Welcome to the Webinar!

Uncertainty Propagation for Force Calibration Systems

Presented by:

Henry Zumbrun, Morehouse Instrument Company

Hosted by PJLA- Tracy Szerszen, President

September 12, 2024
1:00-2:00 PM EST

PJLA

Webinar Housekeeping

- This webinar will be recorded
- All PJLA webinars are made available on our website & YouTube channel

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Uncertainty Propagation for Force Calibration Systems

MHFORCE

Morehouse

THE FORCE IN CALIBRATION SINCE 1925

Uncertainty Propagation for Force Calibration Systems

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What we do

We are a manufacturing company that produces force calibration equipment and adapters, that are used in industry, to measure force.

We have force and torque calibration laboratories and offer calibrations with very low reference standard uncertainties.

Our Purpose

We create a safer world by helping companies improve their force and torque measurements.

Topics Covered

- Overview of typical force systems and uncertainties
- Comparison of existing guidance documents
- Breakdown of uncertainty contributors for ASTM E74 calibrations
- Explanation of the tiered system for force calibration standards
- Practical examples of uncertainty calculations at different tiers
- Discussion of common error sources in force measurements

Outcomes

- The webinar aims to give attendees a comprehensive understanding of uncertainty propagation in force calibration, enabling improved accuracy and reliability in force measurements.

Uncertainty Propagation for Force Calibration Systems

- I will discuss why we developed a method to calculate force CMC's
- I will discuss a general overview of typical force systems and their uncertainties
- I will cover Morehouse recommendations for calculating Calibration and Measurement Capability for force standards calibrated to ASTM E74

Why develop a new method for calculating force CMC's

Guidance Documents

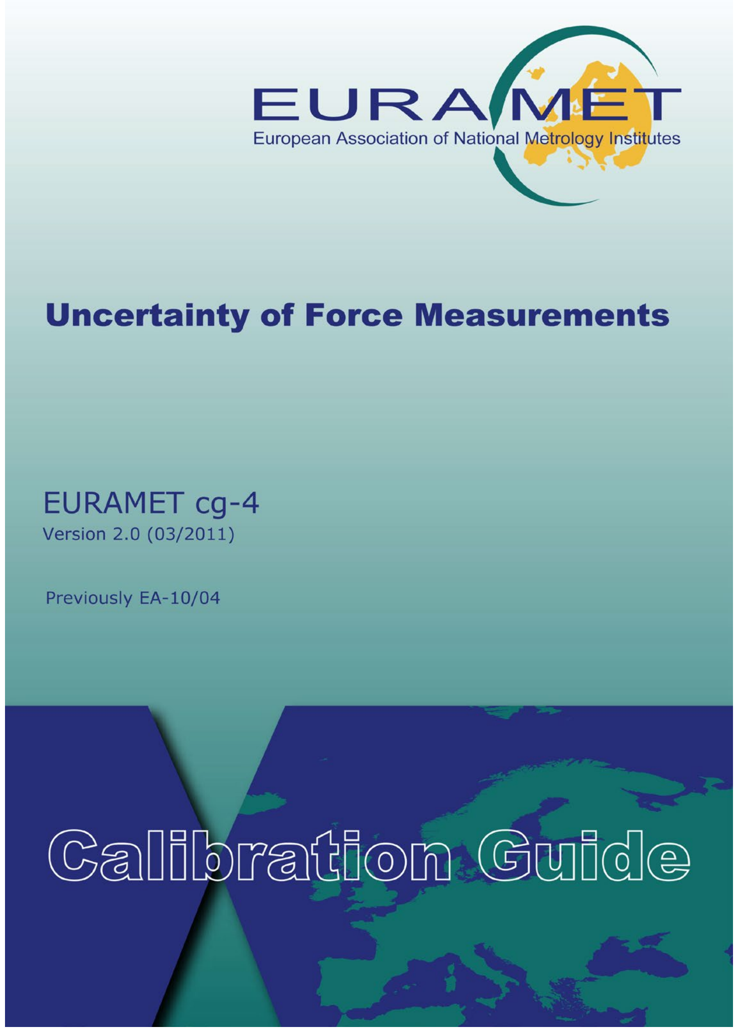
- NCSLI RP-12 Determining and Rpt. Measurement Uncertainties (2013) Section 7
- Euramet cg-4 Uncertainty of Force Measurements (Relies on having the transducer calibrated to the ISO 376 standard)
- ASTM E74 Appendix

Lack of a designated guideline for calculating force uncertainties when using ASTM E74 that complies with the Accreditation Bodies Requirements for calculating CMC

Force Standards Current State

- Euramet cg-4 is the most complete document with 23 pages though it deals with calibrations conforming to ISO 376.
- NCSLI RP-12 pages 75-93 (18 pages, but only 5 deal specifically with the load cell, then Amplifiers are added as well as DC voltage)
- ASTM E74-18 Appendix 7 pages which ends with U = 2 x uc

$$u_c = \sqrt{u_{cal}^2 + u_r^2 + u_z^2}$$



NCSLI RP-12 Determining and Rpt. Measurement Uncertainties (2013)

Parameter Name	Description	Nominal Or Mean Value	Error Containment Limits	Containment Probability (%)
W_C	Calibration Weight or Load	3 lbf	±0.003 lbf	99
S	Load Cell Sensitivity	0.4 mV/V/lbf		
NL	Nonlinearity	0 mV/V	±0.001 mV/V	95
Hys	Hysteresis	0 mV/V	±0.001 mV/V	95
NS	Nonrepeatability	0 mV/V	±0.001 mV/V	95
ZO	Zero Balance	0 mV/V	±0.02 mV/V	95
$TR_{°F}$	Temperature Range	10 °F	±2.0 °F	99
TE_{Out}	Temperature Effect on Output	0 lbf/°F	$\pm 1.5 \times 10^{-4}$ lbf/°F	95
TE_{Zero}	Temperature Effect on Zero	0 mV/V /°F	±0.0001 mV/V /°F	95
V_{ex}	Applied Excitation Voltage	8 V	± 0.25 V	95

What we see happening

This uncertainty budget applies to the following type of measurement:	Should not be used for Force
Applicable range of measurement:	200-2000 lbf
Following calibration procedure no. and rev.:	
All uncertainties are expressed in units of:	lbf
Number of significant figures for reporting of expanded uncertainty:	3 Date prepared: 2017-11-27
Uncertainty budget prepared by:	Not an A2LA auditor

i	Component of Uncertainty	Uncertainty, U(xi)	Distribution	Divisor	Std Unc, u(xi)	
1	Non-Linearity	0.6	Normal, 1s	1.00	0.6	lbf
2	Repeatability between technicians (Measurement Process)	0.00645	Normal, 1s	1.00	0.00645	lbf
3	Repeatability	0.0129	Normal, 1s	1.00	0.0129	lbf
4	Resolution UUT	0.01	Rect x 2	3.46	0.002887	lbf
5	Environmental	0.003	Rectangular	1.73	0.001732	lbf
6	Stability	0.02	Rectangular	1.73	0.011547005	lbf
7	Ref Lab CMC	0.0032	Normal, 2s	2.00	0.0016	lbf
8	Resolution of Ref	0.009	Rect x 2	3.46	0.002598076	lbf
9						
10						
	combined standard uncertainty, u_c				0.6003	lbf
	coverage factor, k				2	
	expanded uncertainty, U_c				1.201	lbf
	Expanded uncertainty rounded UP to 3 significant figures				**1.21**	**lbf**

The load cell was calibrated in accordance with the ASTM E74 Standard and yet no mention of the lower limit factor

At 2000 lbf U = 1.21 lbf or 0.061 %, At 200 lbf U = 1.21 lbf or 0.61 %.

This is why Morehouse came up with a hybrid approach to ASTM E74 uncertainty calculations

We take the ASTM E74 Appendix and combine most of it with requirements of JCGM 100:2008. When we did this, we produced a guide for calculating MU using our UCM machine.

