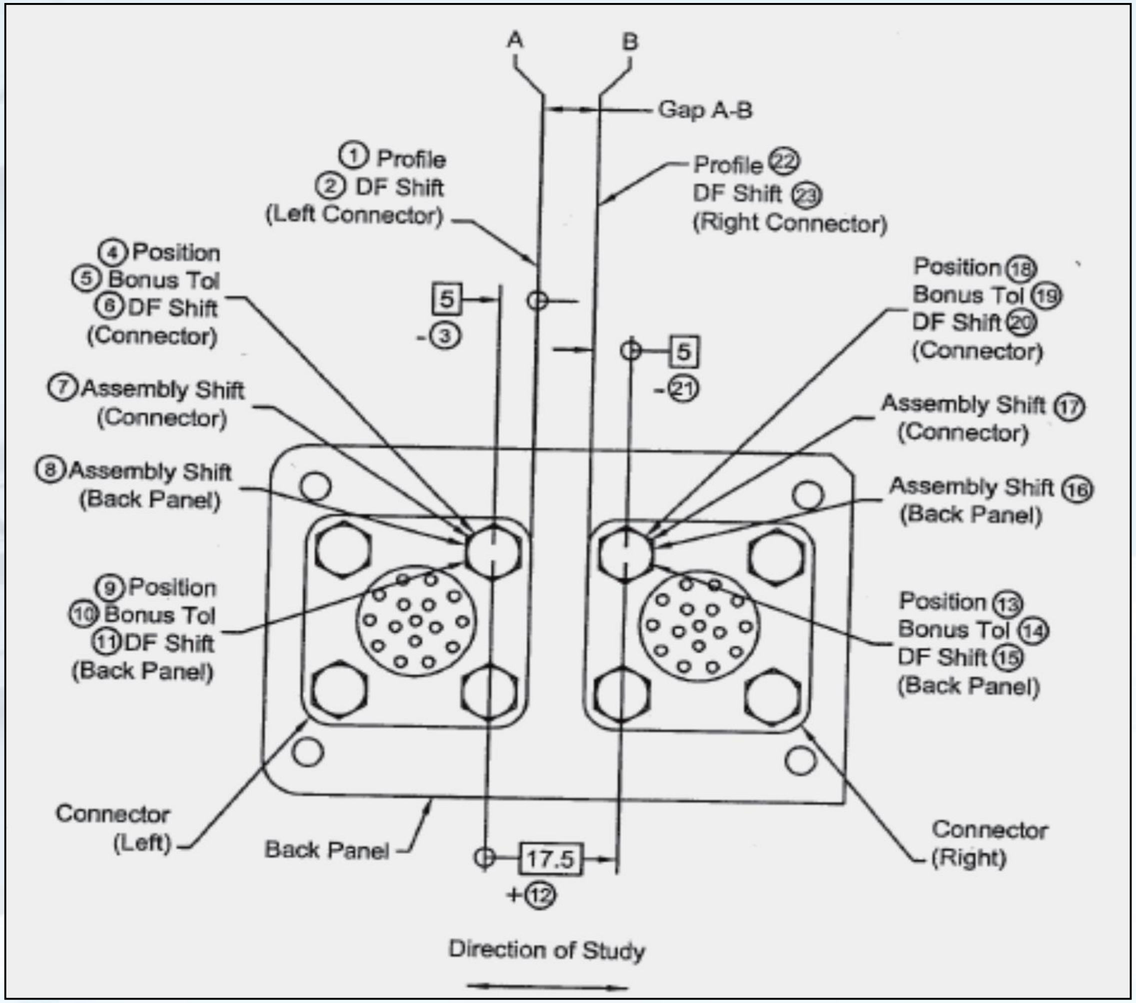


FIGURE 9.31 Composite Position: Option 2 Tolerance Stack up sketch.

Tolerance Stack up with Option 1 Back Panel:

Chain of Dimensions and Tolerances

Lower Segment Tolerances Used for Line Items 9 & 13

Positional Tolerance Example #9.2

Program:	Tolerance Analysis and Stackup Manual
Product:	Part Number: Opt-2 / Rev: A / Description: Connector Module Assembly: Option 2
Problem:	The Connectors Must not Contact Each Other at Assembly
Objective:	Determine if Connectors Make Contact at Assembly

Stack Information:

Stack No:	Figure 9-32
Date:	07/04/02
Revision:	A
Direction:	Horizontal
Author:	BR Fischer

Description of Component / Assy	Part Number	Rev	Item	Description	+ Dims	- Dims	Tol	Percent Contrib	Dim / Tol Source & Calcs
Connector	123-002	A	1	Profile: Edge Along Pt A			+/- 1.0000	14.7%	Profile 2, A, Bm
(Left)			2	Datum Feature Shift: $(DF_{B@MMC} - DFS_B) / 2$			+/- 0.6000	8.8%	= (5.1 + 0.1 - (5.1 - 0.1 - 1)) / 2
			3	Dim: Edge of Connector - Datum B		5.0000	+/- 0.0000	0%	= (30 Basic - 20 Basic) / 2 on Dwg
			4	Position: DF_B Holes			+/- 0.0000	0%	N/A - (See Note 3)
			5	Bonus Tolerance			+/- 0.0000	0%	N/A - (See Note 3)
			6	Datum Feature Shift			+/- 0.0000	0%	N/A - DF_A not a Feature of Size
			7	Assembly Shift: $(Mounting\ Holes_{LMC} - F) / 2$			+/- 0.6000	8.8%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
Back Panel	123-001	A	8	Assembly Shift: $(Mounting\ Holes_{LMC} - F) / 2$			+/- 0.6000	8.8%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
			9	Position (Holes on Left)			+/- 0.5000	7.4%	Position dia 1 @ MMC A (Lower Segment)
			10	Bonus Tolerance			+/- 0.1000	1.5%	= (0.1 + 0.1) / 2
			11	Datum Feature Shift			+/- 0.0000	0.0%	N/A - (See Note 1)
			12	Dim: CL Left Holes - CL Right Holes	17.5000		+/- 0.0000	0%	17.5 Basic on Dwg
			13	Position (Holes on Right)			+/- 0.5000	7.4%	Position dia 1 @ MMC A (Lower Segment)
			14	Bonus Tolerance			+/- 0.1000	1.5%	= (0.1 + 0.1) / 2
			15	Datum Feature Shift			+/- 0.0000	0.0%	N/A - (See Note 1)
			16	Assembly Shift: $(Mounting\ Holes_{LMC} - F) / 2$			+/- 0.6000	8.8%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
Connector	123-002	A	17	Assembly Shift: $(Mounting\ Holes_{LMC} - F) / 2$			+/- 0.6000	8.8%	= ((5.1 + 0.1) - 4) / 2 (See Note 2)
(Right)			18	Position: DF_B Holes			+/- 0.0000	0%	N/A - (See Note 3)
			19	Bonus Tolerance			+/- 0.0000	0%	N/A - (See Note 3)
			20	Datum Feature Shift			+/- 0.0000	0%	N/A - DF_A not a Feature of Size
			21	Dim: Datum B - Edge of Connector		5.0000	+/- 0.0000	0%	= (30 Basic - 20 Basic) / 2 on Dwg
			22	Profile: Edge Along Pt B			+/- 1.0000	14.7%	Profile 2, A, Bm
			23	Datum Feature Shift: $(DF_{B@MMC} - DFS_B) / 2$			+/- 0.6000	8.8%	= (5.1 + 0.1 - (5.1 - 0.1 - 1)) / 2
				Dimension Totals	17.5000	10.0000			
				Nominal Distance: Pos Dims - Neg Dims =		7.5000			

