Level Calibration Analysis

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Executive Summary

Based on comparing the confidence limits of twelve, 5-point calibrations conducted by 4 operaters (3 calibrations each) to their composite regression, which is assumed to be the best estimate of the true calibration coefficients, the 5-point calibration resulted in a worst-case measurement uncertainty of about ±0.004”

Overview

- This analysis has two parts:
  1. Analysis of the individual measurement Repeatability & Reproducibility.
  2. Analysis of the goodness of a 5-point calibration.
- The coefficients of the best fit of the composite measurements (all 60 observations) is considered the best estimate of the true calibration coefficients, aka “Best Cal”.
- The 5-point calibration is an evaluation tool to verify the “Best Cal” is still valid for testing to proceed.

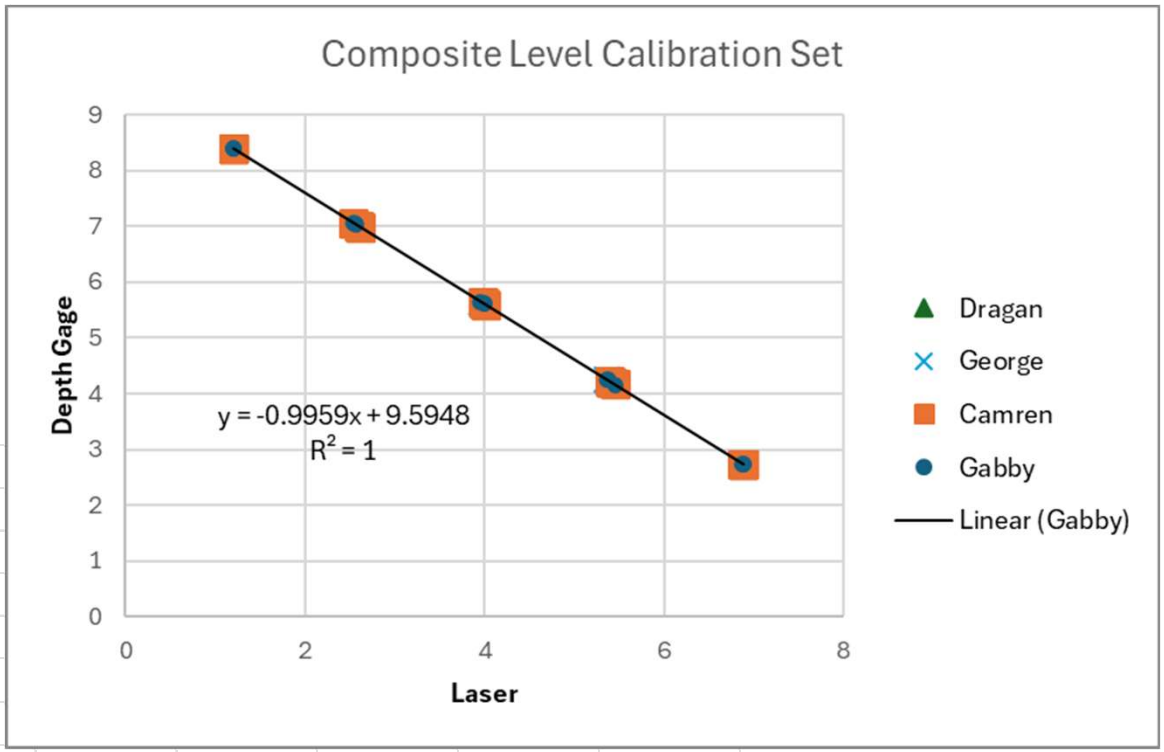
Composite Data Set Measurements

DEFINITIONS

- **Obs** Measurement Number
- **Ope**r Operator ID
- **Rank** Order of Variance from ANOVA
- **Operator** Operator Name
- **Level Set Point** 5 observation points per calibration, the Full point is fixed at 2.75”, Empty is fixed at 8.4” while the three intermediate points are the quintile levels +/- random amount ranging over 0.100”.
- **Laser** Level Value read by the LK-G3000 Keyance Laser
- **Measure** Level Value from the Depth Gage entered by the Operator
- **Cal ID** the number assigned to a 5-point calibration
- **Goodness** the maximum residual from 5-point calibration regression
- **Slope & Intercept** coefficients resulting from 5-point calibration regression.

