

ISO 376 Guidance Relating to Force Equipment



Figure 1: A Morehouse UCM with a Device Under Test (DUT) In Tension Using ISO 376 Compliant Tension Adapters

Table of Contents

Introduction	3
ISO 376:2011 Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines standard requirements.	3
ISO 376 Calibration Procedure Simplified.....	5
Selection of Forces.....	5
ISO Case C or D.....	6
ISO Case C	7
ISO Case D.....	7
Calibration Steps Needed to Perform an ISO 376 Calibration	9
What Coefficients Do	11
Recalibration Dates.....	13
Reporting Criteria.....	13
Morehouse DCM, UCM & PCM Machines & ISO 376 Calibration.....	14
Morehouse DCM.....	15
Morehouse UCM & PCM.....	16
Morehouse Automation	18
Common Error Sources in Force Calibration.....	20
Calibration with the Morehouse UCM - What Replicates Field Use is Often Best Practice	21
Selection of Load Cells for Your Morehouse UCM.....	24
Uncertainty Calculations.....	25
Type A Uncertainty Contributions	25
Type B Uncertainty Contributions	26
Additional Euramet cg-4 Information	26
Summary	30
Additional Information.....	30
References	30

Introduction

In [past articles](#), we have discussed both ISO 376 and ASTM E74 and the differences between these internationally recognized standards. One aspect we have not discussed is the meaning of compliance with ISO 376; specifically, there is a common misconception about equipment "being compliant" with ISO 376. This may come from some testing criteria found in Euramet cg-4, which has some best practices to follow in the evaluation of force equipment and ensuring your equipment can calibrate following the practices found in ISO 376.

We must stress that ISO 376 does not relate to the force calibration equipment used to apply the forces; ISO 376 relates to the instruments used as reference standards in those transfer machines. It is comparable to ISO 9000 and ISO/IEC 17025; those accreditations do not ensure quality product; they ensure you have a quality system but not a quality product.

The proper force equipment will be plumb, level, square, rigid, and have little to no torsion. This article will discuss ISO 376 criteria as it applies to reference standards such as Morehouse load cells, proper adapters for calibration, what criteria make for great force equipment, and provide some information on Common Errors, Measurement Uncertainty, and Euramet cg-4.

ISO 376:2011 Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines standard requirements.

ISO 376 focuses on force proving instruments and **not** the calibration machine such as a Morehouse UCM (Universal Calibration Machine), PCM (Portable Calibration Machine) per section 6.1 Identification by stating, "All the elements of the force-proving instrument (including the cables for electrical connection) shall be individually and uniquely identified, e.g., by the name of the manufacturer, the model, and the serial number. For the force transducer, the maximum working force shall be indicated." The standard then goes on to address the application of force in section 6.2 by stating, "The force transducer and its loading fittings shall be designed so as to ensure axial application of force, whether in tension or compression." Then in section 7.1 ISO 376 further states to ensure "that the attachment system of the force-proving instrument allows axial application of the force when the instrument is used for tensile testing; that there is no interaction between the force transducer and its support on the calibration machine when the instrument is used for compression testing."

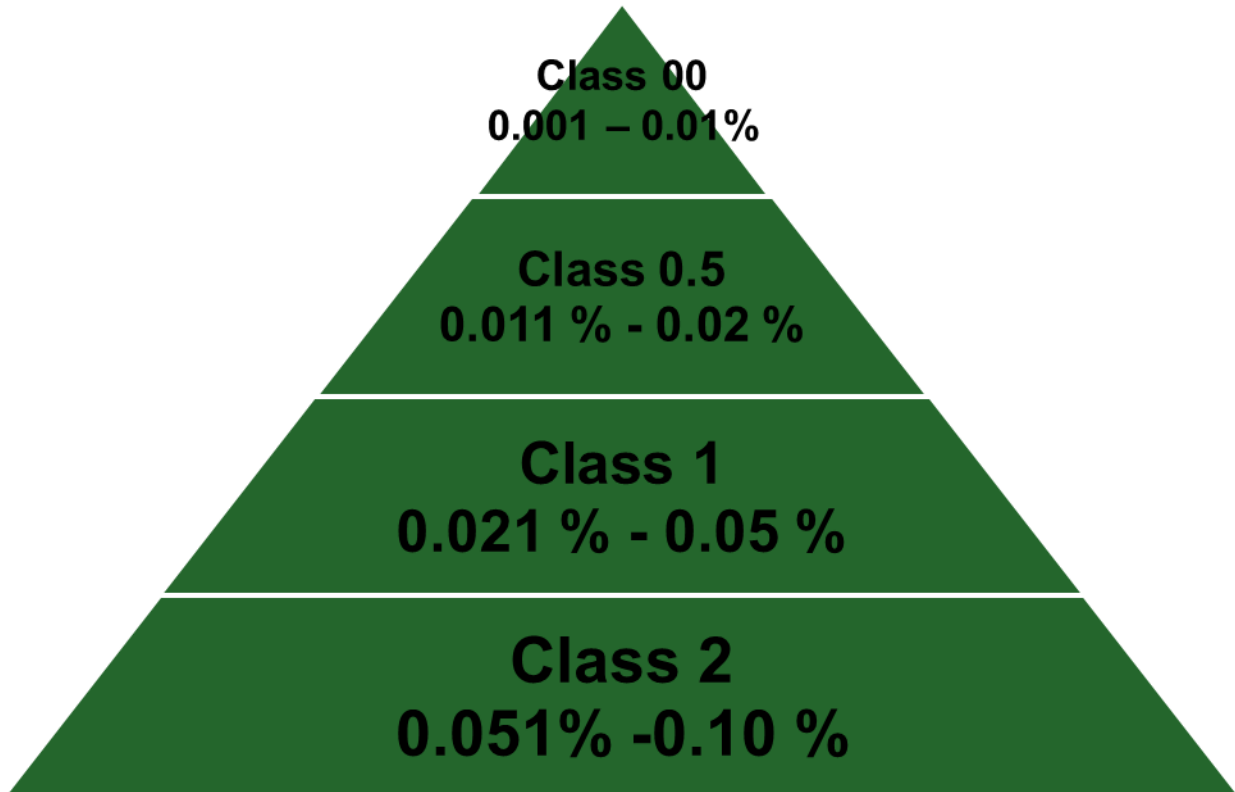


Figure 2: ISO 376 Expanded Uncertainty Required to Classify a Force-Proving Instrument

The above shows the typical range of reference uncertainties needed to achieve the Classification. With Class 00, deadweight primary standards are highly recommended as they can usually achieve better than 0.0025 % of applied force throughout the loading range. Reference standard load cells can achieve the uncertainty needed. However, it is more than likely that multiple standard changes will be required, and several inefficiencies with timing may impact the UUT (Unit Under Test).

