



Advanced Geometric Dimensioning & Tolerancing (GD&T) Per ASME Y14.5-2018

No part of this document may be reproduced in any form
in an electronic retrieval system or otherwise,
without prior written permission of Applied Geometrics, Inc.

Copyright © 2018
Applied Geometrics, Inc.
All rights reserved
Printed in U.S.A.

Table of Contents

Forward	8
----------------------	----------

Biographies	9
--------------------------	----------

Chapter 1

INTRODUCTION	13
---------------------------	-----------

1.0 Course Objectives	13
-----------------------------	----

1.1 Fundamental & Advanced Concepts Overview	14
--	----

Chapter 2

Review of Fundamentals & Introduction of Advanced Concepts	16
---	-----------

2.0 The Simplest Drawing in the World	16
---	----

2.1 Rule #1 and Exceptions	17
----------------------------------	----

2.1.1 Rule #1 with LMC Specified	18
--	----

2.1.2 Exceptions to Rule #1	19
-----------------------------------	----

2.1.2.1 Derived Median Line Straightness	19
--	----

2.2 Calculating Outer Boundaries	22
--	----

2.3 Derived Median Plane Flatness	22
---	----

2.4 Derived Median Line or Plane Per Unit Basis	23
---	----

2.5 Surface Flatness Per Unit Basis	24
---	----

2.6 Cylindricity Per Unit Basis	24
---------------------------------------	----

2.7 Independency	25
------------------------	----

2.7.1 Independency with Flatness Example	25
--	----

2.8 Continuous Feature	26
------------------------------	----

2.9 Defendable Tolerances	27
---------------------------------	----

2.10 The GD&T Control Symbols	28
-------------------------------------	----

2.10.1 Reading a Feature Control Frame (5 Questions)	28
--	----

2.11 Four Ways to Control a Feature	29
---	----

2.12 Hole Pattern Controls	30
----------------------------------	----

2.13 Simultaneous Requirements	32
--------------------------------------	----

2.13.1 Simultaneous Requirements with a Primary Datum Axis	33
--	----

2.14 Application of +/- Linear Dimensions	34
---	----

2.15 Tolerance Accumulation	35
-----------------------------------	----

2.16 Types of Features	37
------------------------------	----

2.16.1 Regular vs. Irregular Features of Size	38
---	----

2.17 Dimension Origin Symbol	39
------------------------------------	----

2.18 Tangent Plane Symbol	40
---------------------------------	----

Chapter 3

Material Modifiers	41
---------------------------------	-----------

3.0 Symbol Meanings	41
---------------------------	----

3.1 Material Condition Modifiers	41
--	----

3.2 Material Boundary Modifiers	42
---------------------------------------	----

3.3 Material Modifier Summary	42
-------------------------------------	----

3.4 Maximum & Least Material Boundaries	43
---	----

3.5 Inner & Outer Boundaries	44
------------------------------------	----

3.6 Maximum Material Modifiers	45
--------------------------------------	----

3.6.1 Bonus Vs. Mobility Tolerance	47
--	----

3.7 Least Material Modifiers	51
------------------------------------	----

3.8 Regardless of Feature Size	55
--------------------------------------	----

Chapter 4

Virtual & Resultant Condition	56
4.0 Virtual Condition	56
4.1 Virtual Condition with MMC Specified	56
4.2 Resultant Condition with MMC Specified	59
4.2.1 Resultant Condition Boundary: Internal Feature with MMC Specified	60
4.2.2 Resultant Condition Boundary: External Feature with MMC Specified	61
4.3 Tolerance Stack-up Analysis - Visualizing Boundaries	63
4.4 Virtual Condition with LMC Specified	64
4.5 Resultant Condition with LMC Specified	65

Chapter 5

Actual Mating & Minimum Material Envelopes	66
5.0 Actual Mating Envelopes	66
5.1 Actual Minimum Material Envelopes	70

Chapter 6

Datum Theory & Terminology	71
6.0 Datum Definition	71
6.1 Datum Terminology	72
6.2 True Geometric Counterparts & Datum Feature Simulators A B C 	73
6.3 Degrees of Freedom & Constraints	74
6.4 Can/May/Must	77
6.5.1 Cylindrical & Width Datum Features - (Primary & Secondary)	78
6.5.2 Datum Feature of Size Secondary RMB	81
6.5.3 Datum Feature of Size Primary RMB	82
6.6 True Geometric Counterparts & Datum Feature Simulators A D E 	83