Obs	Oper Rank	Operator	Level	Set Point	Laser	Measure	Cal ID	Goodness	Slope	Intercept
46	1	Dragan	1	8.4	1.208	8.39	10	0.002	-0.995	9.59
47	1	Dragan	2	6.998	2.613	6.99				
48	1	Dragan	3	5.618	3.993	5.617				
49	1	Dragan	4	4.167	5.454	4.165				
50	1	Dragan	5	2.75	6.883	2.745				
51	1	Dragan	1	8.4	1.209	8.39	11	0.006	-0.996	9.595
52	1	Dragan	2	7.067	2.543	7.06				
53	1	Dragan	3	5.596	4.015	5.596				
54	1	Dragan	4	4.227	5.395	4.228				

Composite Measurement Regression



Regression Statistics	
Multiple R	0.999996
R Square	0.999992
Adjusted R Square	0.999992
Standard Error	0.00576
Observations	60

ANOVA

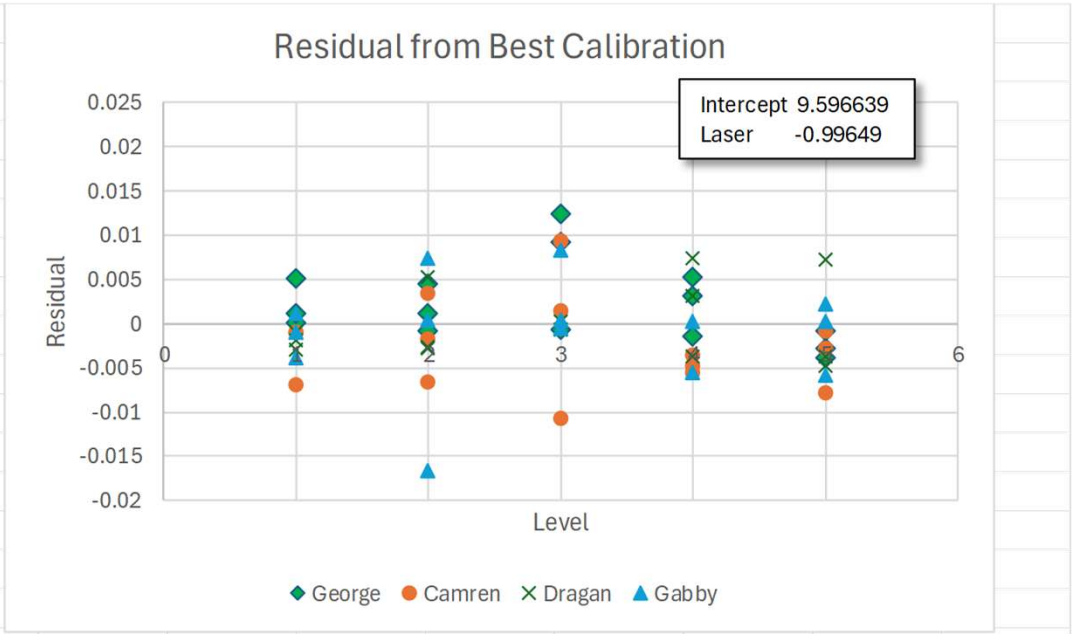
	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	239.377	239.377	7214887	1.9E-149
Residual	58	0.001924	3.32E-05		
Total	59	239.3789			

	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	9.596639	0.001663	5770.792	1E-168	9.59331	9.599968	9.59331	9.599968
Laser	-0.99649	0.000371	-2686.05	1.9E-149	-0.99723	-0.99575	-0.99723	-0.99575

Best estimate of calibration coefficients

Residual Plot & ANOVA Against Best Cal

Level	George	Camren	Dragan	Gabby
1	0.000119476	-0.00089	-0.00288	-0.00388
2	-0.000796079	0.003408	-0.00281	0.000408
3	0.009253255	0.001415	-0.00066	0.000341
4	-0.001451634	-0.00549	0.003211	-0.00549
5	-0.000788522	-0.00279	0.007194	-0.00578
1	0.001122987	-0.00689	-0.00188	-0.00089
2	0.001161788	-0.00658	-0.00257	-0.01656
3	-0.000680034	0.009373	0.000264	0.00832
4	0.005355255	-0.00475	0.007418	0.020485
5	-0.002777989	-0.00778	-0.00376	0.002208
1	0.005122987	-0.00088	-0.00088	0.001116
2	0.004477788	-0.00166	0.005236	0.007334
3	0.01249201	-0.01063	-0.00059	-0.00053
4	0.003197255	-0.00346	-0.00362	0.000204
5	-0.003774477	-0.00078	-0.0048	0.000211



