



## **Geometric Error Compensation**



GEC involves the compensation of inherent geometric and thermal errors of CMMs. With the newest release of Pantec's GEC, dynamic temperature monitoring and compensation as well as linearity and squareness correction is already performed *inside* the Pantec controller. For those customers who require higher accuracy, the full 21-parameter error model (including roll, pitch and yaw errors) is available through our driver-based solution. Both GEC options cover the most common kinematic chains for CMMs, including machine configurations with the following axes sequences: Y-X-Z, X-Y-Z, X-Z-Y.

For convenience and ease of use, the entire compensation procedure is done through the Pantec Support Tool tuning and analysis software. The GEC Wizard incorporates the calibration laser and the machine type to add optimum flexibility in error capture, correction, and validation of results. An efficient design with minimal clicks offers a high level of operational convenience.

The Pantec Support Tool (v4.0.2) is used for the following steps:

- Set-up the GEC configuration
- Automatic or manual capturing of Laser and machine position
- Direct set-up of error
- Review and management of correction parameters in the GEC editor

#### 1. Open Support.Tool v4.0.2 and launch the GEC Wizard

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File	View	Configure	Tools	Window	Help								
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2. Choose the location of the compensation:



Select whether you want to configure a limited error compensation model (i.e. linearity, squareness errors as well as linear thermal expansion) in the EAGLE/CONDOR controller, or a full 21-error parameter model compensation computed by EAGLE.Driver on the host-PC.

GEC Wizard - [CMM Setup]					
oce wizard [etwiwi occup]	CMM Setup				
			Z		
GEC License	Machine is not homed! Please home before p	oceeding!		+	
CMM Setup				ZDY	
T-Sensor Setup				ZDX	Yaw
Measure Linearity			· · · ·	ZRZ	Roll
Measure Squareness			Z	RY	Straightness
Edit Error Map			-	ZRX	aquareness
Configure GEC	Machine Configuration			VP7 Y	RX YDZ
	First axis:		20	→ <sup>1</sup>	
	Second exis:	1		XY	YRY Y
				<b></b>	
	I hird axis:			XRY	
				XRZ XRX	
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	Volume to be compensated	Y Axic	V Avis	7 Avia	
	Ctat appreliate (www)	COD COD	650	Z AXIS	
	Stat coolumate (mm)	10	-050	-300	
	End coordinate [mm]	10	10	10	
	Step [mm]	20	20	20	
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3. Configure the setup for the CMM

On the *CMM Setup* page of the GEC Wizard the CMM-related parameters, such as the machine dimensions, are defined. In case the machine is not homed, a warning is shown. It is mandatory to complete a home procedure before measuring the error parameters



	I-Sensor Setu	Þ						
GEC License	Thermal	expansion coefficients				Set axi	s temperatur	e manually
CMM Setup T-Sensor Setup	X Axis	Custom material	-	12.5	[um/(m °C)]	X 25	°C	Set Temp
Laser Setup	Y Axis	Custom material	-	12.5	[um/(m °C)]	Y 25	°C	
Measure Squareness	Z Axis	Custom material	-	12.5	[um/(m °C)]	Z 25	°C	
Edit Error Map Configure GEC								
						Ac	tivate l'empei	rature Comp.
	Temperatur	re Sensor Type:	Pa	intec T-Bus	Ŧ	🛛 🔽 🖸	isable autom	atic update
	CMM tem	perature sensor configuration						
	Nur	nber (ID)	-	Temp [°C]	Error code		Location	<b>^</b>
	Sens	or 01 (0000033292A828):		24.48	0		Z Axis 1	-
	Sens	sor 02 (00000324505828):		24.55	0		X Axis 1	•
	Sens	sor 03 (00000332857828):		25.91	0		Y Axis 1	•
	Sens	sor 04 (000003328CF128):		25.94	0		Y Axis 2	•
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#### 4. Configure the setup for thermal expansion compensation

To compensate for the effects of thermal expansion a first order correction model is applied. On the *T-Sensor Setup* page, the linear thermal expansion coefficients of the scales attached to the CMM can be adjusted. If a Pantec T-Bus is connected to the controller, the current temperature data provided by the available sensors are shown. Each temperature sensor can be associated to the corresponding axis. Alternative temperature sensor types may be incorporated via our software interface.