Deadweight Primary 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 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. Weights in these machines are adjusted for local gravity, air buoyancy, material density, and the adjustment must be made to correct the weights to force, and most weights will be adjusted better than 0.003 % of applied force.

Lever Amplification Deadweight Machines are a machine in which the deadweight force is amplified using one or more mechanical lever systems, increasing the force by a factor approximately equal to the ratio of the lever arm lengths. These machines often achieve a CMC of better than 0.01 % of applied force and can certify to Class 00.

Hydraulic Amplification uses a deadweight force that is amplified using a hydraulic system with piston/cylinder assemblies of different effective areas, increasing the force by a factor approximately

equal to the ratio of the two areas. These types of machines often achieve CMC's similar to that of lever amplification deadweight machines.

Reference Transducer Force Machines – These are machines such as the Morehouse UCM & PCM. They are based on one or more reference force transducers that have previously been individually calibrated in another machine, preferably deadweight to ISO 376 or ASTM E74.

ISO 376 Calibration Procedure Simplified

Anyone reading this document is highly encouraged to purchase the ISO 376 standard. We are doing for the purpose of this section simplifying the basics so the end-user can understand some of the calibration's procedure. The following text is not meant to be complete. It only represents a mid-level view of some important guidelines that need to be followed during the calibration of force-proving instruments using the ISO 376 standard.

Selection of Forces

ISO 376 requires at least eight force points throughout the range, at least four runs of data, and a creep test if the force-measuring instrument is used for incremental loading only. However, if the force-proving instrument is to be used for both incremental and decremental loading, two extra runs of data are taken, making the total of runs 6. ISO 376 does not allow the first test point to be less than 2 % of the measuring range. It has classifications that specify that the first point cannot be less than 4000 times the resolution for Class 00, 2000 times the resolution for Class 0.5, 1000 times the resolution for Class 1, and 500 times the resolution for class 2.

0
100
250
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0

Figure 3: Calibration Points for a Load Cell

Morehouse typically recommends selecting between twelve calibration points as shown above to classify the instruments easier below 10 %. We typically select a point that is 4000 times the resolution, a 5 % point, and then try to select a point around every 10 % through 100 %. By adding these lower force points, we can narrow in on the Classification providing the end-user with the largest useable range for the Class achieved.

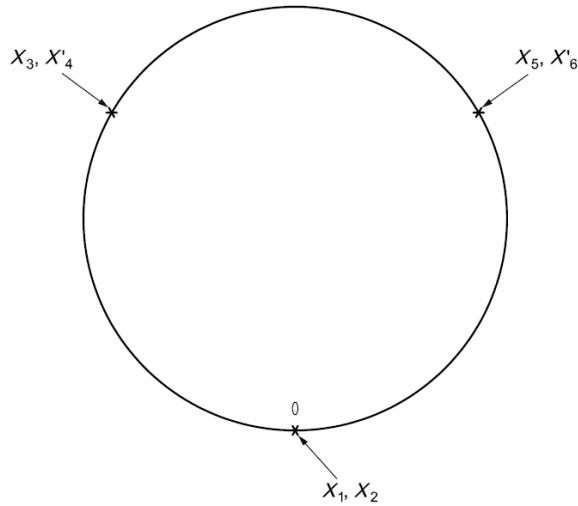


Figure 4 Diagram of Loading Positions

The above diagram shows the recommended loading positions for a full ISO 376 calibration. These positions will vary depending on the Case required and discussed below.

		RUN 1	RUN 2	RUN 3	RUN 4
	Start Temp (°C):	22.9	22.9	22.9	22.9
	End Temp (°C):	22.9	22.9	22.9	22.9
COMPRESSION RAW DATA					
Standard	Force (lbf)	RUN 1	RUN 2	RUN 3	RUN 4
M-8407	0	0	0.00001	0.00001	0
M-8407	100	-0.08379	-0.08377	-0.08378	-0.08378
M-8407	250	-0.20949	-0.20946	-0.20947	-0.20948
M-8407	500	-0.41901	-0.41898	-0.419	-0.41898
M-8407	1000	-0.83813	-0.83808	-0.83812	-0.83809
M-8407	1500	-1.25738	-1.25733	-1.25737	-1.25733
M-8407	2000	-1.67673	-1.67668	-1.67672	-1.67668
M-8407	2500	-2.0962	-2.09614	-2.0962	-2.09614
M-8407	3000	-2.51574	-2.51567	-2.51574	-2.51567
M-8407	3500	-2.93534	-2.93527	-2.93535	-2.93527
M-8407	4000	-3.35501	-3.35494	-3.35502	-3.35493
M-8407	4500	-3.77473	-3.77466	-3.77474	-3.77466
M-8407	5000	-4.19449	-4.19442	-4.19451	-4.19441
M-8407	0	-0.00014	-0.00007	-0.00011	-0.00009
M-8407					
CREEP TEST (Held at Max Force for 90 Seconds)					
	Output 30 Seconds after removing load:				-0.00002
	Output 300 Seconds after removing load:				0.00007

Figure 5 Example of Increasing Raw Data for Case C Increasing Forces and Creep Test

ISO Case C or D

The ISO 376 standard allows for four different cases. Case A and B are for specific force devices. The criteria for Case A is relative reproducibility, repeatability, zero errors, and creep errors. The Criteria for Case B replaces creep with relative reversibility. In reality, most instruments we get requests to calibrate are for Case C or D.

ISO Case C

Case C is for instruments classified for interpolation and incremental-only loading. The criteria for Case C is relative reproducibility, repeatability, zero errors, interpolation error, and creep errors.

