## 17.2 Limitations of Conventional Dimensions and Tolerances

The underlying issue with conventional dimensioning is that there is no standard definition of what it means, how to interpret it, or how to measure it. This is evident in the way that conventional dimensioning and tolerancing address the following:

- Origins of measurement,
- Repeatability of sizes & centers,
- Orientation and angles,
- Tolerance accumulation.

### 17.2.1 Origins of Measurement

It seems reasonable to interpret the dimensions of 450mm and 150mm in Figure 17.3 to mean that the cutout for the electrical outlet is located 450mm up the wall, and the outlet cutout is 150mm tall. Unfortunately, it is not that easy to interpret the intent of conventional dimensions. The question arises, which is the origin of measurement; from the bottom of the wall, or from the floor? Does it make a difference? Conventional dimensions are point-to-point, meaning across directly opposed points. Since the square cutout is part of the wall, one interpretation would have the measurement start at the bottom of the wall. However, if you measure from the bottom of the wall to the cutout, you must include the mouse hole at the base of the wall in your measurements (Figure 17.4a). A second interpretation could argue that you would measure from the floor up to the cutout because you stand on the floor when you reach for the switch (Figure 17.4b). Because the mouse hole extends into the floor, the point-to-point measurement would introduce an error in the measurement (Figure 17.4c). Another interpretation would be to measure from the junction of the wall and the floor, and simulate an equivalent by using a straight edge, essentially establishing a de facto origin of measurement (Figure 17.5a). A final interpretation would argue that all outlets in the room should be at the same height above the floor, no matter where in the room, so you should measure from the flat net equivalent of the entire floor (Figure 17.5b). This is not a valid dimensional interpretation because it is not point-to-point. Ironically, while this net equivalent is not a legitimate interpretation of the point-to-point specification, it does represent the design intent. Unfortunately, there is no effective way to communicate this with conventional dimensioning. Yes, the origin of measurement does make a difference if you want a single interpretation and repeatable results.



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021:  ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.