- https://mhforce.com/wp-content/uploads/2021/05/How-to-Develop-an-Uncertainty-Budget-for-a-Morehouse-Calibrating-Machine.pdf

We also developed a more generic guide.

- https://mhforce.com/wp-content/uploads/2021/05/Guidance-on-Uncertainty-Budgets-for-Force-Measuring-Devices.pdf

Force CMC for ASTM E74 Calibrations

Type A Uncertainty Contributors

1) ASTM Lower Limit Factor (LLF) reduced to 1 Standard Deviation (ASTM LLF is reported with k= 2.4)
2) Repeatability of the Best Existing Device
3) Repeatability and Reproducibility Between Operators

Type B Uncertainty Contributors

1) Resolution of the Best Existing Device
2) Reference Standard Resolution* *If Applicable*
3) Reference Standard Uncertainty
4) Reference Standard Stability
5) Environmental Factors
6) Other Error Sources

Do not use SEB, Nonlinearity, or Hysteresis as they are not appropriate contributors when following the ASTM E74 standard.

Measurement Uncertainty

Morehouse Measurement Uncertainty Calibration and Measurement Capability Worksheet

Start on this sheet and fill in only the light grey boxes. Choose a drop down option for the dark grey boxes.

Section 1: Data Entry

Laboratory	Morehouse		
Technician Initials	DD		
Date:	11/20/2023		
Applied Maximum	100000		
Standards Used (Ref and UUT)	100000 lbf		
Force or Torque/Subrange	Force Compression		
Resolution UUT	0.24	LBF	
Reference Standard Information			
ASTM E74 LLF	0.78	LBF	* This is your ASTM E74 LLF Found on Your ASTM E74 Report. It will be converted to a pooled std dev
Resolution of Reference Standard	0.24	LBF	
Temperature Spec per degree C %	0.0015%		
Max Temperature Variation per degree C of Environment	1		* This is set for a Morehouse load cell based on the specification sheet
Morehouse CMC (Ref Lab)	0.0016%		Optional: If entering Engineering Units, leave blank and complete the Ref Laboratory Uncertainty Per Point (P29 - 40)
Non ASTM or ISO 376 (Tolerance,Non-Linearity,SEB)		%	Leave Blank if Not Used
Miscellaneous Error	0.003	%	Leave Blank if Not Used (Select % or Eng. Units if a constant)
Conv Repeatability Data To Eng. Units	YES		

Enter Information into these color cells	
	Initial Setup and after new calibra
	Initial Setup
Uncertainty Worksheet and R & R Between Techs Need to Filled Out for CMC Summary to be correct	

Ref Standard Stability

	FORCE APPLIED	Change From Previous %	Interpolation Value	Actual LBF	Temperature Effect 0.000015
1	1000	0.000%	-0.08	0	0.015
2	10000	0.007%	-0.08	0.7	0.15
3	20000	0.006%	0.70	1.2	0.3
4	30000	0.002%	0.60	0.6	0.45
5	40000	0.000%	0.00	0	0.6
6	50000	0.002%	1.00	1	0.75
7	60000	0.002%	1.20	1.2	0.9
8	70000	0.002%	1.40	1.4	1.05
9	80000	0.001%	0.80	0.8	1.2
10	90000	0.000%	0.00	0	1.35
11	100000	0.002%	2.00	2	1.5
12			-0.08		0

ISO 376 Uncertainty Coefficients

C0	C1	C2

Expanded Uncertainty = C0 + (C1 * F) + (C2 * F)^2

Where F = Force Applied, C0 = Intercept, C1 = Slope

Repeatability of UUT

	Applied	Run1	Run2	Run3	Run4	Average	Resolution	STD DEV	CONVERTED
1	1000.00	-0.04205	-0.04206	-0.04205		-0.04205333	-23779.3278	5.774E-06	-0.13729
2	10000.00	-0.42028	-0.42029	-0.42027		-0.42028	-23793.6614	1E-05	-0.2379366
3	20000.00	-0.84062	-0.84063	-0.84062		-0.8406	-23791.8687	5.774E-06	-0.1373624
4	30000.00	-1.26104	-1.26106	-1.26105		-1.26105	-23789.6991	1E-05	-0.237897
5	40000.00	-1.68151	-1.68153	-1.68152		-1.68152	-23788.0013	1E-05	-0.23788
6	50000.00	-2.10203	-2.10205	-2.10204		-2.10204	-23786.417	1E-05	-0.2378642
7	60000.00	-2.52258	-2.52261	-2.52260		-2.52259667	-23785.0152	1.528E-05	-0.3633221
8	70000.00	-2.94321	-2.94324	-2.94323		-2.94322667	-23783.4214	1.528E-05	-0.3632978
9	80000.00	-3.36384	-3.36386	-3.36385		-3.36385	-23782.2733	1E-05	-0.2378227
10	90000.00	-3.78448	-3.78451	-3.78450		-3.78449667	-23781.2338	1.528E-05	-0.3632643

Ref Laboratory Uncertainty Per Point

Force	%	Eng. Units	Conv %	Force	MUST SELECT % or Eng.
1000	0.0016%		0.000016	1000	%
10000	0.0016%		0.000016	10000	%
20000	0.0016%		0.000016	20000	%
30000	0.0016%		0.000016	30000	%
40000	0.0016%		0.000016	40000	%
50000	0.0016%		0.000016	50000	%
60000	0.0016%		0.000016	60000	%
70000	0.0016%		0.000016	70000	%
80000	0.0016%		0.000016	80000	%
90000	0.0016%		0.000016	90000	%

http://www.mhforce.com/Files/Support/249/CMC-CALCULATIONS-FOR-FORCE-MEASUREMENTS.xlsx

Typical Uncertainty Tiers For Force Calibration

PRIMARY STANDARDS
0.001 to 0.005 %

SECONDARY STANDARDS
>0.005 % to 0.05 %

WORKING STANDARDS
>0.05 % to 0.5 %

DEVICES FOR FORCE VERIFICATION
>0.5 % to 5 %

Tier 1 Primary Standards a deadweight force applied directly without intervening mechanisms such as levers, hydraulic multipliers, or the like, whose mass has been determined by comparison with reference standards traceable to national standards of mass. Require correction for the effects of Local Gravity and Air Buoyancy

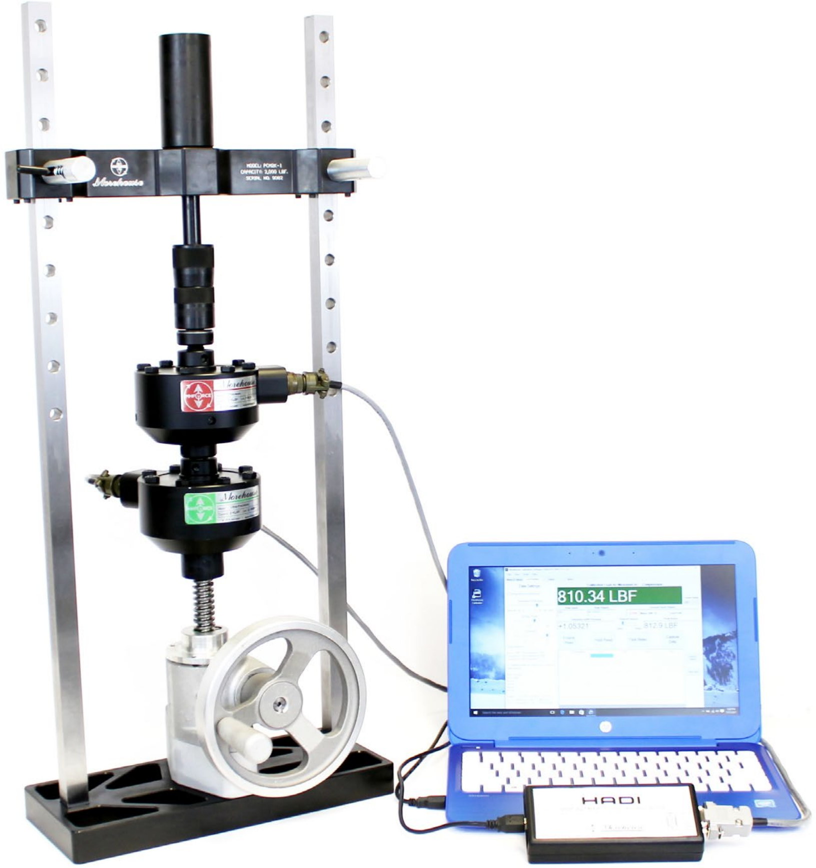
Tier 2 Secondary Standards instruments such as load cells, proving rings, and other force measuring devices or a mechanism, the calibration of which has been established by comparison with primary force standards

Tier 3 Working Standards instruments such as load cells, force gages, crane scales, dynamometers, etc., Where the laboratory falls into this range largely depends on the reference standard used to calibrate the device. To achieve 0.1 % may require very stable devices and calibration by primary standards.