When calibrating instruments using Case C, it is more straightforward to meet the creep error requirement on almost all Morehouse load cells. Our Ultra Precision cells will meet Class 00 on capacities up to 500 kN (112 klbf). Morehouse Ultra-Precision load cells are available in higher capacities, though this is where a trade-off on physical size comes in. Above 500 kN, one may wish to purchase a Precision Multi-Column type cell where the design will dictate Class 00 up to 4.4 MN (1000 klbf). Class 0.5 is highly likely in these cases, with a useable Class 00 range of better than 40 % of capacity is highly likely.

Creep Tests

ISO 376 requires a creep test if only incremental loads are applied. Per section 7.4.4, "If the force-proving instrument is to be calibrated in an incremental-only loading direction, record its output at 30 s and 300 s after application or removal of the maximum calibration force, in each mode of force application, to enable its creep characteristics to be determined. If creep is measured at zero force, the maximum calibration force shall be maintained for at least 60 s prior to its removal. The creep test may be performed at any time after preloading during the calibration procedure."

ISO Case D

Case D is for instruments classified for interpolation and incremental/decremental loading. The criteria for Case D is relative reproducibility, repeatability, zero errors, interpolation error, and relative reversibility error.

Many instruments that pass class 00 for Case C may fail on reversibility. There are several reasons for this. Some of which include:

- Loading profiles with deadweight machines such as cycling weights on and off
- The Hysteresis specification of several load cells might not be as good as the manufacturer claims, or the manufacturer's calculation of hysteresis does not match that of the relative reversibility error calculation.
- If a deadweight machine is not used, the uncertainty of the secondary standard is too high to achieve Class 00 for reversibility

Therefore, only specific load cells are truly capable of achieving Case D classification to Class 00. Morehouse Ultra-Precision cells for capacities up to 500 kN (112 k lbf) will achieve Classification from at least 40 % of the range. Load cells above this capacity will vary depending on the design. However, many Morehouse ultra-precision cells will achieve Case D 00 of better than 50 % of the range.

Above 500 kN, one may wish to purchase a Precision Multi-Column type cell where the design will dictate Class 00 up to 4.4 MN (1000 k lbf). Class 0.5 will be achieved from 20 % or better of the loading range on most non-custom Morehouse load cells.

Calibration Steps Needed to Perform an ISO 376 Calibration

1. Allow the instrument to acclimate
2. Turn on any electronics and warm up as needed
3. Set up the force-proving instrument in the calibration frame
4. After the force-proving instrument is set up in the machine, section 7.4.1 requires the maximum force to be applied to the instrument three times, and the duration of that application should be between 60 and 90 seconds.
5. Carry out the calibration by applying two series of calibration forces to the force-proving instrument with increasing values only, without disturbing the device. 0° orientation X1 and X2. This data will be used to test for repeatability.
6. Apply at least two further series of increasing (shown in figure 6) and, if the force-proving instrument is to be calibrated in an incremental/decremental loading direction, decreasing values. Between each of the further series of forces, rotate the force-proving instrument symmetrically on its axis to positions uniformly distributed over 360° (i.e., 0°, 120°, 240°). See figure 3 for positioning. If this is not possible, it is permissible to adopt the following positions: 0°, 180°, and 360°
7. Perform a creep test – This is the recommendation of Morehouse to perform a creep test if needed at the end of the calibration. ISO 376 allows a creep test to be performed at the beginning of the calibration after exercising or preloading the force-proving instrument.
8. Run the data analysis. Note: ISO 376 allows the use of curves up to a 3rd-degree only.

COMPRESSION CALIBRATION DATA ANALYSIS

FORCE APPLIED	REPEATABILITY W/ ROTATION		REPEATABILITY W/O ROTATION		FIT ERROR		RESOLUTION		MACHINE UNCERTAINTY	
	b (%)	CLASS	b' (%)	CLASS	f _e	CLASS	mV/V	CLASS	%	CLASS
100	0.01	00	0.009	00	0.001	00	8378	00	0.0016	00
250	0.004	00	0.006	00	0	00	20947	00	0.0016	00
500	0.006	00	0.002	00	0	00	41898	00	0.0016	00
1000	0.004	00	0.003	00	0.001	00	83808	00	0.0016	00
1500	0.003	00	0.001	00	0	00	125732	00	0.0016	00
2000	0.002	00	0.001	00	0.001	00	167666	00	0.0016	00
2500	0.003	00	0.001	00	0	00	209612	00	0.0016	00
3000	0.002	00	0.001	00	0	00	251565	00	0.0016	00
3500	0.002	00	0.001	00	0	00	293524	00	0.0016	00
4000	0.002	00	0	00	0	00	335490	00	0.0016	00
4500	0.002	00	0	00	0	00	377461	00	0.0016	00
5000	0.002	00	0	00	0	00	419436	00	0.0016	00

ZERO ERROR		
TEST RUN	f ₀	CLASS
RUN 1	0.003	00
RUN 2	0.002	00
RUN 3	0.003	00
RUN 4	0.002	00

CREEP TEST RESULTS			
Force Held at Max Force for 90 Seconds	mV/V	ERROR	CLASS
Output 30 Seconds after removing load:	-0.00002	0.0021 %	00
Output 300 Seconds after removing load:	0.00007		
Creep Test was performed after the last measurement series			

Combined Expanded Uncertainty Equation for Compression Calibration

The following linear equation has been fitted to the combined uncertainty and applied force values observed at calibration using the method of least squares:

Expanded Uncertainty (lbf) = C ₀ + C ₁ × F
where: F = Force (lbf)
Coefficient C ₀ = 0.009195227
Coefficient C ₁ = 7.20102E-05



Figure 6 Example of Data and Class Assignments on a Morehouse 5 klbF Load Cell

In the above example for Case C, all the data points on this Morehouse 5 klbF load cell calibrated with deadweight primary standards are within the criteria to meet Class 00 classification.