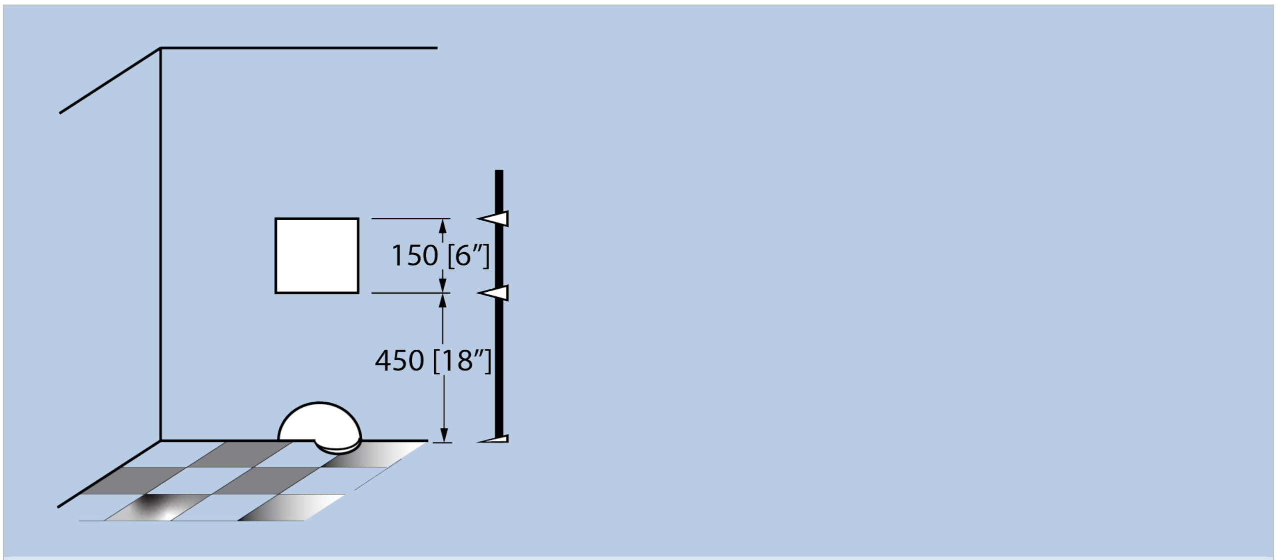


Figure 17.3 Conventional location dimensions

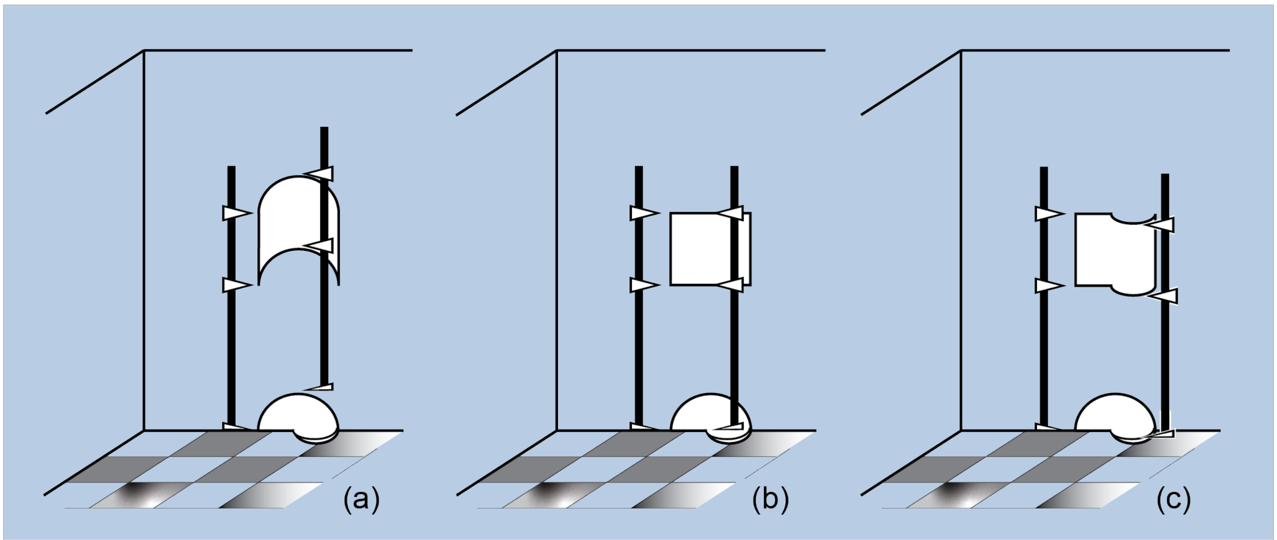


Figure 17.4 Point-to-point measurements



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021: ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.

