Computer Aided Tolerancing

PTC° Live Global JUNE 7-10 - NASHVILLE, TN



Geometric Dimensioning and Tolerancing (GD&T)

- *GD&T* is a language for communicating engineering design specifications
- GD&T includes all the symbols, definitions, mathematical formulae, and application rules necessary to embody a viable engineering language

Statistics gathered by one of the top 3 CAD providers have found that 80% of manufacturing errors were down to incorrect use of GD&T





Tolerance Processes within CREO

1. Annotate Features GD&T Features



- a. 3D Tolerance Analysis
- b. Generates Geometric Dimensioning and Tolerancing Features
- c. Tolerance Optimization for Assembly Quality



MBE requires 3D Model Base Definition

1. UNLESS OTHERWISE SPECIFIED, 🔼 0.1 A BM CM APPLIES TO ALL SURFACES

Model Annotate Render Tools View Applications File 🕶 Analysis Р V Welding Stop Mold/ Simulate Simulate Start Results GDTA GDTA Cast Simulation GDT Advisor Engineering

NOTES:

in 🔁 💿 🞯



2. QUERIED DIMENSIONS SHALL BE RESOLVED TO 2 DECIMAL PLACES 1.17+01 80 GO 0 0.000.001 C. L. P.ST .1 A B(0) C(0) .01 A B(0) C(0) ASME Y14,5M-1994 ASME Y14.41-2003

ALL DIMENSIONS SPECIFIED IN INCHES

Drawing Associativity

NOTES (UNLESS SPECIFIED OTHERWISE):

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5-2009.



Tolerance Analysis with Dimension Boundaries



All R...ences

Distance 0.600000 i

Tolerance Analysis with TAE Feature

 PTC CREO[®] Tolerance Analysis Extension (TAE) solves one-dimensional problems with a Dimension Loop Diagram, generates sensitivities and statistical tolerance analyses



Statistical Analysis and Sensitivity

- 1D Tolerance Stack-up
- For Gap > zero:
 - Sigma Quality Level
 - Defects Per Million Units
 - Percent Yield
 - M & σ of Gap
- Best-Worst Case
- Sensitivity
- Nominal & Tolerances can be adjusted live
- Report Generation

leasure Defin	nition			, potr						
Gan/Stack Dat	finition			Gaal						
Gap/ Stack Del				Guai						
From	Surf:F6(EXTRU	JDE_1):BOX1		Symme	tric		•	Precision 3		
То	Surf:F6(EXTRU	JDE_1):CASE								
Distance	0.5000000		inch	0.500			±	0.010		
		2								
Name		Nominal	Toler	ance	Unit	Ср	Distribution	Sens	Attachment	
HH TAE 3	3	0.5	0.500	±0.010	inch		Normal(0.5; 0.23805)		Center	
BOX1					inch					
↔ dí	1	10	10.00 +0	.50/-0.50	inch	1	Normal(10; 0.16667)	-1	Center	
BOX1	/BOX1	(0)							Center	
BOX1					inch					
↔ d1	1	10	10.00 +0	.50/-0.50	inch	1	Normal(10; 0.16667)	-1	Center	
BOX1	/CASE	(0)							Center	
CASE					inch					
↔ dí	1	20.5	20.50 +0	.10/-0.10	inch	1	Normal(20.5; 0.033	1	Center	
Mangura Vacia	ation	'	Statistical	Worst Ca	ase Se	nsitivity				
measure varia				e			Se	nsitivity		
measure varia			Name							
measure varia			BOX1	:d1				-1 inch	ı/inch v/inch	
Normal(0.5	50000-0 22805)		Name BOX3 BOX3 CASE	:d1 :d1 :d1				-1 inch -1 inch	ı/inch ı/inch	
Normal(0.5 Sigma = 0.1	50000; 0.23805) 0420	,	Name BOX1 BOX1 CASE	:d1 :d1 :d1			1. inch/in	-1 inch -1 inch ch	n/inch n/inch	
Normal(0.5 Sigma = 0.1 %Yield = 3. DPMU = 96	50000; 0.23805) 0420 .3508 66,492	,	Name BOX1 BOX1 CASE	:d1 :d1 :d1			1. inch/in	-1 inch -1 inch	n/inch n/inch	
Normal(0.5 Sigma = 0. %Yield = 3. DPMU = 96	50000; 0.23805) 0420 .3508 66,492		Name BOX1 BOX1 CASE	:d1 :d1			1. indh/in	-1 inch	ŋ/inch ŋ/inch	
Normal(0.5 Sigma = 0. %Yield = 3. DPMU = 96	50000; 0.23805) 0420 3508 66,492		Name BOX3 BOX1 CASE	:d1 :d1 :d1			1. inch/in	-1 inch	ı/inch ı/inch	
Normal(0.5 Sigma = 0.1 %Yield = 3. DPMU = 90	50000; 0.23805) 0420 .3508 66,492		Nam. BOX1 BOX1 CASE	::d1 ::d1 ::d1			1. inch/in	-1 inch	ı/inch ./inch	
Normal(0.5 Sigma = 0. %Yield = 3, DPMU = 90	50000; 0.23805) 0420 .3508 66,492		Nam	::d1 ::d1 ::d1			1. inch/in	-1 inch	ı/inch ./inch	
Normal(0.5 Sigma = 0. %Vield = 3. DPMU = 90	50000; 0.23805) 0420 .3508 66,492	1.6	Nam	:d1 :d1 :d1			1. inch/in	-1 ind -1 ind d	ı/inch ./inch	
Normal(0.5 Sigma = 0.1 %Vrield = 3.1 DPMU = 96	50000; 0.23805) 0420 3508 66,492	1.6	Nam	:d1 :d1			1. inch/in	-1 inch	ı/indh ı/indh	
Normal (0.5 Sigma = 0.1 %/rield = 3.1 DPMU = 90	50000; 0.23805) 0420 3508 66,492 0.5	1.6	Nam	::d1 ::d1			1. inch/in	-1 inch -1 inch	ı/indh ./indh	
Normal (0.5 Sigma = 0.1 %/Yeld = 3. DPMU = 94	50000; 0.23805) 0420 3508 66,492 0,5 0,49 0.51	1.6	Nam	::d1 ::d1			1. inch/in	-1 inch	ı/inch ./inch	