RESULTS:

	Nom	Tol	Min	Max
Arithmetic Stack (Worst Case)	7.5000	+/- 6.8000	0.7000	14.3000
Statistical Stack (RSS)	7.5000	+/- 2.1633	5.3367	9.6633
Adjusted Statistical: 1.5*RSS	7.5000	+/- 3.2450	4.2550	10.7450

Notes:

1 - Datum Feature Shift is not included for the Back Panel in this Tolerance Stackup because Datum Features A, B & C are not Features of Size.
2 - M4 Screw Dimensions: Used 4mm as Major Diameter of Threads
3 - The Positional Tolerance on the Connector's Datum Feature B Holes does not contribute to the Stackup. Because the holes are the secondary Datum Feature, they are the basis from which all other features on the part are located in the direction of the Stackup.

Assumptions:

Suggested Action:

- Using the tolerance in the Lower Segment on Lines 9 & 13, the worst-case Tolerance Stackup result is 0.7 Clearance.

OMNEX
WWW.OMNEX.COM

Positional Tolerance Example #9.3

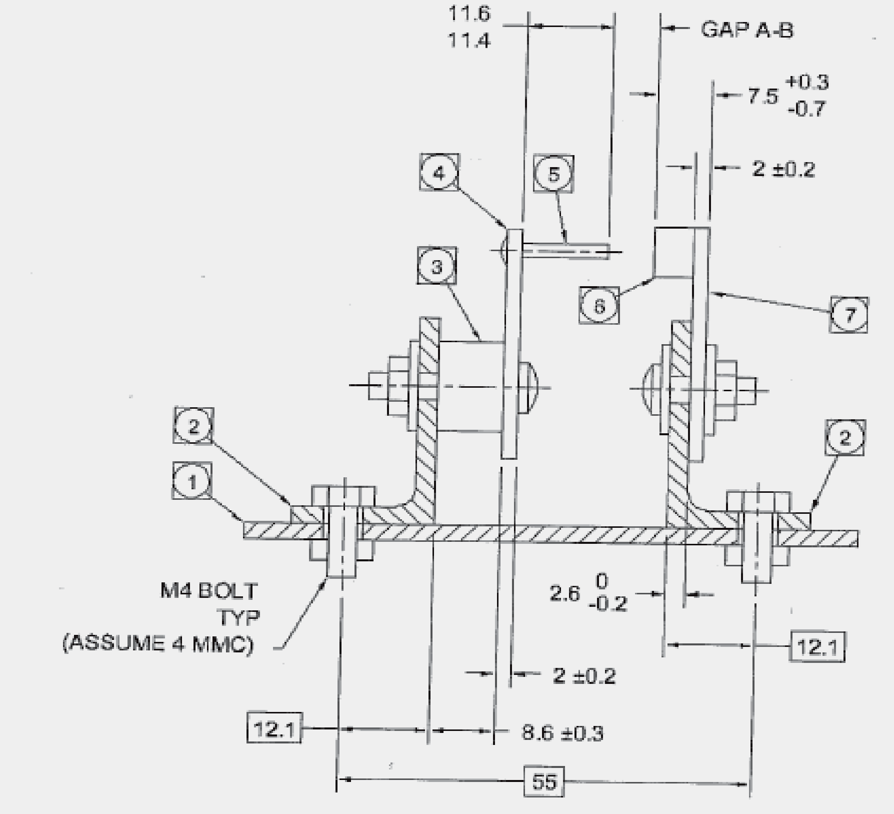
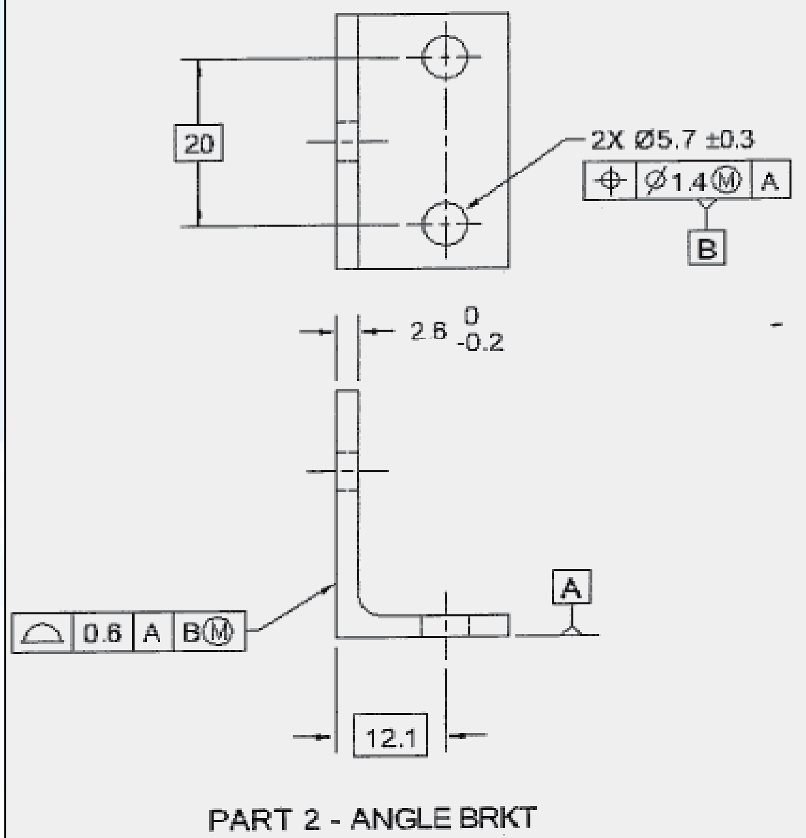
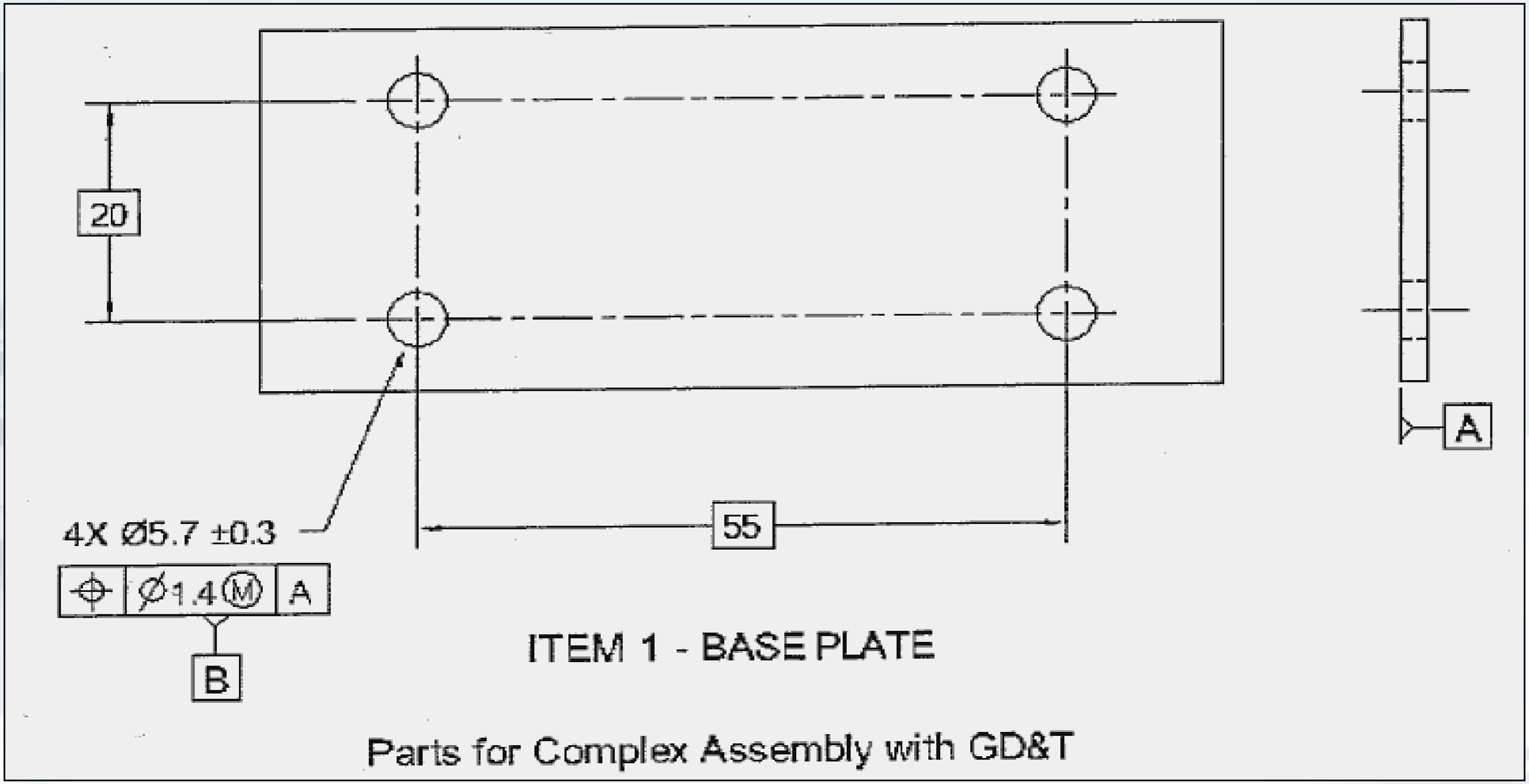


