ASME Y14.5M-1994 Dimensioning & Tolerancing

Zeiss / Applied Geometrics, Inc.
Zeiss

- Carl Zeiss is one of the world's leading enterprises in industrial metrology.
- Carl Zeiss has been an innovative technology leader in optics and precision engineering for more than 150 years.
- It is our goal to provide optimum quality and maximum precision at all times, while ensuring that our customers are given excellent value for their money.
Applied Geometrics, Inc.

Applied Geometrics, Inc. is committed to train manufacturing industry’s personnel how to realize a higher return on investment by utilizing a standardized, concise, internationally accepted language of engineering expression.
HERE IS A DRAWING OF A PIN

They sent this drawing of a pin to two suppliers:

Supplier A / Supplier B

All of the pins from Supplier A fit into their mating parts.
Some of the pins from Supplier B would not fit into their mating parts.
The pins that did not fit were inspected and found to be within their size tolerance.

WHY DON’T THEY FIT?
THEY WOULD NOT FIT INTO THEIR MATING PARTS BECAUSE THEY WERE BENT.

The local size was within tolerance, but a deviation form kept them from fitting inside their mating parts.
WHAT WAS THE DIFFERENCE BETWEEN THE WAY SUPPLIER “A” AND SUPPLIER “B” WERE INTERPRETING THE DRAWING?

Supplier A was taking into account both the effect of local size and form deviation.
Supplier B was only considering local size.

Multiple interpretations of the drawing resulted in inconsistent results.
Interchangeability could not be guaranteed.

By definition it had to be decided whether or not size should be related to form or not.

MIL Standard 8 put into use what we now call, “Rule No. 1”.
Mill Std. 8 1949
Established Rule #1

Unless otherwise specified, the limits of size of an individual feature of size control the form of the feature as well as the size.

Mil Standard 8
Size tolerance imposes an equal form tolerance unless otherwise specified.

One interpretation!

American National Standards Institute
Group of industry professionals that thought it would be good to standardize the civilian manufacturing as well.

ANSI Y14.5-1966
ANSI Y14.5-1973
ANSI Y14.5M-1982
ASME Y14.5M-1994

This is the current standard in use in the USA today.

The standard gives you more tools and vocabulary to fully describe the functional relationships of the features of a part.
The “Feature Control Frame” is a fundamental GD&T “building block.”

What does it do?

Where would you look for the feature control frame?

What other information can I find in the feature control frame?
Spherical Diameter Symbol

The spherical diameter symbol was not defined as a tolerance zone shape until the 1994 standard.
Decoding a Feature Control Frame
(5 Questions)

1) What is the **size** of the tolerance zone?
2) What is the **shape** (**form**) of the tolerance zone?
3) What is **orientation** of the tolerance zone?
4) What is the **location** of the tolerance zone?
5) What must **lie within** the tolerance zone?

First four Questions are regarding the tolerance zone.

The fifth Question is by definition in the standard.

e.g. If I am controlling a hole, the **axis** of the hole must fall within the position tolerance zone in order to meet the requirements of the feature control frame.
Decoding a Feature Control Frame

Each of the answers for five decoding questions can be found in the feature control frame, combined with the Basic dimensions, Datum Feature Symbols on the drawing and definitions in the Y14.5 standard.
Composite FCF’s allow the designer to specify a less restrictive tolerance for a pattern of features than for the features within the pattern to each other. For example, a pattern of holes may have a relatively tight location/orientation requirement to each other for the mating part to assemble with them 100% of the time. That PATTERN of holes, however, may be able to “float” as a group to a greater amount without adversely affecting performance or assembleability.

Note: Some former practices (i.e. prior to the 1982 standard), allowed the mixing of plus/minus type tolerances with the Position feature control frame in order to accomplish this same design requirement. This practice is no longer allowed. Basic dimensions must be specified from the datums referenced out to the considered features.
The top tier, or “PLTZF,” of the Composite FCF acts exactly the same as any other single-line Position FCF.
The bottom tier, or “FRTZF,” of the Composite FCF has certain restrictions placed on it compared to other single-line FCF’s. The datum references in the FRTZF are only allowed to reduce ROTATIONAL degrees of freedom, NOT TRASLATIONAL. In other words, the basic dimensions on the print from the datum references can only control orientation, not location. The only location control invoked by the FRTZF is the location of one feature to the other within the pattern.

How does one derive the tolerance value in the FRTZF?
Composite FCF PLTZF & FRTZF (Two Datums)

The only difference in drafting from this example compared to the previous one is that there are two datum features referenced in the FRTZF here, where only one datum reference existed in the previous example. The PLTZF is exactly the same.
Composite PLTZF

THE PLTZF CONTROLS THE LOCATION OF THE PATTERN TO THE SPECIFIED DATUMS REFERENCED IN THE UPPER ENTRY OF THE FEATURE CONTROL FRAME.