Tier 4 Devices for Force Verification instruments or Universal Testing Machines (UTM) used for testing material or verification of forces. Further dissemination of force is uncommon after this tier as the measurement uncertainty becomes quite large.

Note: All %'s are of applied force

Force CMCs at Different Tiers



Tier 1: Primary Standard 0.0016 % used to calibrate Secondary Standards to Class AA

Tier 2: Secondary Standard 0.02 % used to calibrate load cells to Class A

Force CMCs at Different Tiers






Tier 3 :Calibration of Working Standards using a Comparator (Morehouse Bench Top machine with load cell) to calibrate various different equipment. CMC’s typically vary from 0.03 % to 0.5 %.

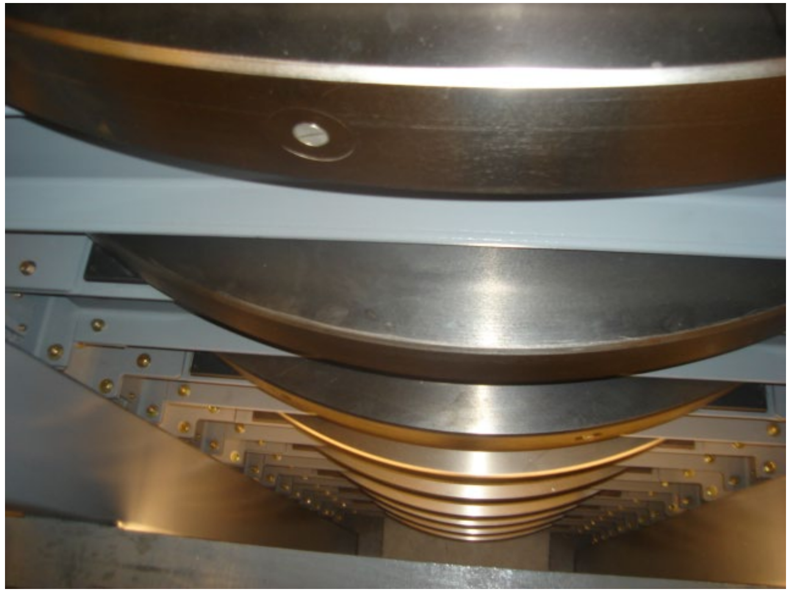
Tier 0 Primary Standard Calibration Requires

Correction for the effects of
- Local Gravity
- Air Buoyancy
- Material Density

Force = M x g / 9.80665 m/s^2 (1 – d/ D)
Where M = mass of weight, g = gravity at fixed location, d = air density, and D = material density

Uncertainty Propagation For Force Calibration Systems Tier 0 Primary Standard

- Tier 0 Primary Standard With Weights Calibrated Directly by NIST These weights, pictured right, were adjusted for the local gravity, material density, and air buoyancy, and their traceability is derived from the international prototype kilogram (SI unit symbol kg)



Uncertainty Propagation For Force Calibration Systems Tier 0 Primary Standard

- We will use the NIST certificate for Ref Uncertainty
- We are going to figure errors due to material density calc, gravity determination, air density variation, environment, temperature, stability etc..,
- We are going to use the "Best Existing Device" to conduct repeatability studies on our machine and factor in resolution of this device as an uncertainty contributor
- We are going to test all of our operators in our lab using a gage R & R

Force CMC for ASTM E74 Calibrations Tier 1

Type A Uncertainty Contributors

1) ASTM Lower Limit Factor (LLF) reduced to 1 Standard Deviation (ASTM LLF is reported with k= 2.4)
2) Repeatability of the Best Existing Device
3) Repeatability and Reproducibility Between Operators

Type B Uncertainty Contributors

1) Resolution of the Best Existing Device
2) Reference Standard Resolution* *If Applicable*
3) Reference Standard Uncertainty from Tier 1
4) Reference Standard Stability
5) Environmental Factors
6) Other Error Sources

Force CMC for ASTM E74 Calibrations Tier 1

We will calibrate a load cell in a Morehouse deadweight machine in accordance with the ASTM E74-18 standard which will give us the ASTM LLF.

ASTM LLF – ASTM E74 standard uses a method of least squares to fit a polynomial function to the data points.

The standard deviation of the all of the deviations from the predicted values by the fit function versus the observed values is found by taking the square root of the sum of all of the squared deviations divided by the number of samples minus the degree of polynomial fit used minus one. This number is then multiplied by a coverage factor (k) of 2.4 and then multiplied by the average ratio of force to deflection from the calibration data.

$$s_m = \sqrt{}((d_1{}^2 + d_2{}^2 + .. + d_n{}^2)/(\text{n-m-1}))$$

Force CMC for ASTM E74 Calibrations

Type A Uncertainty Contributors

1) ASTM LLF reduced to 1 Standard Deviation (ASTM LLF is reported with k= 2.4)

Calibration Procedure: ASTME74-18 Method B

	STANDARD DEVIATION mV/V	RESOLUTION FORCE UNITS	LOWER LIMIT FACTOR FORCE UNITS	CLASS A LOWER VERIFIED RANGE OF FORCE UNITS	CLASS A UPPER VERIFIED RANGE OF FORCE UNITS
COMPRESSION	0.0000097	0.009	0.021	50.00	2000.00

Force CMC for ASTM E74 Calibrations

Measurement Uncertainty Budget Worksheet									
Laboratory	Morehouse								
Parameter	FORCE	Range	2K	Sub-Range					
Technician	HZ	Standards Used							
Date	8/10/2017								
Uncertainty Contributor	**Magnitude**	**Type**	**Distribution**	**Divisor**	**df**	**Std. Uncert**	**Variance (Std. Uncert^2)**	**% Contribution**	**u^4/df**
Repeatability Between Techs	**0.025514849**	**A**	None	0.000	1				
Reproducibility Between Techs	**0.002621177**	**A**	Normal	1.000	18	2.62E-3	6.87E-6	1.65%	2.6E-12
Repeatability	12.9099E-3	A	Normal	1.000	3	12.91E-3	166.67E-6	40.06%	9.3E-9
ASTM E74 LLF	8.7500E-3	A	Normal	1.000	32	8.75E-3	76.56E-6	18.40%	183.2E-12
Resolution of UUT	10.0000E-3	B	Resolution	3.464	200	2.89E-3	8.33E-6	2.00%	347.2E-15
Environmental Conditions	3.0000E-3	B	Rectangular	1.732	200	1.73E-3	3.00E-6	0.72%	45.0E-15
Stability of Ref Standard	20.0000E-3	B	Rectangular	1.732	200	11.55E-3	133.33E-6	32.05%	88.9E-12
Ref Standard Resolution	9.0000E-3	B	Resolution	3.464	200	2.60E-3	6.75E-6	1.62%	227.8E-15
Non ASTM or ISO 376	000.0000E+0	B	Rectangular	1.732	200	000.00E+0	000.00E+0	0.00%	000.0E+0
Miscellaneous Error	6.0000E-3	B	Rectangular	1.732	200	3.46E-3	12.00E-6	2.88%	720.0E-15
Morehouse CMC (REF LAB)	3.2000E-3	B	Expanded (95.45% k=2)	2.000	200	1.60E-3	2.56E-6	0.62%	32.8E-15
			Combined Uncertainty (u_c)=			**20.40E-3**	**416.08E-6**	**100.00%**	**9.5E-9**
			Effective Degrees of Freedom			**18**			
			Coverage Factor (k) =			**2.10**			
			Expanded Uncertainty (U) K =			**0.04**	**0.02143%**		
Slope Regression Worksheet									
	Applied	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Average**	**Std. Dev.**	Ref CMC	LBF
1	200.00	200.00	199.99	200.02	200.01	**200.005**	**0.0129**	0.0016%	0.0032
Repeatability (Of Error)			**Average Standard Deviation of Runs**			**0.012910**			

Repeatability of Best Existing Device

- Repeatability Data – Data needs to be taken for various test points throughout the loading range. This example only shows one data point.

