Tolerance of Position
Part 1

Alessandro Anzalone, Ph.D.

Hillsborough Community College, Brandon Campus
Tolerance of Position, Part 1

Sections:
1. TOP General Information
2. TOP Theories
3. Common TOP RFS Applications
4. Inspecting TOP Applied at RFS
5. Common TOP MMC Applications
6. Inspecting TOP Applied at MMC
7. Summary
8. References
Definitions and Conventions

**True position** is the *theoretically exact location of a FOS* as defined by basic dimensions. A **tolerance of position (TOP) control** is a **geometric tolerance that defines the location tolerance of a FOS from its true position**. When specified on an RFS basis, a TOP control defines a tolerance zone that the center, axis, or centerplane of the AME of a FOS must be within. When specified on an MMC or LMC basis, a TOP control defines a boundary—often referred to as the virtual condition—that may not be violated by the surface or surfaces of the considered feature.

![TOP Feature Control Frames](image)

**FIGURE 8-2** TOP Feature Control Frames
TOP General Information

FIGURE 8-3 TOP Tolerance Zone
TOP General Information

Basic dimensions define the true position of the tolerated FOS relative to the datums referenced in the feature control frame. In certain cases, the basic dimensions in a TOP application are not specified; they are implied. There are two types of implied basic dimensions common in TOP applications:

1. Implied basic 90° angles—A 90° basic angle applies where centerlines of features in a pattern (or surfaces shown at right angles on a drawing) are located and defined by basic dimensions and no angle is specified.

2. Implied basic zero dimension—Where a centerline or centerplane of a FOS is shown in line with a datum axis or centerplane, the distance between the centerlines or centerplanes is an implied basic zero.
The 90° angles for the holes are an implied basic 90° from datum plane A.

The centerline of this diameter is an implied basic zero from datum axis A.

FIGURE 8-4 Implied Basic 90° Angles and Implied Basic Zero Dimension
TOP General Information

Advantages of TOP
In comparison with coordinate tolerancing, TOP offers many advantages. Six important advantages are that TOP:

1. Provides larger tolerance zones; cylindrical tolerance zones are 57% larger than square zones
2. Permits additional tolerances—bonus and datum shift
3. Prevents tolerance accumulation
4. Permits the use of functional gages
5. Protects the part function
6. Lowers manufacturing costs
TOP General Information

Coordinate Tolerancing

TOP Tolerancing

Coordinate tolerance zone 0.2 square

TOP tolerance zone \( \varnothing 0.28 \)

Cylindrical zone allows 57% more tolerance for the hole

FIGURE 8-5 Comparison of Coordinate Tolerancing and TOP Tolerance Zones
TOP General Information

Types of Part Relationships that Can be Controlled with TOP
TOP is commonly used to control four types of part relationships:

1. The distance between features of size, such as holes, bosses, slots, tabs, etc.
2. The location of features of size (or patterns of features of size) such as holes, bosses, slots, tabs, etc.
3. The coaxiality between features of size
4. The symmetrical relationship between features of size
<table>
<thead>
<tr>
<th>Modifier</th>
<th>Commonly used in these functional applications</th>
<th>Bonus or datum shift permissible</th>
<th>Relative cost to produce and verify</th>
</tr>
</thead>
</table>
| M        | • Assembly  
          • Location of a non-critical FOS | Yes                             | Lowest                           |
| L        | • Minimum wall thickness  
          • Minimum part distance  
          • Minimum machine stock  
          • Alignment | Yes                             | Greater than MMC; less than RFS |
| RFS      | • To control a symmetrical relationship  
          • When the effects of bonus or datum shift will be detrimental to the function of the part  
          • To control minimum machine stock.  
          • Centering  
          • Alignment | No                              | Highest                          |

**FIGURE 8-6** Guide for Selecting Modifiers in TOP Controls Based on Product Function
TOP Theories

Two theories can be used to visualize the effects of a TOP control:

1. The virtual condition boundary theory—A theoretical boundary limits the location of the surfaces of a FOS.
2. The axis theory—The axis (or centerplane) of a FOS must be within the tolerance zone.

Both theories are useful and—in most cases—equivalent. However, the axis theory is most common in RFS TOP applications, and the boundary theory is most common in MMC tolerance of position applications.
TOP Theories

VC = MMC - TOP tol value
\( \varnothing 3.8 = \varnothing 4.0 - 0.2 \)

Hole location is limited by the theoretical boundary

Orientation variation is limited by the theoretical boundary

The theoretical boundary is a basic 90° to datum plane A

FIGURE 8-7 TOP Virtual Condition Boundary Theory (Internal FOS)
TOP Theories

FIGURE 8-8 TOP Virtual Condition Boundary Theory (External FOS)
TOP Theories

FIGURE 8-9 TOP Axis Theory (Internal FOS)
TOP Theories

FIGURE 8-10 TOP Axis Theory (External FOS)
Common TOP RFS Applications

FIGURE 8-11 Hole Controlled with TOP Using RFS
Common TOP RFS Applications

FIGURE 8-12 Pattern of Holes Controlled with TOP Using RFS
The axis (of the AME) of the toleranced diameter (RFS) must lie within the tolerance zone cylinder centered about datum axis A.

