MHFORCE Morehouse
THE FORCE IN CALIBRATION SINCE 1925

FUNDAMENTALS OF FORCE CALIBRATION
(Digital Class)

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MHFORCE Morehouse

THE FORCE IN CALIBRATION SINCE 1925

FUNDAMENTALS OF FORCE CALIBRATION

- Henry Zumbrun 2, Morehouse Instrument Company
- 1742 Sixth Ave
- York, PA 17403
- PH: 717-843-0081 web: www.mhforce.com
- contact: hzumbrun@mhforce.com

Course Abstract

- This course will cover applied force calibration techniques and will include demonstrations replicating measurement errors being made in everyday force measurement.

- This course will cover the importance of calibrating force measurement devices in the way they are being used to reduce measurement errors and lower uncertainty.   The student will learn about measurement uncertainty and will be able to quantify key uncertainty components and start to develop an uncertainty budget.

Course Agenda

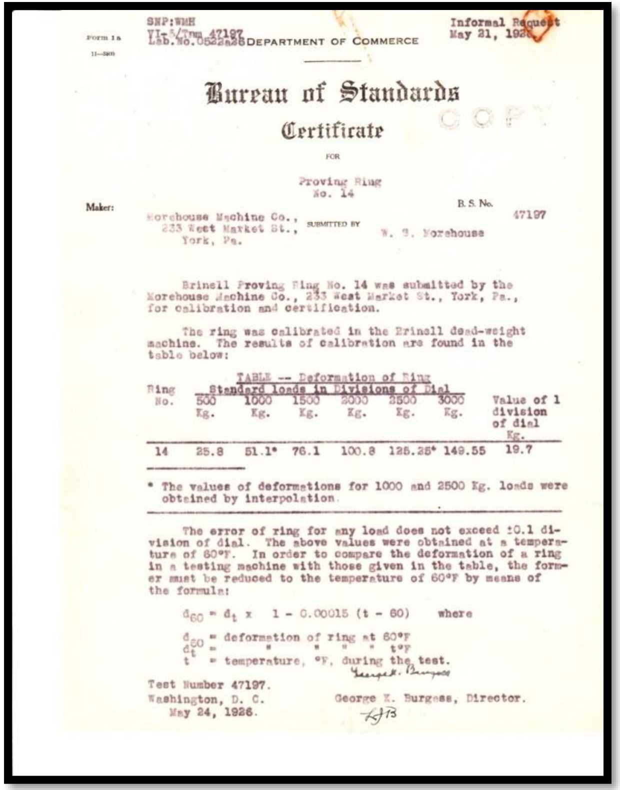
- Company History – Introductions (15 minutes)
- Learning Objectives
- Force Calibration
- Accuracy Precision Resolution and Uncertainty
- Common Types of Force Measuring Instrumentation
- Troubleshooting a load cell
- Calibration Traceability and Force Standards Calibration
- ASTM E74
- Potential Force Measurement Errors with demonstrations
- Uncertainty Analysis

Morehouse

Company History

- 1920's – Morehouse and the U.S. Bureau of Standards started to design and refine force calibration products (Proving Rings) for the purpose of generating an accurate force for Brinell Hardness Testing.

Pictured above: Morehouse Brinell Proving Ring S/N 14 Calibrated by U.S. Bureau of Standards test # 47197 May 24, 1926



SNP:WMH
VI-5/Tm 47197
Lab.No.0522a26

Form 1a
11—5809

DEPARTMENT OF COMMERCE

Informal Request
May 21, 192[illegible]

Bureau of Standards

Certificate

FOR

Proving Ring
No. 14

COPY

Maker:
Morehouse Machine Co.,
233 West Market St.,
York, Pa.

SUBMITTED BY
W. S. Morehouse

B. S. No.
47197

Brinell Proving Ring No. 14 was submitted by the Morehouse Machine Co., 233 West Market St., York, Pa., for calibration and certification.

The ring was calibrated in the Brinell dead-weight machine. The results of calibration are found in the table below:

TABLE -- Deformation of Ring

Ring No.	Standard loads in Divisions of Dial 500 Kg.	1000 Kg.	1500 Kg.	2000 Kg.	2500 Kg.	3000 Kg.	Value of 1 division of dial Kg.
14	25.8	51.1*	76.1	100.8	125.25*	149.55	19.7

* The values of deformations for 1000 and 2500 Kg. loads were obtained by interpolation.

The error of ring for any load does not exceed ±0.1 division of dial. The above values were obtained at a temperature of 60°F. In order to compare the deformation of a ring in a testing machine with those given in the table, the former must be reduced to the temperature of 60°F by means of the formula:

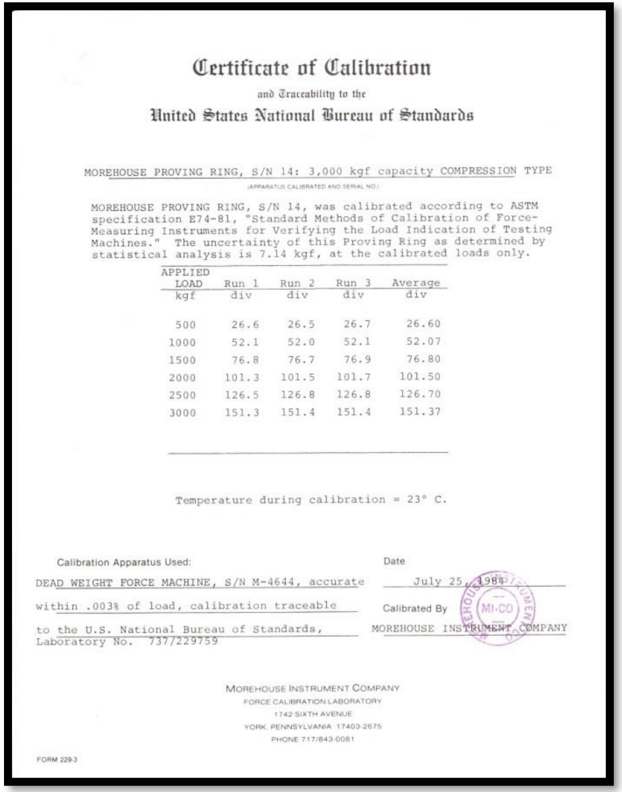
$$d_{60} = d_t \times \quad 1 - 0.00015\ (t - 60) \qquad \text{where}$$

d_{60} = deformation of ring at 60°F
d_t = " " " " t°F
t = temperature, °F, during the test.

George K. Burgess

Test Number 47197.
Washington, D. C.
May 24, 1926.

George K. Burgess, Director.



Certificate of Calibration

and Traceability to the

United States National Bureau of Standards

MOREHOUSE PROVING RING, S/N 14: 3,000 kgf capacity COMPRESSION TYPE
(APPARATUS CALIBRATED AND SERIAL NO.)

MOREHOUSE PROVING RING, S/N 14, was calibrated according to ASTM specification E74-81, "Standard Methods of Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines." The uncertainty of this Proving Ring as determined by statistical analysis is 7.14 kgf, at the calibrated loads only.

APPLIED LOAD kgf	Run 1 div	Run 2 div	Run 3 div	Average div
500	26.6	26.5	26.7	26.60
1000	52.1	52.0	52.1	52.07
1500	76.8	76.7	76.9	76.80
2000	101.3	101.5	101.7	101.50
2500	126.5	126.8	126.8	126.70
3000	151.3	151.4	151.4	151.37

Temperature during calibration = 23° C.

Calibration Apparatus Used:
DEAD WEIGHT FORCE MACHINE, S/N M-4644, accurate within .003% of load, calibration traceable to the U.S. National Bureau of Standards, Laboratory No. 737/229759

Date
July 25, 1984

Calibrated By
MOREHOUSE INSTRUMENT COMPANY

MOREHOUSE INSTRUMENT COMPANY
FORCE CALIBRATION LABORATORY
1742 SIXTH AVENUE
YORK, PENNSYLVANIA 17403-2675
PHONE 717/843-0081

FORM 229-3

- Morehouse Proving Ring S/N 14 Calibrated in 1926 and the last calibration we have on record is July 25, 1984. Ring was in service for over 58 years.

Morehouse

Company History

- 1930's – The Morehouse Proving Ring was refined and used to calibrate Material Testing Machines.

- 1950's – Morehouse developed products for commercial industry, including Force Gauges, Morehouse Universal Calibrating Machines and Morehouse Dead Weight Primary Standards for calibration of load cells, proving rings, etc.

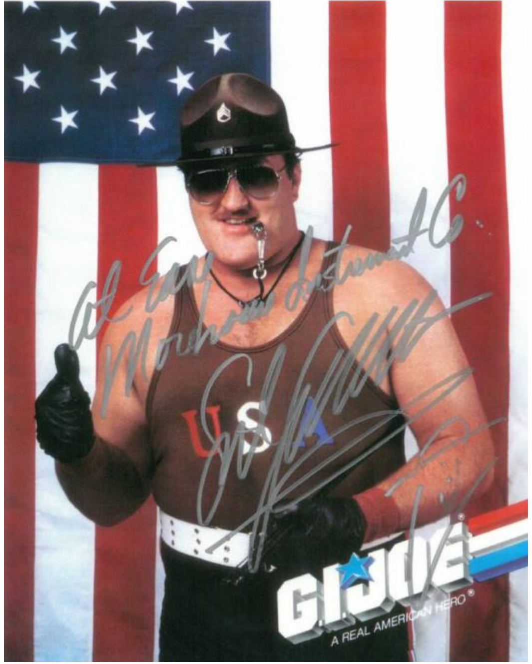
Morehouse

Company History

- 2004 – Morehouse becomes the first accredited commercial calibration laboratory to offer dead weight primary standards calibrations accurate to 0.002 % of applied force up to 120,000 LBF.
- 2009 – Morehouse expands force calibration range offering ASTM E74 calibrations up to 2,250,000 LBF in compression and 1,200,000 LBF in tension.
- 2020 – Morehouse turned 100 ☺

Morehouse

Company History



Morehouse

Company History

- 2010 - Morehouse finishes construction of new torque calibration laboratory. This calibration laboratory features a primary torque calibration standard accurate to 0.002 % of applied torque. This standard was acquired from the National Physical Laboratory in England, which is a National Metrology Institute.
- 2011 Morehouse becomes ISO/IEC Guide 17025 Accredited for Torque Calibration by A2LA.

Morehouse

Company History

Calibration Lab Pictures


The only primary torque calibration laboratory in North America with torque calibration accuracies of 0.002% of applied torque from 1N-m to 2kN-m

The primary torque standard now in our laboratory was developed by the British National Physical Laboratory where it was registered with the BIPM as the national standard for the UK. This primary torque standard meets the criteria set forth in ASTM standard E2428

Morehouse
Torque Calibration Service


CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

Micro-Feature Dimensional and Form Measurements with the NIST Fiber Probe on a CMM

A Programmable Calibration System for Accurate AC Current Measurements at NIS, Egypt

Calibration Management in the ISO/IEC 17025 Accredited Facility

2010
JULY
AUGUST
SEPTEMBER

Introductions

Name ___________________________

Company ________________________

Expectations &
Questions______________________

Common Questions

- What are the common error sources?
- How do I calculate Measurement Uncertainty?
- How do I lower my Measurement Uncertainty?
- How do I know if my devices are “In tolerance”?
- What are traceable measurements?
- Proving Ring versus Load Cell, what is better?
- What adapters do I need to calibrate load cells?
- How do I keep my technicians from squashing load cells?
- No specific question, just here to learn as much as possible!

Expectations

We want your attention.

- **breaks will be given as appropriate.**
- **If you need to check your cell phone, please be courteous and limit cell phone usage to breaks.**

We want you to get the most out of this class for yourself.

- **Participation and questions are encouraged.**

Learning Objectives

By the end of this course, you should be able to

- Identify various types of calibration equipment and perform some basic troubleshooting methods.
- Identify potential force measurement errors.
- Reduce and/or quantify the uncertainty associated with these errors in your uncertainty analysis for force measurement at your calibration facility.
- Implement proper force calibration techniques as discussed and demonstrated in the class.
- Using material provided in the training class, put together an expanded uncertainty budget for force equipment used as secondary standards.

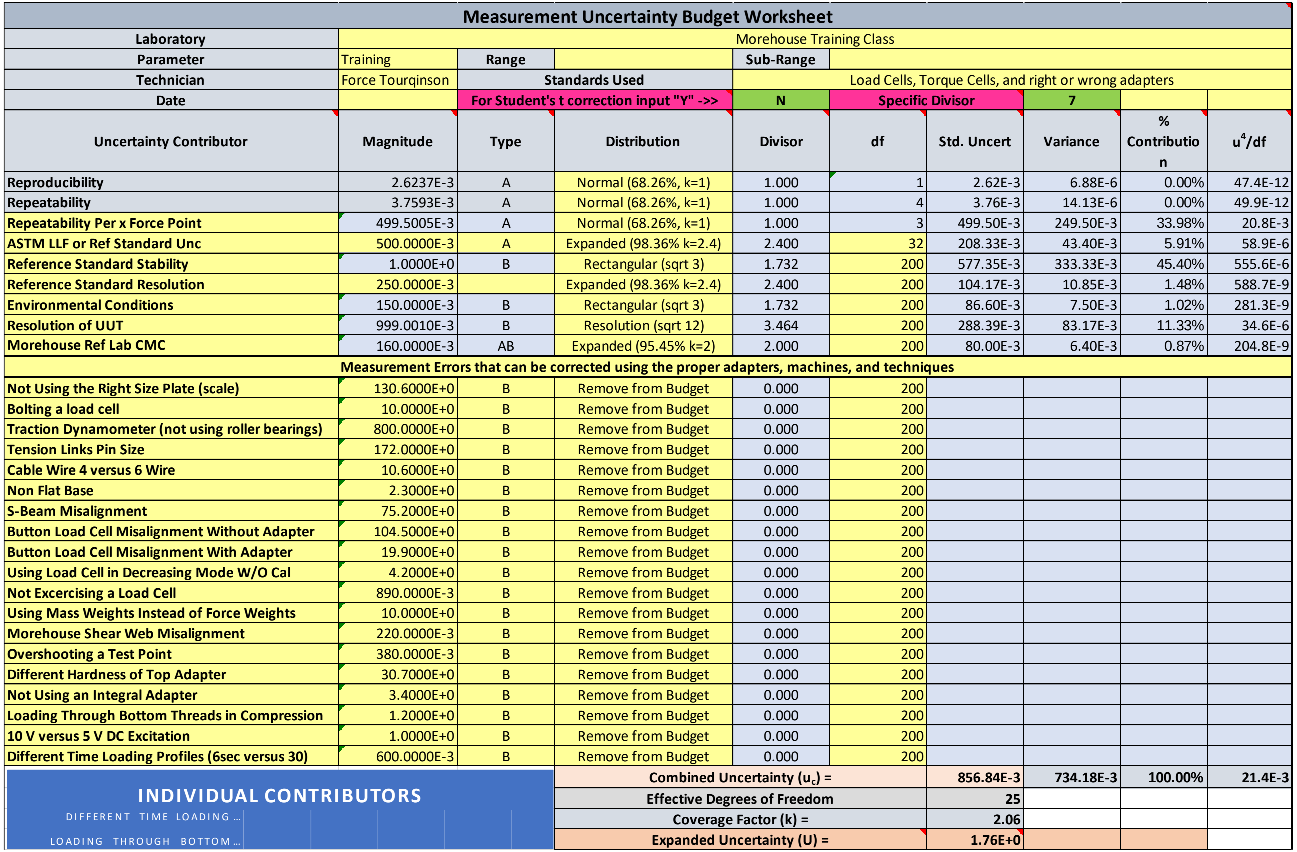
Course Agenda

This course is tailored to meet the needs of the majority in this class. The following are the topics we are prepared to discuss:

Force Calibration

- Measurement Risk
- The Importance of Torque Control and how Torque can affect Force Measurements
- Common Types of Force Measuring Instrumentation
- Troubleshooting a load cell
- Calibration Traceability and Force Standards Calibration
- ASTM E74
- Potential Force Measurement Errors with demonstrations
- Uncertainty Analysis

Uncertainty Budgets

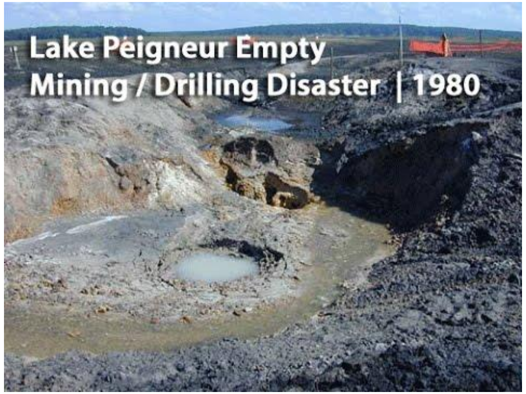


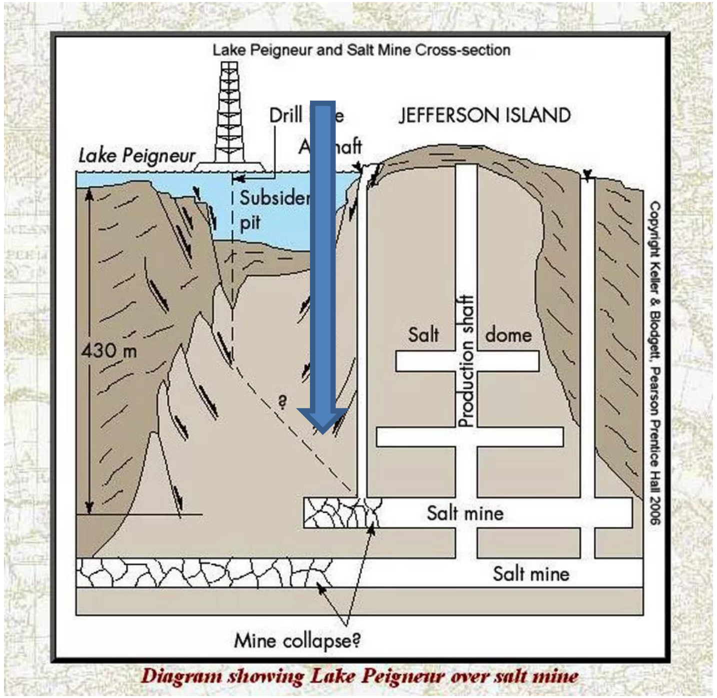
Measurement Uncertainty Budget Worksheet

Laboratory	Morehouse Training Class								
Parameter	Training	**Range**		**Sub-Range**					
Technician	Force Tourqinson	**Standards Used**		Load Cells, Torque Cells, and right or wrong adapters					
Date		**For Student's t correction input "Y" ->>**		**N**	**Specific Divisor**		**7**		
Uncertainty Contributor	**Magnitude**	**Type**	**Distribution**	**Divisor**	**df**	**Std. Uncert**	**Variance**	**% Contribution**	**u^4/df**
Reproducibility	2.6237E-3	A	Normal (68.26%, k=1)	1.000	1	2.62E-3	6.88E-6	0.00%	47.4E-12
Repeatability	3.7593E-3	A	Normal (68.26%, k=1)	1.000	4	3.76E-3	14.13E-6	0.00%	49.9E-12
Repeatability Per x Force Point	499.5005E-3	A	Normal (68.26%, k=1)	1.000	3	499.50E-3	249.50E-3	33.98%	20.8E-3
ASTM LLF or Ref Standard Unc	500.0000E-3	A	Expanded (98.36% k=2.4)	2.400	32	208.33E-3	43.40E-3	5.91%	58.9E-6
Reference Standard Stability	1.0000E+0	B	Rectangular (sqrt 3)	1.732	200	577.35E-3	333.33E-3	45.40%	555.6E-6
Reference Standard Resolution	250.0000E-3		Expanded (98.36% k=2.4)	2.400	200	104.17E-3	10.85E-3	1.48%	588.7E-9
Environmental Conditions	150.0000E-3	B	Rectangular (sqrt 3)	1.732	200	86.60E-3	7.50E-3	1.02%	281.3E-9
Resolution of UUT	999.0010E-3	B	Resolution (sqrt 12)	3.464	200	288.39E-3	83.17E-3	11.33%	34.6E-6
Morehouse Ref Lab CMC	160.0000E-3	AB	Expanded (95.45% k=2)	2.000	200	80.00E-3	6.40E-3	0.87%	204.8E-9
Measurement Errors that can be corrected using the proper adapters, machines, and techniques									
Not Using the Right Size Plate (scale)	130.6000E+0	B	Remove from Budget	0.000	200				
Bolting a load cell	10.0000E+0	B	Remove from Budget	0.000	200				
Traction Dynamometer (not using roller bearings)	800.0000E+0	B	Remove from Budget	0.000	200				
Tension Links Pin Size	172.0000E+0	B	Remove from Budget	0.000	200				
Cable Wire 4 versus 6 Wire	10.6000E+0	B	Remove from Budget	0.000	200				
Non Flat Base	2.3000E+0	B	Remove from Budget	0.000	200				
S-Beam Misalignment	75.2000E+0	B	Remove from Budget	0.000	200				
Button Load Cell Misalignment Without Adapter	104.5000E+0	B	Remove from Budget	0.000	200				
Button Load Cell Misalignment With Adapter	19.9000E+0	B	Remove from Budget	0.000	200				
Using Load Cell in Decreasing Mode W/O Cal	4.2000E+0	B	Remove from Budget	0.000	200				
Not Excercising a Load Cell	890.0000E-3	B	Remove from Budget	0.000	200				
Using Mass Weights Instead of Force Weights	10.0000E+0	B	Remove from Budget	0.000	200				
Morehouse Shear Web Misalignment	220.0000E-3	B	Remove from Budget	0.000	200				
Overshooting a Test Point	380.0000E-3	B	Remove from Budget	0.000	200				
Different Hardness of Top Adapter	30.7000E+0	B	Remove from Budget	0.000	200				
Not Using an Integral Adapter	3.4000E+0	B	Remove from Budget	0.000	200				
Loading Through Bottom Threads in Compression	1.2000E+0	B	Remove from Budget	0.000	200				
10 V versus 5 V DC Excitation	1.0000E+0	B	Remove from Budget	0.000	200				
Different Time Loading Profiles (6sec versus 30)	600.0000E-3	B	Remove from Budget	0.000	200				
			Combined Uncertainty (u_c) =			**856.84E-3**	**734.18E-3**	**100.00%**	**21.4E-3**
			Effective Degrees of Freedom			**25**			
			Coverage Factor (k) =			**2.06**			
			Expanded Uncertainty (U) =			**1.76E+0**			

Why Risk Matters
Lake Peigneur

On November 20, 1980, an oil rig contracted by Texaco accidentally drilled into the Diamond Crystal Salt Company salt mine under the lake. Because of an incorrect or misinterpreted coordinate reference system (the rig with the coordinate system set up backwards) and the 14-inch (36 cm) drill bit entered the mine, starting a chain of events that turned the lake from freshwater to salt-water, with a deep hole. [Video on youtube.]





Measurement Risk

You can see the crash in this video for yourself but let us tell you about the findings of the subsequent investigation. There were **two intertwined causes of the crash.** Heavy rains before takeoff caused fuel to get into data sensors which were responsible for calculating speed and altitude among other things.

Presentation Abstract

This mixture of water and fuel caused condensation to build up on the sensors which were near the planes surface. When maintenance crew were calibrating them before the flight, they were unaware of this build up **causing them to calibrate them wrong.**

It’s only a 2-billion-dollar mistake

Question

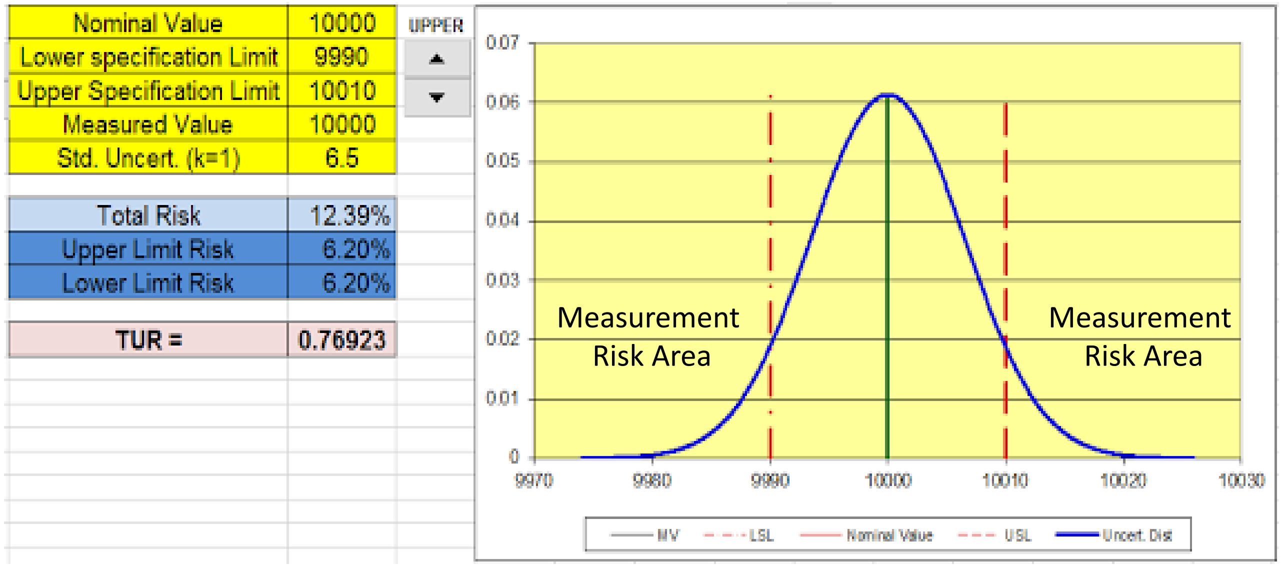
I have a 10,000 lbf device with an accuracy of 0.1 % of full scale ± 10 lbf.

My calibration certificate says the unit reads 10,000 lbf when 10,000 lbf was applied.

Is my device “in tolerance”?

Applied	Reading	Error
5,000	5,000	0
10,000	10,000	0

Would anyone use a ruler to calibrate their gauge blocks?



Nominal Value	10000
Lower specification Limit	9990
Upper Specification Limit	10010
Measured Value	10000
Std. Uncert. (k=1)	6.5

Total Risk	12.39%
Upper Limit Risk	6.20%
Lower Limit Risk	6.20%

TUR =	0.76923

Note: If Measurement Uncertainty is not being reported properly by your service provider, there is **NO way to know if the device is “in-tolerance” and you do not have a traceable measurement!**

Measurement Risk

What does this really mean?

All measurements have a percentage of likelihood of calling something good when it is bad, and something bad when it is good. You might be familiar with the terms consumer's risk and producer's risk. Consumer's risk refers to the possibility of a problem occurring in a consumer-oriented product; occasionally, a product not meeting quality standards passes undetected through a manufacturer's quality control system and enters the consumer market.

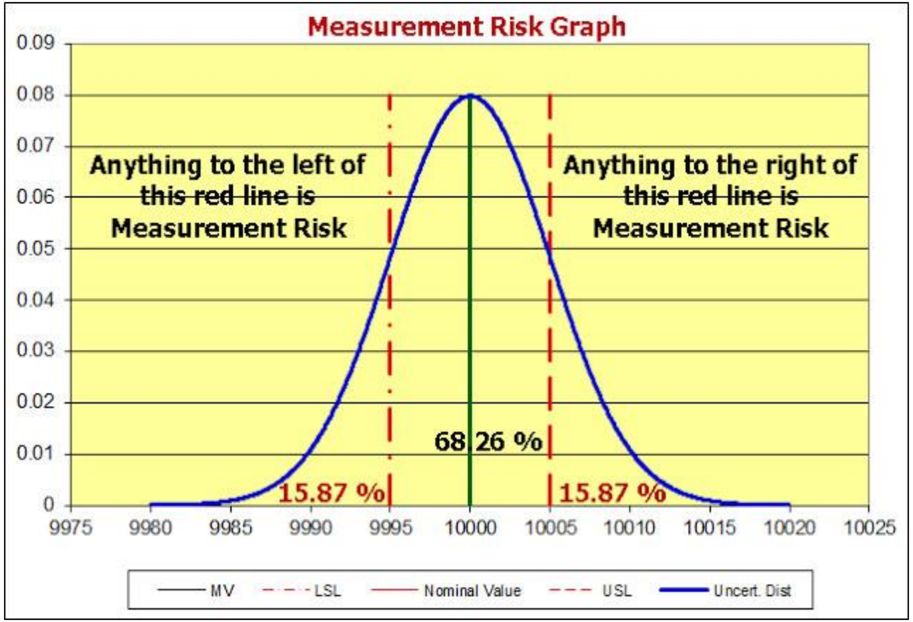
An example of this would be the batteries in the Samsung Note 7 phone. The batteries can potentially overheat, causing the phone to catch on fire. In this case, the faulty battery/charging system of the phone device was approved through the quality control process of the manufacturer, which was basically a 'false acceptance.' If you owned one of these phones, there was a risk of injury to you.

In metrology this is called the probability of false accept (PFA). If the Uncertainty of the Measurement is not less than the tolerance required, there will be a significant risk of false accept. In simplistic terms, a TUR that produces less than ± 2 % upper and lower risk would be required to ensure the measurement is valid.

Measurement Decision Risk

ANSI/NCSLI Z540.3-2006 defines 3.5 Measurement decision risk as probability that an incorrect decision will result from a measurement.

ISO/IEC 17025: 2017 Section 3.7 defines a decision rule as a rule that describes how measurement uncertainty is accounted for when stating conformity with a specified requirement



Risk Management Decision Rules ISO 17025:2017

- 7.8.6.1 When a statement of conformity to a specification or standard for test or calibration is provided, the laboratory shall document the decision rule employed, taking into account the level of risk (such as false accept and false reject and statistical assumptions) associated with the decision rule employed and apply the decision rule
- 7.8.6.2 The laboratory shall report on the statement of conformity such that the statement clearly identifies –a) to which results the statement applies; and –b) which specifications, standard or parts thereof are met or not met; –c) **the decision rule applied** (unless it is inherent in the requested specification or standard)

Measurement Related Terms

Test Uncertainty Ratio: The ratio of the span of the tolerance of a measurement quantity subject to calibration, to twice the 95% expanded uncertainty of the measurement process used for calibration.

- NOTE: This applies to two-sided tolerances.

$$\text{T.U.R.} = \frac{\text{U.U.T. Tolerance}}{\text{Calibration Process Uncertainty}}$$

TUR Defined ANSI/NCSL Z540.3 Handbook

$$\mathrm{TUR} = \frac{\text{Span of the } \pm \text{ UUT Tolerance}}{2 \text{ x } k_{95\%}(\text{Calibration Process Uncertainty})}$$

TUR Formula found in ANSI/NCSLI Z540.3 Handbook

"For the numerator, the tolerance used for Unit Under Test (UUT) in the calibration procedure should be used in the calculation of the TUR. This tolerance is to reflect the organization's performance requirements for the Measurement & Test Equipment (M&TE), which are, in turn, derived from the intended application of the M&TE. In many cases, these performance requirements may be those described by the Manufacturer's tolerances and specifications for the M&TE and are therefore included in the numerator."

ANSI/NCSL Z540.3 Handbook "Handbook for the Application of ANSI/NCSLI 540.3-2006 - Requirements for the Calibration of Measuring and Test Equipment."

TUR Defined ANSI/NCSL Z540.3 Handbook

$$\mathbf{TUR} = \frac{\text{Span of the } \pm \text{ Tolerance}}{2 \text{ x } k_{95\%} \left(\sqrt[2]{\left(\frac{\text{CMC}}{k_{\text{CMC}}}\right)^2 + \left(\frac{\text{Resolution}_{\text{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\text{Repeatability}_{\text{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2} \right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

In most cases, the numerator is the UUT Accuracy Tolerance. The denominator is slightly more complicated. Per the ANSI/NCSL Z540.3 Handbook, "For the denominator, the 95 % expanded uncertainty of the measurement process used for calibration following the calibration procedure is to be used to calculate TUR. The value of this uncertainty estimate should reflect the results that are reasonably expected from the use of the approved procedure to calibrate the M&TE. Therefore, the estimate includes all components of error that influence the calibration measurement results, which would also include the influences of the item being calibrated except for the bias of the M&TE. The calibration process error, therefore, includes temporary and non-correctable influences incurred during the calibration such as **repeatability**, **resolution**, error in the measurement source, operator error, error in correction factors, environmental influences, etc."

TUR Morehouse Vs Typical Force Lab

$$\text{TUR} = \frac{\text{Span of the } \pm \text{Tolerance}}{2 \text{ x } k_{95\%} \left(\sqrt[2]{\left(\frac{\text{CMC}}{k_{\text{CMC}}}\right)^2 + \left(\frac{\text{Resolution}_{\text{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\text{Repeatability}_{\text{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2} \right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

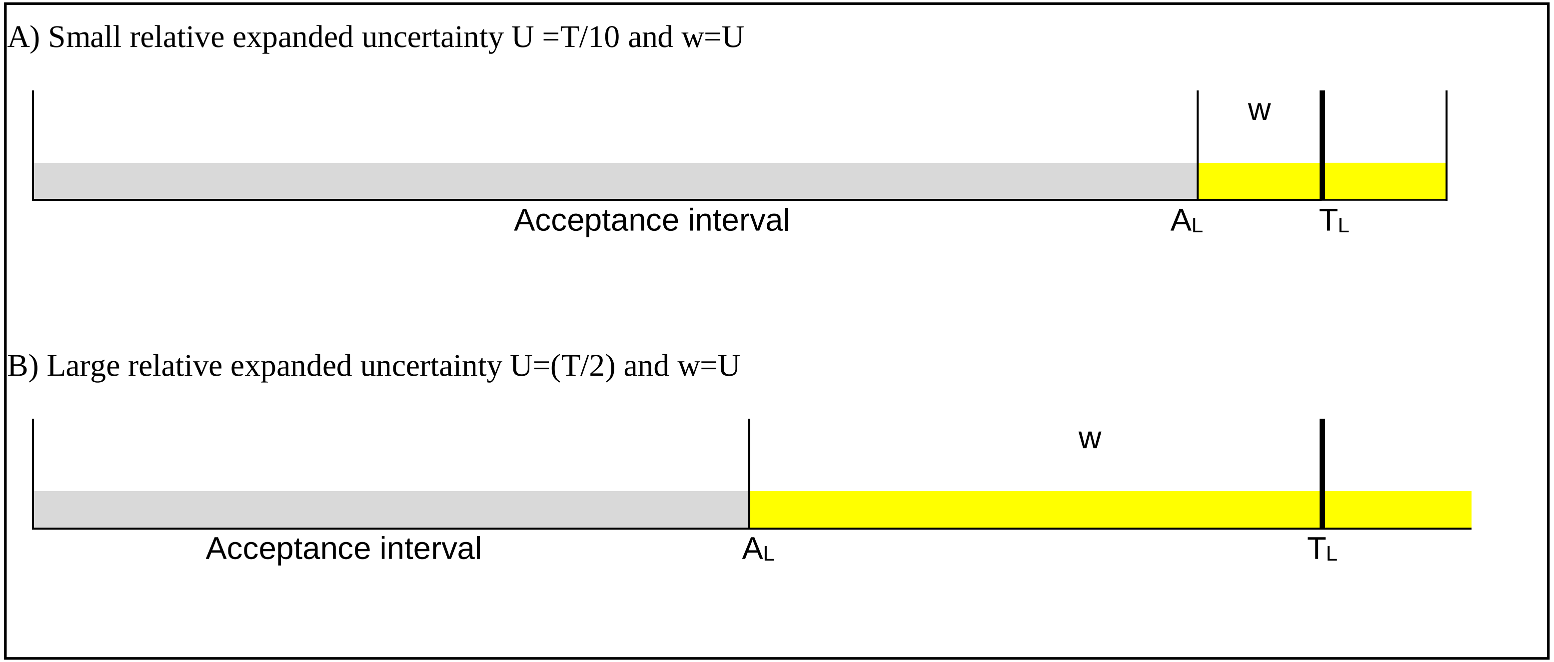
10,000 lbf device accurate to 0.05 % of full scale with a 0.01 lbf Resolution and 0.05 lbf Repeatability

Morehouse CMC = 0.002 % of applied
One Sided Tolerance 5 lbf
Expanded U = 0.22 lbf
TUR = 22:1

10,000 lbf device accurate to 0.05 % of full scale with a 0.01 lbf Resolution and 0.1 lbf Repeatability

Competitor CMC = 0.05 % of applied
One Sided Tolerance 5 lbf
Expanded U = 5.0 lbf
TUR = 1:1

Large versus Small Expanded Unc

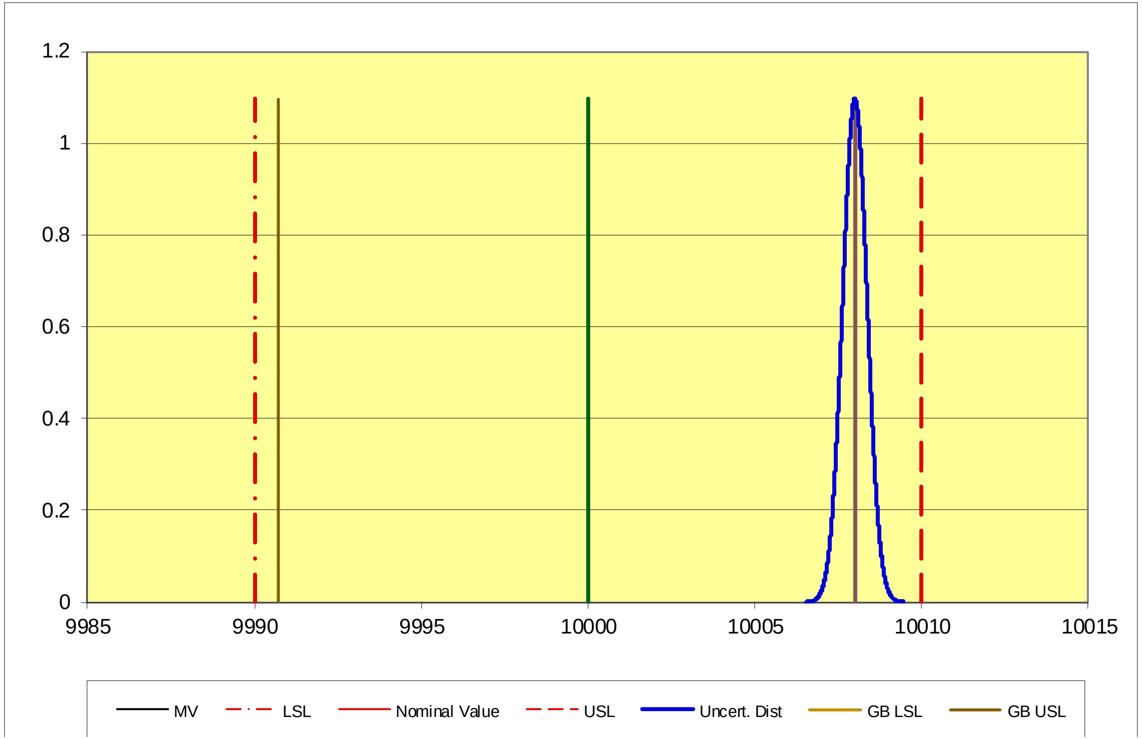


A) Small relative expanded uncertainty U =T/10 and w=U

B) Large relative expanded uncertainty U=(T/2) and w=U

Calibration Process Uncertainty (Morehouse Deadweight)

Nominal Value	10000
Lower specification Limit	9990
Upper Specification Limit	10010
Measured Value	10008.0
Measurement Error	8
Std. Uncert. (k=1)	0.36
Total Risk	0.0000%
Upper Limit Risk	0.0000%
Lower Limit Risk	0.0000%
TUR =	**13.7498972**
TAR=	**62.5**
Cpk=	**1.833319626**
Simple Guard Band with Subtraction Uncertainty Only	
Guard Band LSL	9990.727
Guard Band USL	10009.273
Guard Band Limits to Assure 2 % RISK or Less	
Guard Band LSL	9990.747
Guard Band USL	10009.253



Calibration Process Uncertainty (Commercial Labs Secondary Standards)

Nominal Value	10000
Lower specification Limit	9990
Upper Specification Limit	10010
Measured Value	10008.0
Measurement Error	8
Std. Uncert. (k=1)	1.30

Total Risk	6.1875%
Upper Limit Risk	6.1875%
Lower Limit Risk	0.0000%

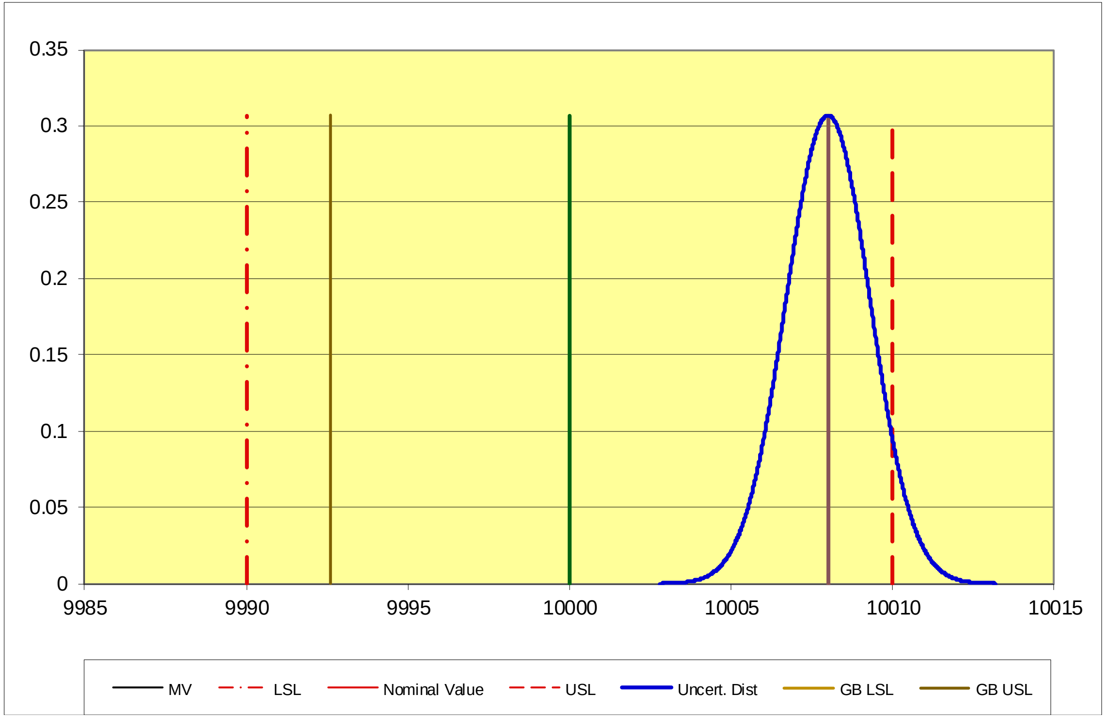
TUR =	**3.84805172**
TAR=	**4**
Cpk=	**0.513073563**

Simple Guard Band with Subtraction Uncertainty Only

Guard Band LSL	9992.599
Guard Band USL	10007.401

Guard Band Limits to Assure 2 % RISK or Less

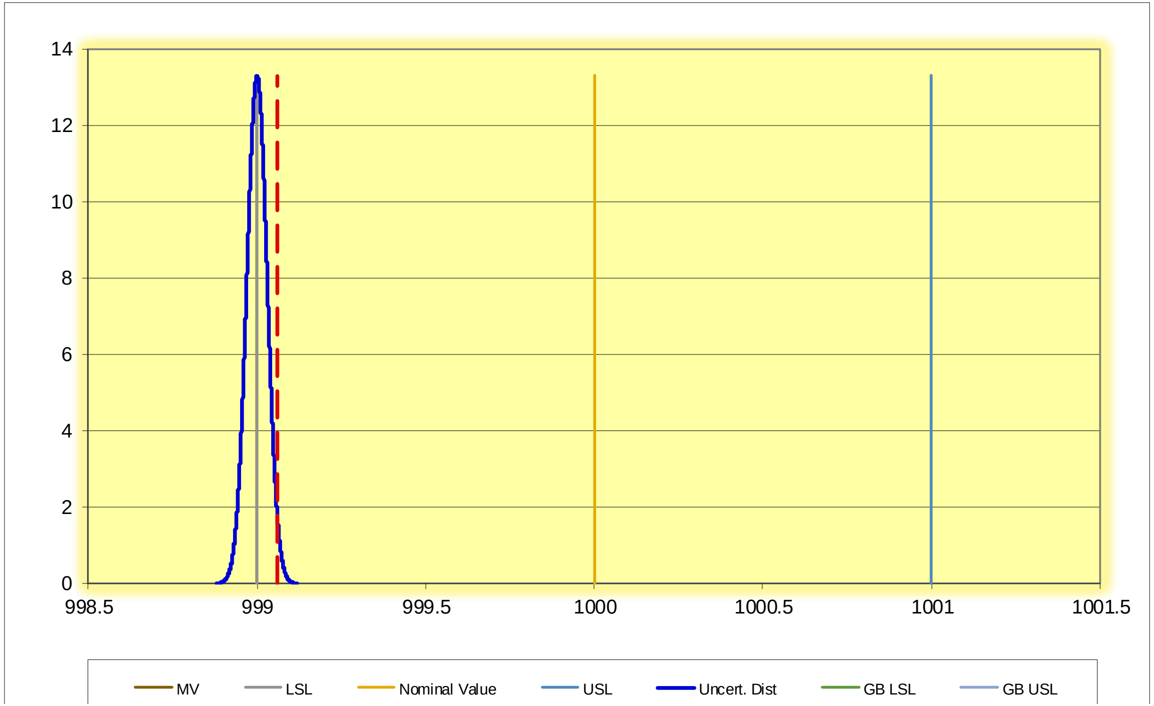
Guard Band LSL	9992.669
Guard Band USL	10007.331



Evaluating Global Consumer Risk

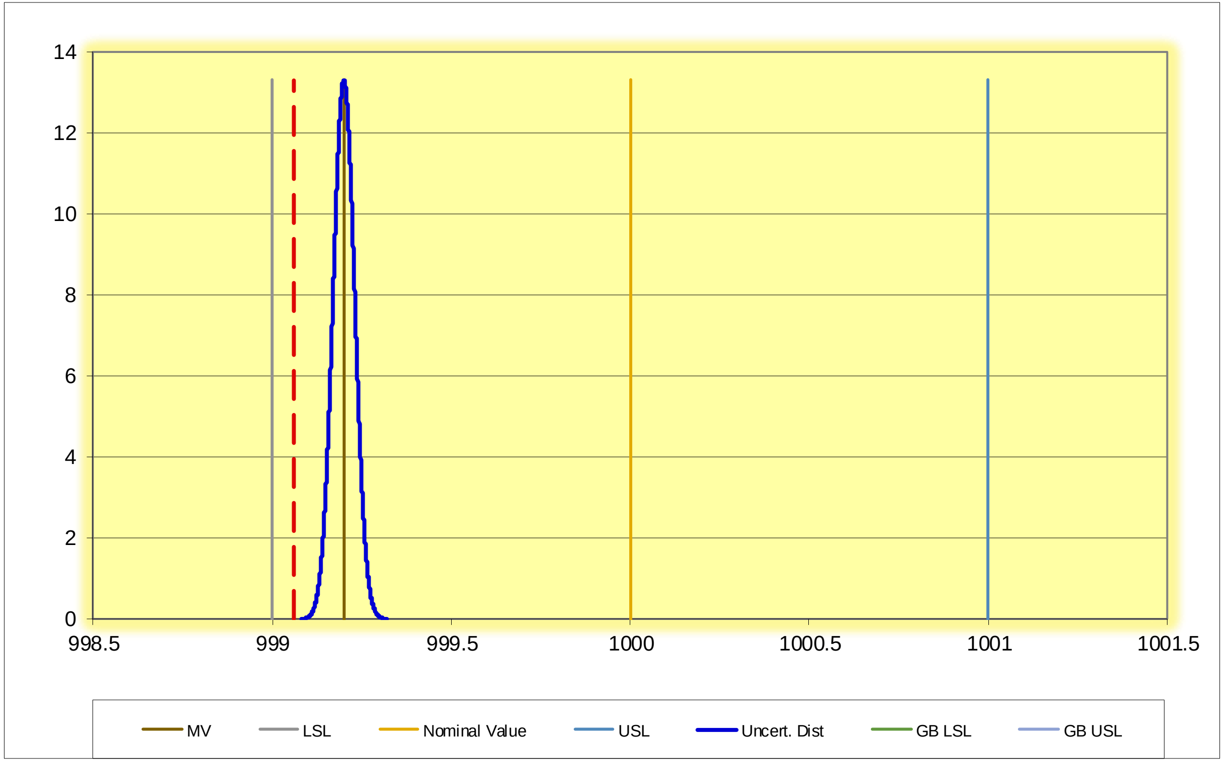
- What happens in a scenario where the LAB asks for a TAR or TUR of 4:1 or some other arbitrary number? Some may say they have evaluated their level of risk, have they?

Nominal Value	1000.0
Lower specification Limit	999.0
Upper Specification Limit	1001.0
Measured Value	999.0
Measurement Error	-1.0
Std. Uncert. (k=1)	0.030
Total Risk	50.000%
Upper Limit Risk	0.000%
Lower Limit Risk	50.000%
TUR =	**16.690958**
TAR=	**62.5**
Cpk=	**0**
Simple Guard Band with Subtraction Uncertainty Only	
Guard Band LSL	999.060
Guard Band USL	1000.940
Guard Band Limits for Risk of	**2.00%**
Guard Band LSL	999.062
Guard Band USL	1000.938



Evaluating Global Consumer Risk

Nominal Value	1000.0
Lower specification Limit	999.0
Upper Specification Limit	1001.0
Measured Value	999.2
Measurement Error	-0.8
Std. Uncert. (k=1)	0.030
Total Risk	0.000%
Upper Limit Risk	0.000%
Lower Limit Risk	0.000%
TUR =	**16.690958**
TAR=	**62.5**
Cpk=	**2.2254611**
Simple Guard Band with Subtraction Uncertainty Only	
Guard Band LSL	999.060
Guard Band USL	1000.940
Guard Band Limits for Risk of	**2.00%**
Guard Band LSL	999.062
Guard Band USL	1000.938



If you do not consider the location of the measurement, you may not be considering risk properly

Cpk (Process Capability Index)

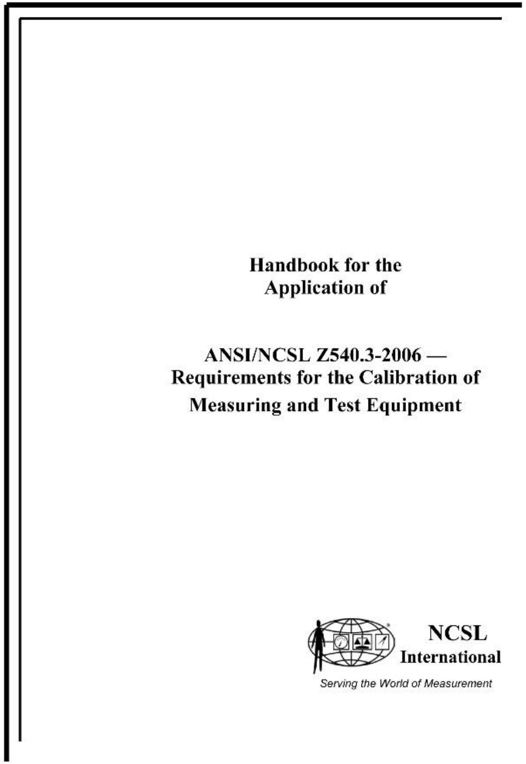
- Cpk is used to estimate how close you are to a given target and how consistent you are to around your average performance. Cpk measures two things well

1. how close the mean of the readings are to the center of the lower and upper spec limits; and
2. how widely spread the readings are

- If Cpk is less than 1.33 it will need some action (different vendor with lower uncertainties, better resolution, adjustments to the instrument, a more repeatable process can make it better)
- If Cpk is higher than 1.66, it is likely that everything is good.

ANSI/NCSL Z540.3

- Most people who implement guard bands are using methods found in this handbook.
- The handbook has 6 methods for guard bands



Handbook for the
Application of

ANSI/NCSL Z540.3-2006 —
Requirements for the Calibration of
Measuring and Test Equipment

NCSL
International
Serving the World of Measurement

ANSI/NCSL Z540.3 Guard Band Methods

- PFA Estimation Method 1, Unconditional - Test Point Population Data
- PFA Estimation Method 2, Unconditional - M&TE Population Data
- PFA Estimation Method 3, Conditional – Acceptance Subpopulation
- PFA Estimation
- Method 4, Conditional – Bayesian
- Guard Band Method 5, Based on the Expanded Calibration Process Uncertainty
- Guard Band Method 6, Based on the Test Uncertainty Ratio

Decision Rule Quote Example

Quotation

Quote number:	7
Sales Person:	Heather Sandoe
Valid until:	09-23-2021

1742 Sixth Ave. York, PA 17403
sales@mhforce.com | www.mhforce.com
717-843-0081

Please ship to the address above and include the quote number and serial number(s) of equipment. No RMA number is required.

Calibrations performed will meet the requirements of ISO/IEC 17025. Best calibration practice is to replicate how an instrument is being used. Please be sure to send any loading pads, fixtures, cables, indicators, and specific instructions as needed, so we can best replicate use.

Bill To	Ship To
ABC Company ABC Company PO Box 231 Billing York, PA, 17403 USA	ABC Company ABC Company 1742 Sixth Ave Shipping York, PA, 17403 USA

All calibrations traceable to SI through NIST.

Cage Code 90562

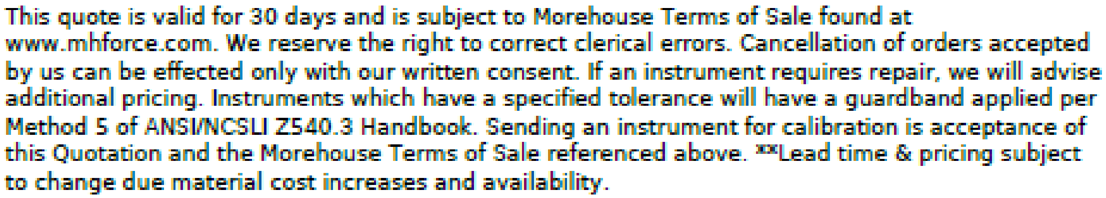
Terms	Shipping Type	Preferred Carrier	Ship Account Number	Current Lead Time
NET 30 Days	ExWorks (Customer Account)	BDP	Shipping notes here	

Quantity	Item	Description	List Price
1.00	PCM-2K-4	2,000 lbf Morehouse Portable/Benchtop Calibrating Machine Range is based on reference standard, up to 2,000 lbf. Reference standards and indicator are quoted separately. Includes reference standard mounting adapter (1/4-28 UNF 2B), tension member, compression plate, top compression load ball adapter, and case. Designed for calibration of small force measurement equipment. Load cells and additional UUT adapters are quoted separately. Height: 34 inches x Width: 9.5 inches x Length: 12 inches Compression and Tension Area: approximately 19 inches. Includes PC-2-055-01 and PC-2-054-03 for 0.250-28	
1.00	PC-2K	2,000 lbf Tension & Compression Morehouse PC-2K Precision Calibration Load Cell Calibrate per ASTM E74 with Deadweight Standards accurate to <0.002 %	

This quote is valid for 30 days and is subject to Morehouse Terms of Sale found at www.mhforce.com. We reserve the right to correct clerical errors. Cancellation of orders accepted by us can be effected only with our written consent. If an instrument requires repair, we will advise additional pricing. Instruments which have a specified tolerance will have a guardband applied per Method 5 of ANSI/NCSLI Z540.3 Handbook. Sending an instrument for calibration is acceptance of this Quotation and the Morehouse Terms of Sale referenced above. **Lead time & pricing subject to change due material cost increases and availability.

Grand Total	
Subtotal:	$1,885.00
Tax:	$0.00
Total	$1,885.00

7.8.6.1 When a statement of conformity to a specification or standard for test or calibration is provided, the laboratory shall document the decision rule employed, taking into account the level of risk (such as false accept and false reject and statistical assumptions) associated with the decision rule employed and apply the decision rule



This quote is valid for 30 days and is subject to Morehouse Terms of Sale found at www.mhforce.com. We reserve the right to correct clerical errors. Cancellation of orders accepted by us can be effected only with our written consent. If an instrument requires repair, we will advise additional pricing. Instruments which have a specified tolerance will have a guardband applied per Method 5 of ANSI/NCSLI Z540.3 Handbook. Sending an instrument for calibration is acceptance of this Quotation and the Morehouse Terms of Sale referenced above. **Lead time & pricing subject to change due material cost increases and availability.

Statement of Conformity

- When performing a measurement and subsequently making a statement of conformity, for example, in or out-of-tolerance to manufacturer's specifications or Pass/Fail to a particular requirement, there are two possible outcomes:
  - The result is reported as conforming with the specification
  - The re ming with the spe

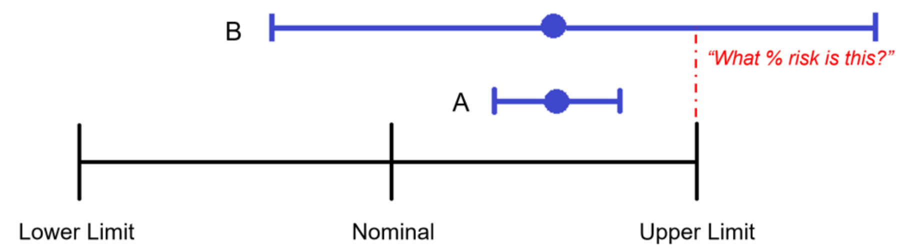
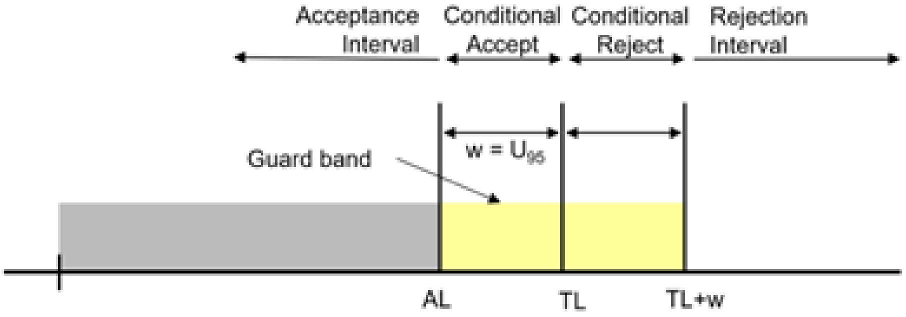
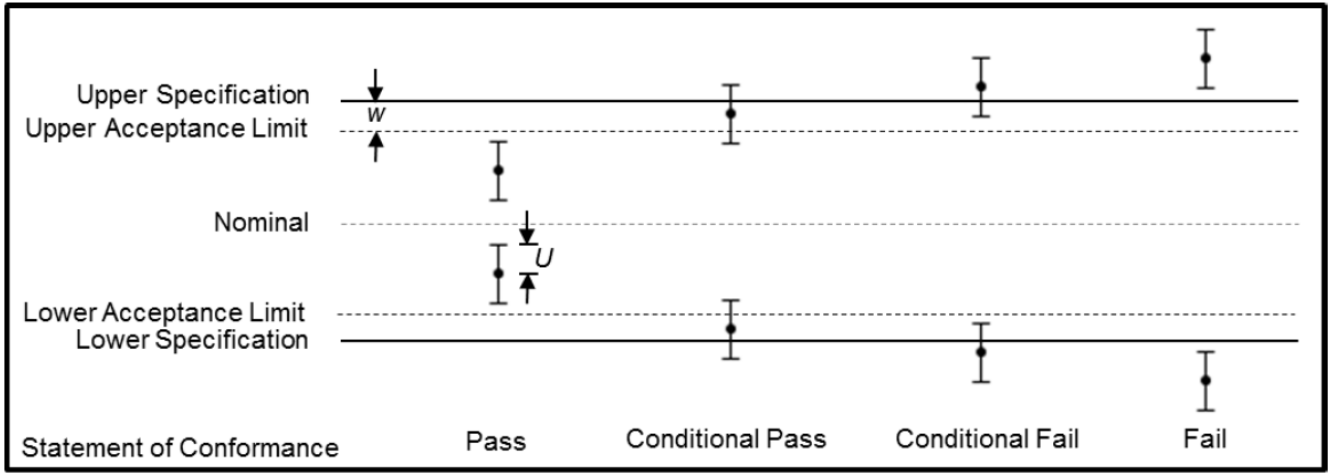


Illustration of Measurement Decision Risk

Non-Binary Acceptance Criteria





NON-BINARY DECISION RULES EXPLAINED

MHFORCE Morehouse
THE FORCE IN CALIBRATION SINCE 1925

Want a company that will meet your needs for force and torque calibration? Contact Morehouse at 717-843-0081 or sales@mforce.com to start the discussion.

ANSI/NCSL Z540.3

Guard Band Method 5, Based on the Expanded Calibration Process Uncertainty:

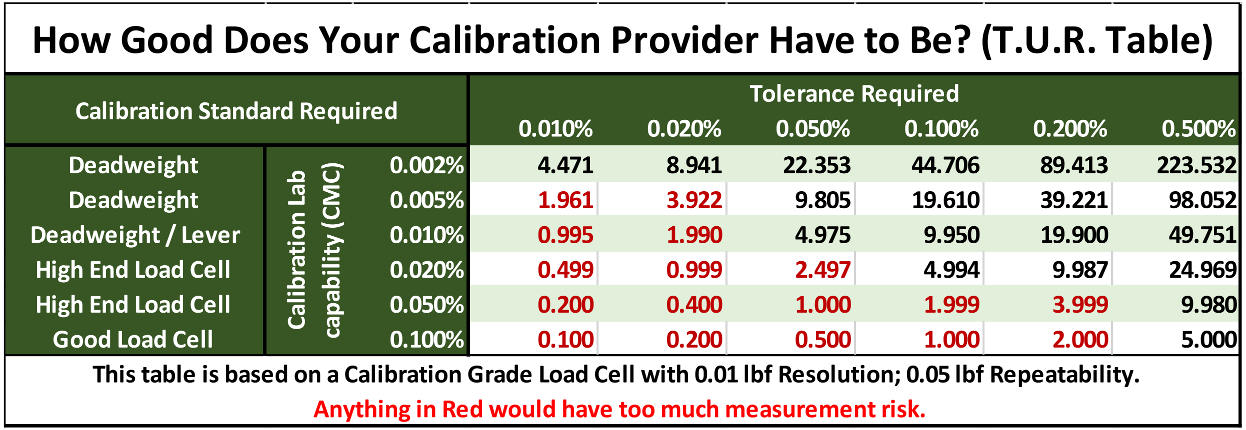
One simple approach to guard banding is to calculate acceptance limits by subtracting the 95 % expanded calibration process uncertainty from the tolerance limits. This is the approach recommended by ILAC G8 and various other documents. If the measurement result is within such acceptance limits, the PFA is very small and is therefore assured of meeting the 2 % PFA requirement. The only information necessary for this guard banding approach is the tolerance and the calibration process measurement uncertainty (page 56) However the definition of **TUR** specifically calibration process uncertainty is only defined well in the ANSI/Z540.3 Handbook

Measurement Risk

How to lower your measurement risk

- Have the calibration provider replicate how the device is being used
- Have competent technicians
- Use the right equipment
- Lower your uncertainties through your calibration provider

Note: There is quite a bit of difference between force measurement labs with CMCs of 0.1 %, 0.05 %, 0.02 %, 0.01 %, 0.005 % and 0.002 % of applied force.



How Good Does Your Calibration Provider Have to Be? (T.U.R. Table)

Calibration Standard Required			Tolerance Required					
			0.010%	0.020%	0.050%	0.100%	0.200%	0.500%
Deadweight	Calibration Lab capability (CMC)	0.002%	4.471	8.941	22.353	44.706	89.413	223.532
Deadweight		0.005%	1.961	3.922	9.805	19.610	39.221	98.052
Deadweight / Lever		0.010%	0.995	1.990	4.975	9.950	19.900	49.751
High End Load Cell		0.020%	0.499	0.999	2.497	4.994	9.987	24.969
High End Load Cell		0.050%	0.200	0.400	1.000	1.999	3.999	9.980
Good Load Cell		0.100%	0.100	0.200	0.500	1.000	2.000	5.000

This table is based on a Calibration Grade Load Cell with 0.01 lbf Resolution; 0.05 lbf Repeatability.

Anything in Red would have too much measurement risk.

Measurement Risk

Have the calibration provider replicate how the device is being used

This is a Sensotec Model RFG/F226-01 load cell. I did a test with two different types of adapters and recorded the readings (10,001.5 vs 9942.3).

There was a difference of 59.2 LBF on a 10,000 LBF cell.

This is a Sensotec Model RFG/F226-01

Different type adapters. (1.5" engagement versus 0.5 " engagement)

Measurement Risk

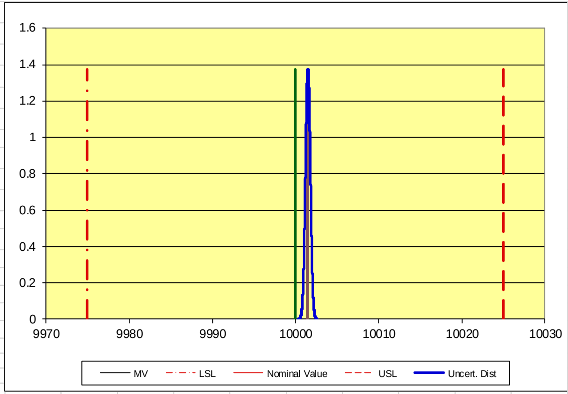
Have the calibration provider replicate how the device is being used

This is a Sensotec Model RFG/F226-01 load cell. I did a test with two different types of adapters and recorded the readings (10,001.5 vs 9942.3).

What is the probability of the measurement being within 0.25 % if the top adapter is changed out?

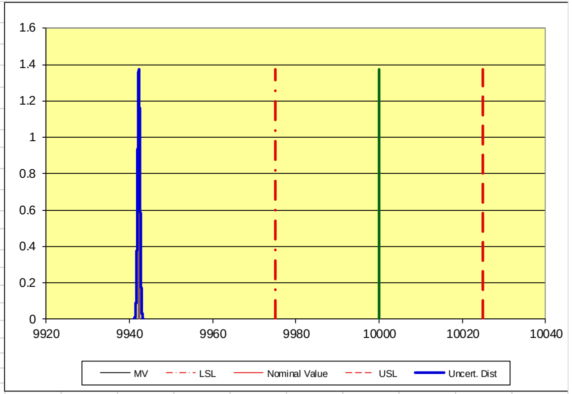
Well within 0.25 %

Nominal Value	10000
Lower specification Limit	9975
Upper Specification Limit	10025
Measured Value	10001.5
Measurement Error	1.5
Std. Uncert. (k=1)	0.29
Total Risk	0.00%
Upper Limit Risk	0.00%
Lower Limit Risk	0.00%
TUR =	**43.1034**



No where near 0.25 %

Nominal Value	10000
Lower specification Limit	9975
Upper Specification Limit	10025
Measured Value	9942.3
Measurement Error	-57.7
Std. Uncert. (k=1)	0.29
Total Risk	100.00%
Upper Limit Risk	0.00%
Lower Limit Risk	100.00%
TUR =	**43.1034**



Measurement Risk

- Have you, or any of your technicians, ever overloaded a load cell?
- Have you, or someone you know, ever used the wrong equipment to try to accomplish a certain task?
- Have you signed a certificate you were unsure about?
- Do you know of any bad measurement practices in your organization that are not being corrected, or do complaints fall on deaf ears?
- How about your calibration provider: Have they ever admitted to making a mistake? If the problem was not corrected, did it just go away?

We are not perfect, but we can mitigate measurement risk by making better measurements, and by replicating the proper use of all instruments to lessen the possibility of devastating errors.

3 Rules to Lessen Your Measurement Risk

Rule #1. Know the Right Requirements - This first rule involves knowing what is needed to accomplish the task at hand.

Rule # 2. Choose the Right Equipment – Always choose Measuring and Test Equipment that is capable of achieving the measurement tolerance required.

Rule # 3. Have the Right Processes – This last rule requires having a training program and proof of training (records) to validate the individuals performing the calibration or using the equipment.

3 Rules to Lessen Your Measurement Risk

Rule #1. Know the Right Requirements -This first rule involves knowing what is needed to accomplish the task at hand.

- The more accurate the system, the higher the costs will be to procure the equipment and have it calibrated.

- For most tests, a T.U.R. of 4:1 will meet the guidelines set fourth in ANSI Z540-1 of ensuring that the total risk is less than 4 %.

- If the requirement is 0.1 % of applied, and the stability of the device is 0.2 % over a one-year period, the device would need to have the calibration interval shortened.

What happens when Rule #1 is not followed

BP Texas Refinery Moments before and immediately after the explosion

Knowing The Right Requirements

The Accident:

- Distillation tower and attached blow down drum overfilled
- ~7600 gallons flammable liquid released
- Liquid ignited by an idling diesel truck

Proximate cause:

- High-level alarm malfunctioned
- Level transmitter miscalibrated
  - Outdated 1975 data sheet
  - Level transmitter indicated liquid level falling
  - Level actually rising rapidly

Knowing The Right Requirements

Root causes:

- Cost-cutting, production pressures, and failure to invest
- Lack of preventative maintenance and safety training
- Procedural workarounds to compensate for the deteriorating equipment

The Cost:

- 15 deaths,
- 180 injured
- Over $2 billion, including lawsuits

The Aftermath

Special Thank You to Scott Mimbs for providing this example

3 Rules to Lessen Your Measurement Risk

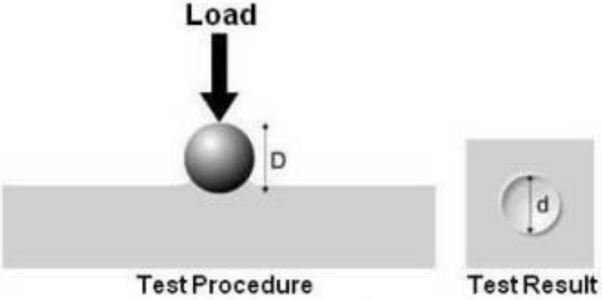
Rule # 2. Choose the Right Equipment – Always choose Measuring and Test Equipment that is capable of achieving the measurement tolerance required.

- If you need to certify that an instrument is within a tolerance of 1 %, you cannot use a standard with a 1 % tolerance to perform the calibration.
- Several manufacturers do not understand T.U.R and do not include the instrument’s resolution or repeatability, or the reference standard used to perform the calibration, in their accuracy claims.
- On most of these instruments, no reference standard in the world may lower the risk if the instrument shows any bias.

The Right Equipment?

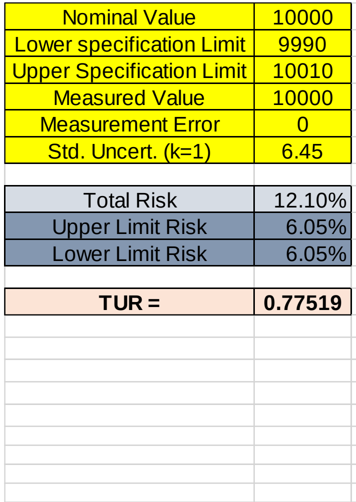
Boilers Blowing Up

1921 Brinell Hardness Machine

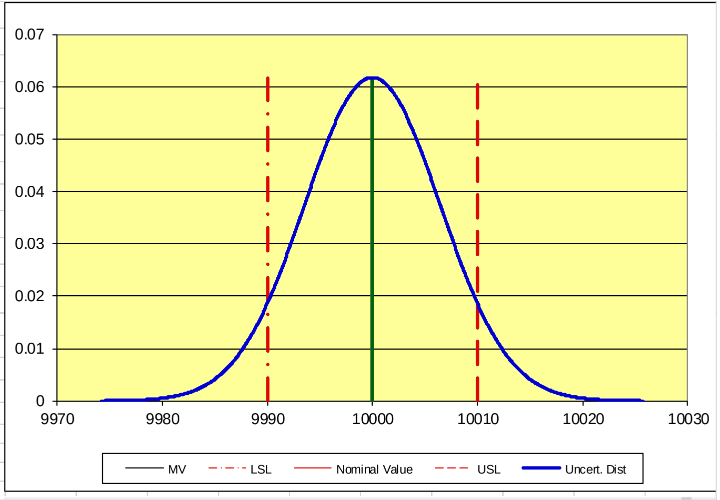


Brinell Testing

Choosing The Right Equipment



Nominal Value	10000
Lower specification Limit	9990
Upper Specification Limit	10010
Measured Value	10000
Measurement Error	0
Std. Uncert. (k=1)	6.45
Total Risk	12.10%
Upper Limit Risk	6.05%
Lower Limit Risk	6.05%
TUR =	**0.77519**



This is the calibration of an Aircraft Scale in our 804000 Press. The scale is repeatable within 10 lbf * and has a resolution of 10 lbf. No matter what reference standard is used, the Total Risk will always be higher than 10 %.

* Note: Unless actions are taken to reduce the repeatability or resolution.

Choosing The Right Equipment

$$\text{TUR} = \frac{\text{Span of the } \pm \text{Tolerance}}{2 \text{ x } k_{95\%} \left(\sqrt[2]{\left(\frac{\text{CMC}}{k_{\text{CMC}}}\right)^2 + \left(\frac{\text{Resolution}_{\text{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\text{Repeatability}_{\text{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2} \right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

Let’s break down the Intercomp Scale

- Toluut = 0.1 % of Applied 10 lbf, (USL – LSL)/2 ((10,010 – 9,990)/2) = **10 lbf**
- CMC uncertainty component = Variable CMC’s
- Ures = **10 lbf**
- Urep = This is found by taking standard deviation of several test points. **5.774**

Urep	
Force Applied	Instrument Reading
10000	10000
10000	9990
10000	10000
10000	9990
STD DEV	5.773502692

Choosing The Right Equipment

$$\mathrm{TUR} = \frac{\text{Span of the } \pm \text{Tolerance}}{2 \text{ x } k_{95\%} \left(\sqrt[2]{\left(\frac{\mathrm{CMC}}{k_{\mathrm{CMC}}}\right)^2 + \left(\frac{\mathrm{Resolution}_{\mathrm{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\mathrm{Repeatability}_{\mathrm{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2} \right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

- Let’s break down the Scale
- Toluut = 10 lbf, (USL – LSL)/2
- CMC uncertainty component = Variable CMC’s
- Ures = 10
- Urep = 5.774

Capacity	Req Tolerance	LSL	USL	Res UUT	Rep UUT	CMC	Std Unc	Exp Unc	TUR
10000	0.100%	9990	10010	10	5.774	0.000%	6.46	12.91	0.775
10000	**0.100%**	**9990**	**10010**	**10**	**5.774**	**0.002%**	**6.46**	**12.91**	**0.774**
10000	0.100%	9990	10010	10	5.774	0.005%	6.46	12.92	0.774
10000	0.100%	9990	10010	10	5.774	0.025%	6.58	13.15	0.760
10000	0.100%	9990	10010	10	5.774	0.050%	6.92	13.85	0.722
10000	0.100%	9990	10010	10	5.774	0.100%	8.17	16.33	0.612

How can we fix this?

Raise the Tolerance?

Capacity	Req Tolerance	LSL	USL	Res UUT	Rep UUT	CMC	Std Unc	Exp Unc	TUR
10000	0.520%	9948	10052	10	5.774	0.000%	6.46	12.91	4.028
10000	**0.520%**	**9948**	**10052**	**10**	**5.774**	0.002%	**6.46**	**12.91**	**4.027**
10000	0.520%	9948	10052	10	5.774	0.005%	6.46	12.92	4.025
10000	0.520%	9948	10052	10	5.774	0.025%	6.58	13.15	3.954
10000	0.520%	9948	10052	10	5.774	0.050%	6.92	13.85	3.756
10000	0.520%	9948	10052	10	5.774	0.100%	8.17	16.33	3.184

Improve Repeatability Only ?

Capacity	Req Tolerance	LSL	USL	Res UUT	Rep UUT	CMC	Std Unc	Exp Unc	TUR
10000	0.100%	9990	10010	10	0	0.000%	2.89	5.77	1.732
10000	**0.100%**	**9990**	**10010**	**10**	**0**	0.002%	**2.89**	**5.78**	**1.731**
10000	0.100%	9990	10010	10	0	0.005%	2.90	5.80	1.726
10000	0.100%	9990	10010	10	0	0.025%	3.15	6.29	1.589
10000	0.100%	9990	10010	10	0	0.050%	3.82	7.64	1.309
10000	0.100%	9990	10010	10	0	0.100%	5.77	11.55	0.866

Improve Resolution and Repeatability ?

Capacity	Req Tolerance	LSL	USL	Res UUT	Rep UUT	CMC	Std Unc	Exp Unc	TUR
10000	0.100%	9990	10010	2	0	0.000%	0.58	1.15	8.660
10000	**0.100%**	**9990**	**10010**	**2**	**0**	0.002%	**0.59**	**1.17**	**8.533**
10000	0.100%	9990	10010	2	0	0.005%	0.63	1.26	7.947
10000	0.100%	9990	10010	2	0	0.022%	1.24	2.48	4.025
10000	0.100%	9990	10010	2	0	0.050%	2.57	5.13	1.949
10000	0.100%	9990	10010	2	0	0.100%	5.03	10.07	0.993

A TUR better than 4:1 would have minimal risk assuming the location of the measurement is within the guard band limits.