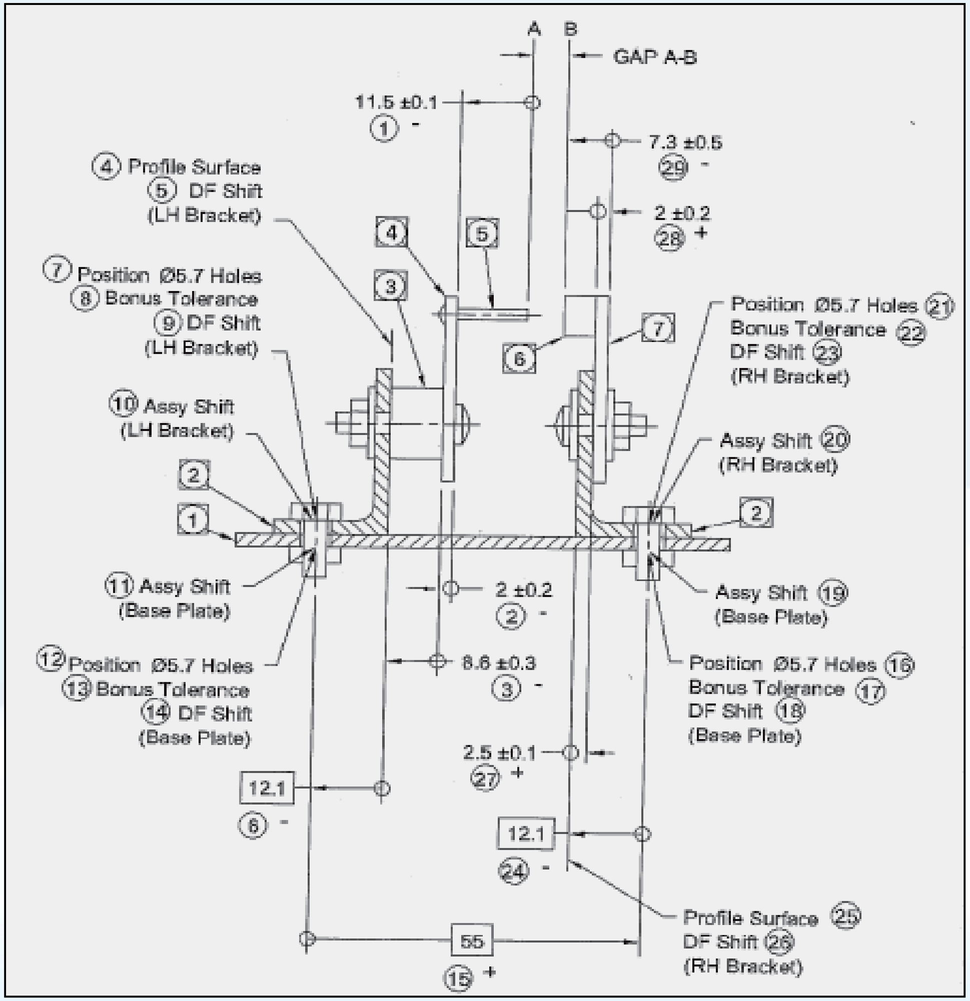
FIGURE 9.33 Complex assembly with GD&T.



Positional Tolerance Example #9.3



Positional Tolerance Example #9.3



Positional Tolerance Example #9.3

Dim No	Part No	+	-	+/-	Description
1	5		11.5	+/- 0.1	Dim: Pin Length
2	4		2	+/- 0.2	Dim: LH Plate Thickness
3	3		8.6	+/- 0.3	Standoff Thickness
4	2			+/- 0.3	Profile of Flange Face on LH Angle Brkt
5	2			+/- 1	Datum Feature Shift: ((5.7 + 0.3) - (5.7 - 0.3 - 1.4)) / 2 = +/-1
6	2		12.1	+/- 0	Dim: Flange Face - CL DFB Holes on LH Angle Brkt (Basic)
7	2			+/- 0	Position of Dia 5.7 DF_B Holes on LH Angle Brkt: N/A
8	2			+/- 0	Bonus Tolerance: N/A
9	2			+/- 0	Datum Feature Shift: N/A
10	2			+/- 1	Assembly Shift: LH Angle Brkt Holes @ LMC: 6 (H) - 4 (F) = 2 / 2 = +/-1
11	1			+/- 1	Assembly Shift: Base Plate LH Holes @ LMC: 6 (H) - 4 (F) = 2 / 2 = +/-1
12	1			+/- 0.7	Position of LH Dia 5.7 DF_B Holes on Base Plate
13	1			+/- 0.3	Bonus Tolerance: (0.3 + 0.3) / 2 = +/-0.3
14	1			+/- 0	Datum Feature Shift: N/A - DF_A not a Feature of Size
15	1	55		+/- 0	Dim: CL LH DF_B Holes - CL RH DF_B Holes on Base Plate (Basic)
16	1			+/- 0.7	Position of RH Dia 5.7 DF_B Holes on Base Plate
17	1			+/- 0.3	Bonus Tolerance: (0.3 + 0.3) / 2 = +/-0.3
18	1			+/- 0	Datum Feature Shift: N/A - DF_A not a Feature of Size
19	1			+/- 1	Assembly Shift: Base Plate LH Holes @ LMC: 6 (H) - 4 (F) = 2 / 2 = +/-1
20	2			+/- 1	Assembly Shift: RH Angle Brkt Holes @ LMC: 6 (H) - 4 (F) = 2 / 2 = +/-1
21	2			+/- 0	Position of Dia 5.7 DF_B Holes on RH Angle Brkt: N/A
22	2			+/- 0	Bonus Tolerance: N/A
23	2			+/- 0	Datum Feature Shift: N/A
24	2		12.1	+/- 0	Dim: CL DFB Holes - Flange Face on RH Angle Brkt (Basic)
25	2			+/- 0.3	Profile of Flange Face on RH Angle Brkt
26	2			+/- 1	Datum Feature Shift: ((5.7 + 0.3) - (5.7 - 0.3 - 1.4)) / 2 = +/-1
27	2	2.5		+/- 0.1	RH Angle Brkt Flange Thickness
28	7	2		+/- 0.2	Thickness of RH Plate
29	6 & 7		7.3	+/- 0.5	Thickness of RH Plate & Boss
		59.5	53.6	+/- 10	Worst Case Tolerance
				+/- 2.79	RSS Tolerance
				+/- 4.18	Adjusted RSS Tolerance (RSS * 1.5)

Positive Total	59.5		
Negative Total	-53.6		
Nominal Gap	5.9	+/- 4.18	Adjusted RSS Tolerance

Max Gap	10.08	Clearance
Min Gap	1.72	Clearance

OMNEX

Positional Tolerance Summary

- Converting positional tolerances to equal bilateral ± tolerances
- Positional tolerances are relatively easy to convert into equivalent ± location tolerances.
- The method used to convert a positional tolerance depends on the material condition modifier (RFS, MMC, or LMC) applied to the tolerance and whether the tolerance is applied to features that affect the location of other features in the Tolerance Stack up.

Composite Positional Tolerance

- The positional tolerance specified in the uppermost segment of the feature control frame represents the total allowable variation in location of the features to a datum reference frame.

- Typically the tolerance defined in the uppermost segment is used in Tolerance Stack ups.