Results summary plot - Sigma Quality metrics



Design Modifications

- Interactive / real time Modification of Tolerance Bounds
- Modifications are associative to the model
- Tolerance Analysis
 Feature can be used with Behavioral
 Modeling

Incourse Definition								
reasure Demnition								
Gap/Stack Definition			Goal					
From Surf:F6(EX	TRUDE_1):BOX1							
			Symm	etric		•	Pre	cision 3
To Surf:F6(EX	TRUDE_1):CASE							
			0.500			± 0	.010	
Distance 0.5000000		inch						
• ¤ ⊨ ×	D.							
Name	Nominal	Tolera	ince	Unit	Ср	Distribution	Sens	Attachment
HI TAE_1	0.5	0.500 ±	0.010	inch		Normal(0.5; 0.0038		Center
BOX1								
↔ d1	10	10.000 ±	0.001	inch	.5	Normal(10; 0.00066	-1	Center
BOX1/BOX1	(0)							Center
BOX1								
↔ d1	10	10.000 ±	0.001	inch	.5	Normal(10; 0.00066	-1	Center
BOX1/CASE	(0)							Center
CASE								
↔ d1	20.5	20.500 ±	0.010	inch	0.9	Normal(20.5; 0.003	1	Center
			W	`aca Se	nsitivity			
Measure Variation		Statistical	WORSTI					
Measure Variation		Statistical	worst	ase se		Ser	sitivity	
Measure Variation		Statistical	d1	.asc 30		Ser	-1 inch	ı/inch
Measure Variation		Statistical	d1			Ser	-1 ind	ı/inch ı/inch
Measure Variation	32)	Statistical	d1 d1 d1 d1			Ser 1. inch/inc	-1 ind -1 ind -1 ind	ı/inch ı/inch
Measure Variation Normal(0.50000; 0.0030 Sigma = 2.6166 9%rield = 99,1118	32)	Statistical	d1 d1 d1			Ser	-1 inch	ı/inch Jinch
Measure Variation Normal(0.50000; 0.003 Sigma = 2.6166 9%Held = 9,1118 DPMU = 8,882.0	82)	Statistical Name BOX1: BOX1: CASE:	d1 d1 d1			Ser 1. inch/inc	-1 inch	/inch /inch
Measure Variation Normal(0.50000; 0.003 Sigma = 2.6166 %Yield = 99.1118 DPMU = 8,882.0	82)	Statistical Name BOX1: BOX1: CASE:	d1d1			Ser	-1 inch -1 inch	/inch /inch
Measure Variation Normal (0.50000; 0.003 Sigma = 2.6166 %/ield = 99,1118 DPMU = 8,882.0	82)	Statistical Name BOX1: BOX1: BOX1: CASE:	d1d1			Ser	-1 inch -1 inch	(inch /inch
Measure Variation	32)	Statistical Name BOX1: BOX1: CASE:	d1d1			Ser	-1 ind -1 ind -1 ind	/inch /inch
Measure Variation	32)	Statistical Name BOX1: BOX1: CASE:	d1d1			Ser	-1 ind -1 ind -1 ind h	/inch /inch
Normal(0.50000; 0.003 Sigma = 2.6166 %/field = 99,1118 DPMU = 8,882.0	52)	Statistical Name BOX1: BOX1: CASE:	d1d1			Ser	h	/inch /inch
Measure Variation	52)	Statistical Name - BOX1: - BOX1: - CASE:	d1d1			Ser	-1 inch -1 inch	/inch /inch
Measure Variation	52)	Statistical Name - BOX1: - BOX1: - CASE:	d1d1			Ser	h	/inch /inch
Measure Variation	52) 0.512 0.51	Statistical Name - BOX1: - BOX1: - CASE:	d1d1			Ser	-1 ind -1 ind	/inch /inch
Measure Variation	82) 0.512 0.51	Statistical Name BOX1: BOX1: CASE:	d1d1			Ser	-1 inch -1 inch	(inch _inch