With a 2 lbf resolution and a CMC of 0.022 %, a 4:1 TUR could be achieved

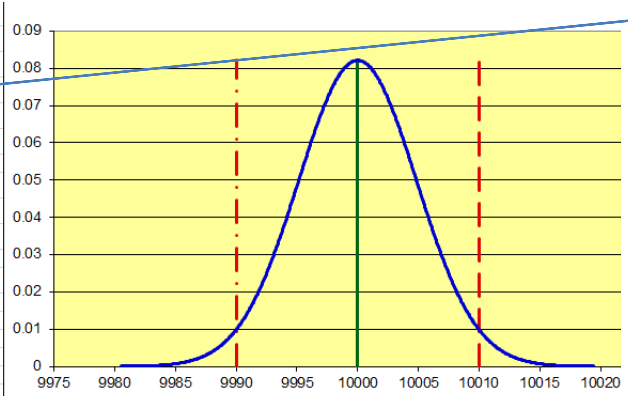
How can we fix this?

We need to figure out how to lower the uncertainty and adjust the acceptance limits to limit lower and upper risk to less than ± 2 %

Nominal Value	10000
Lower specification Limit	9990
Upper Specification Limit	10010
Measured Value	10000
Measurement Error	0
Std. Uncert. (k=1)	4.86

Total Risk	3.96%
Upper Limit Risk	1.98%
Lower Limit Risk	1.98%

TUR =	**1.02881**



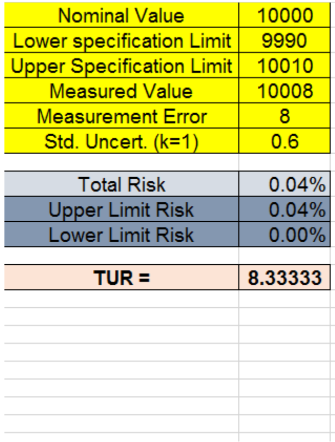
This assumes the location of the measurement is perfect.

Capacity	Req Tolerance	LSL	USL	Res UUT	Rep UUT	CMC	Std Unc	Exp Unc	TUR	U & L RISK	One Sided
10000	0.100%	9990	10010	10	3.77	0.000%	4.75	9.50	1.053	3.53%	1.76%
10000	**0.100%**	**9990**	**10010**	**10**	**3.77**	0.002%	4.75	9.50	**1.053**	3.53%	1.76%
10000	0.100%	9990	10010	10	3.77	0.005%	4.75	9.51	1.052	3.53%	1.76%
10000	0.100%	9990	10010	10	3.77	0.025%	4.91	9.82	1.018	4.17%	6.43%
10000	0.100%	9990	10010	10	3.77	0.050%	5.37	10.73	0.932	6.26%	3.13%
10000	0.100%	9990	10010	10	3.77	0.100%	6.90	13.79	0.725	14.73%	7.36%

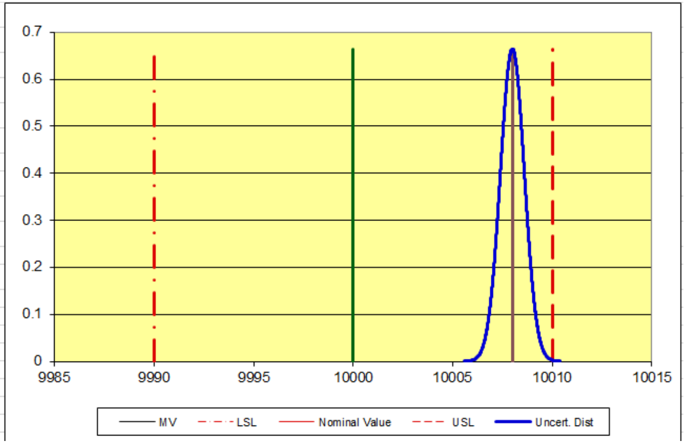
Urep

Force Applied	Instrument Reading
10000	10000
10000	10000
10000	10000
10000	9990
10000	10000
10000	10000
10000	10000
STD DEV	3.77964473

Choosing The Right Equipment



Nominal Value	10000
Lower specification Limit	9990
Upper Specification Limit	10010
Measured Value	10008
Measurement Error	8
Std. Uncert. (k=1)	0.6
Total Risk	0.04%
Upper Limit Risk	0.04%
Lower Limit Risk	0.00%
TUR =	**8.33333**



The only way to lower the Total Risk is to buy a scale with a better repeatability & resolution or change the method (lower the acceptance limits). Evaluating all components in a system is critical.

Note: Changing the process may cause all kinds of measurement problems resulting in a much higher risk. (Example: Switching from deadweights to load cells would raise the CMC and may require lowering the acceptance limit)

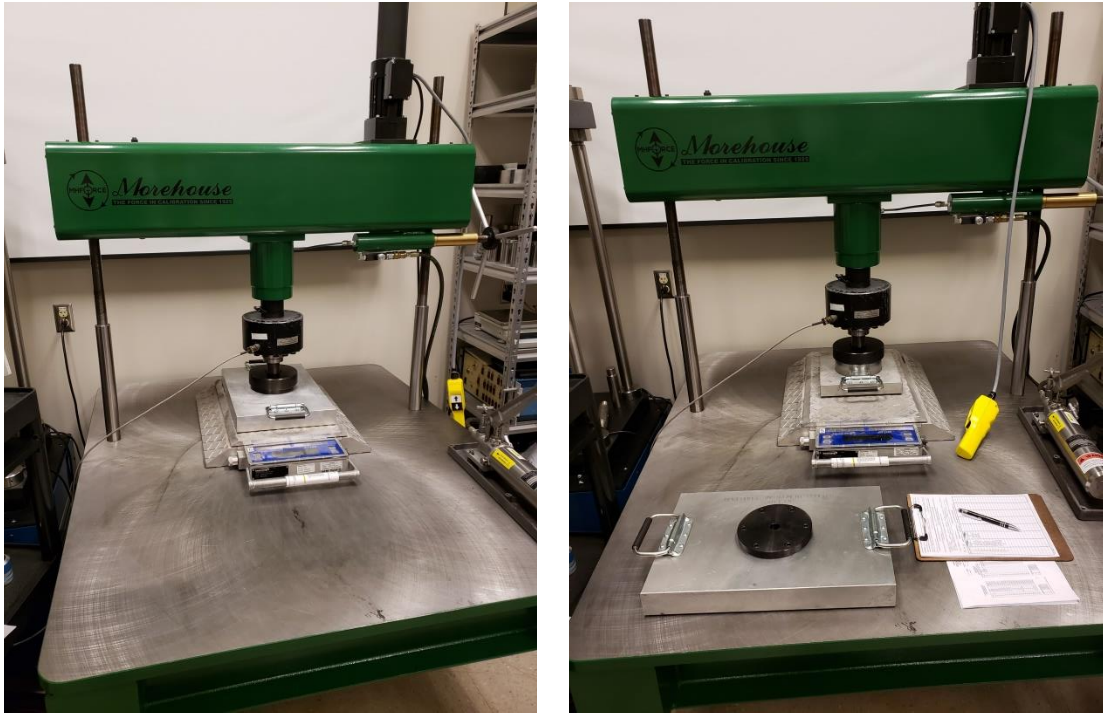
Aircraft and Truck Scale Adapters

Truck and Aircraft Scales are typically used to weigh trucks and airplanes with the tires sitting on several scales. Any adapter used during calibration should be composed of the same type of rubber and should have the same footprint as the tire to ensure accurate results.

[Link to Aircraft and Truck Scale Calibrators]

Truck Scales

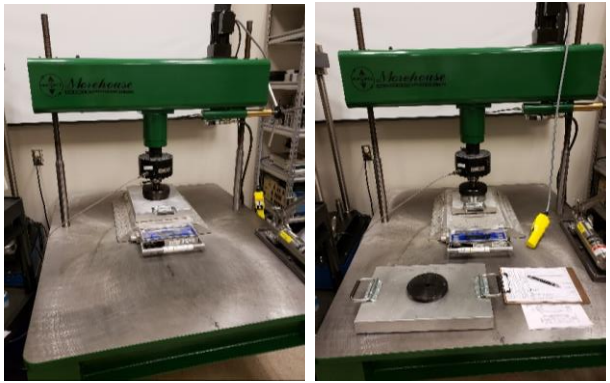
Truck Scales



Pictures Showing Two Different Size Adapters.

Will there be a difference in the measured values?

Calibration of a Truck Scale



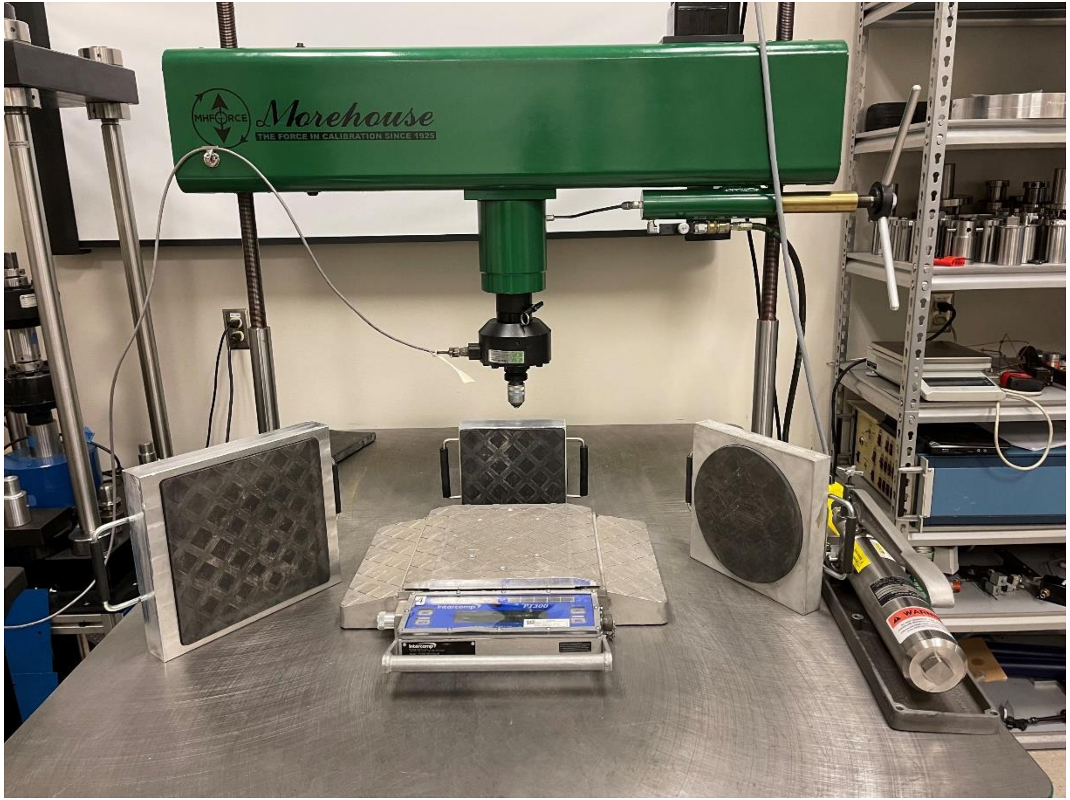
Notes: Calibration of a truck scale in our Morehouse USC-60 Scale Calibrating Machine. This test is comparing the difference in the footprint of different tires on the scale.

Force Applied lbf	Instrument Reading normal pad	Instrument Reading small pad	Difference in lbf	% Difference	Tolerance 1 % of Applied	Tolerance % by using different pads
2000	2000	2000	0	0.00%	20	0%
4000	4000	4000	0	0.00%	40	0%
6000	6020	6020	0	0.00%	60	0%
8000	8020	8020	0	0.00%	80	0%
10000	10040	9980	60	0.60%	100	60%
12000	12040	11980	60	0.50%	120	50%
14000	14060	13980	80	0.57%	140	57%
16000	16060	15960	100	0.63%	160	63%
18000	18060	17940	120	0.67%	180	67%
20000	20060	19920	140	0.70%	200	70%

Calibration of a Truck Scale

Difference in lbf	% Difference	Tolerance 1 % of Applied	Tolerance % by using different pads
0	0.00%	20	0%
0	0.00%	40	0%
0	0.00%	60	0%
0	0.00%	80	0%
60	0.60%	100	60%
60	0.50%	120	50%
80	0.57%	140	57%
100	0.63%	160	63%
120	0.67%	180	67%
140	0.70%	200	70%

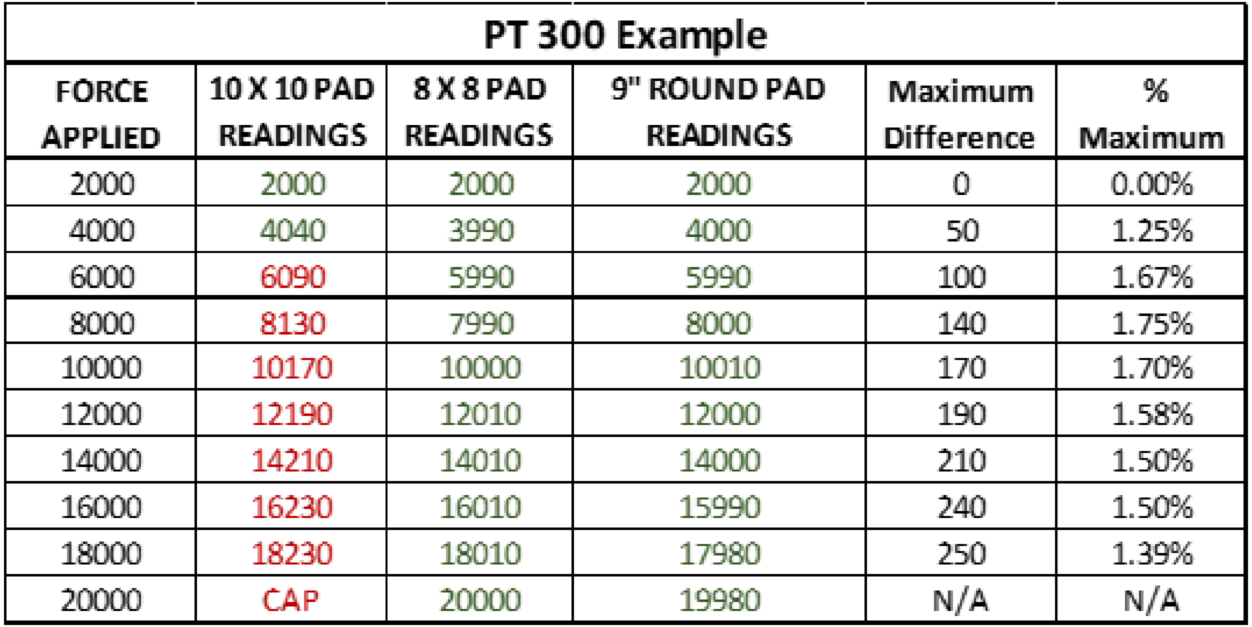
Truck Scales



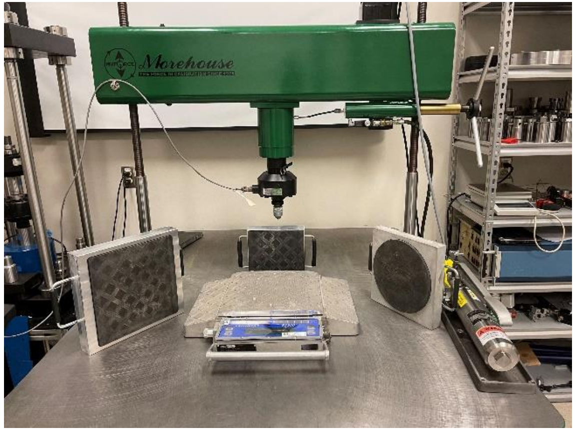
Pictures Showing three Different Size Adapters made by Morehouse.

Will there be a difference in the measured values on a 10,000 lbf PT300 scale?

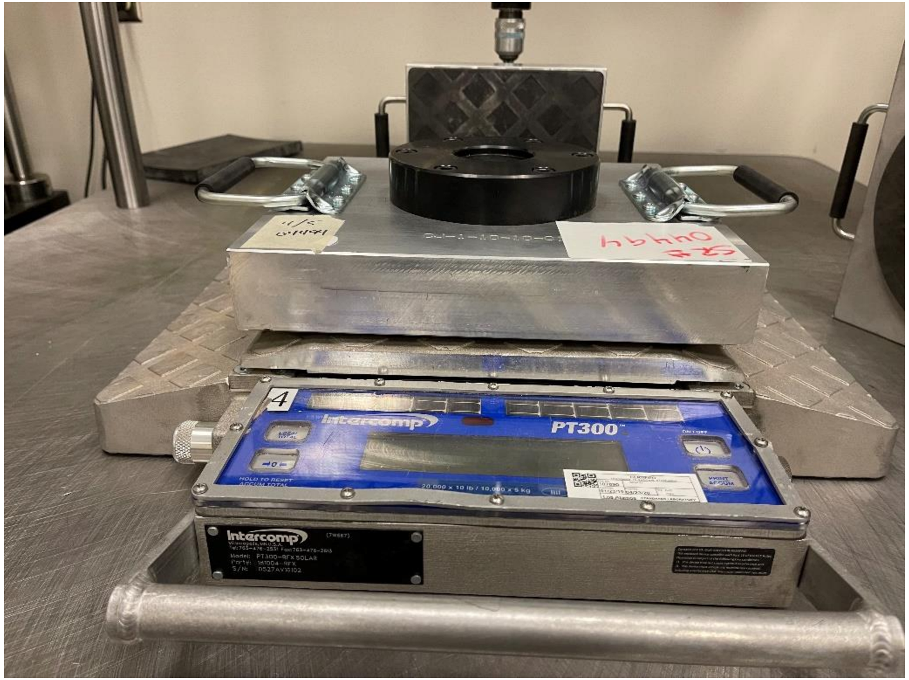
Calibration of a Truck Scale



PT 300 Example					
FORCE APPLIED	10 X 10 PAD READINGS	8 X 8 PAD READINGS	9" ROUND PAD READINGS	Maximum Difference	% Maximum
2000	2000	2000	2000	0	0.00%
4000	4040	3990	4000	50	1.25%
6000	6090	5990	5990	100	1.67%
8000	8130	7990	8000	140	1.75%
10000	10170	10000	10010	170	1.70%
12000	12190	12010	12000	190	1.58%
14000	14210	14010	14000	210	1.50%
16000	16230	16010	15990	240	1.50%
18000	18230	18010	17980	250	1.39%
20000	CAP	20000	19980	N/A	N/A



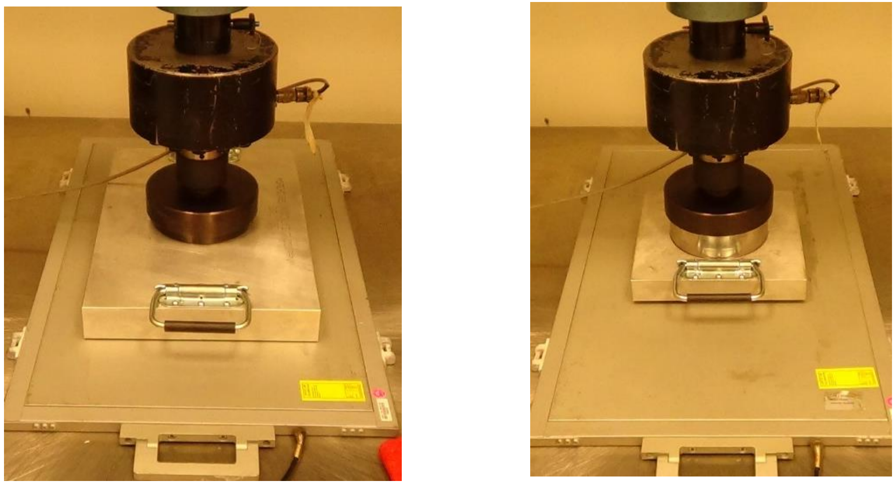
Calibration of a Truck Scale



Thoughts?

Aircraft and Truck Scale Adapters

Morehouse has tested truck and aircraft scales and there is a large difference in using different size plates



Force Applied lbf	Scale Reading w/ Large pad	Scale Reading w/ Small pad		
0	0	0	**Diff in lbf**	**%**
4000	3950	3980	-30	-0.759%
8000	7980	8030	-50	-0.627%
12000	11990	12020	-30	-0.250%
16000	15980	16090	-110	-0.688%
20000	19980	20140	-160	-0.801%
24000	23990	24210	-220	-0.917%
28000	27990	28270	-280	-1.000%
32000	31990	32350	-360	-1.125%
36000	35990	36460	-470	-1.306%
40000	40010	meter saturated		

The Right Equipment

The right equipment for force is going to be made to minimize off-center loading, bending, and torsion. To do this force machines need to be:

1. Plumb
2. Level
3. Square
4. Rigid
5. Free of Torsion

Note: All of the machines shown are designed with these 5 things in mind. They replicate how most instruments are used in the field

The Right Equipment

The right equipment for force is going to be
Plumb-exactly vertical or true

Pictured Right – Morehouse 1,000 lbf automated deadweight machine that is plumb. In this machine the weights hang in a vertical direction and if they are out of plumb, they will introduce misalignment through the vertical line of force.

The Right Equipment

The right equipment for force is going to be

Level-a device for establishing a horizontal line or plane by means of a bubble in a liquid that shows adjustment to the horizontal by movement to the center of a slightly bowed glass tube

Pictured Right – Morehouse 100,000 lbf UCM. The upper and lower platen are ground flat and the adjustable feet allow the end user to obtain a level condition. If level is not achieved, errors from misalignment will happen.

The Right Equipment

The right equipment for force is going to be
Square- for Force Machines this is about having four right angles.

Pictured Right – Morehouse 10,000 lbf Benchtop Machine. The adjustable beam and bottom base form the 4 right angles. This reduces the chance of misalignment. The bottom screw is aligned to the top beam to keep the line of force as plumb as possible.

The Right Equipmen

Rigid – not flexible. If the loading surface starts to bend, all sorts of alignment errors can happen which will impact the results

Pictured Right - Morehouse USC-60K With Reference Load and Morehouse 4215 Indicator – the top and bottom plates are reinforced to keep the machine from bending

The Right Equipment

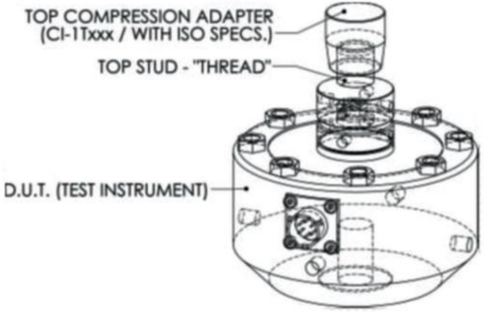
Torsion – the action of twisting or the state of being twisted. Free of torsion means free of being twisted when forces are applied

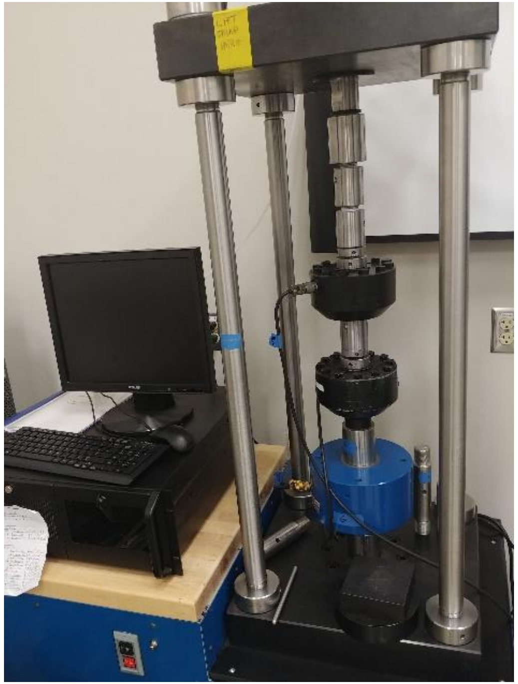
Pictured Right - Morehouse PCM-2K With Reference Load Cell. This machine have special bearings to keep things from twisting. Before putting in the bearings, the measurement errors were higher than 0.1 %, when we added the bearings, the errors became less than 0.02 %, which is better than most transfer standard type machines.

The Right Equipment

Replicates Field Use

Tensile force transducers should be fitted with two ball nuts, two ball cups

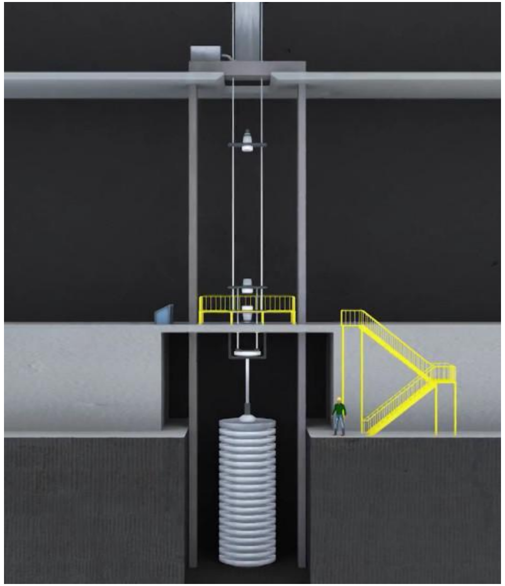


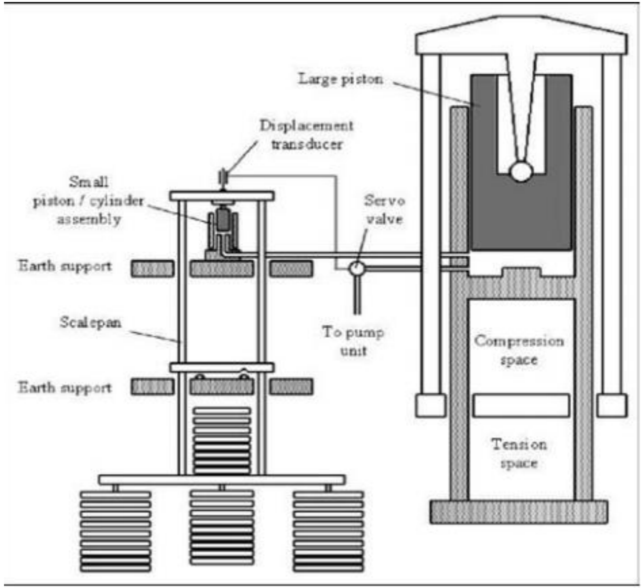


One of these does not replicate how the equipment is used in the field. Which One?

The Right Equipment

Replicates Field Use





The Right Equipment

Replicates Field Use

To Replicate Field Use for ASTM E4 & ISO 7500 Calibrations in These Types of Machines

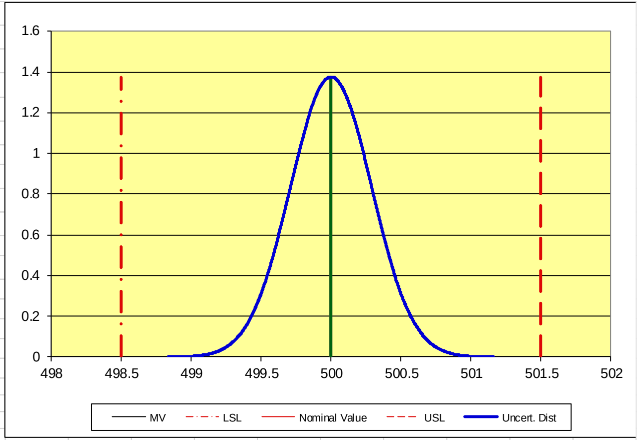
- The Calibration Laboratory Should Not Perform Compression and Tension Calibration in the Same Setup (Common Practice as it is much quicker)
- They Should use the Customer's Top Blocks and make Separate Compression Setups
- In Compression, they Should Require a Baseplate to Load Against
- For Tension Calibration if the End-User is Calibrating per ISO 7500, They Should Use Adapters Recommended Per the ISO Annex, which would be different than what is shown here

Choosing The Right Equipment

Nominal Value	500
Lower specification Limit	498.5
Upper Specification Limit	501.5
Measured Value	500
Measurement Error	0
Std. Uncert. (k=1)	0.29

Total Risk	0.00%
Upper Limit Risk	0.00%
Lower Limit Risk	0.00%

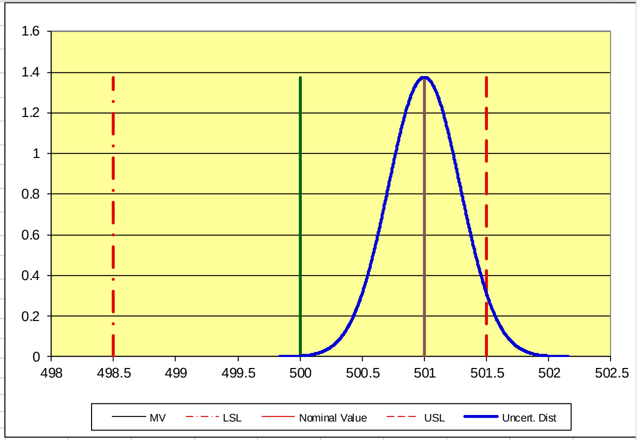
TUR =	**2.58621**



Nominal Value	500
Lower specification Limit	498.5
Upper Specification Limit	501.5
Measured Value	501
Measurement Error	1
Std. Uncert. (k=1)	0.29

Total Risk	4.23%
Upper Limit Risk	4.23%
Lower Limit Risk	0.00%

TUR =	**2.58621**



MSI PORTA-WEIGHT – Some accuracy specifications are 0.1 % of applied and other are 0.1 % of applied ± 1 count.

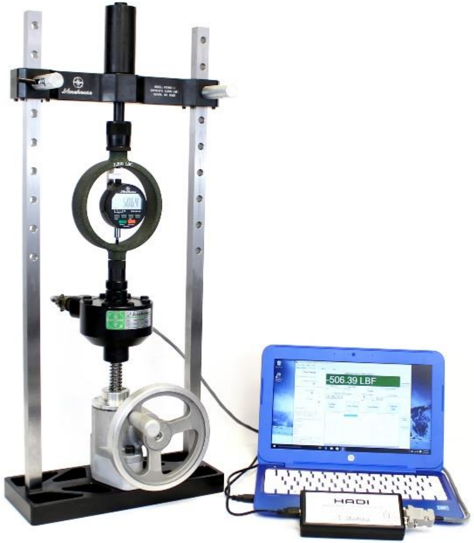
Specification on this model is 0.1 % of applied ± 1 count

Location of the measurement is key.

Great Equipment. Just Remember that location of the measurement is key!

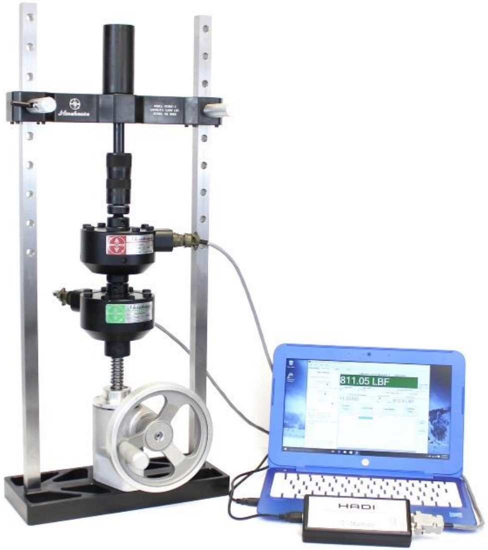
Choosing The Right Equipment
Morehouse 2K-PCM W/ Ultra Precision Load Cell

Is the PCM accurate enough to calibrate the UUT in each of the following scenarios using Method 5? Typical Expanded Uncertainty is 0.02 % of applied force



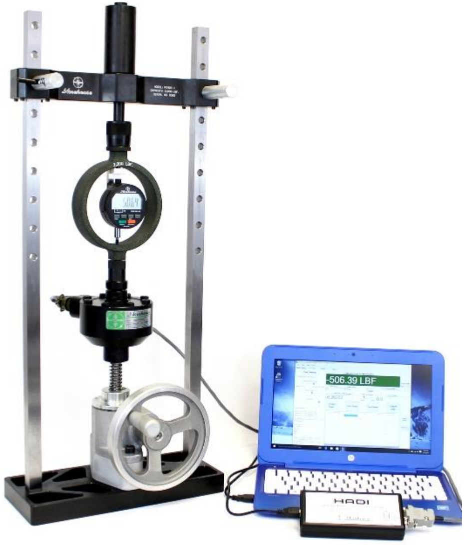
UUT 0.5 % of full scale

UUT 0.1 % of full scale



UUT 0.025 % of full scale

Choosing The Right Equipment
Morehouse 2K-PCM W/ Ultra Precision Load Cell



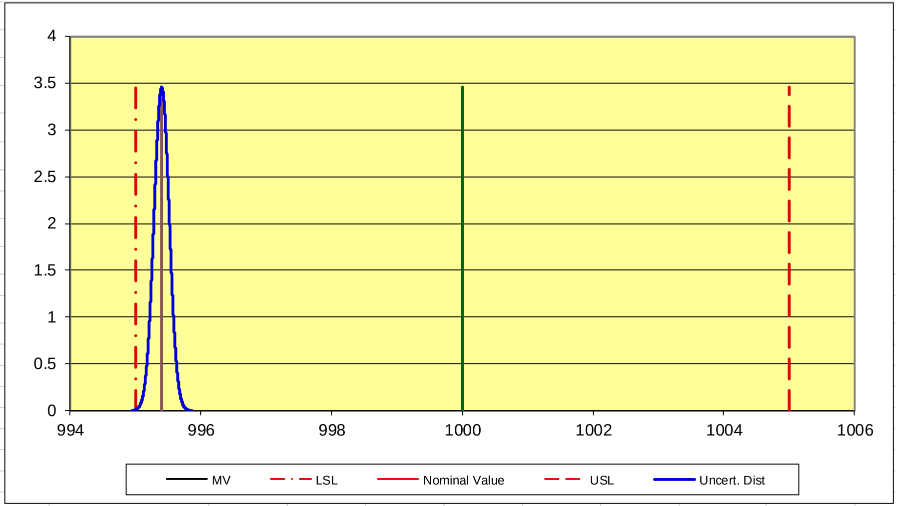
1000 lbf Digital Force Gage UUT 0.5 % of full scale

With a CMC uncertainty component of 0.02 % and a UUT resolution of 0.2 lbf if the UUT reads between 995.4 and 1004.6, the system would be accurate enough to calibrate the UUT.

Nominal Value	1000
Lower specification Limit	995
Upper Specification Limit	1005
Measured Value	995.4
Measurement Error	-4.6
Std. Uncert. (k=1)	0.12

Total Risk	0.03%
Upper Limit Risk	0.00%
Lower Limit Risk	0.03%

TUR =	**21.65047632**

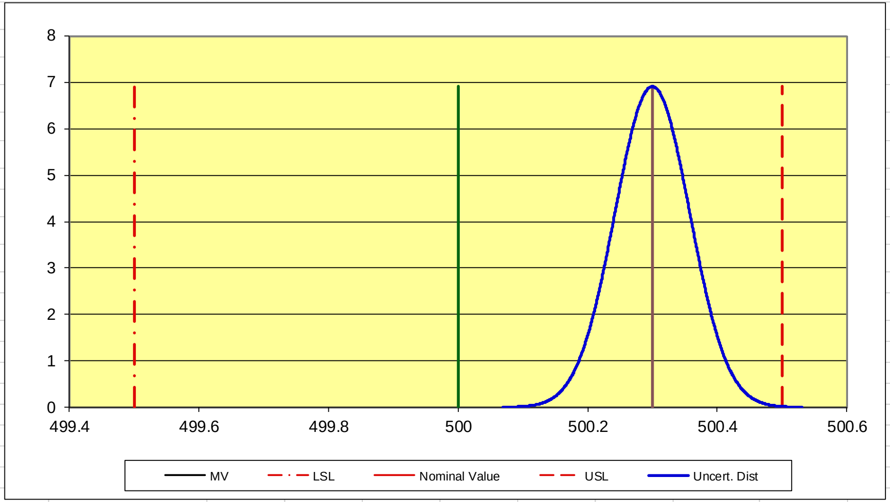


Choosing The Right Equipment
Morehouse 2K-PCM W/ Ultra Precision Load Cell

500 lbf Digital Force Gage UUT 0.1 % of full scale

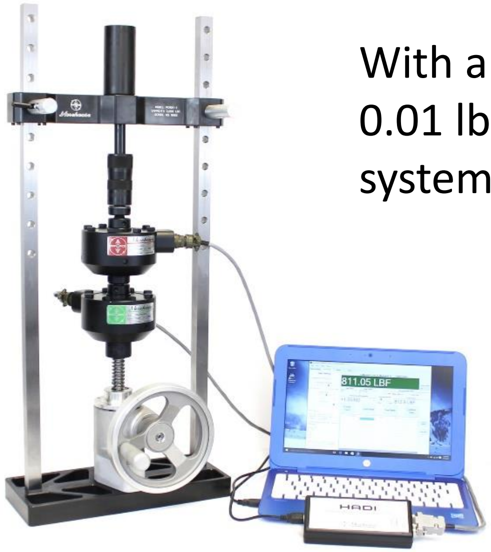
With a CMC uncertainty component of 0.02 % and a UUT resolution of 0.1 lbf if the UUT reads between 499.7 and 500.3, the system would be accurate enough to calibrate the UUT.

Nominal Value	500
Lower specification Limit	499.5
Upper Specification Limit	500.5
Measured Value	500.3
Measurement Error	0.3
Std. Uncert. (k=1)	0.06
Total Risk	0.03%
Upper Limit Risk	0.03%
Lower Limit Risk	0.00%
TUR =	**4.330095263**



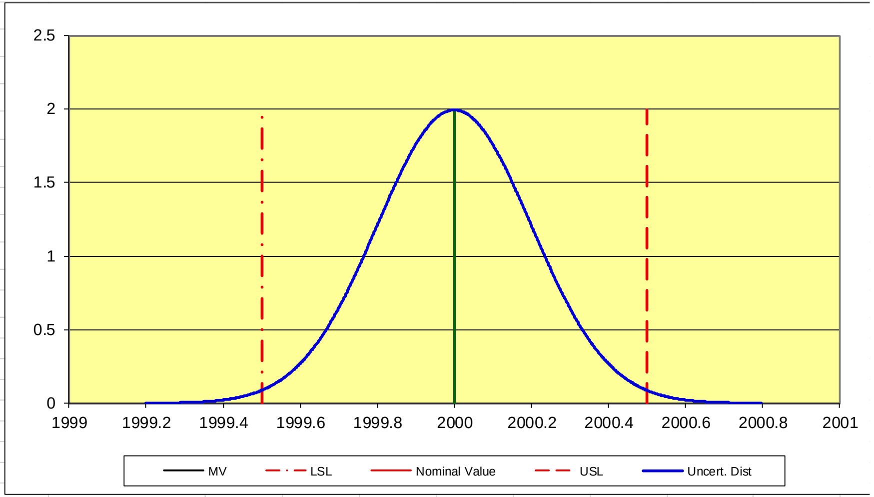
Choosing The Right Equipment
Morehouse 2K-PCM W/ Ultra Precision Load Cell

With a CMC uncertainty component of 0.02 % and a UUT resolution of 0.01 lbf as long as the UUT reads between 1999.91 lbf and 2000.09, the system would be accurate enough to calibrate the UUT.



2000 lbf Load Cell UUT with a tolerance of 0.025 % of full scale

Nominal Value	2000
Lower specification Limit	1999.5
Upper Specification Limit	2000.5
Measured Value	2000
Measurement Error	0
Std. Uncert. (k=1)	0.20
Total Risk	1.24%
Upper Limit Risk	0.62%
Lower Limit Risk	0.62%
TUR =	**1.249869804**



Method 6 would allow between 1999.66 and 2000.34 to pass!

Choosing The Right Equipment

$$\mathrm{TUR} = \frac{\text{Span of the } \pm \text{Tolerance}}{2 \text{ x } k_{95\%} \left(\sqrt[2]{\left(\frac{\mathrm{CMC}}{k_{\mathrm{CMC}}}\right)^2 + \left(\frac{\mathrm{Resolution}_{\mathrm{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\mathrm{Repeatability}_{\mathrm{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2} \right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

The Reference Equipment chosen could affect the TUR in the following ways:

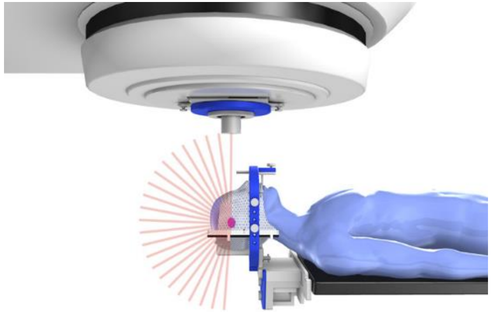
1. **It can raise or lower the TUR**
2. **Different equipment types have different CMC uncertainty components which will raise or lower the TUR**
3. **Different reference standards can make the repeatability of the UUT better or worse. (An example of this would be hydraulic versus deadweight) The stability of the hydraulics would factor into the CMC uncertainty component.**
4. **Different reference standards have different resolution (deadweight has 0, while a 60K load cell may have 0.15 lbf)**
5. **Changing the reference standard type will change the process, resulting in an increase or decrease in the CMC uncertainty components.**

3 Rules to Lessen Your Measurement Risk

- **Rule # 3. Have the Right Processes** – This last rule requires having a training program and proof of training (records) to validate the individuals performing the calibration or using the equipment.
- It is important to maintain and follow procedures that adequately support the end-product performance
- There should be a process in place that ensures all aspects of the standards are being carefully satisfied in the calibration process
- Use of Proper Adapters and making sure the instrument’s calibration matches how it is being used in the field or lab.

The Right Processes?

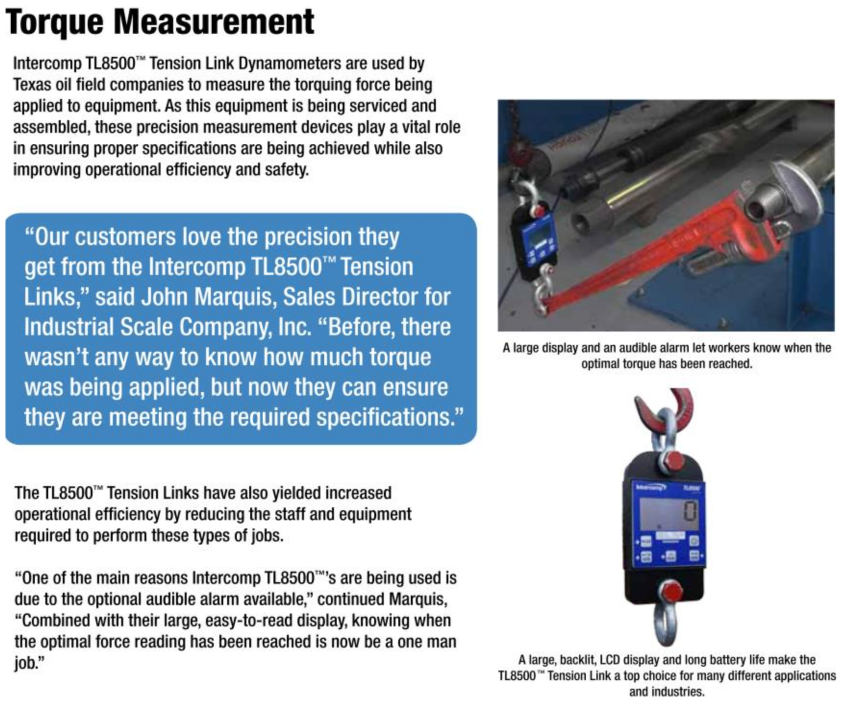
Incorrectly calibrated radiation treatment system overdosed 152 cancer patients



- CoxHealth of Springfield, MO inadvertently overdosed 152 cancer patients, 76 of which received up to 70% higher than prescribed dosages
- The device, a BrainLAB stereotactic radiation system used to treat areas 1.1 centimeters or smaller, was initially incorrectly calibrated by the CoxHealth chief physicist in 2004
- The error went undetected for five years, until September 2009 when another CoxHealth physicist received training on the BrainLAB system
- Although the calibration error was corrected, as of February 2012, the CoxHealth BrainLAB program remains suspended while lawsuits are settled

The Right Processes?

The Right Processes?



Torque Measurement

Intercomp TL8500™ Tension Link Dynamometers are used by Texas oil field companies to measure the torquing force being applied to equipment. As this equipment is being serviced and assembled, these precision measurement devices play a vital role in ensuring proper specifications are being achieved while also improving operational efficiency and safety.

> "Our customers love the precision they get from the Intercomp TL8500™ Tension Links," said John Marquis, Sales Director for Industrial Scale Company, Inc. "Before, there wasn't any way to know how much torque was being applied, but now they can ensure they are meeting the required specifications."

The TL8500™ Tension Links have also yielded increased operational efficiency by reducing the staff and equipment required to perform these types of jobs.

"One of the main reasons Intercomp TL8500™'s are being used is due to the optional audible alarm available," continued Marquis, "Combined with their large, easy-to-read display, knowing when the optimal force reading has been reached is now be a one man job."

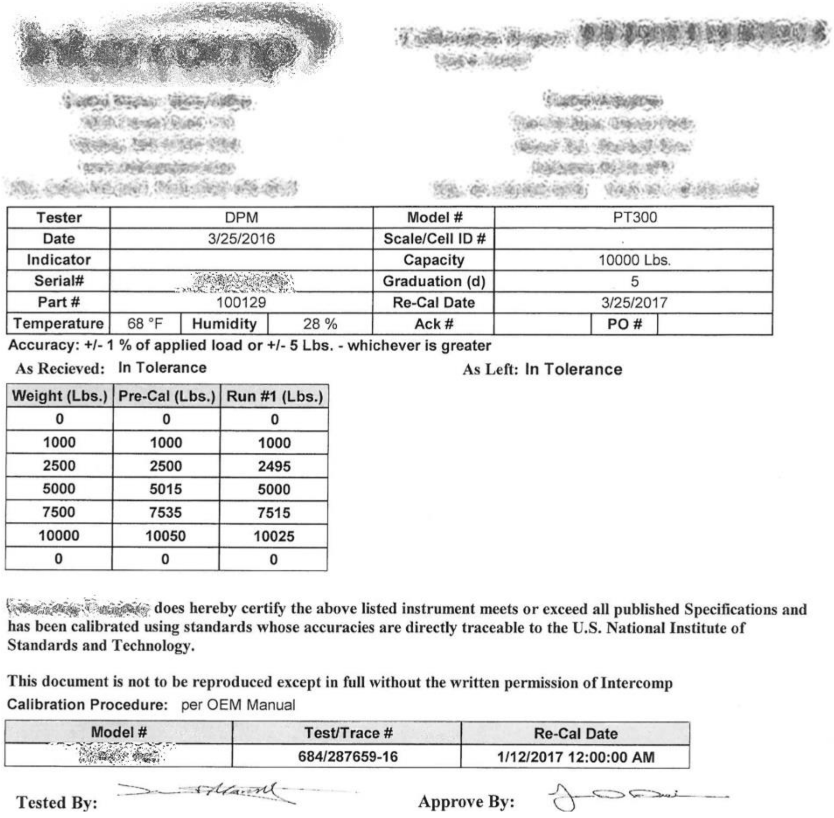
A large display and an audible alarm let workers know when the optimal torque has been reached.

A large, backlit, LCD display and long battery life make the TL8500™ Tension Link a top choice for many different applications and industries.

Torque= lift force x Sin(t) x wrench length
t = angle and assuming 45 degrees based on visual from picture, sine would be square root of 2 divided by 2 or about 0.71 (This equate to about 29 % error in the torque measurement). If the angle where 90 degrees, the sine error goes away.

Anyone this this is a good way to accurately measure torque?

The Right Calibration Provider



[redacted]

[redacted]

[redacted]

[redacted]

Tester	DPM			**Model #**	PT300		
Date	3/25/2016			**Scale/Cell ID #**			
Indicator				**Capacity**	10000 Lbs.		
Serial#	[redacted]			**Graduation (d)**	5		
Part #	100129			**Re-Cal Date**	3/25/2017		
Temperature	68 °F	**Humidity**	28 %	**Ack #**		**PO #**	

Accuracy: +/- 1 % of applied load or +/- 5 Lbs. - whichever is greater

As Recieved: In Tolerance **As Left:** In Tolerance

Weight (Lbs.)	Pre-Cal (Lbs.)	Run #1 (Lbs.)
0	0	0
1000	1000	1000
2500	2500	2495
5000	5015	5000
7500	7535	7515
10000	10050	10025
0	0	0

[redacted] does hereby certify the above listed instrument meets or exceed all published Specifications and has been calibrated using standards whose accuracies are directly traceable to the U.S. National Institute of Standards and Technology.

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Calibration Procedure: per OEM Manual

Model #	Test/Trace #	Re-Cal Date
[redacted]	684/287659-16	1/12/2017 12:00:00 AM

Tested By:

Approve By:

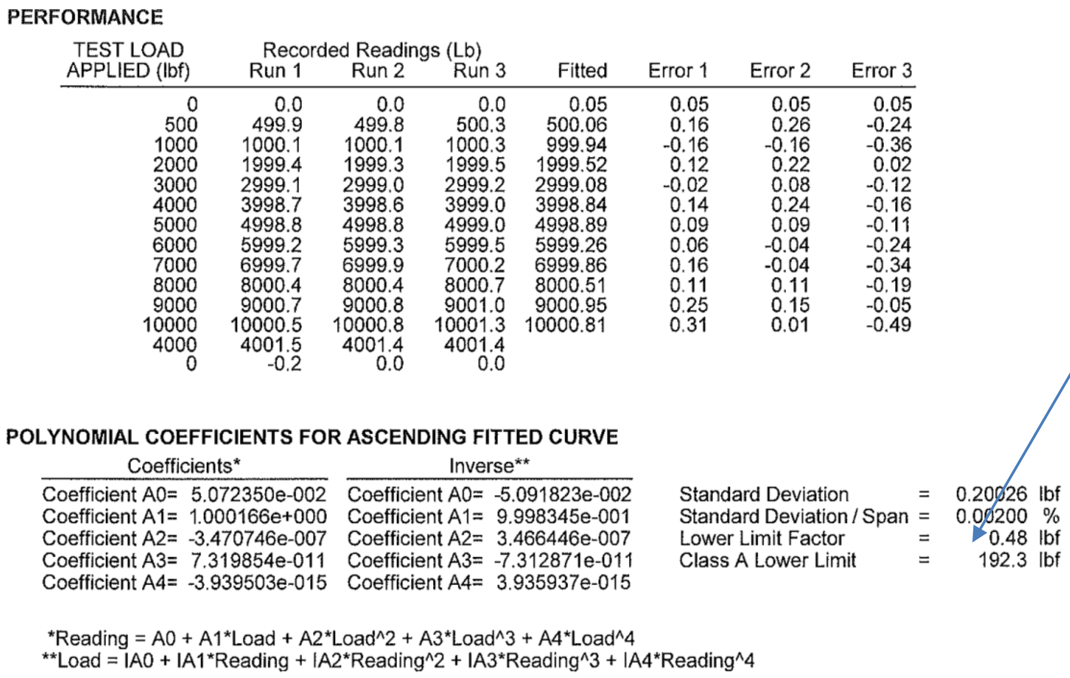
Some calibration providers do not include enough information to provide a traceable measurement.

What is wrong with this cert?

1. No mention of measurement uncertainty of the reference standard.
2. Claims traceability to NIST and not to SI.
3. Does not report uncertainty per point.
4. Meets all published specifications, but does not list any of them
5. Was instrument only exercised once?

The Right Calibration Provider

Not Following The ASTM E74 Standard



PERFORMANCE

TEST LOAD APPLIED (lbf)	Recorded Readings (Lb) Run 1	Run 2	Run 3	Fitted	Error 1	Error 2	Error 3
0	0.0	0.0	0.0	0.05	0.05	0.05	0.05
500	499.9	499.8	500.3	500.06	0.16	0.26	-0.24
1000	1000.1	1000.1	1000.3	999.94	-0.16	-0.16	-0.36
2000	1999.4	1999.3	1999.5	1999.52	0.12	0.22	0.02
3000	2999.1	2999.0	2999.2	2999.08	-0.02	0.08	-0.12
4000	3998.7	3998.6	3999.0	3998.84	0.14	0.24	-0.16
5000	4998.8	4998.8	4999.0	4998.89	0.09	0.09	-0.11
6000	5999.2	5999.3	5999.5	5999.26	0.06	-0.04	-0.24
7000	6999.7	6999.9	7000.2	6999.86	0.16	-0.04	-0.34
8000	8000.4	8000.4	8000.7	8000.51	0.11	0.11	-0.19
9000	9000.7	9000.8	9001.0	9000.95	0.25	0.15	-0.05
10000	10000.5	10000.8	10001.3	10000.81	0.31	0.01	-0.49
4000	4001.5	4001.4	4001.4				
0	-0.2	0.0	0.0				

POLYNOMIAL COEFFICIENTS FOR ASCENDING FITTED CURVE

Coefficients*	Inverse**
Coefficient A0= 5.072350e-002	Coefficient A0= -5.091823e-002
Coefficient A1= 1.000166e+000	Coefficient A1= 9.998345e-001
Coefficient A2= -3.470746e-007	Coefficient A2= 3.466446e-007
Coefficient A3= 7.319854e-011	Coefficient A3= -7.312871e-011
Coefficient A4= -3.939503e-015	Coefficient A4= 3.935937e-015

Standard Deviation = 0.20026 lbf
Standard Deviation / Span = 0.00200 %
Lower Limit Factor = 0.48 lbf
Class A Lower Limit = 192.3 lbf

*Reading = A0 + A1*Load + A2*Load^2 + A3*Load^3 + A4*Load^4
**Load = IA0 + IA1*Reading + IA2*Reading^2 + IA3*Reading^3 + IA4*Reading^4

Some calibration providers claim zero can be used as the first calibrated test point.

This is not true in anyway possible. In the ASTM E74-18 standard the following sections point to this not being allowed.

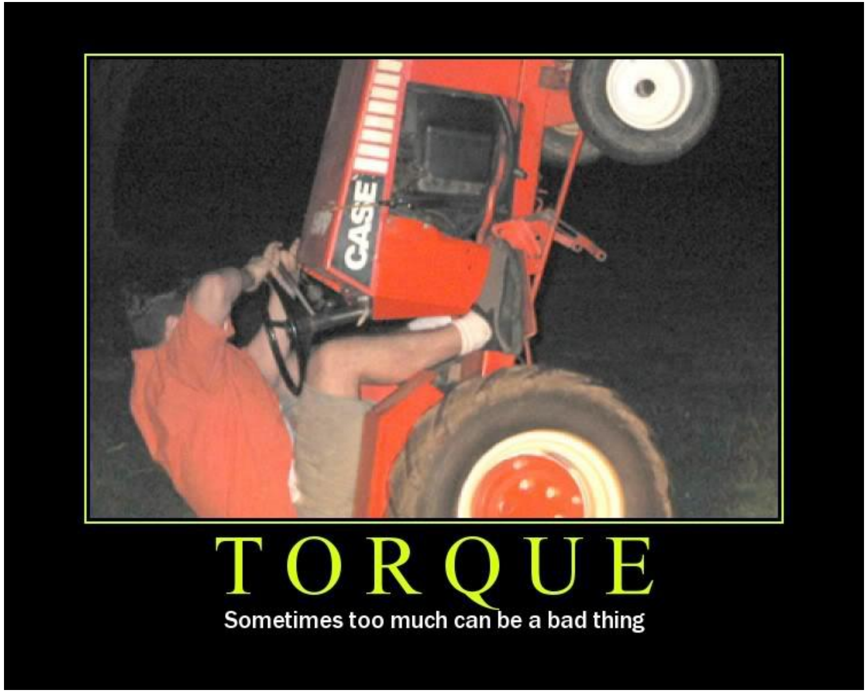
Per Section 8.6.2 of ASTM E74-18 *"The verified range of forces shall not include forces outside the range of forces applied during the calibration. If the lower force limit is less than the lowest non-zero calibration force applied, then the lower force limit of the verified range of forces is equal to the lowest calibration force applied."*

Per Section 7.2.1 of ASTM E74-18 states *"If the lower force limit of the verified range of forces of the force-measuring instrument (see 8.6.1) is anticipated to be less than one tenth of the maximum force applied during calibration, then forces should be applied at or below this lower force limit. In no case should the smallest force applied be below the lower force limit of the force-measuring instrument as defined by the values: 400 x resolution for Class A verified range of forces 2000 x resolution for Class AA verified range of forces "*

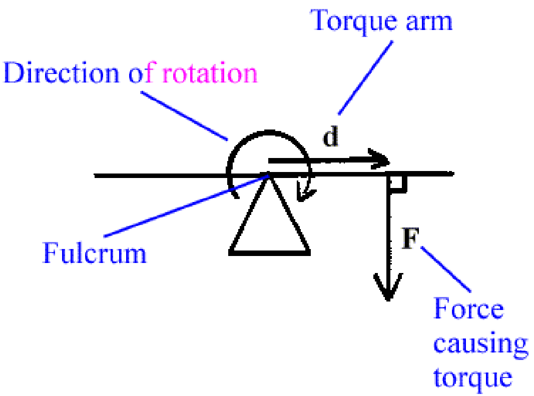
Why Measurements Matter

Why Calibration Matters

The Importance of torque control and how it relates to force measurement



Definition of Torque

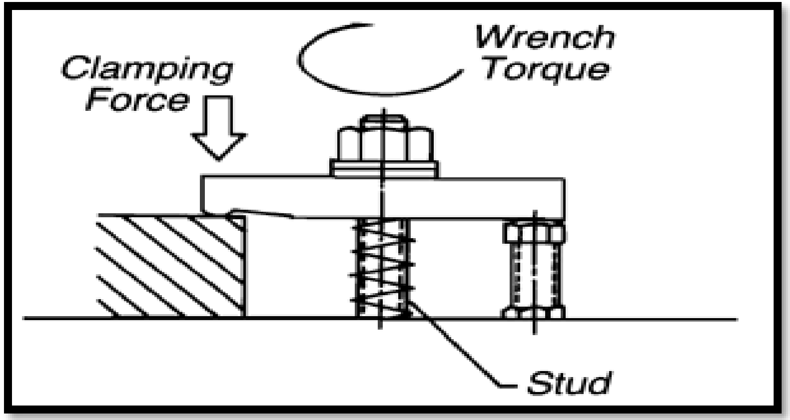


- Torque = Force x Length

- Loosely speaking, torque is a measure of the force required to turn an object such as a bolt or a flywheel. For example, pushing or pulling the handle of a wrench connected to a nut or bolt produces a torque (turning force) that loosens or tightens the nut or bolt.

The Importance of Torque Control

- The object of a threaded fastener is to clamp parts together with a tension greater than the external forces tending to separate them.
- When the bolt is torqued properly, it remains under constant stress and is immune from fatigue.

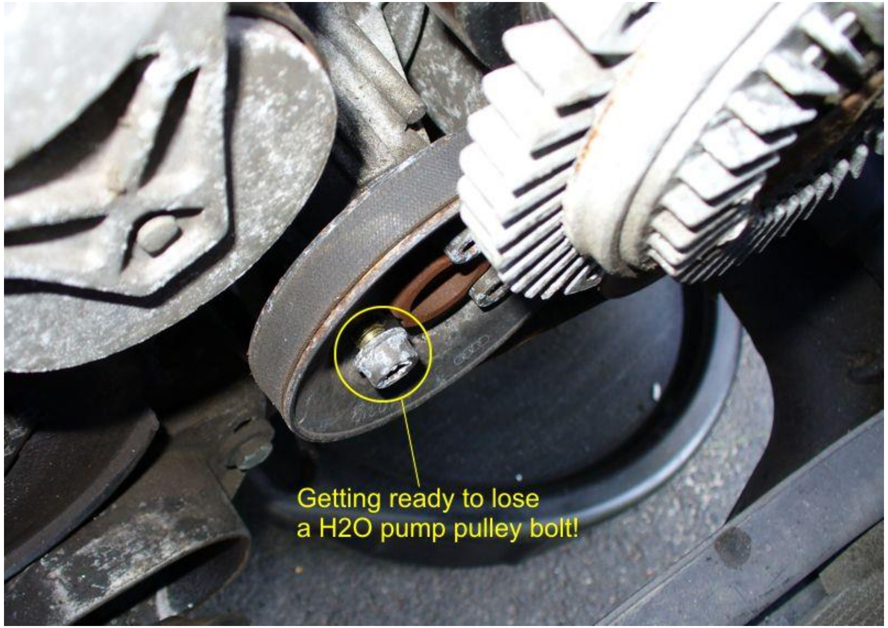


The Importance of Torque Control

- Imagine if one of the one hundred and fifty plus car engine bolts is under-torqued, it loosens over time, and eventually destroys the engine. What if the bolts are under-torqued in an airplane assembly and become loose in mid-flight?
- **Fastener reliability depends on controlling the tightening torque.**
- **Other engineering factors such as fastener material, design, pitch & surface finish may also influence the tightening torque.**

The Importance of Torque Control

- If the torque is not applied properly and the tension on the bolt torque is too low, varying loads will act upon the bolt and it will fail.

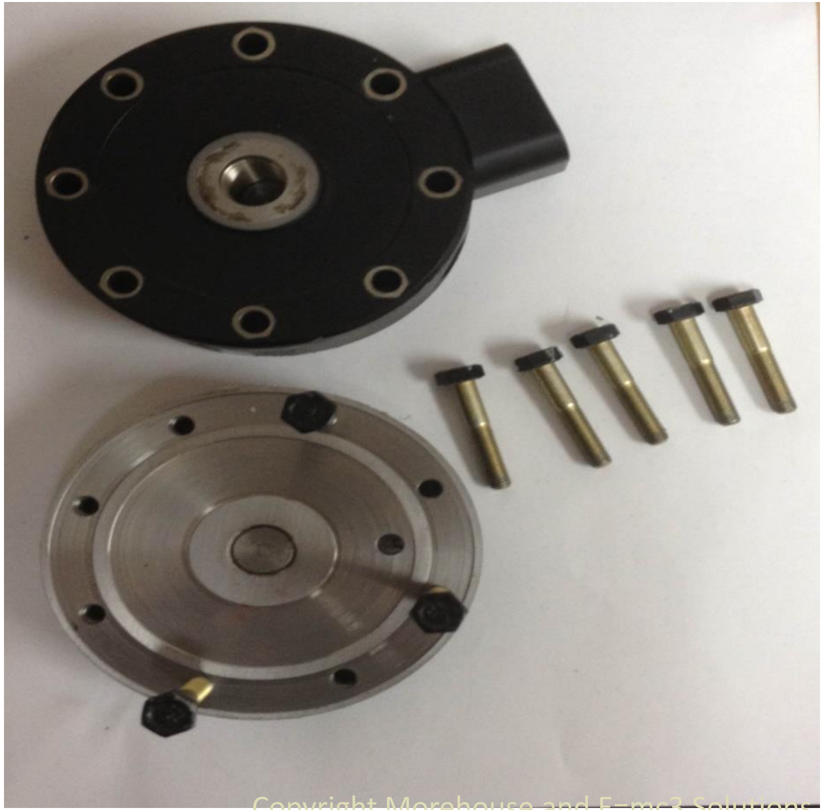


The Importance of Torque Control

- If the tension is too high, the tightening process may cause bolt failure.

Pictured Above: Metal snap from Jeff Nihel’s dragster, apparently the bolts on the left exhaust manifold were over-torqued… bolts then failed, manifold popped off and 4000bhp of exhaust gas launches the car in the air at over 200mph!

The Importance of Torque Control in relation to force measurements

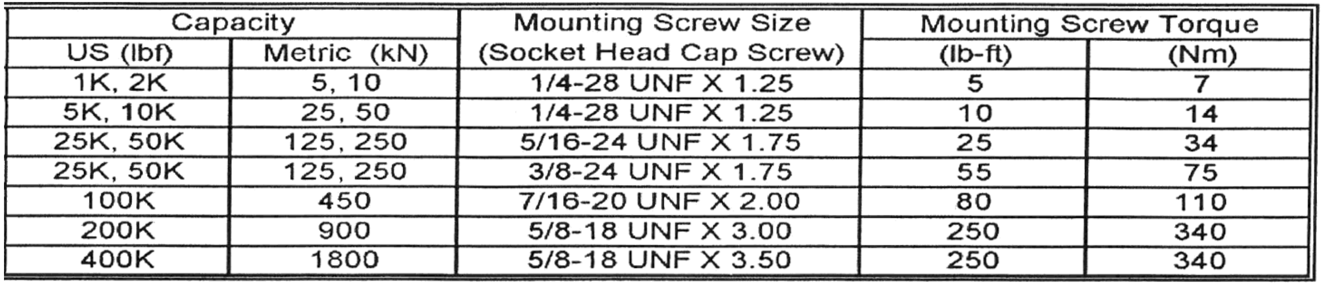


The Importance of Torque Control in relation to force measurements

- Some load cells are bolted in presses or in other various applications where the end user may need to send just the load cell in for calibration.

- The recommendation is always going to be that the load cell should be calibrated in place and not unbolted.

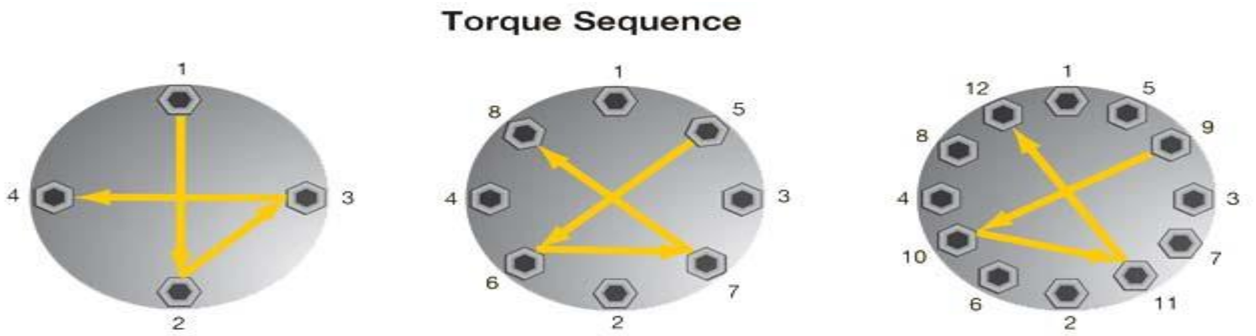
- When this is not possible the calibration lab performing the calibration must follow the appropriate torque specifications set by the manufacturer.



Capacity		Mounting Screw Size	Mounting Screw Torque	
US (lbf)	Metric (kN)	(Socket Head Cap Screw)	(lb-ft)	(Nm)
1K, 2K	5, 10	1/4-28 UNF X 1.25	5	7
5K, 10K	25, 50	1/4-28 UNF X 1.25	10	14
25K, 50K	125, 250	5/16-24 UNF X 1.75	25	34
25K, 50K	125, 250	3/8-24 UNF X 1.75	55	75
100K	450	7/16-20 UNF X 2.00	80	110
200K	900	5/8-18 UNF X 3.00	250	340
400K	1800	5/8-18 UNF X 3.50	250	340

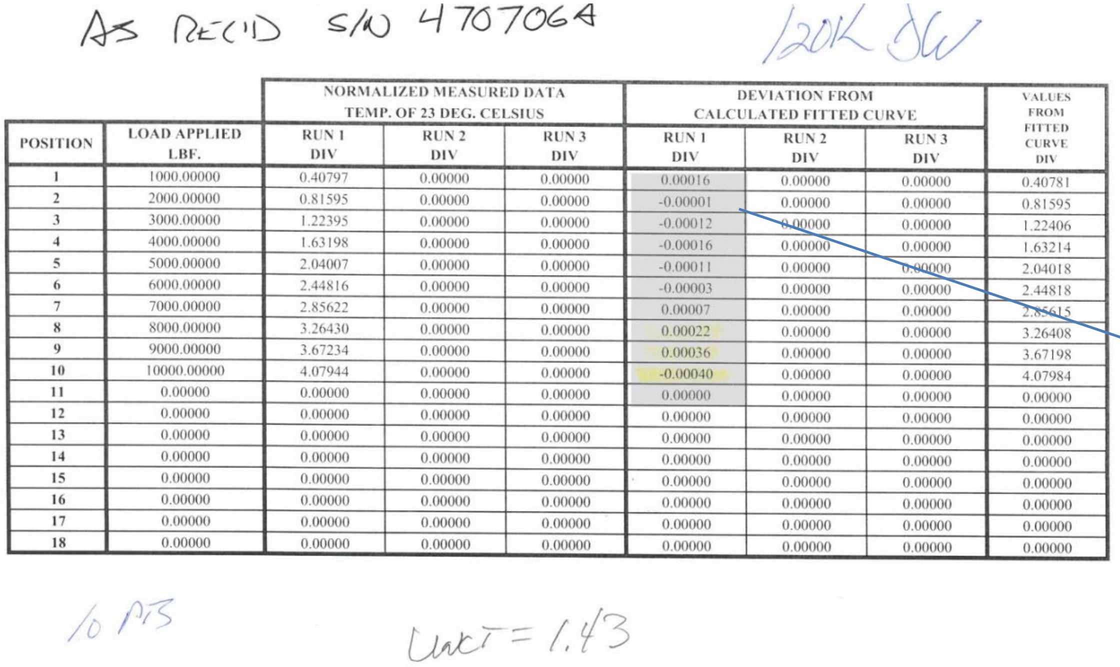
The Importance of Torque Control in relation to force measurements

- When bolting a load cell to a base it necessary to follow a bolting pattern as outlined below



The Importance of Torque Control in relation to force measurements

- Below are raw calibration numbers on a load cell that was sent into us for calibration. Notice the large deviations at higher capacities.



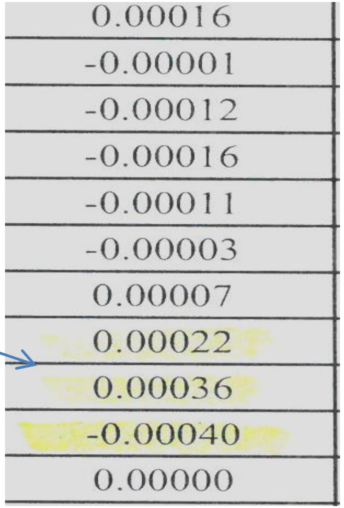
AS REC'D S/N 470706A

120K DW

POSITION	LOAD APPLIED LBF.	NORMALIZED MEASURED DATA TEMP. OF 23 DEG. CELSIUS RUN 1 DIV	RUN 2 DIV	RUN 3 DIV	DEVIATION FROM CALCULATED FITTED CURVE RUN 1 DIV	RUN 2 DIV	RUN 3 DIV	VALUES FROM FITTED CURVE DIV
1	1000.00000	0.40797	0.00000	0.00000	0.00016	0.00000	0.00000	0.40781
2	2000.00000	0.81595	0.00000	0.00000	-0.00001	0.00000	0.00000	0.81595
3	3000.00000	1.22395	0.00000	0.00000	-0.00012	0.00000	0.00000	1.22406
4	4000.00000	1.63198	0.00000	0.00000	-0.00016	0.00000	0.00000	1.63214
5	5000.00000	2.04007	0.00000	0.00000	-0.00011	0.00000	0.00000	2.04018
6	6000.00000	2.44816	0.00000	0.00000	-0.00003	0.00000	0.00000	2.44818
7	7000.00000	2.85622	0.00000	0.00000	0.00007	0.00000	0.00000	2.85615
8	8000.00000	3.26430	0.00000	0.00000	0.00022	0.00000	0.00000	3.26408
9	9000.00000	3.67234	0.00000	0.00000	0.00036	0.00000	0.00000	3.67198
10	10000.00000	4.07944	0.00000	0.00000	-0.00040	0.00000	0.00000	4.07984
11	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
13	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
14	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
18	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

10 PTS

UNCT = 1.43



0.00016
-0.00001
-0.00012
-0.00016
-0.00011
-0.00003
0.00007
0.00022
0.00036
-0.00040
0.00000

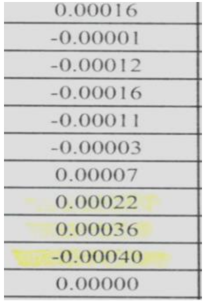
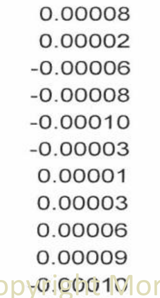
The Importance of Torque Control in relation to force measurements

- Since this is a rather uncommon occurrence we began troubleshooting.
- We used a load cell tester and found all load cell readings were good.
- We then proceeded to check each bolt and found that 2 bolts did not have the appropriate torque applied.