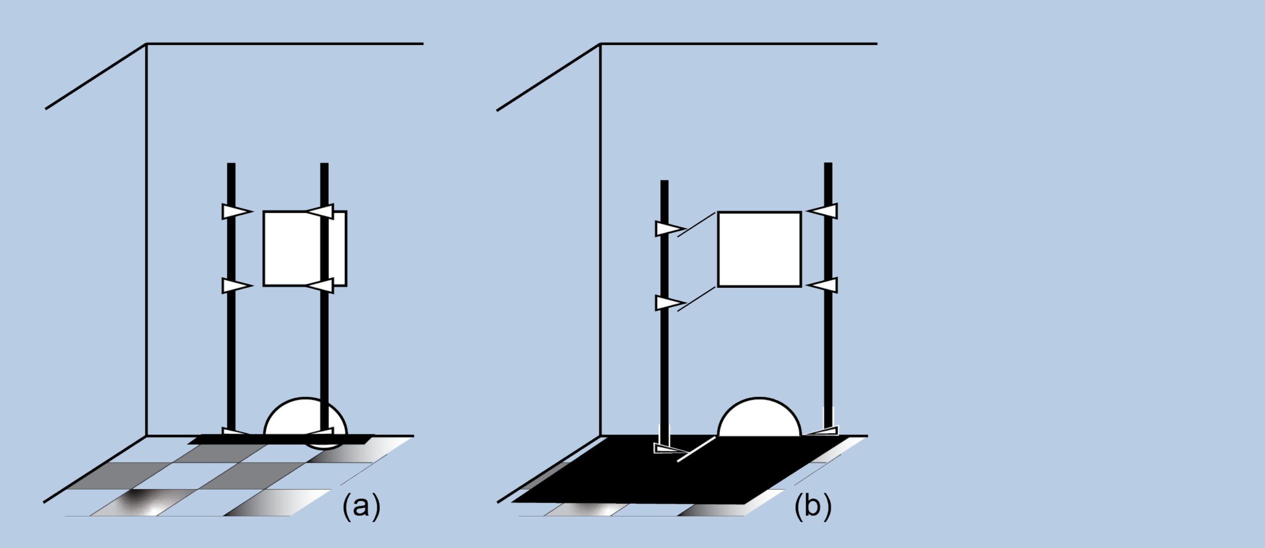


Figure 17.5 De facto origins of measurement

## 17.2.2 Non-Repeatable Sizes and Centers

In conventional dimensioning and tolerancing the sizes and centers cannot be found accurately or repeatably. Consider a simple cylindrical solid (Figure 17.6a). Common practice to measure the hole size would be to take two or more measurements of opposed points (Figure 17.6b), then average the measurements to establish a 9.8mm ***actual*** size. Note that the largest ***measured*** size is 10.3mm diameter, which is larger than the reported size of 9.8mm. Consider if this were a pin that had to precisely fit into a hole. The local or cross-sectional size is irrelevant to the fit. Instead, you need to know how large the pin is ***acting***; that is, what is the equivalent size of a cylinder of perfect form? You can visualize this equivalent or functional size as the smallest ring gauge (a perfect cylinder) that can encapsulate the pin (Figure 17.6c). Unfortunately, an averaged measurement will always change based on where you take your measurements, and will always be smaller than the functional size for a pin, or larger than the functional size for a hole.

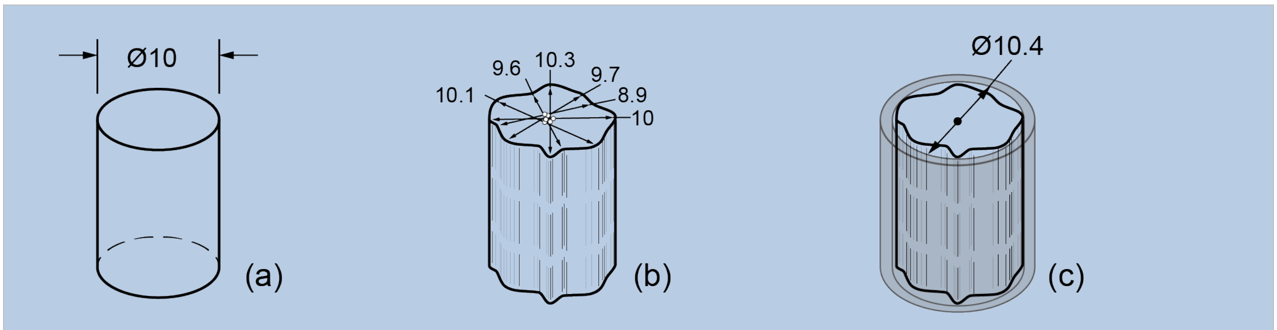


Figure 17.6 Conventional determination of size and centre

Similarly, it is common practice to determine the center of a geometry by halving a measurement between opposed points, or for a series of measurements. Unfortunately, this yields a *cloud of center points* rather than a single true center. Again, each set of opposed points will yield a different, non-repeatable center (Figure 17.6b). Functionally, the center of the equivalent perfect cylinder



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021: ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.