Repeatability of UUT								
Applied	**Run1**	**Run2**	**Run3**	**Run4**	**Average**	**Resolution**	**STD DEV**	**CONVERTED**
200.00	200.00	199.99	200.02	200.01	200.005	1	0.01290994	0.01290994

A good rule may be to take a repeatability point every 10 % for every loading range

Repeatability of Best Existing Device

Repeatability condition of measurement, repeatability condition (VIM 2.20) - condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time

Reproducibility

VIM 2.24 (3.7, Note 2) reproducibility condition of measurement
reproducibility condition - condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects

MSA 4th Edition

Reproducibility This is traditionally referred to as the "between appraisers" variability. Reproducibility is typically defined as the variation in the average of the measurements made by different appraisers using the same measuring instrument when measuring the identical characteristic on the same part.

Repeatability and Reproducibility

Reproducibility – Reproducibility was determined using an R&R study. We had two technicians performed 10 runs of data, and their overall results were compared against one another. A standard deviation of the average was calculated between technicians, converted to the appropriate units and used for the final reproducibility

Reproducibility = Standard Deviation of the Average

Repeatability and Reproducibility Worksheet						
	Technician 1	Technician 2	Technician 3	Technician 4	Technician 5	Technician 6
1	3.23715	3.23715				
2	3.23719	3.23718				
3	3.23721	3.23721				
4	3.23715	3.23723				
5	3.23716	3.23720				
6	3.23721	3.23716				
7	3.23721	3.23720				
8	3.23726	3.23724				
9	3.23728	3.23725				
10	3.23727	3.23721				
Std. Dev.	4.8408E-05	3.26769E-05				
Average	3.237209	3.237203				
Variance	2.34333E-09	1.06778E-09				
Repeatability		**4.12984E-05**		617.82	**0.025514849**	LBF
Reproducibility		**4.24264E-06**			**0.002621177**	LBF

Resolution of Best Existing Device

Resolution – Smallest change in a quantity being measured that causes a perceptible change in the corresponding indication.

Best existing device (ILAC P14): The term "best existing device" is understood as a device to be calibrated that is commercially or otherwise available for customers, even if it has a special performance (stability) or has a long history of calibration. For force calibrations this is often a very stable load cell and indicator with enough resolution to observe differences in repeatability conditions.

Resolution of Unit Under Test (Best Existing Device) = 0.01 FORCE UNITS

Reference Standard Calibration Uncertainty – This is usually the measurement uncertainty in the calibration of reference standard used to calibrate the force measuring device.

Optional: If entering Engineering Units, leave blank and complete the Ref Laboratory

Uncertainty Per Point (P29 - 40)

Morehouse CMC (REF LAB)	**0.0016%**

Reference Standard Stability

Reference Standard Stability – The change in output from one calibration to another. This number is found by comparing multiple calibrations against one another over time.

Ref Standard Stability			
FORCE APPLIED	Change From Previous %	Interpolation Value	Actual LBF
200	0.0100%	0.02	0.02

Environmental Factors

± 1 degree Celsius was used, and this is found on the manufacturer's specification sheet. Converting 0.08/100 degrees F gives us 0.0015 per 1 degree Celsius

Ultra-Precision Shear Web Load Cells

Technical Specifications

Specifications	Model - Capacity (lbf / kN)				
	300-2K / 1-10	5K-10K / 20-50	25K-50K /100-250	100K / 500	200K / 900
Accuracy					
Static Error Band, % R.O.	±0.02	± 0.03	± 0.03	± 0.03	± 0.03
Non-Linearity, % R.O.	±0.02	± 0.03	± 0.03	± 0.03	± 0.03
Hysteresis, % R.O.	± 0.02	± 0.04	± 0.04	± 0.04	± 0.04
Non-Repeatability, % R.O.	± 0.005	± 0.005	± 0.05	± 0.05	± 0.05
Creep, % Rdg / 20 Min.	± 0.015	± 0.015	± 0.015	± 0.015	± 0.015
Off-Center Load Sensitivity, %/in	±0.05	± 0.05	± 0.05	± 0.05	± 0.05
Side Load Sensitivity, %	± 0.05	± 0.05	± 0.05	± 0.05	± 0.05
Zero Balance, % R.O.	± 1.0	± 1.0	± 1.0	± 1.0	± 1.0
Temperature					
Range, Compensated, °F	+15 to +115	+15 to +115	+15 to +115	+15 to +115	+15 to +115
Range, Operating, °F	-65 to +200	-65 to +200	-65 to +200	-65 to +200	-65 to +200
Sensitivity Effect, % Rdg / 100°F	0.08	0.08	0.08	0.08	0.08
Zero Effect, % R.O. / 100°F	0.08	0.08	0.08	0.08	0.08
Electrical					
Recommended Excitation, VDC	10	10	10	10	10
Input Resistance, Ω	350 +40/-3.5	350 +40/-3.5	350 +40/-3.5	350 +40/-3.5	350 +40/-3.5
Output Resistance, Ω	350 ± 3.5	350 ± 3.5	350 ± 3.5	350 ± 3.5	350 ± 3.5
Sensitivity (R.O.), mV/V, Nominal	2	4	4	4	24
Insulation Bridge/Case, MegΩ	5000 @50 VDC	5000 @50 VDC	5000 @50 VDC	5000 @50 VDC	5000 @50 VDC
Mechanical					
Safe Overload, % R.O.	150	150	150	150	150
Weight, lbs	1.0	2.9	9.1	23.5	59
Weight w/Base, lbs	2.5	6.5	21.5	52.5	139
Flexure Material	Aluminum	Steel	Steel	Steel	Steel

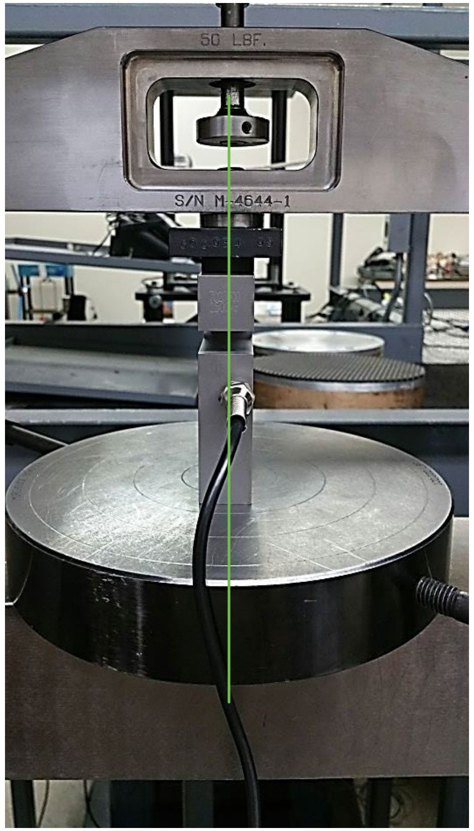
Other Error Sources

- Cable Stiffness and Mounting
- Using Mass Weights instead of Force Weights
- Misalignment
- Thread Depth on Column Load Cell
- Loading through the bottom threads in compression
- Calibration of Button Load Cells
- Cable Length - 4 wire versus 6 wire cable
- Not Following Published Standards
- Different Excitation Voltages
- Errors From Used Batteries
- Static Calibration versus Dynamic Use
- Creep Recovery and Return
- Molecule Excitement Decline
- Proper Pin Sizes with Tension Links
- Ascending versus Descending Curves
- Not using the Appropriate Adapters
- Timing Errors
- Appropriate Exercise Cycles (Especially when switching modes)
- Not Switching Standards to Verify the Entire Loading Range
- Flatness of Load Cell and Adapters
- Difference in Technicians – and how to quantify this error
- Timing
- Thread Depth Errors on Shear Web Load
- Side Load Sensitivity