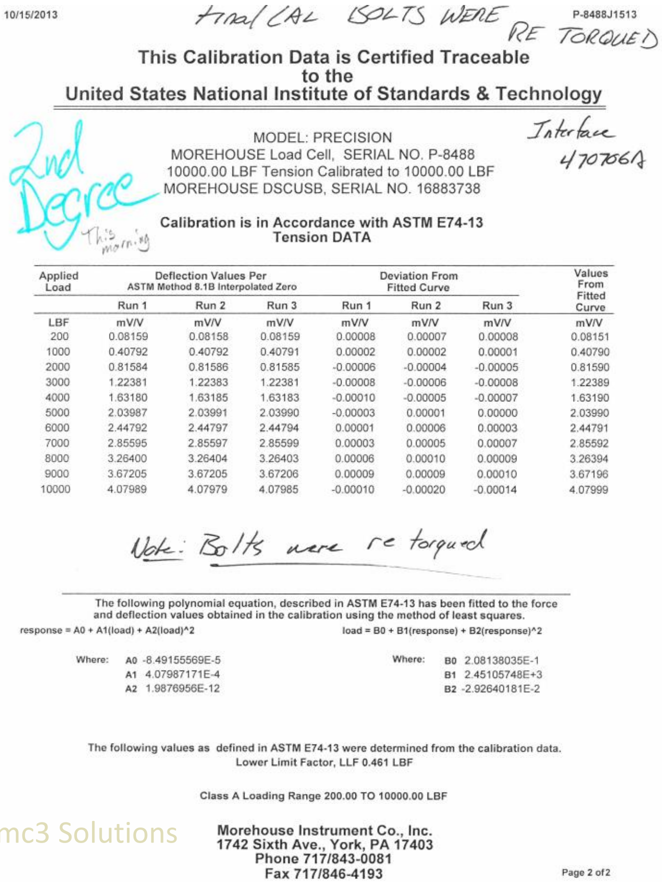
The Importance of Torque Control in relation to force measurements

- We re-torqued the 2 bolts and reran the calibration. New LLF = 0.441 LBF vs OLD LLF = 1.43 LBF

- The deviations from the fitted curve became much better and the standard deviation was approximately 3 times smaller when the bolts were torqued in properly

before	after
0.00016	0.00008
-0.00001	0.00002
-0.00012	-0.00006
-0.00016	-0.00008
-0.00011	-0.00010
-0.00003	-0.00003
0.00007	0.00001
0.00022	0.00003
0.00036	0.00006
-0.00040	0.00009
0.00000	-0.00010



10/15/2013 Final CAL BOLTS WERE RE TORQUED P-8488J1513

This Calibration Data is Certified Traceable
to the
United States National Institute of Standards & Technology

2nd Degree
This morning

Interface
470706A

MODEL: PRECISION
MOREHOUSE Load Cell, SERIAL NO. P-8488
10000.00 LBF Tension Calibrated to 10000.00 LBF
MOREHOUSE DSCUSB, SERIAL NO. 16883738

Calibration is in Accordance with ASTM E74-13
Tension DATA

Applied Load	Deflection Values Per ASTM Method 8.1B Interpolated Zero			Deviation From Fitted Curve			Values From Fitted Curve
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
LBF	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V
200	0.08159	0.08158	0.08159	0.00008	0.00007	0.00008	0.08151
1000	0.40792	0.40792	0.40791	0.00002	0.00002	0.00001	0.40790
2000	0.81584	0.81586	0.81585	-0.00006	-0.00004	-0.00005	0.81590
3000	1.22381	1.22383	1.22381	-0.00008	-0.00006	-0.00008	1.22389
4000	1.63180	1.63185	1.63183	-0.00010	-0.00005	-0.00007	1.63190
5000	2.03987	2.03991	2.03990	-0.00003	0.00001	0.00000	2.03990
6000	2.44792	2.44797	2.44794	0.00001	0.00006	0.00003	2.44791
7000	2.85595	2.85597	2.85599	0.00003	0.00005	0.00007	2.85592
8000	3.26400	3.26404	3.26403	0.00006	0.00010	0.00009	3.26394
9000	3.67205	3.67205	3.67206	0.00009	0.00009	0.00010	3.67196
10000	4.07989	4.07979	4.07985	-0.00010	-0.00020	-0.00014	4.07999

Note: Bolts were re torqued

The following polynomial equation, described in ASTM E74-13 has been fitted to the force and deflection values obtained in the calibration using the method of least squares.

response = A0 + A1(load) + A2(load)^2

Where:
A0 -8.49155569E-5
A1 4.07987171E-4
A2 1.9876956E-12

load = B0 + B1(response) + B2(response)^2

Where:
B0 2.08138035E-1
B1 2.45105748E+3
B2 -2.92640181E-2

The following values as defined in ASTM E74-13 were determined from the calibration data.
Lower Limit Factor, LLF 0.461 LBF

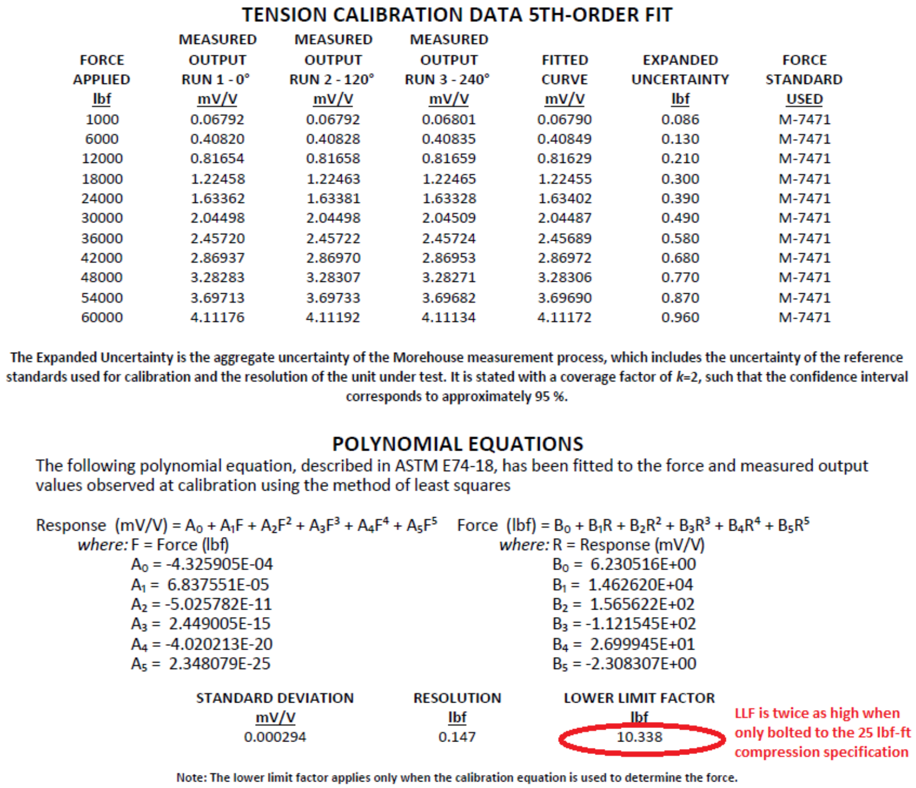
Class A Loading Range 200.00 TO 10000.00 LBF

Morehouse Instrument Co., Inc.
1742 Sixth Ave., York, PA 17403
Phone 717/843-0081
Fax 717/846-4193

Page 2 of 2

The Importance of Torque Control in relation to force measurements

Using the wrong torque specifications 25 lbf-ft compression spec versus 45 lbf-ft



TENSION CALIBRATION DATA 5TH-ORDER FIT

FORCE APPLIED lbf	MEASURED OUTPUT RUN 1 - 0° mV/V	MEASURED OUTPUT RUN 2 - 120° mV/V	MEASURED OUTPUT RUN 3 - 240° mV/V	FITTED CURVE mV/V	EXPANDED UNCERTAINTY lbf	FORCE STANDARD USED
1000	0.06792	0.06792	0.06801	0.06790	0.086	M-7471
6000	0.40820	0.40828	0.40835	0.40849	0.130	M-7471
12000	0.81654	0.81658	0.81659	0.81629	0.210	M-7471
18000	1.22458	1.22463	1.22465	1.22455	0.300	M-7471
24000	1.63362	1.63381	1.63328	1.63402	0.390	M-7471
30000	2.04498	2.04498	2.04509	2.04487	0.490	M-7471
36000	2.45720	2.45722	2.45724	2.45689	0.580	M-7471
42000	2.86937	2.86970	2.86953	2.86972	0.680	M-7471
48000	3.28283	3.28307	3.28271	3.28306	0.770	M-7471
54000	3.69713	3.69733	3.69682	3.69690	0.870	M-7471
60000	4.11176	4.11192	4.11134	4.11172	0.960	M-7471

The Expanded Uncertainty is the aggregate uncertainty of the Morehouse measurement process, which includes the uncertainty of the reference standards used for calibration and the resolution of the unit under test. It is stated with a coverage factor of *k*=2, such that the confidence interval corresponds to approximately 95 %.

POLYNOMIAL EQUATIONS

The following polynomial equation, described in ASTM E74-18, has been fitted to the force and measured output values observed at calibration using the method of least squares

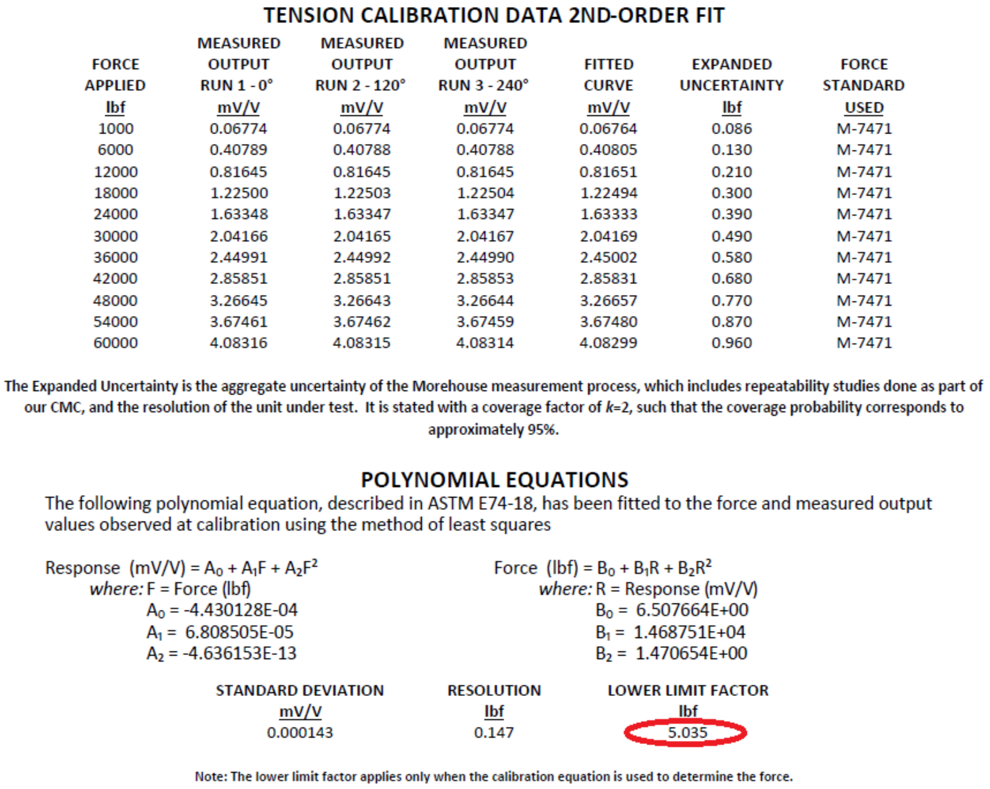
Response (mV/V) = $A_0 + A_1F + A_2F^2 + A_3F^3 + A_4F^4 + A_5F^5$
where: F = Force (lbf)
A_0 = -4.325905E-04
A_1 = 6.837551E-05
A_2 = -5.025782E-11
A_3 = 2.449005E-15
A_4 = -4.020213E-20
A_5 = 2.348079E-25

Force (lbf) = $B_0 + B_1R + B_2R^2 + B_3R^3 + B_4R^4 + B_5R^5$
where: R = Response (mV/V)
B_0 = 6.230516E+00
B_1 = 1.462620E+04
B_2 = 1.565622E+02
B_3 = -1.121545E+02
B_4 = 2.699945E+01
B_5 = -2.308307E+00

STANDARD DEVIATION mV/V	RESOLUTION lbf	LOWER LIMIT FACTOR lbf
0.000294	0.147	10.338

LLF is twice as high when only bolted to the 25 lbf-ft compression specification

Note: The lower limit factor applies only when the calibration equation is used to determine the force.



TENSION CALIBRATION DATA 2ND-ORDER FIT

FORCE APPLIED lbf	MEASURED OUTPUT RUN 1 - 0° mV/V	MEASURED OUTPUT RUN 2 - 120° mV/V	MEASURED OUTPUT RUN 3 - 240° mV/V	FITTED CURVE mV/V	EXPANDED UNCERTAINTY lbf	FORCE STANDARD USED
1000	0.06774	0.06774	0.06774	0.06764	0.086	M-7471
6000	0.40789	0.40788	0.40788	0.40805	0.130	M-7471
12000	0.81645	0.81645	0.81645	0.81651	0.210	M-7471
18000	1.22500	1.22503	1.22504	1.22494	0.300	M-7471
24000	1.63348	1.63347	1.63347	1.63333	0.390	M-7471
30000	2.04166	2.04165	2.04167	2.04169	0.490	M-7471
36000	2.44991	2.44992	2.44990	2.45002	0.580	M-7471
42000	2.85851	2.85851	2.85853	2.85831	0.680	M-7471
48000	3.26645	3.26643	3.26644	3.26657	0.770	M-7471
54000	3.67461	3.67462	3.67459	3.67480	0.870	M-7471
60000	4.08316	4.08315	4.08314	4.08299	0.960	M-7471

The Expanded Uncertainty is the aggregate uncertainty of the Morehouse measurement process, which includes repeatability studies done as part of our CMC, and the resolution of the unit under test. It is stated with a coverage factor of *k*=2, such that the coverage probability corresponds to approximately 95%.

POLYNOMIAL EQUATIONS

The following polynomial equation, described in ASTM E74-18, has been fitted to the force and measured output values observed at calibration using the method of least squares

Response (mV/V) = $A_0 + A_1F + A_2F^2$
where: F = Force (lbf)
A_0 = -4.430128E-04
A_1 = 6.808505E-05
A_2 = -4.636153E-13

Force (lbf) = $B_0 + B_1R + B_2R^2$
where: R = Response (mV/V)
B_0 = 6.507664E+00
B_1 = 1.468751E+04
B_2 = 1.470654E+00

STANDARD DEVIATION mV/V	RESOLUTION lbf	LOWER LIMIT FACTOR lbf
0.000143	0.147	5.035

Note: The lower limit factor applies only when the calibration equation is used to determine the force.

Expressing Torque

Express torque as lbf·ft, lbf·in, ozf · in, or N·m.

- The foot-pound force (symbol: **ft.** · **lbf**) is a unit of work or energy in the Engineering and Gravitational Systems in United States customary and imperial units of measure.

- A **pound-foot** (**lbf·ft**) is a unit of torque or moment of force (a pseudovector). One pound-foot is the torque created by one pound force acting at a perpendicular distance of one foot from a pivot point.

Torque is derived from the SI units of Length, Mass and Time. The metre is the SI base unit of length. The kilogram is the SI base unit of mass. The second is the SI base unit of time. Torque is expressed in terms of SI base units as m2 · kg · s−2.

Morehouse Torque Standard

- 2 kN·m lever deadweight machine
- Realised uncertainty 0.002 %
- Vertical design – pure torque generated via identical weight stacks located at either end of the lever beam
- Twin beam carbon fibre lever arm mounted on a central air bearing
- BS7882 ASTME 2428

Questions?

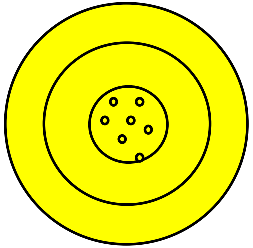
Accuracy and Precision

- It is a common mistake to assume that an accurate device is precise or that a precise device is accurate.

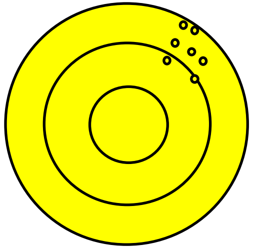
Measurement Related Terms

- **Accuracy:** Closeness of agreement between a measured quantity value and a true quantity value of a measurand. (VIM 2.13)
- **Precision:** closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified condition (VIM 2.15)

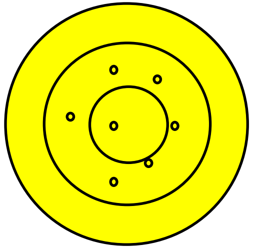
Precision and Accuracy



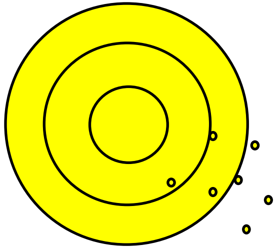
High Precision
High Accuracy (Low Bias)



High Precision
Low Accuracy (High Bias)

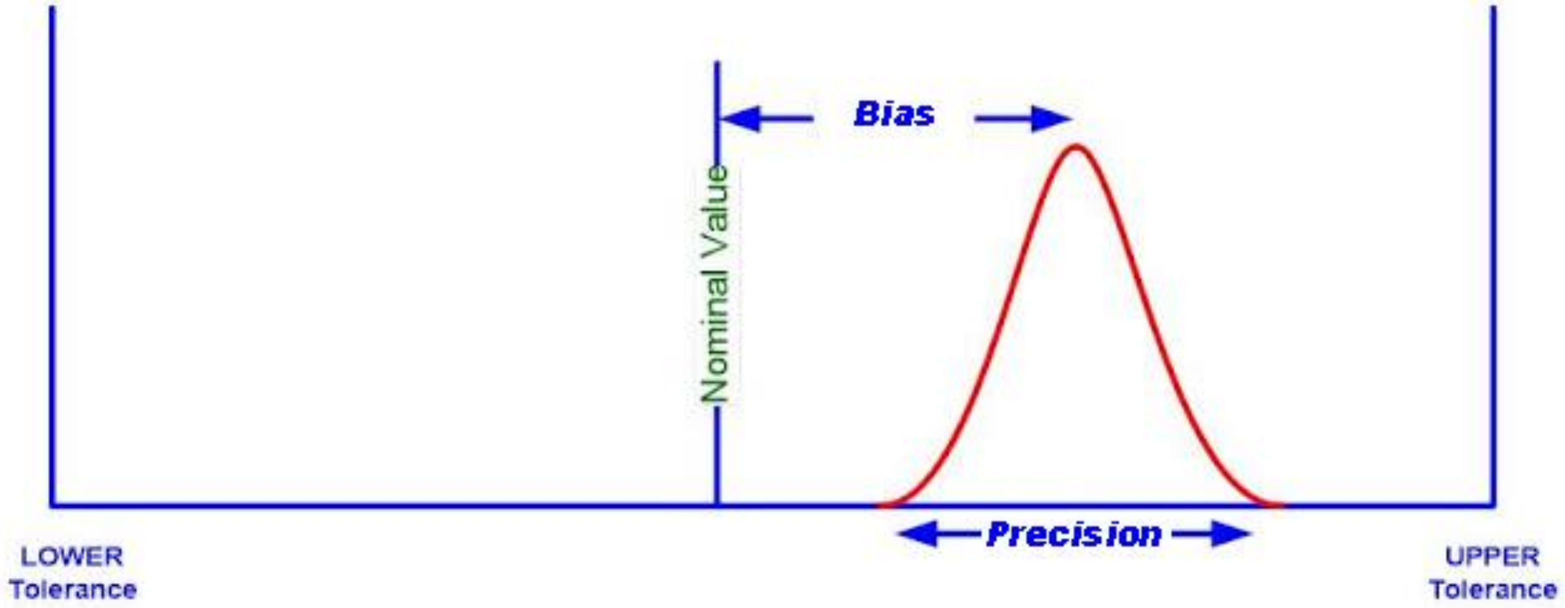


Low Precision
High Accuracy (Low Bias)



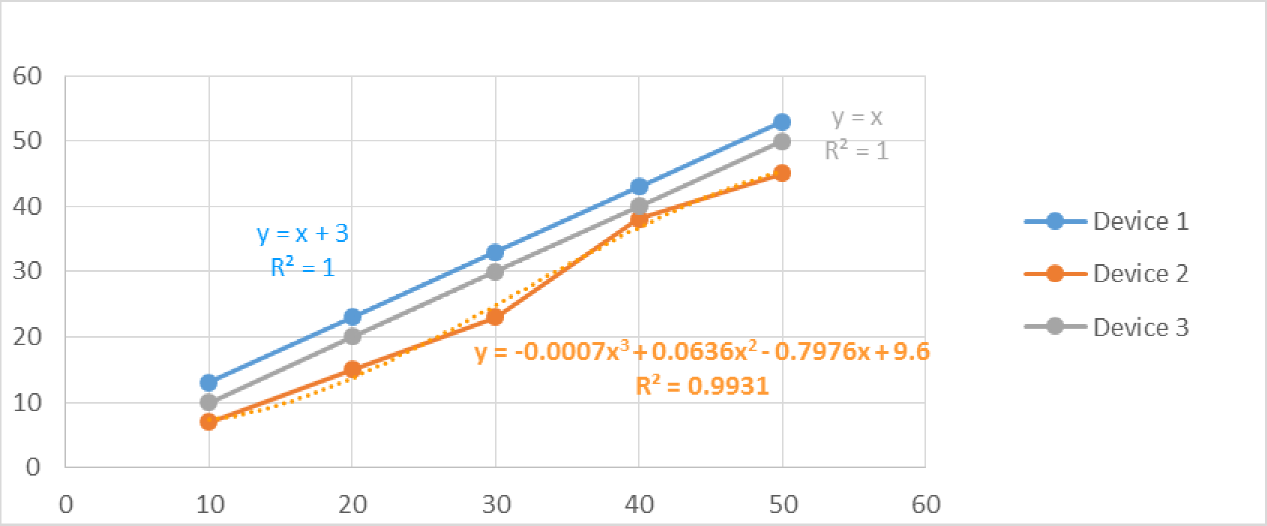
Low Precision
Low Accuracy (High Bias)

Bias and Precision



Precision is a measure of spread – how well the unit repeats under a certain condition

Accuracy is the closeness of agreement between a measured quantity value and a true quantity value of a measurand



Force Applied	Device 1	Error	Device 2	Error	Device 3	Error
10	13	3	7	-3	10	0
20	23	3	15	-5	20	0
30	33	3	23	-7	30	0
40	43	3	38	-2	40	0
50	53	3	45	-5	50	0

Adjusted by adding a constant to Device 1 and 2

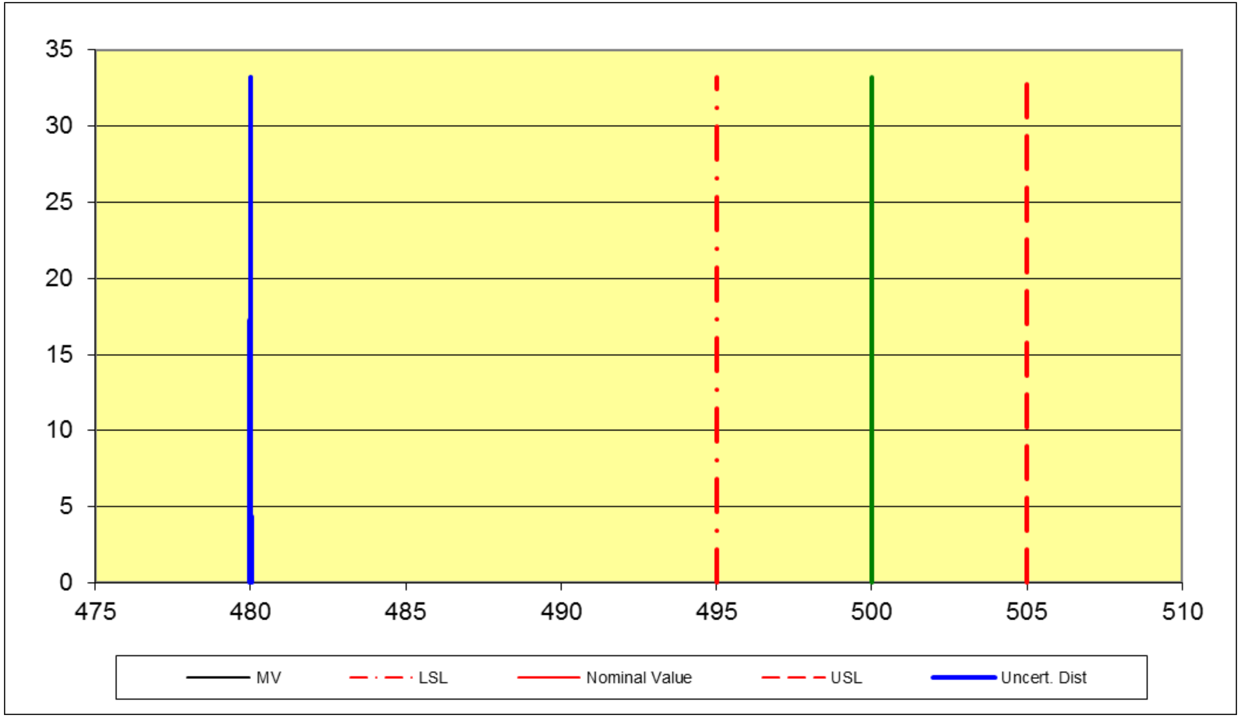
Force Applied	Device 1	Error	Device 2	Error	Device 3	Error
10	10	0	10	0	10	0
20	20	0	18	-2	20	0
30	30	0	26	-4	30	0
40	40	0	41	1	40	0
50	50	0	48	-2	50	0

Precision Example

- Example: 500 LBF was applied 3 times using a dead weight primary standard to a load cell and the load cell indicator's recorded output was 480.01 LB, 479.99 LB, 480.01 LB.

Conclusion:
The instrument is precise to ±0.012 LB when 500 LBF is applied. Standard Deviation of above numbers = 0.0115

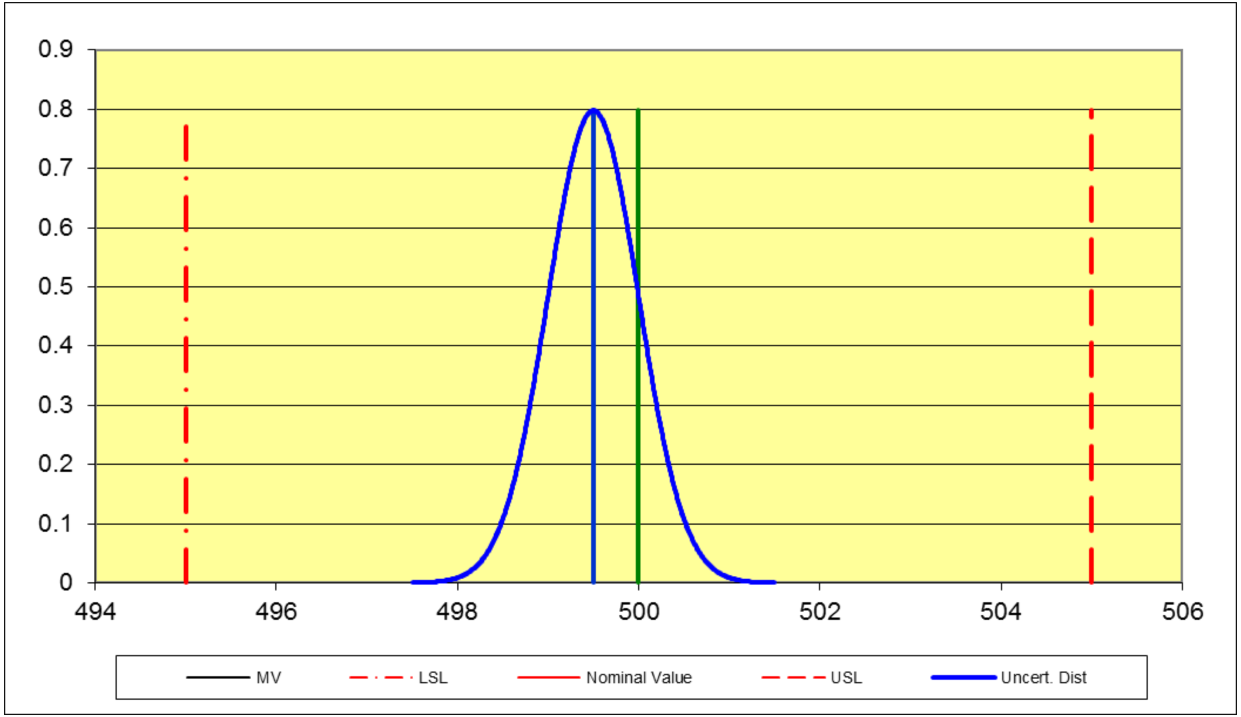
Accuracy/Precision Visualized



Accuracy Example

- Example: A Force Gauge was calibrated against a dead weight primary standard and at 500.0 LBF the recorded output on the indicator was 499.5 LBF. This measurement was repeated and 499.0 LBF was observed a second time. The instrument was re positioned and 500.0 LBF was observed a third time. This force gauge was determined to be accurate to +0.1 % of full scale or ±0.5 LBF from the measurements. Manufacturer's specification is actually 1 % of full scale
- What is the accuracy of the three repeated measurements?
  - 1) 499.5, 2) 499.0, 3) 500.0

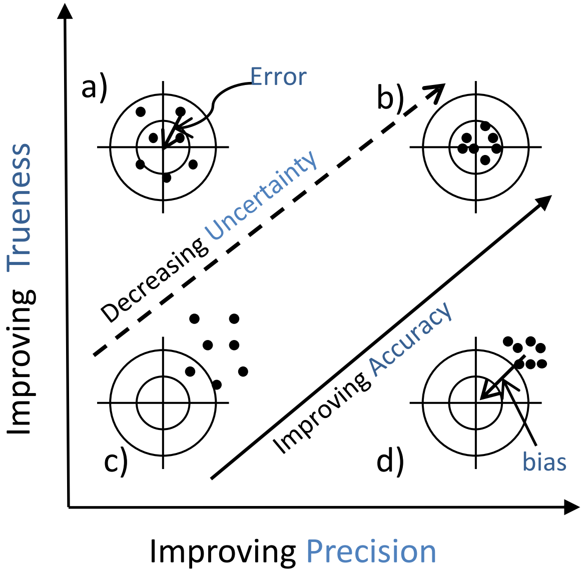
Accuracy/Precision Visualized



Accuracy vs. Uncertainty

Accuracy determined via a calibration is not the same as *uncertainty*!

- an accurate measurement with a large uncertainty is possible.



Uncertainty includes all random effects (including the uncertainty of the bias)

Uncertainty of Force Standards

- Regardless of the force facility to be used, it is important to evaluate the uncertainty of the system. This should include contributions from all influencing parameters (e.g. mass, alignment, and environmental factors).

- The factors or influences to be reflected in calculation of the uncertainty differ between standards as well as processes.

Measurement Related Terms

- **Resolution:** smallest change in a quantity being measured that causes a perceptible change in the corresponding indication.
  - NOTE Resolution can depend on, for example, noise (internal or external) or friction. It may also depend on the value of a quantity being measured.
- **Resolution of a displaying device:** Smallest difference between displayed indications that can be meaningfully distinguished.

Accuracy and Resolution

The topic of resolution requires attention as it relates to overall accuracy. Many times, distinguishing between accuracy and resolution is misinterpreted in determining system needs.

For example, measuring 1 volt within ±0.015 % accuracy requires a **7-digit instrument** capable of displaying **six** decimal places. The fifth decimal place represents 10 micro-Volts, giving this instrument a resolution of 10 micro-Volts.

Value	**Accuracy**	**Minimum**	**Maximum**
1	**0.015%**	**0.999850**	**1.000150**

Measurement Related Terms

- **Nominal value:** Rounded or approximate value of a characterizing quantity of a measuring instrument or measuring system that provides guidance for its appropriate use.
  - EXAMPLE 1 100 Ω as the nominal quantity value marked on a standard resistor.
  - EXAMPLE 2 1 000 ml as the nominal quantity value marked on a single-mark volumetric flask.
  - NOTE “Nominal quantity value” and “nominal value” are not to be confused with “nominal property value”

Measurement Related Terms

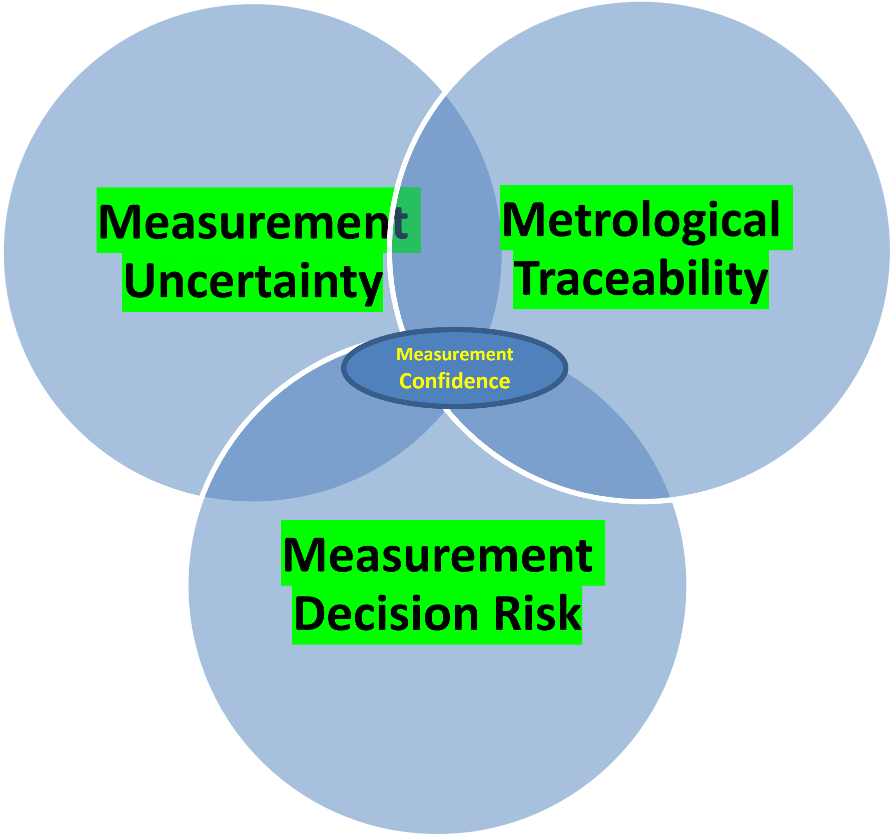
- **Repeatability:** Measurement precision under a set of repeatability conditions of measurement.
- **Repeatability conditions:** condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time.
  - NOTE 1 A condition of measurement is a repeatability condition only with respect to a specified set of repeatability conditions.
  - NOTE 2 In chemistry, the term “intra-serial precision condition of measurement” is sometimes used to designate this concept.

Measurement Related Terms

- **Reproducibility:** Measurement precision under reproducibility conditions of measurement.

- **Reproducibility conditions:** 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.
  - NOTE 1 The different measuring systems may use different measurement procedures.
  - NOTE 2 A specification should give the conditions changed and unchanged, to the extent practical.

Measurement Confidence



Measurement Uncertainty

Metrological Traceability

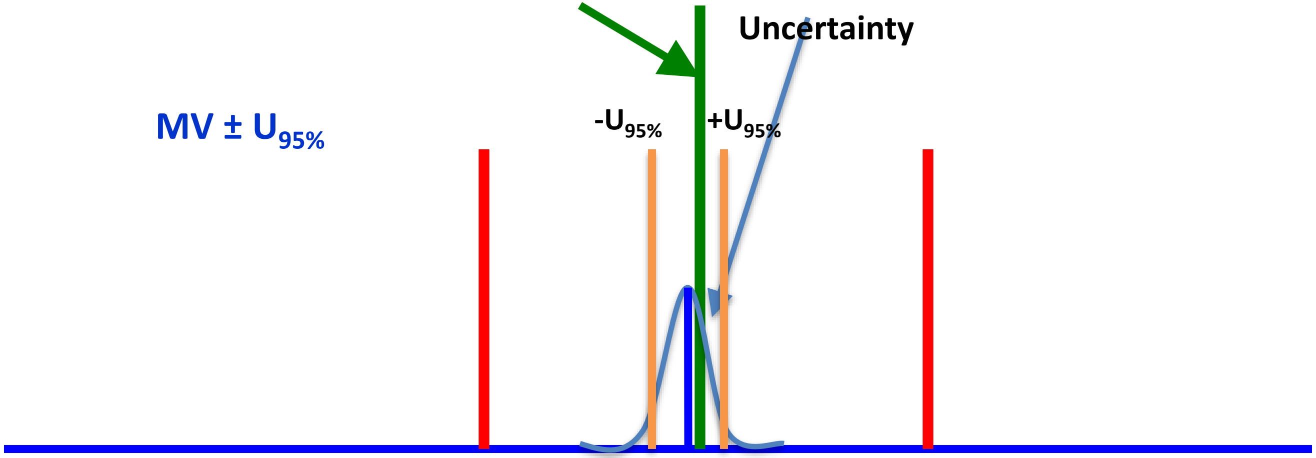
Measurement Confidence

Measurement Decision Risk

Measurement Uncertainty

Measurement uncertainty, Uncertainty of measurement, uncertainty: Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

Measurement Uncertainty Graphically Expressed



Nominal (True) Value

Instrument Measurement Uncertainty

$MV \pm U_{95\%}$

$-U_{95\%}$

$+U_{95\%}$

-Tolerance

Measured Value

+Tolerance

Metrological Traceability

Metrological Traceability: Property of a measurement result whereby the result can be related to a reference through a ***documented unbroken chain of calibrations, each contributing to the measurement uncertainty.***

- NOTE 1 For this definition, a 'reference' can be a definition of a measurement unit through its practical realization, or a measurement procedure including the measurement unit for a non-ordinal quantity, or a measurement standard.
- NOTE 2 Metrological traceability requires an established calibration hierarchy.
- NOTE 3 Specification of the reference must include the time at which this reference was used in establishing the calibration hierarchy, along with any other relevant metrological information about the reference, such as when the first calibration in the calibration hierarchy was performed.
- NOTE 4 For measurements with more than one input quantity in the measurement model, each of the input quantity values should itself be metrologically traceable.

Metrological Traceability

- **Is it NIST Traceable?**

  Myths:
  - **No, nothing is NIST Traceable.**
  - **NIST Report Numbers do not provide evidence of traceability.**

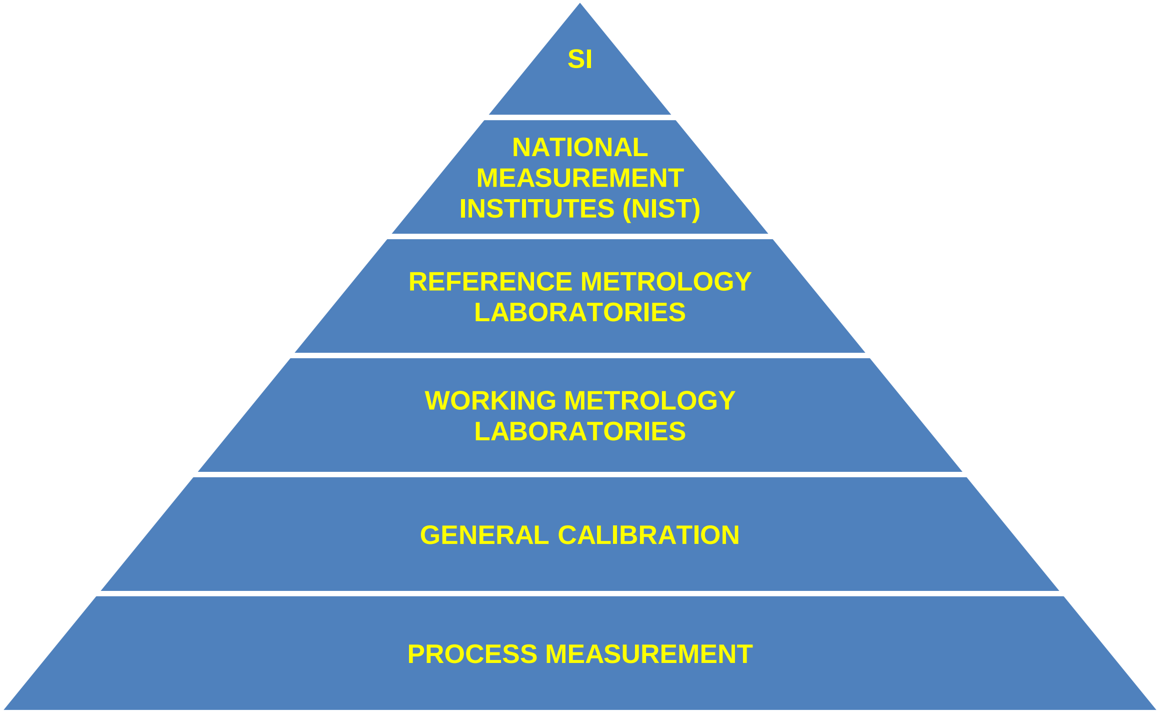
- **Then what does provide Metrological Traceability?**

  - **Traceable to SI Units through a National Metrology Institute (NMI - NIST in the USA) recognized under the CIPM (International Committee on Weights and Measures) MRA (Mutual Recognition Arrangement).**

Test Uncertainty Ratio (TUR)

- **The Test Uncertainty Ratio must be based on the same level of confidence.**
  - **E.g., *k*=2 (95% confidence Interval @ infinite degrees of freedom) for both UUT and Cal. Std.**
- **For a Test Uncertainty Ratio of 4:1, the UUT Tolerance must be 4 times the UUT Calibration Process Uncertainty.**

Metrological Traceability



SI

NATIONAL MEASUREMENT INSTITUTES (NIST)

REFERENCE METROLOGY LABORATORIES

WORKING METROLOGY LABORATORIES

GENERAL CALIBRATION

PROCESS MEASUREMENT

Test Accuracy Ratio (10:1)

BIPM
(100,000)

NATIONAL MEASUREMENT INSTITUTES (NIST)
(10,000)

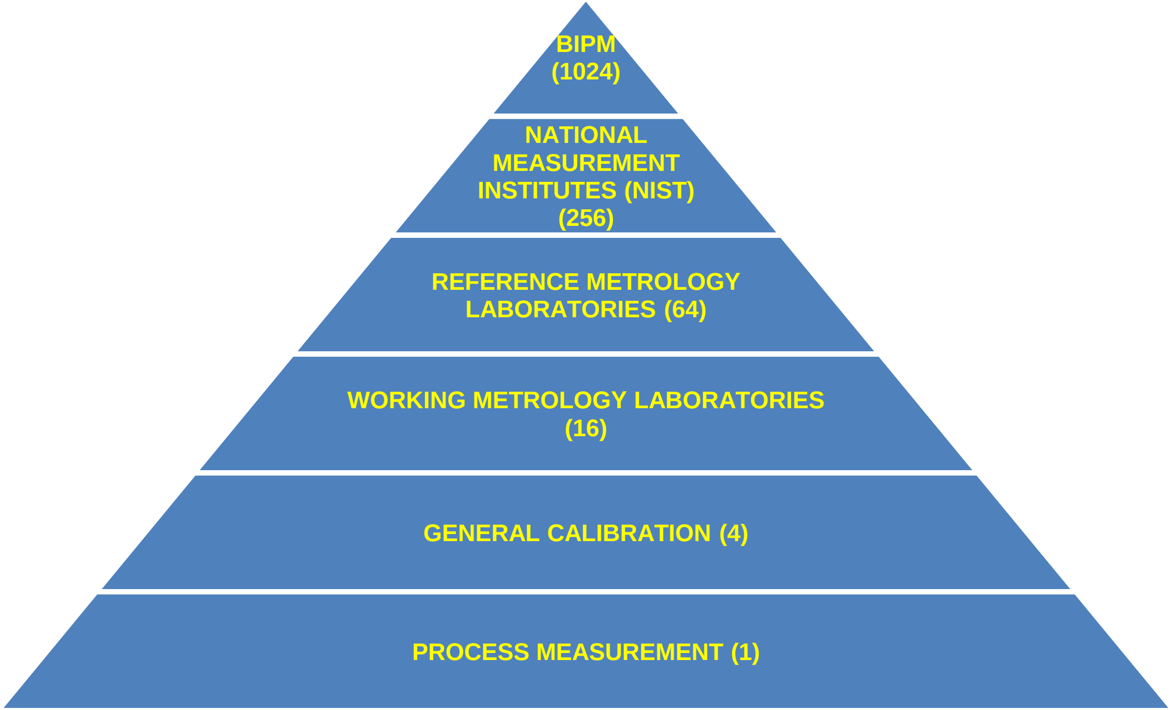
REFERENCE METROLOGY LABORATORIES (1000)

WORKING METROLOGY LABORATORIES
(100)

GENERAL CALIBRATION (10)

PROCESS MEASUREMENT (1)

Test Accuracy Ratio (4:1)



BIPM
(1024)

NATIONAL MEASUREMENT INSTITUTES (NIST)
(256)

REFERENCE METROLOGY LABORATORIES (64)

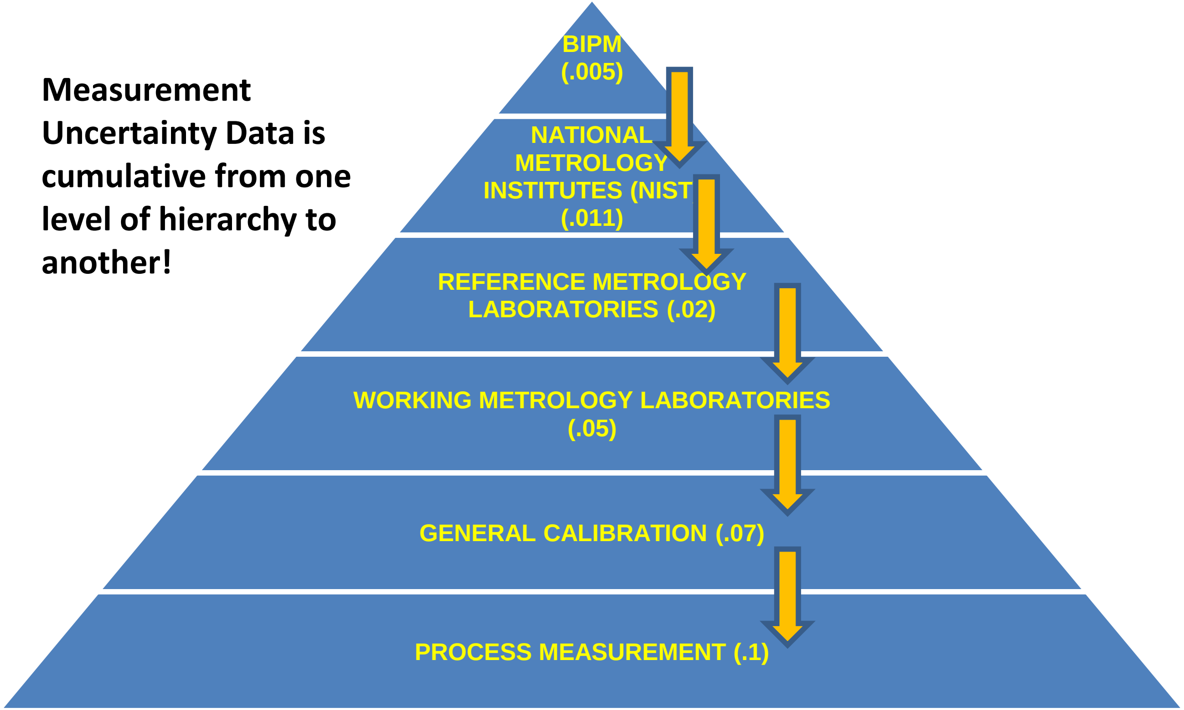
WORKING METROLOGY LABORATORIES
(16)

GENERAL CALIBRATION (4)

PROCESS MEASUREMENT (1)

Metrological Traceability

Measurement Uncertainty Data is cumulative from one level of hierarchy to another!



BIPM (.005)

NATIONAL METROLOGY INSTITUTES (NIST (.011)

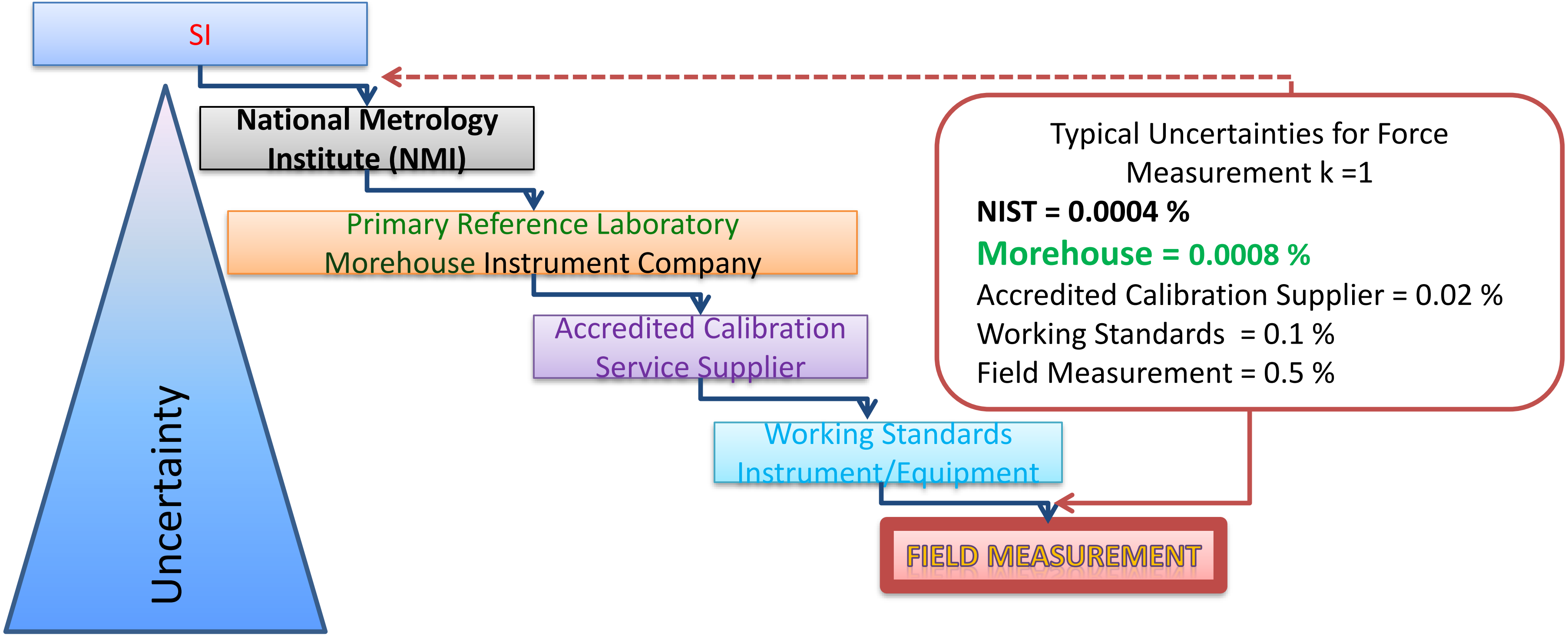
REFERENCE METROLOGY LABORATORIES (.02)

WORKING METROLOGY LABORATORIES (.05)

GENERAL CALIBRATION (.07)

PROCESS MEASUREMENT (.1)

Measurement Uncertainty & the Measurement Hierarchy



Typical Uncertainties for Force Measurement k =1

NIST = 0.0004 %

Morehouse = 0.0008 %

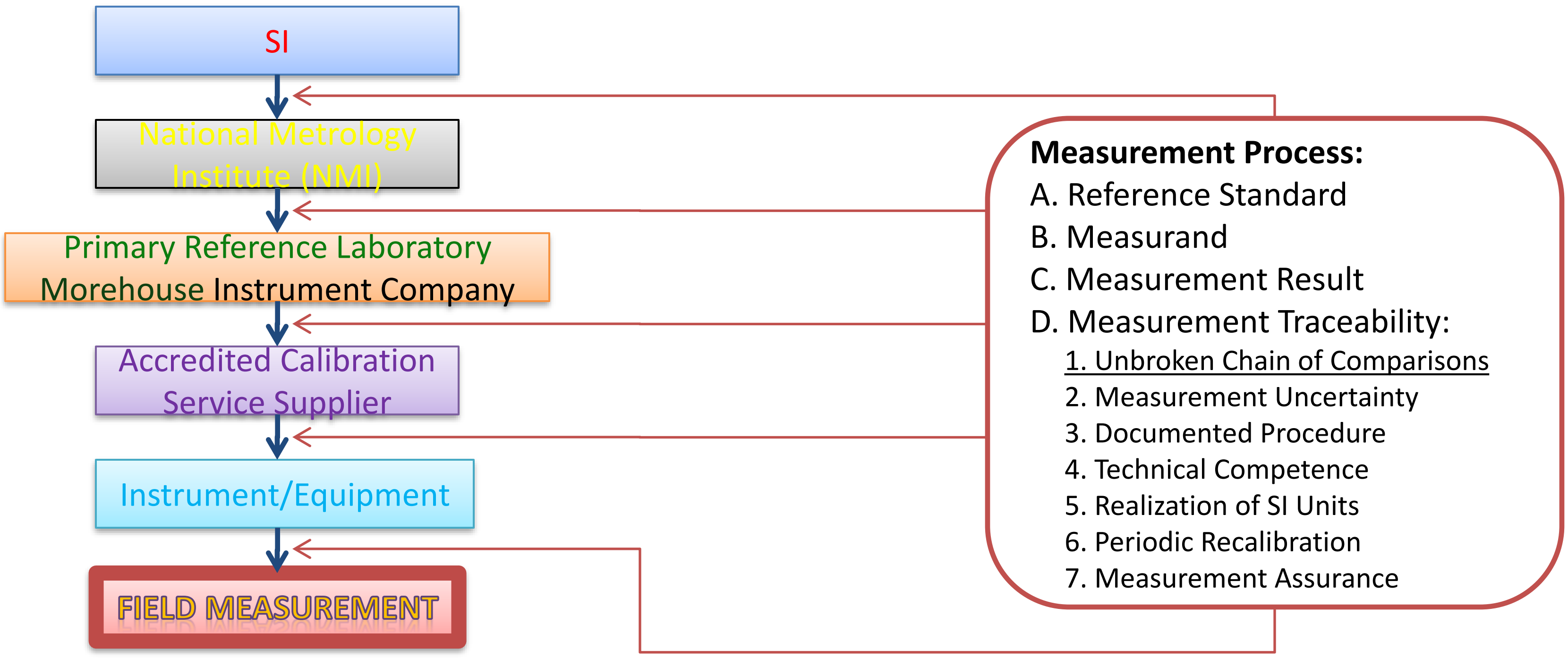
Accredited Calibration Supplier = 0.02 %

Working Standards = 0.1 %

Field Measurement = 0.5 %

Measurement Calibration Hierarchy

Reference Standard used in the calibration of equipment



SI

National Metrology Institute (NMI)

Primary Reference Laboratory
Morehouse Instrument Company

Accredited Calibration Service Supplier

Instrument/Equipment

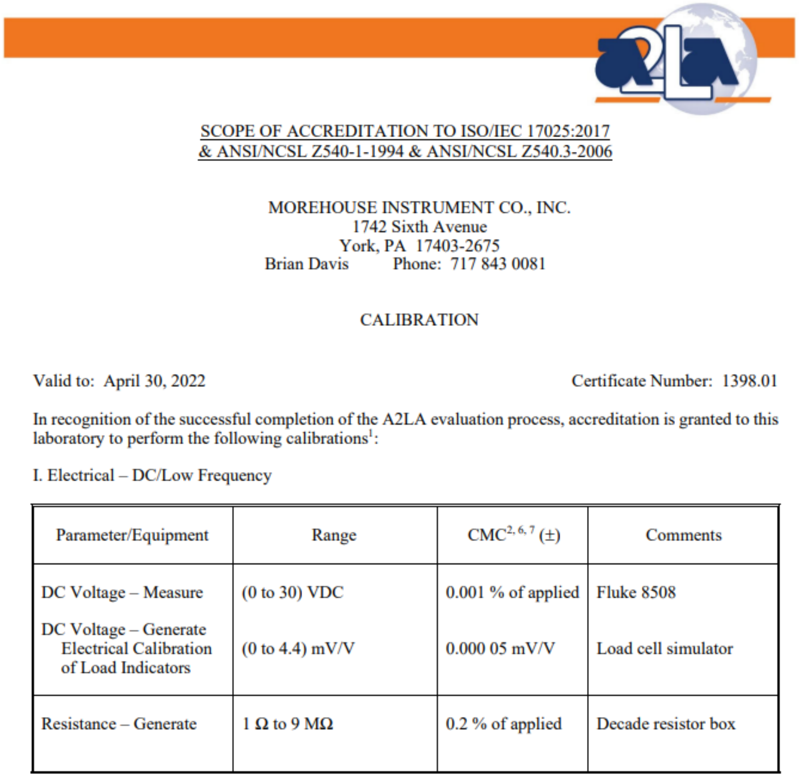
FIELD MEASUREMENT

Measurement Process:

A. Reference Standard
B. Measurand
C. Measurement Result
D. Measurement Traceability:
    1. Unbroken Chain of Comparisons
    2. Measurement Uncertainty
    3. Documented Procedure
    4. Technical Competence
    5. Realization of SI Units
    6. Periodic Recalibration
    7. Measurement Assurance

Calibration Traceability Guidelines

- **It is the scope of accreditation that determines the laboratory's capability.**
- The scope should state the Calibration and Measurement Capability for different ranges. On this scope the (CMC) is 0.003 % for torque calibrations from 20 to 2000 N-m and 0.0016 % for force calibrations up to 120,000 LBF.



SCOPE OF ACCREDITATION TO ISO/IEC 17025:2017
& ANSI/NCSL Z540-1-1994 & ANSI/NCSL Z540.3-2006

MOREHOUSE INSTRUMENT CO., INC.
1742 Sixth Avenue
York, PA 17403-2675
Brian Davis Phone: 717 843 0081

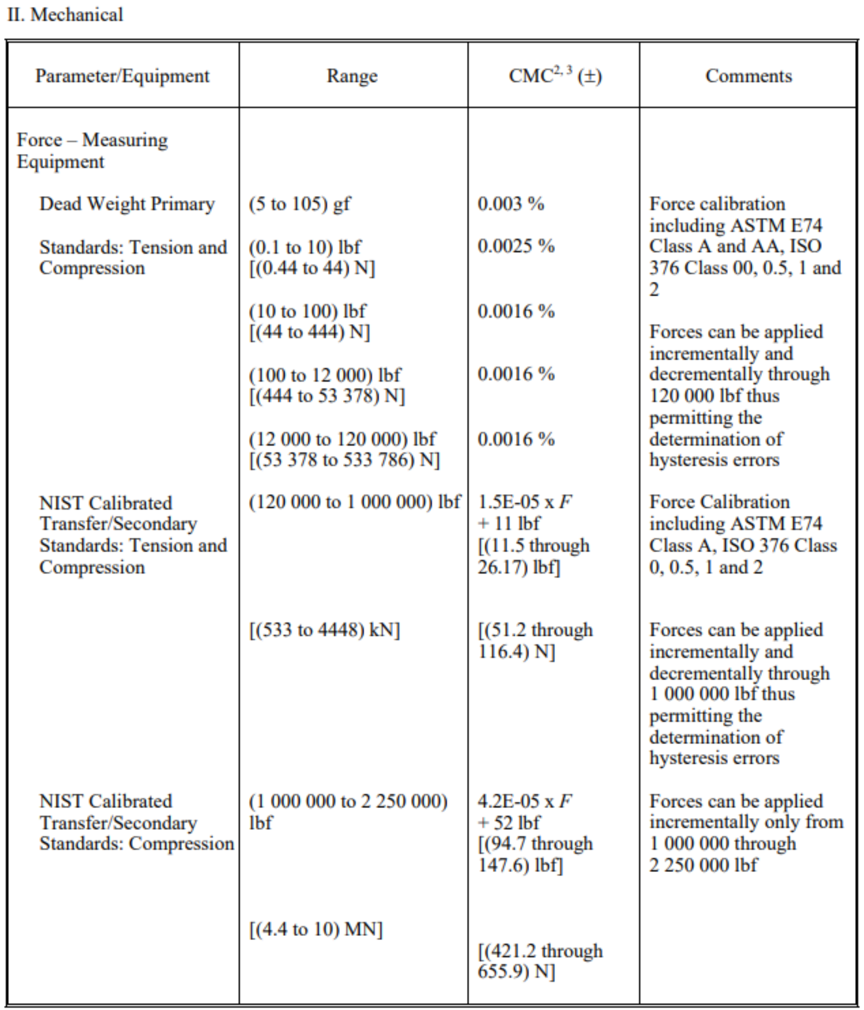
CALIBRATION

Valid to: April 30, 2022 Certificate Number: 1398.01

In recognition of the successful completion of the A2LA evaluation process, accreditation is granted to this laboratory to perform the following calibrations[1]:

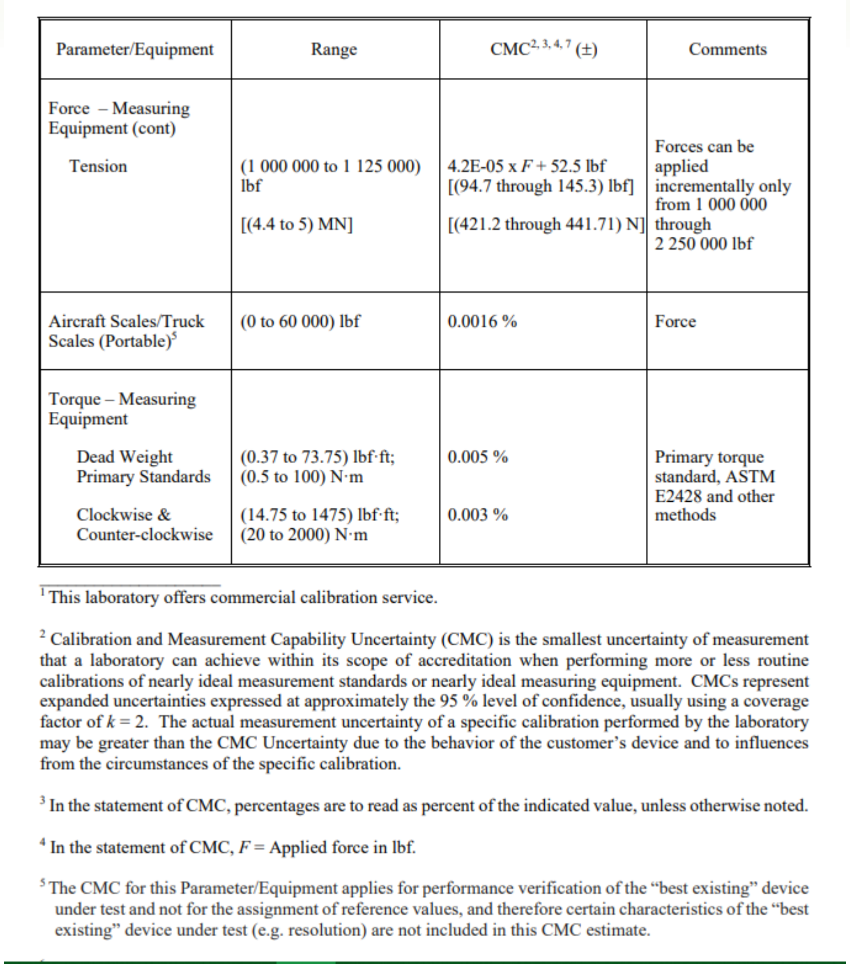
I. Electrical – DC/Low Frequency

Parameter/Equipment	Range	CMC[2, 6, 7] (±)	Comments
DC Voltage – Measure	(0 to 30) VDC	0.001 % of applied	Fluke 8508
DC Voltage – Generate Electrical Calibration of Load Indicators	(0 to 4.4) mV/V	0.000 05 mV/V	Load cell simulator
Resistance – Generate	1 Ω to 9 MΩ	0.2 % of applied	Decade resistor box



II. Mechanical

Parameter/Equipment	Range	CMC^{2,3} (±)	Comments
Force – Measuring Equipment			
Dead Weight Primary	(5 to 105) gf	0.003 %	Force calibration including ASTM E74 Class A and AA, ISO 376 Class 00, 0.5, 1 and 2
Standards: Tension and Compression	(0.1 to 10) lbf [(0.44 to 44) N]	0.0025 %	
	(10 to 100) lbf [(44 to 444) N]	0.0016 %	Forces can be applied incrementally and decrementally through 120 000 lbf thus permitting the determination of hysteresis errors
	(100 to 12 000) lbf [(444 to 53 378) N]	0.0016 %	
	(12 000 to 120 000) lbf [(53 378 to 533 786) N]	0.0016 %	
NIST Calibrated Transfer/Secondary Standards: Tension and Compression	(120 000 to 1 000 000) lbf	1.5E-05 x F + 11 lbf [(11.5 through 26.17) lbf]	Force Calibration including ASTM E74 Class A, ISO 376 Class 0, 0.5, 1 and 2
	[(533 to 4448) kN]	[(51.2 through 116.4) N]	Forces can be applied incrementally and decrementally through 1 000 000 lbf thus permitting the determination of hysteresis errors
NIST Calibrated Transfer/Secondary Standards: Compression	(1 000 000 to 2 250 000) lbf	4.2E-05 x F + 52 lbf [(94.7 through 147.6) lbf]	Forces can be applied incrementally only from 1 000 000 through 2 250 000 lbf
	[(4.4 to 10) MN]	[(421.2 through 655.9) N]	



Parameter/Equipment	Range	CMC^{2,3,4,7} (±)	Comments
Force – Measuring Equipment (cont)			
Tension	(1 000 000 to 1 125 000) lbf [(4.4 to 5) MN]	4.2E-05 x F + 52.5 lbf [(94.7 through 145.3) lbf] [(421.2 through 441.71) N]	Forces can be applied incrementally only from 1 000 000 through 2 250 000 lbf
Aircraft Scales/Truck Scales (Portable)^5	(0 to 60 000) lbf	0.0016 %	Force
Torque – Measuring Equipment			
Dead Weight Primary Standards	(0.37 to 73.75) lbf·ft; (0.5 to 100) N·m	0.005 %	Primary torque standard, ASTM E2428 and other methods
Clockwise & Counter-clockwise	(14.75 to 1475) lbf·ft; (20 to 2000) N·m	0.003 %	

---

[1] This laboratory offers commercial calibration service.

[2] Calibration and Measurement Capability Uncertainty (CMC) is the smallest uncertainty of measurement that a laboratory can achieve within its scope of accreditation when performing more or less routine calibrations of nearly ideal measurement standards or nearly ideal measuring equipment. CMCs represent expanded uncertainties expressed at approximately the 95 % level of confidence, usually using a coverage factor of $k = 2$. The actual measurement uncertainty of a specific calibration performed by the laboratory may be greater than the CMC Uncertainty due to the behavior of the customer's device and to influences from the circumstances of the specific calibration.

[3] In the statement of CMC, percentages are to read as percent of the indicated value, unless otherwise noted.

[4] In the statement of CMC, F = Applied force in lbf.

[5] The CMC for this Parameter/Equipment applies for performance verification of the "best existing" device under test and not for the assignment of reference values, and therefore certain characteristics of the "best existing" device under test (e.g. resolution) are not included in this CMC estimate.

7 Essential Elements
Chain of Metrological Traceability

Measurement Uncertainty

Measurement Assurance

Realization of SI Units

Unbroken Chain of Comparisons

DOCUMENTED PROCEDURE

Technical Competence

Periodic Recalibration

CMC

- A CMC is a calibration and measurement capability available to customers under normal conditions:

- a) as described in the laboratory’s scope of accreditation granted by a signatory to the ILAC Arrangement; or

- b) as published in the BIPM key comparison database (KCDB) of the CIPM MRA.

CMC

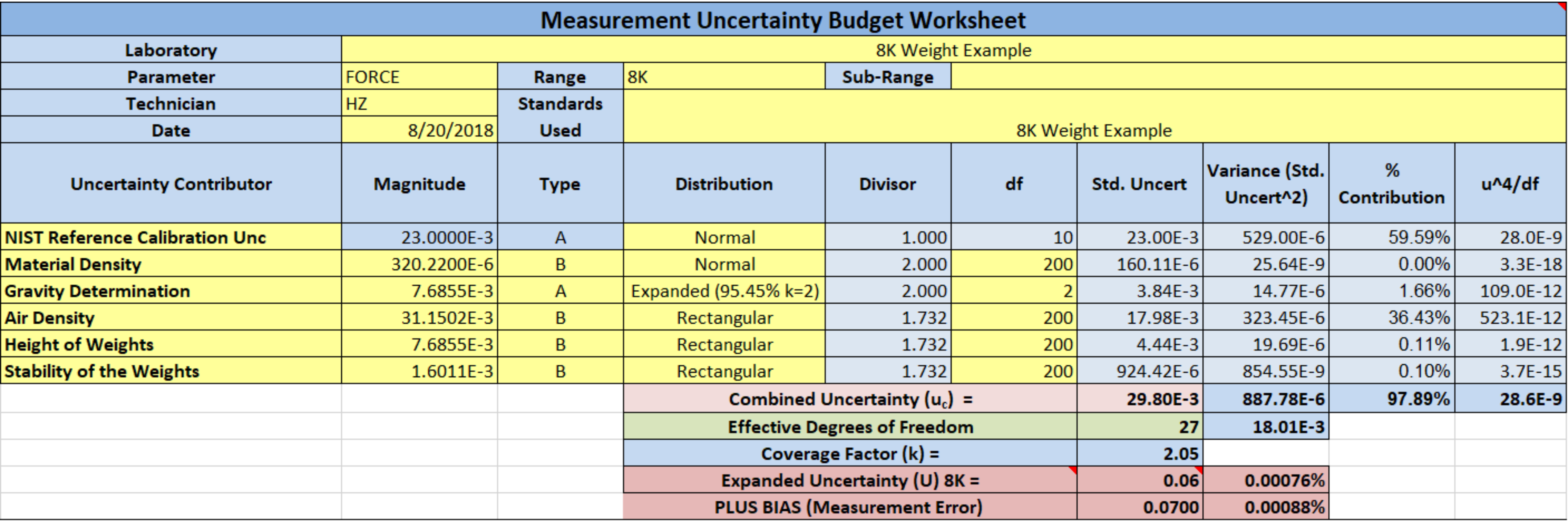
The scope of accreditation of an accredited calibration laboratory shall include the calibration and measurement capability (CMC) expressed in terms of:

- a) measurand or reference material;
- b) calibration/measurement method/procedure and/or type of instrument/material to be calibrated/measured;
- c) measurement range and additional parameters where applicable, e.g., frequency of applied voltage;
- d) uncertainty of measurement.

On the Morehouse deadweight standards, the following was used to determine the Force Uncertainty part of the CMC.

Repeatability of a TI in the machine
NIST Uncertainty (*k*=2) for all the weights used at this point (this includes, air buoyancy correction, stability, wear, local gravity correction)
Resolution of the TI (Test Instrument) or (Unit Under Test)

Force Uncertainty Calculation Example

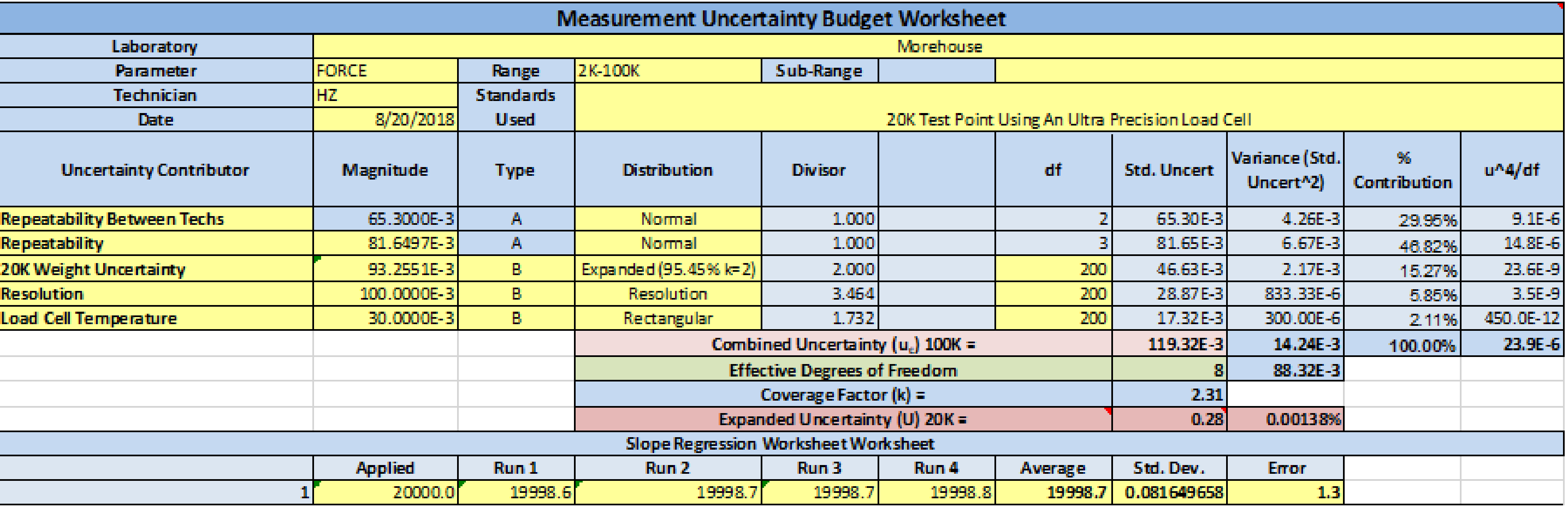


Measurement Uncertainty Budget Worksheet									
Laboratory	8K Weight Example								
Parameter	FORCE	**Range**	8K	**Sub-Range**					
Technician	HZ	**Standards Used**	8K Weight Example						
Date	8/20/2018								
Uncertainty Contributor	**Magnitude**	**Type**	**Distribution**	**Divisor**	**df**	**Std. Uncert**	**Variance (Std. Uncert^2)**	**% Contribution**	**u^4/df**
NIST Reference Calibration Unc	23.0000E-3	A	Normal	1.000	10	23.00E-3	529.00E-6	59.59%	28.0E-9
Material Density	320.2200E-6	B	Normal	2.000	200	160.11E-6	25.64E-9	0.00%	3.3E-18
Gravity Determination	7.6855E-3	A	Expanded (95.45% k=2)	2.000	2	3.84E-3	14.77E-6	1.66%	109.0E-12
Air Density	31.1502E-3	B	Rectangular	1.732	200	17.98E-3	323.45E-6	36.43%	523.1E-12
Height of Weights	7.6855E-3	B	Rectangular	1.732	200	4.44E-3	19.69E-6	0.11%	1.9E-12
Stability of the Weights	1.6011E-3	B	Rectangular	1.732	200	924.42E-6	854.55E-9	0.10%	3.7E-15
			Combined Uncertainty (u_c) =			**29.80E-3**	**887.78E-6**	**97.89%**	**28.6E-9**
			Effective Degrees of Freedom			**27**	**18.01E-3**		
			Coverage Factor (k) =			**2.05**			
			Expanded Uncertainty (U) 8K =			**0.06**	**0.00076%**		
			PLUS BIAS (Measurement Error)			**0.0700**	**0.00088%**		

$$20K\ U = \sqrt{\begin{array}{c}(1K\ weight\ unc)^2 + (1K\ weight\ unc)^2 + (2K\ weight\ unc)^2 \\ +(8K\ weight\ unc)^2 + (8K\ weight\ unc)^2\end{array}}$$

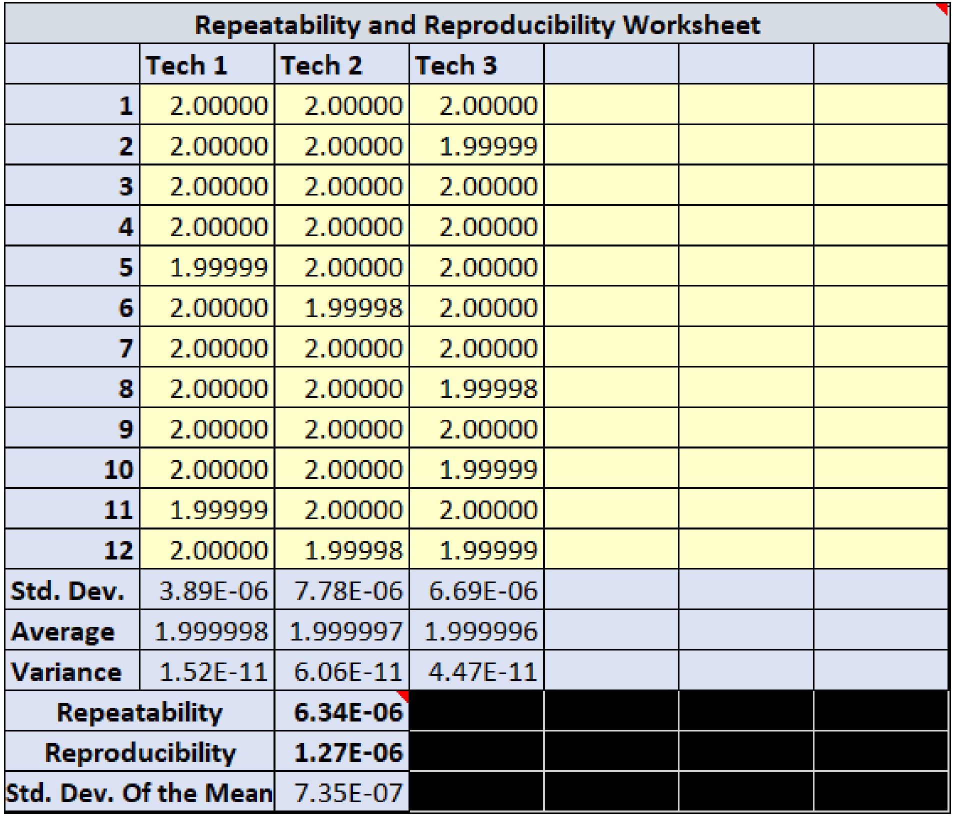
Force Uncertainty Calculation Example

Force Uncertainty Calculation Example



Measurement Uncertainty Budget Worksheet										
Laboratory	Morehouse									
Parameter	FORCE	Range	2K-100K	Sub-Range						
Technician	HZ	Standards Used	20K Test Point Using An Ultra Precision Load Cell							
Date	8/20/2018									
Uncertainty Contributor	Magnitude	Type	Distribution	Divisor		df	Std. Uncert	Variance (Std. Uncert^2)	% Contribution	u^4/df
Repeatability Between Techs	65.3000E-3	A	Normal	1.000		2	65.30E-3	4.26E-3	29.95%	9.1E-6
Repeatability	81.6497E-3	A	Normal	1.000		3	81.65E-3	6.67E-3	46.82%	14.8E-6
20K Weight Uncertainty	93.2551E-3	B	Expanded (95.45% k=2)	2.000		200	46.63E-3	2.17E-3	15.27%	23.6E-9
Resolution	100.0000E-3	B	Resolution	3.464		200	28.87E-3	833.33E-6	5.85%	3.5E-9
Load Cell Temperature	30.0000E-3	B	Rectangular	1.732		200	17.32E-3	300.00E-6	2.11%	450.0E-12
			Combined Uncertainty (u_c) 100K =				119.32E-3	14.24E-3	100.00%	23.9E-6
			Effective Degrees of Freedom				8	88.32E-3		
			Coverage Factor (k) =				2.31			
			Expanded Uncertainty (U) 20K =				0.28	0.00138%		
Slope Regression Worksheet Worksheet										
	Applied	Run 1	Run 2	Run 3	Run 4	Average	Std. Dev.	Error		
1	20000.0	19998.6	19998.7	19998.7	19998.8	19998.7	0.081649658	1.3		

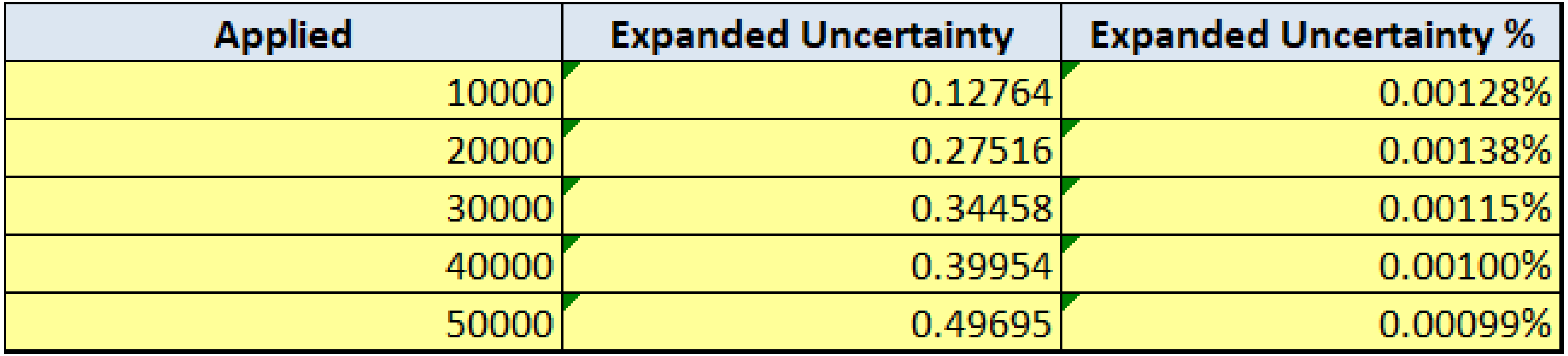
Force Uncertainty Calculation Example



Repeatability and Reproducibility Worksheet

	Tech 1	Tech 2	Tech 3			
1	2.00000	2.00000	2.00000			
2	2.00000	2.00000	1.99999			
3	2.00000	2.00000	2.00000			
4	2.00000	2.00000	2.00000			
5	1.99999	2.00000	2.00000			
6	2.00000	1.99998	2.00000			
7	2.00000	2.00000	2.00000			
8	2.00000	2.00000	1.99998			
9	2.00000	2.00000	2.00000			
10	2.00000	2.00000	1.99999			
11	1.99999	2.00000	2.00000			
12	2.00000	1.99998	1.99999			
Std. Dev.	3.89E-06	7.78E-06	6.69E-06			
Average	1.999998	1.999997	1.999996			
Variance	1.52E-11	6.06E-11	4.47E-11			
Repeatability		**6.34E-06**				
Reproducibility		**1.27E-06**				
Std. Dev. Of the Mean		7.35E-07				

Force Uncertainty Calculation Example



Applied	Expanded Uncertainty	Expanded Uncertainty %
10000	0.12764	0.00128%
20000	0.27516	0.00138%
30000	0.34458	0.00115%
40000	0.39954	0.00100%
50000	0.49695	0.00099%

Measurement Related Terms

- **Type A evaluation of measurement uncertainty, Type A evaluation:** Evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions.
  - NOTE 1 For various types of measurement conditions, see repeatability condition of measurement, intermediate precision condition of measurement, and reproducibility condition of measurement.