#### 5. Laser Setup

GEC Wizzard - [Laser Setup	]		
	Laser Setup		
CMM Setup Laser Setup Measure Roll Measure Pitch/Yaw Measure Position	Laser Equipment: Renishaw ML10	v	
Measure Straightness Measure Squareness Edit Eron Configure GEC	Laser Equipment Connect to Laser Reset data link Disconnect Laser	us: DX10 disconnected ML10 disconnected EC10 off	
	Laser (ML10) Signal strength	Environment (EC10) Air Temperature °C Pressure mbar Humidity %RH Compensation mode none	
pantec			

On the Laser Setup page the user is intended to connect to a laser. Currently, the Renishaw XL80 and ML10 (via USB interface) including their corresponding environmental measurement stations are supported. Once connected, the current laser signal strength and environmental data are displayed.

Subsequently, the various error parameters are measured with the laser or using other devices. It is recommended to measure the parameters according to the order presented in the GEC Wizard.



### 6. Measurement of roll errors

GEC Wizard - [Measure Roll]	]								
GEC License	Parameter Roll XX (XRX)	CMM operation Start Coordinate	-600	mm		Ro	II X (XRX) Coordinates [mm]	Deviation [micron/mm]	Sprez *
<ul> <li>Crimi Setup</li> <li>T-Sensor Setup</li> <li>Laser Setup</li> <li>Measure Roll</li> <li>Measure Pitch/Yaw</li> <li>Measure Linearity</li> </ul>	<ul> <li>Roll YY (YRY)</li> <li>Roll ZZ (ZRZ)</li> </ul>	End Coordinate Step Velocity	0 20 25	mm mm mm/s			-600 -580 -560 -540	0 0 0 0	E
Measure Straightness Measure Squareness Edit Error Map Configure GEC		Move To End Controller Position:	99.9997		mm		-520 -500 -480 -460 -440	0 0 0 0	
	Offset to the base of CMM quill:	Reverse directio	n				-420 -400 -380 -360	0 0 0 0	
	Y [mm]: 0 Z [mm]: 0	Make Step					-340 -320 -300 -280	0 0 0 0	
						Lection Contraction	1-260 		•
pantec							Load Clea	Petition (mm) Edit	Store
								Back	Next

The angular error due to roll is commonly not measured by a laser, but by other tools and devices. On this page the user can move the machine in steps along the predefined grid, perform the measurement and then enter the deviations into the given fields corresponding to the current coordinates. It is also possible to load external data, as well as scaling and storing the entered data for later use.



### 7. Measurement of pitch and yaw errors

	Measure Pitch/Yaw						
	Parameter	CMM and Laser Operation					
GEC License CMM Setup	X Pitch (XRY)			Align laser beam	Coordinates [mm]	Deviation [micron/mm]	Sprea *
T-Sensor Setup	X Yaw (XRZ)	Start Coordinate [mm]	600	-600	-340	-0.0057165	0.010(
Laser Setup		End Coordinate [mm]	)	0	-320	-0.00559275	0.010
Measure Roll	Y Pitch (YRX)				-300	-0.005984	0.010
Measure Pitch/Yaw	Y Yaw (YRZ)	Velocity [mm/s]	25	Move To End	-280	-0.00534575	0.0098
Measure Linearity	Z Pitch (ZBX)	velocity [iiiii,5]		Move to Ena	-260	-0.005809	0.010
Measure Scraightness Measure Scruareness	© 21 non (210 t)	Machina mayoa alang V a	rial		-240	-0.0058505	0.0104
Edit Error Map	© Z Yaw (ZRY)	Machine moves along 1 a	us!		-220	-0.0059845	0.0098
Configure GEC		Monouromont modo:	© Elv d	Stop & Co	-200	-0.005387	0.010
	Offset of reflector to	measurement mode.		Stop & Go	-180	-0.0057165	0.010
	base of CMM quill:	Step [mm]:	20		-160	-0.00536625	0.010
	×( )	Add dolay [soc]:	3	_	-140	-0.00524275	0.009(
	X [mm]: 0	Add deidy [sec].			-120	-0.004604	0.009
	Y [mm]: 0	# Runs: 1		Bidirectional	-100	-0.00410975	0.0098
					-80	-0.00306925	0.0100
	Z [mm]: 0				-60	-0.00250275	0.008
		Controller Reading (unc.):	-0.0183	mm	-40	-0.002369	0.007(
		Laser Reading: +/-	0.0	micron/mm	-20	-0.002284	0.001
					0	-0.00126	0.002: -
		Clear Laser error Sy	nc Laser rea	dings	۰ III		•
	584 Vbw 43	Laser signal: 🗸 Aven	aging	4 sec	100- 100- 100- 100- 100- 100- 100- 100-	of the state of th	
antec	Click to magnify	Start Stop			Load Clea	Pastion (mm)	Store