Misalignment Error on S-beam Load Cell

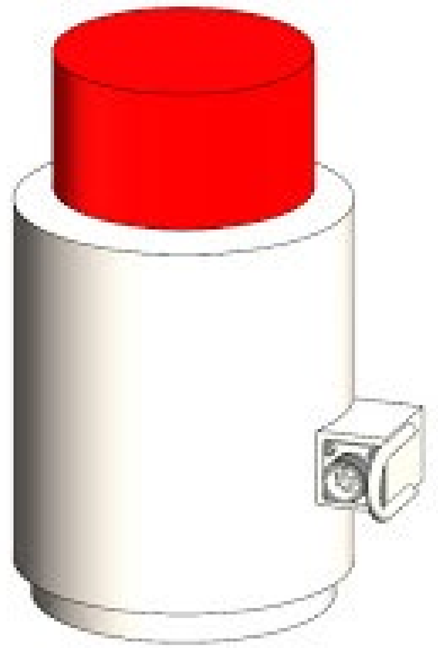
Misalignment Demonstrating 0.752 % error

Output in mV/V
Aligned in machine
-1.96732 mV/V



Output in mV/V
Slightly misaligned in machine
-1.98211 mV/V

Different Hardness of Top Adaptors



Different hardness of top adapters on column load cells can produce errors as high as 0.3 %.

6/23/2017		6/23/2017		
4340 Top Block		Hardened Top Block		Difference
0	120	0	120	
-48968	-48960	-49120	-49109	-0.307%
-244290	-244308	-244990	-244971	-0.279%
-487279	-487320	-488596	-488570	-0.263%

Loading Through Different Thread Depths

Below is a test Morehouse did with two different types of adaptors and recorded the readings with 10,000 lbf applied. Output was 10,001.5 lbf with 1.5” of engagement vs 9942.3 LBF with 0.5” engagement. There was a difference of 59.2 lbf on a 10,000 lbf cell.

Column Type Cell
Model RFG/F226-01

Different Type Adaptors.
1.5” versus 0.5” engagement

The error on this measurement was over 0.5 % on a device expected to be better than 0.025% (20 times expected). How are your devices being calibrated?

Tension Links Improper Vs Proper Pin Diameter

Difference of 860 lbf or 1.72 % error at 50,000 lbf from not using the proper size load pins.

Out of Tolerance Versus In Tolerance

Note: Tension links of this design seem to exhibit similar problems. If you are unsure, TEST!

Force CMC for ASTM E74 Calibrations Tier 1

Type A Uncertainty Contributors

1) ~~ASTM LLF reduced to 1 Standard Deviation (ASTM LLF is reported with *k*= 2.4)~~
2) ~~Repeatability of the Best Existing Device~~
3) ~~Reproducibility Between Operators~~

Type B Uncertainty Contributors

1) ~~Resolution of the Best Existing Device~~
2) ~~Reference Standard Resolution* *If Applicable*~~
3) ~~Reference Standard Uncertainty~~
4) ~~Reference Standard Stability~~
5) ~~Environmental Factors~~
6) ~~Other Error Sources~~

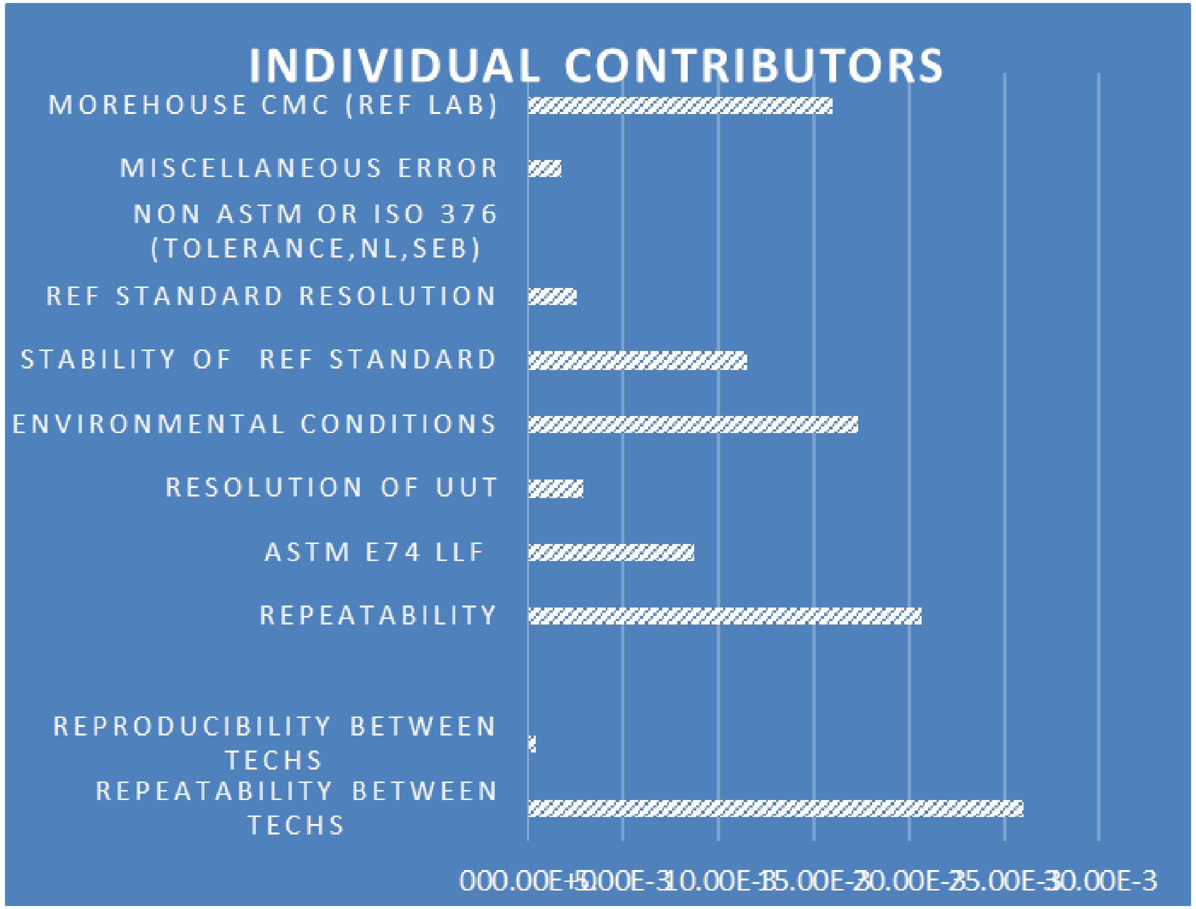
Force CMC for ASTM E74 Calibrations

Type A Uncertainty Contributors

1) ASTM LLF reduced to 1 Standard Deviation (ASTM LLF is reported with k= 2.4)
2) Repeatability of the Best Existing Device
3) Reproducibility

Type B Uncertainty Contributors

1) Resolution of the Best Existing Device
2) Reference Standard Resolution* *If Applicable*
3) Reference Standard Uncertainty
4) Reference Standard Stability
5) Environmental Factors
6) Other Error Sources



Applied	Expanded Uncertainty	Expanded Uncertainty %
200	0.04269	0.02134%
400	0.04862	0.01216%

Next step is to do the same thing again for the next point in the range.