Measurement Related Terms

- **Type B evaluation of measurement uncertainty, Type B evaluation:** Evaluation of a component of measurement uncertainty determined by means other than a Type A evaluation of measurement uncertainty.
  - EXAMPLES Evaluation based on information. — associated with authoritative published quantity values, — associated with the quantity value of a certified reference material, — obtained from a calibration certificate, — about drift, — obtained from the accuracy class of a verified measuring instrument, — obtained from limits deduced through personal experience.

Measurement Related Terms

- **Expanded uncertainty, expanded measurement uncertainty:** Product of a combined standard measurement uncertainty and a factor larger than the number one.
  - NOTE 1 The factor depends upon the type of probability distribution of the output quantity in a measurement model and on the selected coverage probability.
  - NOTE 2 The term “factor” in this definition refers to a coverage factor.
  - NOTE 3 Expanded measurement uncertainty is termed “overall uncertainty” in paragraph 5 of Recommendation INC-1 (1980) (see the GUM) and simply “uncertainty” in IEC documents.

Measurement Related Terms

- **Validation:** verification, where the specified requirements are adequate for an intended use.
  - EXAMPLE A measurement procedure, ordinarily used for the measurement of mass concentration of nitrogen in water, may be validated also for measurement in human serum.

Measurement Related Terms

- **Verification:** provision of objective evidence that a given item fulfils specified requirements.
  - EXAMPLE 1 Confirmation that a given reference material as claimed is homogeneous for the quantity value and measurement procedure concerned, down to a measurement portion having a mass of 10 mg.
  - EXAMPLE 2 Confirmation that performance properties or legal requirements of a measuring system are achieved.
  - EXAMPLE 3 Confirmation that a target measurement uncertainty can be met.

“Typical” Performance Specification:

At 10 Clucks: ± 2 mClucks (aka ± 0.002 Clucks) *
(on 0 – 20 Clucks scale and 0.01 Cluck resolution)

The Fine Print:

* Achieved if the equipment is used with left hand[1] only, while standing on right foot[2] only and the right eye[3] closed, while maintaining a 23 ^{0}F ± 0.033 ^{0}F environment[4] using “**hypertronic-wormhole ™**“ temperature control[5].

[1] If used with right hand, the results will vary (and we won’t tell you by how much – we used left-handed technician)

[2] If standing on left foot, you may get more tired, and we won’t guarantee performance.

[3] If right or both eyes are closed, you are on your own – **Good Luck!**

[4] **Do not attempt to use at -5 ^{0}C as we do not sanction its use on Celsius scale**. Do not even think about the Rankine scale (We really do not know what Rankine is)!!!

[5] Achieved once, never repeated. Fine tuning hammer used at times. We call it ***single measurement bliss.***

(Happiest place to work –looking for warm breathing bodies – will not train).

Happy Days Instrument Company (where Precision =Accuracy=Resolution or whatever)

Enjoy our fine, master crafted Instrument – knocking out one at a time!

FU

Do we multiply our FU's by a coverage factor of k or *k?*

Is the accuracy +/- or ± FU's?

If we report are FU's in % is it 1.1% or 1.1 % ?

Was our temperature reported at 22.6° C or

22.6 °C ?

Calibration Traceability Guidelines (Useless Knowledge Section)

- Q: Why does the International Organization of Standards (IOS) call the standards ISO ?
- A: The term **ISO** is not an abbreviation, but instead derives from the Greek word īsos, **meaning** equal

Course Agenda

- Force
- Common Types of Force Measuring Instrumentation
- Troubleshooting a load cell
- Calibration Traceability and Force Standards Calibration
- ASTM E74
- Accuracy Precision Resolution and Uncertainty
- Potential Force Measurement Errors with demonstrations
- Uncertainty Analysis

Common Types of Force Measuring Instrumentation and load cell troubleshooting procedures

Learning Objectives

By the end of this section, you should be able to

- Troubleshooting a load cell
- Identify potential force measurement errors
- Start to implement proper force calibration techniques

Force = Mass X Acceleration

- CIPM/BIPM defines 1N as the force required to accelerate one kg to one meter **per second** per second in a vacuum.
- Definition - strength or power exerted upon an object

Force General information
Why is force measurement important?

- Picture of a collapsed bridge.

What could happen if you fail to get the force measurement correct.

- Incorrect Concrete Strength Measurement
- Incorrect Steel Strength Measurement
- Cables not checked properly for prestress or post tension

Force General information
Why is force measurement important?

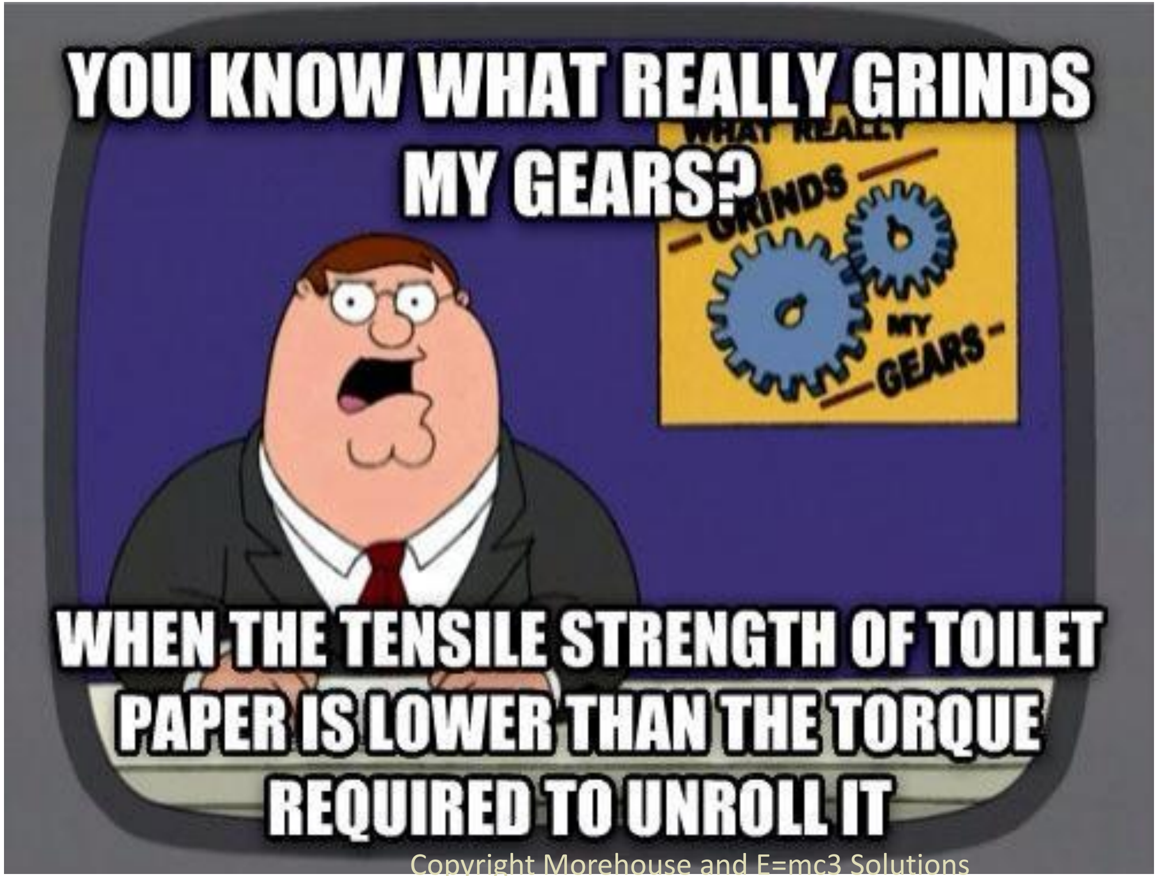
- *The measurement of force is performed so frequently and routinely that we tend to take these measurements for granted.*
- Almost every material item is tested using some form of traceable force measurement.

Force General information
Why is force measurement important?

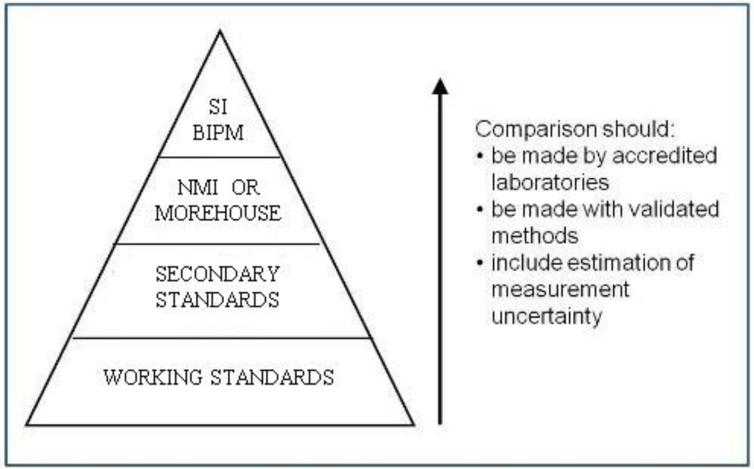
- Manufacturers are often required to do sample testing on the products they manufacture.

- These products may vary from the wood that was used to build your house to the cardboard that holds your toilet paper on the roll.

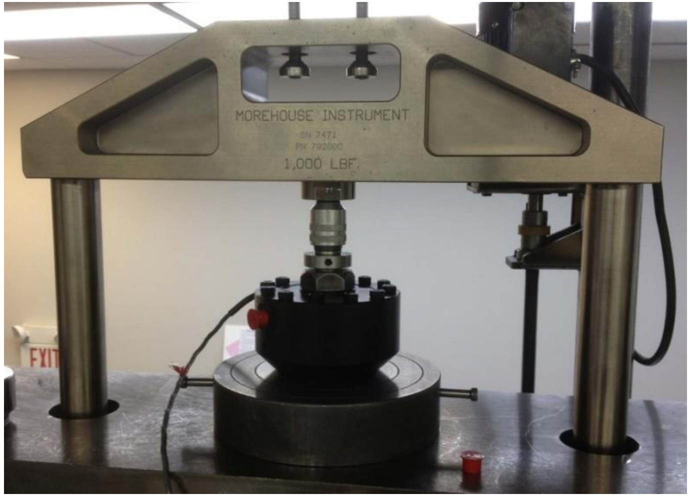
And Speaking of toilet paper



The role of Morehouse in the force measurement hierarchy or chain



Comparison should:
- be made by accredited laboratories
- be made with validated methods
- include estimation of measurement uncertainty



- Morehouse calibrates the Secondary or Working Standards that are then used to calibrate other force instrumentation or testing machines.

Force General information
Everyday life

- Soaps, Shampoo, Cosmetics
- All packaging for these products is checked for tensile, peel, compressive and tear strength.

- Clothing, Fabrics
- Shirts, trousers, undergarments, etc., tablecloths, napkins, etc., all checked for tensile strength, tear strength, seam slippage, etc.

Force General information
Everyday life

- Building Materials
- Concrete, glass, rebar, I beam, wood, structural composite material tested for tensile strength, flexural strength, shear strength, rupture strength, impact strength.
- Concrete, Asphalt
- Concrete, asphalt, rebar material tested for tensile strength, flexural strength, shear strength, rupture strength, impact strength.
- Car Interior / Exterior
- Body material, lamps, interior trim, etc., tested for tensile strength, flexural strength, ductility, shear strength, tear strength, rupture strength, impact strength.

Force General information
Everyday life

- Computers and Peripherals
- Computer monitor and parts are tested for tensile, flexure and shear strength as well as impact resistance. Additionally, keyboards are tested for click and operational forces.
- Clothing
- Seams, buttons, snaps, embellishments, etc., are all checked for tensile strength and pull-off forces.
- Towels, Washcloths
- Towels are tested for strength in both weft and warp directions, also checked for seam slippage. Yarn is tested for tensile strength.

Force Testing Examples

Fig 10. Testing the ripeness of apples using a set of Magnus Taylor probes

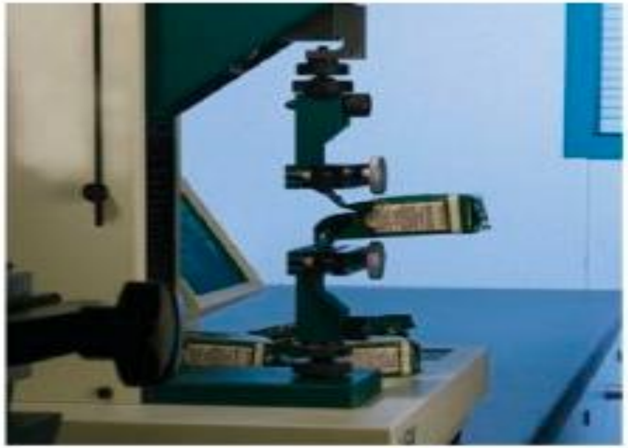


Fig 11. Testing the strength of coffee packaging using the quick release vise grips, HT55

Force Testing Examples

Fig 12. Testing the strength of fishing line using single bollard grips, HT33

Fig 19. Testing the adhesive peeling forces of foil packaging

Force Testing Examples

Fig 15. Testing the crushing strength of pills

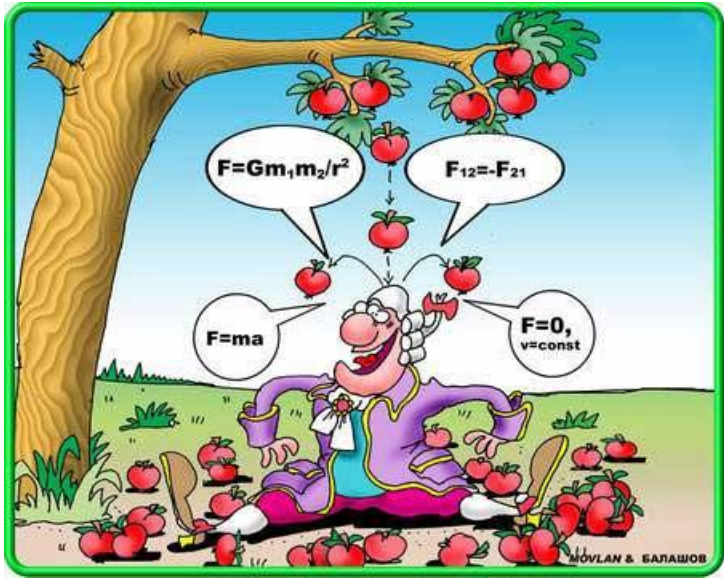
Fig 21. Determining the force to remove the lid from a plastic package

Force General information

Why is force measurement important?


Aircraft Weighing Applications

Force General information



- Sir Isaac Newton, in his second law, stated that force controls motion; therefore, if we are to control the motion, we must control the force.

Force Conversion Factors

newton (N) to lbf = MULTIPLY BY 0.2248089431
newton (N) to kgf = MULTIPLY BY 0.1019716212978
newton (N) to ozf = MULTIPLY BY 3.59694309

lbf to newton (N) = MULTIPLY BY 4.4482216152605
lbf to kgf = MULTIPLY BY 0.45359237
lbf to ozf = MULTIPLY BY 0.0625

kgf to lbf = MULTIPLY BY 2.20462262
kgf to newton (N) = MULTIPLY BY 9.80665
kgf to ozf = MULTIPLY BY 35.27396

ozf to newton (N) = MULTIPLY BY 0.2780139
ozf to lbf = MULTIPLY BY 16
ozf to kgf = MULTIPLY BY 0.0283495231

What is a Transducer?

A battery is a transducer that converts chemical energy into electrical energy.

A thermometer is a transducer that converts heat energy into mechanical displacement of a liquid column.

Force or Torque Transducer – a transducer that translates an input of mechanical energy into equivalent electrical signals for measuring and/or controlling the input phenomena

- In a broad sense of the term, a transducer is a device that transforms one type of energy into another.

Common types of Force Equipment (We Are about to get brutally honest in this section)

- Bolt Testers
- Proving Rings
- Force Gauges
- Brinell Calibrators
- Traction Dynamometers
- Tension Links
- Crane Scales
- Load Cells –multiple types

Bolt Testers

- Used to test high-strength bolts on site

- Calibration requires special fixtures based on factory recommendations.   Accuracy is typically 1 % of applied reading between 20-80 percent of the range.

Proving Rings

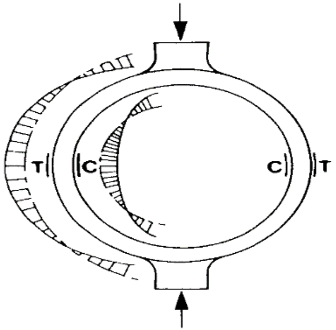
Reliability

- It has been proven that a steel ring made of the correct steel alloy and properly manufactured will perform as a near perfect elastic member. The Proving Ring, if used and maintained properly, can last indefinitely.

Repeatability

- Proving Rings, unlike other force measuring instruments, are not sensitive to rotation/positioning problems.

Proving Ring



- The bending moment of a Proving Ring does not vary significantly in the region of the horizontal diameter, which leads to a nearly uniform strain distribution.

THIS CALIBRATION DATA IS CERTIFIED TRACEABLE
TO THE
UNITED STATES NATIONAL INSTITUTE OF STANDARDS & TECHNOLOGY

08/05/03
MOREHOUSE PROVING RING NO-6803
CAPACITY 2,000 LBF COMPRESSION

CALIBRATION IN ACCORDANCE WITH ASTM METHOD E 74
COMPRESSION DATA FOR 23 DEGREES C

APPLIED LOAD	DEFLECTIONS OBSERVED DURING CALIBRATION			DEVIATION FROM FITTED CURVE			VALUES FROM FITTED CURVE
	RUN 1	RUN 2	RUN 3	RUN 1	RUN 2	RUN 3	
LBF	DIV	DIV	DIV	DIV	DIV	DIV	DIV
50.00	27.37	27.39	27.39	-0.02	0.00	0.00	27.39
200.00	108.72	108.76	108.76	-0.03	0.01	0.01	108.75
400.00	217.75	217.82	217.81	-0.10	-0.03	-0.04	217.85
600.00	327.68	327.78	327.67	0.01	0.11	0.00	327.67
800.00	438.30	438.24	438.22	0.11	0.05	0.03	438.19
1,000.00	549.43	549.49	549.48	0.00	0.06	0.05	549.43
1,200.00	661.25	661.25	661.33	-0.12	-0.12	-0.04	661.37
1,400.00	774.07	774.10	774.09	0.04	0.07	0.06	774.03
1,600.00	887.34	887.36	887.34	-0.05	-0.03	-0.05	887.39
1,800.00	1,001.41	1,001.41	1,001.39	-0.06	-0.06	-0.08	1,001.47
2,000.00	1,116.33	1,116.31	1,116.34	0.07	0.05	0.08	1,116.26

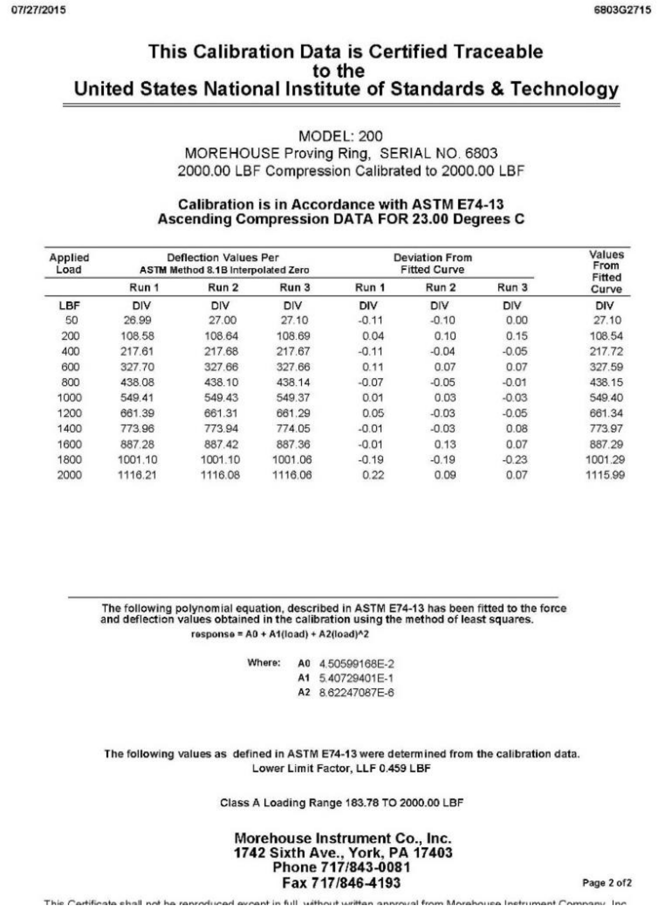
THE FOLLOWING CALIBRATION EQUATION, DESCRIBED IN SECTION 7.2 OF ASTM METHOD E74, HAS BEEN FITTED TO THE CALIBRATION DATA BY THE METHOD OF LEAST SQUARES.

DEFLECTIONS = (A) + (B)(LOAD) + (C)(LOAD SQUARED)

VALUES OF CONSTANTS ARE.

a = 0.3538256D+00
b = 0.5401942D+00
c = 0.8878805D-05

ASTM UNCERTAINTY = 0.28 = (2.4 TIMES S) IN LBF



07/27/2015 6803G2715

This Calibration Data is Certified Traceable
to the
United States National Institute of Standards & Technology

MODEL: 200
MOREHOUSE Proving Ring, SERIAL NO. 6803
2000.00 LBF Compression Calibrated to 2000.00 LBF

Calibration is in Accordance with ASTM E74-13
Ascending Compression DATA FOR 23.00 Degrees C

Applied Load	Deflection Values Per ASTM Method 8.1B Interpolated Zero			Deviation From Fitted Curve			Values From Fitted Curve
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
LBF	DIV	DIV	DIV	DIV	DIV	DIV	DIV
50	26.99	27.00	27.10	-0.11	-0.10	0.00	27.10
200	108.58	108.64	108.69	0.04	0.10	0.15	108.54
400	217.61	217.68	217.67	-0.11	-0.04	-0.05	217.72
600	327.70	327.66	327.66	0.11	0.07	0.07	327.59
800	438.08	438.10	438.14	-0.07	-0.05	-0.01	438.15
1000	549.41	549.43	549.37	0.01	0.03	-0.03	549.40
1200	661.39	661.31	661.29	0.05	-0.03	-0.05	661.34
1400	773.96	773.94	774.05	-0.01	-0.03	0.08	773.97
1600	887.28	887.42	887.36	-0.01	0.13	0.07	887.29
1800	1001.10	1001.10	1001.06	-0.19	-0.19	-0.23	1001.29
2000	1116.21	1116.08	1116.06	0.22	0.09	0.07	1115.99

The following polynomial equation, described in ASTM E74-13 has been fitted to the force and deflection values obtained in the calibration using the method of least squares.

response = A0 + A1(load) + A2(load)^2

Where:
A0 4.50599168E-2
A1 5.40729401E-1
A2 8.62247087E-6

The following values as defined in ASTM E74-13 were determined from the calibration data.
Lower Limit Factor, LLF 0.459 LBF

Class A Loading Range 183.78 TO 2000.00 LBF

Morehouse Instrument Co., Inc.
1742 Sixth Ave., York, PA 17403
Phone 717/843-0081
Fax 717/846-4193

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- There are two certificates above. One is in 2003 and another one in 2015.

Proving Ring

2015	2003	% Diff
108.54	108.75	0.193%
217.72	217.85	0.060%
327.59	327.67	0.024%
438.15	438.19	0.009%
549.40	549.43	0.005%
661.34	661.37	0.005%
773.97	774.03	0.008%
887.29	887.39	0.011%
1001.29	1001.47	0.018%
1115.99	1116.26	0.024%

- 12 Year Change From Previous.
- Note: Morehouse does not recommend 12-year calibration intervals.

Digital Proving Rings

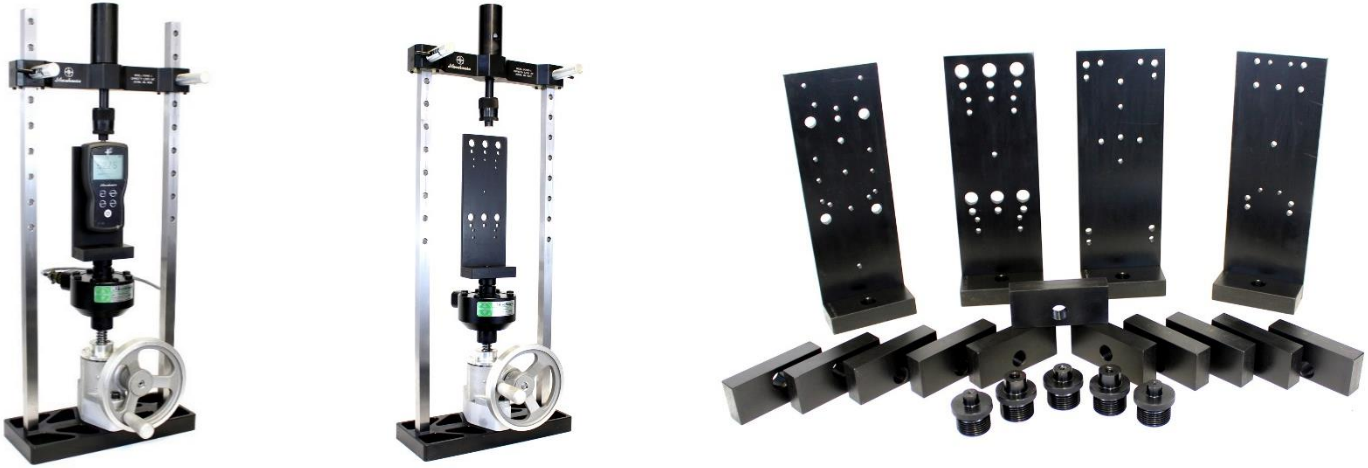
- Digital Proving Rings have been designed to lower uncertainties by reducing operator error associated with reading mechanical contacts. The calibration cycle time is also improved with digital rings.

Force Gauges

- Typically used for calibration of certain testing machines, weighing devices, assembly presses, control instruments, cable tension, soil testing, or other equipment measuring force. Also, as a prime weighing device or permanent load-sensing component in testing or production equipment.

- Force Gauges can either be analog or digital, and usually have an accuracy anywhere from 0.1 % of full scale to 2 % of full scale.

Adapters for hand-held force gauges



Morehouse L-Bracket kits are available for tension and compression calibration of hand-held force gauges. These kits simplify setup and reduce errors with stacking weights

Brinell Calibrators

- Typically used for calibration of Brinell hardness testers and calibrated in accordance with ASTM E74 as a limited load device.

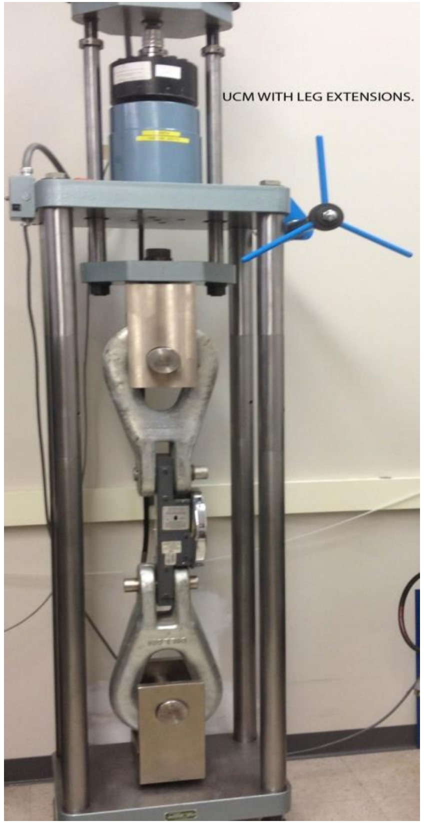
- The Brinell hardness test for steel involves impressing a ball, 10 mm diameter, of hard steel or tungsten carbide, with a loading of 3000 kilograms into the steel surface. The hardness of the steel is then determined by measurement of the indentation. For steel with a hardness over 500 BHN, the Vickers test is more reliable.

Traction Dynamometers

- Typically used for adjusting tension on guy wires, field testing chain, rope, wire, or anything requiring precision force or tension measurement.

- Calibration should be performed with shackles if possible. Typical accuracy is 0.5 % of full scale, which may be difficult to achieve on some models.

Traction Dynamometers

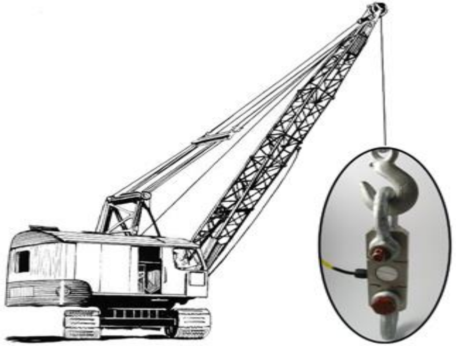


- Pictured is a typical setup in a Morehouse 100K UCM. 2 sets of leg extensions are needed to elongate the machine to perform this calibration.
- These shackles have caged roller bearings with inner race installed. The anticipated difference between using roller bearings, as intended by the manufacture and pinning the instrument directly, is above 5 %. (We observed an 8 % error when we tested this.)

Traction Dynamometers

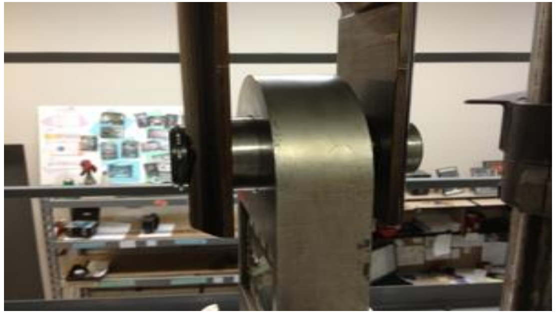
- Adjustments are made by loosening these two Allen screws and sliding the mechanism up or down.
- Adjustments on these can be very tedious, as it is a bit of hit-or-miss.
- If any part of the shackle is touching the actual instrument, there will be additional errors. (probably around 3 % error)

Tension Links



- Typically used for lift tests, towing tension, cable tension, crane scale, hoist scale, and tensile testing systems.
- Calibration should be performed with the same load pins the end user is using with the device.

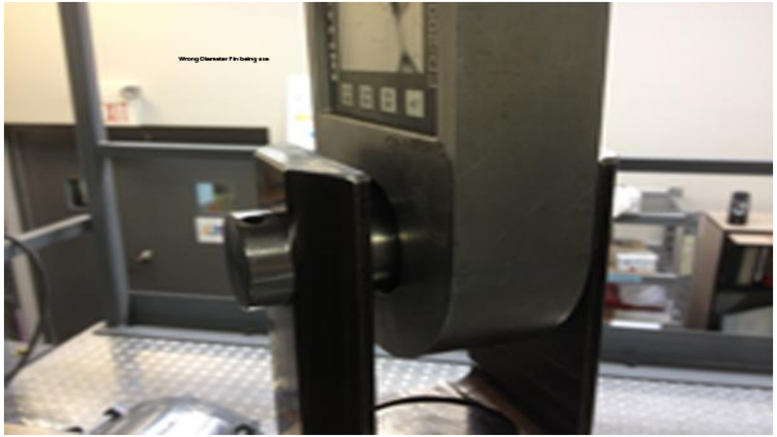
Tension Links Pin Diameter



- Do you think the output will vary?

Tension Links PROPER PIN DIAMETER ON DILLON ed2000

- Loaded without the proper Pin Diameter to 50,000 LBF



Tension Links PROPER PIN DIAMETER

- Loaded with the proper Pin Diameter to 50,000 LBF

Tension Links 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: Most Tension links of this design seem to exhibit similar problems.

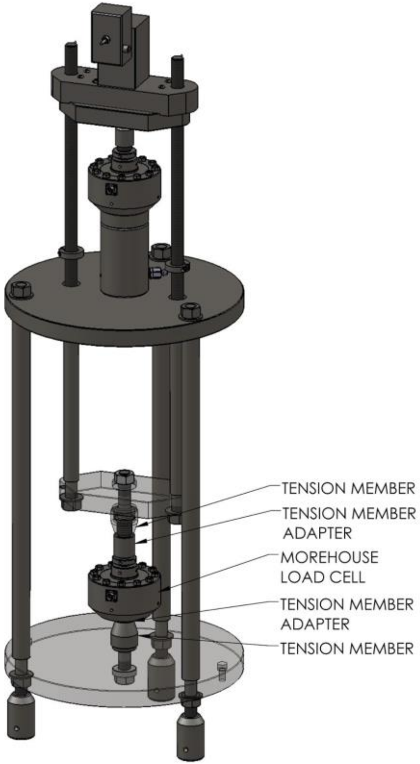
Tension Link Calibration

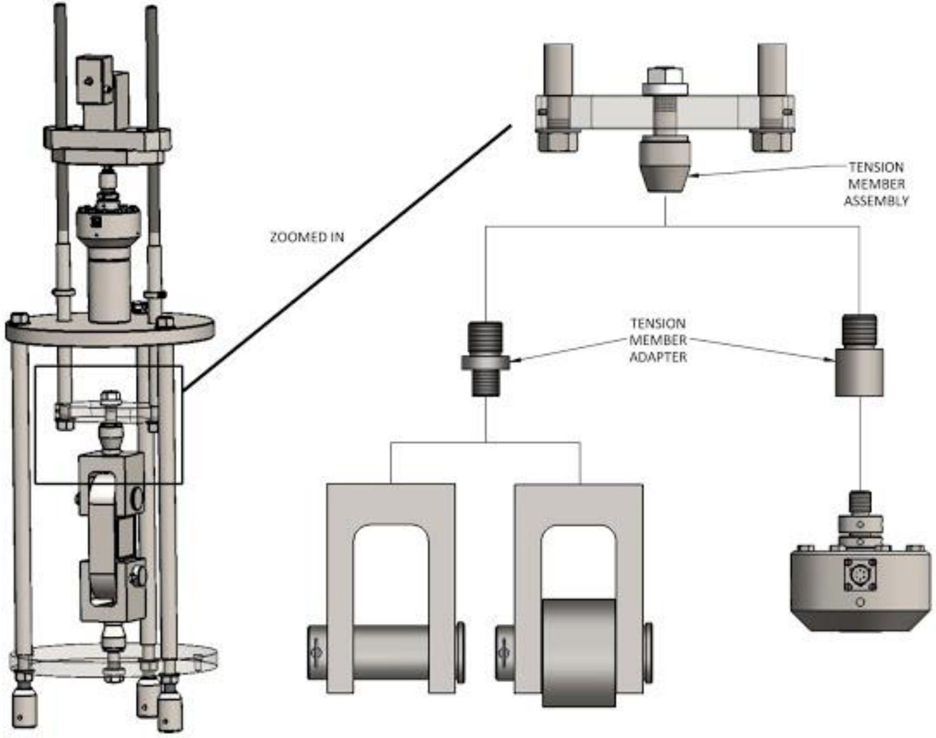
Discussion on tension link calibration

Tension Links Good measurement practice

- This following summary is from Dillon.
- Using correctly sized pins is critical.
- If links are damaged, highly used, or worn, decrease the time between recalibrations.
- The same size and style of shackle and pin used during operation should be used for calibration.
- Other factors have a larger effect on accuracy than pin rotation.
- Maintaining pin orientation may be best practice but is not required to stay in tolerance.

Morehouse Quick-Change Adapter System





Proper Adapters for Tension Links

☑ Precision machining lowers calibration errors

☑ Can be used with Morehouse Quick-Change Tension Adapter system

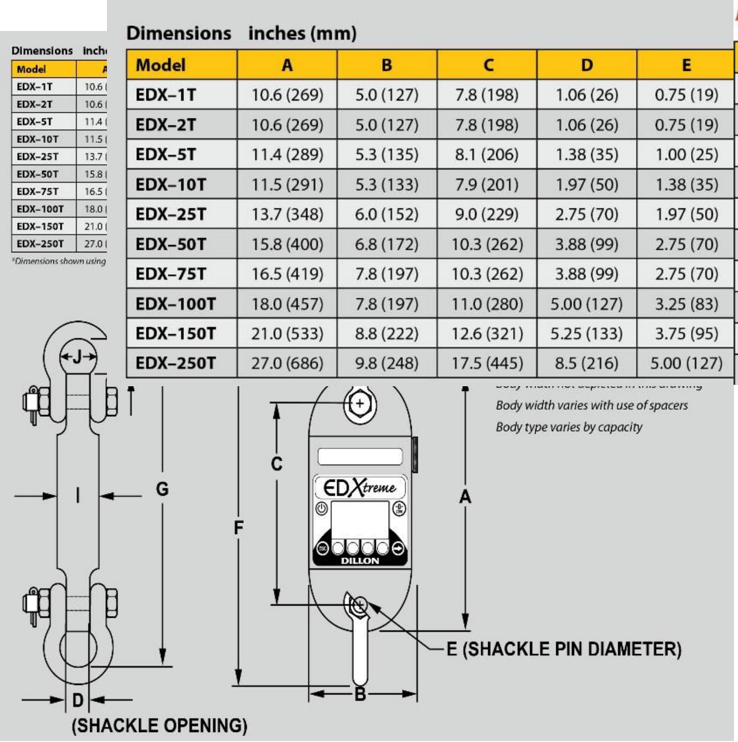
☑ Rust-resistant black oxide coating

☑ Adaptable to numerous instruments through various available shoulder pins

☑ Remarkable savings on calibration adapters cost

The Clevis assemblies are Patented (No. 11,078,052).

Proper Adapters for Tension Links



Dimensions inches (mm)

Model	A
EDX–1T	10.6
EDX–2T	10.6
EDX–5T	11.4
EDX–10T	11.5
EDX–25T	13.7
EDX–50T	15.8
EDX–75T	16.5
EDX–100T	18.0
EDX–150T	21.0
EDX–250T	27.0

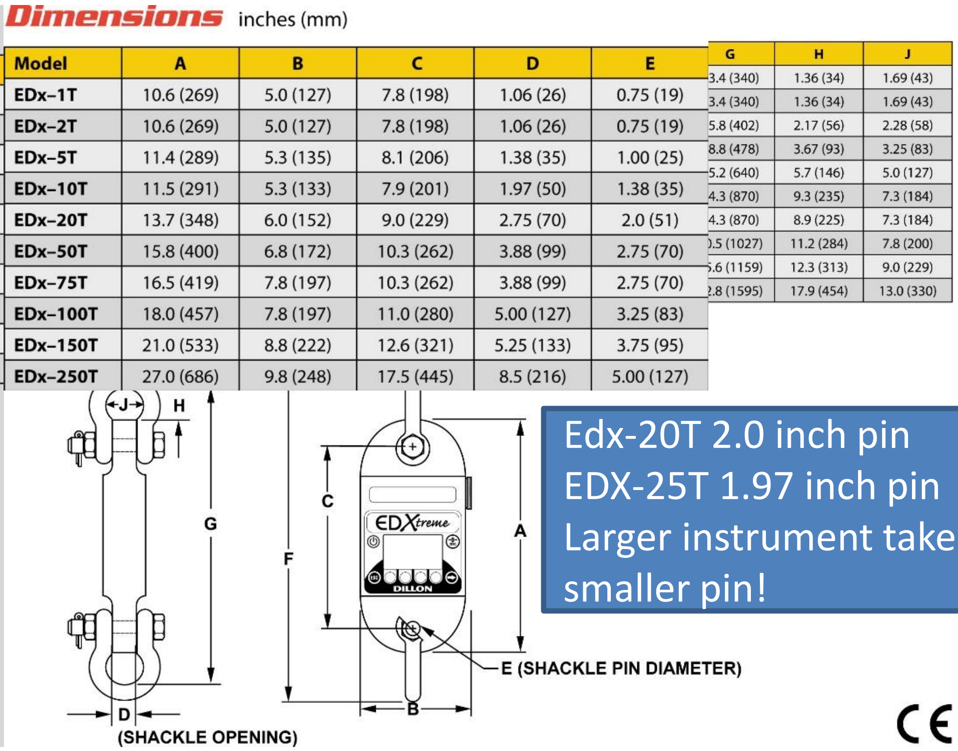
*Dimensions shown using

Dimensions inches (mm)

Model	A	B	C	D	E
EDX–1T	10.6 (269)	5.0 (127)	7.8 (198)	1.06 (26)	0.75 (19)
EDX–2T	10.6 (269)	5.0 (127)	7.8 (198)	1.06 (26)	0.75 (19)
EDX–5T	11.4 (289)	5.3 (135)	8.1 (206)	1.38 (35)	1.00 (25)
EDX–10T	11.5 (291)	5.3 (133)	7.9 (201)	1.97 (50)	1.38 (35)
EDX–25T	13.7 (348)	6.0 (152)	9.0 (229)	2.75 (70)	1.97 (50)
EDX–50T	15.8 (400)	6.8 (172)	10.3 (262)	3.88 (99)	2.75 (70)
EDX–75T	16.5 (419)	7.8 (197)	10.3 (262)	3.88 (99)	2.75 (70)
EDX–100T	18.0 (457)	7.8 (197)	11.0 (280)	5.00 (127)	3.25 (83)
EDX–150T	21.0 (533)	8.8 (222)	12.6 (321)	5.25 (133)	3.75 (95)
EDX–250T	27.0 (686)	9.8 (248)	17.5 (445)	8.5 (216)	5.00 (127)

Body width varies with use of spacers

Body type varies by capacity



Dimensions inches (mm)

Model	A	B	C	D	E
EDx–1T	10.6 (269)	5.0 (127)	7.8 (198)	1.06 (26)	0.75 (19)
EDx–2T	10.6 (269)	5.0 (127)	7.8 (198)	1.06 (26)	0.75 (19)
EDx–5T	11.4 (289)	5.3 (135)	8.1 (206)	1.38 (35)	1.00 (25)
EDx–10T	11.5 (291)	5.3 (133)	7.9 (201)	1.97 (50)	1.38 (35)
EDx–20T	13.7 (348)	6.0 (152)	9.0 (229)	2.75 (70)	2.0 (51)
EDx–50T	15.8 (400)	6.8 (172)	10.3 (262)	3.88 (99)	2.75 (70)
EDx–75T	16.5 (419)	7.8 (197)	10.3 (262)	3.88 (99)	2.75 (70)
EDx–100T	18.0 (457)	7.8 (197)	11.0 (280)	5.00 (127)	3.25 (83)
EDx–150T	21.0 (533)	8.8 (222)	12.6 (321)	5.25 (133)	3.75 (95)
EDx–250T	27.0 (686)	9.8 (248)	17.5 (445)	8.5 (216)	5.00 (127)

G	H	J
3.4 (340)	1.36 (34)	1.69 (43)
3.4 (340)	1.36 (34)	1.69 (43)
5.8 (402)	2.17 (56)	2.28 (58)
8.8 (478)	3.67 (93)	3.25 (83)
5.2 (640)	5.7 (146)	5.0 (127)
4.3 (870)	9.3 (235)	7.3 (184)
4.3 (870)	8.9 (225)	7.3 (184)
.5 (1027)	11.2 (284)	7.8 (200)
.6 (1159)	12.3 (313)	9.0 (229)
.8 (1595)	17.9 (454)	13.0 (330)

Edx-20T 2.0 inch pin
EDX-25T 1.97 inch pin
Larger instrument takes smaller pin!

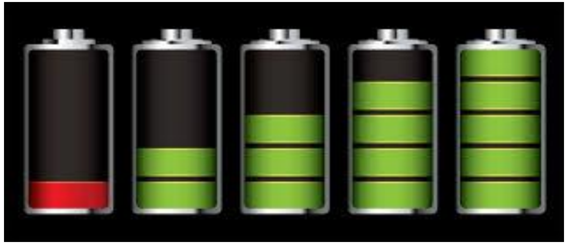
Link to Morehouse Clevis kits

Crane Scale

- Typically used for lift tests, towing tension, cable tension, crane scale, hoist scale, and tensile testing systems
- These devices tend be very forgiving in fixture selection for calibration. Accuracies are typically 0.1 % applied force ± 1 count (MSI specifically) or for some manufacturers, 1 % of full scale.

Batteries

Confidence in your test and measurement results starts with your calibration provider.



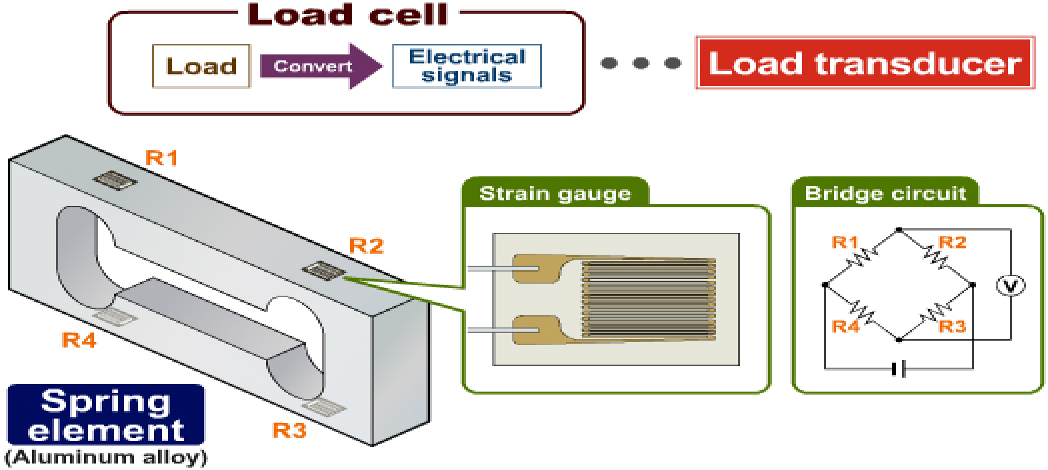
To produce more confidence in our measurements, Morehouse has adopted a new policy to calibrate instruments with a new set of fully charged batteries. These batteries are shipped back with your instruments, as well as any batteries provided. Most instruments will operate fine with a lesser charge; the word “most” is what concerns us. The Morehouse mission is to be regarded as the best independent force calibration resource in the world. In keeping with our mission, Morehouse provides a new set of batteries to ensure we can provide meaningful measurement results with the lowest uncertainties possible.

Batteries

Force Applied	"As Received" With Customer Supplied Batteries	Error lbf	"As Returned" With New Batteries	Error lbf	Difference Between Used Versus New
-	0	0	0	0	
25,000	24900	-100	25000	0	100
50,000	49900	-100	50100	100	200
75,000	74800	-200	75100	100	300
100,000	99700	-300	100200	200	500
125,000	124700	-300	125200	200	500
150,000	149600	-400	150200	200	600
175,000	174600	-400	175200	200	600
200,000	199600	-400	200200	200	600
225,000	224500	-500	225200	200	700
250,000	249500	-500	250200	200	700
-	0	0	0	0	

Difference of 700 lbf @ Capacity 0.28 % on a Device with an Accuracy Specification of 0.1 % of Full Scale ± 250 lbf.

Load Cells



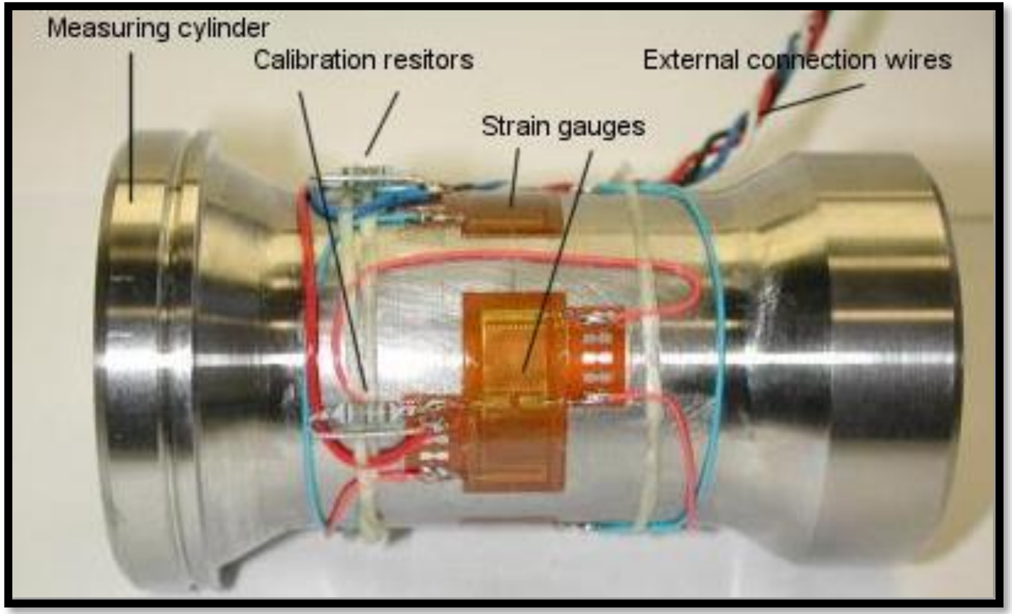
A load cell is a force sensor that receives a voltage (excitation) from a regulated power source (usually a digital indicator or signal conditioner) and sends back a low voltage signal (signal) when force is applied.

Load Cells

The load cell signal is converted to a visual or numeric value by a “digital indicator.” When there is no load on the cell, the two signal lines are at equal voltage. As a load is applied to the cell, the voltage on one signal line increases very slightly, and the voltage on the other signal line decreases very slightly. The difference in voltage between the two signals is read by the indicator.

Load Cells

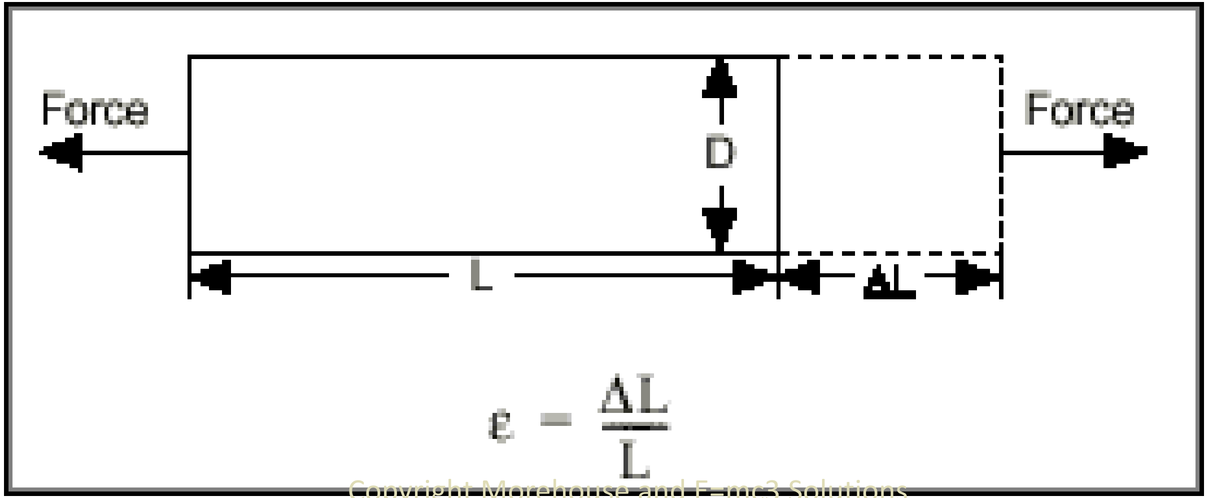
Multiple strain gauges are often used to measure difference in voltage between the two signals. The strain gauge is the heart of the load cell.



Strain

Most Force or Torque Transducers use strain gauges.

Strain – is the amount of deformation of a body due to applied force. More specifically, strain is defined as the fractional change in length.



$$\varepsilon = \frac{\Delta L}{L}$$

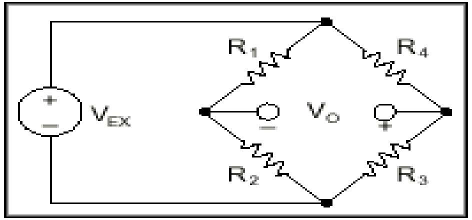
Strain Gauge

Strain Gauge – A device whose electrical resistance varies in proportion to the amount of strain in the device.

To measure small changes in resistance, strain gauges are almost always used in a bridge configuration with a voltage excitation source.

Strain Gauge

Most load cells or force transducers use a series of four resistive arms with an excitation voltage Vex that is applied across the bridge.



Some manufacturers will also dummy gauges to eliminate temperature effects. It is important to look at the manufacturer’s temperature specifications to determine if the load cell is temperature compensated.

Temperature-dependent influences on strain gauge measurements

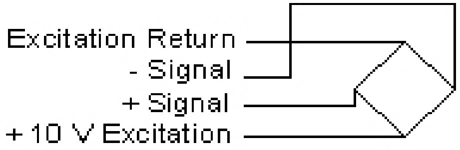
- Material strain (apparent strain)
- Cable resistance
- Temperature coefficient and gauge factor
- Temperature dependence of modulus elasticity (ratio of measured strain to mechanical stress)
- Self-heating of the strain gauge (excitation voltage)
- Creep of the adhesive (exceeding temperature limits can cause softening of adhesives to a point where they can no longer transfer the strain)

Cable Length Error

- Load cells used with meters that have a 4-wire configuration are subject to additional error. This is because of voltage drop over cable lengths, and the effect on thermal span characteristics of the load cell, as temperature changes can alter cable resistance.

Cable Length Error

- Substitution of a 4-wire cable at a given length with another 4-wire cable of a different length or gauge will produce additional errors. (Calibration will be required)



What you need to know about 4 wire systems.

1. *If you damage or replace your cable, the system may need to be calibrated immediately following replacement or repair.*
2. *Operating at different temperatures will change the resistance, which will cause a voltage drop, resulting in a change of measured output.*
3. *Cable substitution will result in additional error and should be avoided.*
4. *Cables used for 4-wire systems should have a S/N, or a way to make sure the same cable stays with the system, it was calibrated with. - This would be a Good Measurement Practice Technique Morehouse highly recommends.*

Cable Length Error

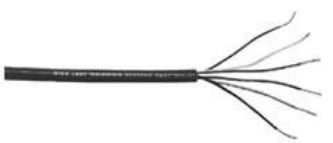
- If the cable in an existing 4-wire system is changed, there will be a loss of sensitivity of approximately 0.37 % per 10 feet of 28-gauge cable and 0.09 % per 10 feet of 22-gauge cable.

- Most of this error can be eliminated if a 6-wire cable is run to the end of the load cell cable or connector and used in conjunction with an indicator that has sense lead capability.

Temperature Effects on Cables

- Since cable resistance is a function of temperature, the cable response to temperature change affects the thermal span characteristics of the load cell/cable system.
- For non-standard 4-wire cable lengths, there will be an effect on thermal span performance.

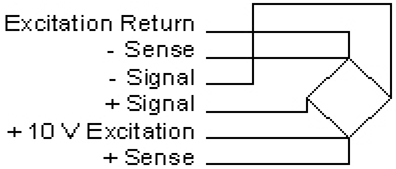
Cable Length Error



- If using a 6-wire meter and wired properly, this error becomes minimalized.
- With a 6-wire setup, the sense lines are separate from the excitation lines, thereby eliminating effects due to variations in lead resistance.
- This allows long cable runs in outdoor environments with extreme temperatures.

Cable Length Error

- Wiring a 6-wire cable for sense is as easy as running two lines from the load cell's positive excitation pin and two wires from the load cell's negative excitation pin; the remaining 2 wires are run to positive and negative sense.



Cable Length Conclusion

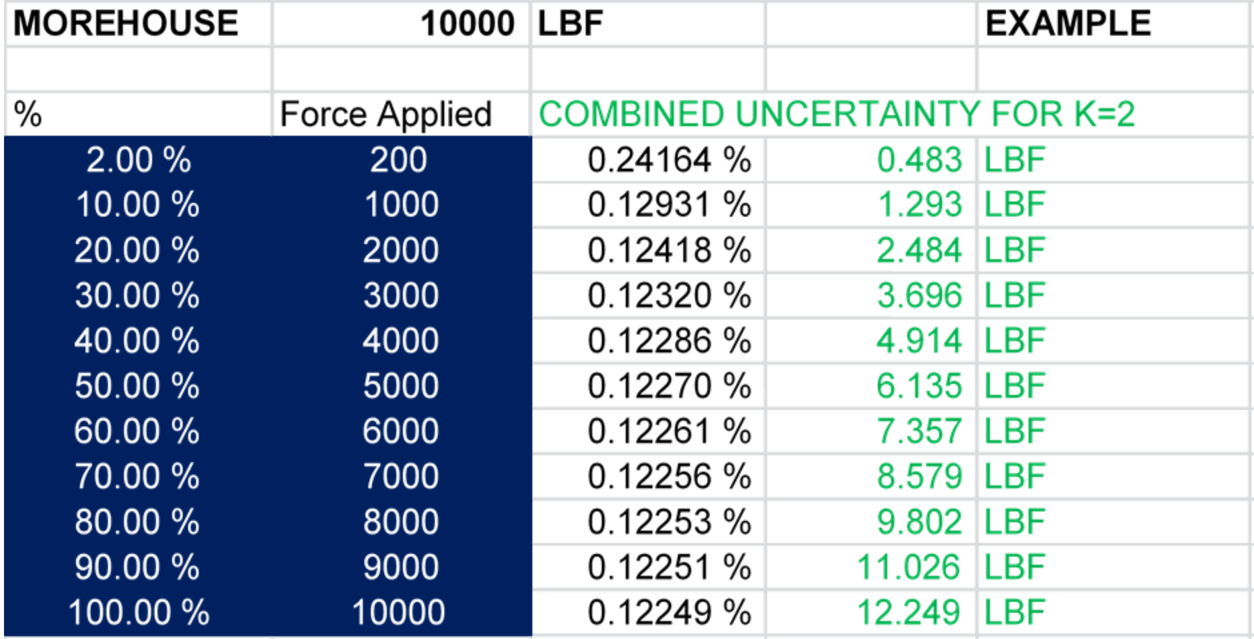
From the results, it should become clear that a 4-wire cable cannot be interchanged without requiring the system to be recalibrated.

A 6-wire cable will yield similar readings, regardless of length and gauge.

The worst-case scenario in this test was – 1.97642 VS 1.97852 so interchanging between cables in this example would produce an error of 0.106 %

Cable Length Conclusion

On the left 0.106 % error added to the combined uncertainty vs Standard analysis on the same cell with 6 wire cable



MOREHOUSE	10000	LBF		EXAMPLE
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00 %	200	0.24164 %	0.483	LBF
10.00 %	1000	0.12931 %	1.293	LBF
20.00 %	2000	0.12418 %	2.484	LBF
30.00 %	3000	0.12320 %	3.696	LBF
40.00 %	4000	0.12286 %	4.914	LBF
50.00 %	5000	0.12270 %	6.135	LBF
60.00 %	6000	0.12261 %	7.357	LBF
70.00 %	7000	0.12256 %	8.579	LBF
80.00 %	8000	0.12253 %	9.802	LBF
90.00 %	9000	0.12251 %	11.026	LBF
100.00 %	10000	0.12249 %	12.249	LBF

6 Wire Cable CMC

0.417	LBF
0.417	LBF
0.419	LBF
0.421	LBF
0.424	LBF
0.428	LBF
0.434	LBF
0.440	LBF
0.446	LBF
0.454	LBF
0.462	LBF

Temperature Change on Metals

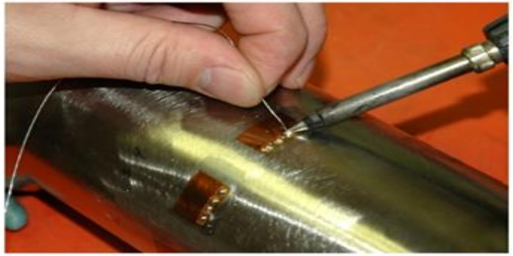
Temperature increases result in

- Thermal expansion with increasing dimensions and volumes
- Increasing specific heat, thermal expansion coefficient, thermal conductivity, and electrical resistivity
- Decreasing hardness, stiffness (elastic modulus), all strength properties

These changes may be reversible or irreversible, depending on material, range duration of temperature excursion, previous mechanical and thermal history.

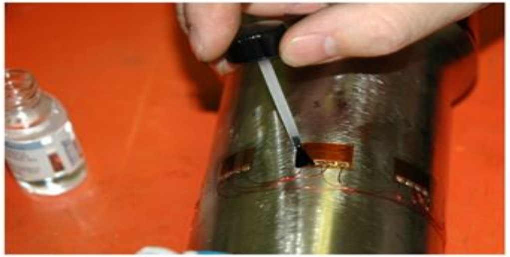
Load Cell Gauging Process (Single Column Cell)

Machining of Viscount 44 bar stock.



Tinning of strain-gage solder tabs.

Wired Wheatstone bridge of load cell.



Removing excess soldering flux.

Ground wire added.

Preparation for testing

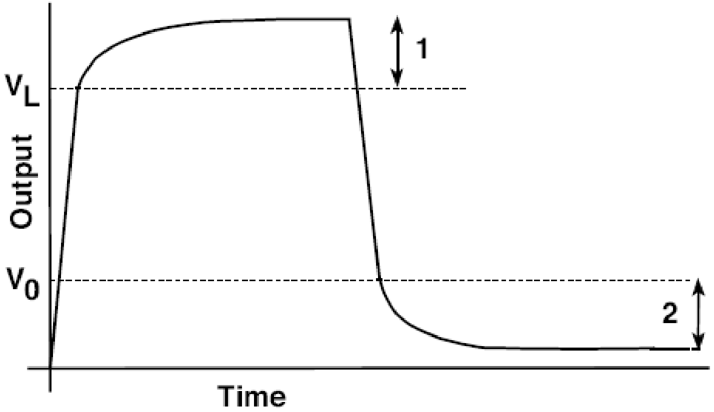
Load Cell Terms

- Creep
- Nonlinearity
- Hysteresis

Load Cell Terms

Creep

- The change in Load Cell Signal occurring with time while under load and with all environmental conditions remaining constant.

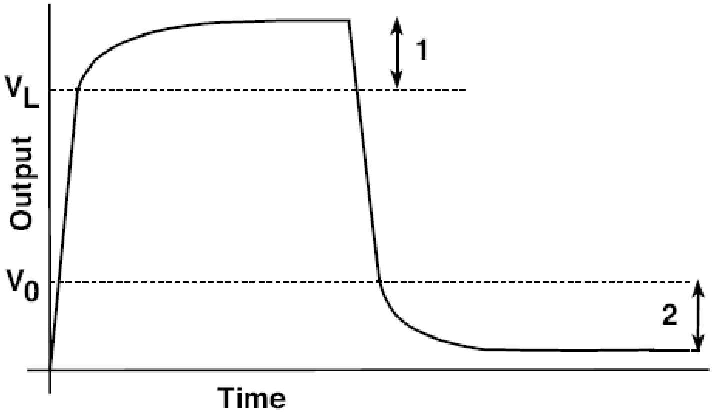


Load Cell Terms

Creep Recovery

2. The change in LOAD CELL SIGNAL occurring with time immediately after removal of a load which had been applied for a specified time interval, environmental conditions and other variables remaining constant during the loaded and unloaded intervals.

Normally expressed in units of % of applied load over a specified time interval. Normally the applied interval and the recovery interval are equal.



Notes on Creep

Unfortunately, the commercial loadcell world mostly ignores formal definitions and calls most time dependent stuff just creep.

- Under load the sensor is creeping in the sense that it will physically elongate. It is just a very small distance. (Loadcells have the opposite problem to deal with also, time dependent change in shape after removing load)

- Likewise, there is relevant stress relaxation going on at the strain gage.

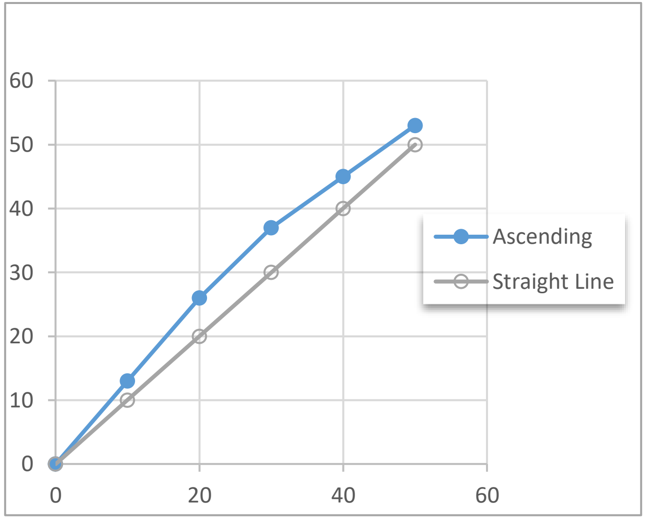
- Care is taken to balance these mechanisms, so they come close to cancelling under certain conditions.

- Thinking about the metal creeping and the strain gaging relaxing is a good enough model to design a decent loadcell. However, the actual situation is much more complicated as both these things are going on at the same time in real world parts.

Load Cell Terms

Nonlinearity

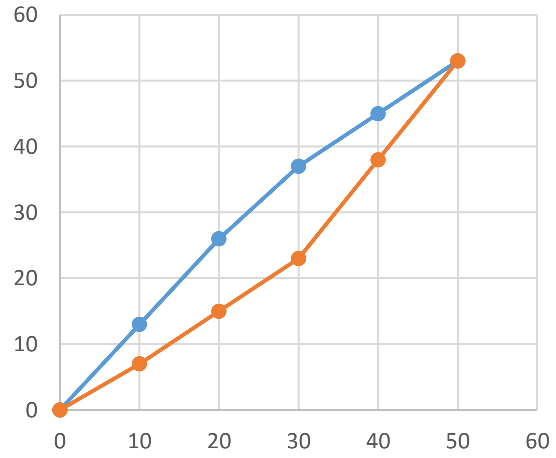
- The algebraic difference between OUTPUT at a specific load and the corresponding point on the straight line drawn between MINIMUM LOAD and MAXIMUM LOAD.
- Normally expressed in units of %FS. It is common for characterization to be measured at 40-60 %FS.



Load Cell Terms

HYSTERESIS

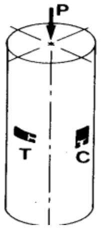
- The algebraic difference between OUTPUT at a given load descending from MAXIMUM LOAD and OUTPUT at the same load ascending from MINIMUM LOAD.
- Normally expressed in units of %FS. It is common for characterization to be measured at 40-60% FS.

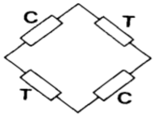


Types of Load Cells

- Column Load Cell (Single-Column or High- Stress Load Cells)
- Multi-Column Load Cell
- S-Beam or S-Type
- Button or Pancake
- Shear Web

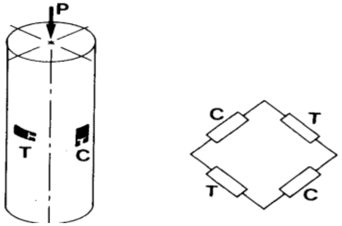
Column Load Cell





- The spring element is intended for axial loading, and typically has a minimum of four strain gauges, two in the longitudinal direction, and two oriented transversally to sense the Poisson strain.

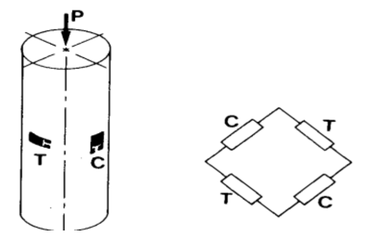
Column Load Cell



Advantages

- physical size and weight - It is not uncommon to have a 1,000,000 LBF column cell weigh less than 100 lbs.

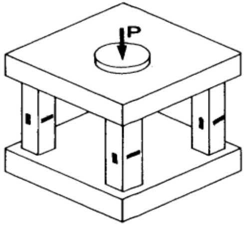
Column Load Cell



Disadvantages

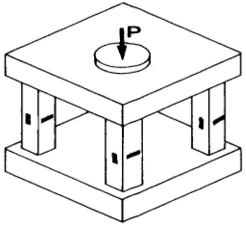
- reputation for inherent non-linearity. This deviation from linear behavior is commonly ascribed to the change in the cross-sectional area of the column (due to Poisson’s ratio), which occurs with deformation under load.
- Sensitivity to off center loading can be high
- larger creep characteristic than other cells and often do not return to zero as well as other cells. (ASTM Method A typically yields larger LLF)

Multi - Column Load Cell



- In this type of design, the load is carried by four or more small columns, each with its own complement of strain gauges. The corresponding gauges from all of the columns are connected in a series in the appropriate bridge arms.

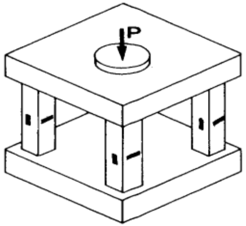
Multi - Column Load Cell



Advantages

- Multi-Column load cells can be more compact than high-stress column cells
- Improved discrimination against the effects of off-axis load components.

Multi - Column Load Cell



Advantages Continued

- These cells typically have less creep and have better zero returns than single-column cells.
- In many cases, a properly designed shear-web spring element can offer greater output, better linearity, lower hysteresis, and faster response.

Multi - Column Load Cell

Non ground base originally installed in load cell

What do you think happens if a non flat base is used?

Multi - Column Load Cell

- Error associated with installing a non flat base on a multi-column cell. This is an actual test result we observed on a Revere multi-column cell.

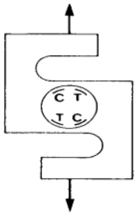
Force Applied	Non-Flat Base Maximum Error In Rotation LBF	Flat Base Maximum Error In Rotation LBF
30000	12	4
150000	136	24
300000	342	68
	% error	% error
30000	0.040%	0.013%
150000	0.091%	0.016%
300000	0.114%	0.023%

Bottom Plates

- A flat bottom plate may be needed to improve performance. It is often not recommended the practice to load against the machine surface as it could be uneven, or the base of the load cell could deform the machine surface.

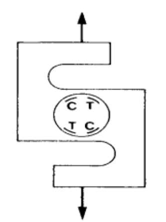
- Pictured left is a Morehouse 60K rod end style load cell with spherical threaded adapter, top compression pad and load cell base plate.

S-beam Load Cell



- This type of design is often used in weighing applications. There are four gauges placed inside the beam.

S-beam Load Cell

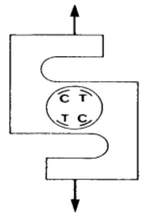


Advantages

- In general, linearity will be enhanced by minimizing the ratio of deflection (at rated load) to the length of the sensing beam, thus minimizing the change in shape of the element.

- Ideal for measuring small forces (under 10 LBF) when physical weights cannot be used.

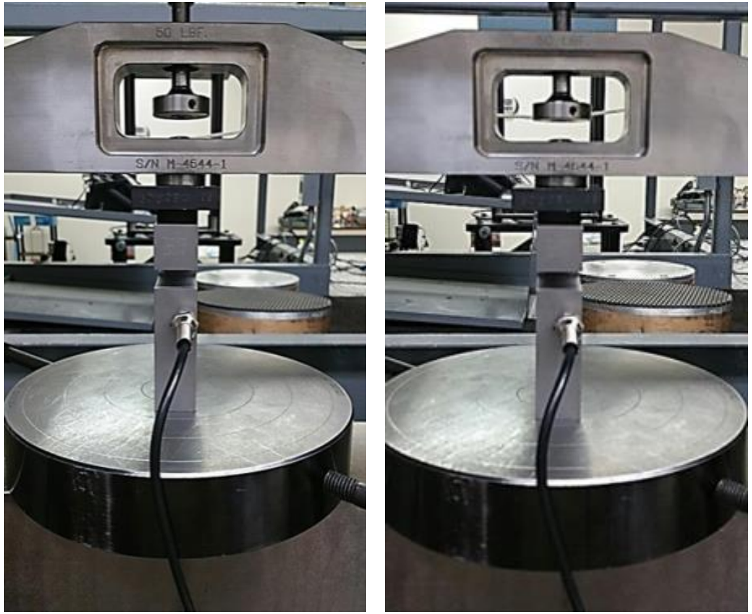
S-beam Load Cell



Disadvantages

- These cells are very sensitive to off-axis loading -ideally suited for scales or tension applications.
- Compression output will be different if the cell is loaded through the threads versus flat against each base

S-beam



Does anything look different when comparing these two pictures?