COMPRESSION CALIBRATION DATA

FORCE APPLIED lbf	MEASURED OUTPUT				FITTED CURVE mV/V	EXPANDED UNCERTAINTY lbf
	RUN 1 mV/V	RUN 2 mV/V	RUN 3 mV/V	RUN 4 mV/V		
100	-0.08378	-0.08378	-0.08379	-0.08378	-0.08378	0.0164
250	-0.20947	-0.20946	-0.20947	-0.20947	-0.20947	0.0272
500	-0.41898	-0.41897	-0.41899	-0.41896	-0.41898	0.0452
1000	-0.83809	-0.83807	-0.8381	-0.83806	-0.83809	0.0812
1500	-1.25733	-1.25731	-1.25734	-1.2573	-1.25732	0.1172
2000	-1.67667	-1.67665	-1.67668	-1.67664	-1.67667	0.1532
2500	-2.09612	-2.09611	-2.09615	-2.09609	-2.09611	0.1892
3000	-2.51565	-2.51563	-2.51568	-2.51561	-2.51564	0.2252
3500	-2.93524	-2.93522	-2.93528	-2.93521	-2.93524	0.2612
4000	-3.3549	-3.35489	-3.35494	-3.35486	-3.35491	0.2972
4500	-3.77461	-3.7746	-3.77465	-3.77458	-3.77462	0.3332
5000	-4.19436	-4.19435	-4.19441	-4.19432	-4.19436	0.3692

The expanded uncertainty was calculated based on the method defined by ISO 376 standard for calibrating force-proving instruments. Expanded uncertainty is expressed with a coverage factor of k=2, such that the coverage probability corresponds to approximately 95%.

POLYNOMIAL EQUATIONS

The following polynomial equation, described in ISO 376:2011 has been fitted to the force and measured output values observed at calibration using the method of least squares:

Response (mV/V)= $A_0+A_1 \times F+A_2 \times F^2+A_3 \times F^3$ where: F= Force (lbf)	Force (lbf)= $B_0+B_1 \times R+B_2 \times R^2+B_3 \times R^3$ where: R= Response (mV/V)
Coefficient A_0 = 1.182527E-06	Coefficient B_0 = 1.573713E-03
Coefficient A_1 = -8.378091E-04	Coefficient B_1 = -1.193588E+03
Coefficient A_2 = -2.965424E-10	Coefficient B_2 = -5.031229E-01
Coefficient A_3 = 1.677959E-14	Coefficient B_3 = -3.401547E-02

Figure 7 A Page from the Calibration Report Showing Expanded Uncertainty and Calibration Coefficients

The sample page from a Morehouse ISO 376 calibration report shows reduced data and the expanded uncertainty, including the reference standard used to perform the calibration CMC and a summation of the errors from reproducibility, repeatability, interpolation, zero return, and creep. The ISO 376 standard provides detailed guidance on the equations to perform this analysis.

What Coefficients Do

The report shows calibration coefficients for both solving for force and for solving for the response. ASTM E74, ISO 376, and other standards may use calibration coefficients better to characterize the performance characteristics of continuous reading force-measuring equipment. These standards may use higher-order fits such as a 2nd or 3rd order fit (ISO 376) or up to as high as a 5th order fit (ASTM E74). Both standards use observed data and fit the data to a curve. In simple terms, these higher-order fits give instructions on how best to predict an output given a measured input. That output can either be the force at a specific response or the response when the force is known. We can use these equations to accurately predict the appropriate coordinate for any point in the measurement range, typically above the first non-zero point on the curve.

The coefficients of A_0 and B_0 are the constants at which the equation crosses the y-intercept. $A_1 \times F$ and $B_1 \times R$ are the linear terms and define the slope of the line. $A_2 \times F^2$ and $B_2 \times R^2$ are the quadratic terms. A positive quadratic coefficient causes the ends of the parabola to point upward, while a negative quadratic coefficient causes the parabola to point downward. $A_3 \times F^3$ and $B_3 \times R^3$ are the cubic terms. This coefficient makes the graph "wider" or "skinnier," or reflects it. If the coefficient is negative or more significant, the graph is skinnier.

When the coefficients are used to predict the response or the force, the error is below that of interpolation error, as calculated as part of the ISO 376 Expanded uncertainty on the calibration report. Thus, using the equation is imperative not to raise the overall uncertainty. In the test cases below, we show the errors from using the coefficients versus trying to enter the values from the calibration report using the span calibration found in several commercially available indicators.

B Coefficients Additional Error				
mV/V	Predicted	Read on Meter	Difference	%
LB S/N 12140				
-0.03999	47.92	47.92	0.00	0.000%
-0.07998	95.91	95.91	0.00	0.000%
-0.19995	239.88	239.88	0.00	0.000%
-0.39991	479.80	479.80	0.00	0.000%
-0.79979	959.51	959.51	0.00	0.000%
-1.19970	1439.13	1439.13	0.00	0.000%
-1.59962	1918.64	1918.64	0.00	0.000%
-1.99952	2398.04	2398.04	0.00	0.000%
-2.39942	2877.35	2877.34	0.01	0.000%
-3.19927	3835.81	3835.81	0.00	0.000%
-3.99901	4793.94	4793.94	0.00	0.000%
-4.39888	5272.96	5272.95	0.01	0.000%

Figure 8 Error When Coefficients are Entered into the Morehouse 4215 Plus or Software

Morehouse has done testing on various scenarios using the formula for B coefficients embedded into a 4215 Plus meter or using additional free-to-download Morehouse software. We developed an algorithm in the meter to display force values using the B coefficients in the above figure. When tested, the prediction error was almost zero, though there were slight rounding errors, as shown above. We know some people in the industry take the calibration reports and then enter mV/V into the meter. Thus, we decided to follow the same steps using a 5-pt calibration and entering those values into a meter and report the errors.