Force CMC for ASTM E74 Calibrations

Tier 2

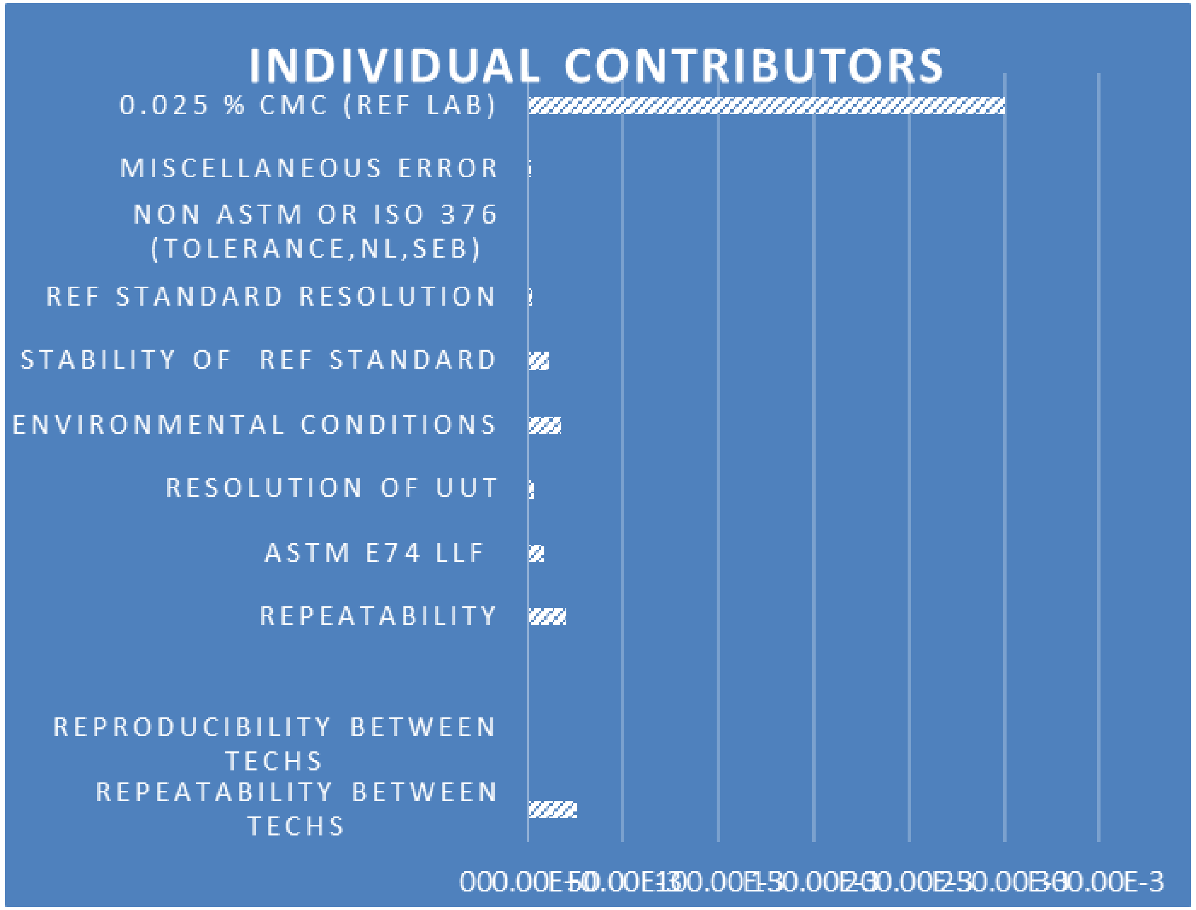
Not using deadweight drastically raises the Expanded Uncertainty

Type A Uncertainty Contributors

1) ASTM LLF reduced to 1 Standard Deviation (ASTM LLF is reported with *k*= 2.4)
2) Repeatability of the Best Existing Device
3) Reproducibility

Type B Uncertainty Contributors

1) Resolution of the Best Existing Device
2) Reference Standard Resolution* *If Applicable*
3) Reference Standard Uncertainty – Changed to 0.025 %
4) Reference Standard Stability
5) Environmental Factors
6) Other Error Sources



Applied	Expanded Uncertainty	Expanded Uncertainty %
200	0.06380	0.03190%
400	0.10778	0.02695%

At the 400 lbf point, the Expanded Uncertainty more than doubles, At capacity it can be 5 to 10 times higher!

Force CMC for ASTM E74 Calibrations

Next step is to do the same thing again for the next point in the range. Though its quite probable that only 3 things may change.

Type A Uncertainty Contributors

1) ASTM LLF reduced to 1 Standard Deviation (ASTM LLF is reported with k= 2.4)
2) Repeatability of the Best Existing Device - this will change as it is per points throughout the loading range
3) Reproducibility Between Operators

Type B Uncertainty Contributors

1) Resolution of the Best Existing Device – Several devices may be needed throughout the range, but the same device typically is used from 10 % to 100 %.
2) Reference Standard Resolution* *If Applicable*
3) Reference Standard Uncertainty - The reference standard used may change at some point in the loading range
4) Reference Standard Stability – This will change at each test point.
5) Environmental Factors
6) Other Error Sources

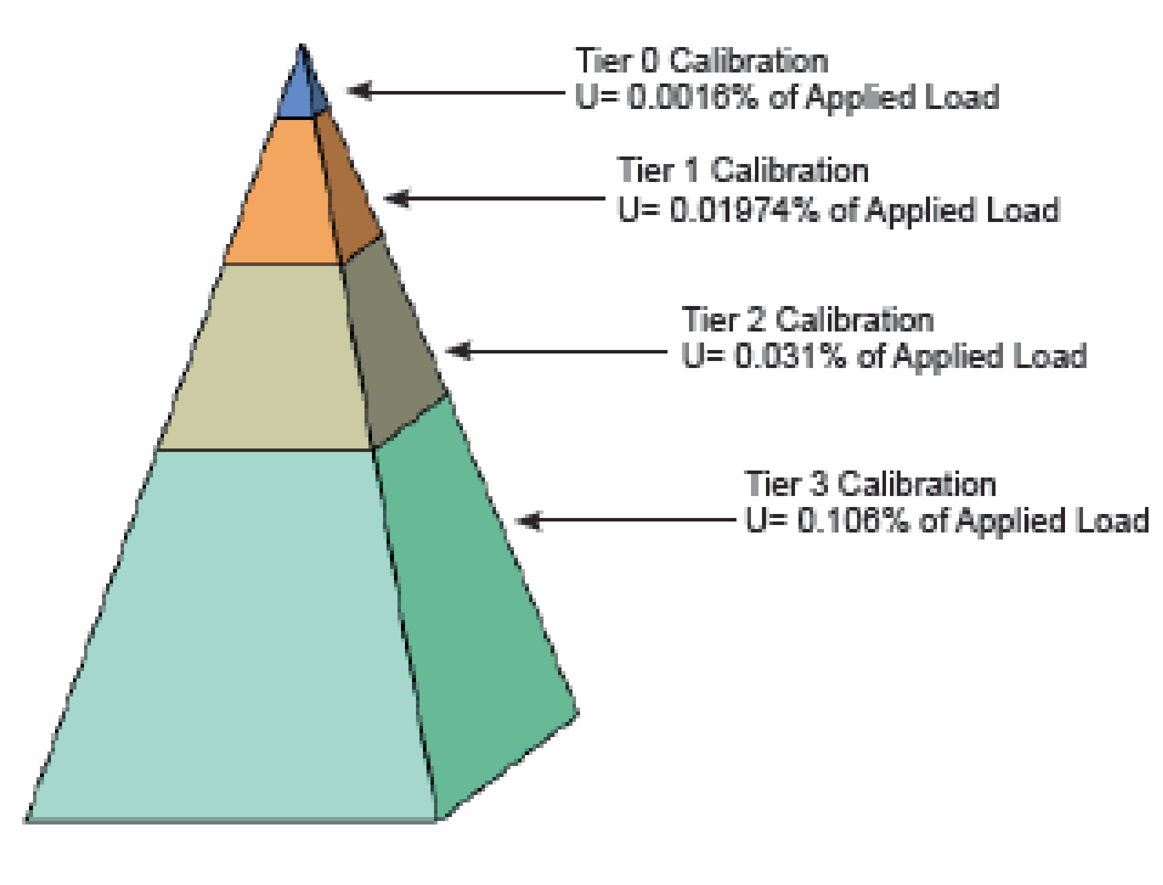
Uncertainty Propagation for Force Calibration Systems