		Tolera	ance Analysis po	wered by C	ETOL Technology				×
 Measure Definition 									
Gap/Stack Definition				ioal					
From \$	Surf:F6(EXTRUDE_1):C4	ASE	L	imits		Precision 3			
To	Surf:F6(EXTRUDE_1):B0	DX1					1.500		
Distance (0.5000000		inch				0.000		
	× D.								
Name	Nomin	al Tole	rance Un	it Cp	Distribution	Sens	Attachment		
HH TAE_2	0.5	1.500	1/0.000 inc	h	Normal(0.5; 0.23805)		Center		
V 🗐 CASE			inc	h					
↔ d1	20.5	20.50 +0	.10/-0.10 inc	h 1	Normal(20.5; 0.033	1	Center		
ASE/BOX1	(0)						Center		
🔻 📕 BOX1			inc	h					
↔ d1	10	10.00 +0	.50/-0.50 inc	h 1	Normal(10; 0.16667)	-1	Center		
BOX1/BOX1	(0)						Center		
🔻 📕 BOX1			inc	h					
↔ d1	10	10.00 +0	.50/-0.50 inc	h 1	Normal(10; 0.16667)	-1	Center		
Dimension Loop Diagr	am	0.00 +0.50/-0.50	20.50 +0.1	0/-0.10		0		CASE BOX1 BOX1	The second secon
Diagram Results	Feature								
Saved		 Analysis N 	Name: TAE_	2			~	~	X

Cp relates the mean and variability of the process or machine to the permissible range of dimensions allowed by the specification or tolerance

Gap/Stack Definition		G	oal						
From Surf:F6(EXTRU	DE_1):CASE		Limits Precision 3 +						
To Surf:F6(EXTRU	DE_1):BOX1	1.500							
Distance 0.5000000 inch 0.000									
▶ □ □ □ ₩ × D				\frown					
Name	Nominal	Tolerance	Unit	Ср	Distribution	Sens	Attachment		
HH TAE_2	0.5	1.500/0.000	inch		Normal(0.5; 0.23805)		Center		
V CASE			inch						
↔ d1	20.5	20.50 +0.10/-0.10	inch	1	Normal(20.5; 0.033	1	Center		
ASE/BOX1	(0)						Center		
T BOX1			inch						
↔ d1	10	10.00 +0.50/-0.50	inch	1	Normal(10; 0.16667)	-1	Center		
BOX1/BOX1	(0)						Center		
T BOX1			inch						
↔ d1	10	10.00 +0.50/-0.50	inch	1	Normal(10; 0.16667)) -1 Center			
Measure Variation		Statistical Worst Ca	ase Ser	sitivity					
Normal(0.50000; 0.23805)		Name			Se	ensitivity			
Sigma = 2.3685 %Yield = 98.2141 DPMU = 17,859 -0.6 0.5	1.6	CASE:d1 BOX1:d1 BOX1:d1			1 inch <i>l</i> ir	-1 in -1 in -1 in	ch/inch ch/inch		
Diagram Results Feature									
Saved	▼ A	Analysis Name: TAE	_2			٠	✓×		

Do the two components assemble?