5 PT mV/V SPAN CALIBRATION				
mV/V	Predicted Force Values	Read on Meter LB S/N 12140	Difference	%
-0.03999	47.92	47.95	-0.03	-0.058%
-0.07998	95.91	95.91	0.00	0.004%
-0.19995	239.88	239.75	0.13	0.054%
-0.39991	479.80	479.54	0.26	0.055%
-0.79979	959.51	959.05	0.46	0.048%
-1.19970	1439.13	1438.59	0.54	0.037%
-1.59962	1918.64	1918.14	0.50	0.026%
-1.99952	2398.04	2397.51	0.53	0.022%
-2.39942	2877.35	2876.86	0.49	0.017%
-3.19927	3835.81	3835.33	0.48	0.013%
-3.99901	4793.94	4793.46	0.48	0.010%
-4.39888	5272.96	5272.52	0.44	0.008%
Programmed @ 1,2,3,4,5K				

Figure 9 Error When the Values are Written as a Span to the Meter as Opposed to Using the Coefficients

When we entered values programmed at 20 % increments and the corresponding mV/V values, the error on a device one expects to be better than the ISO 376 Interpolation Error is much higher at almost all test points. So the main issue here is if the end-user assumes they can do this and maintain the same uncertainty, they are mistaken. The other error from trying to span the points into a meter needs to be accounted for in any uncertainty analysis as it can be significant and should be avoided.

Recalibration Dates

ISO 376 in section 8.3.2 allows for the maximum validity of the calibration certificate to not exceed 26 months.

Reporting Criteria

ISO 376 requires:

- the identity of all elements of the force-proving instrument and loading fittings and of the calibration machine;
- the mode of force application (tension/compression);
- that the instrument is in accordance with the requirements of preliminary tests;
- the Class and the range (or forces) of validity and the loading direction (incremental-only or incremental/decremental);
- the date and results of the calibration and, when required, the interpolation equation;
- the temperature at which the calibration was performed;
- the uncertainty of the calibration results (one method of determining the uncertainty is given in Annex C);
- details of the creep measurement, if performed.

Morehouse DCM, UCM & PCM Machines & ISO 376 Calibration



Figure 10 A Morehouse Load Cell Showing What Eccentric Forces Are

Force Calibration is about using the right equipment and following the proper procedures. In this section, we will discuss equipment selection. The equipment chosen must have the means to incorporate the proper adapters as recommended by the ISO 376 Annex. Equipment should operate to keep the vertical line of force free from eccentric forces.

Morehouse DCM



Figure 11 A Morehouse Deadweight Calibration Machine

Laboratories with top-quality force calibration machines, such as deadweight calibrating machines, are classified as primary standards. If designed correctly, error sources such as these can be reduced:

- Repeatability of the force measurement instrument: Several laboratories have found the repeatability of a top-quality force-measuring instrument using primary standards to be less than 0.0005 %.
- Resolution: The resolution of a top-quality force-measuring instrument can be better than 0.0002 % if high-quality indicators reading six decimal places are used.
- Reproducibility and repeatability between technicians: When combined with the proper adapters, reproducibility and repeatability between technicians are often insignificant. The Morehouse [force measurement uncertainty tool](#) has methods for testing reproducibility and repeatability between technicians using ANOVA (Analysis of Variances). Tests must be performed to prove the appropriate significance of these errors.

It is essential to understand that these three error sources may be insignificant using deadweight primary standards but can become significant at the next measurement tier, which often involves more factors than just alignment and proper adapters. For example, it is likely that there will be some sort of control, whether manual or automatic. Timing and the inability to hold the force point for 20 seconds can be problematic.



Figure 12 Morehouse PCM

Morehouse UCM & PCM

The next tier of calibration machines usually consists of a machine manufactured to mount the reference standard calibrated by the Deadweight Primary Standard or lever deadweight system (not discussed). Like any machine, including the deadweight, the machines designed to apply a force using the reference standard may contribute to the measurement uncertainty (discussed later). If appropriately designed, the significant contribution to Measurement Uncertainty will typically come from the reference standard and the calibration of what will become the reference in the machine.

The calibration of a force-measuring instrument in a Morehouse Universal Calibrating Machine will be carried out by a documented procedure, such as ISO 376 or ASTM E74. The uncertainty of the calibration results will depend on the reference standard calibration at the primary lab. The machine's CMC will further be determined by an additional set of standards used to test repeatability, as well as uncertainty from proficiency tests, if higher than the claimed CMC. An excellent method to test performance is to compare two like standards calibrated by the primary laboratory over the calibration range. If the values fall within the claimed CMC, all is good.

ISO 376 classification criteria include additional contributors to measurement uncertainty that ASTM E74 does not. As such, the magnitude of the uncertainty of the applied force is often very dominant. **For this reason, the CMC of a Morehouse UCM or PCM is often set to equal the applied force used in the reference ISO 376 calibration.** Many accreditation bodies might require some additional contributors, such as repeatability, environmental conditions, stability, and other error sources covered later in the uncertainty section.