Table 1. Uncertainty Propagation Analysis for Load Cell Calibrations

TIER >>>			TIER 0 Primary Standards	TIER 1 Primary Lab	TIER 2 Secondary Lab
UUT Info >>>			No UUT (Deadweight CMC Calculation)	Load Cell Calibrated by Primary Standard (Class AA Assigned)	Load Cell Calibrated by Secondary Standard (Class A Assigned)
Uncertainty Source		**Divisor**	**Primary Cal (Deadweight)**	**Primary Cal (Deadweight)**	**Working Cal (UCM)**
Reference	U_{REF}	2	0.396893 N †	1.42 N	17.57 N
Resolution (Reference)	$U_{RES,REF}$	3.464	N/A (deadweight)	1.07 N	1.07 N
Resolution (UUT)	$U_{RES,UUT}$	3.464	0.2780 N ††	1.07 N	1.07 N
UUT Repeatability	U_{REP}	1	0.2567 N	1.7646 N	1.7646 N
B/W Techs Reproducibility and Repeatability	$U_{R\&R}$	1	0.49 N	3.910 N	3.910 N
Stability	U_{STA}	1.732	0.0178 N	4.45 N	4.45 N
Environmental	U_{ENV}	1.732	Included in U_{REF}	0.667 N †††	0.667 N
Side Load Sensitivity	U_{MISC}	1.732	N/A (deadweight frame)	2.67 N	2.67 N
ASTM Lower Limit Factor (LLF)	U_{ASTM}	2.4		18.296 N (Class AA Assigned)	23.718 N (Class A Assigned)
Expanded Uncertainty	U	-	0.0016 % (1.42 N) ‡	0.01974 % (17.57 N) ‡‡	0.031 % (27.45 N) ‡‡‡

Tier 0 is CMC of Morehouse Machine, Tier 1 Calibration by Primary Standards Class AA loading Range Assigned, Tier 2 actual CMC of Secondary Standard. The % error is based on a 20 % test point. Download our paper here.

What We Found at Different Tiers at the 20 % of Capacity Point



The Expanded Uncertainty is more than 5 times higher in tier 3 (Calibration done with Secondary Standards) than tier 1 (Calibration done with Primary Standards).

Uncertainty Attainable

	Morehouse ASTM Method	Euramet cg-4 (ISO 376 Calibrations)
Tier 1 Primary Standards Deadweight	0.0016%	0.0010%
Tier 2 Comparator with one or three reference force transducers	0.02%	0.05%

Morehouse Method
Type A Uncertainty Contributions

1) ASTM LLF reduced to 1 Standard Deviation (ASTM LLF is reported with k= 2.4)
2) Repeatability with the Best Existing Device
3) Repeatability and Reproducibility

Type B Uncertainty Contributors

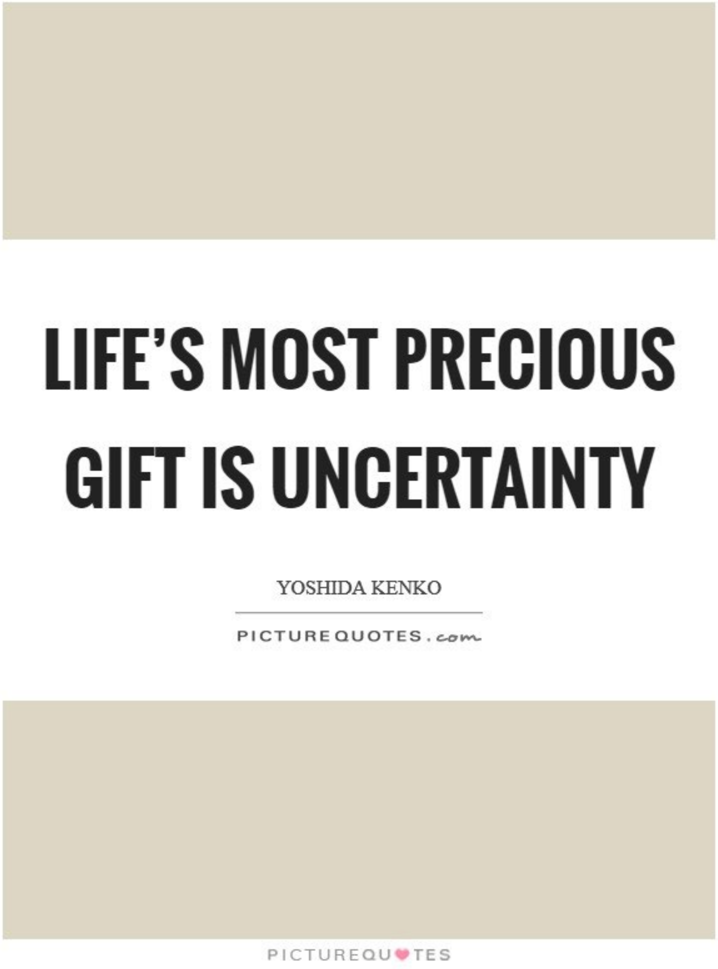
1) Resolution of the Best Existing Device
2) Reference Standard Resolution* If Applicable
3) Reference Standard Uncertainty
4) Reference Standard Stability
5) Environmental Factors
6) Other Error Sources

Type of machine	Typical range of CMCs (expanded relative uncertainty)
Deadweight	5×10^{-5} to 1×10^{-4}
Hydraulic amplification	1×10^{-4} to 5×10^{-4}
Lever amplification	1×10^{-4} to 5×10^{-4}
Comparator with one or three reference force transducers	5×10^{-4} to 5×10^{-3}

Table 2 — Characteristics of force-proving instruments

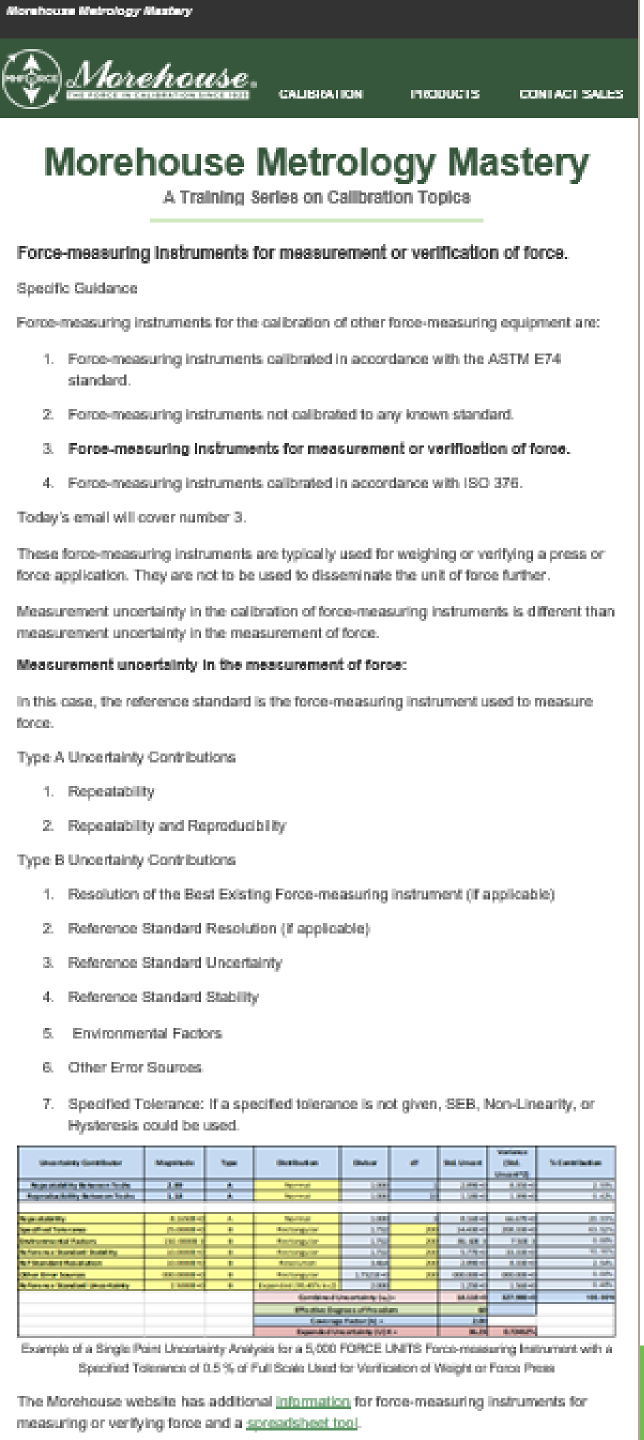
Class	Relative error of the force-proving instrument %						Expanded uncertainty of applied calibration force (95 % level of confidence) %
	of reproducibility b	of repeatability b'	of interpolation f_c	of zero f_0	of reversibility v	of creep c	
00	0,05	0,025	±0,025	±0,012	0,07	0,025	±0,01
0,5	0,10	0,05	±0,05	±0,025	0,15	0,05	±0,02
1	0,20	0,10	±0,10	±0,050	0,30	0,10	±0,05
2	0,40	0,20	±0,20	±0,10	0,50	0,20	±0,10