Configurations for Gap Analysis



Motor TAE Example Exploded View



Mechanical Tolerance Stacks –Loop Diagram



Typical Requirements

- The gap between the shaft and the inner bearing cap must always be greater than zero (to ensure that the rotor is clamped and the bearings are preloaded)
- The gap between the housing cap and the housing must always be greater than zero (to ensure that the stator is clamped)
- Amount of "squeeze" on an o-ring
- Amount of "preload" on bearings
- Sufficient "material" for subsequent machining processes
- Interference requirements, such as when pressing pins into holes
- Optical requirements, such as alignment of optical elements



Circuit Board TAE Example





GD&T Definitions are required for Tolerance Analyses

Mechanical Tolerance Stacks – Loop Diagram

Name	Nominal	Tolerance	Unit	Ср	Distribution	Sens	Attachment
HH TAE_1	0.1	1.000/0.000	mm		Normal(0.1; 0.11055)		Center
V E PAN			mm				
↔ d39	146	146.0 ±0.1	mm	1	Normal(146; 0.0333	1	Center
↔ d8	119.2	[POS[0.2(M)]	mm	1	Normal(119.2; 0.033	-1	
Ø d9	3.5	3.5 +0.1/0.0	mm	1	Normal(3.55; 0.016	0	Center
PAN/SCREW	(0)						Center 💌
V SCREW			mm				
Ø d1	3.4	3.4 +0.0/-0.1	mm	1	Normal(3.35; 0.016	0	Center
SCREW/PCB	(0)						Center 💌
V PCB			mm				
Ø d267	3.5	3.50 +0.10/0.00	mm	1	Normal(3.55; 0.016	0	Center
↔ d266	25	25.0 ±0.2	mm	1	Normal(25; 0.06666	-1	Center
↔ d43	7.1	7.1 ±0.2	mm	1	Normal(7.1; 0.0666	1	Center
A PCB/REC-3PIN	(0)						Center
REC-3PIN			mm				
↔ d137	8.8	[POS]0.2]	mm	1	Normal(8.8; 0.0333	-1	

Measure Variation

Name	Statistical Contribution	
PCB:d266	36	5.36 %
PCB:d43	36	5.36 %
REC-3PIN:d137	9.09 %	
PAN:d8	9.09 %	
PAN:d39	9.09 %	
PAN:d9	0.00 %	
SCREW:d1	0.00 %	
PCB:d267	0.00 %	

. . .

Name	Nominal	Tolerance	Unit	Ср	Distribution	Sens	Attachment
H TAE_1	0.15	1.000/0.000	mm		Lambda(0.2; 0.12546; 0		Center
V 🔲 PAN			mm				
↔ d39	146	146.0 ±0.1	mm	1	Normal(146; 0.033333)	1	Center
↔ d8	119.2	[POS 0.2(M)]	mm	1	Normal(119.2; 0.033333)	-1	
Ø d9	3.5	3.5 +0.1/0.0	mm	1	Normal(3.55; 0.016667)	9	Center
PAN/SCREW	(0)	0.150/-0.150	mm		Lambda(0; 0.058135; 0;		Float 💌
V SCREW			mm				
Ø d1	3.4	3.4 +0.0/-0.1	mm	1	Normal(3.35; 0.016667)	-(.5	Center
SCREW/PCB	(0.0500000000000						Left 🔻
V 📕 PCB			mm				
Ø d267	3.5	3.50 +0.10/0.00	mm	1	Normal(3.55; 0.016667)	0.5	Center
↔ d266	25	25.0 ±0.2	mm	1	Normal(25; 0.066667)	-1	Center
↔ d43	7.1	7.1 ±0.2	mm	1	Normal(7.1; 0.066667)	1	Center
A PCB/REC-3PIN	(0)						Center
V 🔲 REC-3PIN			mm				

Statistical Worst Case Sensitivity

Name	Statistical Contribution
PCB:d266	28.24 %
PCB:d43	28.24 %
PAN/SCREW:Clearance	21.18 %
PAN:d8	7.06 %
PAN:d39	7.06 %
REC-3PIN:d137	7.06 %
SCREW:d1	0.59 %
PCB:d267	0.44 %
PAN:d9	0.15 %

Typical TAE Application

- DOD Quality performance requirements
- Reliability and Materiel availability metrics as KPP
- Demonstration of compliance with virtual prototypes
- Immediate feedback during development process
- Experimental Validation is required

ICD Solid Model

This Model is in "Chrome Plated", Final condition. Dims to the mean tolerance.