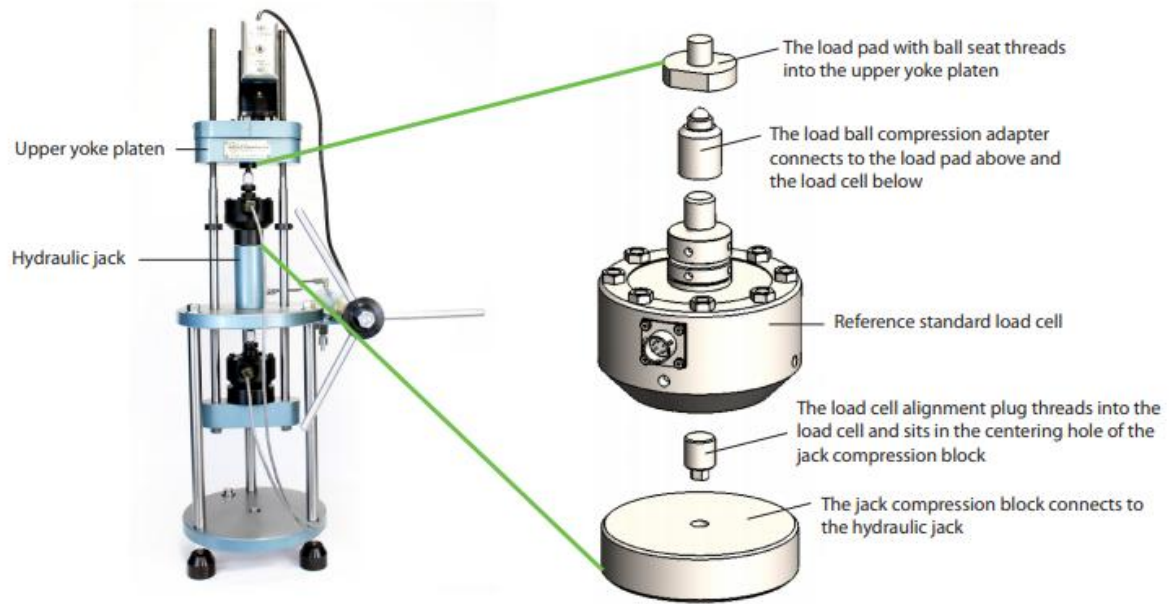


Figure 13 Morehouse UCM and Reference Cell Mounting

A Morehouse UCM was designed to mount the reference load cell in the machine under compression to exactly simulate how the reference was calibrated. This is why most UCM's designed by Morehouse are two-bar systems, as the frame mimics the yoke used in the DCM. Thus, the expected performance of the device is captured from the ISO 376 calibration. The end-user will further de-rate the specifications by using the reference standard at different temperatures, using different adapters (we hope not), or by using non-Morehouse machines that may not be designed with the optimal characteristics.



Figure 14 Morehouse 10 MN UCM

Morehouse Machines are designed to minimize off-center loading, bending, and torsion. To do this, force machines need to be:

- Plumb - Exactly vertical or true. Morehouse Force Machines are designed to keep everything vertical and true.
- Level - The upper and lower platen are ground flat, and the adjustable feet allow the end-user to obtain a level condition.
- Square - The adjustable yoke and frame form the four right angles. This reduces the chance of misalignment.
- Rigid – All loading surfaces and support structures are designed to keep the machine from bending
- Free of Torsion - the action of twisting or the state of being twisted. Free of torsion means free of being twisted when forces are applied. The Morehouse UCM mounts the reference standard using a ball adapter; the adapters used for calibration of the Device Under Test (DUT) are designed with sphericals or minimum contact points. Our Hydraulic Ram pushes everything straight minimizing torsion.

Morehouse Automation

Morehouse has manufactured Universal Calibrating Machines for over 70 years. The Automated Force Calibration System (AFCS) automates the control and data gathering of Morehouse UCMs with capacities from 10 klbf through 2500 klbf. The system applies forces from 1 % to 100 % of the hydraulic jack capacity and is designed to work with a reference load cell calibrated with a Morehouse 4215 meter.

Automation reduces operator influence on the calibration. The system exercises the instrument to specified forces for a set number of cycles, runs calibration sequences with an unlimited number of points, and holds individual calibration points for specified times. These capabilities support the time/loading profile requirements in ISO 376 and ISO 7500-1, such as applying force for 30 s and automating the 300 s creep measurement. The system can gather data from an unlimited number of devices under test, which reduces transcription errors from manual recording.



Figure 15 Morehouse Automation Upgrade

Common Error Sources in Force Calibration

The force-measuring instrument's end-user must ensure the laboratory performing the calibration replicates how the instrument will be used. Certain calibrating machines that perform tension and compression in the same setup do not replicate use.

Fixturing and adapters used with a force-measuring instrument may significantly contribute to the force-measuring instrument's overall uncertainty. Morehouse has observed errors as high as 0.05 % of the output from using top blocks of different hardness. Common error sources for force calibration include:

- Not replicating via calibration how the equipment is being used
- Alignment (this can be overcome with proper adapters)
- Using a different hardness of adapter than was used for calibration
- Using different size adapters than what was used for calibration as shown in Consideration #2
- Loading against the threads instead of the shoulder
- Loading through the bottom threads in compression
- Temperature effects on non-compensated force-measuring instruments
- Temperature effect coefficients on zero and rated output
- Cable length errors on a four-wire system
- Using electronic instruments (indicators) that were not used during calibration
- Using an excitation voltage that is different from the voltage used at the time of calibration
- Variations in bolting a force transducer to a base for calibration while the application is different
- Electronic cabling regarding shielding, proper grounding, use or non-use of sensing lines, cable length
- Failure to exercise the force-measuring instrument to the capacity it was calibrated at prior to use
- Difference between the output of a high-quality force transducer when compared to the current machine and realized value from the deadweight calibration

Note: Morehouse has several articles, videos, webinars, and other training courses, including on-site courses that focus on these error sources and how to correct them.

Calibration with the Morehouse UCM - What Replicates Field Use is Often Best Practice



*Figure 16 Picture of a Compression/Tension Machine that **Does Not** Replicate Field Use*

Do we get asked questions such as why should we use your machine? This is a fair question to answer. One reason is cost. The machine ranks among the most versatile and cost-effective solutions on the market to calibrate all different types of force instruments. However, that is not the answer that should be the most important. The most important answer is that our Morehouse UCM allows the end-user to replicate best how the equipment is used in the field, such as different setups for tension and compression using the proper adapters recommended by several standards, including ISO 376. Figure 10 best shows this with a machine capable of performing compression and tension calibrations using the same setup. **What replicates field use is often best practice.** To replicate use, different setups need to be made with different adapters for tension and compression. The ISO 376-recommended adapters do not specify an adapter suitable for both compression and tension calibrations.



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

Figure 17 Morehouse Tension Adapters Designed Using Recommendations from ISO 376

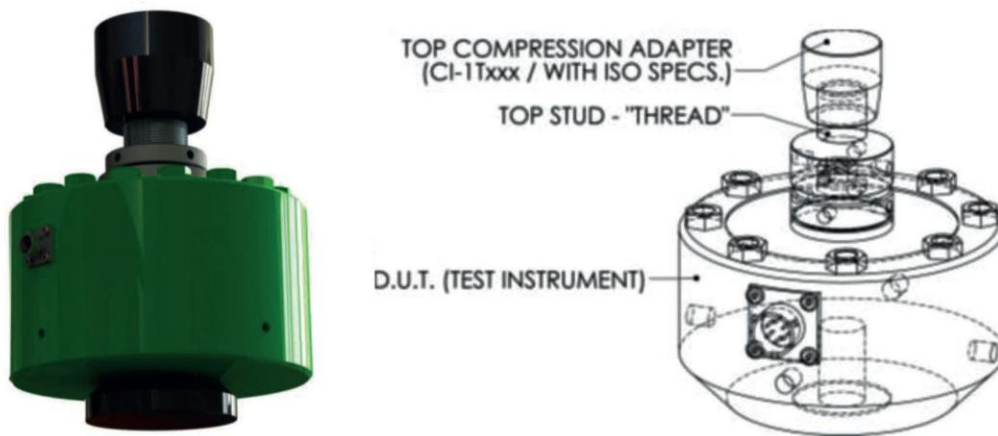


Figure 18 Morehouse Compression Adapters Designed Using Recommendations from ISO 376

Most testing machines calibrated to ISO 7500 are calibrated in compression and tension. The technician will use different setups for each mode. Most will use calibration adapters as recommended in section A 4.1, which states, "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."