ANOVA with Gabby

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
George	15	0.032034	0.002136	2.05E-05
Camren	15	-0.0384	-0.00256	2.46E-05
Dragan	15	-0.00114	-7.6E-05	1.59E-05
Gabby	15	0.007505	0.0005	6.42E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000171	3	5.69E-05	1.815393	0.15484	2.769431
Within Groups	0.001754	56	3.13E-05			
Total	0.001924	59				

H_0: There is no reproducibility difference between operators.

H_A: There is a significant difference between operators.

Since P-value is > 0.05 can NOT reject H_0

**Post Hoc analysis show a significant difference between Dragan and Gabby (rank 1 to rank 4).

Compare Measurement Residuals

with and without Gabby

Residuals with Gabby			*Residuals sans Gabby*
Mean	5.18E-16		5.92E-17
Standard Error	0.000737		0.000715
Standard Deviation	0.005711		0.004799
Sample Variance	3.26E-05		2.3E-05
Kurtosis	2.713376		0.410725
Skewness	0.622239		0.572689
Range	0.037042		0.02312
Minimum	-0.01656		-0.01047
Maximum	0.020485		0.012647
Count	60		45
Confidence Level(95.0%	0.001475		0.001442

Indicates there is a significant difference in the shape of the distribution tails.

ANOVA sans Gabby

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Dragan	15	0.00138	9.20037E-05	1.67E-05		
Camren	15	-0.03592	-0.002394852	2.42E-05		
George	15	0.034543	0.002302848	1.96E-05		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000166	2	8.28517E-05	4.104267	0.023545	3.219942
Within Groups	0.000848	42	2.01867E-05			
Total	0.001014	44				

H_0: There is no reproducibility difference between operators.

H_A: There is a significant difference between operators.

Since P-value is < 0.05 Reject H_0 Accept H_A

**Post Hoc Tukey analysis would be warranted to compare operators.

Composite Data Set Calibrations

DEFINITIONS

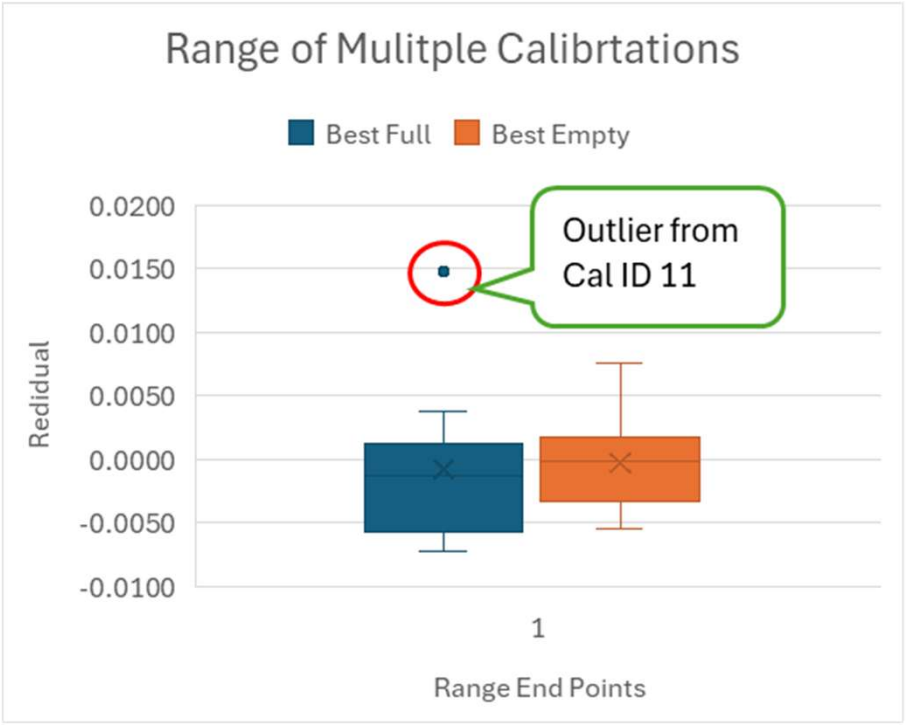
- **Full =7** This is the Lazer reading to give near Full Level measurement.
- **Empty=1.2** This is the Laser reading to give near Empty Level measurement.
- **Best Full** Residual from this calibration fit to the Best Cal fit at the Full point.
- **Best Empty** Residual from this calibration fit to the Best Cal fit at the Empty point.