The PLTZF looks the same as in the last example, and it IS.
The FRTZF in this example has two datum references, but the rules are still the same as before. The FRTZF datum references are only allowed to eliminate ROTATIONAL degrees of freedom. Therefore, the orientation and location of the tolerance zones TO EACH OTHER defined by this FRTZF is always 1.000 inch apart in one direction and 1.500 inches apart in the other. The group of tolerance zones must also remain ORIENTED relative to datum B.

NOTE that the group of 4 holes is not being LOCATIONALLY controlled by the FRTZF relative to datum B – only the ORIENTATION (i.e. no basic dimension from B for the control provided by the tolerance in the FRTZF).

Is there any location control on these 4 holes relative to B? If so, how much? If not, why not?
Two Single Segment FCF

Note the difference in drafting between this specification and the last example.
Two Single Segment FCF
(TOP TIER)

Again, the top tier is exactly the same as any other single-line FCF. The definition and meaning of this FCF is exactly the same for all three examples.

The orientation and location of the tolerance zones is being defined by this FCF.
The difference between this example and the last Composite FCF example is that the lower tier of the Two Single-Segment FCF is also exactly the same as any other FCF. It is allowed to eliminate both translational and locational degrees of freedom.

Why would one ever wish to specify this type of control versus the Composite?
<table>
<thead>
<tr>
<th>HOLE</th>
<th>DIMENSION</th>
<th>MMC HOLE SIZE</th>
<th>POSITION TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>( \phi )</td>
</tr>
<tr>
<td>HOLE 1</td>
<td>1.000</td>
<td>1.000</td>
<td>0.528</td>
</tr>
<tr>
<td>ACTUAL</td>
<td></td>
<td></td>
<td>*ALLOWABLE POS TOL</td>
</tr>
<tr>
<td></td>
<td>DEVIATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOLE 2</td>
<td>PER DRAWING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACTUAL</td>
<td></td>
<td></td>
<td>*ALLOWABLE POS TOL</td>
</tr>
<tr>
<td></td>
<td>DEVIATION</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2x \( \phi_{0.530}^{+0.008}_{-0.002} \)
\( \odot \phi_{0.014}^{+M}{A}{B}{C} \)
Hole #1 is per print since the actual location of its axis lies within the specified tolerance zone.
Hole #2 is per print because the actual location of its axis lies within the total available position tolerance zone.

Note that hole #2 is per print only after considering the extra tolerance allowed by the MMC specification in the Feature Control Frame.
If we decode this composite feature control frame one tier at a time, we see that there are two tolerance zones created for each hole's axis. The tolerance zones defined by the top tier (PLTZF) are completely fixed in their respective locations due to the elimination of all six degrees of freedom per the DRF.

The tolerance zones defined by the lower tier (FRTZF) are fixed in location relative to each other (and orientation to datum A), but are free to rotate and translate as a group relative to datums B & C.
<table>
<thead>
<tr>
<th>HOLE 1</th>
<th>DIMENSION</th>
<th>MMC HOLE SIZE</th>
<th>POSITION TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PER DRAWING X</td>
<td>1.000</td>
<td>2.500</td>
</tr>
<tr>
<td></td>
<td>ACTUAL</td>
<td>1.018</td>
<td>2.483</td>
</tr>
<tr>
<td></td>
<td>DEVIATION</td>
<td>.018</td>
<td>-.017</td>
</tr>
<tr>
<td>HOLE 2</td>
<td>PER DRAWING X</td>
<td>3.000</td>
<td>2.500</td>
</tr>
<tr>
<td></td>
<td>ACTUAL</td>
<td>3.0185</td>
<td>2.4825</td>
</tr>
<tr>
<td></td>
<td>DEVIATION</td>
<td>.0185</td>
<td>-.0175</td>
</tr>
<tr>
<td>HOLE 3</td>
<td>PER DRAWING X</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>ACTUAL</td>
<td>1.0178</td>
<td>.9831</td>
</tr>
<tr>
<td></td>
<td>DEVIATION</td>
<td>.0178</td>
<td>-.0169</td>
</tr>
<tr>
<td>HOLE 4</td>
<td>PER DRAWING X</td>
<td>3.000</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>ACTUAL</td>
<td>3.0178</td>
<td>.9828</td>
</tr>
<tr>
<td></td>
<td>DEVIATION</td>
<td>.0178</td>
<td>-.0172</td>
</tr>
</tbody>
</table>

*ALLOWABLE POS TOL |

```
Inspection data and calculation results
```
Here are the “True Positions” of the four holes (Basic Dimension locations), along with the ACTUAL locations of the axes of the four holes (plotted on a magnified scale).
Here are the tolerance zones defined by the PLTZF (top tier).

Note that each zone is its own size based on the FCF specification, including the extra tolerance afforded to it by the MMC modifier in the FCF.
When we superimpose all of our data, we can see that the holes’ axes do not fall within their respective tolerance zones for the PLTZF. They do not meet the print specifications for the PLTZF-defined zones. They do not fall into their respective zones for the FRTZF either, until we consider the mobility allowed by the DRF of the FRTZF.

In other words, the FRTZF tolerance zones are free to move (translate AND rotate) relative to datums B & C since those datum references are not called out in the FRTZF.