After the rough alignment of the laser the precise alignment and actual laser measurement are done with the GEC Wizard according to the following steps:

- Open the "Measure Pitch/Yaw" page
- Select Pitch or Yaw for the desired axis
- Align laser using the "Move To End"/"Move To Start" button and ensure that the signal strength is sufficient and does not change significantly along the whole moving path
- If the laser beam was obscured it may be necessary to click on "Clear laser error".
- Make sure that the rotation direction is correct: tap on mirror and check if the laser reading follows the right-hand rule. The rotation direction can be changed by clicking on the "+/-" button.
- At the start coordinates click on "Zero laser readings"
- Enter the number of runs and whether to perform the measurement bidirectional or unidirectional
- Press "Start" to begin with automatic data gathering
- When data gathering is completed it is recommended to store the data in a file (for potential later use) by clicking on the "Store" button below the diagram.
- To redo the measurement click on "Clear" below the diagram and press "Start" again



	Measure Linearity							
	Parameter	CMM and Laser C	)neration			Linearity X (XDX	)	
GEC License	<ul> <li>X Linearity (XDX)</li> </ul>	onin and Easer a	perduon		Align laser beam	Coordinates	Deviation	Spread
CMM Setup T-Sensor Setup		Start Coordinate	[mm] -	600	-600	-15	0.458375	75
Laser Setup	Y Linearity (YDY)	End Coordinate	[mm] (		0	-35	0.430375	75
Measure Roll	Z Linearity (ZDZ)	End obbidinate	fund 6			-55	1 752125	71
Measure Pitch/Yaw				-		-75	1 4445	75
Measure Linearity		Velocity [	mm/sj 2	25	Move To End	-95	2 543	71
Measure Straightness	Reflector Setup					-115	3.342625	78
Measure Squareness Edit Error Man						-135	3.450125	78
Configure GEC	Retro Reflector	Measurement mo	de:	🗇 Fly 🛛 🧕	Stop & Go	-155	3.418125	75
	Plane Mirror	Stop [m	ml	20		-175	3.950375	78
		Otep [iii		20		-195	4.0685	75
		Add dela	ay [sec]:	3		-215	4.0355	78
		#Runs:	1	V E	idirectional	-235	4.595125	75
	Offset of reflector to					-255	4.4105	78
	base of CMM quill:					-275	4.11525	81
	X [mm]: 0	Controller Readin	a (unc.):	99.9997	mm	-295	4.355	84
	Alimit.	Lecor Reading:	+/-	0.0	mm	-315	4.549625	81
	Y [mm]: 0	Laser Reading.		0.0		-335	4.828125	81
	Z [mm]: 0	Clear Laser error	r Syr	ic Laser read	lings	-355	5.095	84
	Z [mm].					۰ III		۱.
		Laser signal:	✓ Avera	ging 🗌	4 sec	; there are		
						1 1 N	na.	
						2.4	ممر ،	and the second
	Side View -							- N.
	$\square$					1		್
			-			• *********	Position (mm)	
A.	interest Max	Start	Stop					
ntec	Click to magnify					Load	Eait	Store

## 8. Measurements of linearity and straightness deviations

The procedure for linearity and straightness errors is the same as shown in the previous step. The only additional option concerns the chosen mirror setup.