(Figure 17.6c) is repeatable and of importance when designing mating components. The underlying issue is that conventional dimensioning does not consider the form errors in a feature, and there are no conventional tolerances for form.

## 17.2.3 Orientation and Angles

Figure 17.7a).

Assuming that line-to-line contact would fit, the Ø10 peg should fit into a Ø10 hole that is perpendicular to the surface of a mating plate while the faces of the two plates contact fully (Figure 17.7b). No manufacturing is ever perfect, so even a perfectly-sized peg will be at an angle to the first plate's surface (Figure 17.8a). If we try to engage the Ø10 hole in the mating plate, the parts will fit together, but the plates will not mate flush (Figure 17.8b). With conventional dimensioning and inspection philosophies, the size and location for the peg would be measured, but the orientation of the peg would rarely be inspected unless it is visibly out of perpendicular with respect to the plate surface. The typical resolution for this issue is to rework the hole until it allows the peg to fully engage in the hole (Figure 17.9a), and the plate faces to mate (Figure 17.9b).

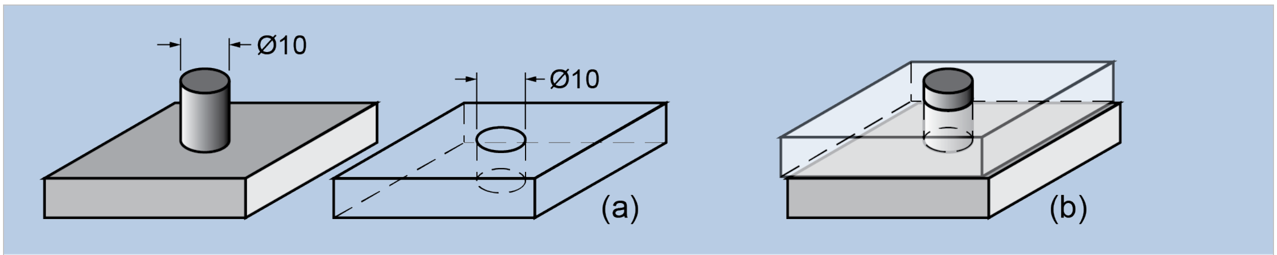


Figure 17.7 Mating with perfect boss orientation

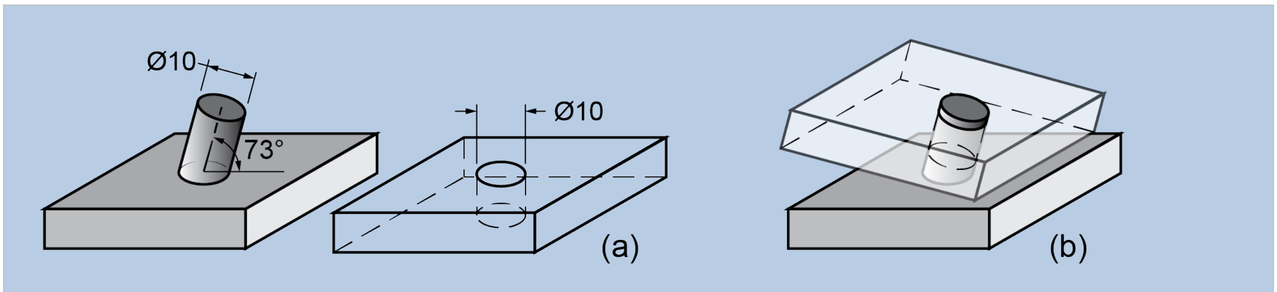


Figure 17.8 Mating with boss orientation error

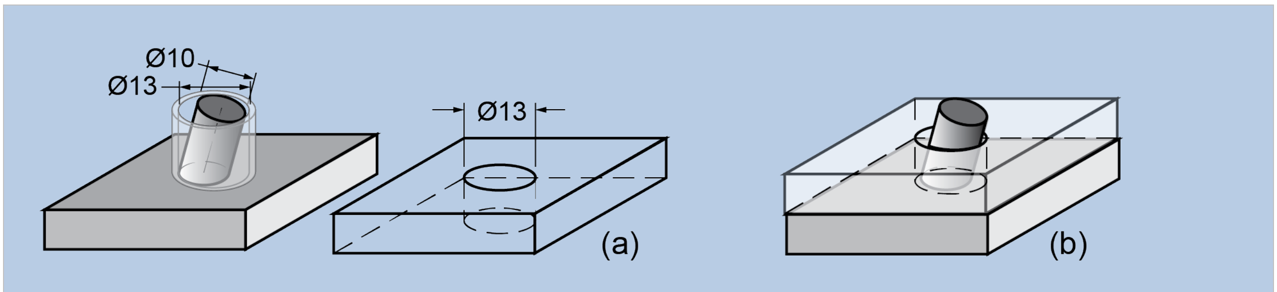


Figure 17.9 Typical mating feature adjustment to compensate for boss orientation error



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021: ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.