Note that if datum B were called out as a secondary datum reference in the DRF of the FRTZF, the tolerance zones defined by the FRTZF would still be allowed to TRANSLATE relative to datums B & C, but not ROTATE.
Here is one possible location of the FRTZF-defined tolerance zones.
Here is another possible location of the FRTZF-defined tolerance zones.
Yet another possible location of these zones....
And another possible location of the zones….

Notice that these four holes’ axes were almost perfectly located to each other, thus they are per print for the FRTZF specification.
This is a “Feature Control Frame”.

Where would you look for the feature control frame?

What information can I find in the feature control frame?

Material condition modifiers can be found in two different places in the feature control frame. What is the same, and what is different about the two MMC symbols in the example above?
So how does the datum feature MMC modifier work?
Considered feature bonus tolerance is realized on each considered feature individually, based on that considered feature’s AMS.
Considered Feature Bonus Tolerance
Gives “MORE TOLERANCE” to Each Individual Considered Feature

Both Features at MMC
AMS=.490 diameter
Worst Case Position

Suppose these two considered features were at their MMC AMS of .490 diameter.
Considered Feature Bonus Tolerance Gives “MORE TOLERANCE” to Each Individual Considered Feature

Features at MMC
AMS=.490 diameter
.017 off True Position

If these .490 diameter holes were .017 off of their respective True Positions, then they would not meet the print requirements.

Notice that the datum feature’s AMS is at its MMC size.
Considered Feature Bonus Tolerance
gives \textbf{“MORE TOLERANCE”} to each individual considered feature.

Features at LMC size
AMS=.510 diameter
.020 “Bonus Tol.”

Datum Feature at MMC
AMS=.730 diameter

If the considered features’ AMS were increased to the LMC size, then each considered feature’s tolerance zone would increase from the .014 diameter in the FCF to the .034 diameter and would just barely meet the print requirements.

Notice that the AMS of the datum feature is still at its MMC size.
So how does the datum feature MMC modifier work?
Datum Feature Bonus Tolerance Gives “MOBILITY TOLERANCE” for the Pattern of Features as a Group.

Features at LMC size
AMS=.510 diameter
.017 off True Position

Datum Feature at MMC
AMS=.730 diameter

Suppose we have the same LMC-sized AMS for each of the considered features, and they are located off of their respective True Positions by the .017 as before.
Bonus “MOBILITY TOLERANCE” is NOT Simply Added to the Tolerance Value

Features at LMC size AMS=.510 diameter .037 off True Position

Datum Feature at MMC AMS=.730 diameter

Now we will imagine that we have pushed these considered features away from each other until their actual positions are .037 off of their respective True Positions.

With the datum feature at an AMS of the MMC size, this part does not meet the print requirements.
Bonus “MOBILITY TOLERANCE” is NOT Simply Added to the Tolerance Value

Features at LMC size AMS=.510 diameter .037 off True Position

Datum Feature at LMC AMS=.770 diameter

If, however, we increase the AMS of the datum feature to its LMC size, then we gain mobility of the coordinate system. Therefore we should be able to make these two considered features meet the requirements – right???
Bonus “MOBILITY TOLERANCE” is NOT Simply Added to the Tolerance Value

If we shift the coordinate system to its extreme in one direction, we can make the top considered feature meet its print requirement, but the bottom considered features position only got worse – and does not meet the print requirements.
Bonus "MOBILITY TOLERANCE" is NOT Simply Added to the Tolerance Value

Shifting the coordinate system in the other direction does not fix the problem, as we now have the bottom considered feature within its print requirements, but we have pushed the top hole out of its requirements.
“Mobility” Bonus Tolerance is Realized When the Pattern of Features Shifts in the Same Direction

Suppose now we look at a part (different part that we have already been checking) where the two considered feature holes have been placed .037 off of their respective True Positions, but in the same direction.
“Mobility” Bonus Tolerance is Realized When the Pattern of Features Shifts in the Same Direction

This time the coordinate system can be shifted such that it causes both holes to meet their respective print requirements at the same time.

The DRF mobility bonus tolerance is only realized when the considered features are off their respective True Positions in the same direction at the same time.
The Significance of a Datum Reference Frame

- The Datums are specified by the designer based on *Function!*
- The DRF in the FCF is a set of instructions that specifies how to establish the *Functional* coordinate system
CMMs: Strengths and Weakness

- CMMs are great for measuring from point to point.
- CMMs are lousy at establishing a datum reference frame on their own.
- CMM limitations do not (should not) drive a functional design.
Facts About CMM’s

A CMM that produces reliable results costs a LOT LESS than the operational costs of one that produces unreliable results

- This reliability is more dependent on operator knowledge than on the CMM manufacturer’s purported accuracy or precision

- The greater the Datum Features’ geometric errors, the more uncertainty exists in the collected data and its subsequent analysis
Making Better Use of Your CMM

- The most common use of a CMM is to determine if a part is “Per Print” or not.
- The most valuable use of a CMM is to provide analysis of data and feedback to the manufacturing process.