- The tolerance zones defined in the lower segments of a composite feature control frame are not basically located to a datum reference frame— they may only be basically oriented to a datum reference frame and are basically located to each other in the case of a pattern.

Composite Positional Tolerance

- both are included and formatted in the Tolerance Stack up report the same way as a single segment positional tolerance.

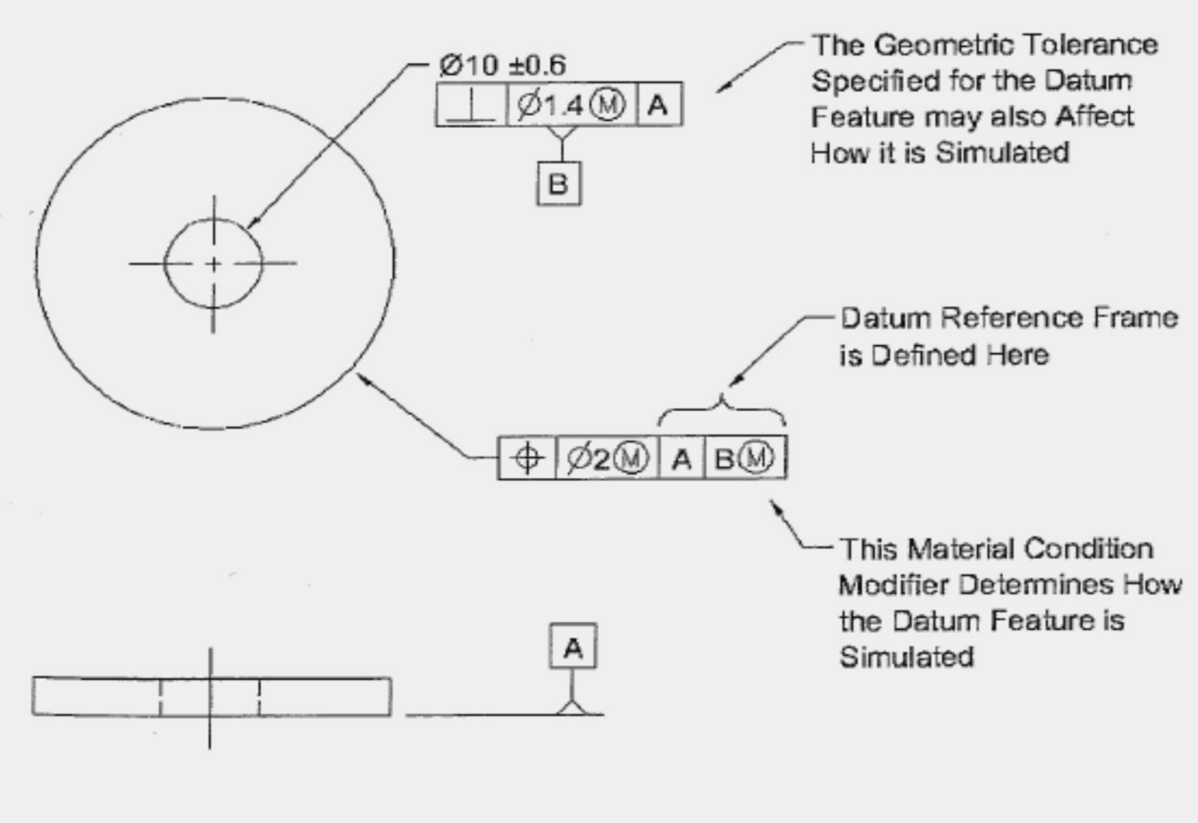
- Three lines are entered into the Tolerance Stack up report: the positional tolerance is entered on the first line, the bonus tolerance is entered on the second line, and datum feature shift is entered on the third line.

- The positional tolerance specified in a lower segment may be used in a Tolerance Stack up if the Tolerance Stack up is between features in a pattern. The positional tolerance specified in a lower segment may also be used with more advanced tolerancing techniques, such as when "simultaneous requirements" is explicitly stated

Datum Feature Shift

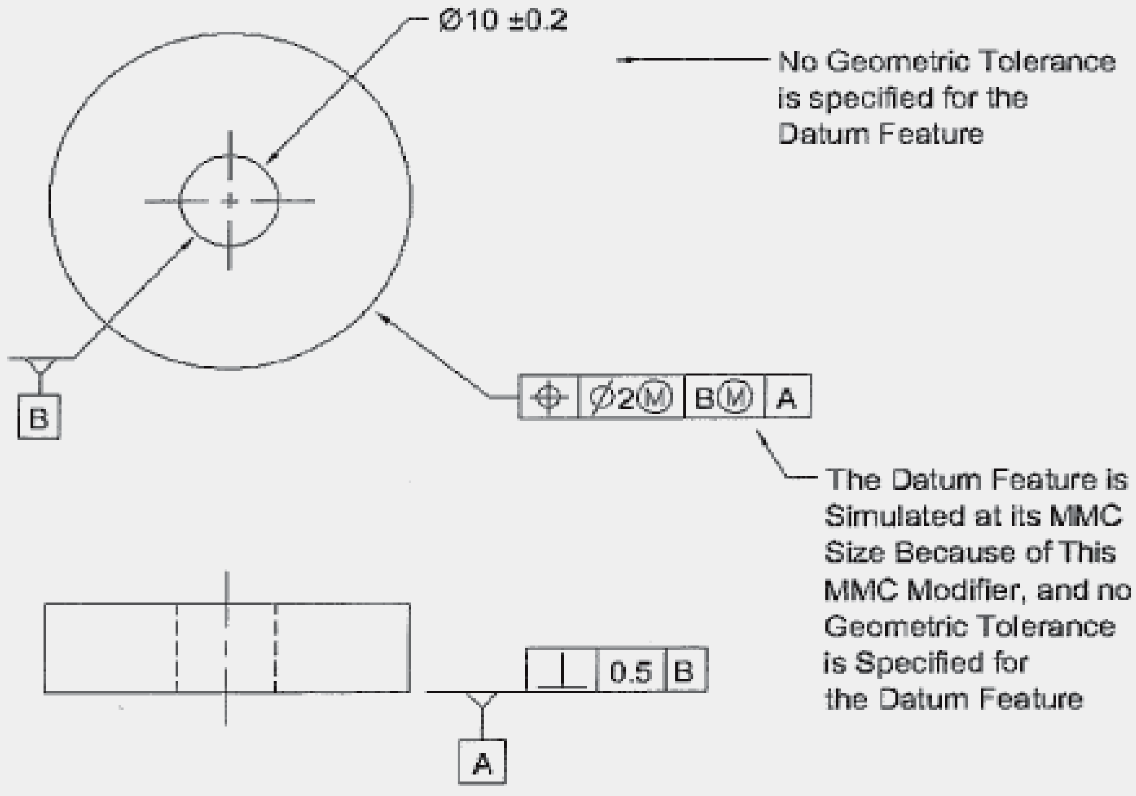
- When datum features of size are referenced at MMC or LMC, their datum feature simulators may be smaller or larger than the datum features of size, which allows the part to shift or move relative to the datum feature simulators.
- The worst-case difference in size between the datum features and their simulators is the amount of datum feature shift.
- Datum shift means the datum features can shift during the inspection process—there is not a one-to-one relationship between the datum features and the datum feature simulators.