Angular tolerances (± degrees) present two problems of interpretation; wedge-shaped tolerance zones and how to distribute the tolerance. First, consider an included angle between two sides of a triangle (Figure 17.10). Angular tolerances create wedge-shaped tolerance zones (Figure 17.11a). Notice that the width of the tolerance zone increases as you move further away from the inflection point of the tolerance zone. This means that the longer the surface, the greater the allowable error on it. Now, consider that the toleranced angular dimension applies to all three vertices of the triangle. The result is that the inflection point of the tolerance zone wedge can be at either end of any side of the triangle (Figure 17.11b). This is a valid interpretation of the tolerance callout because no standard exists for interpretation of conventional tolerances. Furthermore, the inflection point can be anywhere along the side of the triangle, resulting in even more confusing but valid interpretations (Figure 17.11c).

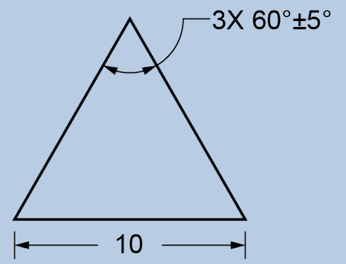


Figure 17.10 Conventional angular tolerance

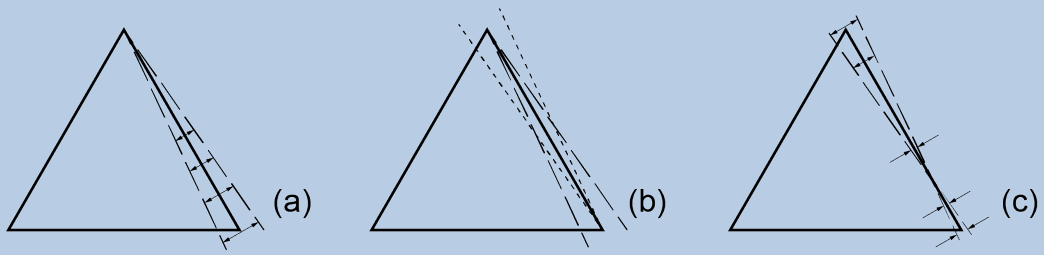


Figure 17.11 Wedge-shaped tolerance zones

Three valid interpretations for this angular callout are shown (Figure 17.12) and other interpretations may be just as valid. The difference between the interpretations shown is how the angular tolerance is distributed. The tolerance can be assigned to one side or the other. The tolerance could be distributed equally or unequally between the two sides. Again, there is no standard by which to interpret this callout.



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021: ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.