Figure 19 Picture of a Tinius Olsen Universal Testing Machine

Replicating field use should give the end-user confidence in their measurements. With a Morehouse UCM, the user is forced to change setups for compression and tension, thus reducing common errors that many other machines allow for. These errors are using different adapters than those used during calibration and loading through the bottom threads in compression. Other machines performing Tension and Compression in the same setup may not apply the force for 30 seconds as specified in the Time/loading profile in both ISO 7500-1 and ISO 376. **There is a reason most NMI force standard machines have separate areas for compression and tension setups.** There is also a debate on static versus dynamic calibration, which should not be debated as dynamic calibration is not supported per the standard.

Dynamic force is different than static, and a dynamic machine should not be used for calibration following ISO 376. Per ISO 376 Section C.2.11, "This International Standard concerns only static force measurement. If the force-proving instrument is used under dynamic conditions, additional contributions should be taken into account. For example, the frequency responses of the force transducer and indicator, and the interaction with the mechanical structure, can strongly influence the measurement results. This requires a detailed analysis of dynamic measurement, which is not part of this International Standard."

The final reason for selecting a Morehouse machine might be that we have been in business for well over one hundred years and offer guidance that other companies do not. We are upfront from the initial discussions and give you as much guidance as possible to help make the world safer, as it benefits all of us. Our passion is to help you make better force measurements, as everyone wins when this is accomplished.

Selection of Load Cells for Your Morehouse UCM

Class	Relative error of the force-proving instrument						Expanded uncertainty of applied calibration force (95 % level of confidence) %
	%						
	of reproducibility <i>b</i>	of repeatability <i>b'</i>	of interpolation <i>f_c</i>	of zero <i>f₀</i>	of reversibility <i>v</i>	of creep <i>c</i>	
00	0,05	0,025	±0,025	±0,012	0,07	0,025	±0,01
0,5	0,10	0,05	±0,05	±0,025	0,15	0,05	±0,02
1	0,20	0,10	±0,10	±0,050	0,30	0,10	±0,05
2	0,40	0,20	±0,20	±0,10	0,50	0,20	±0,10

Figure 20 ISO 376 Relative Error Needed to Achieve Classification

We have discussed uncertainties relating to Calibration and Measurement Capability Uncertainty, and what can be achieved in previous papers and several guidance documents found [here](#). The selection of reference standards will vary depending on what is needed, using Case C or Case D, and the Class needed.

If Class 00 is required, an uncertainty of $\pm 0.01\%$ is required for the expanded uncertainty of the applied calibration force or reference (2-3 reference standards). To achieve this is likely going to require a standard change at every 40 % of the capacity desired. To achieve Class 0.5, a standard change at every 20 % of the capacity being calibrated is required (2 reference standards). Then at Class 1, 0.05 %, one could likely accomplish this calibration with 1-2 reference standards, and Class 2 likely would only require one reference standard.

Typical recommendations for achieving Class 00 calibrations in order of importance are as follows:

1. Use a reference laboratory using deadweight primary standards or with the lowest CMC uncertainty parameter
2. Select instrumentation with excellent hysteresis specifications for Case D, as well as non-linearity specification, non-repeatability, and temperature specification for Case C or D.
3. Use of transfer standards in the range above 40 % of their maximum capacity. This helps minimize interaction effects; it also reduces uncertainty from resolution. *
4. Select instrumentation with a resolution of 1 part in 200 000 at each calibration force (this is a primary reason a 4 mV/V load cell can cover 50 % to 100 %, thus leaving a need for the 40 % test point).
 - **Note: Obtaining Class 00 of better than 20 % is achievable with special load cells that are about double the price of the Morehouse UPC load cell.**

Several of these recommendations are found or elaborated upon in Euramet cg-04

If Euramet cg-04 is the requirement, there is a different method that will be discussed later. Most non Euramet national laboratories and accreditation bodies will audit assuming ASTM E74 or ISO 376 is used as a calibration method to determine the CMC Uncertainty parameter. The verification of the CMC Uncertainty Parameter is often done by comparing two standards that were calibrated in deadweight machines against one another. If the error is within the claimed uncertainty, the values should pass most audits. ISO/IEC 17025 requires each laboratory to have a four-year proficiency test plan to prove a laboratory's capability. Unfortunately, there is often a lack of good enough reference standards for claiming uncertainties lower than 0.01 %. Hence, the recommendation for having additional standards calibrated by deadweight and making the comparison in the machine.

Morehouse has done this on our machines, and the values typically agree to within 0.005 to 0.02 % throughout the loading range. When we do the test, we do it using the recommended adapters and with skilled technicians. The equipment manufacturer should not do this test as it would not involve your technicians who need to be part of the overall measurement uncertainty. An additional advantage of a spare reference load cell or two is that they can be used to set up cross-checks and SPC (statistical process control) that can be used to monitor and spot trends and reduce Measurement Uncertainty if done correctly.

Uncertainty Calculations

Uncertainty is the value assigned to "doubt" about the validity of an assigned calibration value. Documented measurement uncertainties are required on a calibration certificate to support metrological traceability. Uncertainty will likely be much more than any accuracy statement. Uncertainty may not include the bias from accuracy and will be broken down into several contributors. Of these contributors, uncertainty is often broken down into two types: Type A and Type B.

Type A is often derived from statistical data or evaluation of uncertainty by the statistical analysis of a series of observations. Type B is an evaluation of uncertainty by means other than the statistical analysis of a series of observations. Examples of both types are below.