Datum Feature Shift



Datum Feature of Size Specified at MMC

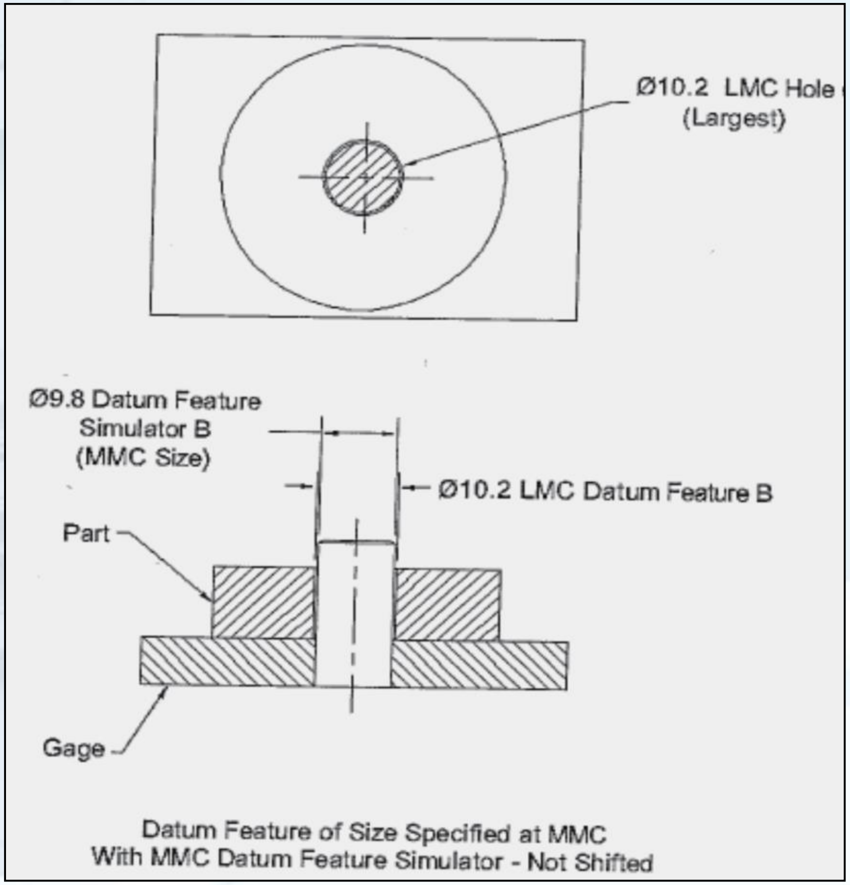
Datum Feature Shift

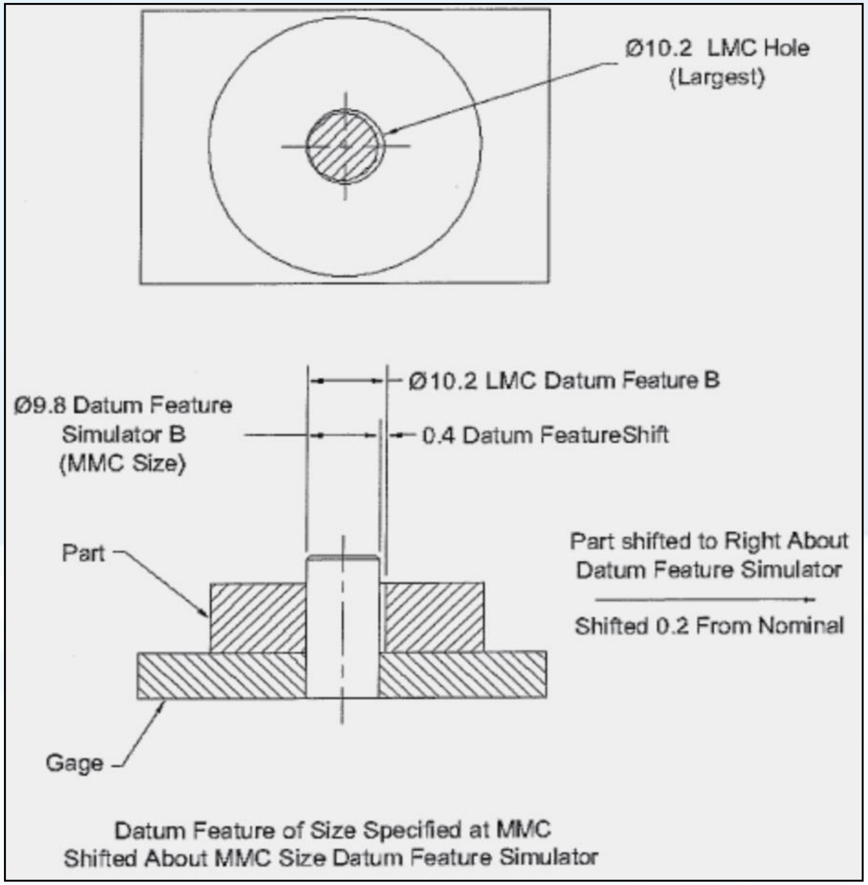


Datum Feature of Size Specified at MMC:
To Be Simulated at Its MMC Size

OMNEX
WWW.OMNEX.COM

Datum Feature Shift





No Datum Shift | **Datum Shift**

OMNEX

WWW.OMNEX.COM

Datum Feature Shift

$$
\begin{aligned}
\text{MMC size} = \; & \varnothing 10.0 \text{ nominal size} \\
& \underline{-0.2 \text{ size tolerance}} \\
= \; & \varnothing 9.8 \text{ MMC size}
\end{aligned}
$$