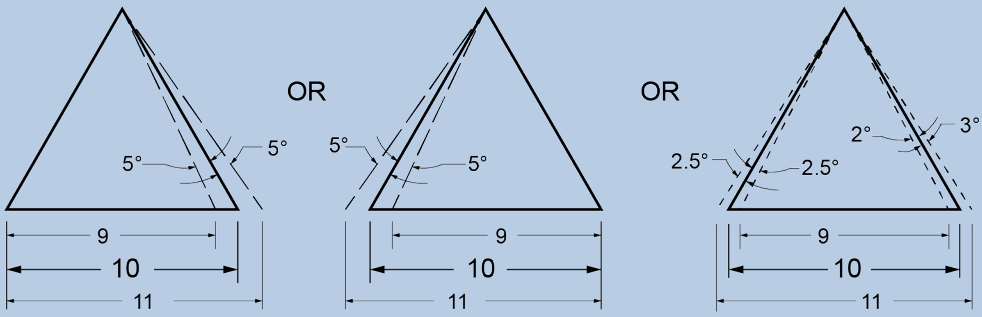


Figure 17.12 Valid interpretations for distribution of an angular tolerance

## 17.2.4 Tolerance Accumulation

With conventional dimensioning and tolerancing practices, tolerance accumulation is sensitive to how you layout the dimensions as well as the tolerances applied to each dimension. Three dimensional layouts are shown in Figure 17.13, Figure 17.15 ,Figure 17.17 to demonstrate the issues of tolerance accumulation. For each layout, the tolerance zone on each feature in the dimension path is provided for visualization (Figure 17.14, Figure 17.16,Figure 17.18). The tolerance (A, B, C respectively) on the length of the center horizontal section will be determined.

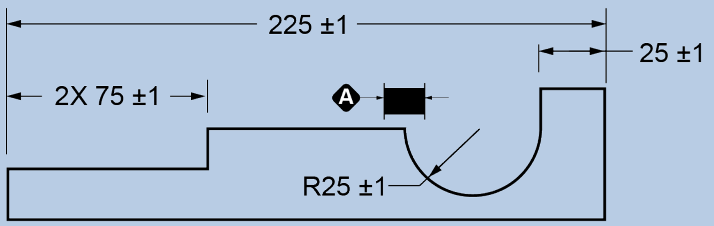


Figure 17.13 Dimension layout A

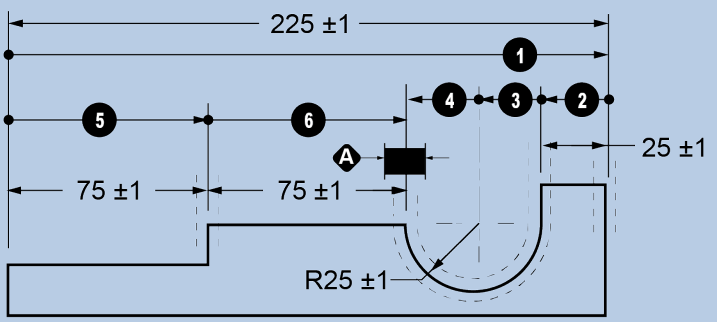


Figure 17.14 Tolerance zones and vectors for layout A



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021: ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.

For Layout A (Figure 17.13), there are two dimension-vector-paths from the left side of the part to the right end of the center horizontal segment; these are designated $A_{1\text{-}2\text{-}3\text{-}4}$ and $A_{5\text{-}6}$ in Figure 17.14. For tolerance analyses, tolerance values add together and do not cancel each other out.
Tolerance $A_{1\text{-}2\text{-}3\text{-}4} = (\pm1)_{225} + (\pm1)_{25} + (\pm1)_{R25} + (\pm1)_{R25} = \pm4$.
Tolerance $A_{5\text{-}6} = (\pm1)_{75} + (\pm1)_{75} = \pm2$. Clearly the results conflict, which means that the specification is invalid.