Summary/Questions?



Using the proposed method a lab can achieve CMC's of about 0.02 % of applied force using a comparator such as a UCM, PCM, or Force Machine capable of holding the force and not overshooting test points.

This method will most likely require 2 or more load cells to cover the measuring range of what is being calibrated and they will need to be calibrated by deadweight primary standards.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Force-measuring instruments for measurement or verification of force.

Specific Guidance

Force-measuring instruments for the calibration of other force-measuring equipment are:

1. Force-measuring instruments calibrated in accordance with the ASTM E74 standard.
2. Force-measuring instruments not calibrated to any known standard.
3. **Force-measuring instruments for measurement or verification of force.**
4. Force-measuring instruments calibrated in accordance with ISO 376.

Today's email will cover number 3.

These force-measuring instruments are typically used for weighing or verifying a press or force application. They are not to be used to disseminate the unit of force further.

Measurement uncertainty in the calibration of force-measuring instruments is different than measurement uncertainty in the measurement of force.

Measurement uncertainty in the measurement of force:

In this case, the reference standard is the force-measuring instrument used to measure force.

Type A Uncertainty Contributions

1. Repeatability
2. Repeatability and Reproducibility

Type B Uncertainty Contributions

1. Resolution of the Best Existing Force-measuring Instrument (if applicable)
2. Reference Standard Resolution (if applicable)
3. Reference Standard Uncertainty
4. Reference Standard Stability
5. Environmental Factors
6. Other Error Sources
7. Specified Tolerance: If a specified tolerance is not given, SEB, Non-Linearity, or Hysteresis could be used.

Example of a Single Point Uncertainty Analysis for a 5,000 FORCE UNITS Force-measuring Instrument with a Specified Tolerance of 0.5 % of Full Scale Used for Verification of Weight or Force Press

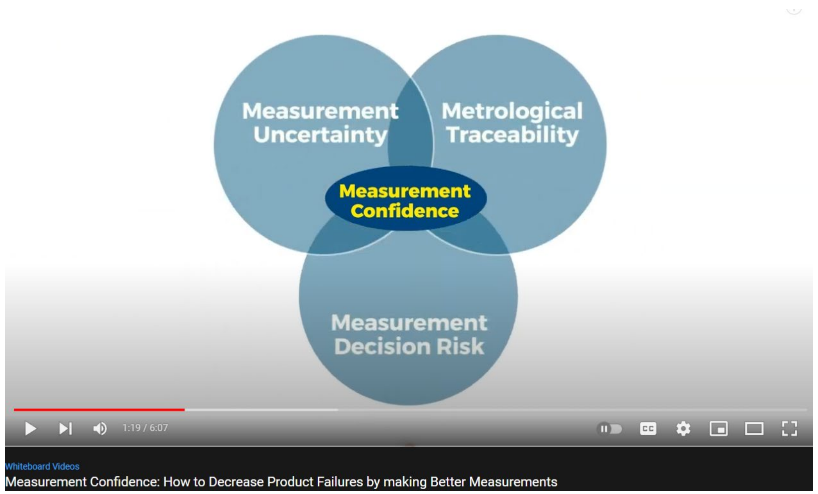
The Morehouse website has additional information for force-measuring instruments for measuring or verifying force and a spreadsheet tool.

Force Calibration Email Training Series

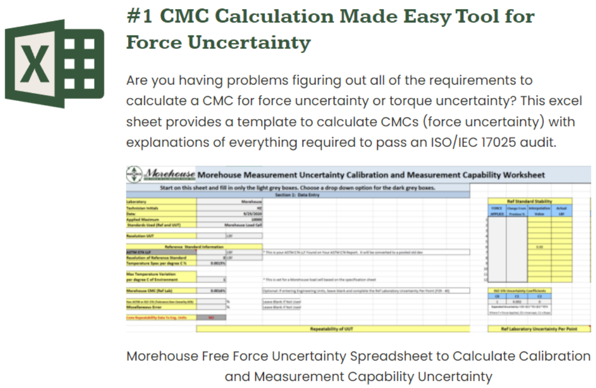
- Elevate your calibration skills with the Morehouse Metrology Mastery Series, a free weekly email calibration training campaign for metrology professional development. Whether you're a metrology novice or a seasoned professional, these short, insightful emails are designed for a practical 10 minutes of calibration training and metrology professional development from Tuesday through Thursday. Each email provides valuable insights that contribute to your metrology professional development and help you learn more about metrology, empowering you to enhance your force and torque calibration expertise at your own pace.

https://mhforce.com/metrology-mastery-metrology-professional-development/

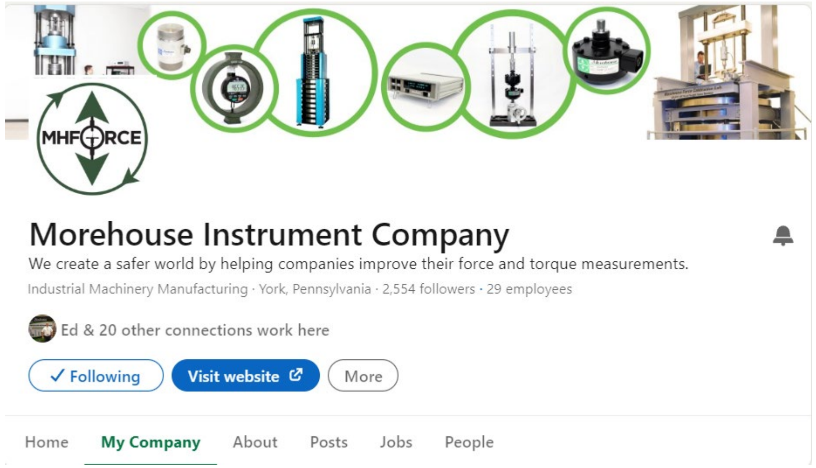
Want More Information?



[Morehouse YouTube Videos]



[Morehouse Free Downloads]



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Free 1 Hour Webinars !

Wednesday, October 9, 2024 - 1:00pm ET
Navigating ISO/IEC 17025:2017 – Section 7.8 "Reporting of Results"

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Intro to Internal Auditing
Tuesday, September 17, 2024 - 1:00-3:00pm ET

Approaches to Competence for Personnel
Tuesday, October 15, 2024 - 1:00-3:00pm ET

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PJLA

Thank You!