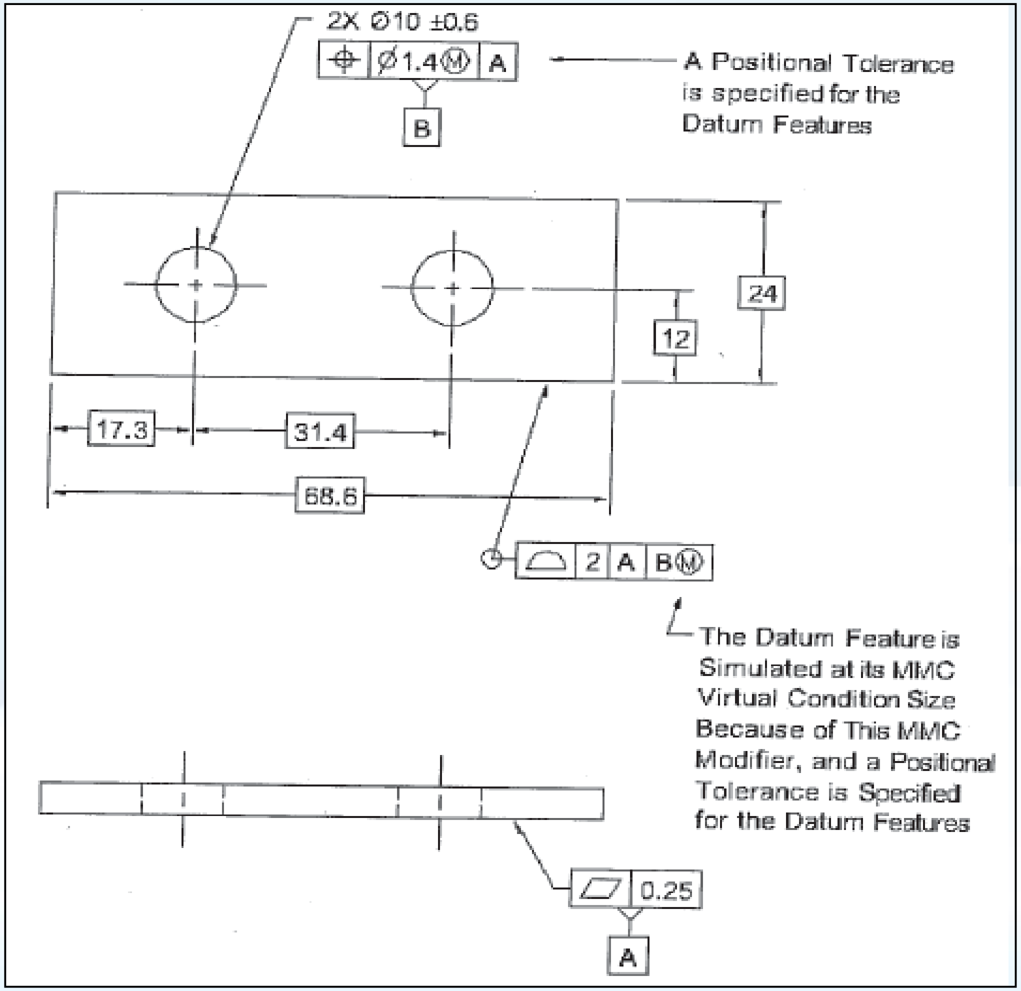
$$
\begin{aligned}
\text{LMC (largest) size of the hole} = \; & \varnothing 10.0 \text{ nominal size} \\
& \underline{+0.2 \text{ size tolerance}} \\
= \; & \varnothing 10.2 \text{ LMC size}
\end{aligned}
$$

$$
\begin{aligned}
\text{Datum feature shift} = \; & \varnothing 10.2 \text{ LMC Size} \\
& \underline{-\varnothing 9.8 \text{ MMC Size}} \\
= \; & 0.4 \text{ Datum Feature Shift}
\end{aligned}
$$

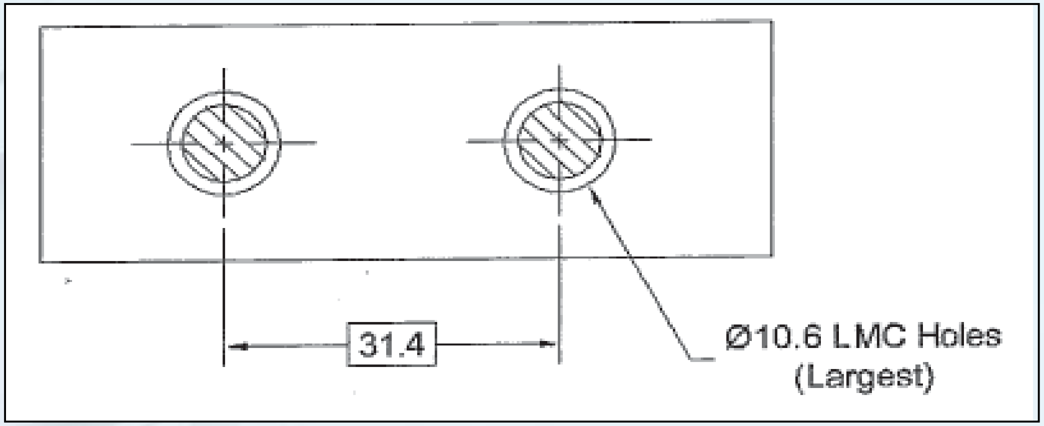
- Divide the datum feature shift by 2 $= 0.4/2 = \pm 0.2$. This is the equal bilateral $\pm$ equivalent