The idea is to assess the individual 5-point calibrations against the Best Cal.

ID	Oper Rank	Operator	Cal ID	Goodness	Slope	Intercept	Full =7	Empty=1.2	Best Full	Best Empty
1	1	Dragan	10	0.002	-0.995	9.590	2.625	8.396	0.0038	-0.0049
2	1	Dragan	11	0.006	-0.996	9.595	2.623	8.400	0.0018	-0.0011
3	1	Dragan	12	0.005	-0.998	9.600	2.614	8.402	-0.0072	0.0015
4	2	George	1	0.008	-0.997	9.599	2.620	8.403	-0.0012	0.0017
5	2	George	2	0.005	-0.997	9.598	2.619	8.402	-0.0022	0.0007
6	2	George	3	0.008	-0.998	9.606	2.620	8.408	-0.0012	0.0075
7	3	Camren	4	0.003	-0.997	9.599	2.620	8.403	-0.0012	0.0017
8	3	Camren	5	0.013	-0.997	9.594	2.615	8.398	-0.0062	-0.0033
9	3	Camren	6	0.008	-0.997	9.594	2.615	8.398	-0.0062	-0.0033
10	4	Gabby	7	0.003	-0.997	9.596	2.617	8.400	-0.0042	-0.0013
11	4	Gabby	8	0.015	-0.993	9.587	2.636	8.395	0.0148	-0.0055
12	4	Gabby	9	0.005	-0.997	9.600	2.621	8.404	-0.0002	0.0027

Calibration v Best Cal Residuals Statistics

	Full		*Empty*
Mean	2.6204		8.4006
Standard Error	0.0017		0.0010657
Median	2.62		8.4007
Mode	2.62		8.4026
Standard Deviation	0.0059		0.0036918
Sample Variance	3E-05		1.363E-05
Kurtosis	4.076		0.3510147
Skewness	1.7249		0.5006853
Range	0.022		0.013
Minimum	2.614		8.3954
Maximum	2.636		8.4084
Sum	31.445		100.8072
Confidence Level(95.0%)	0.0038		0.0023456



Cal ID 11 with a “Goodness” score of 15 is suspect and generated this outlier. Should it be eliminated from the analysis?

Cal ID 8 with a “Goodness” score of 13 is marginal?

Calibration Full & Empty Reproducibility

SLOPE	George	Dragan	Camren	Gabby
	-0.997	-0.995	-0.997	-0.997
	-0.997	-0.996	-0.997	-0.993
	-0.998	-0.998	-0.997	-0.997

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
George	3	-2.992	-0.9973	3.33E-07
Dragan	3	-2.989	-0.9963	2.33E-06
Camren	3	-2.991	-0.9970	0.00E+00
Gabby	3	-2.987	-0.9957	5.33E-06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.92E-06	3	1.64E-06	0.819444	0.518657	4.066181
Within Groups	0.000016	8	0.000002			
Total	2.09E-05	11				

INTERCEPT	George	Dragan	Camren	Gabby
	9.599	9.590	9.599	9.596
	9.598	9.595	9.594	9.587
	9.606	9.600	9.594	9.600

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
George	3	28.803	9.6010	1.90E-05
Dragan	3	28.785	9.5950	2.50E-05
Camren	3	28.787	9.5957	8.33E-06
Gabby	3	28.783	9.5943	4.43E-05