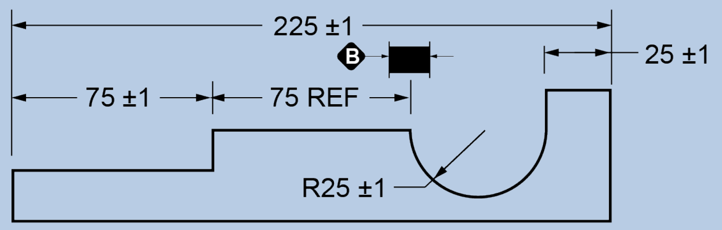


Figure 17.15 Dimension layout B

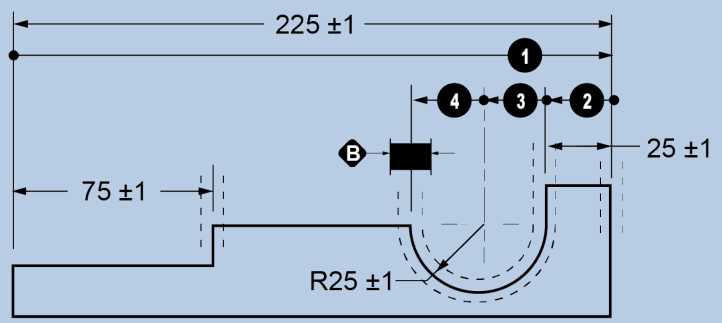


Figure 17.16 Tolerance zones and vectors for layout B

For Layout B (Figure 17.15), the length of the center segment is provided as a reference dimension; therefore, the tolerance applicable to the location of the right-end of the segment is entirely based on chain $B_{1\text{-}2\text{-}3\text{-}4}$. Tolerance $B_{1\text{-}2\text{-}3\text{-}4} = (\pm1)_{225} + (\pm1)_{25} + (\pm1)_{R25} + (\pm1)_{R25} = \pm4$ (Figure 17.16).

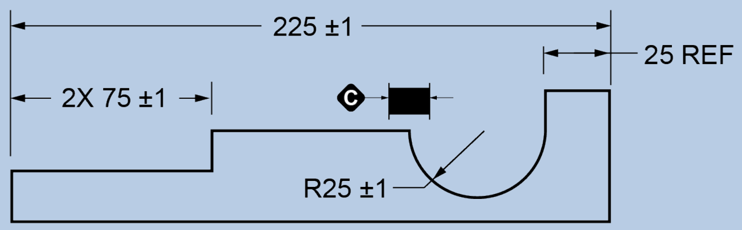


Figure 17.17 Dimension layout C



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021: ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.

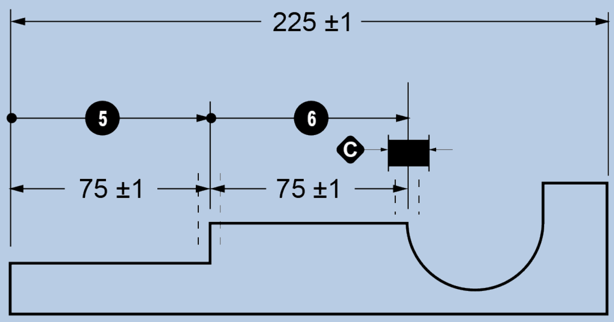


Figure 17.18 Tolerance zones and vectors for layout C

For Layout C (Figure 17.17), the length of the far-right horizontal section is provided as a reference dimension. The tolerance applicable to the location of the right-end of the center segment is $C_{1\text{-}2} = (\pm 1)_{75} + (\pm 1)_{75} = \pm 2$ (Figure 17.18).
Though both dimensional layouts B and C are valid, comparing tolerances B and C establishes that the feature's tolerance is dependant on the dimension layout.



Content from Injection Mold Design Handbook, B. Catoen, Chapter 17: Dimensioning and Tolerancing by Jim Sykes, Carl Hanser Publishing, Munich, 2021: ISBN 978-1-56990-815-0, eBook ISBN 978-1-56990-816-7.