Chapter 7

Datum Feature Shift/Displacement	85
7.0 Datum Reference Frame Mobility	85
7.1 Cylindrical & Width Features with MMB Specified	86
7.1.1 Sample Part: Cylindrical Datum Feature of Size Secondary MMB	88
7.1.2 Sample Part: Cylindrical Datum Feature of Size Primary MMB	90
7.2 Evaluating & Validating DRF Mobility Availability	94
7.2.1 DRF Mobility for a Primary Datum Referenced MMB	98
7.2.2 DRF Mobility for Secondary Datum Features Referenced MMB	101
7.2.3 Exercise: Datum Feature D MMB Calculations	103
7.2.4 Datum Feature E MMB Calculations (Primary, Secondary, Tertiary)	104
7.2.5 Exercise: Calculate Mobility Tolerance	105
7.2.5.1 Exercise: Datum Reference Frame Mobility	106
7.3 Patterns as Datum Features	106
7.4 Patterns & Simultaneous Requirements	112

Chapter 8

Datum Axis Two or More Coaxial Diameters	115
8.0 Datum Axis Definition with Two (or more) Short Diameters	115

Chapter 9

Rotation Constraint About an Axis	117
9.0 Datum Features Constraining Rotation about a Datum Axis	117
9.1 Datum Feature B Referenced at RMB	117
9.2 Datum Feature B Referenced at MMB	119
9.3 Datum Feature B Referenced with A Translation Modifier	120
9.3.1 Translation Modifier & i,j,k Vector	121
9.4 Opposed Planar Feature RMB	121
9.5 Opposed Planar Feature MMB	123
9.6 Opposed Planar Feature Referenced MMB vs. RMB	124
9.7 Offset Planar Feature Reference RMB	125
9.8 Offset Planar Feature Referenced MMB	126
9.9 Offset Planar Feature Referenced LMB	127
9.10 Offset Planar Feature with BASIC Modifier	128

Chapter 10

Other Datum Feature Considerations	129
10.0 Unstable Datum Features (Rocking)	129
10.1 Irregular Features of Size as Datum Features	129
10.2 Explicit True Geometric Counterpart Boundaries	130

Chapter 11

Part Evaluations with Different Datum Feature Specifications	131
11.0 Planar Datum Feature B	131
11.1 Datum Feature of Size W RMB	133
11.2 Datum Feature of Size W MMB	137
11.3 Datum Feature of Size W LMB	139
11.4 Other Form Control Calculations	142

Chapter 12

Flexible / Non-Rigid Parts	144
12.0 General Terms	144
12.1 Flexible Part	144
12.2 Free & Restrained State	146
12.3 Unrestrained Datum Targets	146

Chapter 13

Custom Datum Reference Frames	147
--------------------------------------	------------

Chapter 14

Movable Datum Targets	149
------------------------------	------------

Chapter 15

Determining Tolerance Values	152
15.0 Where do They Come From?	152
15.1 Calculated vs. R&D	152
15.3 Inspectability & Manufacturability	152
15.4 X-Y Coordinate Measurement To Cylindrical Value	153
15.5 Validation Practice Exercises	154
15.6 Floating & Fixed Fastener Formulas	157
15.6.1 Floating Fastener	158
15.6.2 Fixed Fastener	162
15.7 Working with Outside Agencies	166
15.8 Mixed Fastener Example	167
15.9 Minimum Wall Exercise with LMC	169

Chapter 16

Datum Feature Selection Exercise	173
16.0 Datum Feature Selection Criteria	173

Chapter 17

AGI Geometric Design Process	176
17.0 Datum Feature Selection Criteria (for Existing Design Concepts)	176
17.1 Exercise: Calculate Position Tolerance for the Holes	178
17.2 Exercise: Fixed Fastener & Potential Datum Overlap	183

Chapter 18

Extended Principles of Position Tolerance	184
18.0 Zero Position Tolerance at MMC	184
18.0.1 Addition Reference Material	186
18.1 Zero Position Exercises	187
18.2 Minimum Wall Exercise	188
18.2.1 GD&T Solutions Replace +/- Linear Dimensions	194
18.3 Position Tolerance Width Features	197
18.4 Position Tolerance Common Center Planes	198
18.5 Position Tolerance Coaxiality	199
18.6 Repetitive Patterns of Features	201
18.6 Position Without a Datum Reference	201
18.7 Projected Tolerance Zones	202

Chapter 19

Composite & Multiple Single Segment Position Tolerance	206
19.0 Composite Position	206
19.1 Multiple Single Segment Position	211
19.2 Composite Position - FRTZF with Three Datum References	213
19.3 Comparing Two Composite Position Controls	214
19.4 Three Segment Composite Position Tolerance	217
19.4 Multiple Single-Segment FCF - Lower Segment with a Different DRF	217