Misalignment on S-beam

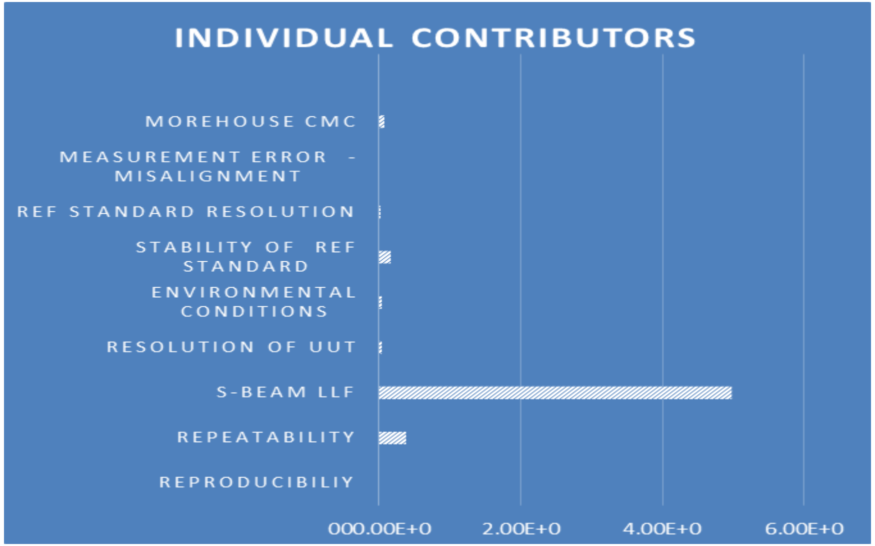
Misalignment Demonstrating 0.752 % error

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

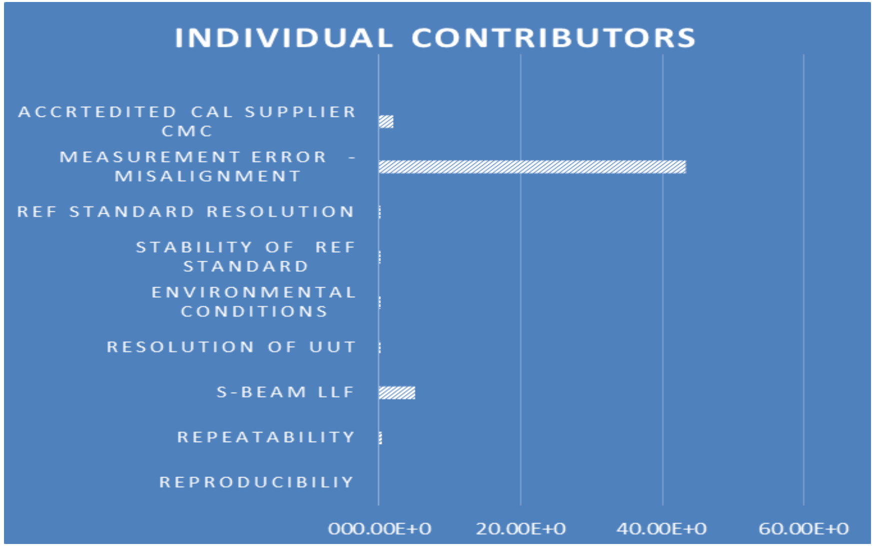
Output in mV/V
Slightly misaligned in machine
-1.98211 mV/V

Misalignment on 10,000 LBF S-beam

Misalignment Demonstrating 0.752 % Error

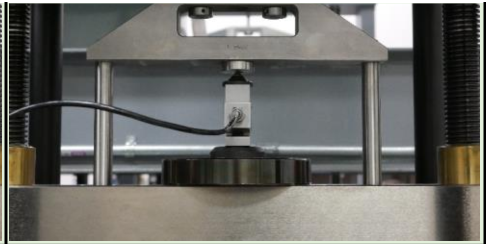


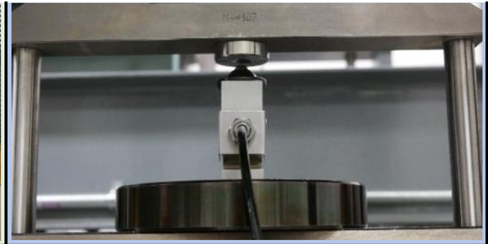
Output in mV/V
Aligned in machine
-1.96732 mV/V
Expanded Uncertainty 9.95 LBF



Output in mV/V
Slightly misaligned in machine
-1.98211 mV/V
Expanded Uncertainty 85.0 LBF

S-Beam Loading Errors

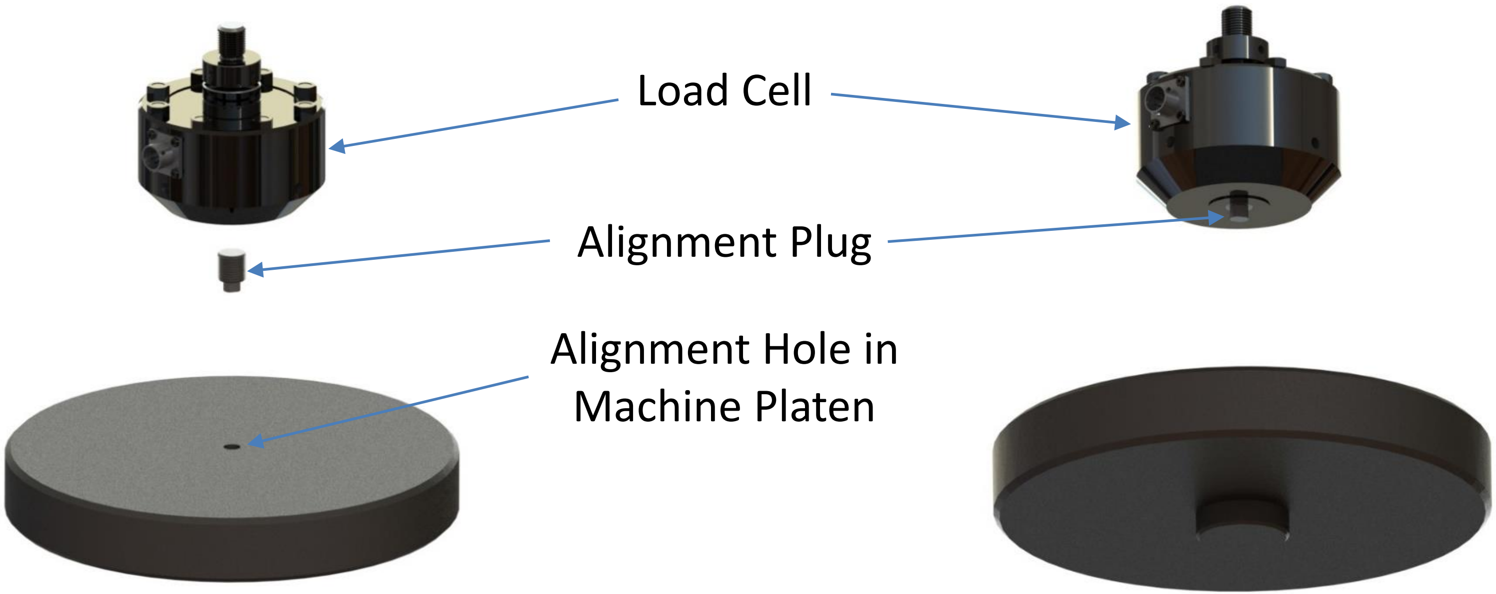




Instrument Reading Thread Loading Loose Both Ends Output in mV/V	Instrument Reading Thread Loading Tight Both Ends Output in mV/V	Instrument Reading Thread Loaded on Top / Flat Base Output in mV/V	Instrument Reading Flat on Flat Output in mV/V
1.50136	1.50241	1.50182	1.50721
3.00381	3.00581	3.00459	3.01326

Maximum Difference mV/V	Maximum Difference lbf	Maximum % Difference	Smallest % Diffference
0.00585	4.618066191	0.369%	0.029%
0.00945	7.459953077	0.298%	0.025%

Alignment Plugs Help Reduce Error



Load Cell

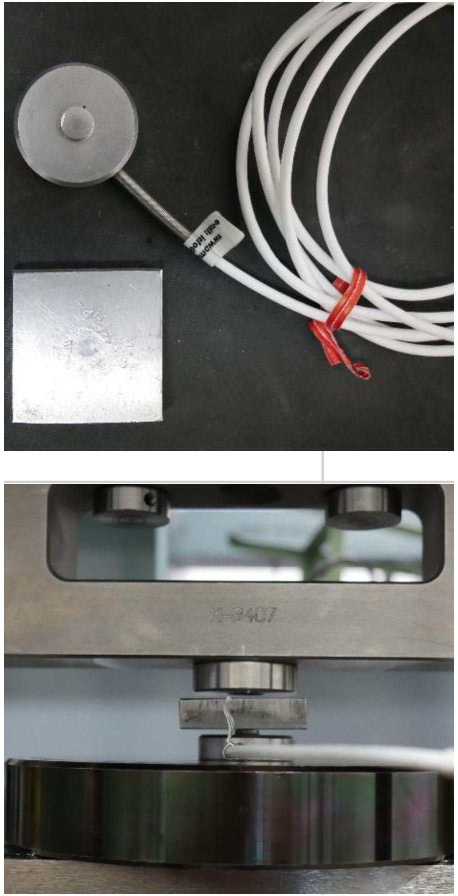
Alignment Plug

Alignment Hole in Machine Platen

Button Load Cell

- This type of design is often used in weighing applications or when there is minimum room to perform a test. The load cells on the left exhibit high errors from any misalignment. A 0.1 % misalignment can produce a large cosine error. The cells on the right are generally a much better alternative though they are also a more expensive option. Some of these cells typically have errors anywhere from 1 % to 10 % of rated output. The cells on the right are the exception as they can be as good as 0.05 % or better.

Button Load Cell Calibration



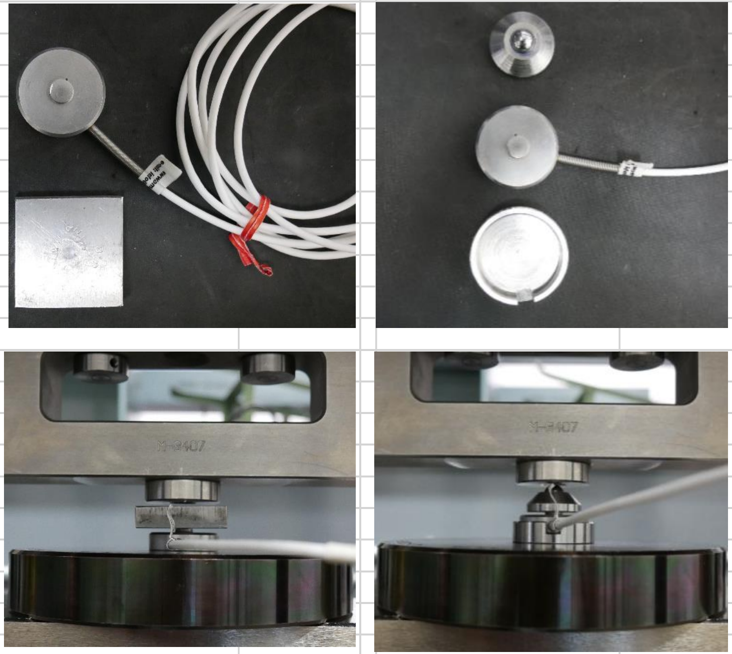
Does this setup look familiar?

Manually Aligned	Data
0 degree	2011
120 degree	1997
240 degree	2018
Average	2008.66667
Standard Deviation	10.6926766
Max Deviation	21
% Error	1.045%

Button Load Cell Calibration

Morehouse Button Load Cell Adapters improved the measurement result by 525 %

Standard Setup versus Morehouse Adapters in Morehouse Deadweight



Manually Aligned	Data
0 degree	2011
120 degree	1997
240 degree	2018
Average	2008.66667
Standard Deviation	10.6926766
Max Deviation	21
% Error	1.045%

Aligned with Adapter	Data
0 degree	2008
120 degree	2006
240 degree	2010
Average	2008
Standard Deviation	2
Max Deviation	4
% Error	0.199%

Button and Washer Load Cell

- Above are pictures of button load cell adapters

Shear Web Load Cell

- This type of load cell is typically the most accurate when installed on a tapered base with an integral threaded rod installed. These cells typically have very low creep and are not as sensitive to off-axis loading as the other cells discussed. These cells would be the recommended choice for force applications from 100 LBF through 100,000 LBF. After 100,000 LBF, the weight of the cell makes it very difficult to use as a field standard. A 100,000 LBF Shear Web cell weighs approximately 57 lbs. and a 200,000 LBF shear web cell weighs over 140 lbs.

Shear Web Load Cell

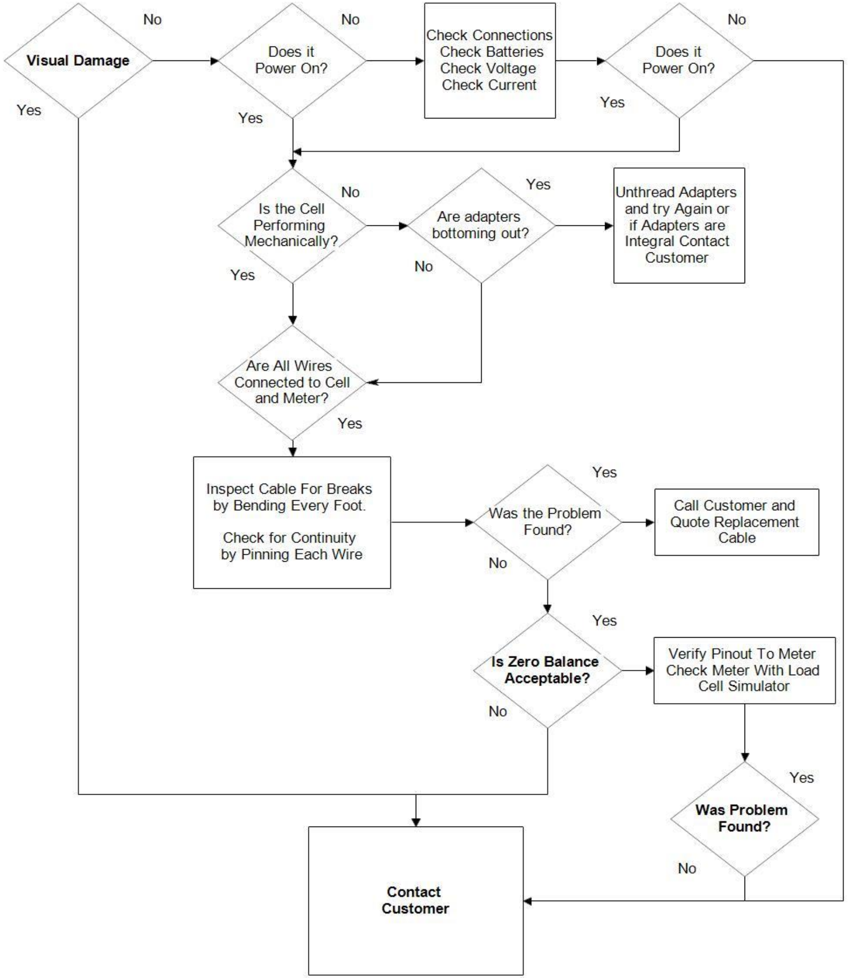
- If these cells are used without a base or without an integral top adapter, there may be significant errors associated with various loading conditions.

Morehouse 7 Step process for troubleshooting a load cell

Load Cell Common Troubleshooting Tips

- 1. Visual inspection for noticeable damage
- 2. Power the system up and make sure all connections are made and verify that batteries have enough voltage and are installed
- 3. If everything is appearing to be working, but the output does not make sense, check for mechanical issues. Some load cells have internal stops that may cause the output to plateau. Make sure any adapters threaded into the transducer are not bottoming out.
- 4. Check and make sure the leads (all wires) are properly connected to the load cell and meter.
- Inspect the cable for breaks - With everything hooked up proceed to test the cable making a physical bend every foot
- 5. Check for continuity of the cable (pin each individual connection) – If the cable is common to the system, check another load cell and verify the other cell is working properly.
- 6. Use a load cell tester or another meter to check the zero resistance of the load cell – If you do not have a load cell tester you can check the bridge resistance with a common multi-meter
- 7. Check voltage and current on the power supply

Morehouse Load Cell Troubleshooting Guide



Visual Damage

No

Yes

Does it Power On?

No

Yes

Check Connections
Check Batteries
Check Voltage
Check Current

Does it Power On?

No

Yes

Is the Cell Performing Mechanically?

No

Yes

Are adapters bottoming out?

Yes

No

Unthread Adapters and try Again or if Adapters are Integral Contact Customer

Are All Wires Connected to Cell and Meter?

Yes

Inspect Cable For Breaks by Bending Every Foot.

Check for Continuity by Pinning Each Wire

Was the Problem Found?

Yes

No

Call Customer and Quote Replacement Cable

Is Zero Balance Acceptable?

Yes

No

Verify Pinout To Meter
Check Meter With Load Cell Simulator

Was Problem Found?

Yes

No

Contact Customer

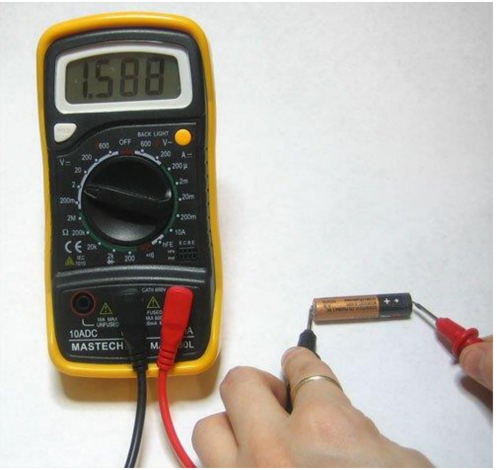
Morehouse 7 Step process for troubleshooting a load cell

Step # 1 Visual inspection for noticeable damage

Any idea what load cell is damaged?

Morehouse 7 Step process for troubleshooting a load cell

Step # 2 Power the system up and make sure all connections are made and verify that batteries have enough voltage and are installed



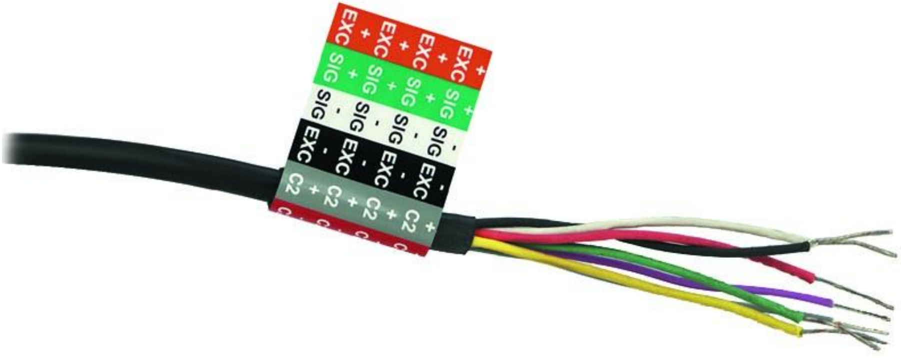
Morehouse 7 Step process for troubleshooting a load cell

Step # 3. If everything is appearing to be working, but the output does not make sense, check for mechanical issues. Some load cells have internal stops that may cause the output to plateau. Make sure any adapters threaded into the transducer are not bottoming out.

This Threaded Adapter should never be removed as it voids the calibration. However, we have noticed several people doing this and if they bottom the thread out into the load cell, it could cause the output to plateau. If the threaded adapter has been removed, the cell will need to be calibrated again.

Morehouse 7 Step process for troubleshooting a load cell

Step 4. Check and make sure the leads (all wires) are properly connected to the load cell and meter. If the load cell is new and you wired a cable. Verify everything is wired properly.

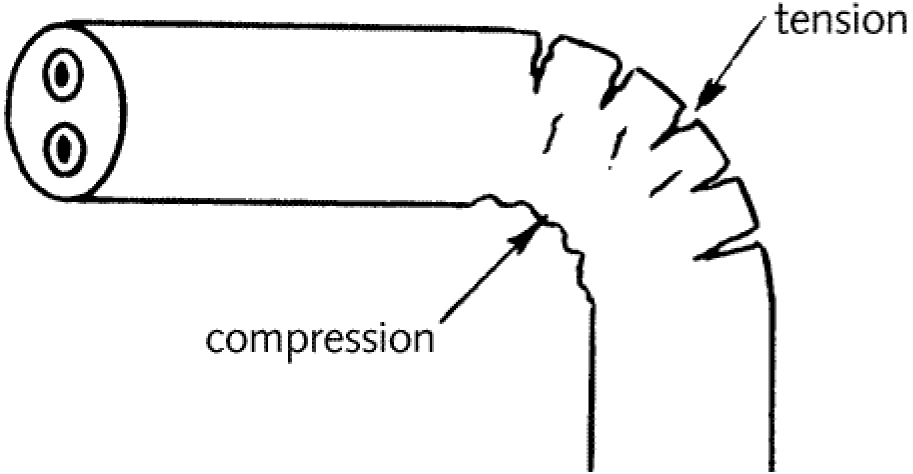


Morehouse 7 Step process for troubleshooting a load cell

Step 5. Check for continuity of the cable (pin each individual connection) – If the cable is common to the system, check another load cell and verify the other cell is working properly.

Morehouse 7 Step process for troubleshooting a load cell

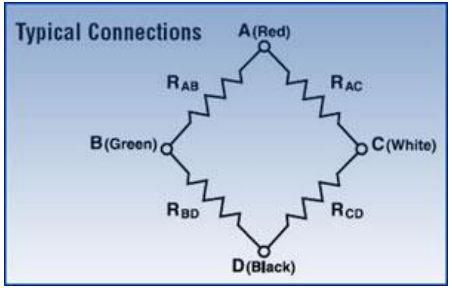
Step 5. Check for continuity of the cable (pin each individual connection) – If the cable is common to the system, check another load cell and verify the other cell is working properly.



If the problem is intermittent, have someone else bend the cable every foot while performing the continuity check. The bending should help find intermittent problems

Morehouse 7 Step process for troubleshooting a load cell

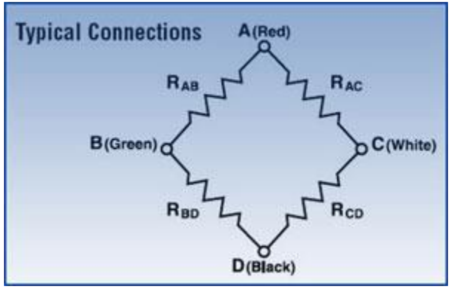
Step 6. Use a load cell tester or another meter to check the zero resistance of the load cell – If you do not have a load cell tester you can check the bridge resistance with a common multi-meter.




SIGNAL OUTPUT
≅ 32.84%

Typically, if the signal output is over 5 %, the load cell has either been overloaded or there is corrosion somewhere in the cable or cell.

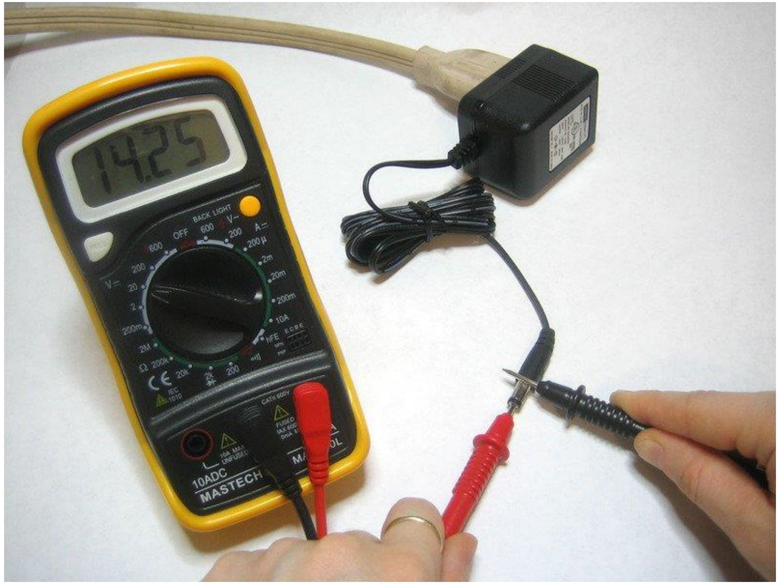
Load Cells – Check Bridge Resistance against manufacturer’s spec sheet



- Bridge Input Resistance - Pins A and D should be 350 Ohm ± 3.5 Ohm (350 Ohm is most common)
- Bridge Output Resistance - Pins B and C should be 350 Ohm ± 3.5 Ohm
- You may also check RAB, RAC, RCD, RBD for symmetry
- If everything is pinned correctly and a reading cannot be obtained, there is a good probability that a wire may have come loose, or the gauges may have become un bonded from the metal

Morehouse 7 Step process for troubleshooting a load cell

Step 7. Check voltage and current on the power supply



Load Cells – What Happens to a Load Cell When it is Overloaded

Load Cells - Overloaded

- Typically, most cells are manufactured to withstand a rated safe overload. This can usually be found on the manufacturer's spec sheet. (Note: The mechanical safe overload is typically 150% of rated output.)

- This does not mean that the internal components will not be altered if the load cell is loaded past a certain point.

Load Cells - Overloaded

SIGNAL OUTPUT
32.84%

- A good diagnostic tool in checking the cell is to check and monitor the load cell's zero balance to ensure it is within manufacturer's tolerance. If the zero balance is not within the manufacturer's tolerance or has changed significantly from what it has been previously, there is a chance that the load cell may have been overloaded.

Load Cells – Overloaded?

What happens to a load cell when it has been overloaded?

- Residual stresses and strains are introduced into the structure.
- The past mechanical history of the flexure, gauge alloy, backing and adhesive is altered.
- The load cell symmetry is affected as well as the compression and/or tension output from what it was prior to the overload.
- Strain Gauge characteristics are modified, such as Resistance and Gauge factor, which will modify the temperature coefficients.

Load Cells – Overloaded?

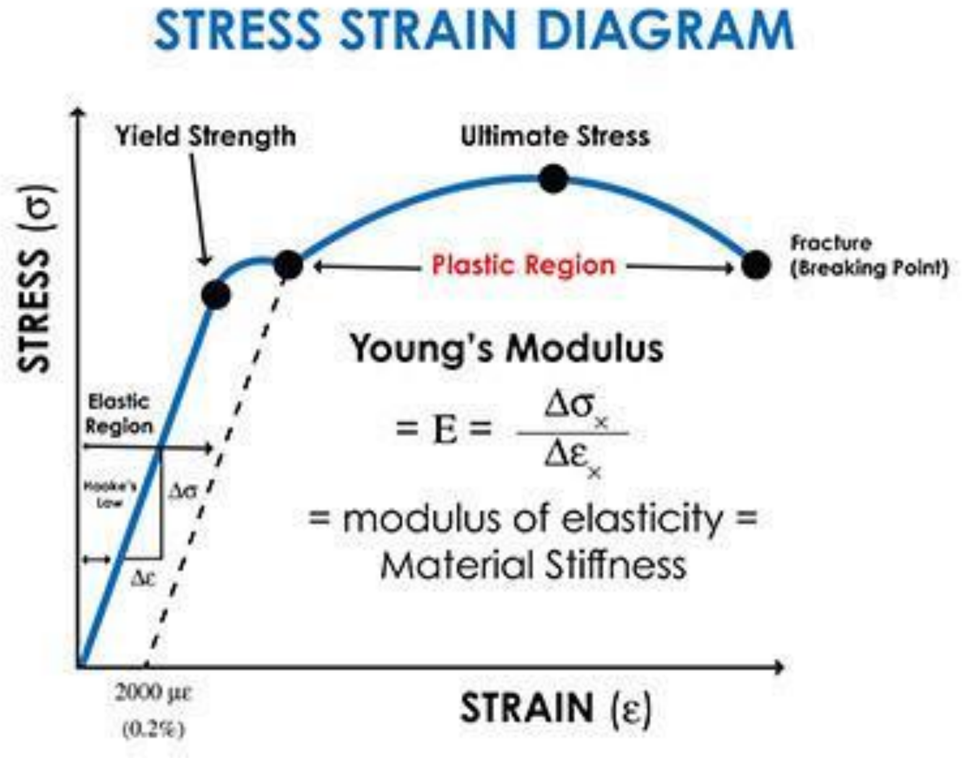
- If the load cell has been overloaded, mechanical damage has been done that is not repairable. Overloading causes permanent deformation within the flexural element and gauges, which destroys the carefully balanced processing.

- While it is possible to electrically re-zero a load cell following overload, it is not recommended because this does nothing to restore the affected performance parameters or the degradation to structural integrity.

Load Cells – Overloaded?

- All material has what is called an elastic limit. *The elastic limit is the point on the stress-strain diagram where the relationship between stress and strain is no longer linear.* If a material has a load applied to it that causes the stress in the material to exceed the elastic limit, the material will no longer return to its original size after the load is removed.

Load Cells – Overloaded?



What causes material deformation?

Material with a lower yield strength than what is being applied will deform until the maximum compressive stress is below the material yield point.

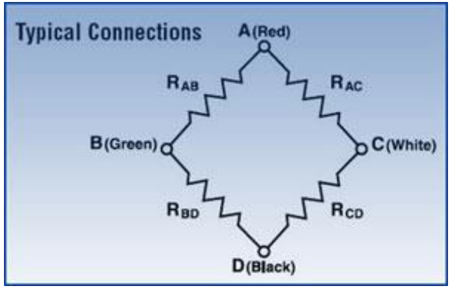
Deformation until Compressive Stress < yield stress.

A steep radius concentrates the force over a smaller area and may cause material to permanently deform. Therefore, we recommend having a compression top block mated to any load cell.

Load Cells – Overloaded?

- **Demonstration** of some diagnostics checks
- Check Bridge Resistance against manufacturer's spec sheet
- Check Resistance to ground – We will use a load cell tester unit to perform this test. (Note: This will test for a short in the cable or cell.) If this test fails, the cell may be okay, as the problem may be in the cable.
- Check Zero Balance
- If everything checks out, then check the cell against a working or test standard that you have confidence in. If it does not check out, then either replace the load cell or repair and/or recalibrate it.

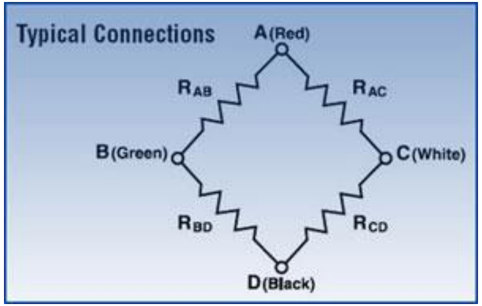
Load Cells – Check Bridge Resistance against manufacturer's spec sheet



- Bridge Input Resistance - Pins A and D should be 350 Ohm ± 3.5 Ohm (350 Ohm is most common)
- Bridge Output Resistance - Pins B and C should be 350 Ohm ± 3.5 Ohm
- You may also check RAB, RAC, RCD, RBD for symmetry
- If everything is pinned correctly and a reading cannot be obtained, there is a good probability that a wire may have come loose, or the gauges may have become un bonded from the metal.

- This test can be performed with an inexpensive handheld meter.

Load Cells – Check Bride Resistance against manufacturer's spec sheet



- Bridge Input Resistance –
- Pins A and D Reading ______________
- Pins A and D Reading ______________

- Bridge Output Resistance –
- Pins B and C Reading________________
- Pins B and C Reading________________

Check Resistance to Ground

- **Insulation resistance, shield to conductors:** Connect all the conductors together, and measure the resistance between all those wires and the shield in the cable.
- **Insulation resistance, load cell flexure to conductors:** Connect all the conductors together and measure the resistance between all those wires and the metal body of the load cell.

Check Resistance to Ground

- The tests described can be performed using a standard ohm meter, although best results are obtained with a megohmmeter. If resistance is beyond the standard ohmmeter range, about 10 Megohms, the cell is probably okay. However, some kinds of electrical shorts show up only when using a megohmmeter or with voltages higher than most ohmmeters can supply.
- This test would typically require a megohmmeter.

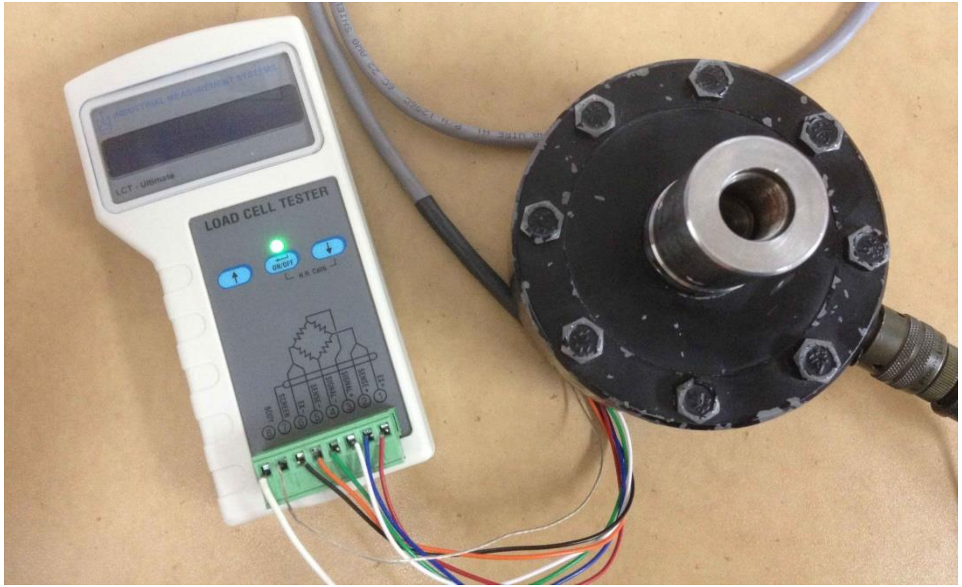
Check Zero Balance

- Check Zero Balance against manufacturer’s spec sheet. To do this, the load cell must be hooked up to a multi meter or device that can send voltage through the excitation pins of the load cell and read the signal.

- This test would typically involve the use of a good multi meter.

USING A LOAD CELL TESTER

- A load cell tester can be used to properly troubleshoot load cells. Video can be found here http://www.youtube.com/watch?v=zQNUpe2Bh5Y&feature=youtu.be



USING A LOAD CELL TESTER

- Hold the power button for 3 seconds.
- When the unit boots up, it will need to be calibrated if you want to take Shield to Bridge, Body to Bridge or Shield to Body measurements.
- To calibrate it, press the on/off button with the down arrow.

A LOAD CELL TESTER

- Can be used to check
- Input and Output Resistance
- Resistance difference between sense and excitation leads
- Signal Output
- Shield to Bridge
- Body to Bridge
- Shield to Body

- And some models will also display linearity

USING A LOAD CELL TESTER

- Input or Output Resistance

- If the resistance is not in range, there may be a cable or connector problem. There may be internal damage to the bridge of the load cell.

- Check the manufacturer's specifications to know what the resistance should be. The tester should show a value within plus or minus 5 to 10 ohm of what the manufacturer states.

USING A LOAD CELL TESTER

- Sense is Too High
- - If the Sense is too high (6-wire cell), the sense lines may not be connected (4-wire cell). Or, if one of the sense readings is high, then there is probably a cable error.

USING A LOAD CELL TESTER

- Signal Output is Too High

- Typically, if the signal output is over 5 %, the load cell has either been overloaded or there is corrosion somewhere in the cable or cell.

USING A LOAD CELL TESTER

- Shield to Bridge, Body to Bridge and Shield to Body
- The load cell insulation resistance specifications for load cell body to bridge is >5000 MegOhm at 23 °C. (on the tester Shield to Body > 5000, 5000 MegOhm)
- We typically do not recommend that the shield is attached to the load cell body to prevent ground loops so the shield to body or bridge will generally meet the same specification. This will most likely be > 5000MegaOhm and the meter will flash red if it is not okay.

What we have learned

Can everyone

- Identify various types of calibration equipment and perform some basic troubleshooting methods ?

Common Low Force Calibration Problems – Hand-Held Force Gauge

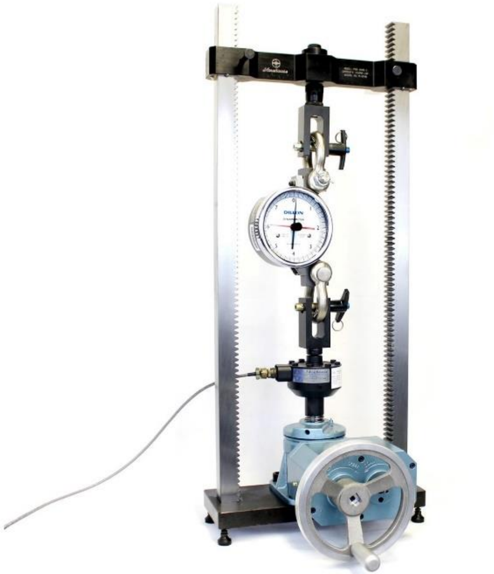
Stacking Weights Issues

- Slow and dangerous
- Ergonomic issue
- Often not corrected for force (corrections for force must include correcting for gravity, air density, and material density)

Common Low Force Calibration Problems – Hand-Held Force Gauge

Not Correcting Mass Weights To Force

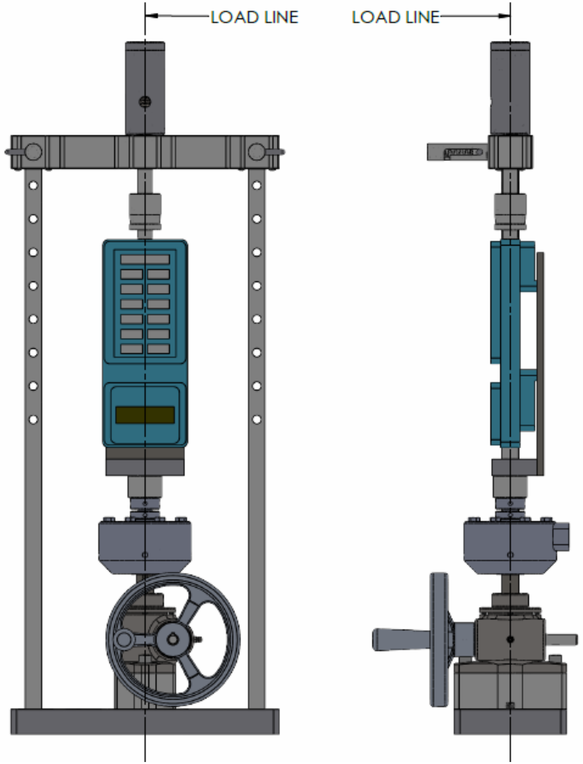
- Morehouse Blog on Using Mass Weights
- Blog shows these errors to be from 0.05 % up to 0.185 %



Common Low Force Calibration Problems – Hand-Held Force Gauge

Off Center Loading Issues

- Most hand-held force gauges require different centering fixtures for alignment - If the line of force is not pure, a large measurement error should be expected



Adapters for hand-held force gauges

Morehouse L-Bracket kits are available for tension and compression calibration of handheld force gauges. These kits simplify setup and reduce errors with stacking weights. This kit can be used on both the Mechanical Tensiometer and PCM.

Link to Hand-Held Force Gauge Kit

Common Low Force Calibration Problems - Alignment

Alignment Issues

- Misalignment can cause errors that exceed 1 % of applied reading on certain load cells and other devices.
- Using the right adapters will help reduce these errors

PCM-2K
Low Capacity

Morehouse Portable Calibrating Machine features:

- Tension and compression calibrations in one setup
- Fine adjustment of the calibration load
- Lowering the risk of overloading small force measurement
- Capable of calibrating handheld force
- Eliminates the need for carrying and stacking weights
- Quick-Change Tension Member system
- Quick calibration height adjustment
- Quick reference standard change capabilities
- Capable of controlling force application as low as 0.005 lbf
- Low-maintenance, manual operation system

PCM-2K Low-Cost

- Low cost when compared to paying someone to manually lift weights onto a pan and take a reading
- Low cost when compared against technicians sustaining an injury
- Low Cost when compared against other systems that are not as versatile or have the proper adapters

Question

- What equipment is currently being used by your company to calibrate cable tensiometers?

- What are the current challenges to calibrated this equipment?

Mechanical Tensiometer

A cable tensiometer is a device with an accuracy specification that is typically 1-5 % of capacity force. They are used to check the tension of wire cables (typically used in aircraft rigging and textile manufacturer).

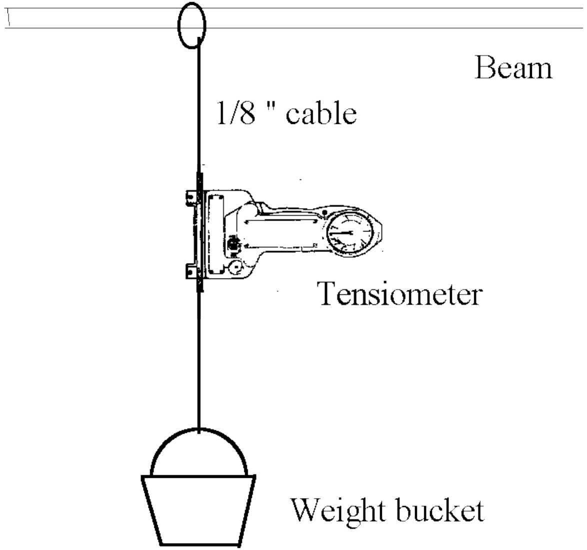
Mechanical Tensiometer
How They Work

They use a force gauge to react against the cable, via a riser, and display the result, through a gearbox, onto a dial scale. The dial is often just a linear scale numbered 0 through 100, a conversion table is then drawn up to convert the number to a meaningful result in lbf.

Mechanical Tensiometer
How They Work

Calibration is often done by loading to the same force point several times and taking an average of the readings. The tensiometers should be calibrated based on use and other factors. Some common problems to watch for are physical damage, overstretching of the spring (can happen when the correct riser is not installed for calibration), corrosion, and damaged risers.

Mechanical Tensiometer



Some calibration procedures may be very questionable. A common method of calibration is fixing one point of the cable and stacking weights, or even filling a bucket with the appropriate amount of weight to generate the force.

Note: Anyone think the bucket method is metrologically sound or would it pass an audit?

Mechanical Tensiometer
Low Capacity

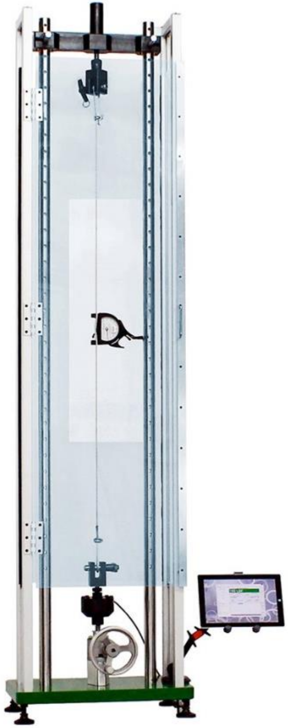
Mechanical Tensiometer Calibrator (model PCM-2MD-T1) is an easy-to-use solution for problems associated with calibrating force instruments and cable tension meters (tensiometers) properly up to 2000 lbf capacity.

This machine provides the user with fine and stable control on the applied force and offers a large working area which long enough to test tensiometers on standard cables lengths of 5 ft.

Mechanical Tensiometer
Low Capacity

The system is equipped with several time-saving features that enable a quality force calibration on a wide range of force sensors such as shear web load cells, S-type load cells, force gauges, button load cells, beam load cells, etc.

Mechanical Tensiometer
Low Cost



- Low cost when compared to paying someone to manually lift weights onto a pan and take a reading

- Low cost when compared to a $ 90,000.00 plus deadweight machine

- Low cost when compared against technicians sustaining an injury

- Low cost when comparing against a less accurate method of back calculating torque and not getting the right result

Learning Objectives

- Name the following and discuss potential measurement issues.

Learning Objectives

- How do I check bridge resistance?

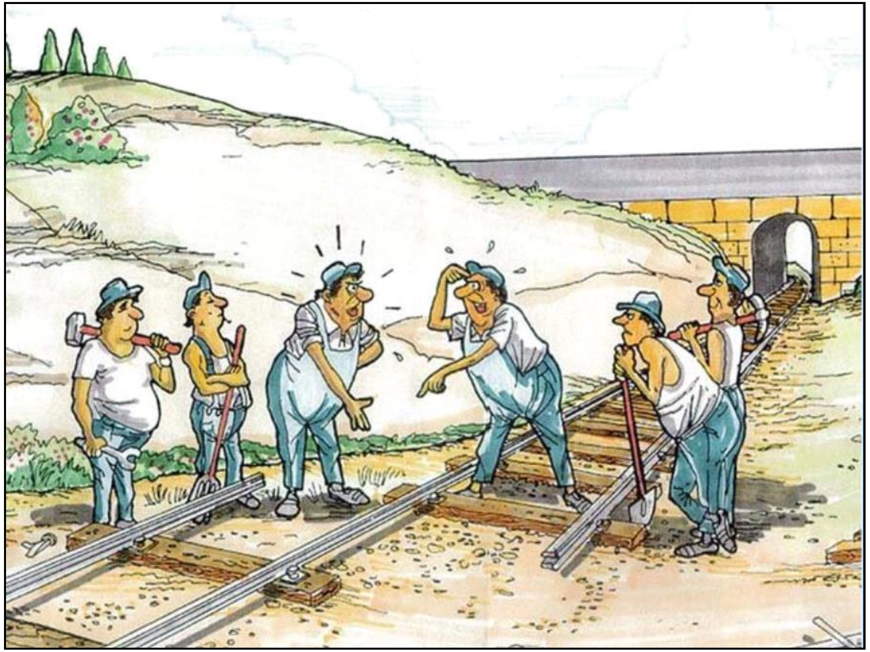
- What is a good indication that a load cell is overloaded?

Celebration of Knowledge

Can you

- Identify potential force measurement errors?
- Which is better, 4- or 6-wire cable?
- If you do not know how the instrument should be calibrated what should you do?

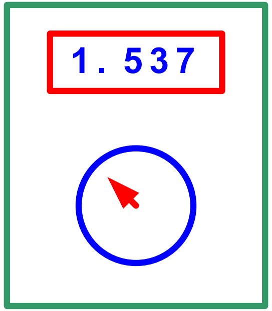
A misinterpretation of a measurement can have disastrous and costly results.



Measurement Principles

Digital measuring instruments:

In digital measuring instruments, the measurement is converted into decimal digits, so it is easy to read. While it is easy to read, many take the measured reading for granted. It is easy for manufacturers of digital meters to add more digits to the display (i.e., more decimal places). This (more resolution) may, imply more accuracy to some. The extra resolution may support other ranges in the meter. The user should consult the manufacturer’s specifications to determine the accuracy claims. The parallax error of analog instruments is eliminated from the digital instrument as all users will see the same numbers.



Measurement Principles

- Sometimes, the least significant digit on the meter will toggle 1 or 2 digits up and down. Sometimes the least significant digit will toggle from 0 to 5 and back. This depends on how the meter is designed to convert data on the display. Pay attention to this information when selecting the instrument to make measurements.

Measurement Principles

<u>Ways to improve measurements:</u>

- 1. Make the measurement with an instrument that can resolve to the smallest unit. Do not confuse the resolution of an instrument with the accuracy of the equipment. For the accuracy claim, the engineer must refer to the equipment specifications. It is wrong to assume that the smaller the unit, or fraction of a unit, on the measuring device, the more accurate the device can measure.
- If you want to measure to 2 decimal places, use an instrument that will resolve to at least 3 or more decimal places. Using a 2 decimal place instrument will result in approximately 25 % decrease in the precision (repeatability) of your data collected.

Measurement Principles

Note that any value that is calculated from the measurements is also carried to one more decimal. It is always a good practice to round at the very end of calculations then in the beginning or in the middle.

	Same Measurement, Different Resolution	
	3 Decimal	2 Decimal
1	4.996	5.00
2	5.002	5.00
3	5.001	5.00
4	5.005	5.01
5	4.995	5.00
6	4.996	5.00
7	5.006	5.01
8	4.993	4.99
9	4.991	4.99
10	4.995	5.00
Average	4.9981	5.000
Standard Deviation	0.0051	0.007
Difference in Std. Dev.		24%

TUR Defined

$$\text{T.U.R.} = \frac{\text{U.U.T. Tolerance}}{\text{Calibration Process Uncertainty}}$$

- **The ratio of the span of the tolerance of a measurement quantity subject to calibration to twice the 95% expanded uncertainty of the measurement process used for calibration.** ANSI/NCSLI Z540.3-2006

- **The ratio of the tolerance, TL, of a measurement quantity, divided by the 95% expanded measurement uncertainty of the measurement process where TUR = TL/U.** ILAC G8:2019

TUR Defined ANSI/NCSL Z540.3 Handbook

$$\mathrm{TUR} = \frac{\text{Span of the } \pm \text{ UUT Tolerance}}{2 \text{ x } k_{95\%}(\text{Calibration Process Uncertainty})}$$

TUR Formula found in ANSI/NCSLI Z540.3 Handbook

"For the numerator, the tolerance used for Unit Under Test (UUT) in the calibration procedure should be used in the calculation of the TUR. This tolerance is to reflect the organization's performance requirements for the Measurement & Test Equipment (M&TE), which are, in turn, derived from the intended application of the M&TE. In many cases, these performance requirements may be those described by the Manufacturer's tolerances and specifications for the M&TE and are therefore included in the numerator."

ANSI/NCSL Z540.3 Handbook "Handbook for the Application of ANSI/NCSLI 540.3-2006 - Requirements for the Calibration of Measuring and Test Equipment."

TUR Defined ANSI/NCSL Z540.3 Handbook

$$\text{TUR} = \frac{\text{Span of the } \pm \text{Tolerance}}{2 \text{ x } k_{95\%} \left(\sqrt[2]{\left(\frac{\text{CMC}}{k_{\text{CMC}}}\right)^2 + \left(\frac{\text{Resolution}_{\text{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\text{Repeatability}_{\text{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2} \right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

In most cases, the numerator is the UUT Accuracy Tolerance. The denominator is slightly more complicated. Per the ANSI/NCSL Z540.3 Handbook, "For the denominator, the 95 % expanded uncertainty of the measurement process used for calibration following the calibration procedure is to be used to calculate TUR. The value of this uncertainty estimate should reflect the results that are reasonably expected from the use of the approved procedure to calibrate the M&TE. Therefore, the estimate includes all components of error that influence the calibration measurement results, which would also include the influences of the item being calibrated except for the bias of the M&TE. The calibration process error, therefore, includes temporary and non-correctable influences incurred during the calibration such as **repeatability**, **resolution**, error in the measurement source, operator error, error in correction factors, environmental influences, etc."

ILAC P-14

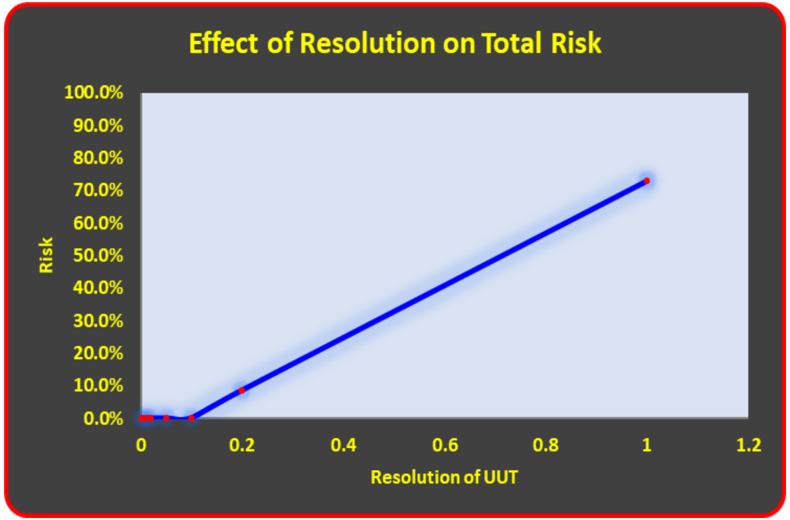
$$\text{TUR} = \frac{\text{Span of the } \pm \text{ Tolerance}}{2 \text{ x } k_{95\%} \left(\sqrt[2]{\left(\frac{\text{CMC}}{k_{\text{CMC}}}\right)^2 + \left(\frac{\text{Resolution}_{\text{UUT}}}{\sqrt[2]{12}}\right)^2 + \left(\frac{\text{Repeatability}_{\text{UUT}}}{1}\right)^2 + \cdots (u_{Other})^2} \right)}$$

Example of a TUR Formula (Adapted from the ANSI/NCSL Z540.3 Handbook)

This definition of the TUR denominator aligns very closely with ILAC P14:09/2020, which states, "Contributions to the uncertainty stated on the calibration certificate shall include relevant short-term contributions during calibration and contributions that can reasonably be attributed to the customer's device. Where applicable, the uncertainty shall cover the same contributions to uncertainty that were included in evaluation of the CMC uncertainty component, except that uncertainty components evaluated for the best existing device shall be replaced with those of the customer's device. Therefore, reported uncertainties tend to be larger than the uncertainty covered by the CMC."

The Effect of UUT Resolution on Risk & Uncertainty

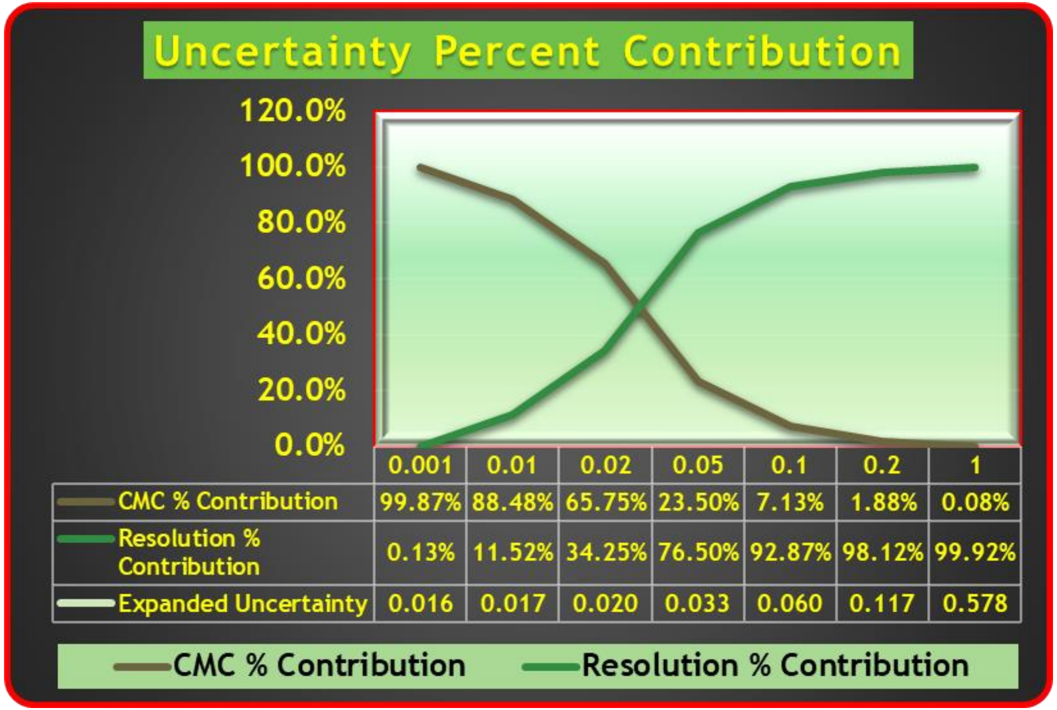
Resolution and the Effect on Total Risk Using a 1 000 kgf Morehouse Load Cell and Varying the Indicator Resolution



The risk starts to increase quite dramatically as the resolution increases so, does the overall uncertainty

The Effect of UUT Resolution on Risk & Uncertainty

Resolution and the Effect on Total Risk Using a 1 000 kgf Morehouse Load Cell and Varying the Indicator Resolution



	0.001	0.01	0.02	0.05	0.1	0.2	1
CMC % Contribution	99.87%	88.48%	65.75%	23.50%	7.13%	1.88%	0.08%
Resolution % Contribution	0.13%	11.52%	34.25%	76.50%	92.87%	98.12%	99.92%
Expanded Uncertainty	0.016	0.017	0.020	0.033	0.060	0.117	0.578

When the resolution is 0.001 kgf, it is insignificant. At 0.01 kgf, it is 11.52 % of the overall budget, and when raised to 0.05 kgf, it becomes dominant.

The Effect of UUT Resolution on Risk & Uncertainty

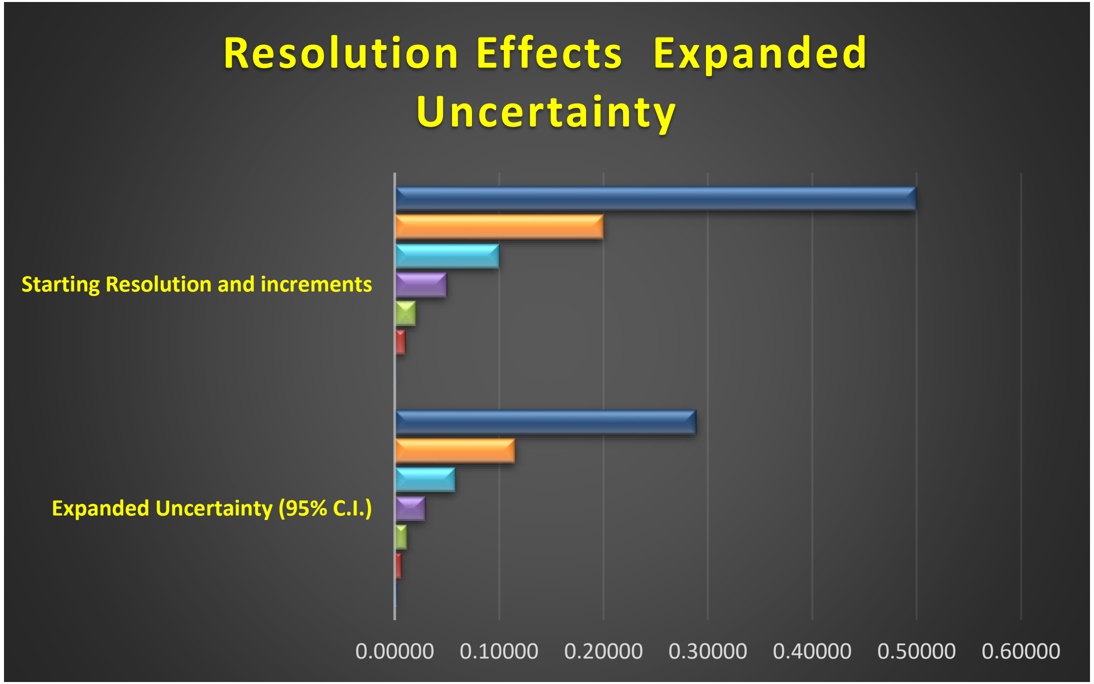
If adhering to the common practice of requesting a TUR > 4:1 (other guides and standards may recommend different minimum ratios) before making a statement of conformity, then the proper formula for TUR must be followed. Realizing the problem with other guides and standards, JCGM 106:2012_E states, "Care has to be taken when such rules are encountered because they are sometimes ambiguously or incompletely defined."

The Effect of UUT Resolution on Risk & Uncertainty

TUR cannot be the ratio of the Manufacturer's accuracy tolerance to the reference standard uncertainty, per ANSI/NCSL Z540.3 and ILAC-G8:09/2019

When the resolution is considered, the TUR starts at 6.25:1 with a UUT resolution of 0.001 kgf and then declines to 0.17:1 with a UUT resolution of 1.0 kgf. When the resolution is not accounted for, the TUR ratio stays at 6.25:1 regardless of the resolution. If a calibration laboratory uses the Test Value Uncertainty, then the UUT's resolution could be ignored in the conformity assessment.

The Effect of UUT Resolution on Expanded Uncertainty



Measurement Principles

- Know your instruments! Use proper techniques when using the measuring instrument and reading the value measured. On analog instruments, avoid parallax errors by always taking readings by looking straight down (or ahead) at the measuring device. Looking at the measuring device from a left or right angle will provide an incorrect value.

- Any measurement made with a measuring device is approximate. If a measurement of an object is made two different times, the two measurements may not be the same. Repeat the same measure several times to get a good average. Avoid the *"one measurement bliss"*. It is only after more than one measurement is taken that one knows the first measurement may be correct

Measurement Principles

- Measure under controlled conditions. If the parameter that is measured can change size depending upon climatic conditions (swell or shrink), be sure to measure it under the same conditions each time. This may apply to measuring instruments as well. Follow the environmental conditions under which the equipment is designed to work .

- If one wished to measure the resistance of some component that is located a significant distance away from the Ohmmeter, one would need to consider the resistance of the test leads as the Ohmmeter would measure all the resistance including that of the wire. In another scenario, measuring small resistances would be difficult if the test lead resistance was significantly larger than the artifact being measured.

Measurement Principles

From Ohm’s Law,:

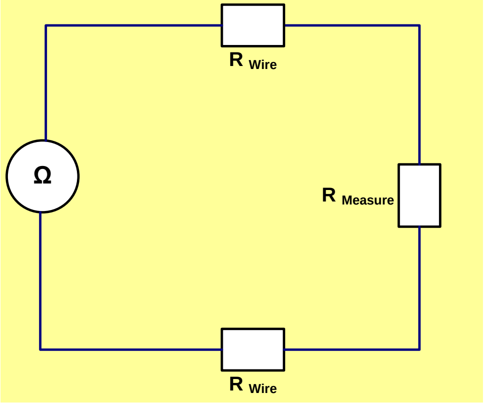
Resistance (R) = Volts (V)/ Current (I)

- A way to measure small resistance or resistance from a long distance involves the use of both an ammeter and a voltmeter. From Ohm's Law that resistance is equal to voltage divided by current (R = V/I). The resistance can be determined of the Device Under Test (DUT) if we measure the current and voltage across it is measured.

Measurement Principles

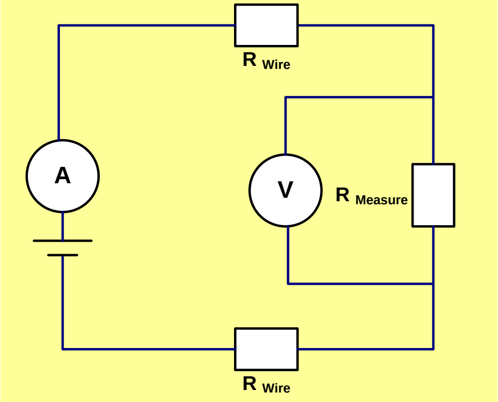
In the circuit below, the Ohmmeter measures both the test leads and the DUT Resistance R:

$$R = R_{WIRE} + R_{WIRE} + R_{MEASURE}$$



Measurement Principles

In the 4-wire measurement circuit below, the more accurate resistance of the DUT resistance is only measured:

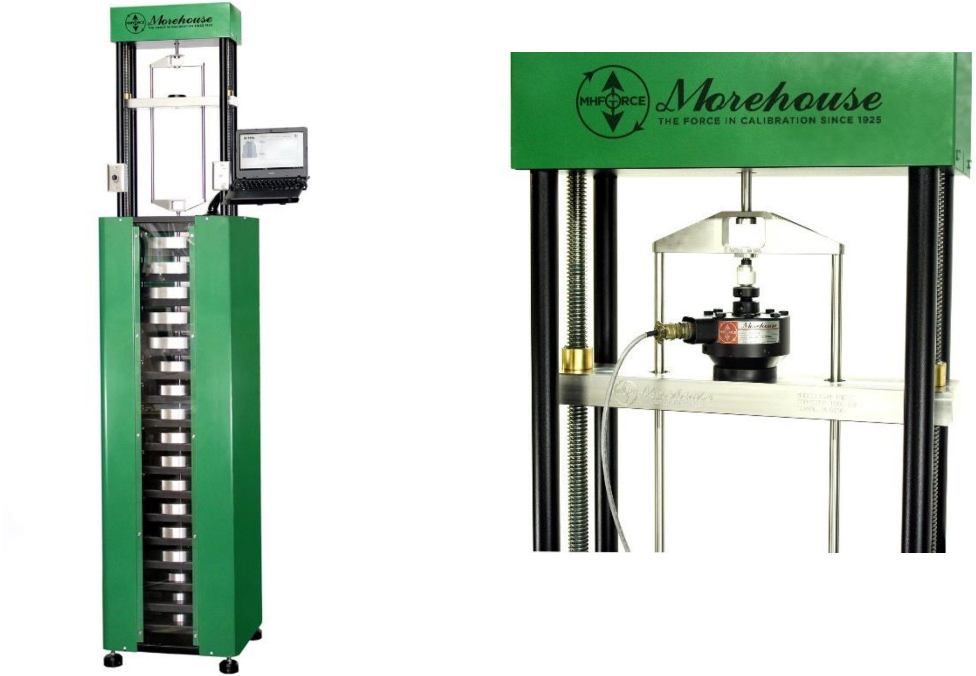


Calibration Defined

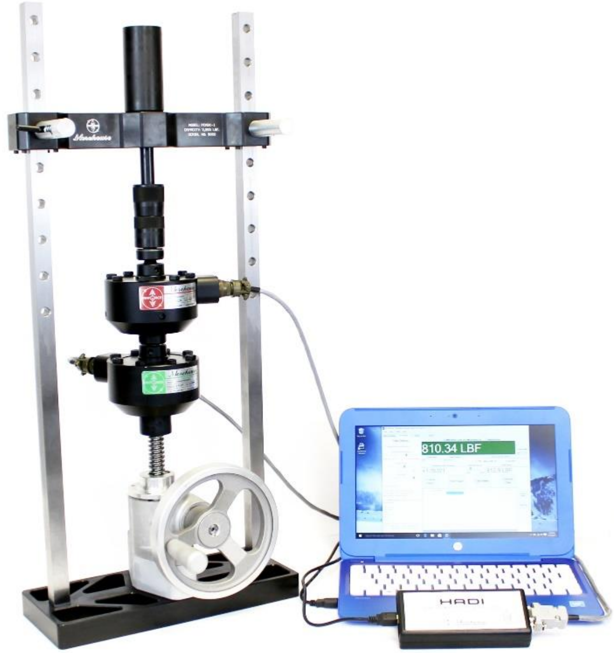
- Calibration is the comparison of an unknown (typically referred to as the Unit Under Test or UUT) to a device known within a certain error(typically referred to as the Calibration Standard or Reference Standard) for the purpose of characterizing the unknown

- Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and , in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

Force Uncertainties at Different Tiers



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



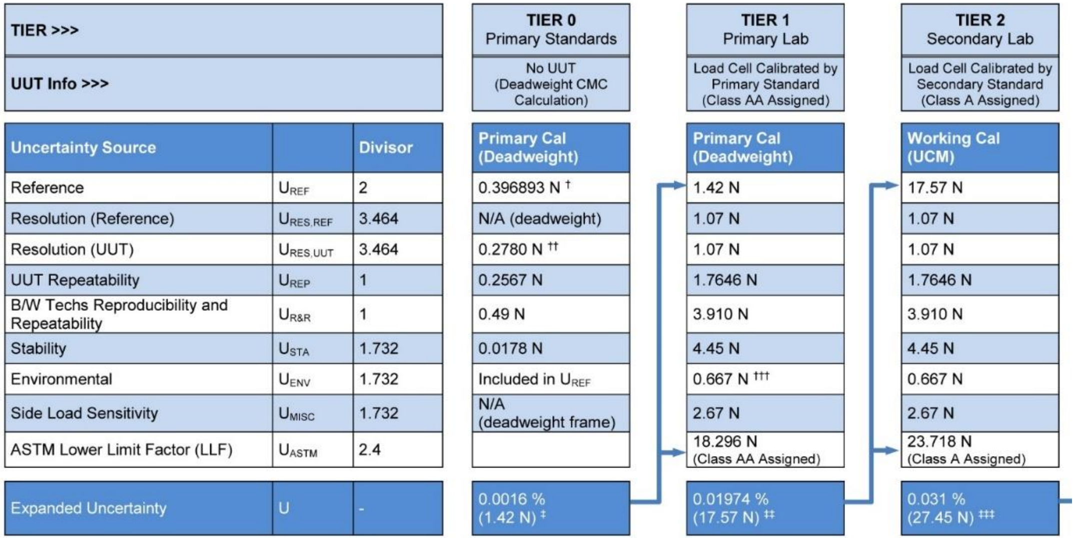
Tier 2: Secondary Standard 0.02 % used to calibrate load cells to Class A

Force Uncertainties at Different Tiers

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

Uncertainty Propagation For Force Calibration Systems

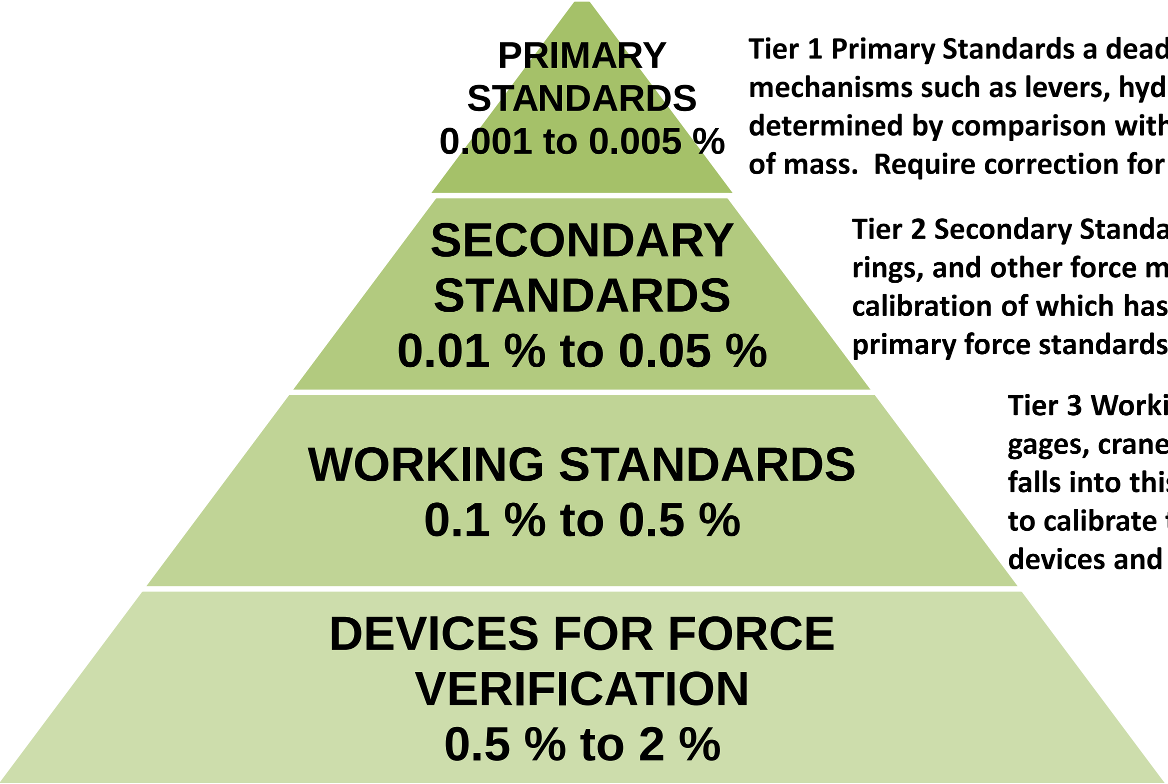
Table 1. Uncertainty Propagation Analysis for Load Cell Calibrations



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

Uncertainty Tiers For Force Calibration



PRIMARY STANDARDS
0.001 to 0.005 %

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

SECONDARY STANDARDS
0.01 % to 0.05 %

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

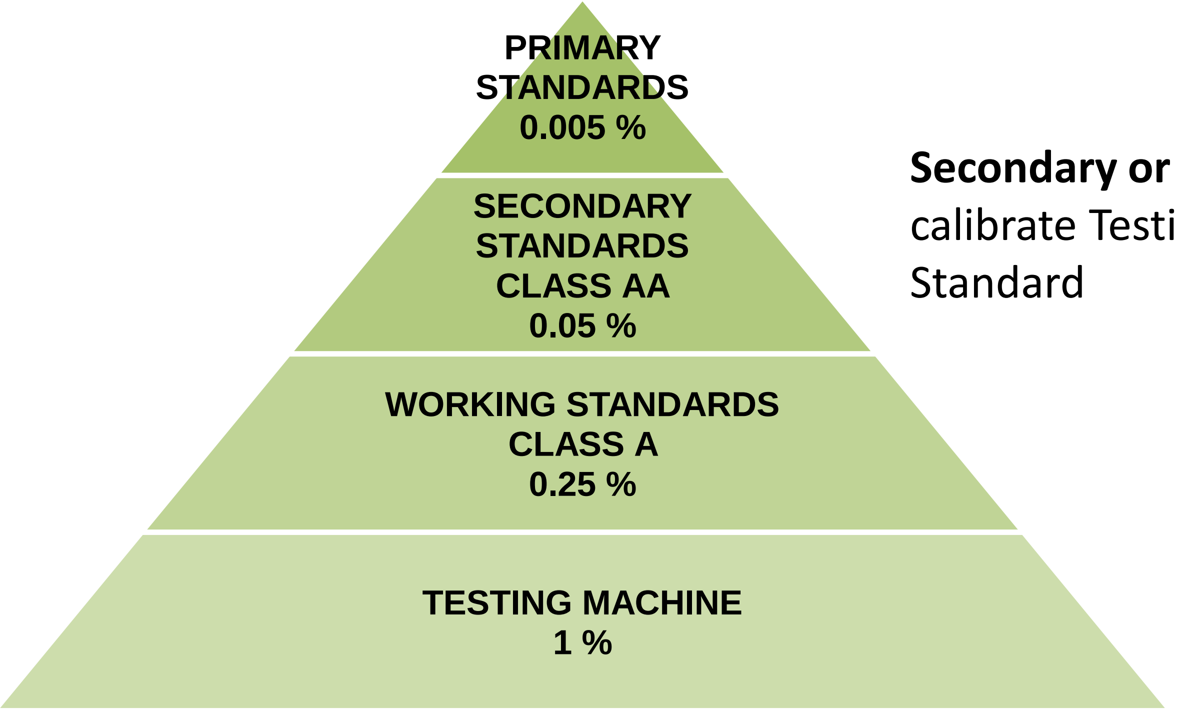
WORKING STANDARDS
0.1 % to 0.5 %

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.

DEVICES FOR FORCE VERIFICATION
0.5 % to 2 %

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.

ASTM E74



PRIMARY STANDARDS
0.005 %

SECONDARY STANDARDS
CLASS AA
0.05 %

WORKING STANDARDS
CLASS A
0.25 %

TESTING MACHINE
1 %

Secondary or Working Standards are used to calibrate Testing Machines to the ASTM E4 Standard

ASTM E4

ASTM E4 is the calibration standard for force verification of testing machines followed by those individuals calibrating testing machines from Tinius Olsen, TestMark, Mark-10, Instron, Forney, Lloyd, MTS, and other manufactures

Calibration in accordance with the ASTM E4 standard may require compliance with these related standards:

D76/D76M Specification for Tensile Testing Machines for Textiles

E74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines

E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

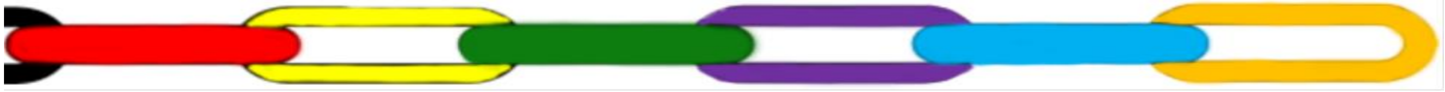
Primary Force Standard (as defined by ASTM E74-18)

- Primary Force Standard – 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
- To be a classified as a primary standard the masses of the weights shall be determined within 0.005 % of their values by comparison with reference standards traceable to the International System of Units (SI) for mass (ASTM E74-18 section 6.1.2)

Primary Force Standard (as defined by ASTM E74-18)

- Require correction for the effects of
- Local Gravity
- Air Buoyancy
- Must be adjusted to within 0.005 % or better (NIST weights are adjusted to within U = 0.0005 %, Morehouse U= 0.002 %)
- Per ASTM E74-18 section 6.1 *“weights shall be made of rolled, forged or cast metal. Adjustment cavities should be closed by threaded plugs or suitable seals. External surfaces of weights shall have a Roughness Average of 3.2 μm or less as specified by ASME B46.1”   note: Stainless Steel preferred material*

Measurement Uncertainty



BIPM/SI

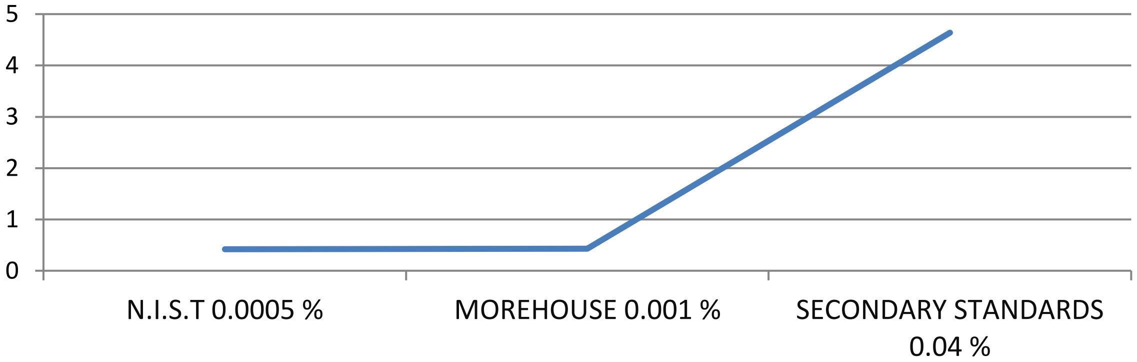
NMI

Primary Standards

Accredited Cal. Lab

Working Standards

Field Measurement



- The further away from calibration by primary standards the larger the Overall Uncertainty will become

Secondary Force Standard (as defined by ASTM E74-18)

- Secondary Force Standard – an instrument or mechanism, the calibration of which has been established by comparison with **primary force standards**.
- In order to perform calibrations in accordance with ASTM E74 your force standard must be calibrated with primary standards

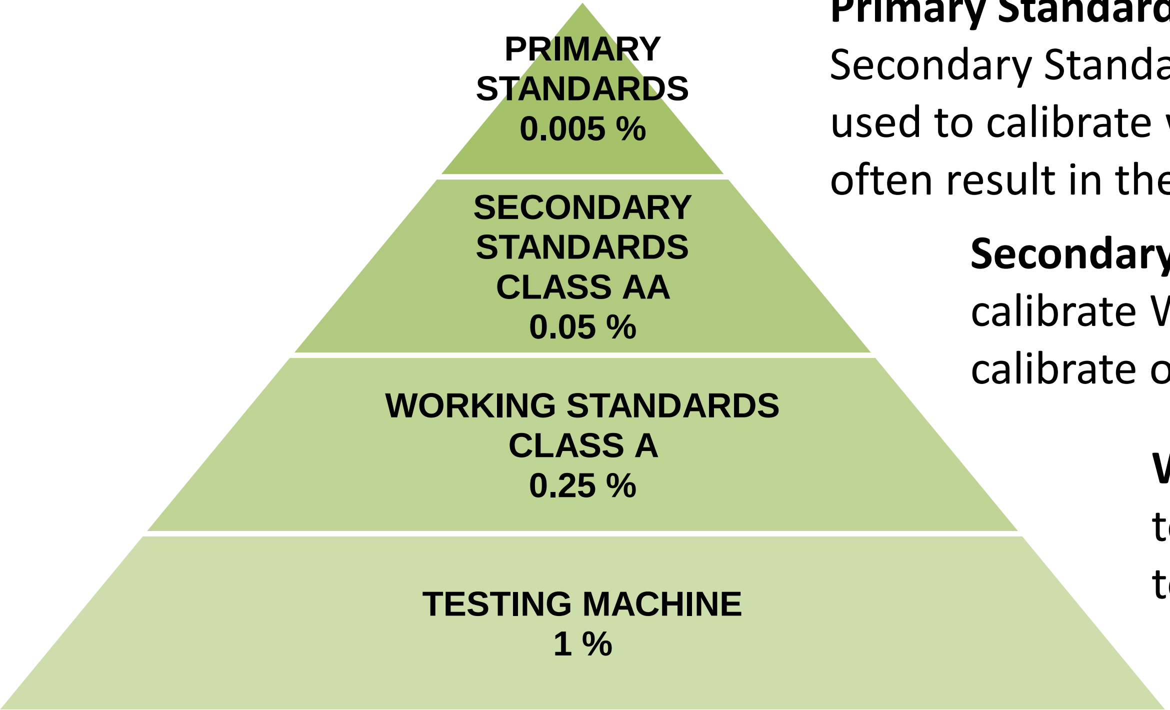
Secondary Force Standard as defined by ASTM E74

Secondary Force Standard – Range of use limited by the verified range of forces established by the standard

- ASTM E74 Class AA verified range of forces for calibration of secondary standard load cells. This is found by multiplying the lower limit factor by 2000 (0.05 %) 5:1 ratio
- ASTM E74 Class A verified range of forces for calibration of testing machine . This is found by multiplying the lower limit factor by 400 (0.25 %) 4:1 ratio.