FIGURE 8-13 Coaxial Diameters Controlled with TOP (RFS)
Inspecting TOP Applied at RFS

FIGURE 8-14 Inspecting TOP Applied
# Common TOP MMC Applications

<table>
<thead>
<tr>
<th></th>
<th>MMC</th>
<th>RFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tolerance zone</td>
<td>A boundary zone</td>
<td>An axis zone (or centerplane)</td>
</tr>
<tr>
<td>Bonus tolerance permissible</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Gaging</td>
<td>Functional (fixed)</td>
<td>Variable</td>
</tr>
</tbody>
</table>

**FIGURE 8-15** TOP MMC/RFS Comparison
Common TOP MMC Applications

FIGURE 8-16 Hole Location Controlled with TOP Using MMC
Common TOP MMC Applications

FIGURE 8-17 Pattern Location Controlled with TOP MMC
## Common TOP MMC Applications

### Coaxial Diameter Applications

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Method</th>
<th>Example</th>
<th>Max Permissible Bonus/Datum Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opposed Diameters</strong></td>
<td>Use one diameter to establish the datum axis. Locate the second diameter relative to the datum axis.</td>
<td><img src="image" alt="Example" /></td>
<td>Bonus = 0.2, Datum shift = 0.6</td>
</tr>
<tr>
<td><strong>Non-Opposed Diameters</strong></td>
<td>Implied self-datum or Specified self-datum</td>
<td><img src="image" alt="Example" /></td>
<td>Bonus = 0.04, Datum shift = 0</td>
</tr>
<tr>
<td><strong>(Same Size)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non-Opposed Diameters</strong></td>
<td>Use both diameters as datums, and relate each diameter to the common axis.</td>
<td><img src="image" alt="Example" /></td>
<td>Bonus = 0.2, Datum shift = 0</td>
</tr>
<tr>
<td><strong>(Different Size)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8-18** Coaxial Diameters Controlled with TOP MMC
Common TOP MMC Applications

**QUESTIONS**

1. Is the TOP control applied to a FOS?
   - Yes: Continue with question 3.
   - No: Continue with question 2.

2. Are datum references specified? Also, the datum references must be logical for the type of part and tolerated FOS.
   - Yes: Continue with question 3.
   - No: This is an ILLEGAL specification of a TOP control.

3. Are basic dimensions used to establish the true position of the tolerated feature relative to the datums referenced?
   - Yes: This is a LEGAL specification of a TOP control.
   - No: Continue with question 4.

4. Is the following modifier specified?
   - Yes: This is a LEGAL specification of a TOP control.
   - No: Continue with question 2.

FIGURE 8-19 Legal Specification Flowchart for Tolerance of Position
Inspecting TOP Applied at MMC

A TOP applied at MMC can be verified in a number of ways. Variable gages, open inspection, CMM, and functional gaging are all common methods of verifying parts dimensioned with TOP. In this text, we will explain the use of functional gaging.

**Functional Gage**

A **functional gage** is a gage that **verifies functional requirements of part features** as defined by the geometric tolerances. For example, if holes on a part are intended to fit over studs of a mating part, a function of the holes would be to assemble over the studs. To verify the location of the holes, a functional gage that simulates the studs of the mating part could be used.

A functional gage does not provide a numerical reading of a part parameter. A functional gage often provides a “pass” or “fail” assessment of a part feature. A functional gage is often referred to as an attribute gage or a fixed gage because it checks attributes of a part FOS (location and orientation).
Inspecting TOP Applied at MMC

Cartoon Gage

Often, it is desirable to analyze a max. or mm. distance on a part in the design stage. Since a functional gage defines the extreme limits of a part FOS, it can be used as a simple method to analyze part distances. Because the functional gage does not exist in the design stage, a cartoon gage is used. A cartoon gage is a sketch of a functional gage. A cartoon gage defines the same part limits that a functional gage would, but it does not represent the actual gage construction of a functional gage.

The steps for drawing a cartoon gage are described below:

1. Determine the size of the gage feature. Using the MMC of the tolerated feature, subtract (or add, for an external FOS) the TOP tolerance value to find the virtual condition or gage size of the tolerated FOS.

2. Establish the simulated datums (surfaces or axes) for the datums referenced in the TOP callout.

3. Locate the gage features relative to their respective datums. The basic dimensions from the product drawing are used to locate the gage features relative to the datums.
Inspecting TOP Applied at MMC

**STEP 1**
Determine the size of the gage feature.

**STEP 2**
Establish the simulated datums.

**STEP 3**
Locate the gage features relative to their respective datums.

FIGURE 8-20 Steps for Drawing a Cartoon Gage
Inspecting TOP Applied at MMC

FIGURE 8-21 Cartoon Gage for a Coaxial Diameter TOP Application
## Summary

<table>
<thead>
<tr>
<th>TOP control</th>
<th>Datum reference required</th>
<th>Can be applied to a Surface</th>
<th>Can be applied to a FOS</th>
<th>Can affect WCB</th>
<th>Can use ( \circ ) or ( \bullet ) modifier</th>
<th>Can be applied at RFS</th>
<th>Overrides Rule #1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes*</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes**</td>
<td>No</td>
</tr>
</tbody>
</table>

* Coaxial diameter exception  
** Is automatic per Rule #2

**FIGURE 8-22  Summarization of TOP**
References

http://www.tarleton.edu/~tbarker/2153/Notes_Handouts/CHAP12_GD&T.pdf
http://www.etinews.com/tip_mnth_rulespostol.html
http://www.efunda.com/designstandards/gdt/2D_bonus_tol.cfm
http://www.jjjtrain.com/vms/geotol_true_pos_tol_zone/geotol_tp_00.html
http://www.toolingu.com/definition-350310-12380-position-tolerance.html