Chapter 20

Profile.....	218
20.0 Controlling Cones.....	218
20.1 Profile Levels of Control	219
20.2 Composite Profile.....	221
20.3 Composite Profile - Closed Polygon.....	223
20.4 Position Combined with Profile (Boundary Position)	227
20.5 Profile Exercise #1	231
20.6 Profile Exercise #2	232
20.7 Profile Exercise #3	233
20.8 NONUNIFORM Profile	234
20.8.1 Nonuniform Profile Using From - To Symbol	235
20.10 Dynamic Profile Modifier - Composite Feature Control Frame.....	236
20.11 Dynamic Profile Modifier - Multiple Single-Segment FCF	247
20.12 Tangent Plane Runout or Profile.....	251
20.13 Profile of a Line.....	252
20.13.1 Profile of a Line for Radial Elements.....	254
20.13.2 Orientation of a Curved Surface	254

Chapter 21

Runout on an Assembly	255
21.0 Runout on an Assembly	255
Ref. Fig. 2-28, pg 32: Simultaneous Requirements Exercise	256
Ref. Fig. 7-15, pg 103: Datum Feature D MMB Calculations	256

Appendix	256
-----------------------	------------

Ref. Fig. 7-19, pg 105: Mobility Tolerance Calculation Exercise #1 Solution.....	257
Ref. Fig. 7-20, pg 106: Mobility Tolerance Calculation Exercise #2 Solution	258
Ref. Fig. 15-5, pg 154: Validation Practice #1 Solution	258
Ref. Fig. 15-7, pg 155: Validation Practice #2 Solution	259
Ref. Fig. 15-9, pg 156: Validation Practice #3 Solution	259
Ref. Fig. 15-12, pg 158: Floating Fastener Exercise Solution #1.....	260
Ref. Fig. 15-15, pg 160: Floating Fastener Exercise Solution #2.....	260
Ref. Fig. 15-16, pg 160: Floating Fastener Exercise Solution #3.....	260
Ref. Fig. 15-17, pg 161: Floating Fastener Exercise Solution #4.....	261
Ref. Fig. 15-18, pg 161: Floating Fastener Exercise Solution #5.....	261
Ref. Fig. 15-20, pg 162: Fixed Fastener Exercise Solution #1	262
Ref. Fig. 15-25, pg 165: Fixed Fastener Exercise Solution #2	262
Ref. Fig. 15-26, pg 165: Floating Fastener Exercise Solution #3.....	262
Ref. Fig. 15-27, pg 166: 1st Outside Agency Exercise Solution.....	263
Ref. Fig. 15-28, pg 166: 2nd Outside Agency Exercise Solution	263
Ref. Fig. 15-29, pg 167: Mixed Fastener Exercise Solution	264
Ref. Fig. 17-16, pg 183: Fixed Fastener with Datum Feature Overlap Solution	264
Ref. Fig. 16-2, 16-1, pg 174: Basic Solution for Clamp Assembly Specifying Datum Feature & Position Tolerance	265
Ref. Fig. 18-5, pg 187: 1st Zero Position Exercise Solution	267
Ref. Fig. 18-6, pg 187: 2nd Zero Position Exercise Solution	267
Ref. Fig. 18-16, pg 199: Position Tolerance Width Features Exercise Solution.....	268
Ref. Fig. 18-21, pg 202: Coaxiality Exercise #1 Solution.....	268
Ref. Fig. 18-22, pg 202: Coaxiality Exercise #2 Solution.....	269
Ref. Fig. 20-23, pg 233: Profile Exercise #1 Solution.....	269
Ref. Fig. 20-24, pg 234: Profile Exercise #2 Solution.....	270
Ref. Fig. 20-26, pg 235: Profile Exercise #3 Solution.....	270
A-Y Co-ordinate Measurement to Cylindrical Tolerance Value Charts - Metric.....	271

Forward

This text covers the more advanced concepts and rules of GD&T per the ASME Y14.5-2018 standard. Determining which topics and information within the Y14.5 standard should be categorized as, “fundamental” versus, “advanced” is very subjective. We, at Applied Geometrics, have divided our text materials into our, “Fundamentals of GD&T” and this, “Advanced GD&T” texts in what we feel is a logical manner based on our experience in industry, both as users of and as educators in the Y14.5 and related standards. This text reviews the fundamentals-level material, but dives even deeper into those concepts than was covered in our “Fundamentals of GD&T” text, and then we explore topics and rules that, while perhaps common needs in industry, are more complex and difficult for the learner to initially comprehend and understand. As always, our focus remains educating the learner in the technical topics with the end goal being practical application and proper interpretation.

Applied Geometrics has written this text to use the same language found in the ASME Y14.5-2018 standard, but with “plain” language added to help the learner fully comprehend the subjects. Our goal is two-fold. We want users to both be able to read and understand the standard technically, for example, for passing the GDTP certification exam, but also to be able to use the standard effectively in real life.