Range of use cannot be less than the lowest applied force. Loading range cannot be less than 400 for Class A or 2000 for Class AA times the resolution.

Test Accuracy Ratio ASTM E74


PRIMARY STANDARDS
0.005 %

SECONDARY STANDARDS
CLASS AA
0.05 %

WORKING STANDARDS
CLASS A
0.25 %

TESTING MACHINE
1 %

Primary Standards are required to calibrate Secondary Standards. Primary Standards can be used to calibrate working standards as this will often result in the lowest possible loading ranges

Secondary Standards are required to calibrate Working Standards. They cannot calibrate other Secondary Standards

Working Standards are used to calibrate Testing Machines to ASTM E4

Calibration Preparation - Stabilization

- Temperature Stabilization – It is recommended that a device be kept in the area or lab where it is to be calibrated for the device to stabilize in the environment. A good rule of thumb is to allow 24 hours for temperature stabilization. Recommended Temperature is 23 degrees C
- Electrical Stabilization – Depending on the equipment common practice is to allow 15-30 minutes to warm up.
- Exercise the instrument to be calibrated. The instrument should be set up in the machine and exercised to the maximum force that is to be applied during the actual calibration. Typically, we recommend 3-4 exercise cycles; most standards require a minimum of 2 exercise cycles.

Calibration In Accordance with ASTM E74

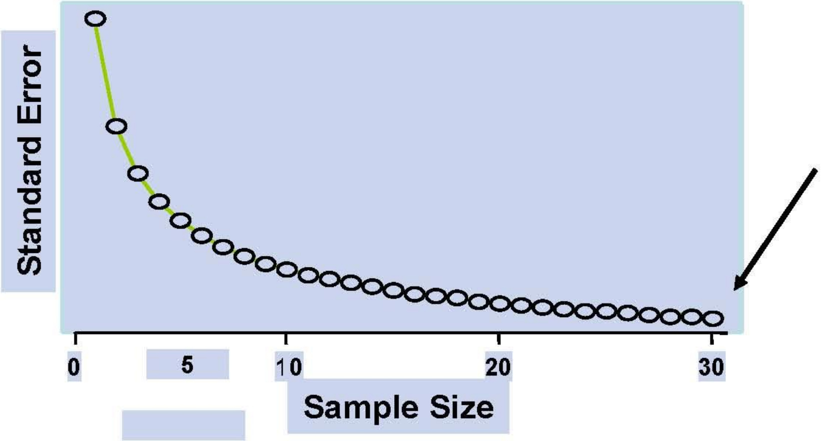
- At least 30 force applications are required (we typically recommend 3 runs of 11 or 33 force applications)

- There should be at least one calibration force for each 10 % interval throughout the loading range and if the instrument is to be used below 10% of its capacity a low force should be applied. This low force must be greater than the resolution of the device multiplied by 400 for Class A or 2000 for Class AA devices

Number of Calibration Values

- The rate of change in the standard error approaches zero at about 30 samples
- This is why 30 samples is often recommended when generating summary statistics such as the mean and standard deviation
- This is also the point at which the t and Z distributions become nearly equivalent

$$S_{\bar{x}} = \frac{S_x}{\sqrt{n}}$$



Calibration Temperature

- ASTM E74 requires that the temperature be monitored during calibration as close to the device as possible and that the temperature change not exceed ± 1 degree C during calibration.

Temperature corrections must be applied to non-compensated devices.

- Deflection generally increases by 0.027 % for each 1 degree C increase in temperature. If the calibration laboratory is not operating at 23 degrees C they should make corrections by correcting the applied force accordingly.

ASTM E74 Calibration Procedure

Randomization of Loading Conditions – Major change in ASTM E74-18

Per section 7.5.1 & 2 “In a compression/tension calibration, position the force-measuring instrument to a 0-degree reference position, and then rotate to positions of approximately 120 degrees and 240 degrees. An exception is made for force-measuring instruments that cannot be rotated by 120 degrees such as some proving rings, force dynamometers, and Brinell Hardness Test Calibrators. For these types of force-measuring instruments, position the force-measuring instrument at 0 degrees, and then rotate to positions of approximately 60 degrees and 300 degrees, keeping its force axis on the center force axis of the machine. This exception is made to minimize parallax error.”

ASTM E74 Calibration Procedure

Randomization of Loading Conditions

- For Tension and Compression calibration, intersperse the loadings. Be sure to re-exercise the force-measuring instrument prior to any change in setup.

- Zero Return during calibration - This is lab-dependent and it is recommended that no more than 5 forces be applied before return to zero.

ASTM E74 Calibration Procedure

Deflection calculation Methods

- Method B Deflection readings should be calculated as the difference between readings at the applied force and the average or interpolated zero force readings before and after the applied force readings.

- Method A Deflection readings are calculated as the difference between the deflection at the applied force and the initial deflection at zero force.

ASTM E74 Calibration Procedure

LOAD REVERSAL OR DESCENDING LOADING – New in ASTM E74-18

Per section 7.4.1 “Force-measuring instruments are usually used under increasing forces, but if a force-measuring instrument is to be used under decreasing force, it shall be calibrated under decreasing forces as well as under increasing force. Use the procedures for calibration and analysis of data given in Sections 7 and 8 except where otherwise noted. When a force-measuring instrument is calibrated with both increasing and decreasing forces, the same force values should be applied for the increasing and decreasing directions of force application, but separate calibration equations should be developed.”

ASTM E74 Calibration Procedure

LOAD REVERSAL OR DESCENDING LOADING

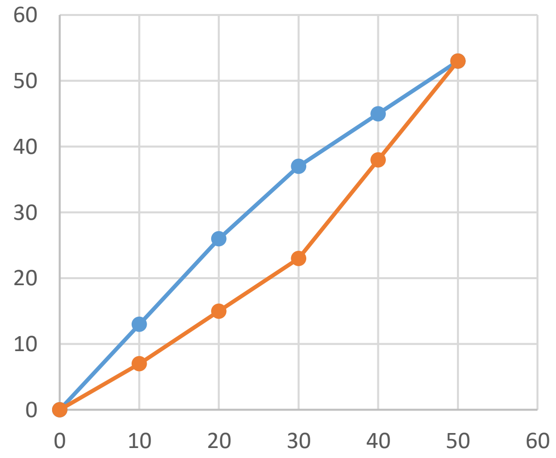
- If a force measuring device is to be used to measure forces during decreasing load sequences, then it must be calibrated in this manner.

- Separate calibration curves can be used for Ascending values and Descending Values

- A combined curve may also be used though the STD DEV of the combined curve will be much higher than using separate curves.

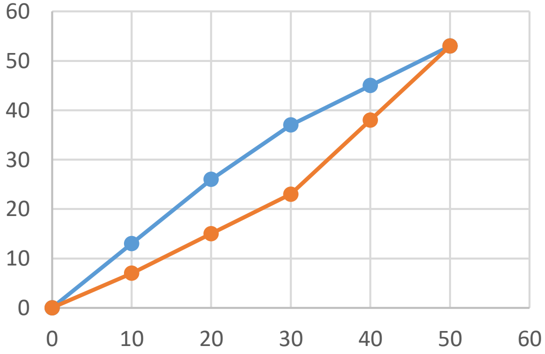
Calibration In Accordance with ASTM E74

- The LLF for a combined curve will typically be 3-4 more than the LLF of an increasing only calibration.
- A Descending Curve is only valid if the device loaded to full capacity.
- An ascending curve can be used for increasing calibration and a combined curve would be recommended for any descending values as the user would not have to apply the maximum force.



Decreasing loading

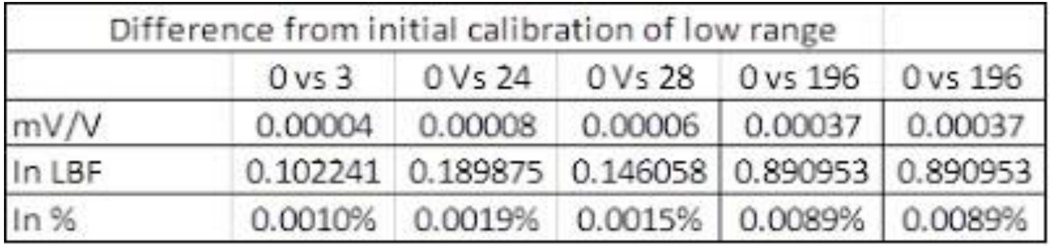
If a load cell is to be used to make descending measurements, it must be calibrated with a descending range



The difference in output on an ascending curved versus a descending curve can be quite different. A very good 100K load cell had an output of -2.03040 on the ascending curve and -2.03126 on the descending curve. Using the ascending only curve would result in an additional error of 0.042 %.

Using only part of the calibrated range

Not exercising the load cell to full range may produce additional errors.



Difference from initial calibration of low range					
	0 vs 3	0 Vs 24	0 Vs 28	0 vs 196	0 vs 196
mV/V	0.00004	0.00008	0.00006	0.00037	0.00037
In LBF	0.102241	0.189875	0.146058	0.890953	0.890953
In %	0.0010%	0.0019%	0.0015%	0.0089%	0.0089%

- The load cell exhibited a decline in output, which correlated to the amount of time between the additional applications of forces. The potential error ranged from 0.001 % to 0.0089 %. This error could be considerable when using the load cell as a secondary reference standard to calibrate other load cells. A Secondary Standard, as defined by ASTM E74-18, is one that is calibrated by Primary Standards (deadweights) and has a test accuracy ratio of better than 0.05 %. A maximum difference of 0.0089 % was observed.

ASTM E74 Calibration Procedure

Criteria for Use of Higher Degree Curve Fits

- Resolution must exceed 50,000 counts
- An F distribution test is used to determine the appropriate best degree of fit (instructions for this test can be found in the Annex A1 of the ASTM E74 Standard)
- The Standard deviation for the established curve fit is calculated as before using all the individual deflection values

ASTM E74 Calibration Procedure

Criteria for Lower Load Limit

- LLF = 2.4 * STD DEV – This corresponds to a 98.36 % Confidence Level

- Based on LLF or Resolution whichever is higher
- Class A 400 times the LLF or resolution
- Class AA 2000 times the LLF or resolution

NOTE: Any force-measuring instrument that is either modified or repaired should be recalibrated

Recalibration is required for a permanent zero shift exceeding 1.0 % of full scale

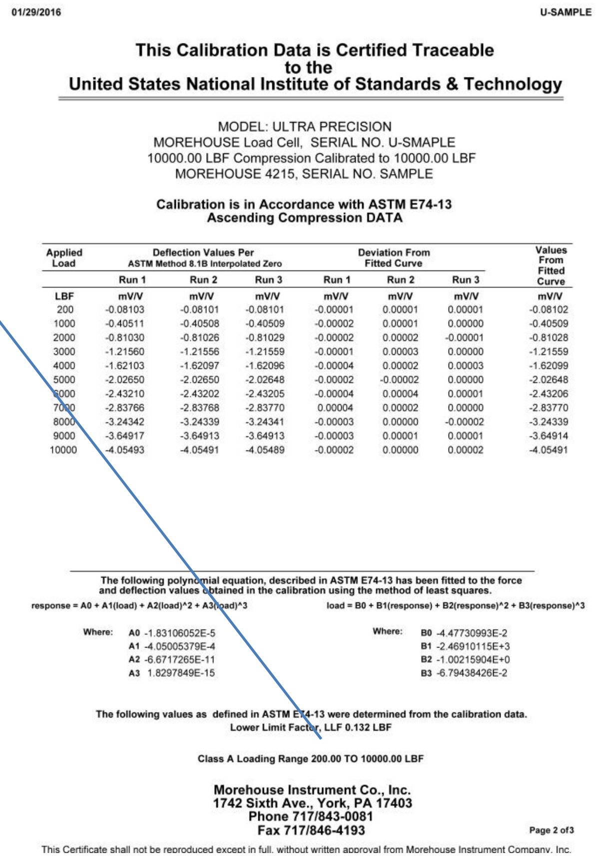
ASTM E74 Calibration Interval

Calibration Interval Per ASTM E74-18 section 11.2.1

- *"Force-measuring instruments shall demonstrate changes in the calibration values over the range of use during the recalibration interval of less than 0.032 % of reading for force-measuring instruments and systems used over the Class AA verified range of forces and less than 0.16 % of reading for those instruments and systems used over the Class A verified range of forces"*
- 11.2.2 *"Force-measuring instruments not meeting the stability criteria of 11.2.1 shall be recalibrated at intervals that shall ensure the stability criteria are not exceeded during the recalibration interval"*

ASTM E74 Calibration

- The Class A or Class AA verified range of forces cannot be less than the first applied **nonzero force point** (400 x 0.132 = 52.8)
- Per Section 8.6.2 of ASTM E74-18 *"The verified range of forces shall not include forces outside the range of forces applied during the calibration. If the lower force limit is less than the lowest non-zero calibration force applied, then the lower force limit of the verified range of forces is equal to the lowest calibration force applied."*



01/29/2016 U-SAMPLE

This Calibration Data is Certified Traceable
to the
United States National Institute of Standards & Technology

MODEL: ULTRA PRECISION
MOREHOUSE Load Cell, SERIAL NO. U-SMAPLE
10000.00 LBF Compression Calibrated to 10000.00 LBF
MOREHOUSE 4215, SERIAL NO. SAMPLE

Calibration is in Accordance with ASTM E74-13
Ascending Compression DATA

Applied Load	Deflection Values Per ASTM Method 8.1B Interpolated Zero			Deviation From Fitted Curve			Values From Fitted Curve
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
LBF	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V
200	-0.08103	-0.08101	-0.08101	-0.00001	0.00001	0.00001	-0.08102
1000	-0.40511	-0.40508	-0.40509	-0.00002	0.00001	0.00000	-0.40509
2000	-0.81030	-0.81026	-0.81029	-0.00002	0.00002	-0.00001	-0.81028
3000	-1.21560	-1.21556	-1.21559	-0.00001	0.00003	0.00000	-1.21559
4000	-1.62103	-1.62097	-1.62096	-0.00004	0.00002	0.00003	-1.62099
5000	-2.02650	-2.02650	-2.02648	-0.00002	-0.00002	0.00000	-2.02648
6000	-2.43210	-2.43202	-2.43205	-0.00004	0.00004	0.00001	-2.43206
7000	-2.83766	-2.83768	-2.83770	0.00004	0.00002	0.00000	-2.83770
8000	-3.24342	-3.24339	-3.24341	-0.00003	0.00000	-0.00002	-3.24339
9000	-3.64917	-3.64913	-3.64913	-0.00003	0.00001	0.00001	-3.64914
10000	-4.05493	-4.05491	-4.05489	-0.00002	0.00000	0.00002	-4.05491

The following polynomial equation, described in ASTM E74-13 has been fitted to the force and deflection values obtained in the calibration using the method of least squares.

response = A0 + A1(load) + A2(load)^2 + A3(load)^3

Where:
A0 -1.83106052E-5
A1 -4.05005379E-4
A2 -6.6717265E-11
A3 1.8297849E-15

load = B0 + B1(response) + B2(response)^2 + B3(response)^3

Where:
B0 -4.47730993E-2
B1 -2.46910115E+3
B2 -1.00215904E+0
B3 -6.79438426E-2

The following values as defined in ASTM E74-13 were determined from the calibration data.
Lower Limit Factor, LLF 0.132 LBF

Class A Loading Range 200.00 TO 10000.00 LBF

Morehouse Instrument Co., Inc.
1742 Sixth Ave., York, PA 17403
Phone 717/843-0081
Fax 717/846-4193

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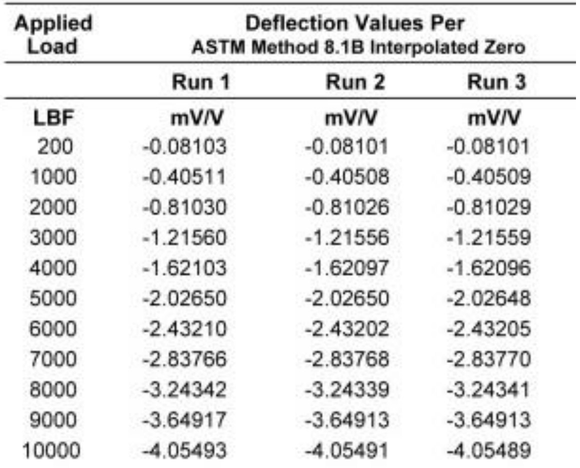
ASTM E74 Calibration

- It is recommended that the lower force limit be not less than 2 % (1⁄50) of the capacity of the instrument.

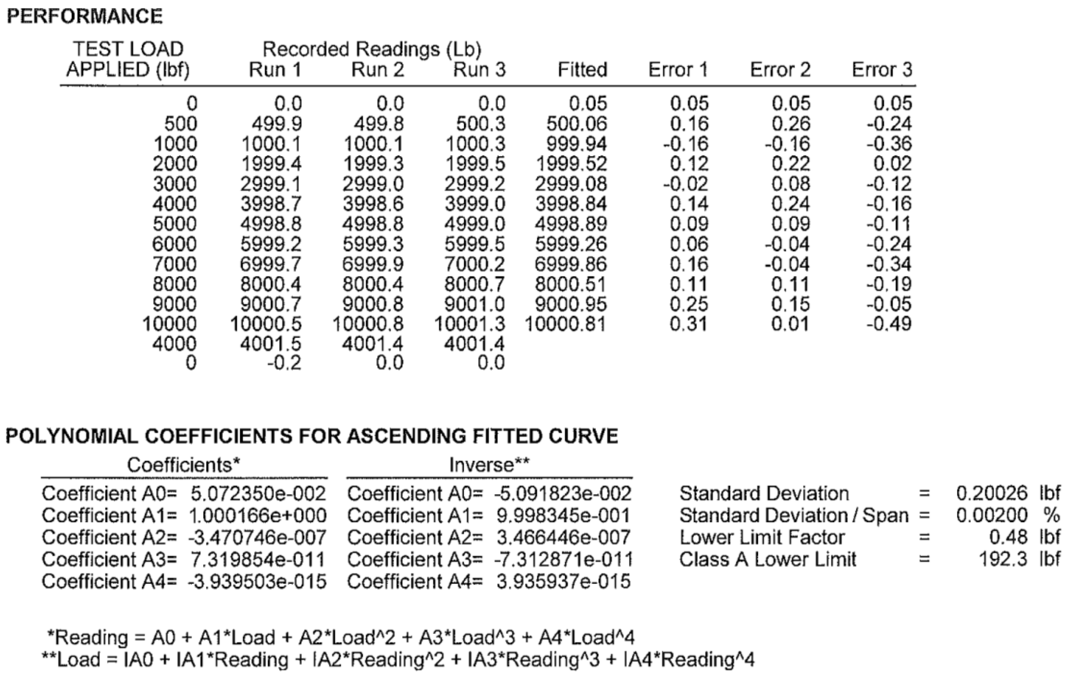
- Per Section 7.2.1 *“If the lower force limit of the verified range of forces of the force-measuring instrument (see 8.6.1) is anticipated to be less than one tenth of the maximum force applied during calibration, then forces should be applied at or below this lower force limit. In no case should the smallest force applied be below the lower force limit of the force-measuring instrument as defined by the values: 400 x resolution for Class A verified range of forces 2000 x resolution for Class AA verified range of forces ”*



Applied Load	Deflection Values Per ASTM Method 8.1B Interpolated Zero		
	Run 1	Run 2	Run 3
LBF	mV/V	mV/V	mV/V
200	-0.08103	-0.08101	-0.08101
1000	-0.40511	-0.40508	-0.40509
2000	-0.81030	-0.81026	-0.81029
3000	-1.21560	-1.21556	-1.21559
4000	-1.62103	-1.62097	-1.62096
5000	-2.02650	-2.02650	-2.02648
6000	-2.43210	-2.43202	-2.43205
7000	-2.83766	-2.83768	-2.83770
8000	-3.24342	-3.24339	-3.24341
9000	-3.64917	-3.64913	-3.64913
10000	-4.05493	-4.05491	-4.05489

Example of not following the standard

What's Wrong Here?



PERFORMANCE

TEST LOAD APPLIED (lbf)	Recorded Readings (Lb) Run 1	Run 2	Run 3	Fitted	Error 1	Error 2	Error 3
0	0.0	0.0	0.0	0.05	0.05	0.05	0.05
500	499.9	499.8	500.3	500.06	0.16	0.26	-0.24
1000	1000.1	1000.1	1000.3	999.94	-0.16	-0.16	-0.36
2000	1999.4	1999.3	1999.5	1999.52	0.12	0.22	0.02
3000	2999.1	2999.0	2999.2	2999.08	-0.02	0.08	-0.12
4000	3998.7	3998.6	3999.0	3998.84	0.14	0.24	-0.16
5000	4998.8	4998.8	4999.0	4998.89	0.09	0.09	-0.11
6000	5999.2	5999.3	5999.5	5999.26	0.06	-0.04	-0.24
7000	6999.7	6999.9	7000.2	6999.86	0.16	-0.04	-0.34
8000	8000.4	8000.4	8000.7	8000.51	0.11	0.11	-0.19
9000	9000.7	9000.8	9001.0	9000.95	0.25	0.15	-0.05
10000	10000.5	10000.8	10001.3	10000.81	0.31	0.01	-0.49
4000	4001.5	4001.4	4001.4				
0	-0.2	0.0	0.0				

POLYNOMIAL COEFFICIENTS FOR ASCENDING FITTED CURVE

Coefficients*	Inverse**
Coefficient A0= 5.072350e-002	Coefficient A0= -5.091823e-002
Coefficient A1= 1.000166e+000	Coefficient A1= 9.998345e-001
Coefficient A2= -3.470746e-007	Coefficient A2= 3.466446e-007
Coefficient A3= 7.319854e-011	Coefficient A3= -7.312871e-011
Coefficient A4= -3.939503e-015	Coefficient A4= 3.935937e-015

Standard Deviation = 0.20026 lbf
Standard Deviation / Span = 0.00200 %
Lower Limit Factor = 0.48 lbf
Class A Lower Limit = 192.3 lbf

*Reading = A0 + A1*Load + A2*Load^2 + A3*Load^3 + A4*Load^4
**Load = IA0 + IA1*Reading + IA2*Reading^2 + IA3*Reading^3 + IA4*Reading^4

Per Section 8.6 of ASTM E74-18 *"The verified range of forces shall not include forces outside the range of forces applied during the calibration."*

ASTM E74 Calibration (Do Not)

Do Not assign a Class A or Class AA verified range of forces below the first non-zero force point. Note: We have observed numerous labs violating this rule!

- Per Section 8.6.2 of ASTM E74-18 *"The verified range of forces shall not include forces outside the range of forces applied during the calibration. If the lower force limit is less than the lowest non-zero calibration force applied, then the lower force limit of the verified range of forces is equal to the lowest calibration force applied."*

- Per Section 7.2.1 of ASTM E74-18 states *"If the lower force limit of the verified range of forces of the force-measuring instrument (see 8.6.1) is anticipated to be less than one tenth of the maximum force applied during calibration, then forces should be applied at or below this lower force limit. In no case should the smallest force applied be below the lower force limit of the force-measuring instrument as defined by the values: 400 x resolution for Class A verified range of forces 2000 x resolution for Class AA verified range of forces "*

Calibration In Accordance with ASTM E74

Secondary Force Standard – an instrument or mechanism, the calibration of which has been established by comparison with **primary force standards**.

Criteria for Lower Load Limit

- LLF = 2.4 * STD DEV – This corresponds to a 98.2 % Confidence Level
- Based on LLF or Resolution whichever is higher
- Class A 400 times the LLF or resolution
- Class AA 2000 times the LLF or resolution

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2508330017	Interface, Inc.	1620AJH-25K	Gold Standard Load Cell	08/15/2013	08/15/2015

Applied Deflections Observed Curve Curve Values Deviation From Curve Values

22500 -36.735
25000 -40.819

Deflections = (A) + (B) * (L

Values of consta
A = 1.3403263
B = -1.6319647
C = -4.3885004

Class AA = 8761.37 lbf

Class A = 2500 lbf

CLASS AA? THIS IS NOT CORRECT. CALIBRATION LAB IS USING A LOAD CELL TO ASSIGN A CLASS AA LOADING RANGE

ASTM E74 Calibration (Do Not)

Do Not Assign a Class AA verified range of forces, unless you are calibrating with primary standards accurate to better than 0.005 %

Do Not Assign a Class A verified range of forces, unless you are calibrating the device using a secondary standard that was calibrated directly by primary standards.

Note: A force-measuring instrument with Class A verified range of forces cannot assign Class A verified range of forces.

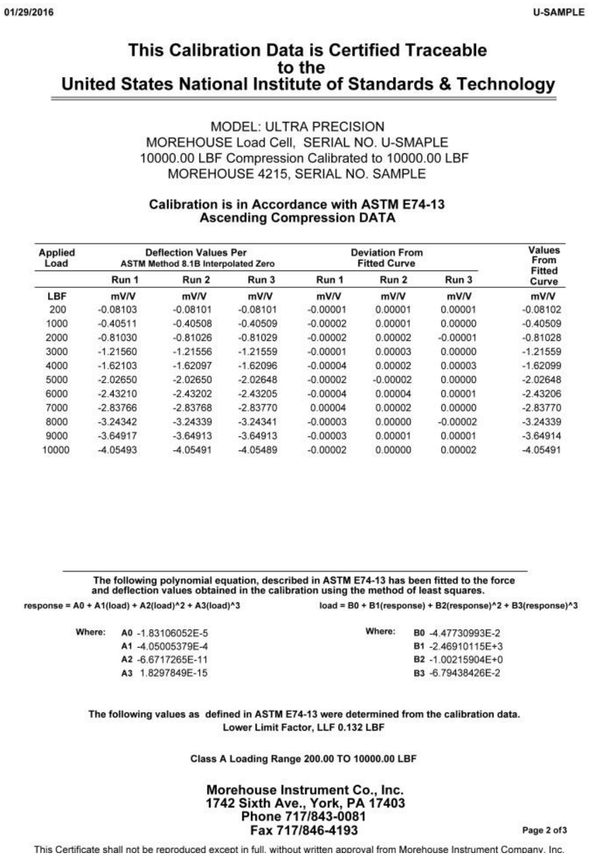
Note: A force measuring instrument with Class AA verified range of forces cannot assign Class AA verified range of forces.

ASTM E74 Calibration Data Analysis

- Deviations from the fitted curve
- These are the differences between the fitted curve and the observed values
- Standard Deviation is the square root of the sum of all the deviations squared/n-m-1

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

- N = sample size, m = the degree of polynomial fit
- Calibration equation Deflection or Response = A0+A1(load)+A2(load)^2+…A5(load)^5
- LLF is 2.4 times the standard deviation
- Class A range is 400 times the LLF. Class AA range is 2000 times the LLF.



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This Calibration Data is Certified Traceable
to the
United States National Institute of Standards & Technology

MODEL: ULTRA PRECISION
MOREHOUSE Load Cell, SERIAL NO. U-SMAPLE
10000.00 LBF Compression Calibrated to 10000.00 LBF
MOREHOUSE 4215, SERIAL NO. SAMPLE

Calibration is in Accordance with ASTM E74-13
Ascending Compression DATA

Applied Load	Deflection Values Per ASTM Method 8.1B Interpolated Zero			Deviation From Fitted Curve			Values From Fitted Curve
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
LBF	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V
200	-0.08103	-0.08101	-0.08101	-0.00001	0.00001	0.00001	-0.08102
1000	-0.40511	-0.40508	-0.40509	-0.00002	0.00001	0.00000	-0.40509
2000	-0.81030	-0.81026	-0.81029	-0.00002	0.00002	-0.00001	-0.81028
3000	-1.21560	-1.21556	-1.21559	-0.00001	0.00003	0.00000	-1.21559
4000	-1.62103	-1.62097	-1.62096	-0.00004	0.00002	0.00003	-1.62099
5000	-2.02650	-2.02650	-2.02648	-0.00002	-0.00002	0.00000	-2.02648
6000	-2.43210	-2.43202	-2.43205	-0.00004	0.00004	0.00001	-2.43206
7000	-2.83766	-2.83768	-2.83770	0.00004	0.00002	0.00000	-2.83770
8000	-3.24342	-3.24339	-3.24341	-0.00003	0.00000	-0.00002	-3.24339
9000	-3.64917	-3.64913	-3.64913	-0.00003	0.00001	0.00001	-3.64914
10000	-4.05493	-4.05491	-4.05489	-0.00002	0.00000	0.00002	-4.05491

The following polynomial equation, described in ASTM E74-13 has been fitted to the force and deflection values obtained in the calibration using the method of least squares.

response = A0 + A1(load) + A2(load)^2 + A3(load)^3

Where:
A0 -1.83106052E-5
A1 -4.05005379E-4
A2 -6.6717265E-11
A3 1.8297849E-15

load = B0 + B1(response) + B2(response)^2 + B3(response)^3

Where:
B0 -4.47730993E-2
B1 -2.46910115E+3
B2 -1.00215904E+0
B3 -6.79438426E-2

The following values as defined in ASTM E74-13 were determined from the calibration data.
Lower Limit Factor, LLF 0.132 LBF

Class A Loading Range 200.00 TO 10000.00 LBF

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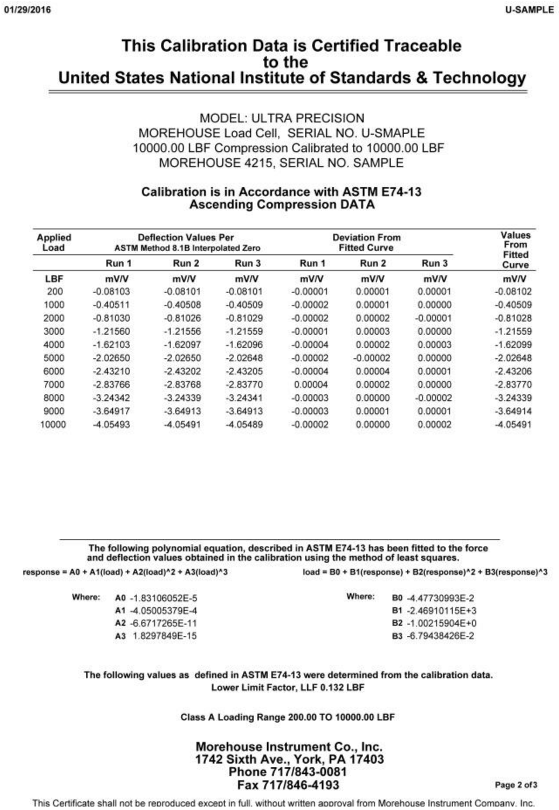
Calibration In Accordance with ASTM E74

Substitution of Electronic Instruments

- The indicating device used in the original calibration and the device to be substituted shall have been calibrated and the measurement uncertainty determined
- The uncertainty of each device shall be less than 1/3 of the uncertainty for the force measurement system.
- Excitation amplitude, wave form, and frequency shall be maintained
- Cable substitutions should be verified with a transducer simulator

Summary of Calibration Procedure

- Allow UUT to come to room temperature
- Warm up Instrumentation
- Select 10-11 Test points
- Fixture UUT in Test Frame
- Exercise UUT 2-4 times
- Apply 1st series of forces (Run1)
- Rotate the UUT 120 degrees if possible, for run 2
- Apply 2nd series of forces (Run2)
- *IF UUT IS COMPRESSION AND TENSION SWITCH TO OTHER MODE AFTER FINISHING RUN 2 AND EXERCISE AND REPEAT ABOVE STEPS*
- Rotate the UUT another 120 degrees if possible, for run 3
- Apply 3rd series of forces (Run3)



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to the
United States National Institute of Standards & Technology

MODEL: ULTRA PRECISION
MOREHOUSE Load Cell, SERIAL NO. U-SMAPLE
10000.00 LBF Compression Calibrated to 10000.00 LBF
MOREHOUSE 4215, SERIAL NO. SAMPLE

Calibration is in Accordance with ASTM E74-13
Ascending Compression DATA

Applied Load	Deflection Values Per ASTM Method 8.1B Interpolated Zero			Deviation From Fitted Curve			Values From Fitted Curve
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
LBF	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V
200	-0.08103	-0.08101	-0.08101	-0.00001	0.00001	0.00001	-0.08102
1000	-0.40511	-0.40508	-0.40509	-0.00002	0.00001	0.00000	-0.40509
2000	-0.81030	-0.81026	-0.81029	-0.00002	0.00002	-0.00001	-0.81028
3000	-1.21560	-1.21556	-1.21559	-0.00001	0.00003	0.00000	-1.21559
4000	-1.62103	-1.62097	-1.62096	-0.00004	0.00002	0.00003	-1.62099
5000	-2.02650	-2.02650	-2.02648	-0.00002	-0.00002	0.00000	-2.02648
6000	-2.43210	-2.43202	-2.43205	-0.00004	0.00004	0.00001	-2.43206
7000	-2.83766	-2.83768	-2.83770	0.00004	0.00002	0.00000	-2.83770
8000	-3.24342	-3.24339	-3.24341	-0.00003	0.00000	-0.00002	-3.24339
9000	-3.64917	-3.64913	-3.64913	-0.00003	0.00001	0.00001	-3.64914
10000	-4.05493	-4.05491	-4.05489	-0.00002	0.00000	0.00002	-4.05491

The following polynomial equation, described in ASTM E74-13 has been fitted to the force and deflection values obtained in the calibration using the method of least squares.

response = A0 + A1(load) + A2(load)^2 + A3(load)^3

Where:
A0 -1.83106052E-5
A1 -4.05005379E-4
A2 -6.6717265E-11
A3 1.8297849E-15

load = B0 + B1(response) + B2(response)^2 + B3(response)^3

Where:
B0 -4.47730993E-2
B1 -2.46910115E+3
B2 -1.00215904E+0
B3 -6.79438426E-2

The following values as defined in ASTM E74-13 were determined from the calibration data.
Lower Limit Factor, LLF 0.132 LBF

Class A Loading Range 200.00 TO 10000.00 LBF

Morehouse Instrument Co., Inc.
1742 Sixth Ave., York, PA 17403
Phone 717/843-0081
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Celebration of Knowledge!

Primary Standards - To be classified as a primary standard the masses of the weights shall be determined within 0.005 % of their values. Weights used as primary force standards require correction for local gravity and air buoyancy. It is very important the gravity value for the Laboratory's location be established. Not establishing and correcting for gravity could result in significant errors, up to twenty times that required by the ASTM E74-18 standard.

ASTM E74-18 defines a **secondary force standard** as an **instrument or mechanism**, the **calibration** of which has been established **by comparison with primary force standards**. To use a secondary force standard to perform a calibration in accordance with ASTM E74-18, the secondary force standard must be calibrated by comparison with primary force standards.

7 Steps for Evaluating Measurement Uncertainty

Note: Ensure that the *process of determining uncertainties is under statistical control before starting.*

1. ***Identify the uncertainties in the measurement process.***
2. ***Classify type of uncertainty (A or B).***
3. ***Quantify (evaluate and calculate) individual uncertainty by various methods.***
4. ***Document in an uncertainty budget.***
5. ***Combine uncertainty (Root Sum Square (RSS) method).***
6. ***Assign appropriate k factor multiplier to combined uncertainty to report expanded uncertainty.***
7. ***Document in an Uncertainty report with the appropriate information (add notes and comments for future reference).***

Standard Uncertainty Calculations

Uncertainty Calculations

- Primary calculations encountered are:
  - **Basic statistics (mean, range std. dev. variance etc.)**
  - **Standard Deviations (Sample and Population)**
  - **Other statistical methods may be useful:**
    - **Analysis of Variance**
    - **Gage R. & R.**
    - **Design of Experiments (DOE)**

Classify type of Uncertainty (A or B)

Uncertainty Evaluation Methods

Assess uncertainty (and assign uncertainty type A or B).

<u>Type A evaluation method:</u>

The method of evaluation of uncertainty of measurement by the statistical analysis of series of observations.

<u>Examples:</u>

_Standard Deviation of a series of measurements

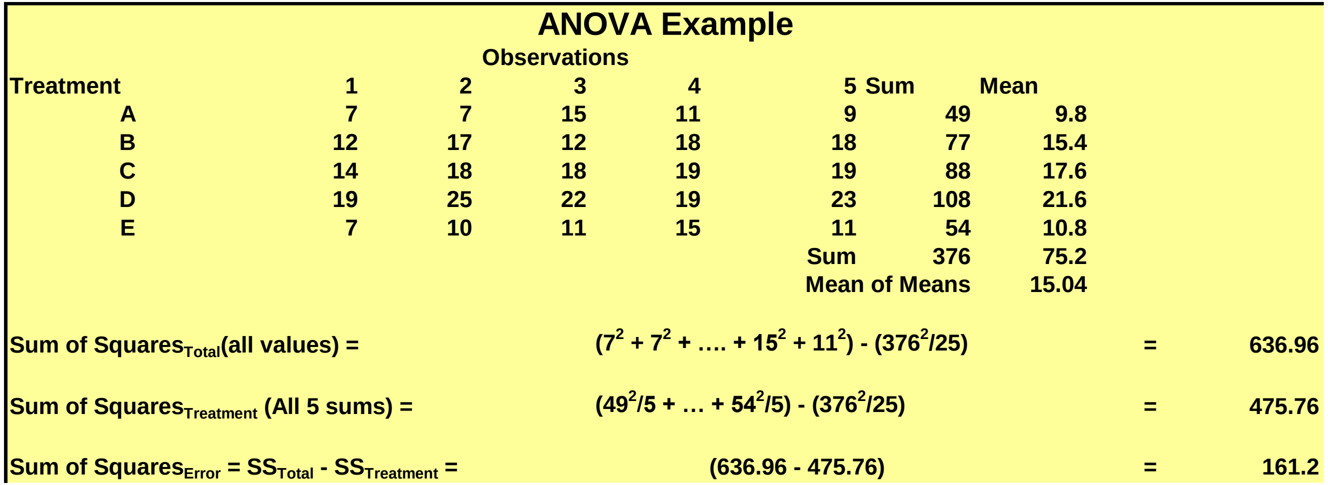
_Other statistical evaluation methods (ANOVA, DOE)

Type A Example

A series of measurements are taken to determine the uncertainty of measurement:

n	Measurement
1	1.000030
2	0.999966
3	0.999983
4	1.000012
5	0.999959
6	1.000019
7	0.999972
8	0.999993
9	1.000013
10	1.000046
Sum	9.999996
Mean	1.000000
Standard Deviation (Standard Uncertainty)	2.91633E-05

Analysis of Variance (ANOVA)



ANOVA Example

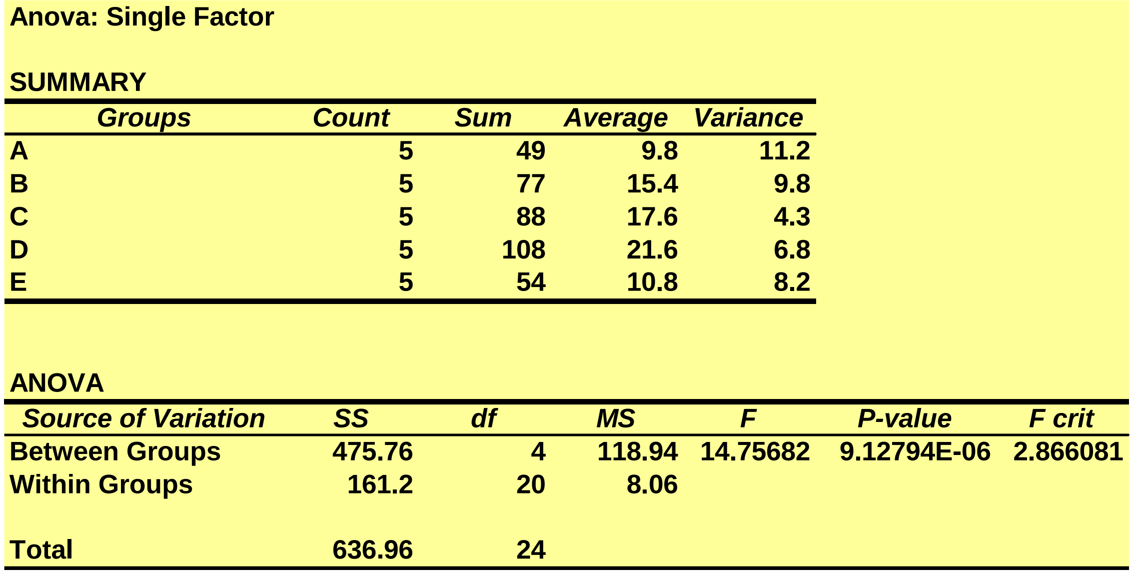
	Observations						
Treatment	1	2	3	4	5	Sum	Mean
A	7	7	15	11	9	49	9.8
B	12	17	12	18	18	77	15.4
C	14	18	18	19	19	88	17.6
D	19	25	22	19	23	108	21.6
E	7	10	11	15	11	54	10.8
					Sum	376	75.2
					Mean of Means		15.04

Sum of $\text{Squares}_{\text{Total}}$(all values) = $(7^2 + 7^2 + \ldots. + 15^2 + 11^2) - (376^2/25)$ = 636.96

Sum of $\text{Squares}_{\text{Treatment}}$ (All 5 sums) = $(49^2/5 + \ldots + 54^2/5) - (376^2/25)$ = 475.76

Sum of $\text{Squares}_{\text{Error}} = SS_{\text{Total}} - SS_{\text{Treatment}}$ = (636.96 - 475.76) = 161.2

Analysis of Variance (ANOVA)



Anova: Single Factor

SUMMARY

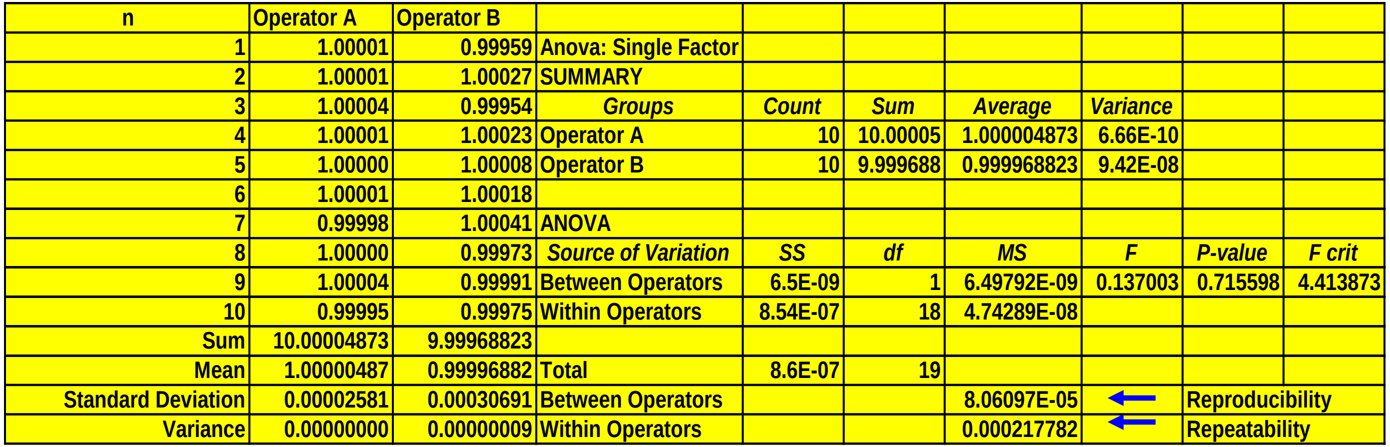
Groups	*Count*	*Sum*	*Average*	*Variance*
A	5	49	9.8	11.2
B	5	77	15.4	9.8
C	5	88	17.6	4.3
D	5	108	21.6	6.8
E	5	54	10.8	8.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	475.76	4	118.94	14.75682	9.12794E-06	2.866081
Within Groups	161.2	20	8.06			
Total	636.96	24				

Type A Example

Repeatability and Reproducibility Data

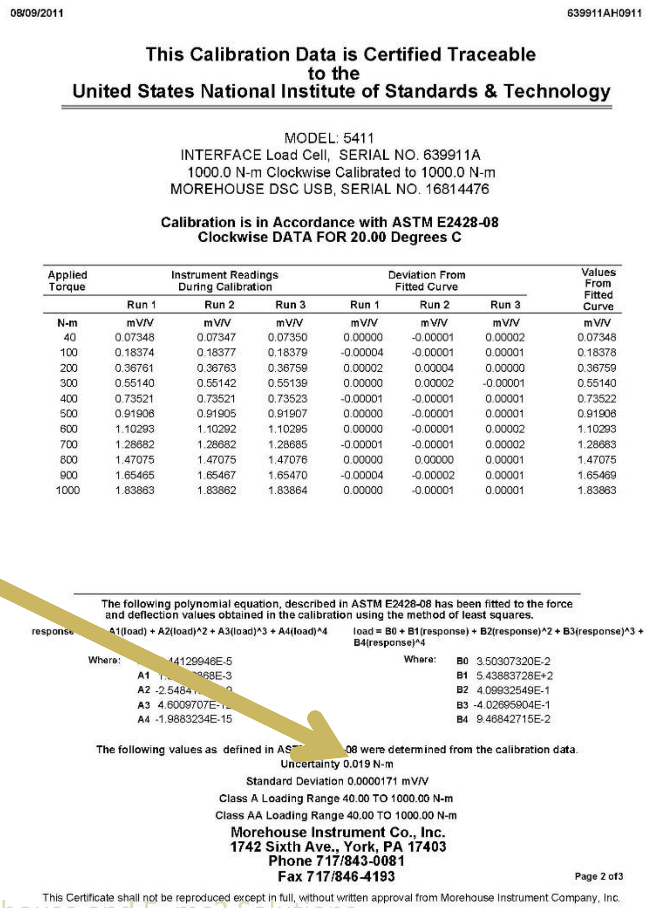


n	Operator A	Operator B							
1	1.00001	0.99959	Anova: Single Factor						
2	1.00001	1.00027	SUMMARY						
3	1.00004	0.99954	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
4	1.00001	1.00023	Operator A	10	10.00005	1.000004873	6.66E-10		
5	1.00000	1.00008	Operator B	10	9.999688	0.999968823	9.42E-08		
6	1.00001	1.00018							
7	0.99998	1.00041	ANOVA						
8	1.00000	0.99973	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
9	1.00004	0.99991	Between Operators	6.5E-09	1	6.49792E-09	0.137003	0.715598	4.413873
10	0.99995	0.99975	Within Operators	8.54E-07	18	4.74289E-08			
Sum	10.00004873	9.99968823							
Mean	1.00000487	0.99996882	Total	8.6E-07	19				
Standard Deviation	0.00002581	0.00030691	Between Operators			8.06097E-05	←	Reproducibility	
Variance	0.00000000	0.00000009	Within Operators			0.000217782	←	Repeatability	

Uncertainty

- Type A Example

- A series of measurements are taken to determine the Type A uncertainty of the measurement.



08/09/2011 639911AH0911

This Calibration Data is Certified Traceable
to the
United States National Institute of Standards & Technology

MODEL: 5411
INTERFACE Load Cell, SERIAL NO. 639911A
1000.0 N-m Clockwise Calibrated to 1000.0 N-m
MOREHOUSE DSC USB, SERIAL NO. 16814476

Calibration is in Accordance with ASTM E2428-08
Clockwise DATA FOR 20.00 Degrees C

Applied Torque	Instrument Readings During Calibration			Deviation From Fitted Curve			Values From Fitted Curve
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
N-m	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V
40	0.07348	0.07347	0.07350	0.00000	-0.00001	0.00002	0.07348
100	0.18374	0.18377	0.18379	-0.00004	-0.00001	0.00001	0.18378
200	0.36761	0.36763	0.36759	0.00002	0.00004	0.00000	0.36759
300	0.55140	0.55142	0.55139	0.00000	0.00002	-0.00001	0.55140
400	0.73521	0.73521	0.73523	-0.00001	-0.00001	0.00001	0.73522
500	0.91906	0.91905	0.91907	0.00000	-0.00001	0.00001	0.91906
600	1.10293	1.10292	1.10295	0.00000	-0.00001	0.00002	1.10293
700	1.28682	1.28682	1.28685	-0.00001	-0.00001	0.00002	1.28683
800	1.47075	1.47075	1.47076	0.00000	0.00000	0.00001	1.47075
900	1.65465	1.65467	1.65470	-0.00004	-0.00002	0.00001	1.65469
1000	1.83863	1.83862	1.83864	0.00000	-0.00001	0.00001	1.83863

The following polynomial equation, described in ASTM E2428-08 has been fitted to the force and deflection values obtained in the calibration using the method of least squares.

response A1(load) + A2(load)^2 + A3(load)^3 + A4(load)^4

Where: 44129946E-5
A1 1. 868E-3
A2 -2.54841
A3 4.6009707E-1
A4 -1.9883234E-15

load = B0 + B1(response) + B2(response)^2 + B3(response)^3 + B4(response)^4

Where: **B0** 3.50307320E-2
B1 5.43883728E+2
B2 4.09932549E-1
B3 -4.02695904E-1
B4 9.46842715E-2

The following values as defined in AS -08 were determined from the calibration data.

Uncertainty 0.019 N-m

Standard Deviation 0.0000171 mV/V

Class A Loading Range 40.00 TO 1000.00 N-m

Class AA Loading Range 40.00 TO 1000.00 N-m

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Uncertainty

- ASTM E2428 (TORQUE) and ASTME74 (FORCE) calibration test for the reproducibility and repeatability condition of measurement and is an example of Type A Uncertainties.

- The term used in these standards is Lower Limit Factor which applies a coverage factor of 2.4 for force and 2.0 for torque.

- If the equipment used to perform the test has a relatively low overall uncertainty, then a large percentage of the TTU (Total Test Uncertainty) will be quantified with reproducibility and repeatability

Classify type of Uncertainty (A or B)

Uncertainty Evaluation Methods

Assess uncertainty (and assign uncertainty type A or B).

Type B evaluation method:

The method of evaluation of uncertainty of measurement by means other than the statistical analysis of series of observations.

Examples:

_History of parameter

_Other knowledge of the process parameter

_Based on specification

_torque or load cell temperature effect, drift, resolution, etc.

Uncertainty

Type B Examples

- The temperature effect on force or torque cell output is ± 0.004 % per degrees Celsius

- The specification of the torque arm is ± 0.00006 inches

- Bending, cross-force, cosine error, etc.

Uncertainty Distributions

- **4 distributions are normally encountered when estimating Uncertainty:**
  - **Normal (Gaussian)**
  - **Rectangular**
  - **Triangular**
  - **U – shaped (trough)**

Uncertainty Distributions

- **One cannot combine <u>normal</u> (Gaussian) and "<u>non-normal"</u> distributions when combining uncertainties.**

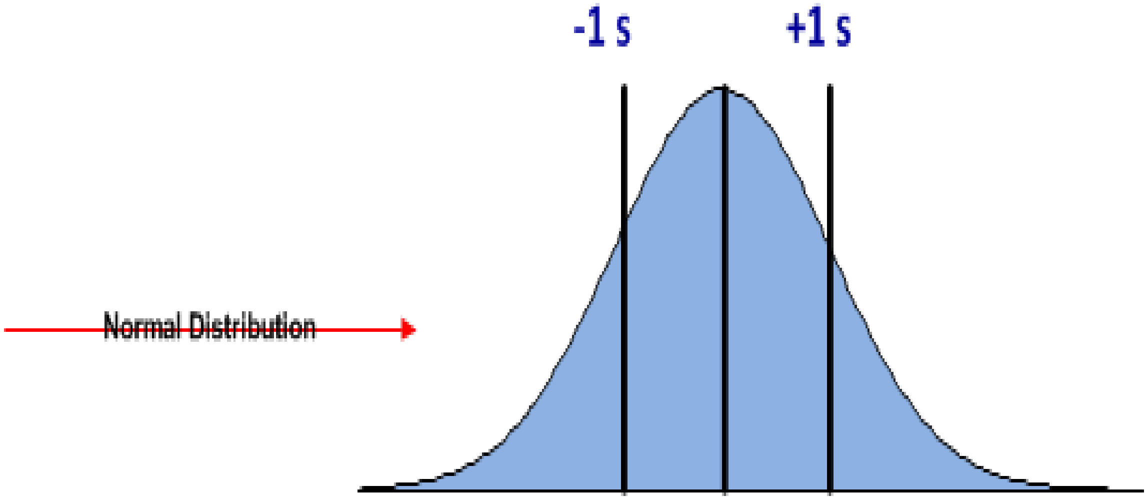
- **<u>Correction factors</u> apply when combining normal and non-normal distributions**.

Uncertainty Distributions

- **Normal Distribution**

- **Normal distribution is one way to evaluate uncertainty contributors so that they can be quantified and budgeted for. It allows a manufacturer to take into account prior knowledge, manufacturer's specifications, etc. Normal distribution helps understand the magnitude of different uncertainty factors and understand what is important.**
- **The normal distribution is used when there is a better probability of finding values closer to the mean value than further away from it, and one is comfortable in estimating the width of the variation by estimating a certain number of standard deviations.**

Normal Distribution
(1 Std. Deviation)

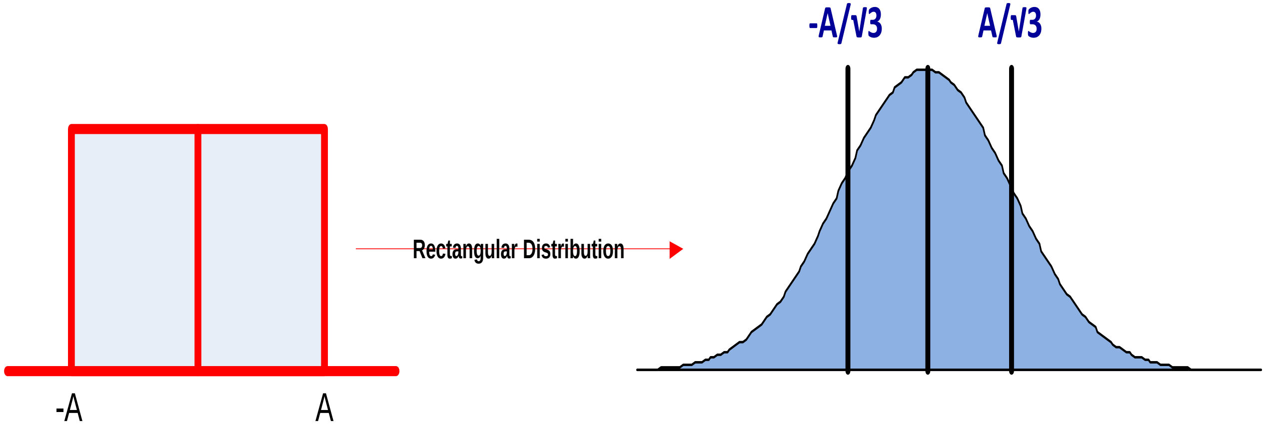


Uncertainty Distributions

- **<u>Rectangular Distribution</u>**

- **Rectangular distribution is the most conservative distribution. The manufacturer has an idea of the variation limits, but little idea as to the distribution of uncertainty contributors between these limits.**
- **It is often used when information is derived from calibration certificates and manufacturer's specifications.**

Rectangular Distribution to Standard Uncertainty (1 Std. Deviation)



Rectangular Distribution Example

A manufacturer specifies that the XYZ Gage has a specification of +/- 0.001 units.

The standard uncertainty for this ***rectangular distribution*** is:

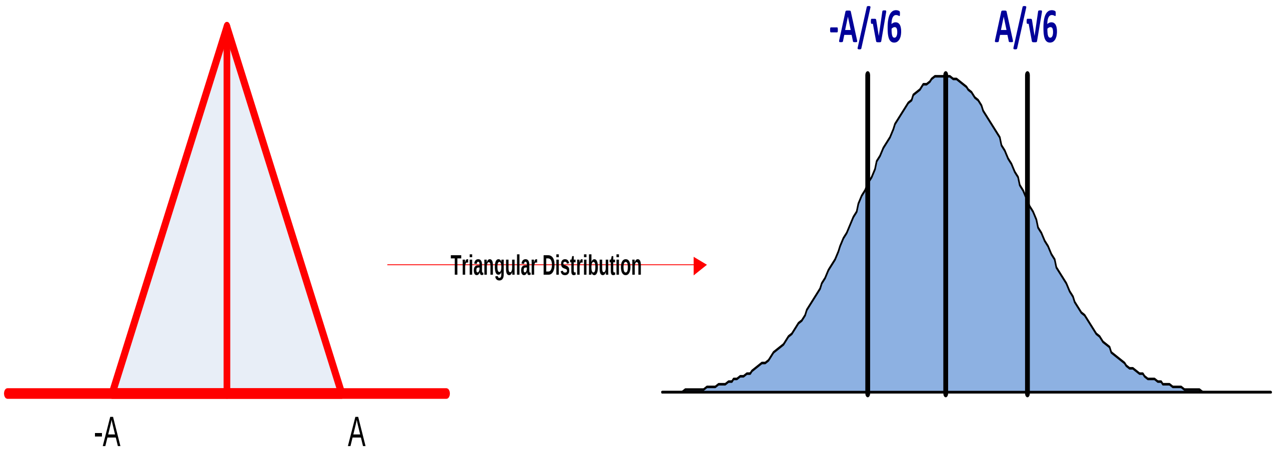
$$u = \frac{0.001}{\sqrt{3}} = 577.35E - 06$$

Uncertainty Distributions

- **Triangular Distribution**

- **Triangular distribution is often used in evaluations of noise and vibration. The manufacturer must be more comfortable estimating the width of variation using "hard" limits rather than a certain number of standard deviations.**
- **Typical examples of where triangular distribution is used are noise and vibration**

Triangular Distribution to Standard Uncertainty (1 Std. Deviation)



Triangular Distribution Example

A series of measurements taken indicate that most of the measurements fall at the center with a few spreading equally (±) 0.5 units away from the mean.

The standard uncertainty for this ***triangular distribution*** is:

$$u = \frac{0.5}{\sqrt{6}} = 204.124E - 03$$

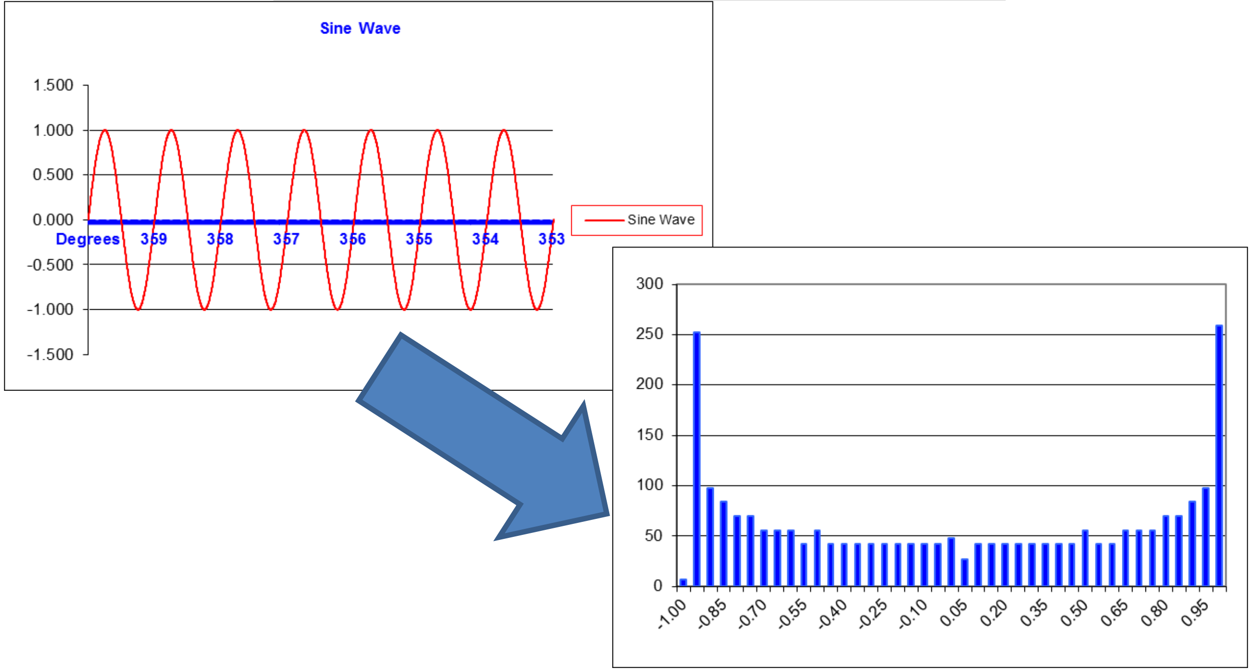
Uncertainty Distributions

- **U-shaped Distribution**

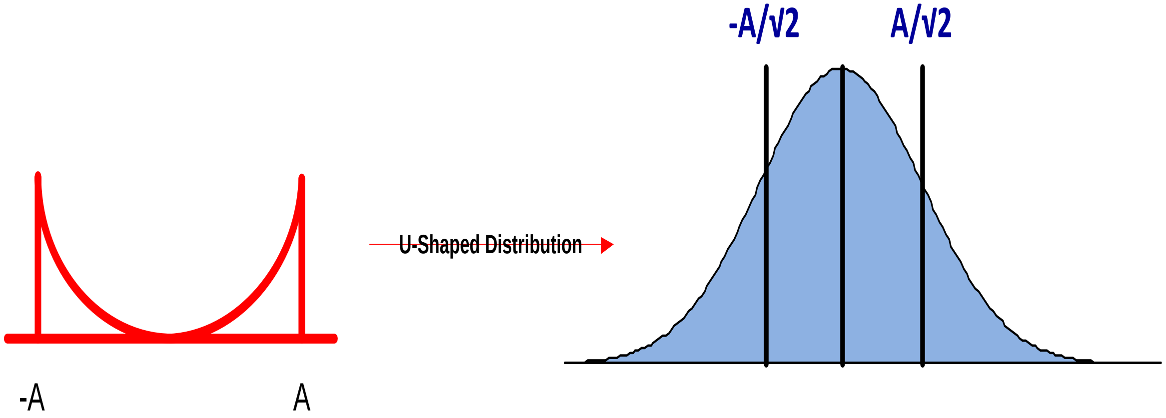
- **U-shaped distribution is attributed to cyclic events, such as temperature, often yield uncertainty contributors that fall into a sine wave type pattern.**
- **U-shaped distribution is the probability density function for a sine wave.**

Uncertainty Distributions

- **U-shaped Distribution**



U-Shaped Distribution to Standard Uncertainty (1 Std. Deviation)



U-Shaped Distribution Example

The temperature of the oil bath stated by the manufacturer is **100.000 +/- 0.20** Celsius.

The standard uncertainty for this ***U-shaped (trough) distribution*** is:

$$u = \frac{0.2}{\sqrt{2}} = 141.421E - 03$$

Uncertainty Distributions
Correction factors

Distribution	Divide by	Divisor	1/Divisor
Rectangular	Square-root 3	1.7321	0.5774
Triangular	Square-root 6	2.4495	0.4082
U - Shaped	Square-root 2	1.4142	0.7071
Resolution	Square-root 12	3.4641	0.2887

RESOLUTION BASED:

RESOLUTION = 0.001_ ← $^{0-4}_{5-9}$

$$0.001/(2\sqrt{3})$$

$$= 0.001/(\sqrt{2 \times 2 \times 3})$$

$$= 0.001/\sqrt{12}$$

$$= 0.000289$$

Quantify (evaluate and calculate) individual Uncertainty by various methods.

Calculate Uncertainty

Document in an Uncertainty Budget.

Uncertainty Budget Example:

TYPE A UNCERTAINTY	STD Uncert	Variance
Air Density	2.38E-05	5.66E-10
Repeated Observations	1.58E-02	2.50E-04
Indication	2.89E-03	8.35E-06

TYPE B UNCERTAINTY	STD Uncert	Variance
Weights	2.04E-02	4.16E-04
Density of Weights	1.30E-05	1.69E-10
Gravity Acceleration	2.05E-05	4.20E-10
Length of Arm	3.20E-04	1.02E-07
Temperature	6.93E-07	4.80E-13

Combine Uncertainty
(Root Sum Square (RSS) method).

$$u_{c_a} = \sqrt{u_{c_{a1}}{}^2 + u_{c_{a2}}{}^2 + \ldots\ldots}$$

$$u_{c_b} = \sqrt{u_{c_{b1}}{}^2 + u_{c_{b2}}{}^2 + \ldots\ldots}$$

Combine Uncertainty
(Root Sum Square (RSS) method).

$$u_c = \sqrt{{u_{c_a}}^2 + {u_{c_b}}^2}$$

Assign appropriate *k* factor multiplier to Combined Uncertainty to report expanded uncertainty.

Coverage Factor (k)	Confidence Level
1.000	68.27
1.645	90.00
1.960	95.00
2.000	95.45
2.576	99.00
3.000	99.73

Assign appropriate k factor multiplier to Combined Uncertainty to report expanded uncertainty.

$$U = k \cdot u_c$$

U also expressed as:

$U_{k=2}$ or $U_{95\%}$

Assign appropriate k factor multiplier to Combined Uncertainty to report expanded uncertainty.

- ***k* coverage factor is normally 2 for *approximately 95%* confidence interval for infinite degrees of freedom.**

However, it may differ based on effective degrees of freedom.

Effective Degrees of Freedom

$$V_{eff} = \frac{u_c{}^4(y)}{\sum_{i=1}^{N} \frac{c_i{}^4 u^4(x_i)}{v_i}}$$

Welch-Satterthwaite Formula

Effective Degrees of Freedom

Once effective degrees of freedom is calculated, The Student's *t*-table is referenced to obtain the correct *k* coverage factor multiplier.

Exercise

Identify (Type A or B) and calculate the uncertainty for the following:

Explain your reasoning.

Uncertainty value 3.2 with a **95% level of confidence** and ***k*** **coverage factor of 1.96.**

DISTRIBUTION: EXPANDED UNCERTAINTY (*k*=1.96)

BASED ON *k*=1.96 (Expanded Uncertainty):

3.2/1.96 = 1.63

Exercise

Identify (Type A or B) and calculate the uncertainty for the following:

Explain your reasoning.

A digital indicating multi meter with a **+/-0.5-digit resolution.**

DISTRIBUTION: RESOLUTION BASED:

$$0.5/\sqrt{3} = 0.289$$

or

$$0.5/\sqrt{12} = 0.144$$

Exercise

Identify (Type A or B) and calculate the uncertainty for the following:

Explain your reasoning.

Morehouse load cell's side-load sensitivity is specified at:

0.05 %/inch. Typical Morehouse Universal Calibrating Machines demonstrate a misalignment of less than 1/16 inch

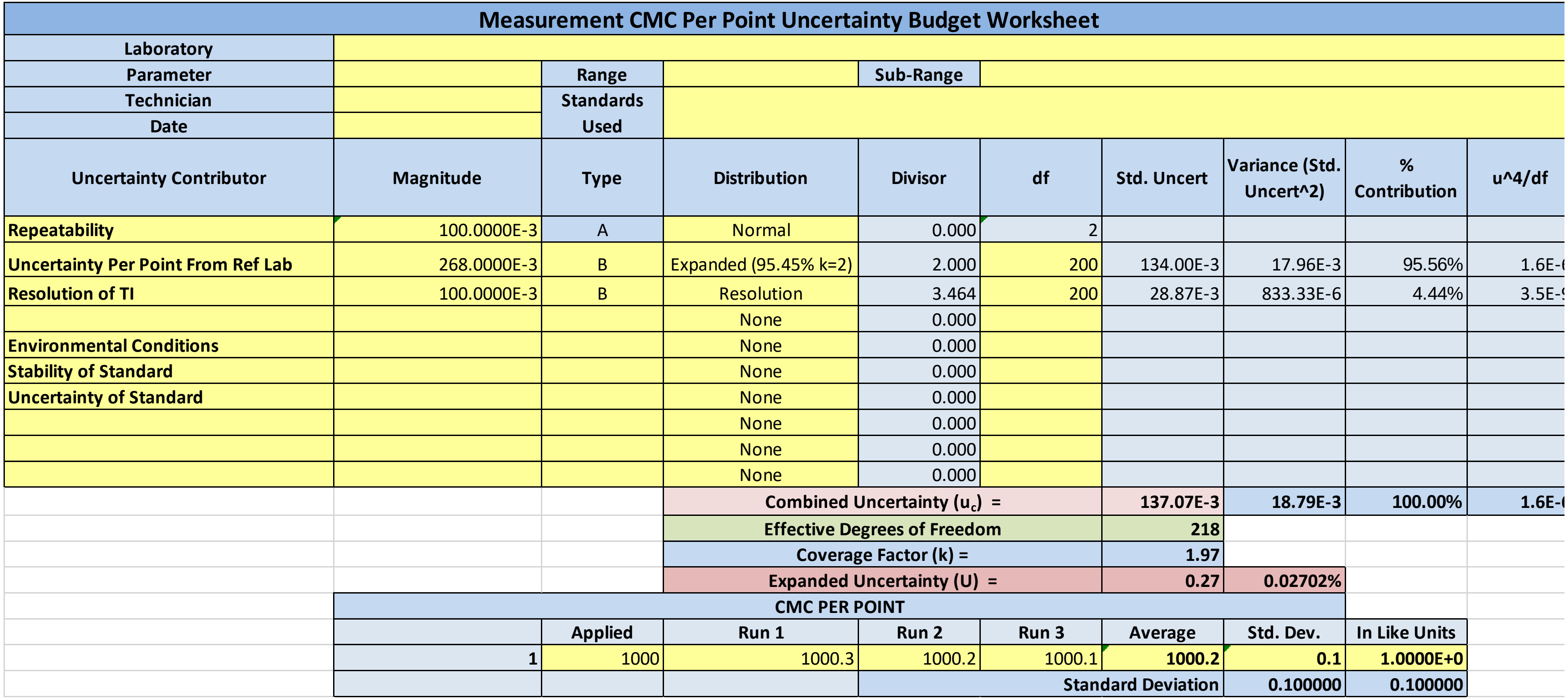
DISTRIBUTION: RECTANGULAR:

(0.05% x 0.0625 inch)/√3 = 18.04E-6

Development of a Measurement Uncertainty Spreadsheet

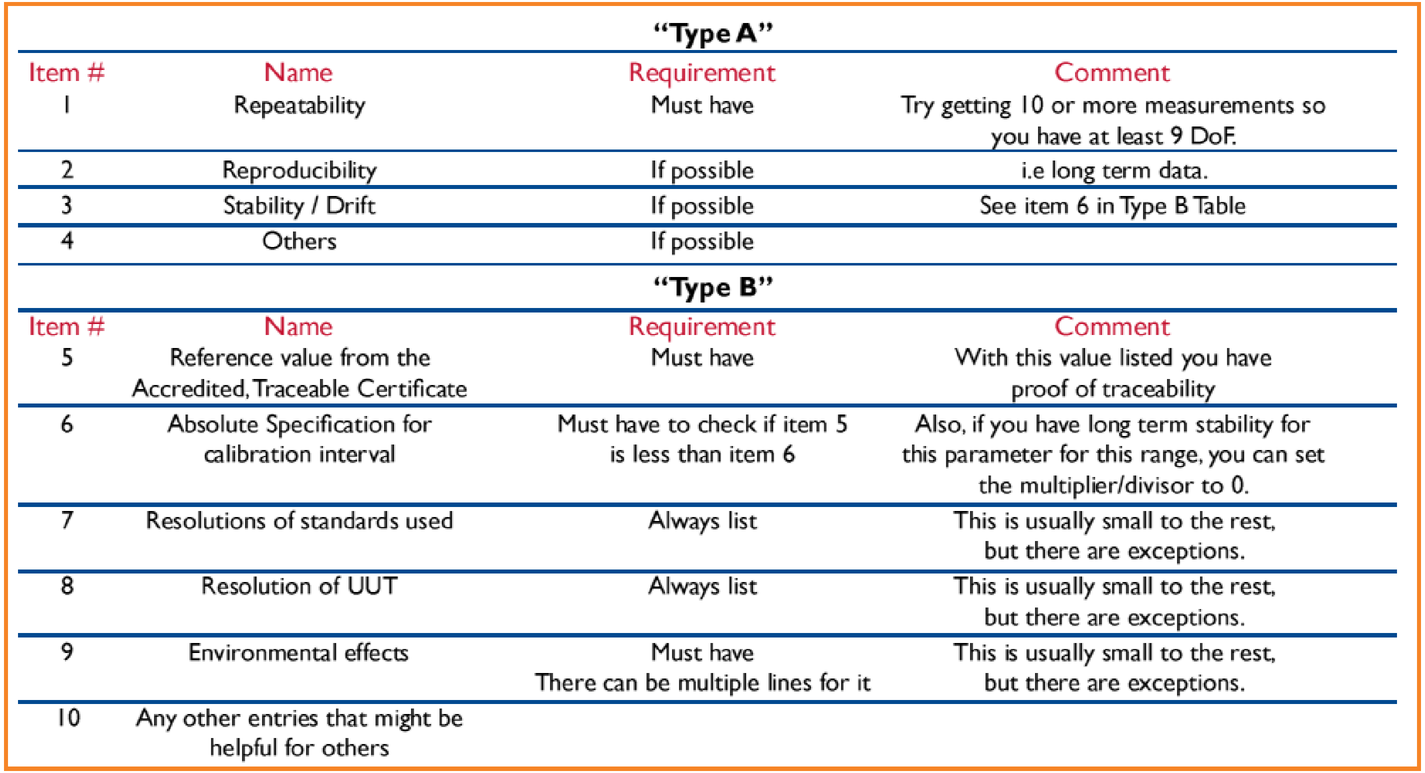
Development of a Measurement Uncertainty Spreadsheet

1. **Collect data**
2. **Apply spreadsheet functions**
3. **Verify and validate data calculations using other method such as a calculator.**
4. **Design the spreadsheet template**
5. **Apply correction factors as applicable**
6. **Enter data (see 3. above)**



Measurement CMC Per Point Uncertainty Budget Worksheet									
Laboratory									
Parameter		**Range**		**Sub-Range**					
Technician		**Standards Used**							
Date									
Uncertainty Contributor	**Magnitude**	**Type**	**Distribution**	**Divisor**	**df**	**Std. Uncert**	**Variance (Std. Uncert^2)**	**% Contribution**	**u^4/df**
Repeatability	100.0000E-3	A	Normal	0.000	2				
Uncertainty Per Point From Ref Lab	268.0000E-3	B	Expanded (95.45% k=2)	2.000	200	134.00E-3	17.96E-3	95.56%	1.6E-
Resolution of TI	100.0000E-3	B	Resolution	3.464	200	28.87E-3	833.33E-6	4.44%	3.5E-
			None	0.000					
Environmental Conditions			None	0.000					
Stability of Standard			None	0.000					
Uncertainty of Standard			None	0.000					
			None	0.000					
			None	0.000					
			None	0.000					
			Combined Uncertainty (u_c) =			**137.07E-3**	**18.79E-3**	**100.00%**	**1.6E-**
			Effective Degrees of Freedom			**218**			
			Coverage Factor (k) =			**1.97**			
			Expanded Uncertainty (U) =			**0.27**	**0.02702%**		
	CMC PER POINT								
		Applied	**Run 1**	**Run 2**	**Run 3**	**Average**	**Std. Dev.**	**In Like Units**	
	1	1000	1000.3	1000.2	1000.1	**1000.2**	**0.1**	**1.0000E+0**	
				Standard Deviation			**0.100000**	**0.100000**	

Basic Contributors to Measurement Uncertainty to Consider *(Source A2LA June 2009 Newsletter)*



"Type A"

Item #	Name	Requirement	Comment
1	Repeatability	Must have	Try getting 10 or more measurements so you have at least 9 DoF.
2	Reproducibility	If possible	i.e long term data.
3	Stability / Drift	If possible	See item 6 in Type B Table
4	Others	If possible	

"Type B"

Item #	Name	Requirement	Comment
5	Reference value from the Accredited, Traceable Certificate	Must have	With this value listed you have proof of traceability
6	Absolute Specification for calibration interval	Must have to check if item 5 is less than item 6	Also, if you have long term stability for this parameter for this range, you can set the multiplier/divisor to 0.
7	Resolutions of standards used	Always list	This is usually small to the rest, but there are exceptions.
8	Resolution of UUT	Always list	This is usually small to the rest, but there are exceptions.
9	Environmental effects	Must have There can be multiple lines for it	This is usually small to the rest, but there are exceptions.
10	Any other entries that might be helpful for others		

Uncertainty

- A2LA Policy R205 - A2LA Policy on Measurement Uncertainty in Calibration
- A2LA Policy R205 states:
- “Every measurement uncertainty shall take into consideration the following standard contributors, even in the cases where they are determined to be insignificant, and documentation of the consideration shall be made”

Uncertainty

These uncertainty contributors are:

- **R**epeatability (Type A)
- **R**esolution
- **R**eproducibility
- **R**eference Standard Uncertainty
- **R**eference Standard Stability
- **E**nvironmental Factors

Uncertainty

Determining the Uncertainty of a Measurement (UOM) is different from the practice of Determining the Expected Performance of a Device.