	Weasure Straightness			Otrainkterne VD	v	
	Parameter	CMM and Laser Operation		Straightness XD	Ŷ	
GEC License GMM Setup	<ul> <li>X axis (XDY)</li> </ul>		Align laser beam	Coordinates [mm]	Deviation [micron]	Spread [micron]
T-Sensor Setup		Start Coordinate [mm] -600	-600	-600	0	
Laser Setup		End Coordinate [mm] 0	0	-580	0	
Measure Roll	Z axis (ZDX)			-560	0	
Measure Pitch/Yaw		Volocity [mm/s] 25	Move To End	-540	0	
Measure Linearity		velocity [mm/s] 25	Move to End	-520	0	
Measure Straightness Measure Squareness	Straightness			-500	0	
Edit Error Map				-480	0	
Configure GEC	Horizontal	Measurement mode: O Hy @	) Stop & Go	-460	0	
	Vertical	Step [mm]: 20		-440	0	
	Venicar			-420	0	
		Add delay [sec]: 3		-400	0	
	DX10 Options	# Runs: 1 🔍 E	idirectional	-380	0	
	DATO Options			-360	0	
	@ Long			-340	0	
	( Long	Controller Reading (unc.): 99.9997	mm	-320	0	
	Short	Laser Reading: +/- 0.0	mm	-300	0	
				-280	0	
		Clear Laser error Sync Laser read	lings	-260	0	
	Offset of reflector to base of CMM quill: X [mm]: 0 Y [mm]: 0 Z [mm]: 0	Laser signal: I Averaging	4 sec			
Intec		Start Stop		Load Clea	Pettion (mm)	Store

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### 9. Squareness measurement

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GEC Witzard (Masture Seuareners)					
Measure Squareness					
CMM Setup	Squareness XY				
Measure Roll		Nominal [mm]	Measured [mm]	Difference [um/m]	
Measure Pitch/Yaw Measure Position	Position 1 (-45°):	200	200.023	4 71000000000	
Measure Straightness  Measure Sourcess	Position 2 (+45°):	200	199.081	-+.71000000000	
Edit Error Map					
Contigure GEC	Squareness XZ				
		Nominal [mm]	Measured [mm]	Difference [um/m]	
	Position 1 (-45°):			0	
	Position 2 (+45°):				
	Squareness ZY				
		Nominal [mm]	Measured [mm]	Difference [um/m]	
	Position 1 (-45°):			0	
	Position 2 (+45°):				
pantec					
				Ba	ck Next
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The squareness error is commonly measured with gauges. Enter the values for nominal and measured distance into the corresponding fields for squareness XZ and ZY. The compensation parameter is computed immediately.



## 10. Error map editor

pantec	Load Clear Store Load Clear Store Load Clear Store Back Next	Support.Tool File View Configure Tools Wi III III III III IIII IIIIIIIIIIIIIIII	ndow Help A A A A A A A A A A A A A A A A A A A	Position X Coordinate Deviation 20 0	Position Y  Coordinate Deviatio  Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordinate Deviatio Coordina	Position Z Coordinate 	Deviation     0	- □ X
	Back Next	pantec		Load Clear St	re Load Clear S	Store Load	Labertaria	

The error map editor allows further adjustment of the error compensation data.



GEC Wizard - IConfigure GE	a				
loce mana (compare or	Configure GEC				
GEC License CMM Setup T-Sensor Setup Laser Setup Measure Roll Yaw Measure Pitch/Yaw Measure Straightness Measure Straightness Edit Error Map • Configure GEC	Enable Error Compensation Compensate for the selected Axes === Transla XDX YDX XDY YDY XDZ YDZ === Rotati XRX YRX XRY YRY Select All	Flags demons: tions === ZDX ZDY ZDY ZDZ cons === ZRX ZRY ZRY Deselect All	Rectangularity Squareness Tool Offsets Tool Offsets	Thermal expansion Axes	
pantec	Update GEC with 2.5E	(.grid) file		Update GEC files	
				Back	Finish

# 11. Configuration of the geometric error compensation

On the final page the various compensation parameters can be activated and deactivated. The compensation data files and the GEC configuration are written when pressing the button "Update GEC files".



#### **12.** Example: squareness compensation

In this example the measurement of a 300.001 mm ring measured in the XZ plane without compensation shows a clear deviation from rectangularity.



Using the GEC Wizard the squareness compensation parameter was determined. After the update of the compensation data files with the new values the situation improves significantly. The remaining deviations are due to other error components.