CAD Integration

FULLPROJECTILE2 (Active) - Pro/ENGINEER

<u>File Edit View Insert Analysis Info Applicatio</u>

ြိုင်းမြို့ 🔒 🔒 🗳 🖸

Select dimension to define 1D stack

- · Checked feature types will be displayed in the model tree.
- · Feature redefined successfully.

Tolerance Analysis Report

Report Generated On Fri July 16 2010 @ 08:20:35 pm Analysis Report By: Maiki Vlahinos Company : GD OTS

Measurement Details

Pro/E Model	FULLPROJECTILE2.asm
Tolerance Analysis Measurement	CETOL_2
Design Specification	1.26/0.00
Solved Nominal	1.26

Measurement Results

Dimension Details

Name:	Dim./Tolerance:	Ср	Sensitivity	Variance/Contribution Statistical		
PROJECTILEASSEMBLY:d1	277.25 +0.50/-0.50	1.00	-1	37.04%		
FRONTBELLTOWINDSHIELD:d1	154.23 +0.45/-0.45	1.00	-1	30.00%		
CASING:dl	470.46 +0.40/-0.40	1.00	-1	23.70%		
CASEBASEASSEMBLY:d1	79.30 +0.25/-0.25	1.00	-1	9.26%		
CONTAINER2:d6	982 ±0	1.00	1	0.00%		

Sampling in Stack-up Tolerance Example

Typical Results of Tolerance Analyses

Tolerance Analysis of Projectile for ICD Compliance

Using BMX's Statistical Design Studies for Sigma quality evaluation

File - Model An	alysis Annotate Render Tools V	iew Applications											
Analysis	🛱 User-Defined Analysis 📓 Mathcad Analysis	Mass Properties 🔻	(JH)	Geometry Report	 Mesh Surface 	± 01	Sensitivity Analysis	111					
비남 Saved Analysis	🔣 Excel Analysis 🕅 Prime Analysis	A Short Edge	()))	🔟 Draft	🌺 Dihedral Angle	adadatdat	Reasibility/Optimization						
Performance Monitor	문 Toolkit-Based 같 External Analysis	Thickness	Measure	Dairs Clearance	🗲 Curvature 🔻	Tolerance Analysis 🔻	Statistical Design Study	Simulate Analysis					
Manage 🔻	Custom	Model Report	Measure	Inspect Ge	eometry *		Design Study						
							File Setup Tools Design Study Name SDS1 Design Variables Name d2:TOL_BMX d4:TOL_BMX d2:TOL_BMX d2:TOL_BMX	Mean 70 6 8	Statistical De Distribution Normal Normal	Esign Study Type S S Details standard dev standard dev	ingle IODS riation=1 riation=1 riation=1		
			/		7		Properties						
							Design Goals						
							Name	Min	Max	Distribution	Lower Limit	Upper Limit	Details
							DISTANCE:MEASURE_DI	S		Normal			
			_				Properties	Compute				Close	×

Live Demonstration of BMX Statistical Design Studies

What is CETOL 6o?

CETOL6

Tolerance analysis software that answers:

- ✓ Does is assemble?
- ✓ Does it work?
- ✓ Is it repeatable?
- ✓ Is it understood?

✓ Is it profitable?

And where to make improvements if not.

NOTES (UNLESS SPECIFIED OTHERWISE):

CETOL Demo – Model Intro

Requirement: Tip of blue part (Claw) always behind the plane of notch in grey side plate

Steps for 3D Tolerance Analysis

- Define appropriate GD&T of all relevant components
- Define as measurements the functional performance requirements
- Define the joints and constraints between parts
- Examine the part dimensioning details
- Validate model / configurations
- Calculate sensitivities
- Evaluate results
- Select critical impactful mean values
- Select critical impactful tolerance values