What does this mean?

Celebration Of Knowledge

Can you?

- Explain the difference between accuracy and uncertainty?
- Start to explain what may be included in a measurement uncertainty analysis (5Rs and an E)
- Type A example ?
- Type B example ?

Course Agenda

What questions do you have?

- Common Types of Force Measuring Instrumentation
- Troubleshooting a load cell
- Calibration Traceability and Force Standards
- ASTM E74
- Uncertainty

Sometimes this applies

Agenda

- Force Potential Measurement Errors
- Uncertainty Analysis

Learning Objectives

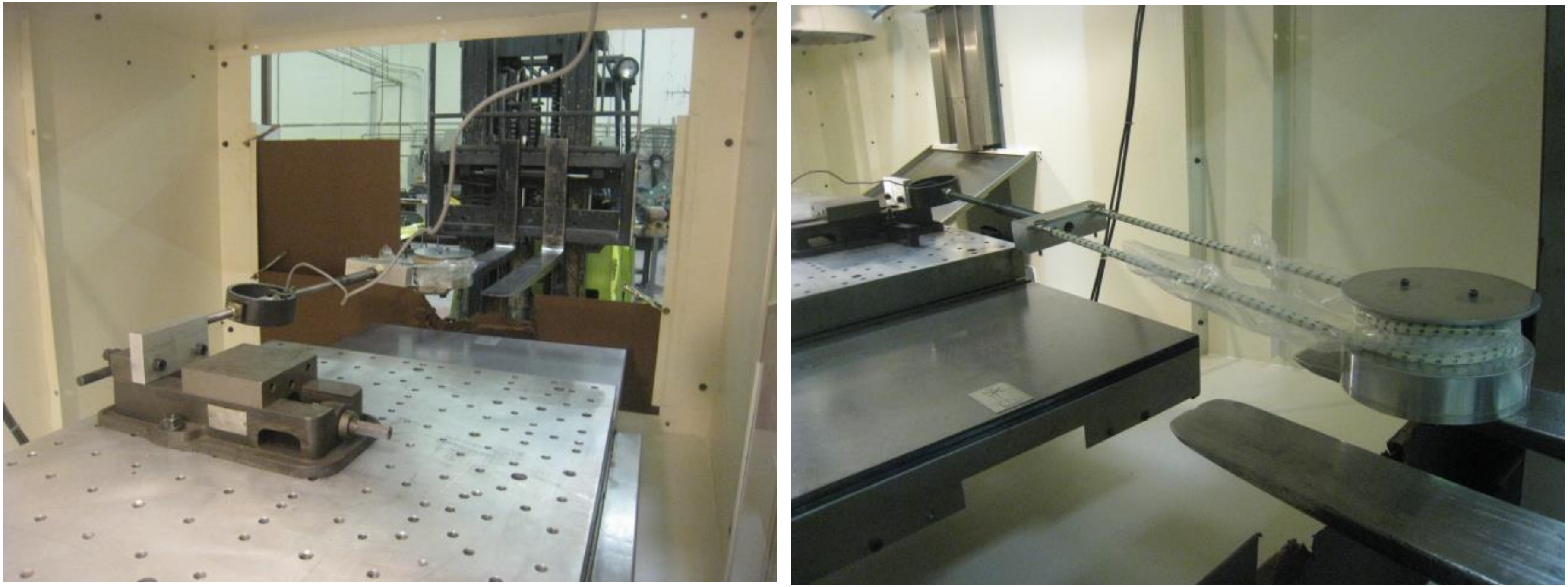
By the end of this section, you should be able to

- Identify potential force measurement errors.
- Reduce and/or quantify the uncertainty associated with these errors in your uncertainty analysis for force measurement at your calibration facility.
- Implement proper force calibration techniques as discussed in the class.
- Using material provided in the training class, put together an expanded uncertainty budget for force equipment used as secondary standards.

Force Potential Measurement Errors

- Cable Stiffness and Mounting
- Using Mass Weights instead of Force Weights
- Misalignment
- Different Hardness of Top Adapters
- Thread Depth – Shoulder Loading Versus Thread Loading
- Loading through the bottom threads in compression
- Cable Length - (Covered earlier)
- Other Error Sources

Pull Test with a Model 45C?



What do you think was the cause of this?

[Force Safety Blog](#)

Cable Stiffness and Mounting

Cable Stiffness may influence the measurement if it provides a parallel load path. On smaller cells, this effect can be very significant.

It is often recommended that the transducer be oriented so that the “live end” is mounted towards where the force is being generated from.

Using Mass Instead of Force Weights

- It is very important that the gravitational value for the Laboratory is established. The effect of not doing this could be a variation in the force produced by the weight of perhaps 0.1 % or more of reading. It is therefore strongly recommended that you establish the local value of gravity (g) for your Laboratory and use weights that have been calibrated at that gravitational constant.
- The ideal solution is to have the gravity measured on site by the national geological survey agency.

Gravity Correction

- There are several formulae, usually based on latitude and sometimes altitude above sea level. These are quite inaccurate, often being incorrect by 800-900 milligals, or about 0.1 %. Obviously, these may be used if the stated uncertainty of a measurement is correspondingly coarse, but it’s not a good idea.

Converting Force (lbf) to Mass(lbs)

Exercise

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

CM = Conventional Mass of the artifact. The conventional mass is defined as the mass of material of a specified density that would exactly balance the unknown object if the weighing were carried out at a temperature 20 °C in air of density 0.0012 g/cm3.

Additional Information

Using Mass Weights for Force

Converting Force (lbf) to Mass(lbs)

The Correct Method that should be used for weighing different material

- **Step 1. Obtain Measured Force Value**
  10,000 lbf
- **Step 2. Find the gravity at the location of the measurement**
  9.79620 m/s^2

- **Step 3. Find Air Density and Material Density (or use conventional mass formula)**
  For Denver, at around 24 degrees C Air Density may be estimated at 0.960 kg/m3 and Material density assuming Stainless Steel is 7916.453 kg /m3

- **Step 4. Use the following Formula**
  Mass = Force x 9.80665/(local gravity*(1-d/D)

Mass = 10,000 lbf x 9.80665/(9.79620*(1-0.960/7916.453))

Mass = 10,011.89 lbs

Converting Force (lbf) to Mass(lbs)

Find the gravity at the location of the measurement

- Use https://www.geoplaner.com/ to get the Longitude and Latitude

- http://www.ngs.noaa.gov/TOOLS/Gravity/gravcon.html

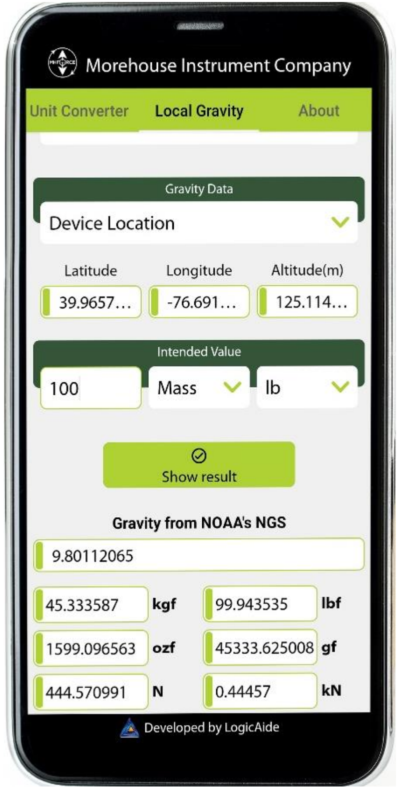
Gravity Correction

- The expanded uncertainty from this calculation is likely to be within 5 ppm anywhere in the US. This uncertainty value (as a maximum), or the actual reported value, belongs in any uncertainty budget for pressure, etc., as described above. Of course, the mean value of g reported must also be applied to the actual measurement data as a correction.

- You can also hire survey firms or universities to visit your location and measure the actual values. It's not possible to do better than about 0.5 mgal this way because, even though the daily changes in g can be averaged by a survey, a single calibration or measurement of a customer's UUT will not take these daily changes into account.

- The last 2 slides on Gravity Correction came from a paper from Philip Stein.

Converting Force (lbf) to Mass(lbs)



Gravity Data

Device Location

Latitude	Longitude	Altitude(m)
39.9657…	-76.691…	125.114…

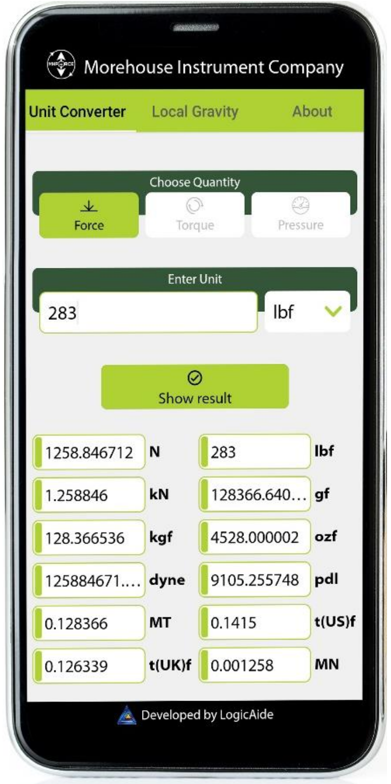
Intended Value

100 Mass lb

Gravity from NOAA's NGS

9.80112065

45.333587	kgf	99.943535	lbf
1599.096563	ozf	45333.625008	gf
444.570991	N	0.44457	kN

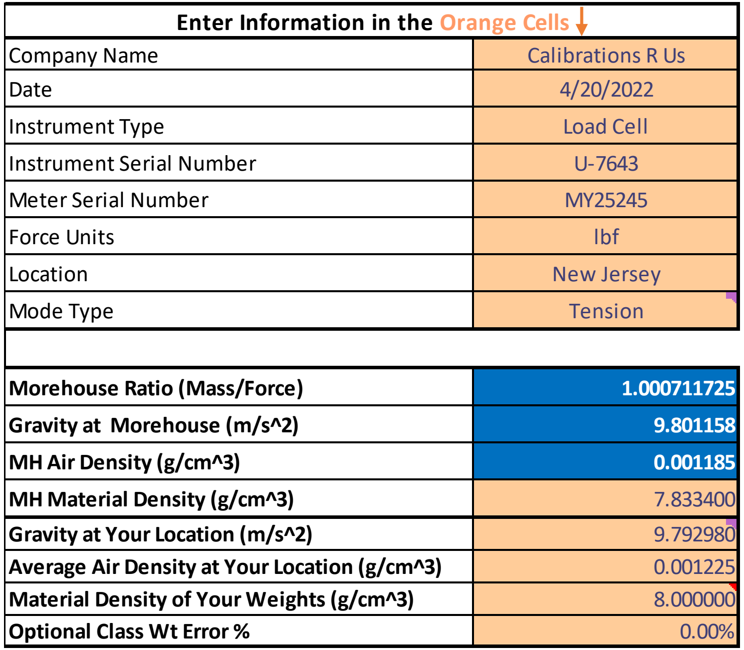


Enter Unit

283 lbf

1258.846712	N	283	lbf
1.258846	kN	128366.640…	gf
128.366536	kgf	4528.000002	ozf
125884671….	dyne	9105.255748	pdl
0.128366	MT	0.1415	t(US)f
0.126339	t(UK)f	0.001258	MN

MHFORCE Morehouse THE FORCE IN CALIBRATION SINCE 1925



Enter Information in the Orange Cells

Company Name	Calibrations R Us
Date	4/20/2022
Instrument Type	Load Cell
Instrument Serial Number	U-7643
Meter Serial Number	MY25245
Force Units	lbf
Location	New Jersey
Mode Type	Tension

Morehouse Ratio (Mass/Force)	**1.000711725**
Gravity at Morehouse (m/s^2)	**9.801158**
MH Air Density (g/cm^3)	**0.001185**
MH Material Density (g/cm^3)	7.833400
Gravity at Your Location (m/s^2)	9.792980
Average Air Density at Your Location (g/cm^3)	0.001225
Material Density of Your Weights (g/cm^3)	8.000000
Optional Class Wt Error %	0.00%

https://mhforce.com/wp-content/uploads/2022/05/Force-to-Mass-1.xlsx

Converting Force (lbf) to Mass(lbs)

Force to Mass						
MH Force	MH Mass	Mass Req'd at Customer Site	Customer Mass Weight	Force Applied by Customer Weight	Gravity Error	Total Error Diff
250.0	250.1779	250.3873	250.00	249.61	-0.084%	0.1547%
500.0	500.3559	500.7746	500.00	499.23	-0.084%	0.1547%
1000.0	1000.7117	1001.5493	1000.00	998.45	-0.084%	0.1547%
1500.0	1501.0676	1502.3239	1500.00	1497.68	-0.084%	0.1547%
2000.0	2001.4234	2003.0985	2000.00	1996.91	-0.084%	0.1547%
2500.0	2501.7793	2503.8732	2500.00	2496.13	-0.084%	0.1547%
3000.0	3002.1352	3004.6478	3000.00	2995.36	-0.084%	0.1547%

Note: This sheet is to calculate potential differences from force to Mass. A full Measurement Uncertainty budget still needs to be created if using mass weights for a force application.

The Importance of Adapters

Keeping the line of force pure (free from eccentric forces) is key to the calibration of load cells. ASTM E74 does not address the various adapter types, but ISO 376 does.

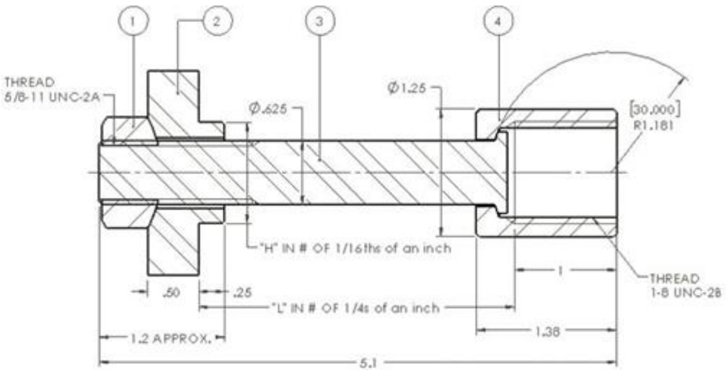
Alignment

- The position of the unit under test in relation to the force being applied or measured that influences the introduction of bending moments into the instrument under test during compression or tension loading.

Alignment is key

- In compression, using a ball adapter (pictured right) if the machine has a ball adapter often yields the best results. If a ball adapter does not exist, a spherical alignment adapter (pictured left) will help align the force.
- From the previous slides, some load cells are just more sensitive to alignment and thread engagement issues making adapters even more critical.

ISO 376: 2011 (International Standard)



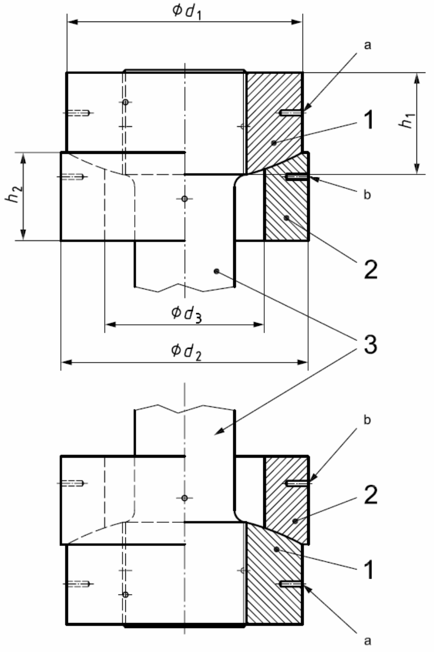
ISO 376 recognizes the importance of adapters in reproducibility conditions of the measurement. Proper adaptor use in accordance with ISO 376 Annex A, helps ensure the reliability of reported measurements. Note: Annex A is not a requirement for labs to adhere to.

A.4 Loading fittings

A.4.1 General

- Loading fittings should be designed in such a way that the line of force application is not distorted. As a rule, tensile force transducers should be fitted with two ball nuts, two ball cups and, if necessary, with two intermediate rings, while compressive force transducers should be fitted with one or two compression pads.

ISO 376 Morehouse Tension Adapters



Tensile force transducers should be fitted with two ball nuts, two ball cups

Old Adapters Can Have Issues

- Service life of force calibration adapters depend on the several factors including design, number of load cycles, and magnitude of each load.
- Better material manufacturing and quality control processes provide more reliable strength values for design engineers than 20 years ago.
- It is recommended that old adapters be inspected and replaced if they have been used for more than 20 years or 100,000 load cycles (10,000 calibrations)

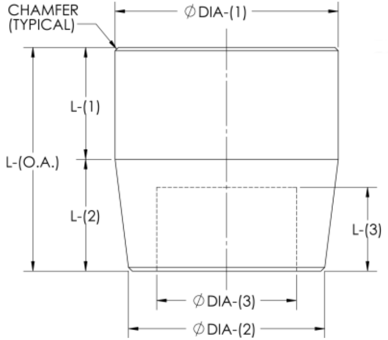
The Wrong Tension Adapters

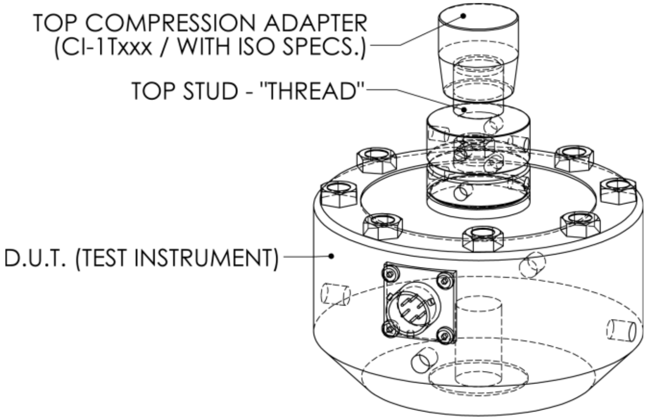


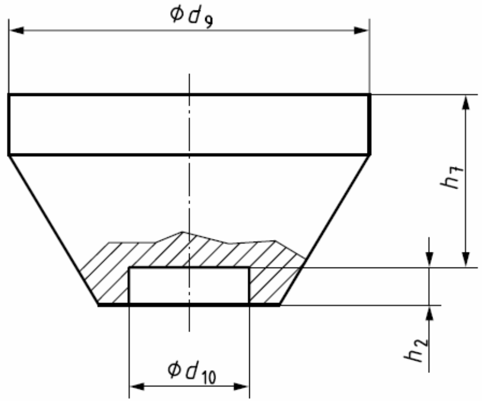
- If any of these look like tension adapters in your calibration lab, there is a problem.
- Even straight threaded rod can introduce misalignment issues as they can distort the line of force in non Morehouse machines.
- Any machine misalignment of 0.01 degrees can affect the reproducibility of some load cells. Even our spherical adapters can only overcome about 0.1 degree of misalignment.

ISO 376 Compression Adapters

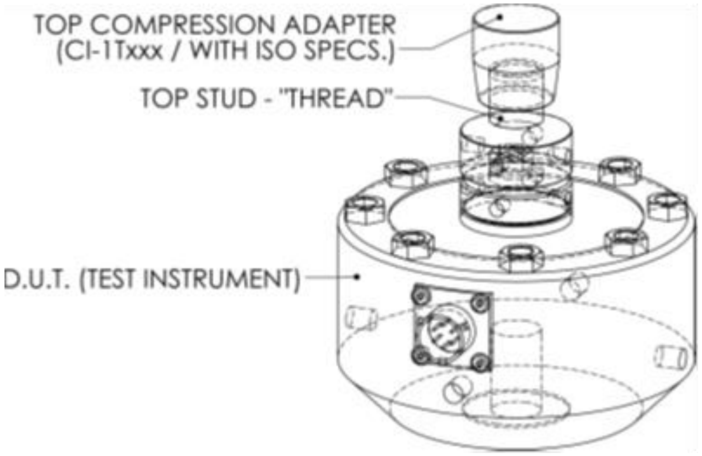
- Compressive force transducers should be fitted with one or two compression pads







Morehouse Compression Adapters



- Pictured above is a ISO 376 recommended compression adapters

Link to Concrete 600K set with adapters

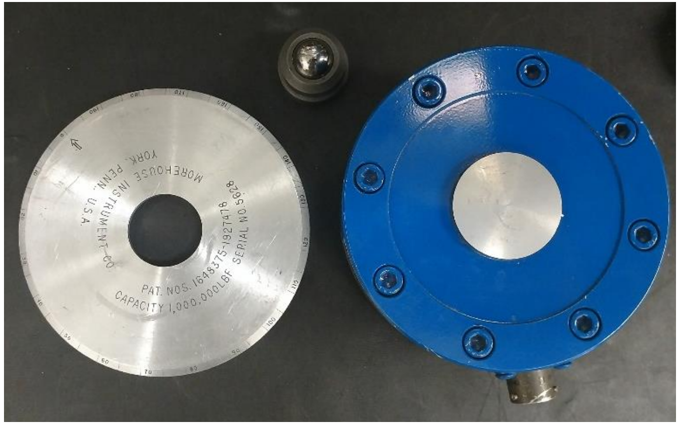
The Importance of Adapters

- Best practice is to send any top blocks or plates with the load cell being calibrated.
- Each load cell should have top blocks and they should be ground flat.
- Using Tension Adapters with a steep spherical radius will provide a better vertical line of force, producing better results.

Misalignment

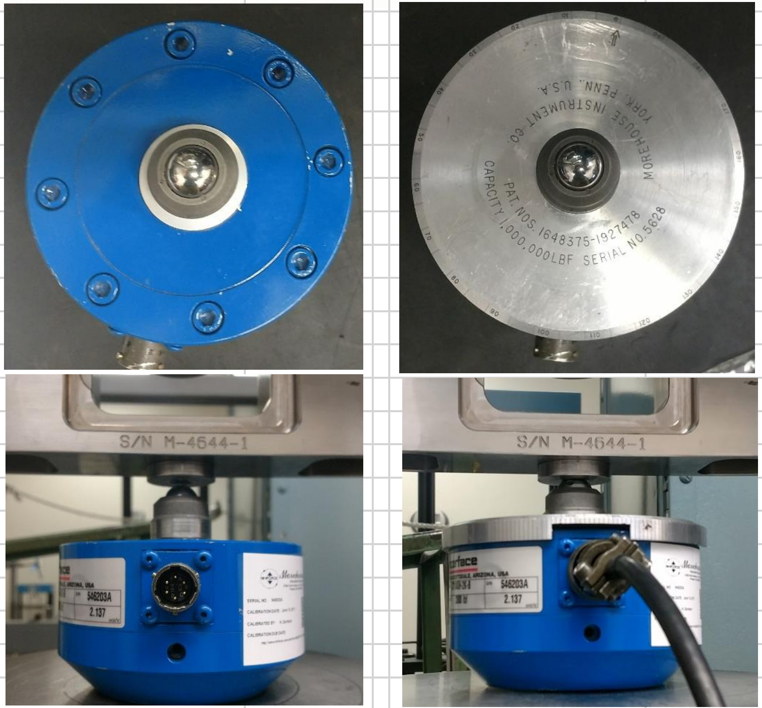
- For compression loading, a load pad or button can be used and the surface should be ground flat.
- We have shown large deviations on ASTM E74 calibrations by using a beat-up, non-flat pad.
- For tension, it is recommended to use adapters with a spherical to reduce additional bending moments.

Misalignment



Compression only load cell that is compensated for off center loading

Manually Aligned versus Misaligned in Morehouse Deadweight



Manually Aligned	Data
0 degree	1998.6
120 degree	1998.7
240 degree	1998.5
Average	1998.6
Standard Deviation	0.1
Max Deviation	0.2
% Error	0.010%

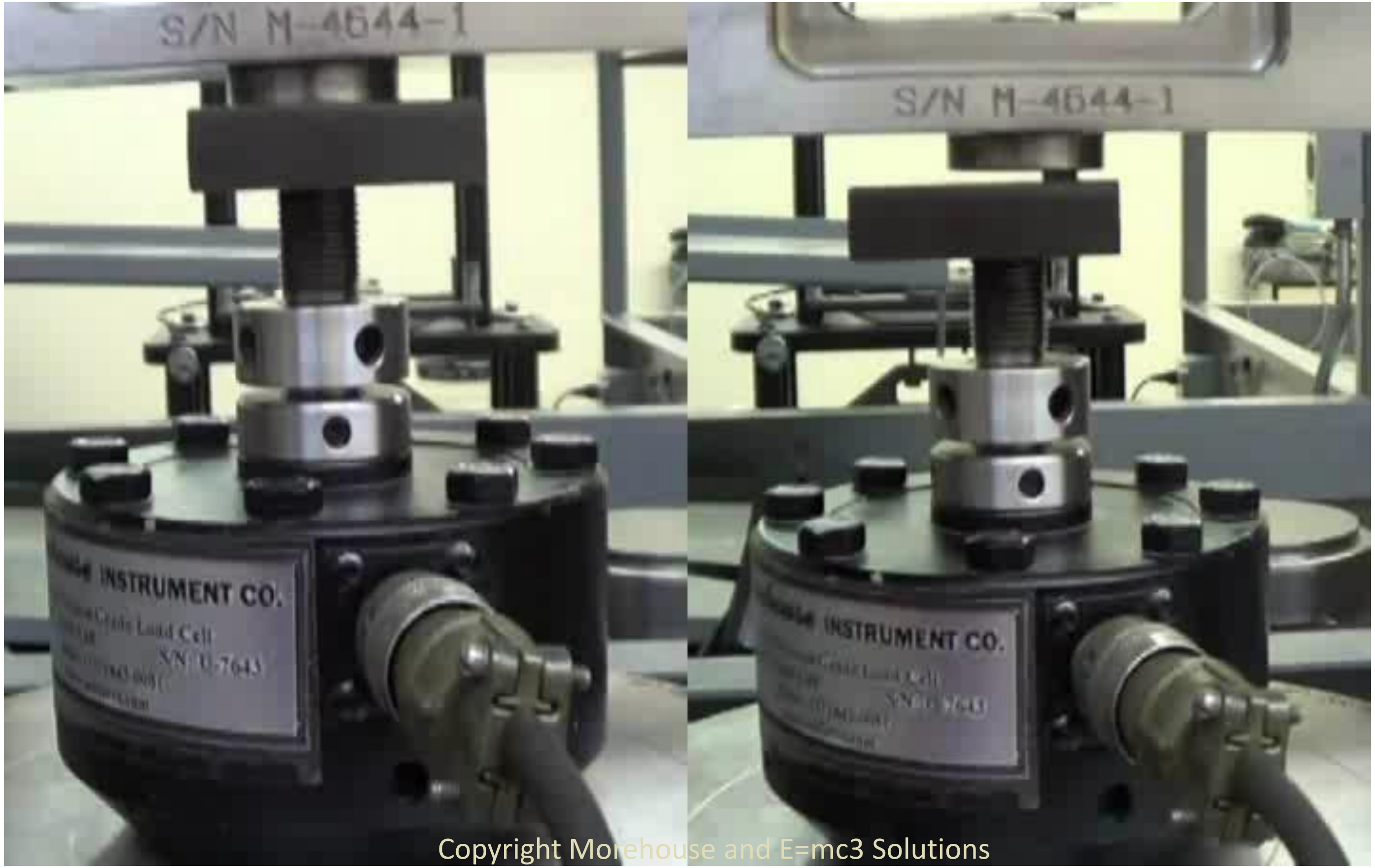
Aligned with Adapter	Data
0 degree	1998.8
120 degree	1998.8
240 degree	1998.8
Average	1998.8
Standard Deviation	0
Max Deviation	0
% Error	0.000%

Misalignment

- A well aligned calibration machine may demonstrate bending less than 2 %.   Some transducers also specify this error. The % can usually be found on the load cell spec sheet under Side Load Sensitivity.
- The use of proper calibration adapters are required to minimize this error.

- Morehouse UCM 1/16 inch possible misalignment.

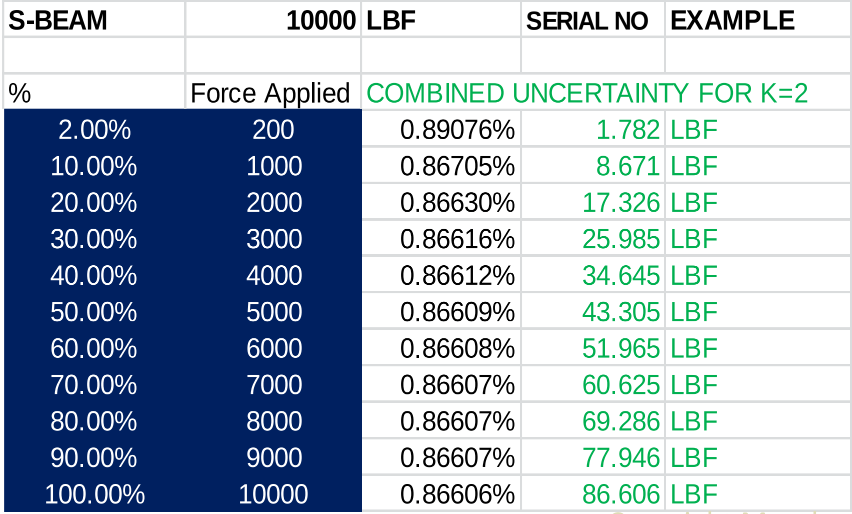
Misalignment VIDEO Shear web cell



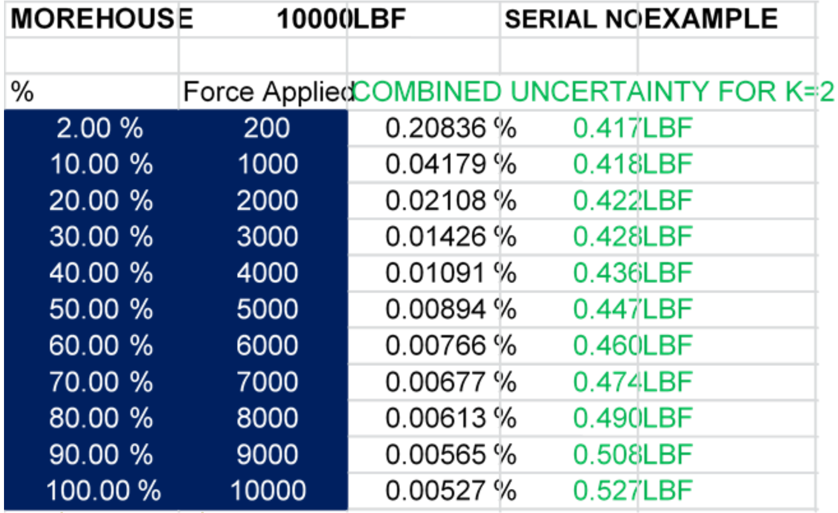
Misalignment VIDEO Shear web cell

Note: From the previous video with the S-beam cell the error observed was 0.75 % on the S-Type cell and 0.0022 % on the Morehouse Shear Web cell.
Assume both load cells had an ASTM E74 LLF = 0.5 LBF

S-BEAM WITH 0.75 % VERSUS MOREHOUSE WITH 0.0022 %



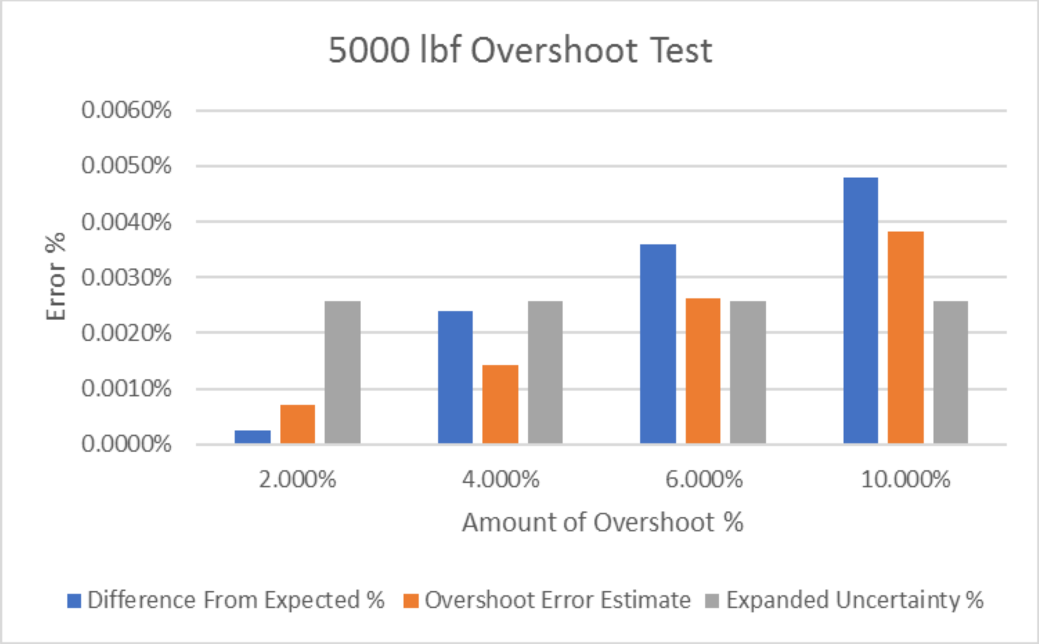
S-BEAM	10000	LBF	SERIAL NO	EXAMPLE
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00%	200	0.89076%	1.782	LBF
10.00%	1000	0.86705%	8.671	LBF
20.00%	2000	0.86630%	17.326	LBF
30.00%	3000	0.86616%	25.985	LBF
40.00%	4000	0.86612%	34.645	LBF
50.00%	5000	0.86609%	43.305	LBF
60.00%	6000	0.86608%	51.965	LBF
70.00%	7000	0.86607%	60.625	LBF
80.00%	8000	0.86607%	69.286	LBF
90.00%	9000	0.86607%	77.946	LBF
100.00%	10000	0.86606%	86.606	LBF



MOREHOUSE	10000	LBF	SERIAL NO	EXAMPLE
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00 %	200	0.20836 %	0.417	LBF
10.00 %	1000	0.04179 %	0.418	LBF
20.00 %	2000	0.02108 %	0.422	LBF
30.00 %	3000	0.01426 %	0.428	LBF
40.00 %	4000	0.01091 %	0.436	LBF
50.00 %	5000	0.00894 %	0.447	LBF
60.00 %	6000	0.00766 %	0.460	LBF
70.00 %	7000	0.00677 %	0.474	LBF
80.00 %	8000	0.00613 %	0.490	LBF
90.00 %	9000	0.00565 %	0.508	LBF
100.00 %	10000	0.00527 %	0.527	LBF

Overshooting a Force Point

Force Applied	% Overshoot	Output	Diff from expected %	Repeatability Error %	Overshoot Error Estimate
5000	0%	-4.18260	0	0.0010%	
5000	2%	-4.18259	0.0002%	0.0010%	-0.0007%
5000	4%	-4.1827	0.0024%	0.0010%	0.0014%
5000	6%	-4.18275	0.0036%	0.0010%	0.0026%
5000	10%	-4.1828	0.0048%	0.0010%	0.0038%

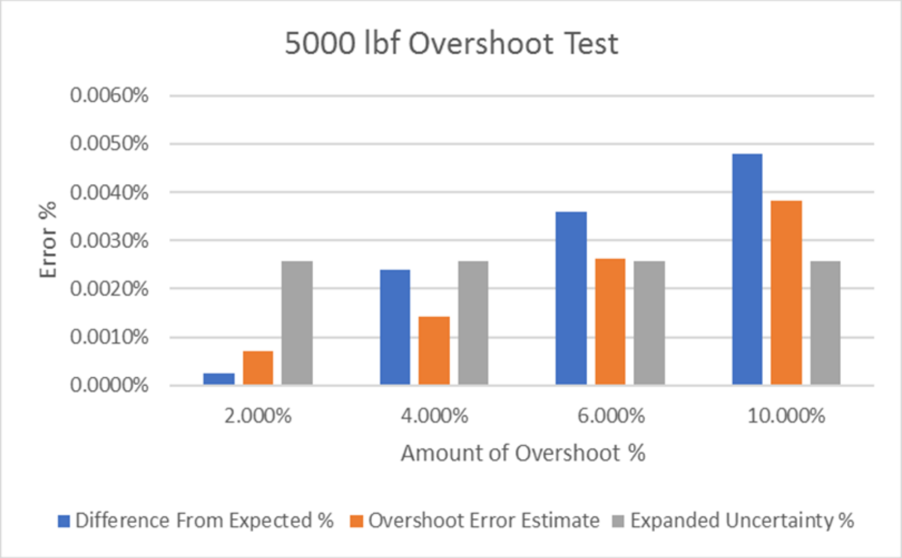


Overshooting a Force Point

% Overshoot	Difference From Expected %	Overshoot Error Estimate	Expanded Uncertainty %	Combined Uncertainty	Difference
2.000%	0.0002%	0.0007%	0.0026%	0.0029%	0.0004%
4.000%	0.0024%	0.0014%	0.0026%	0.0038%	0.0013%
6.000%	0.0036%	0.0026%	0.0026%	0.0058%	0.0033%
10.000%	0.0048%	0.0038%	0.0026%	0.0081%	0.0055%

$$u = \sqrt{(\frac{CMC}{k})^2 + (\frac{Res}{3.464})^2 + (\frac{Rep}{1})^2}$$

More Info can be found here



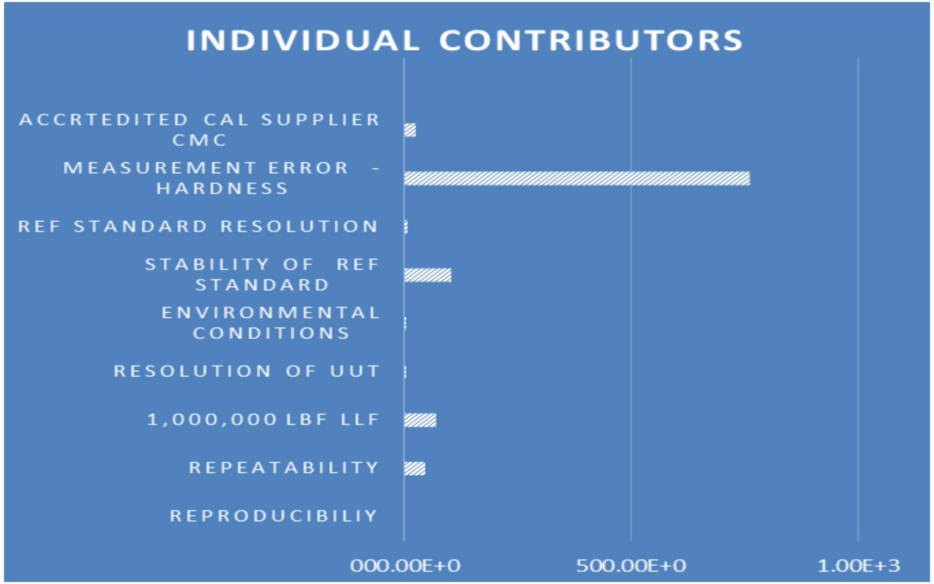
Different Hardness of Top Adaptors

- Example: A customer brought in a 1,000,000 LBF load cell for calibration. Morehouse performed a calibration. The output of the load cell was recorded as 1,500 LBF higher than the previous calibration for a force applied 1,000,000 LBF.

- Is this a stability issue, or an adaptor issue?

- After calling the customer, we were informed a new top loading block was supplied with this load cell for the current calibration. When we told them what was happening, they sent the original top loading block. When tested, the original block resulted in an output of 1,000,180 LBF when loaded to 1,000,000 LBF.

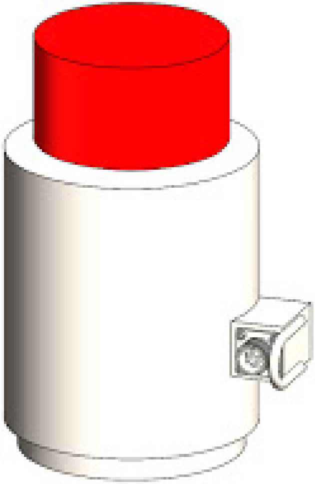
Different Hardness of Top Adaptors



When using the new adaptor and figuring the measurement error between the different top blocks (adaptors), Expanded Uncertainty would have increased from **269 LBF** with original top adaptor to 1,490 LBF using the newly fabricated adaptor.

Top Adapters - Hardness

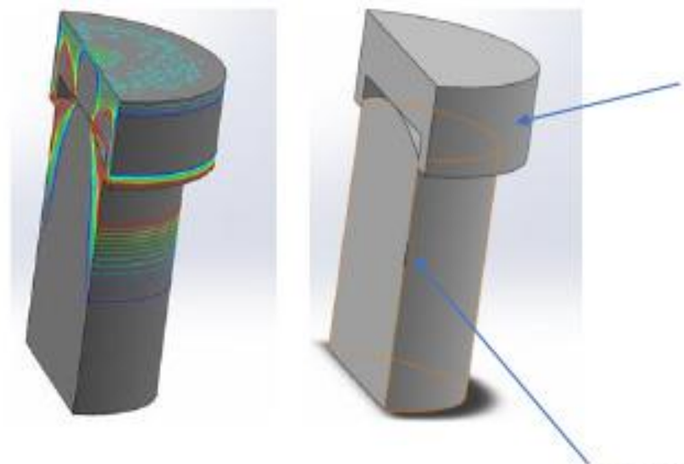
Do you have a top block that can be sent with the Force Measuring Device?



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%

Top Adapters - Hardness



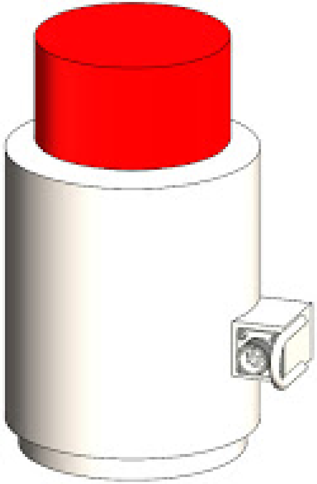
Loading Block

2% Difference in Strain at the Gage
between Hard and Soft Loading Block

Strain Gage

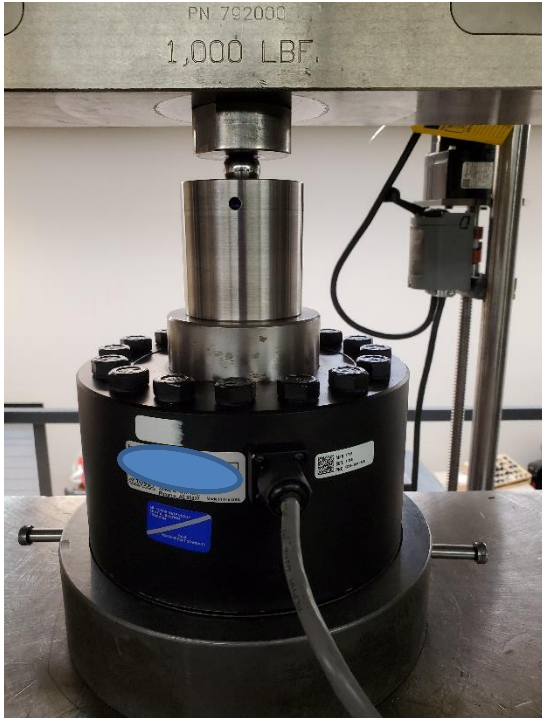
Materials with different hardness experience different amounts of lateral deflection under the same amount of load. Therefore, the varying hardness causes different amounts of stress between the block and the load cell. The above analysis shows steel to steel. It gets much worse if we use a softer material. The right adapters can eliminate these errors that could be as high as 0.5 %.

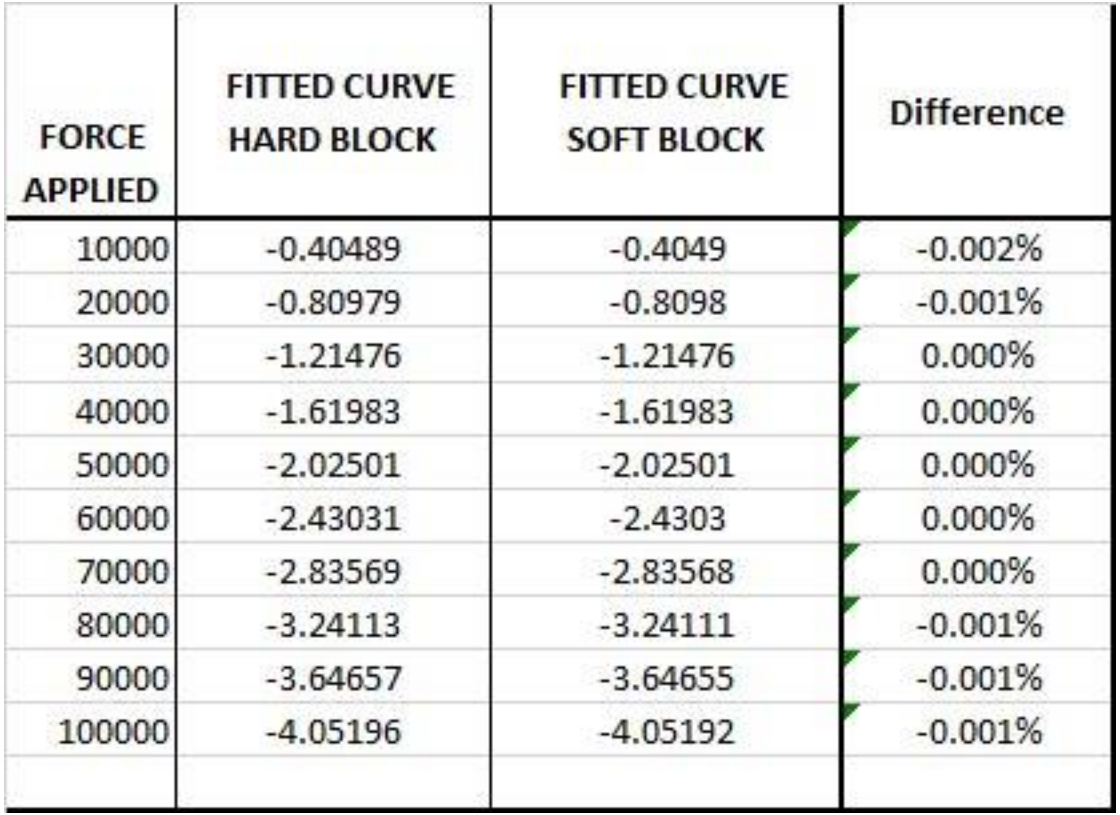
Different Hardness of Top Adaptors



Flatness and smoothness of the block is important in that it will change the contact position on the load cell. The assumption is the load cell has a radius maybe R17 and is designed to be loaded exactly at the center of the spherical section, but an unbalanced or non flat block can shift the contact point off center. As your stress analysis shows, a small amount of shift will change the stress distribution. The key is to use the same adapters in use as used in calibration. The adapters should be manufactured not to produce off axis loads.

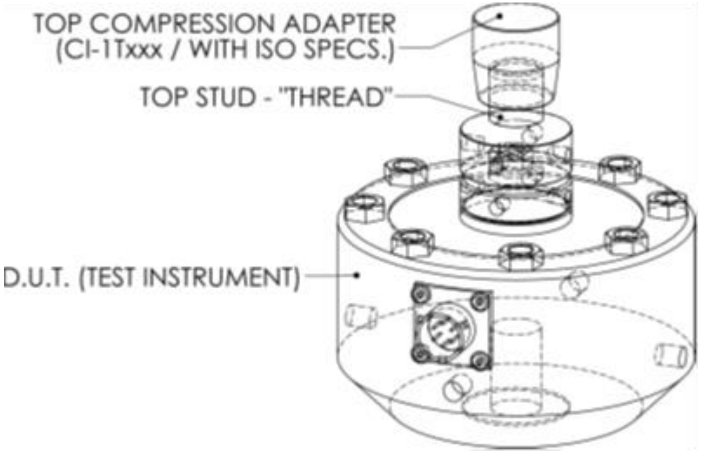
Different Hardness of Top Adaptors Shear Web Cell





FORCE APPLIED	FITTED CURVE HARD BLOCK	FITTED CURVE SOFT BLOCK	Difference
10000	-0.40489	-0.4049	-0.002%
20000	-0.80979	-0.8098	-0.001%
30000	-1.21476	-1.21476	0.000%
40000	-1.61983	-1.61983	0.000%
50000	-2.02501	-2.02501	0.000%
60000	-2.43031	-2.4303	0.000%
70000	-2.83569	-2.83568	0.000%
80000	-3.24113	-3.24111	-0.001%
90000	-3.64657	-3.64655	-0.001%
100000	-4.05196	-4.05192	-0.001%

Morehouse Compression Adapters



- Pictured left is a Morehouse Concrete set with top and bottom bases and pictured right is an ISO 376 recommended compression adapter

Shear Web - Different Hardness of Top Adapters

- The expected results will be that the load cell will have more deflection with the harder material.

- The observed difference between these two different top adapters is on the next slide

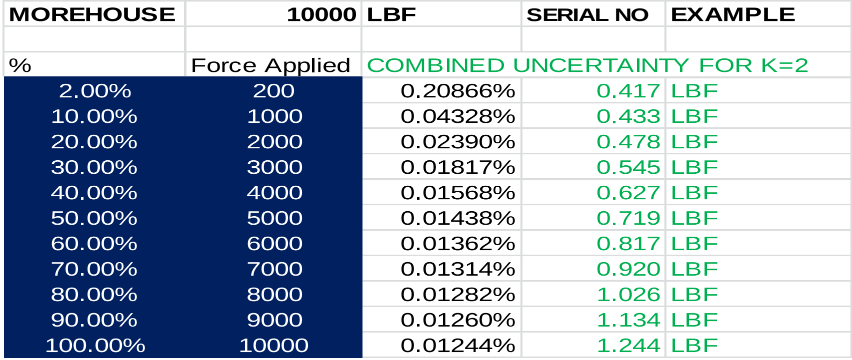
- Load Ball Hardness of RC 46-48

- Softer Material Hardness RA 50 (much softer than RC 48-48)

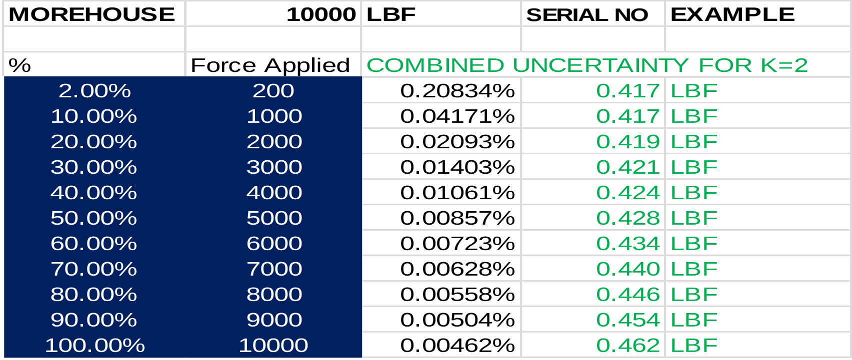
Different Hardness of Top Adapters

Potential Error due to varying hardness of top adapter on Morehouse Cell

0.01 % Error with different adapters vs using the same hardness top adapter



MOREHOUSE	10000	LBF	SERIAL NO	EXAMPLE
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00%	200	0.20866%	0.417	LBF
10.00%	1000	0.04328%	0.433	LBF
20.00%	2000	0.02390%	0.478	LBF
30.00%	3000	0.01817%	0.545	LBF
40.00%	4000	0.01568%	0.627	LBF
50.00%	5000	0.01438%	0.719	LBF
60.00%	6000	0.01362%	0.817	LBF
70.00%	7000	0.01314%	0.920	LBF
80.00%	8000	0.01282%	1.026	LBF
90.00%	9000	0.01260%	1.134	LBF
100.00%	10000	0.01244%	1.244	LBF



MOREHOUSE	10000	LBF	SERIAL NO	EXAMPLE
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00%	200	0.20834%	0.417	LBF
10.00%	1000	0.04171%	0.417	LBF
20.00%	2000	0.02093%	0.419	LBF
30.00%	3000	0.01403%	0.421	LBF
40.00%	4000	0.01061%	0.424	LBF
50.00%	5000	0.00857%	0.428	LBF
60.00%	6000	0.00723%	0.434	LBF
70.00%	7000	0.00628%	0.440	LBF
80.00%	8000	0.00558%	0.446	LBF
90.00%	9000	0.00504%	0.454	LBF
100.00%	10000	0.00462%	0.462	LBF

Compression LOADING THROUGH THE THREADS POTENTIAL ERROR

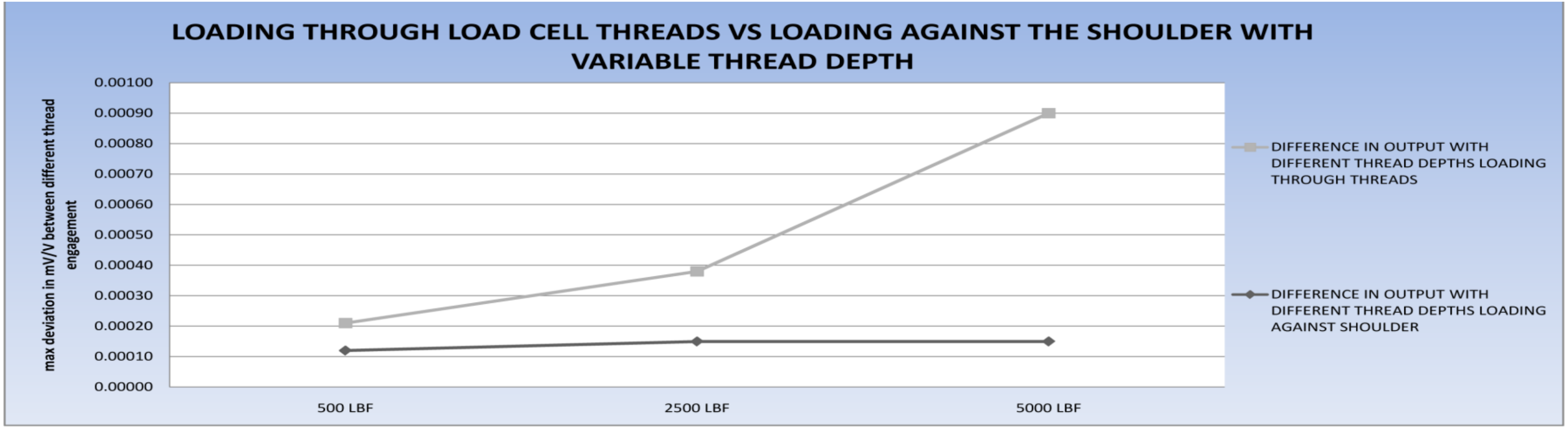
On the left 0.034 % error added to the combined uncertainty vs Standard analysis on the same cell with integral adapter locked into place

MOREHOUSE	**10000**	**LBF**		**EXAMPLE**
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00 %	200	0.21201 %	0.424	LBF
10.00 %	1000	0.05728 %	0.573	LBF
20.00 %	2000	0.04449 %	0.890	LBF
30.00 %	3000	0.04169 %	1.251	LBF
40.00 %	4000	0.04067 %	1.627	LBF
50.00 %	5000	0.04019 %	2.009	LBF
60.00 %	6000	0.03992 %	2.395	LBF
70.00 %	7000	0.03976 %	2.783	LBF
80.00 %	8000	0.03966 %	3.172	LBF
90.00 %	9000	0.03958 %	3.563	LBF
100.00 %	10000	0.03953 %	3.953	LBF

INTEGRAL ADAPTER LOCKED INTO PLACE CMC

0.417	LBF
0.417	LBF
0.419	LBF
0.421	LBF
0.424	LBF
0.428	LBF
0.434	LBF
0.440	LBF
0.446	LBF
0.454	LBF
0.462	LBF

Thread Depth – Shoulder loading Versus Thread Loading



Thread Depth – Same error applies AS IN COMPRESSION DEMONSTRATRION

- Locking an adapter in with a jam nut or using a fixed adapter will decrease this error.
- We did a test where we varied the tension thread depth by about ¼" inch of engagement and observed a 0.034 % error. (We have seen this error as high as several %)

Thread Depth – Shoulder loading Versus Thread Loading ON SHEAR WEB CELLS

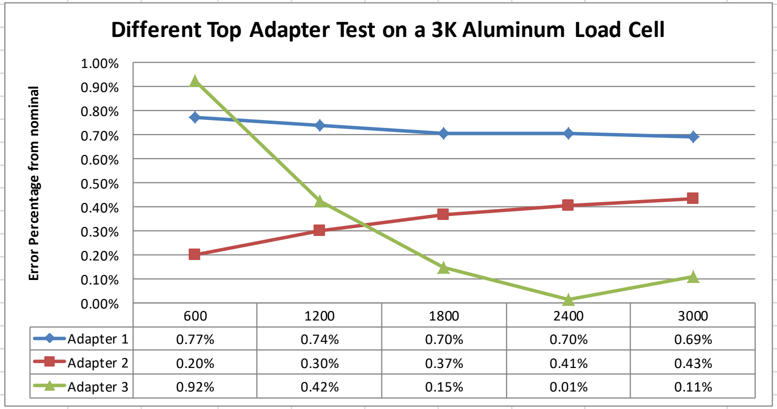
Can we assume that all load cells act the same way?   Or that all shear web load cells act the same?

- We ran a test on an aluminum 3,000 LBF shear web load cell to find out. This example is on the next slide.

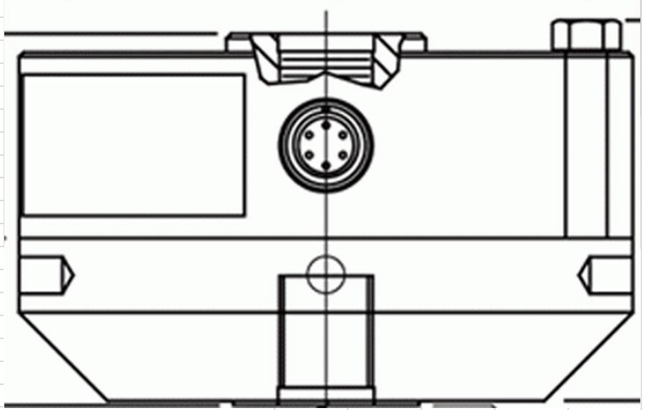
ALUMINUM LOAD CELL OUTPUT USING DIFFERENT Compression ADAPTERS LOADED TIGHT AGAINST THE SHOULDER

Aluminum Load Cell Top Fixture Test

Force Applied	Adapter 1 Readings	Adapter 2 Readings	Adapter 3 Readings	Max Error Between Adapters	Max % Error
600	595.4	598.8	605.6	**10.2**	1.70%
1200	1191.2	1196.4	1205.1	**13.9**	1.16%
1800	1787.4	1793.4	1802.7	**15.3**	0.85%
2400	2383.2	2390.3	2399.7	**16.5**	0.69%
3000	2979.4	2987.1	2996.7	**17.3**	0.58%



	600	1200	1800	2400	3000
Adapter 1	0.77%	0.74%	0.70%	0.70%	0.69%
Adapter 2	0.20%	0.30%	0.37%	0.41%	0.43%
Adapter 3	0.92%	0.42%	0.15%	0.01%	0.11%



Note: This test was done on Aluminum type Shear Web Cell. Steel cells behave much differently. Aluminum cells are usually from 100 LBF - 3,000 LBF

Different Thread Depths On a Non Shear Web Cell

- What about non shear web type cells?
- The different thread length of adapters may increase or decrease the amount of strain.

Different Thread Depths On a Non Shear Web Cell

This is a Sensotec Model RFG/F226-01 load cell. I did a test with two different types of adapters and recorded the readings (10,001.5 vs 9942.3).

There was a difference of 59.2 LBF on a 10,000 LBF cell.

This is a Sensotec Model RFG/F226-01

Different type adapters. (1.5" engagement versus 0.5 " engagement)

Different Thread Depths On a Non-Shear Web Cell

Discussion

What should we do?

How should we proceed?

Different Thread Depths on a Non-Shear Web Cell

Solution.

Called the customer and asked for adapters (contract review)

Customer instructed us to do what we thought was best. Everything was documented and we put this on the certificate per ISO/IEC 17025 5.10.1 paragraph 2.

The above identified instrument was calibrated in accordance with ASTM International's (American Society for Testing and Materials) standard E74-13a entitled, "Standard Practice of Calibration of Force-Measuring Instruments...", "As Returned". We could not provide an "As Received" calibration because the indicator had to be set up prior to calibration. Note: In compression, the adaptor was threaded tight against the top of the load cell. An adaptor used by Morehouse Instrument Company was threaded approximately 1.5 inches for tension and compression. The zero return values were taken approximately 30 seconds after the load was released. This calibration is in conformance with the requirements of Morehouse QAM Rev. 12.1, dated 05/02/14, ISO/IEC 17025.

Different Top Adapters ON AN ALUMINUM LOAD CELL

- Learning Objective:

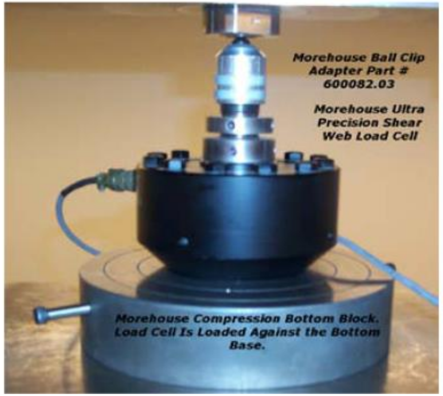
- Identify potential force measurement errors and reduce and/or quantify the uncertainty associated with these errors.
- By running the last two tests, we have effectively quantified potential error sources on 2 different types of shear web load cells.

- What do both of these tests show us?

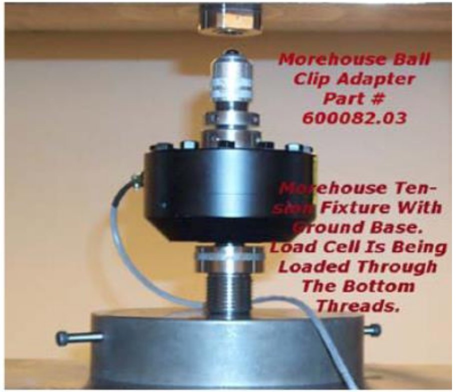
Loading through the bottom threads in compression

Do you think these loading profiles create a different result?

Loading through the bottom threads in compression

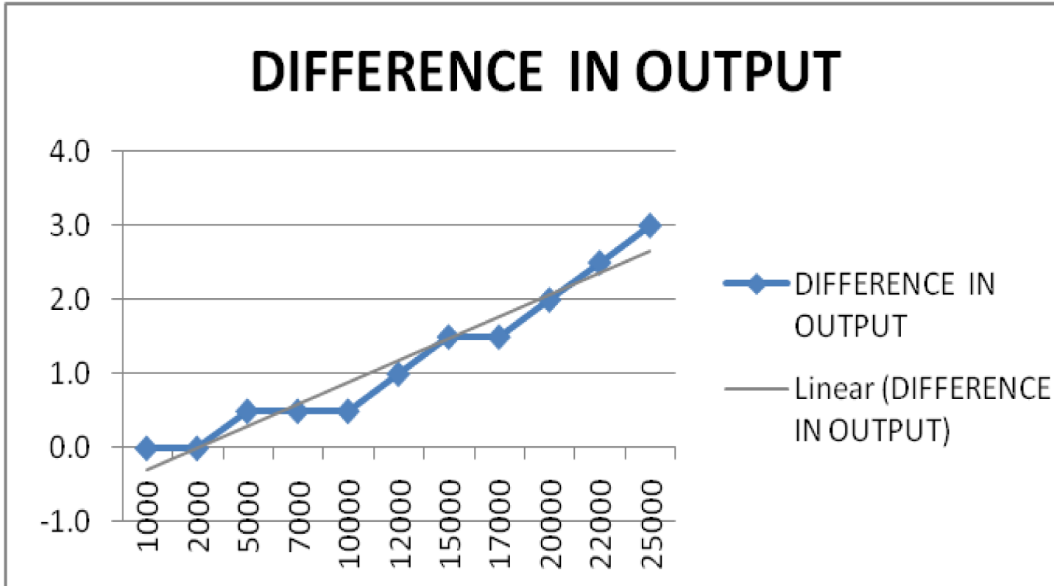


FORCE APPLIED LBF	LOAD CELL OUTPUT LOADED AGAINST BOTTOM BASE	LOAD CELL OUTPUT LOADED AGAINST BOTTOM THREADS
1000	**999.0**	**999.0**
2000	**1998.0**	**1998.0**
5000	**4996.0**	**4996.5**
7000	**6995.0**	**6995.5**
10000	**9994.5**	**9995.0**
12000	**11994.0**	**11995.0**
15000	**14993.5**	**14995.0**
17000	**16993.5**	**16995.0**
20000	**19994.0**	**19996.0**
22000	**21994.0**	**21996.5**
25000	**24994.0**	**24997.0**



Loading through the bottom threads in compression

FORCE APPLIED LBF	DIFFERENCE IN OUTPUT	% DIFF
1000	0.0	0.000%
2000	0.0	0.000%
5000	0.5	0.010%
7000	0.5	0.007%
10000	0.5	0.005%
12000	1.0	0.008%
15000	1.5	0.010%
17000	1.5	0.009%
20000	2.0	0.010%
22000	2.5	0.011%
25000	3.0	0.012%

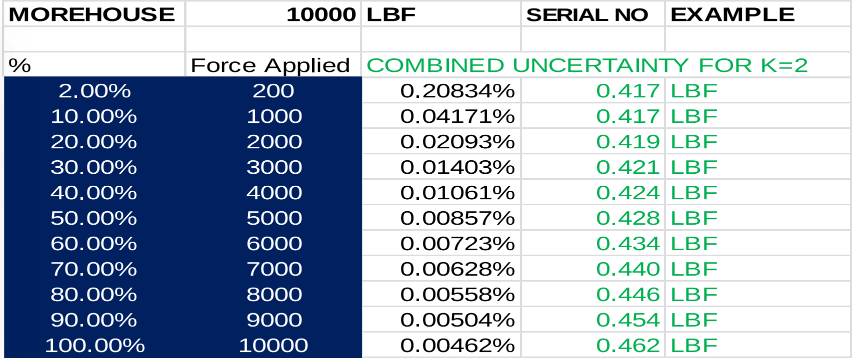


Loading through the bottom threads in compression

Potential Error due to loading through the bottom threads versus flat

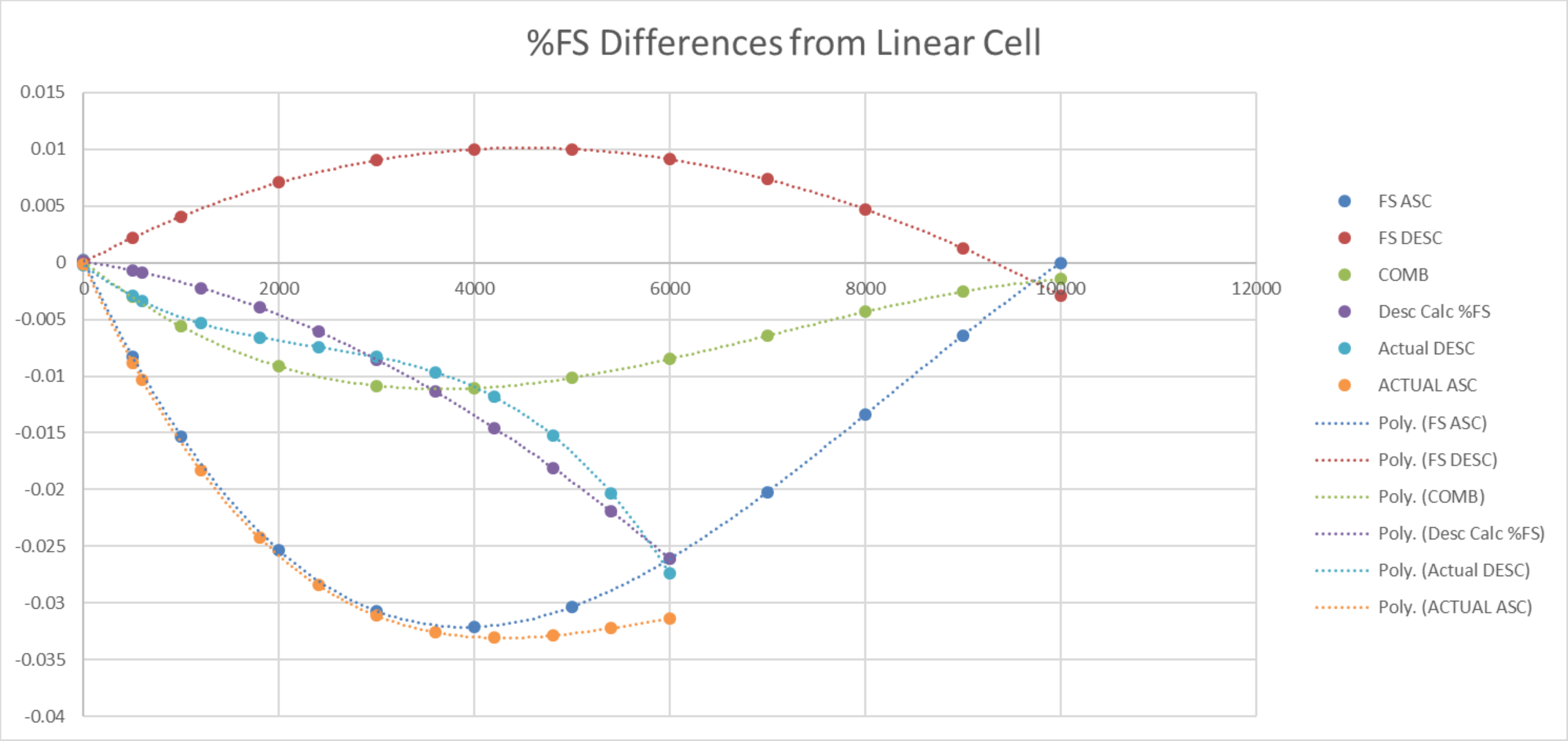
0.012 % Error with different adapters vs loading against the base

MOREHOUSE	10000	LBF	SERIAL NO	EXAMPLE
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00%	200	0.20880%	0.418	LBF
10.00%	1000	0.04396%	0.440	LBF
20.00%	2000	0.02510%	0.502	LBF
30.00%	3000	0.01972%	0.592	LBF
40.00%	4000	0.01745%	0.698	LBF
50.00%	5000	0.01629%	0.815	LBF
60.00%	6000	0.01563%	0.938	LBF
70.00%	7000	0.01521%	1.065	LBF
80.00%	8000	0.01494%	1.195	LBF
90.00%	9000	0.01475%	1.327	LBF
100.00%	10000	0.01461%	1.461	LBF



MOREHOUSE	10000	LBF	SERIAL NO	EXAMPLE
%	Force Applied	COMBINED UNCERTAINTY FOR K=2		
2.00%	200	0.20834%	0.417	LBF
10.00%	1000	0.04171%	0.417	LBF
20.00%	2000	0.02093%	0.419	LBF
30.00%	3000	0.01403%	0.421	LBF
40.00%	4000	0.01061%	0.424	LBF
50.00%	5000	0.00857%	0.428	LBF
60.00%	6000	0.00723%	0.434	LBF
70.00%	7000	0.00628%	0.440	LBF
80.00%	8000	0.00558%	0.446	LBF
90.00%	9000	0.00504%	0.454	LBF
100.00%	10000	0.00462%	0.462	LBF

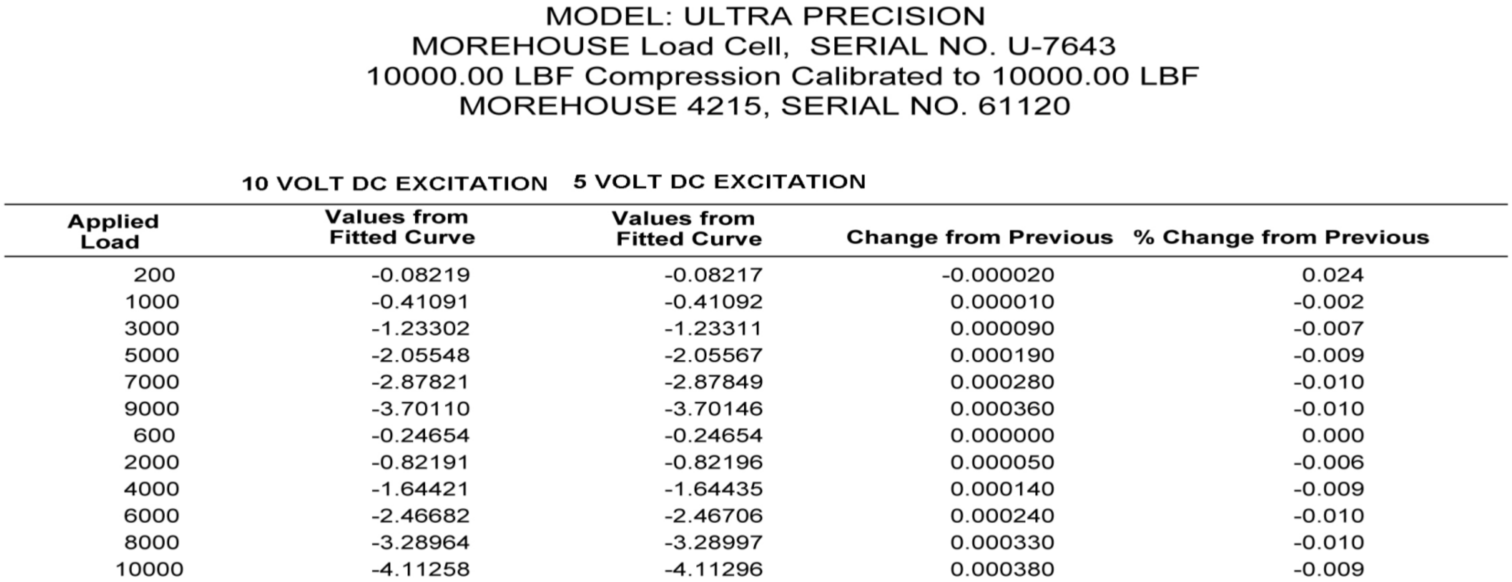
Not Using Different Curves for Decreasing Forces



10 Volt Versus 5 Volt DC Excitation

- Another potential error source is using a different excitation voltage than that which the load cell was calibrated at.
- Testing should be done using dead weight primary standards, as the difference in output may be small at around 0.00020 to a larger error of 0.00070 mV/V at full capacity, typically around 0.001% to 0.020 % depending on the load cell and meter.