OMNEX

Datum Feature Shift



Datum Feature Shift



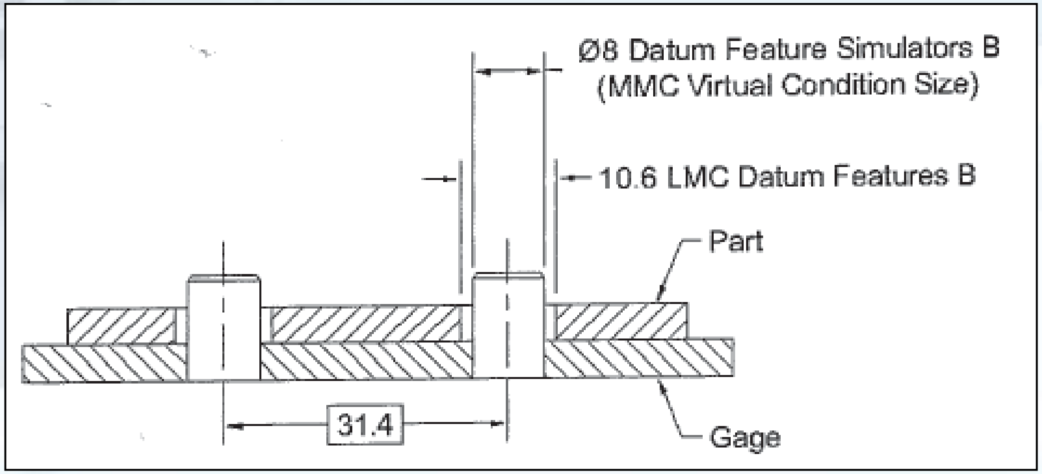


FIGURE 9.44 Datum feature shift: Datum feature of size to be simulated at MMC VC with datum feature simulator, no shift.

Datum Features of Size Referenced at MMC:

With MMC Virtual Condition Datum Feature Simulators - Not Shifted

OMNEX
WWW.OMNEX.COM

Datum Feature Shift

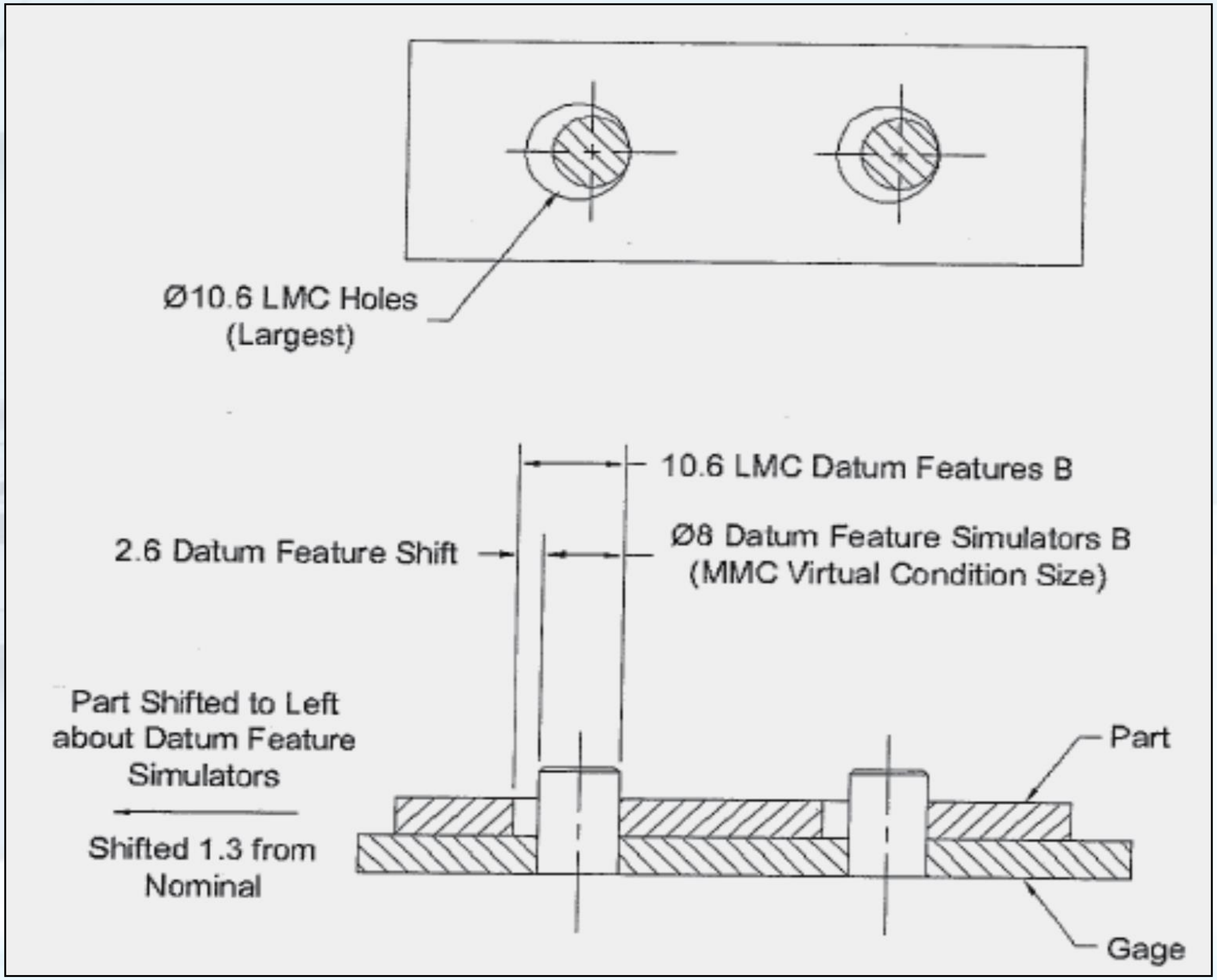


FIGURE 945 Datum feature shift: Datum feature of size to be simulated at MMC VC with datum feature simulator, shifted.

Datum Features of Size Referenced at MMC:

Shifted About MMC Virtual Condition Datum Feature Simulators

THANK YOU

Are there any Questions?

Info-in@omnex.com

WWW.OMNEX.COM