ANOVA

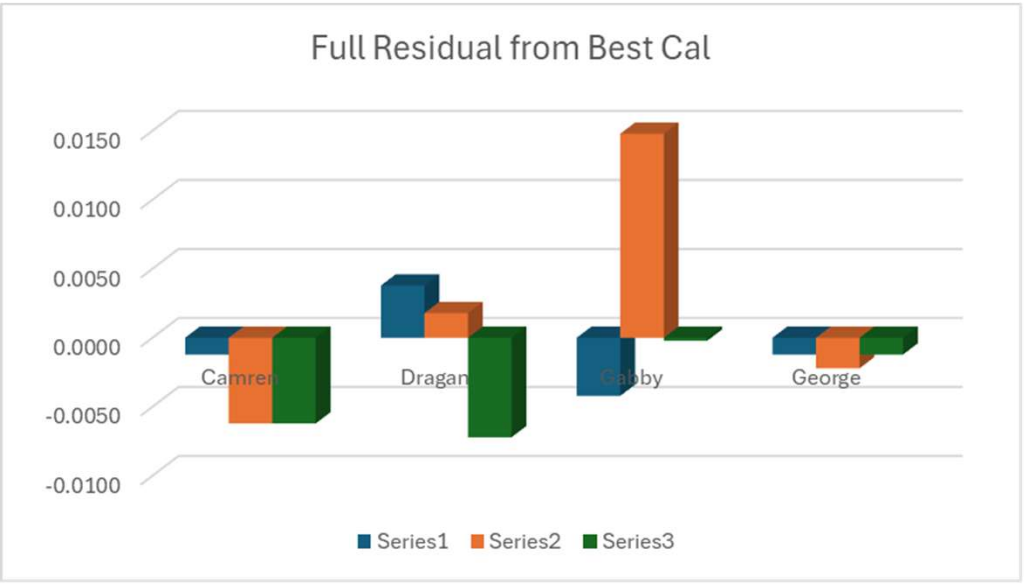
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.36667E-05	3	3E-05	1.15402	0.3851226	4.066180551
Within Groups	0.000193333	8	2E-05			
Total	0.000277	11				

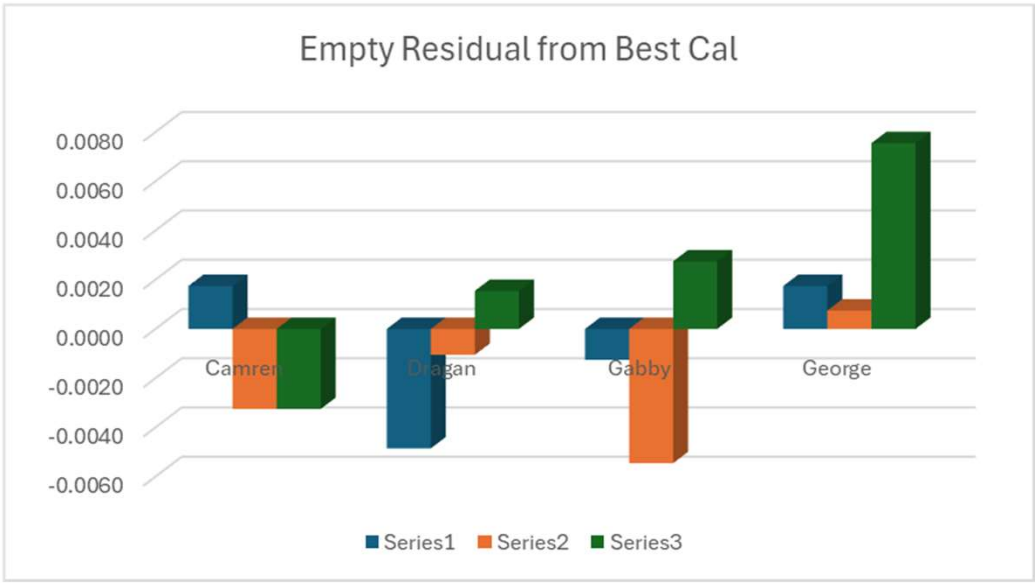
H_0: There is no reproducibility difference between operators.

H_A: There is a significant difference between operators.

Since P-value is >> 0.05 can NOT reject H_0

Calibration Full & Empty Reproducibility Plot





Conclusion

- Determine what is the acceptable System Measurement Uncertainty to set Target TP (see below).
- Need to determine the “Goodness” Criteria for flagging a calibration verification issue prior to ATP Testing.