10 Volt Versus 5 Volt DC Excitation



MODEL: ULTRA PRECISION
MOREHOUSE Load Cell, SERIAL NO. U-7643
10000.00 LBF Compression Calibrated to 10000.00 LBF
MOREHOUSE 4215, SERIAL NO. 61120

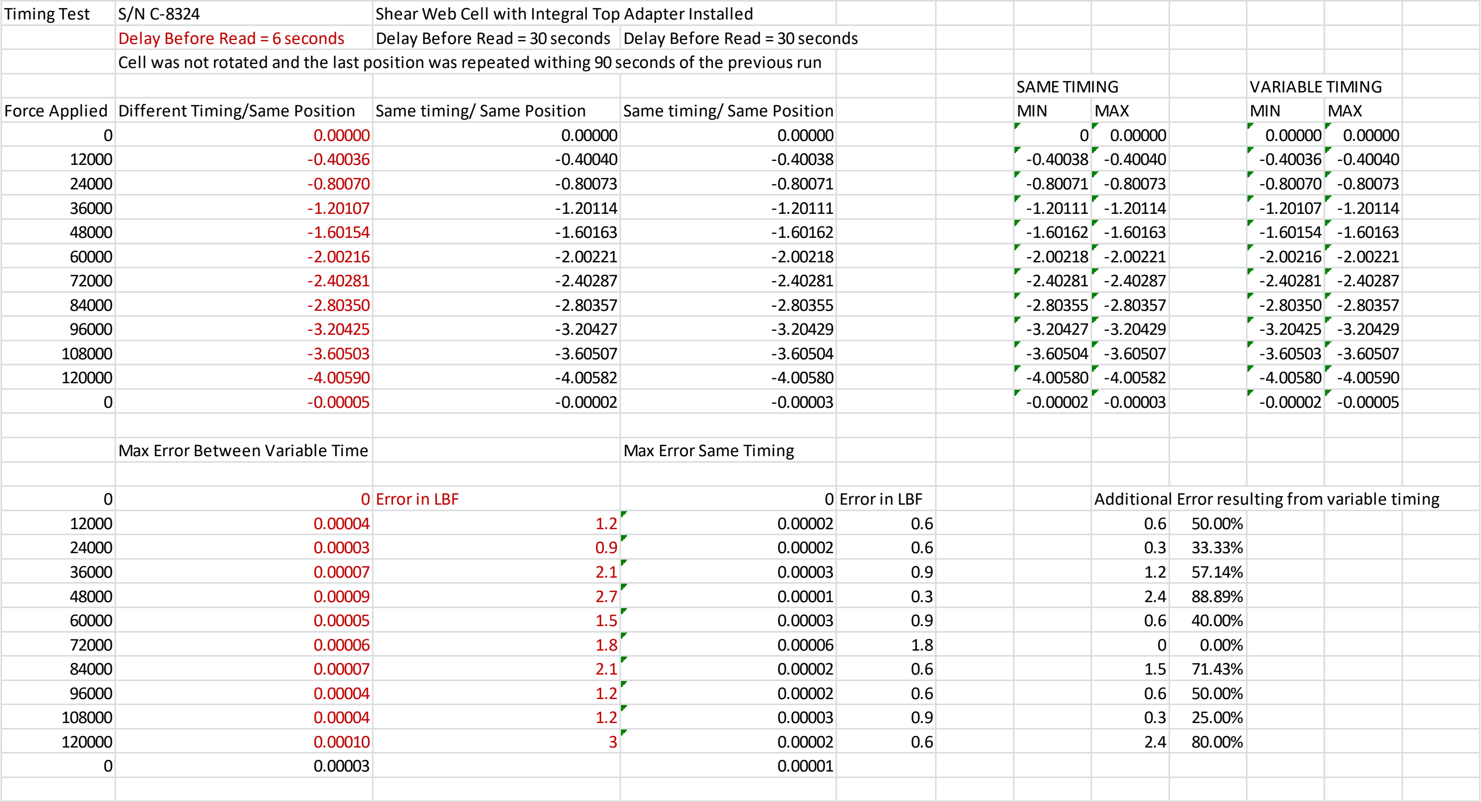
	10 VOLT DC EXCITATION	5 VOLT DC EXCITATION		
Applied Load	**Values from Fitted Curve**	**Values from Fitted Curve**	**Change from Previous**	**% Change from Previous**
200	-0.08219	-0.08217	-0.000020	0.024
1000	-0.41091	-0.41092	0.000010	-0.002
3000	-1.23302	-1.23311	0.000090	-0.007
5000	-2.05548	-2.05567	0.000190	-0.009
7000	-2.87821	-2.87849	0.000280	-0.010
9000	-3.70110	-3.70146	0.000360	-0.010
600	-0.24654	-0.24654	0.000000	0.000
2000	-0.82191	-0.82196	0.000050	-0.006
4000	-1.64421	-1.64435	0.000140	-0.009
6000	-2.46682	-2.46706	0.000240	-0.010
8000	-3.28964	-3.28997	0.000330	-0.010
10000	-4.11258	-4.11296	0.000380	-0.009

Cable Length Error (discussed earlier)

If the cable in an existing 4-wire system is changed, there will be a loss of sensitivity of approximately 0.37% per 10 feet of 28-gauge cable, and 0.09% per 10 feet of 22 gauge cable.

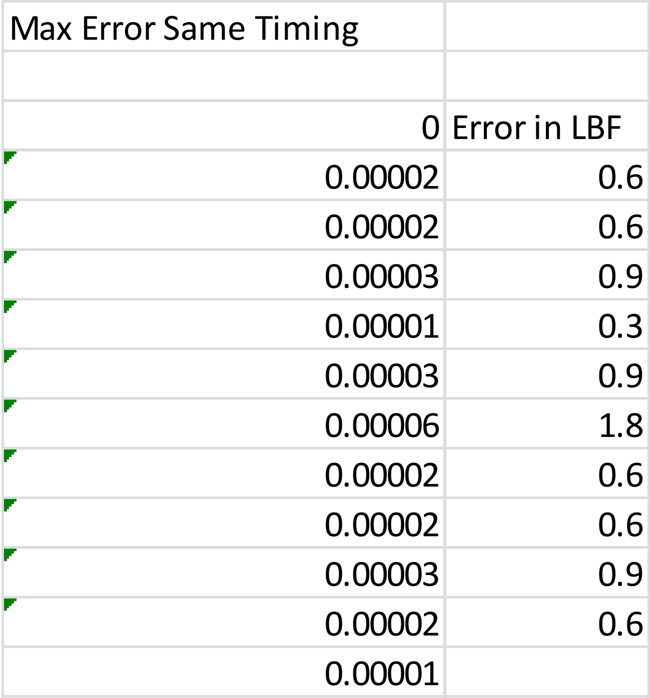
This error can be eliminated if a six-wire cable is run to the end of the load cell cable or connector and used in conjunction with an indicator that has sense lead capability.

Time differences in calibrations
Sample tests on a shear web Cell



Timing Test	S/N C-8324	Shear Web Cell with Integral Top Adapter Installed								
	Delay Before Read = 6 seconds	Delay Before Read = 30 seconds	Delay Before Read = 30 seconds							
	Cell was not rotated and the last position was repeated withing 90 seconds of the previous run									
						SAME TIMING			VARIABLE TIMING	
Force Applied	Different Timing/Same Position	Same timing/ Same Position	Same timing/ Same Position			MIN	MAX		MIN	MAX
0	0.00000	0.00000	0.00000			0	0.00000		0.00000	0.00000
12000	-0.40036	-0.40040	-0.40038			-0.40038	-0.40040		-0.40036	-0.40040
24000	-0.80070	-0.80073	-0.80071			-0.80071	-0.80073		-0.80070	-0.80073
36000	-1.20107	-1.20114	-1.20111			-1.20111	-1.20114		-1.20107	-1.20114
48000	-1.60154	-1.60163	-1.60162			-1.60162	-1.60163		-1.60154	-1.60163
60000	-2.00216	-2.00221	-2.00218			-2.00218	-2.00221		-2.00216	-2.00221
72000	-2.40281	-2.40287	-2.40281			-2.40281	-2.40287		-2.40281	-2.40287
84000	-2.80350	-2.80357	-2.80355			-2.80355	-2.80357		-2.80350	-2.80357
96000	-3.20425	-3.20427	-3.20429			-3.20427	-3.20429		-3.20425	-3.20429
108000	-3.60503	-3.60507	-3.60504			-3.60504	-3.60507		-3.60503	-3.60507
120000	-4.00590	-4.00582	-4.00580			-4.00580	-4.00582		-4.00580	-4.00590
0	-0.00005	-0.00002	-0.00003			-0.00002	-0.00003		-0.00002	-0.00005
	Max Error Between Variable Time		Max Error Same Timing							
0	0	Error in LBF	0	Error in LBF			Additional Error resulting from variable timing			
12000	0.00004	1.2	0.00002	0.6			0.6	50.00%		
24000	0.00003	0.9	0.00002	0.6			0.3	33.33%		
36000	0.00007	2.1	0.00003	0.9			1.2	57.14%		
48000	0.00009	2.7	0.00001	0.3			2.4	88.89%		
60000	0.00005	1.5	0.00003	0.9			0.6	40.00%		
72000	0.00006	1.8	0.00006	1.8			0	0.00%		
84000	0.00007	2.1	0.00002	0.6			1.5	71.43%		
96000	0.00004	1.2	0.00002	0.6			0.6	50.00%		
108000	0.00004	1.2	0.00003	0.9			0.3	25.00%		
120000	0.00010	3	0.00002	0.6			2.4	80.00%		
0	0.00003		0.00001							

Sample tests on a Shear Web Cell
Max Error observed between a delay of 30 seconds on 2 runs of data.



Max Error Same Timing	
0	Error in LBF
0.00002	0.6
0.00002	0.6
0.00003	0.9
0.00001	0.3
0.00003	0.9
0.00006	1.8
0.00002	0.6
0.00002	0.6
0.00003	0.9
0.00002	0.6
0.00001	

Additional error analysis comparing 2 runs with a delay before read = 6 seconds versus a delay before read of 30 seconds

Additional Error resulting from variable timing				
0.6	50.00%			
0.3	33.33%			
1.2	57.14%			
2.4	88.89%			
0.6	40.00%			
0	0.00%			
1.5	71.43%			
0.6	50.00%			
0.3	25.00%			
2.4	80.00%			

Other Error Sources

- Drift of Calibration Standards with Time

Other Error Sources

- Dissemination Error - This error applies to Calibration Laboratories using secondary standards to calibrate other secondary standards. The dissemination error can be estimated by comparing the result of a secondary standard calibrated by the primary standard laboratory standard using another secondary standard with the calibration result from the secondary standard laboratory.

- Quantify the error by comparing 2 secondary standards that were both calibrated by primary standards against one another.

What Questions Do You Have?

Takeaways?
What are you going to implement in your lab?

Uncertainty ANALYSIS Review

Forms of Distribution:

1. Normal
2. Rectangular
3. Triangular
4. U-Shaped
5. Resolution (rectangular but check divisor based on type of resolution)

Uncertainty Distributions
Correction factors

Distribution	Divide by	Divisor	1/Divisor
Rectangular	Square-root 3	1.7321	0.5774
Triangular	Square-root 6	2.4495	0.4082
U - Shaped	Square-root 2	1.4142	0.7071
Resolution	Square-root 12	3.4641	0.2887

RESOLUTION BASED:

RESOLUTION = 0.001_ ← $^{0\text{-}4}_{5\text{-}9}$

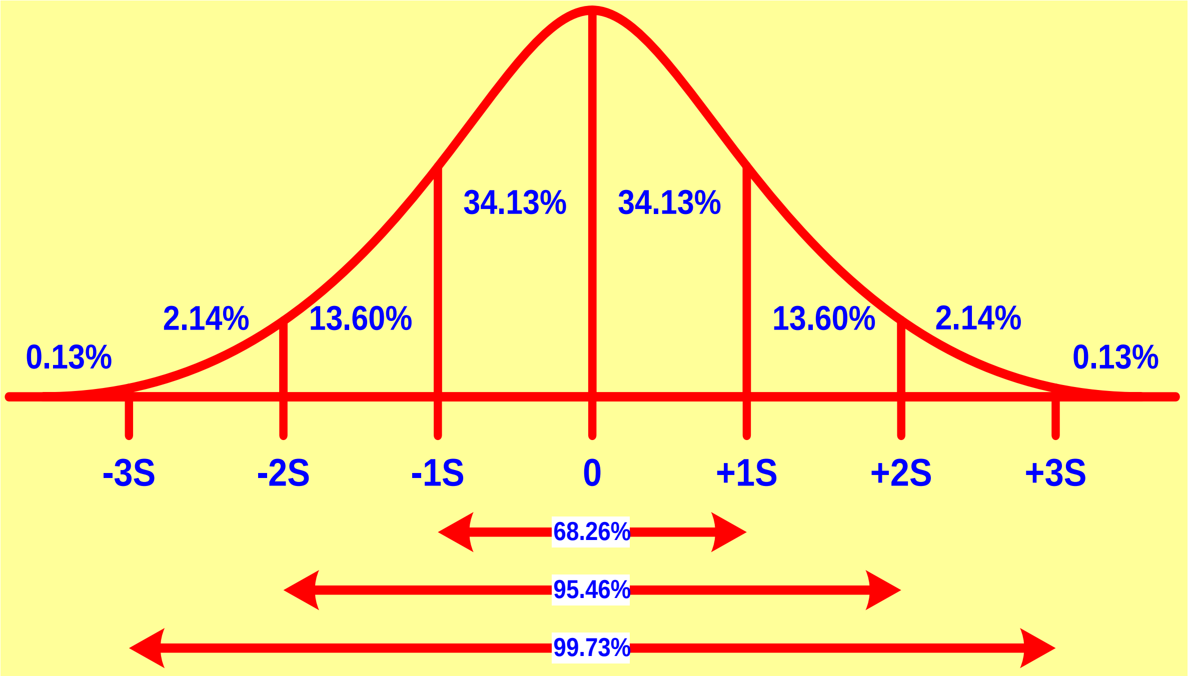
$$0.001/(2\sqrt{3})$$

$$= 0.001/(\sqrt{2 \times 2 \times 3})$$

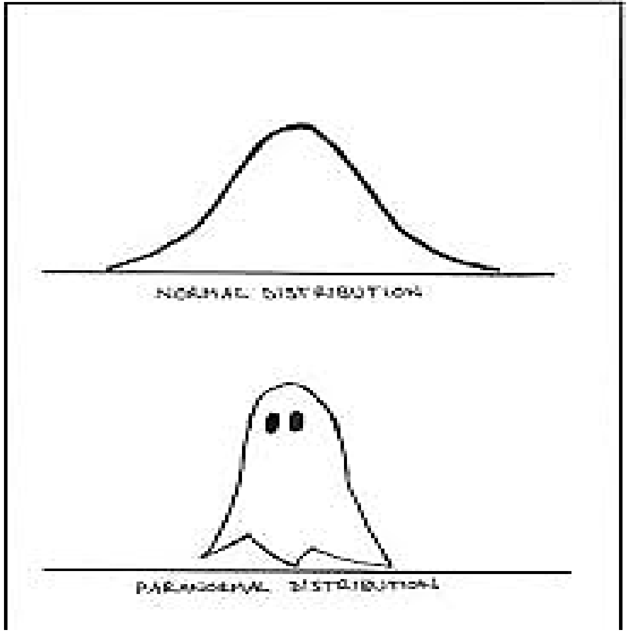
$$= 0.001/\sqrt{12}$$

$$= 0.000289$$

Standard Deviation Probability



Uncertainty Distributions



Uncertainty Distributions

When in doubt

For Type A use a Normal Distribution

For Type B use a Rectangular Distribution

Performance & Uncertainty

What Type are these:

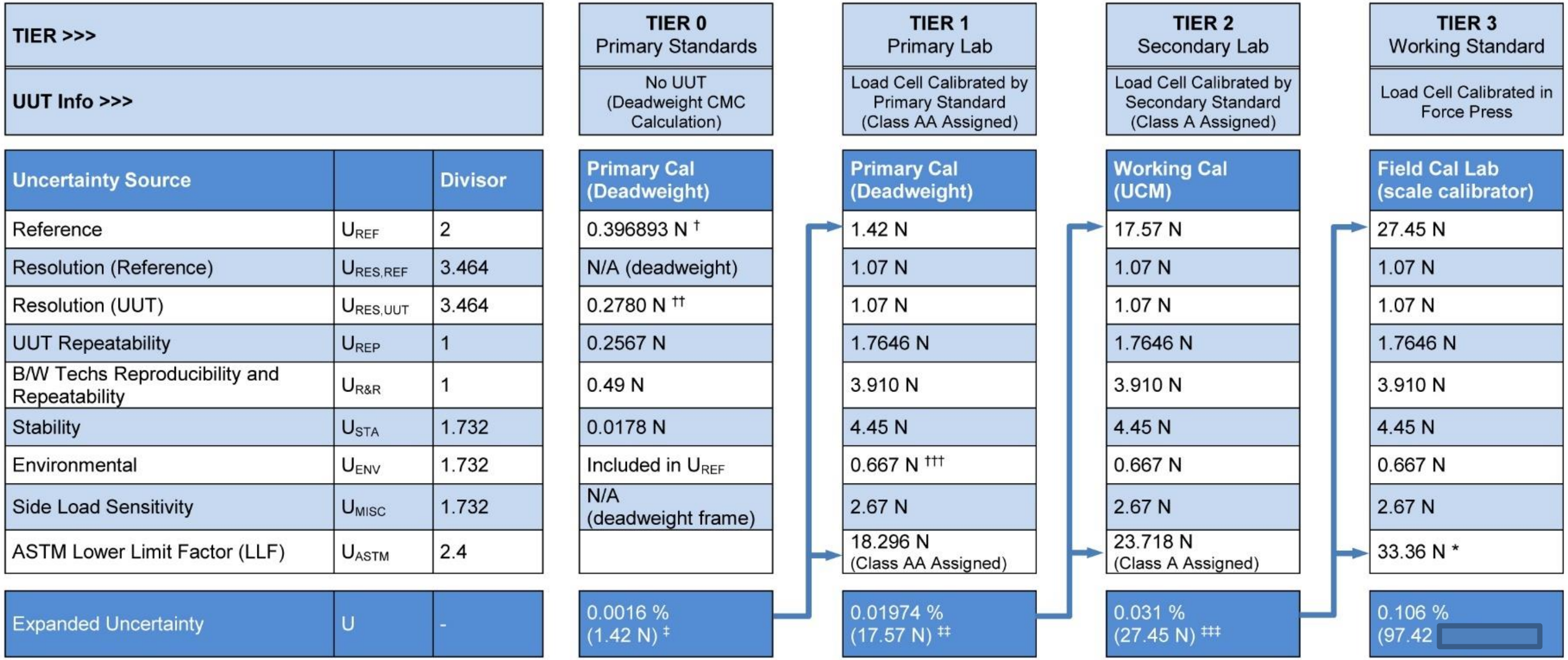
- **R**epeatability (Type ?)
- **R**esolution (Type ?)
- **R**eproducibility (Type ?)
- **R**eference Standard Uncertainty (Type ?)
- **R**eference Standard Stability (Type ?)
- **E**nvironmental Factors (Type ?)

Performance & Uncertainty

- These uncertainty contributors are:
- **R**epeatability (Type A)
- **R**esolution (Type B)
- **R**eproducibility (Type A)
- **R**eference Standard Uncertainty (Typically Type B)
- **R**eference Standard Stability (Type A or B)
- **E**nvironmental Factors (Type A or B)

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	**TIER 3** Working Standard
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)	Load Cell Calibrated in Force Press
Uncertainty Source		**Divisor**	**Primary Cal (Deadweight)**	**Primary Cal (Deadweight)**	**Working Cal (UCM)**	**Field Cal Lab (scale calibrator)**
Reference	U_{REF}	2	0.396893 N †	1.42 N	17.57 N	27.45 N
Resolution (Reference)	$U_{RES,REF}$	3.464	N/A (deadweight)	1.07 N	1.07 N	1.07 N
Resolution (UUT)	$U_{RES,UUT}$	3.464	0.2780 N ††	1.07 N	1.07 N	1.07 N
UUT Repeatability	U_{REP}	1	0.2567 N	1.7646 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	3.910 N
Stability	U_{STA}	1.732	0.0178 N	4.45 N	4.45 N	4.45 N
Environmental	U_{ENV}	1.732	Included in U_{REF}	0.667 N †††	0.667 N	0.667 N
Side Load Sensitivity	U_{MISC}	1.732	N/A (deadweight frame)	2.67 N	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)	33.36 N *
Expanded Uncertainty	U	-	0.0016 % (1.42 N) ‡	0.01974 % (17.57 N) ‡‡	0.031 % (27.45 N) ‡‡‡	0.106 % (97.42 [redacted]

Tier 0 is CMC uncertainty component of Morehouse Machine, Tier 1 Calibration by Primary Standards Class AA loading Range Assigned, Tier 2 actual CMC of Secondary Standard, Tier 3 calibration in the field.

ASTM E4 Tier

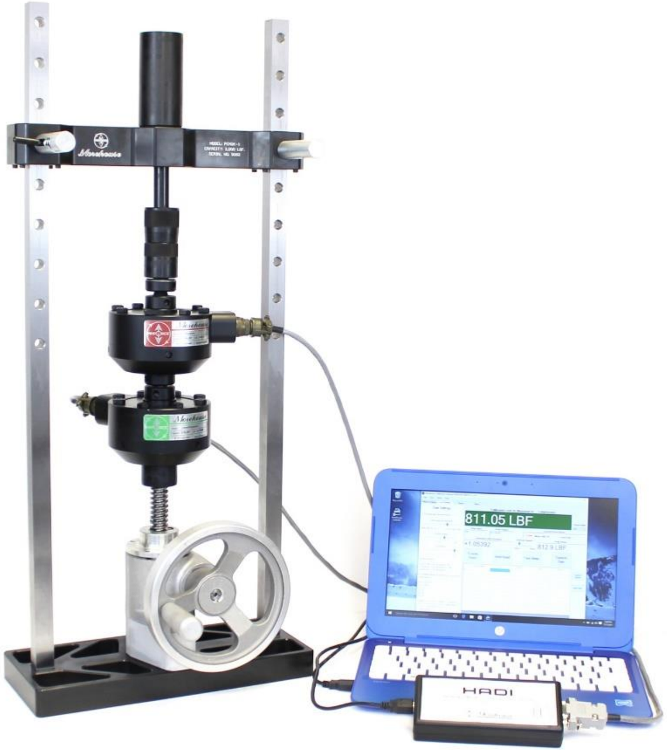
- U_{cal} = Uncertainty of the reference lab + resolution of your device
- U_{e4} = Expected Performance of the load cell. This is typically 0.25 % for a Class A device
- U_{res} = Resolution of the machine being calibrated
- U_{rep} = Uncertainty of the repeatability measurements you are making
- U_{env} = Uncertainty related to Environmental conditions. (This is usually the temperature specification on the load cell spec sheet)
- $U_{stability}$ = Uncertainty from one calibration to another
- $U_{indicator}$ = Uncertainty components of indicator calibration if it is not married as a system
- U_{other} = Uncertainty from off-axis, timing, repeatability, and other error sources

Uncertainty Example Class Exercise

- *At this point, we can discuss and/or work through an uncertainty example together*.

Force CMC uncertainty component for ASTM E74 Calibrations

- In this example we are using our 2000 lbf Portable Calibrating Machine (PCM)
- The load cell has been calibrated by deadweight and we are trying to figure out the CMC of our new PCM with this 2000 lbf calibrated load cell standard and another 2000 lbf calibrated load cell



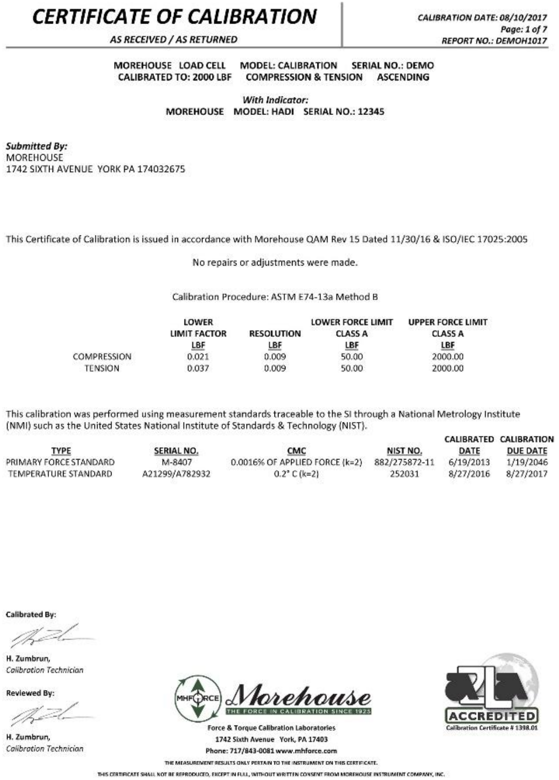
Force CMC uncertainty component for ASTM E74 Calibrations

We will need the following:

1. **Calibration Report for the Device which needs to include Measurement Uncertainty**
2. **The uncertainty of the instrument(s) that were used to perform the calibration (*U*ref)**
3. **Calibration History (if available)**
4. **Manufacturer's Specification Sheet (For Environmental)**
5. **Error Sources, if known**

The end user will then have to conduct the following tests:

1. **Repeatability study**
2. **R & R between technicians**
3. **Complete Proficiency Testing Requirements**



CERTIFICATE OF CALIBRATION

AS RECEIVED / AS RETURNED

CALIBRATION DATE: 08/10/2017
Page: 1 of 7
REPORT NO.: DEMOH1017

MOREHOUSE LOAD CELL MODEL: CALIBRATION SERIAL NO.: DEMO
CALIBRATED TO: 2000 LBF COMPRESSION & TENSION ASCENDING

With Indicator:
MOREHOUSE MODEL: HADI SERIAL NO.: 12345

Submitted By:
MOREHOUSE
1742 SIXTH AVENUE YORK PA 174032675

This Certificate of Calibration is issued in accordance with Morehouse QAM Rev 15 Dated 11/30/16 & ISO/IEC 17025:2005

No repairs or adjustments were made.

Calibration Procedure: ASTM E74-13a Method B

	LOWER LIMIT FACTOR LBF	RESOLUTION LBF	LOWER FORCE LIMIT CLASS A LBF	UPPER FORCE LIMIT CLASS A LBF
COMPRESSION	0.021	0.009	50.00	2000.00
TENSION	0.037	0.009	50.00	2000.00

This calibration was performed using measurement standards traceable to the SI through a National Metrology Institute (NMI) such as the United States National Institute of Standards & Technology (NIST).

TYPE	SERIAL NO.	CMC	NIST NO.	CALIBRATED DATE	CALIBRATION DUE DATE
PRIMARY FORCE STANDARD	M-8407	0.0016% OF APPLIED FORCE (k=2)	882/275872-11	6/19/2013	1/19/2046
TEMPERATURE STANDARD	A21299/A782932	0.2° C (k=2)	252031	8/27/2016	8/27/2017

Calibrated By:

H. Zumbrun,
Calibration Technician

Reviewed By:

H. Zumbrun,
Calibration Technician

MHFORCE Morehouse
THE FORCE IN CALIBRATION SINCE 1925

Force & Torque Calibration Laboratories
1742 Sixth Avenue York, PA 17403
Phone: 717/843-0081 www.mhforce.com

THE MEASUREMENT RESULTS ONLY PERTAIN TO THE INSTRUMENT ON THIS CERTIFICATE.

THIS CERTIFICATE SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT WRITTEN CONSENT FROM MOREHOUSE INSTRUMENT COMPANY, INC.

A2LA ACCREDITED
Calibration Certificate # 1398.01

Force CMC uncertainty component 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	LOWER FORCE LIMIT CLASS A FORCE UNITS	UPPER FORCE LIMIT CLASS A FORCE UNITS
COMPRESSION	0.0000166	0.009	0.037	50.00	2000.00

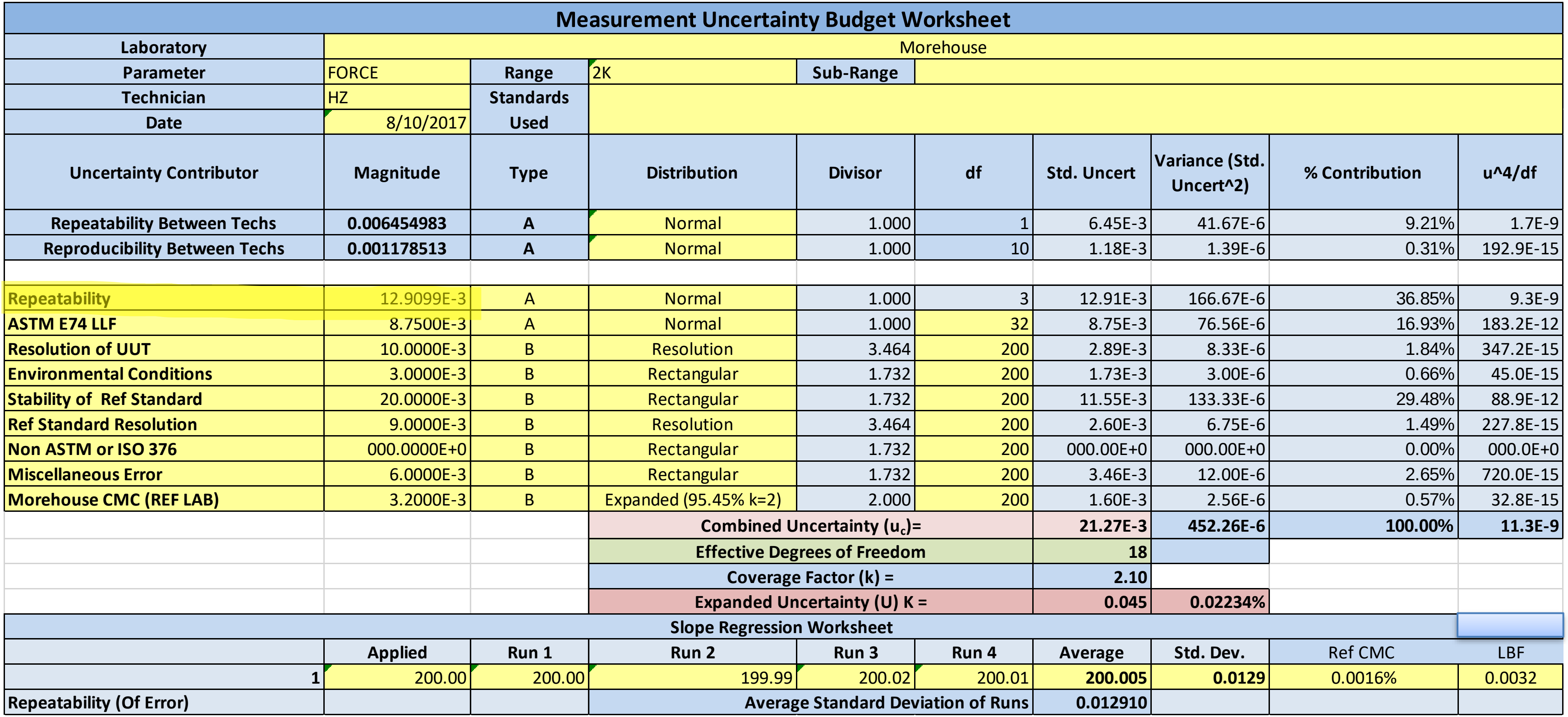
Force CMC uncertainty component for ASTM E74 Calibrations

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.

ASTM LLF = 0.21 FORCE UNITS (This is Divided by 2.4 to get 1 Standard Deviation) and is found on the calibration report.

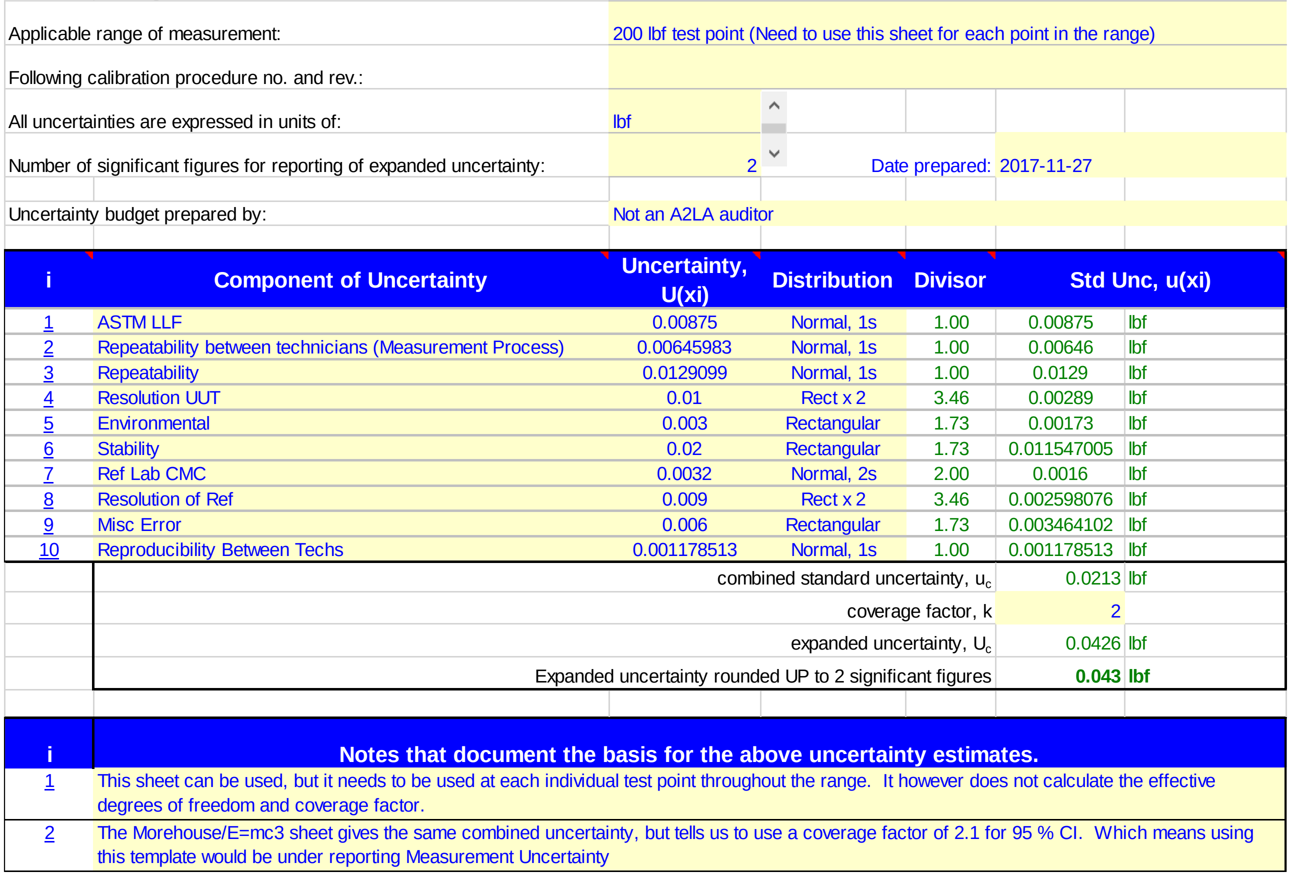
The excel sheet will reduce 0.021 FORCE UNITS by 2.4 which equals 0.00875 FORCE UNITS

Force CMC uncertainty component 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	0.006454983	A	Normal	1.000	1	6.45E-3	41.67E-6	9.21%	1.7E-9
Reproducibility Between Techs	0.001178513	A	Normal	1.000	10	1.18E-3	1.39E-6	0.31%	192.9E-15
Repeatability	12.9099E-3	A	Normal	1.000	3	12.91E-3	166.67E-6	36.85%	9.3E-9
ASTM E74 LLF	8.7500E-3	A	Normal	1.000	32	8.75E-3	76.56E-6	16.93%	183.2E-12
Resolution of UUT	10.0000E-3	B	Resolution	3.464	200	2.89E-3	8.33E-6	1.84%	347.2E-15
Environmental Conditions	3.0000E-3	B	Rectangular	1.732	200	1.73E-3	3.00E-6	0.66%	45.0E-15
Stability of Ref Standard	20.0000E-3	B	Rectangular	1.732	200	11.55E-3	133.33E-6	29.48%	88.9E-12
Ref Standard Resolution	9.0000E-3	B	Resolution	3.464	200	2.60E-3	6.75E-6	1.49%	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	2.65%	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	0.57%	32.8E-15
			Combined Uncertainty (u_c)=			21.27E-3	452.26E-6	100.00%	11.3E-9
			Effective Degrees of Freedom			18			
			Coverage Factor (k) =			2.10			
			Expanded Uncertainty (U) K =			0.045	0.02234%		
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			

Comparing another sheet versus Morehouse/EMC^3



Applicable range of measurement: 200 lbf test point (Need to use this sheet for each point in the range)

Following calibration procedure no. and rev.:

All uncertainties are expressed in units of: lbf

Number of significant figures for reporting of expanded uncertainty: 2

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	ASTM LLF	0.00875	Normal, 1s	1.00	0.00875	lbf
2	Repeatability between technicians (Measurement Process)	0.00645983	Normal, 1s	1.00	0.00646	lbf
3	Repeatability	0.0129099	Normal, 1s	1.00	0.0129	lbf
4	Resolution UUT	0.01	Rect x 2	3.46	0.00289	lbf
5	Environmental	0.003	Rectangular	1.73	0.00173	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	Misc Error	0.006	Rectangular	1.73	0.003464102	lbf
10	Reproducibility Between Techs	0.001178513	Normal, 1s	1.00	0.001178513	lbf
	combined standard uncertainty, u_c				0.0213	lbf
	coverage factor, k				2	
	expanded uncertainty, U_c				0.0426	lbf
	Expanded uncertainty rounded UP to 2 significant figures				**0.043**	**lbf**

i	Notes that document the basis for the above uncertainty estimates.
1	This sheet can be used, but it needs to be used at each individual test point throughout the range. It however does not calculate the effective degrees of freedom and coverage factor.
2	The Morehouse/E=mc3 sheet gives the same combined uncertainty, but tells us to use a coverage factor of 2.1 for 95 % CI. Which means using this template would be under reporting Measurement Uncertainty

0.045 lbf on Morehouse/ E=mc^3 Sheet

4.45 % difference

Force CMC uncertainty component 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) 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

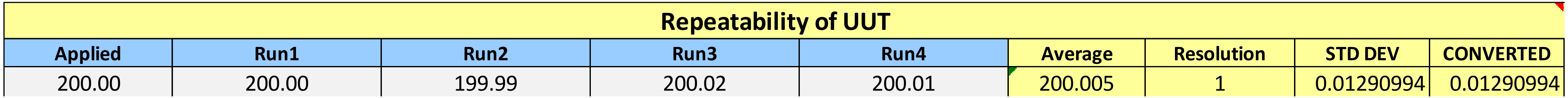
Do not use SEB, Nonlinearity, or Hysteresis as they are not appropriate contributors when following the ASTM E74 standard.

Repeatability of Best Existing Device

- **Repeatability** – Repeatability is defined as the standard deviation of a series of at least two measurements at the same test point. The purpose of this test is for the determination of the uncertainty of force generation in a force calibrating machine or test frame. For laboratories testing multiple ranges, it is recommended that a repeatability point be taken for every ten percent of the ranges they calibrate. Example would be a lab performing calibrations from 10 N through 10,000 N. The ranges calibrated may be 10 N - 100 N, 100 N - 1,000 N, and 1,000 N - 10,000 N. Recommended practice would be to take test points at 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, 9,000, and 10,000 N. *Note: For this application zero should never be considered as a first test point. A force measuring device should not be used to calibrate other devices outside the range it was calibrated over. Example. A device calibrated from 10 % through 100 % of its range should not be capable of calibrating devices outside of this range.*

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. Calculations should be run for several data points throughout the loading range.



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

Force CMC uncertainty component 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) 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

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

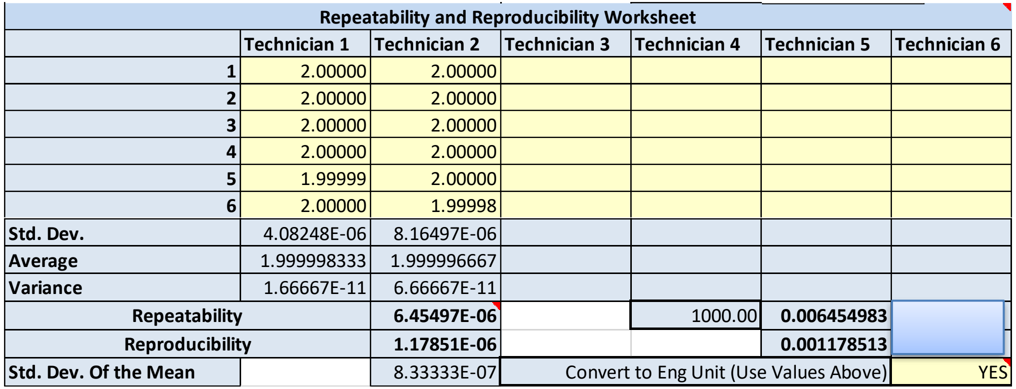
Repeatability and Reproducibility

Repeatability and Reproducibility Between Technicians – Repeatability between technicians is found by taken the square root of the average variance of the same test point taken multiple times. Reproducibility between technicians is found by taking the standard deviation of the averages of the same test point taken multiple times.

Repeatability and Reproducibility between technicians – This should only need to be performed once per every parameter on the scope of accreditation and be conducted amongst all technicians who perform calibrations using the equipment

Repeatability and Reproducibility

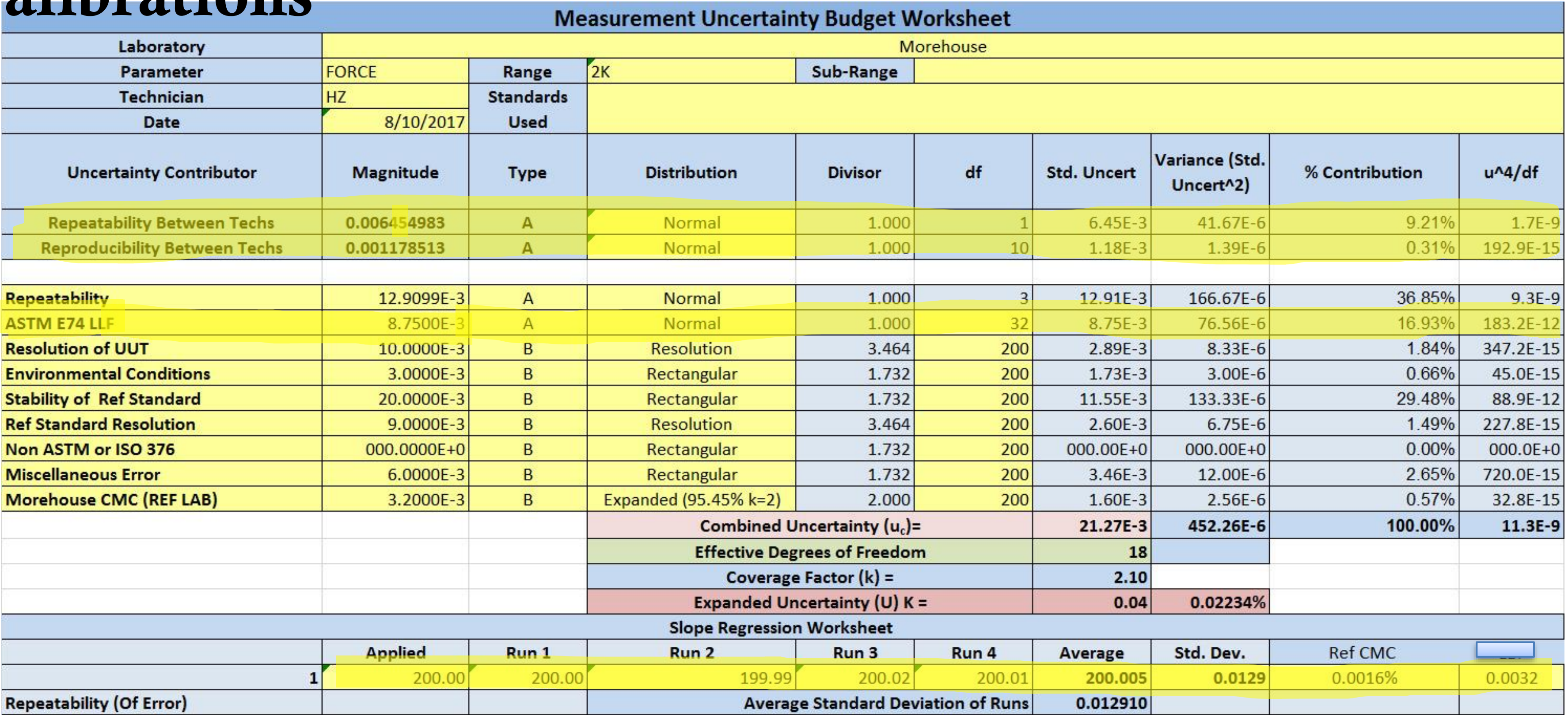
This example uses two technicians recording readings at the same measurement point. The readings were taken in mV/V and were then converted to force units. Repeatability between technicians is found by taken the square root of the averages. Reproducibility between technicians is found by taking the standard deviation of the averages.



Repeatability and Reproducibility Worksheet

	Technician 1	Technician 2	Technician 3	Technician 4	Technician 5	Technician 6
1	2.00000	2.00000				
2	2.00000	2.00000				
3	2.00000	2.00000				
4	2.00000	2.00000				
5	1.99999	2.00000				
6	2.00000	1.99998				
Std. Dev.	4.08248E-06	8.16497E-06				
Average	1.999998333	1.999996667				
Variance	1.66667E-11	6.66667E-11				
Repeatability		**6.45497E-06**		1000.00	**0.006454983**	
Reproducibility		**1.17851E-06**			**0.001178513**	
Std. Dev. Of the Mean		8.33333E-07	Convert to Eng Unit (Use Values Above)			YES

Force CMC uncertainty component 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	0.006454983	A	Normal	1.000	1	6.45E-3	41.67E-6	9.21%	1.7E-9
Reproducibility Between Techs	0.001178513	A	Normal	1.000	10	1.18E-3	1.39E-6	0.31%	192.9E-15
Repeatability	12.9099E-3	A	Normal	1.000	3	12.91E-3	166.67E-6	36.85%	9.3E-9
ASTM E74 LLF	8.7500E-3	A	Normal	1.000	32	8.75E-3	76.56E-6	16.93%	183.2E-12
Resolution of UUT	10.0000E-3	B	Resolution	3.464	200	2.89E-3	8.33E-6	1.84%	347.2E-15
Environmental Conditions	3.0000E-3	B	Rectangular	1.732	200	1.73E-3	3.00E-6	0.66%	45.0E-15
Stability of Ref Standard	20.0000E-3	B	Rectangular	1.732	200	11.55E-3	133.33E-6	29.48%	88.9E-12
Ref Standard Resolution	9.0000E-3	B	Resolution	3.464	200	2.60E-3	6.75E-6	1.49%	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	2.65%	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	0.57%	32.8E-15
			Combined Uncertainty (u_c)=			21.27E-3	452.26E-6	100.00%	11.3E-9
			Effective Degrees of Freedom			18			
			Coverage Factor (k) =			2.10			
			Expanded Uncertainty (U) K =			0.04	0.02234%		

Slope Regression Worksheet									
	Applied	Run 1	Run 2	Run 3	Run 4	Average	Std. Dev.	Ref CMC	
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			

Force CMC uncertainty component 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) ~~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

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

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 - is defined 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

Resolution of the Reference

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

Resolution of the Reference = 0.009 FORCE UNITS (This should be on the Certificate of Calibration)

STANDARD DEVIATION mV/V	RESOLUTION FORCE UNITS	LOWER LIMIT FACTOR FORCE UNITS
0.0000166	0.009	0.037

Force CMC uncertainty component 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) ~~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

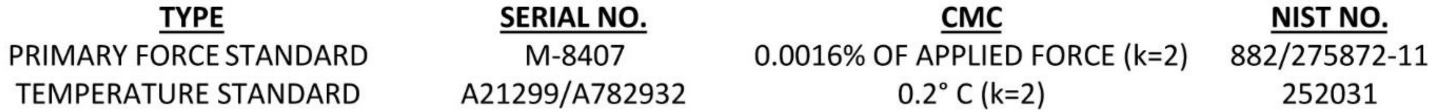
Do not use SEB, Nonlinearity, or Hysteresis as they are not appropriate contributors when following the ASTM E74 standard.

Reference Standard Uncertainty

Reference Standard Calibration Uncertainty – This is usually the CMC uncertainty component of the reference standard used to calibrate the force measuring device. It is the uncertainty of the calibration of the calibration of the force measuring device. The repeatability study done for the CMC, can be removed if a new repeatability with the unit currently being calibrated is conducted.

Reference Standard Uncertainty

Reference Standard Calibration Uncertainty – The lab performing the calibration of this device used deadweight primary standards with a CMC uncertainty component of 0.0016 % of applied for this device. 200 FORCE UNITS x 0.0016 % = 0.0032 FORCE UNITS and this is then divided by the appropriate coverage factor to get the standard uncertainty.



TYPE	SERIAL NO.	CMC	NIST NO.
PRIMARY FORCE STANDARD	M-8407	0.0016% OF APPLIED FORCE (k=2)	882/275872-11
TEMPERATURE STANDARD	A21299/A782932	0.2° C (k=2)	252031

Force CMC uncertainty component 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) ~~Repeatability and Reproducibility~~

Type B Uncertainty Contributors

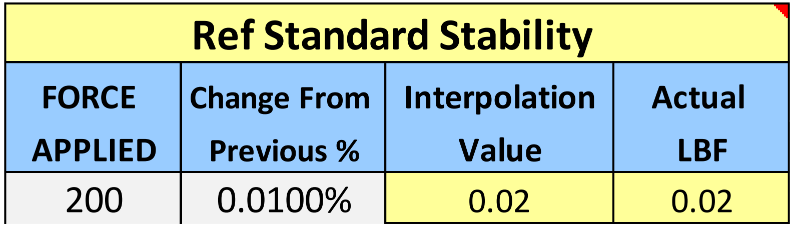
1) ~~Resolution of the Best Existing Device~~
2) ~~Reference Standard Resolution* *If Applicable*~~
3) ~~Reference Standard Uncertainty~~
4) Reference Standard Stability
5) Environmental Factors
6) Other Error Sources

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

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. If the instrument is new, the suggestion is to contact the manufacturer for stability estimation on similar instruments. This should be on any ASTM E74 report as Change from Previous and the exact value change from one calibration to the next should be used.

Reference Standard Stability – This is calculated per point and 0.01 % change between the same 200 FORCE UNITS calibration point was used which corresponded to 0.02 FORCE UNITS.



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

Force CMC uncertainty component 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) ~~Repeatability and Reproducibility~~

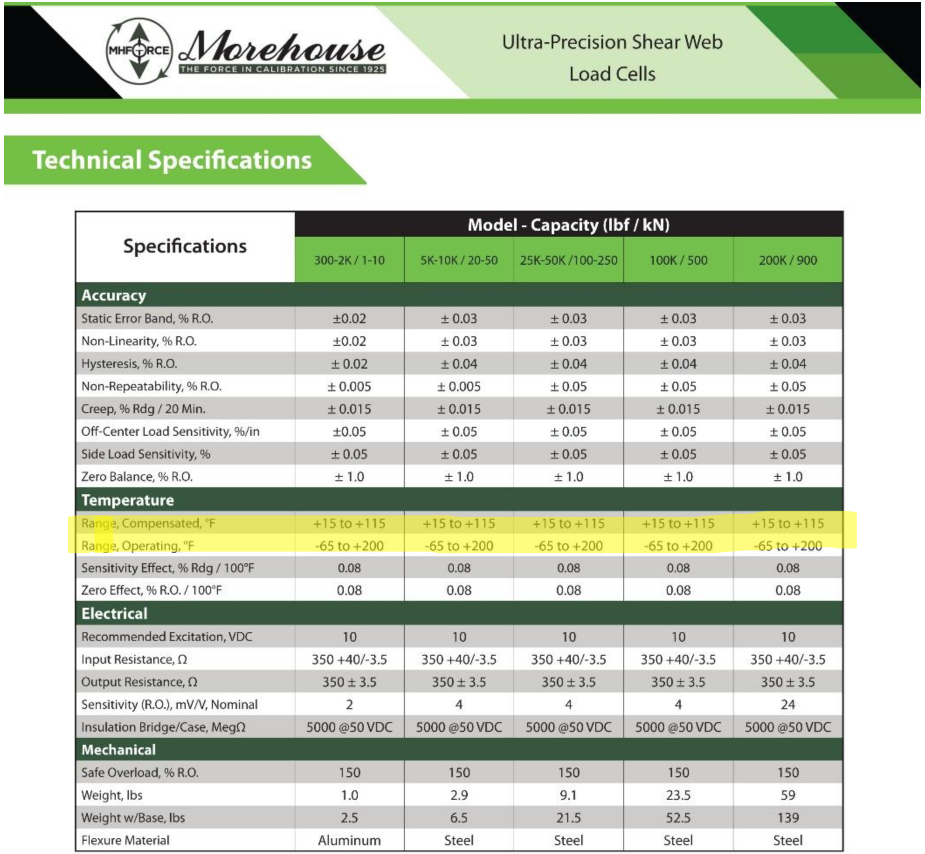
Type B Uncertainty Contributors

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

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

Environmental Factors

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



MHFORCE Morehouse
THE FORCE IN CALIBRATION SINCE 1925

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

Environmental Factors

Environmental Factors ± degree Celsius was used and this is found on the manufacturers specification sheet. The temperature effect is 0.0015 percent per degree C. If the reference laboratory controls the temperature to within ± 1 degree, the contribution formula is Force Applied x Temperature Specification per 1 degrees = Environmental Error. 200 Force Units x 0.0015 % = 0.003 FORCE UNITS

Force CMC uncertainty component 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) ~~Repeatability and Reproducibility~~

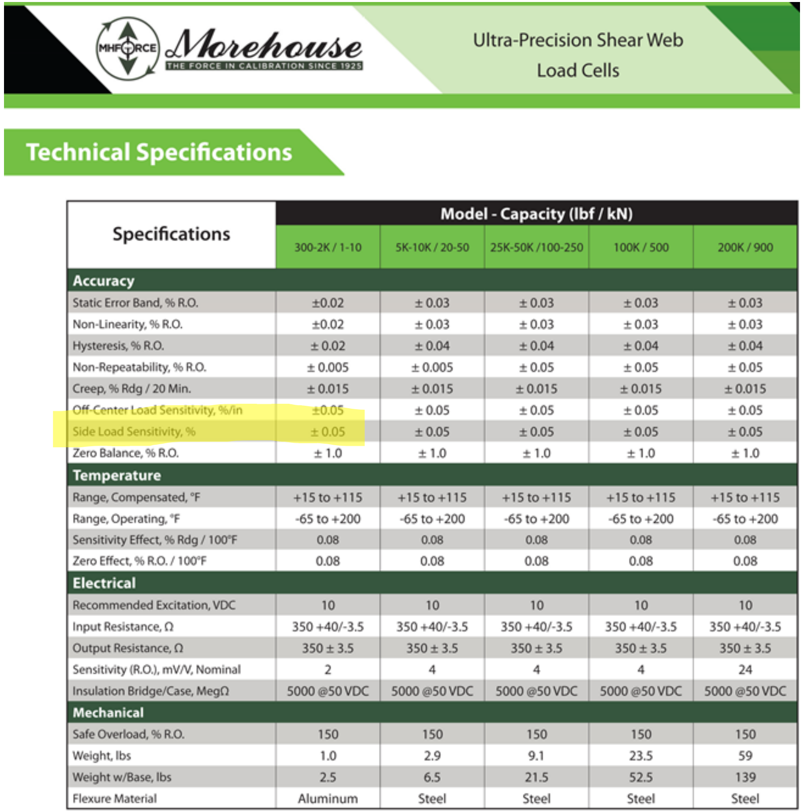
Type B Uncertainty Contributors

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

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

Other Error Sources

Other Error Sources – In this example the alignment of the force transfer machine 1/16th inch measured off centerline of the load cell (From the specification sheet side load sensitivity 0.05 % x 0.0625 = 0.003 % = 0.15 FORCE UNITS). Other Error Sources could include geometric alignment, timing, and contributors associated with using different indicators, if the device is calibrated with a different indicator than was used for calibration.



MHFORCE Morehouse THE FORCE IN CALIBRATION SINCE 1925

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

Indicator Uncertainty – If the force measuring device is not used with the same indicator that was used for calibration and additional error source will need to be accounted for and measurement traceability for the indicator will have to be verified. It is recommended practice to use the same indicating system at the time of calibration as this will reduce the overall measurement uncertainty by removing an additional uncertainty source.

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
- Difference in timing profiles
- 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
- Thread Depth Errors on Shear Web Load

Force CMC for ASTM E74 Calibrations

Type A Uncertainty Contributors

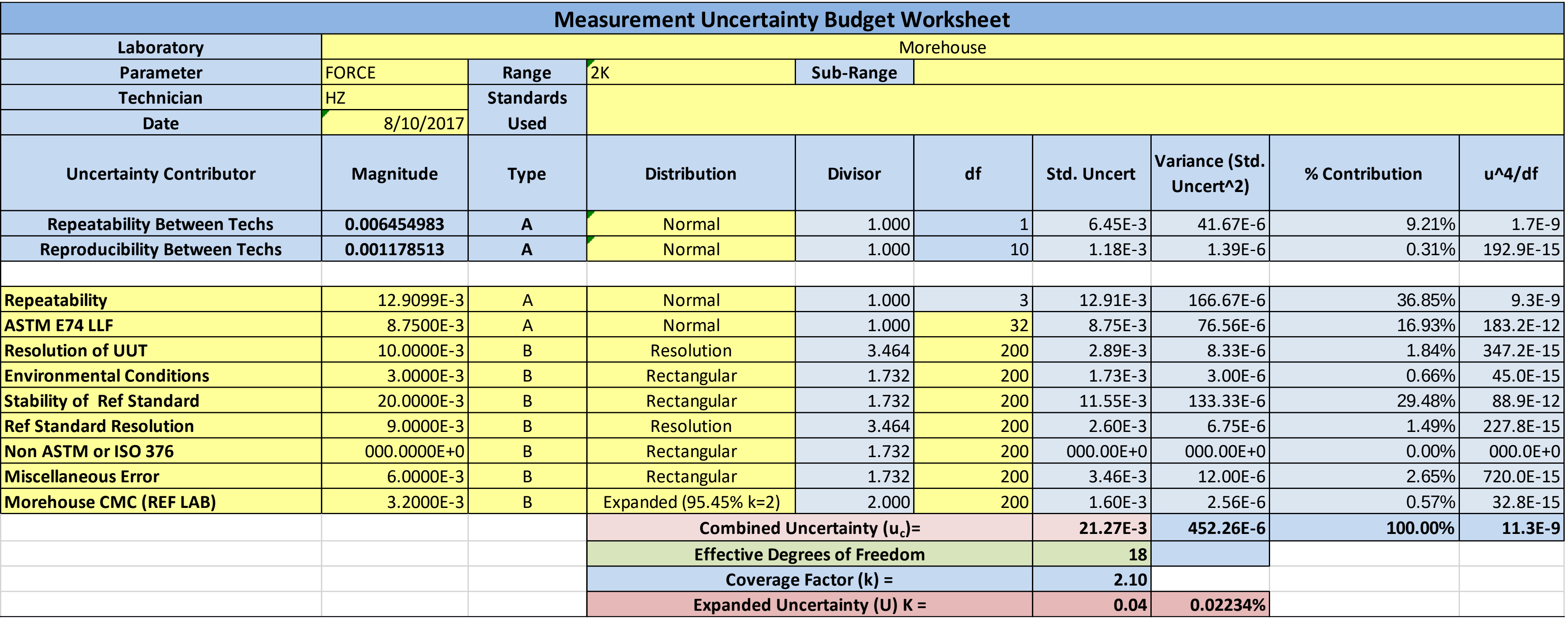
1) ~~ASTM LLF reduced to 1 Standard Deviation (ASTM LLF is reported with k= 2.4)~~
2) ~~Repeatability of the Best Existing Device~~
3) ~~Repeatability and Reproducibility~~

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~~

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

Force CMC uncertainty component 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	**0.006454983**	**A**	Normal	1.000	1	6.45E-3	41.67E-6	9.21%	1.7E-9
Reproducibility Between Techs	**0.001178513**	**A**	Normal	1.000	10	1.18E-3	1.39E-6	0.31%	192.9E-15
Repeatability	12.9099E-3	A	Normal	1.000	3	12.91E-3	166.67E-6	36.85%	9.3E-9
ASTM E74 LLF	8.7500E-3	A	Normal	1.000	32	8.75E-3	76.56E-6	16.93%	183.2E-12
Resolution of UUT	10.0000E-3	B	Resolution	3.464	200	2.89E-3	8.33E-6	1.84%	347.2E-15
Environmental Conditions	3.0000E-3	B	Rectangular	1.732	200	1.73E-3	3.00E-6	0.66%	45.0E-15
Stability of Ref Standard	20.0000E-3	B	Rectangular	1.732	200	11.55E-3	133.33E-6	29.48%	88.9E-12
Ref Standard Resolution	9.0000E-3	B	Resolution	3.464	200	2.60E-3	6.75E-6	1.49%	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	2.65%	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	0.57%	32.8E-15
			Combined Uncertainty (u_c)=			**21.27E-3**	**452.26E-6**	**100.00%**	**11.3E-9**
			Effective Degrees of Freedom			**18**			
			Coverage Factor (k) =			**2.10**			
			Expanded Uncertainty (U) K =			**0.04**	**0.02234%**		

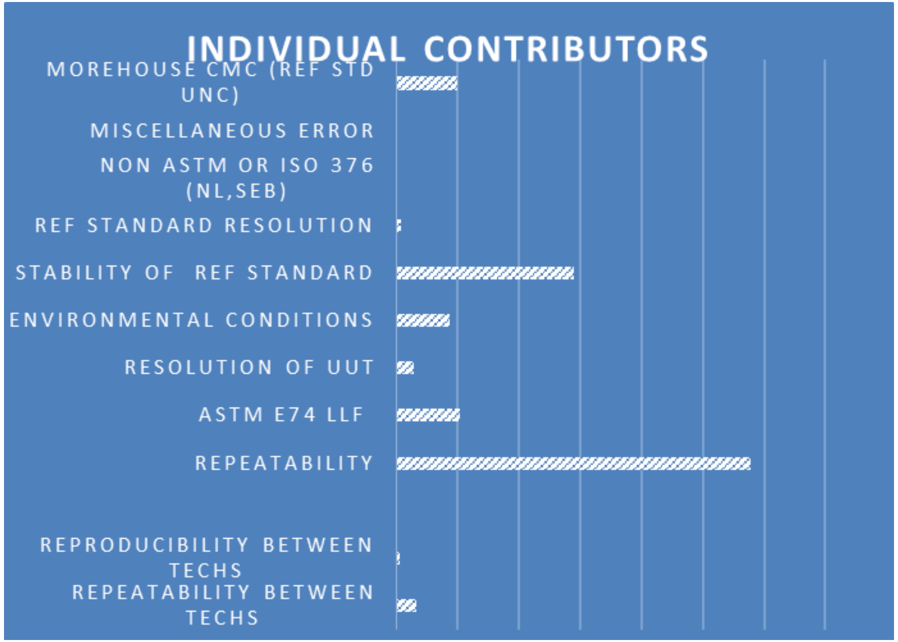
Force CMC uncertainty component for ASTM E74 Calibrations

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) 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



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

Force CMC uncertainty component 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.

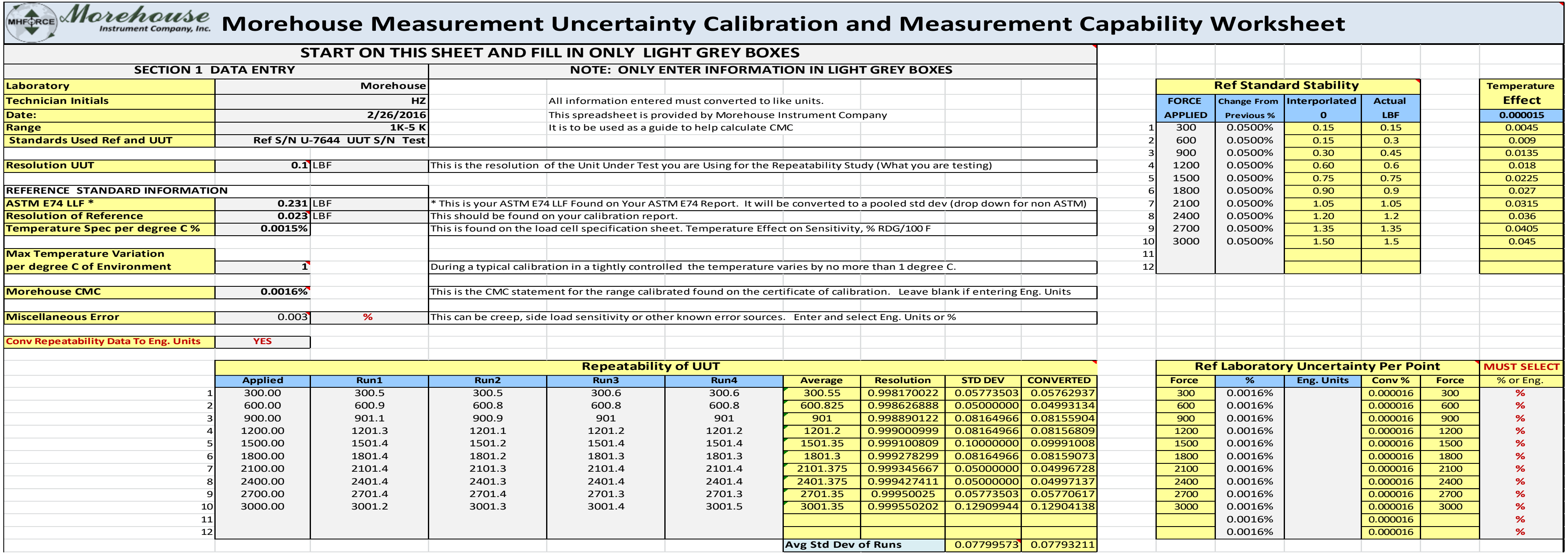
Type A Uncertainty Contributors

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) Repeatability and Reproducibility

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

Morehouse CMC sheet



Morehouse Measurement Uncertainty Calibration and Measurement Capability Worksheet

START ON THIS SHEET AND FILL IN ONLY LIGHT GREY BOXES

SECTION 1 DATA ENTRY			NOTE: ONLY ENTER INFORMATION IN LIGHT GREY BOXES
Laboratory	Morehouse		
Technician Initials	HZ		All information entered must converted to like units.
Date:	2/26/2016		This spreadsheet is provided by Morehouse Instrument Company
Range	1K-5 K		It is to be used as a guide to help calculate CMC
Standards Used Ref and UUT	Ref S/N U-7644 UUT S/N Test		
Resolution UUT	0.1	LBF	This is the resolution of the Unit Under Test you are Using for the Repeatability Study (What you are testing)
REFERENCE STANDARD INFORMATION			
ASTM E74 LLF *	0.231	LBF	* This is your ASTM E74 LLF Found on Your ASTM E74 Report. It will be converted to a pooled std dev (drop down for non ASTM)
Resolution of Reference	0.023	LBF	This should be found on your calibration report.
Temperature Spec per degree C %	0.0015%		This is found on the load cell specification sheet. Temperature Effect on Sensitivity, % RDG/100 F
Max Temperature Variation per degree C of Environment	1		During a typical calibration in a tightly controlled the temperature varies by no more than 1 degree C.
Morehouse CMC	0.0016%		This is the CMC statement for the range calibrated found on the certificate of calibration. Leave blank if entering Eng. Units
Miscellaneous Error	0.003	%	This can be creep, side load sensitivity or other known error sources. Enter and select Eng. Units or %
Conv Repeatability Data To Eng. Units	YES		

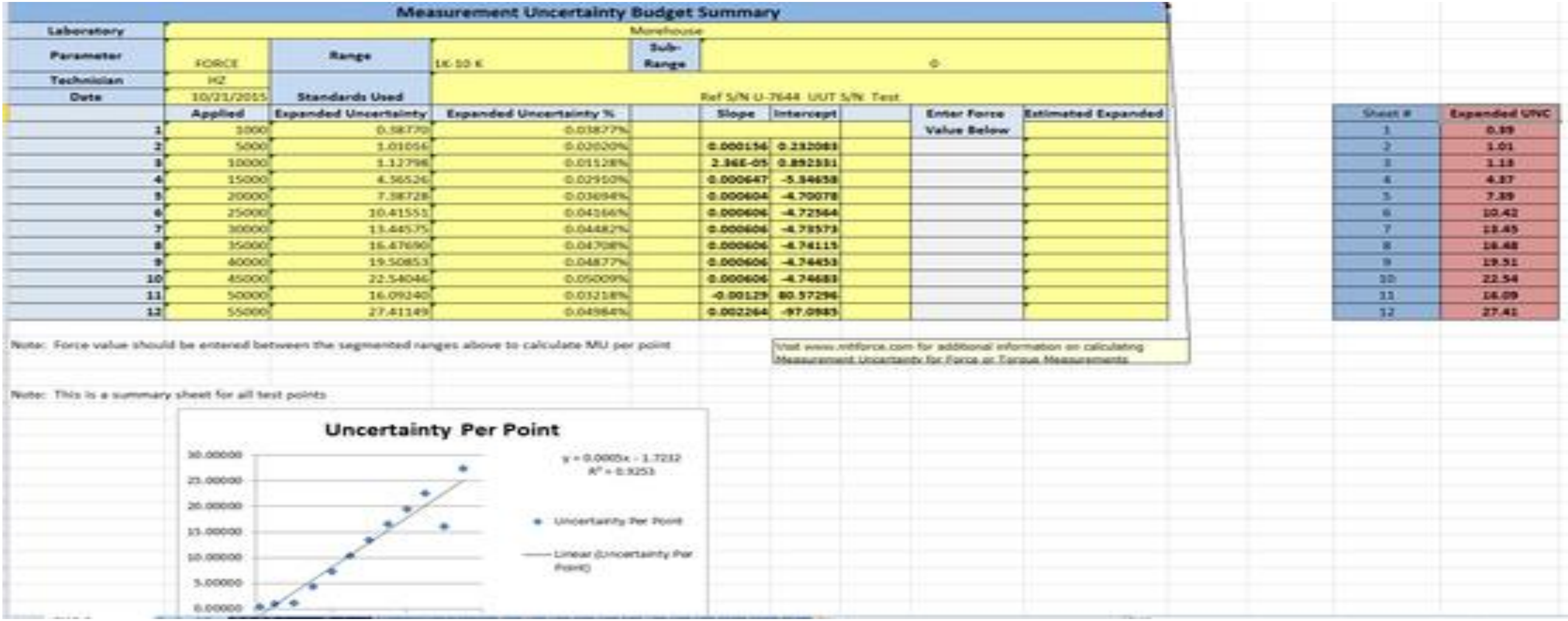
	Ref Standard Stability				Temperature Effect
	FORCE APPLIED	Change From Previous %	Interporlated 0	Actual LBF	0.000015
1	300	0.0500%	0.15	0.15	0.0045
2	600	0.0500%	0.15	0.3	0.009
3	900	0.0500%	0.30	0.45	0.0135
4	1200	0.0500%	0.60	0.6	0.018
5	1500	0.0500%	0.75	0.75	0.0225
6	1800	0.0500%	0.90	0.9	0.027
7	2100	0.0500%	1.05	1.05	0.0315
8	2400	0.0500%	1.20	1.2	0.036
9	2700	0.0500%	1.35	1.35	0.0405
10	3000	0.0500%	1.50	1.5	0.045
11					
12					

	Repeatability of UUT								
	Applied	Run1	Run2	Run3	Run4	Average	Resolution	STD DEV	CONVERTED
1	300.00	300.5	300.5	300.6	300.6	300.55	0.998170022	0.05773503	0.05762937
2	600.00	600.9	600.8	600.8	600.8	600.825	0.998626888	0.05000000	0.04993134
3	900.00	901.1	900.9	901	901	901	0.998890122	0.08164966	0.08155904
4	1200.00	1201.3	1201.1	1201.2	1201.2	1201.2	0.999000999	0.08164966	0.08156809
5	1500.00	1501.4	1501.2	1501.4	1501.4	1501.35	0.999100809	0.10000000	0.09991008
6	1800.00	1801.4	1801.2	1801.3	1801.3	1801.3	0.999278299	0.08164966	0.08159073
7	2100.00	2101.4	2101.3	2101.4	2101.4	2101.375	0.999345667	0.05000000	0.04996728
8	2400.00	2401.4	2401.3	2401.4	2401.4	2401.375	0.999427411	0.05000000	0.04997137
9	2700.00	2701.4	2701.4	2701.3	2701.3	2701.35	0.99950025	0.05773503	0.05770617
10	3000.00	3001.2	3001.3	3001.4	3001.5	3001.35	0.999550202	0.12909944	0.12904138
11									
12									
						Avg Std Dev of Runs		0.07799573	0.07793211

Ref Laboratory Uncertainty Per Point					MUST SELECT
Force	%	Eng. Units	Conv %	Force	% or Eng.
300	0.0016%		0.000016	300	%
600	0.0016%		0.000016	600	%
900	0.0016%		0.000016	900	%
1200	0.0016%		0.000016	1200	%
1500	0.0016%		0.000016	1500	%
1800	0.0016%		0.000016	1800	%
2100	0.0016%		0.000016	2100	%
2400	0.0016%		0.000016	2400	%
2700	0.0016%		0.000016	2700	%
3000	0.0016%		0.000016	3000	%
	0.0016%		0.000016		%
	0.0016%		0.000016		%

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

Uncertainty Example –CMC



Measurement Uncertainty Budget Summary

Laboratory	Morehouse				
Parameter	FORCE	**Range**	1K-10 K	**Sub-Range**	0
Technician	HZ				
Date	10/21/2015	**Standards Used**	Ref S/N U-7644 UUT S/N Test		

	Applied	**Expanded Uncertainty**	**Expanded Uncertainty %**		**Slope**	**Intercept**		**Enter Force Value Below**	**Estimated Expanded**
1	1000	0.38770	0.03877%						
2	5000	1.01056	0.02020%		0.000156	0.232081			
3	10000	1.12798	0.01128%		2.36E-05	0.892331			
4	15000	4.36526	0.02910%		0.000647	-5.34658			
5	20000	7.38728	0.03694%		0.000604	-4.70078			
6	25000	10.41551	0.04166%		0.000606	-4.72564			
7	30000	13.44575	0.04482%		0.000606	-4.73573			
8	35000	16.47690	0.04708%		0.000606	-4.74115			
9	40000	19.50853	0.04877%		0.000606	-4.74453			
10	45000	22.54046	0.05009%		0.000606	-4.74683			
11	50000	16.09240	0.03218%		-0.00129	80.57296			
12	55000	27.41149	0.04984%		0.002264	-97.0985			

Sheet #	Expanded UNC
1	0.39
2	1.01
3	1.13
4	4.37
5	7.39
6	10.42
7	13.45
8	16.48
9	19.51
10	22.54
11	16.09
12	27.41

Note: Force value should be entered between the segmented ranges above to calculate MU per point

Visit www.mhforce.com for additional information on calculating Measurement Uncertainty for Force or Torque Measurements

Note: This is a summary sheet for all test points

All data has been entered and individual per point analysis has been done. **Welch–Satterthwaite equation** is used to calculate an approximation to the effective degrees of freedom of a linear combination of independent sample variances, also known as the **pooled degrees of freedom**

Uncertainty Example

- **This example is just a guideline for calculating expanded uncertainty. The actual uncertainty components in your system may vary.**

Rounding Rules GLP 9

Force Rounding Example

ASTM E74 LLF of 0.237 LBF (*K*=2.4) is now 0.223 LBf @ 10 % and 1.053 LBF for *K*=2 at full scale capacity.

Following Rounding Rules

ASTM E74 LLF of 0.24 LBF (*K*=2.4) is now 0.22 LBf @ 10 % and 1.05 LBF for *K*=2 at full scale capacity.

Rounding Rules GLP 9

1. Round the uncertainty to two significant figures
2. Round the correction/error to the last figure affected by the uncertainty
3. Report the rounded correction value and uncertainty to the same level of significance

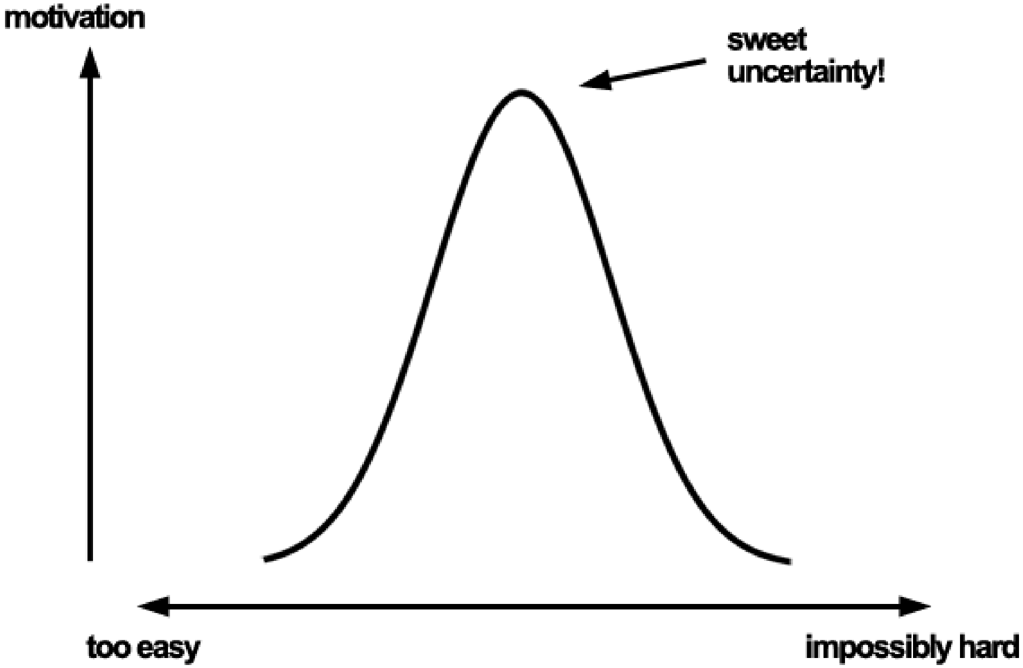
Even/Odd when the digit beyond the one to be retained is exactly five, and the retained digit is even, leave it unchanged; conversely if the digit is odd, increase the retained figure by one. Thus, 3.450 becomes 3.4 but 3.550 becomes 3.6 to two significant figures

Celebration of knowledge

Can you

- Identify some potential force measurement errors?
- Implement proper force calibration techniques as discussed and demonstrated in the class?
- Using material provided in the training class, put together an expanded uncertainty budget for force equipment used as secondary standards?

QUESTIONS?



Thank You

MHFORCE

Morehouse

THE FORCE IN CALIBRATION SINCE 1925