Type A Uncertainty Contributions

The GUM states that all data analyzed statistically is treated as a Type A contribution with a normal statistical distribution. Typical examples are:

- Repeatability (required by the GUM, A2LA R205, and UKAS M3003)
- Reproducibility
- Stability / Drift
- Others (This would include ASTM E74 If, ISO 376 Uncertainty, Non-Linearity, or SEB for commercial calibrations)

For our example, stability shall be treated as type B because we are taking values over a range using previous measurement data. Stability data may be treated as Type A if an evaluation is made using statistical methods.

Type B Uncertainty Contributions

Per section 4.3 of the GUM Type B, evaluation of standard uncertainty may include:

- Previous measurement data
- Experience with or general knowledge of the behavior and properties of relevant materials and instruments
- Manufacturer's specifications
- Data provided in calibration and other certificates
- Uncertainties assigned to reference data taken from handbooks
- Resolution of the reference standard
- Resolution of the best existing force-measuring instrument or the force-measuring instrument used for repeatability studies
- Reference standard uncertainty
- Reference standard stability
- Environmental factors
- Other error sources

A more thorough analysis on calculating CMC uncertainty published by A2LA and written by Morehouse can be found [here](#).

Additional Euramet cg-4 Information

Euramet cg-4, Guidelines on the Uncertainty of Force Measurements, is a calibration guide. The standard provides guidance on establishing traceability through the country's National Metrology Institute (NMI). The standard relies on a Force Standard Machine (FSM) such as Morehouse Machines to be used with Force-proving Instruments and calibrated or verified by additional reference load cells calibrated by the NMI's National Force Standard Machines (NFSMs). The two examples listed in Euramet cg-4 are as follows:

1. When the machines are calibrated using reference load cells calibrated by the NFSM Euramet cg-4 states, "The forces generated within calibration laboratory FSMs are usually traceable to those generated within NFSMs (or other FSMs of the required uncertainty in generated force) through exercises using force transfer standards, and the accredited calibration and measurement capability (CMC) of the calibration laboratory will be based on the results of these exercises."

- When one purchases equipment with calibration from Morehouse and verifies their CMC claims, Euramet cg-4 states, "The calibration of a force-measuring instrument in an FSM will generally be carried out in accordance with a documented procedure, such as ISO 376, and the uncertainty of the calibration results will be dependent on the machine's CMC, as well as on the performance of the instrument during the calibration. ISO 376 classification criteria include the magnitude of the uncertainty of the applied force and, for high-quality force transducers, this value is often the dominant uncertainty contribution. For this reason, the CMC of an FSM is often set to be equal to the uncertainty of the applied force, ignoring any other uncertainty contributions that may be present during the calibration."

Many European laboratories Morehouse has provided force equipment to have been either NMI's themselves, or labs choosing to use Morehouse for calibration of the references to ISO 376 and having the NMI validate their CMC claims.

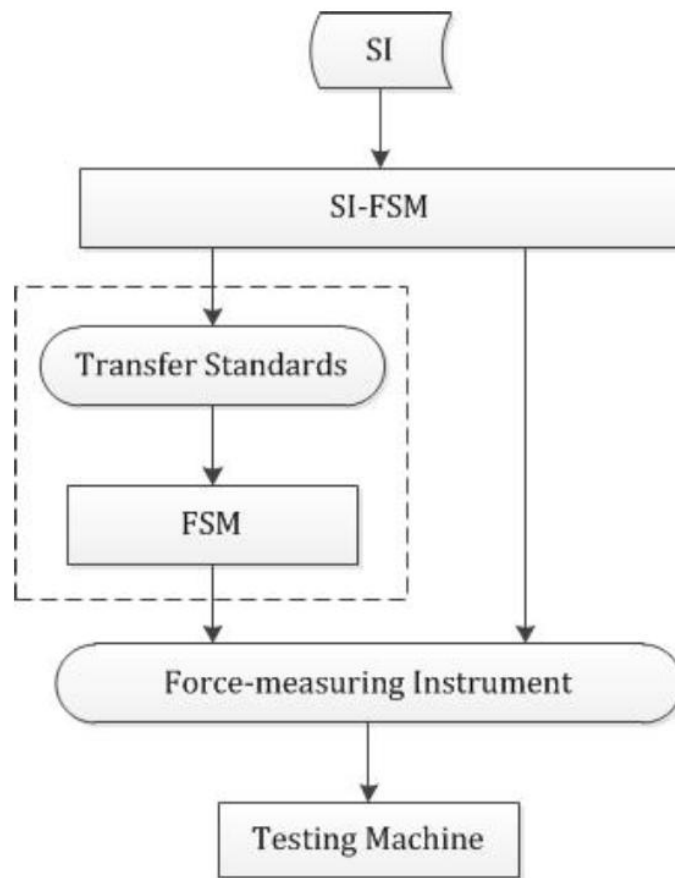


Figure 21 Force Traceability to the SI from Euramet cg-4

If the machine purchased from Morehouse is a deadweight primary standard machine, that machine would be designated as an SI-FSM (SI-reference Force Standard Machine).

Deadweight SI-FSM Machines

The unit of force is realized through SI units of Time, Mass, and Length.

$$F = mg \left(1 - \frac{\rho_a}{\rho_m} \right)$$

Figure 22 Equation to Determine Force

$$\left(\frac{u(F)}{F} \right)^2 \approx \left(\frac{u(m)}{m} \right)^2 + \left(\frac{u(g)}{g} \right)^2 + \left(\frac{u(\rho_a)}{\rho_m} \right)^2 + \frac{\rho_a^2}{\rho_m^2} \left(\frac{u(\rho_m)}{\rho_m} \right)^2$$

Figure 23 Uncertainty Equation in Euramet cg-4 for SI-FSM Deadweight Machines

The uncertainty for Morehouse deadweight includes the standard mass uncertainty, the determination of the acceleration of gravity, standard uncertainty of air density, standard uncertainty of the density of the weight.

The uncertainty budget for the machine also needs to consider possible force-generating mechanisms other than gravity and air buoyancy, including magnetic, electrostatic, and aerodynamic effects.

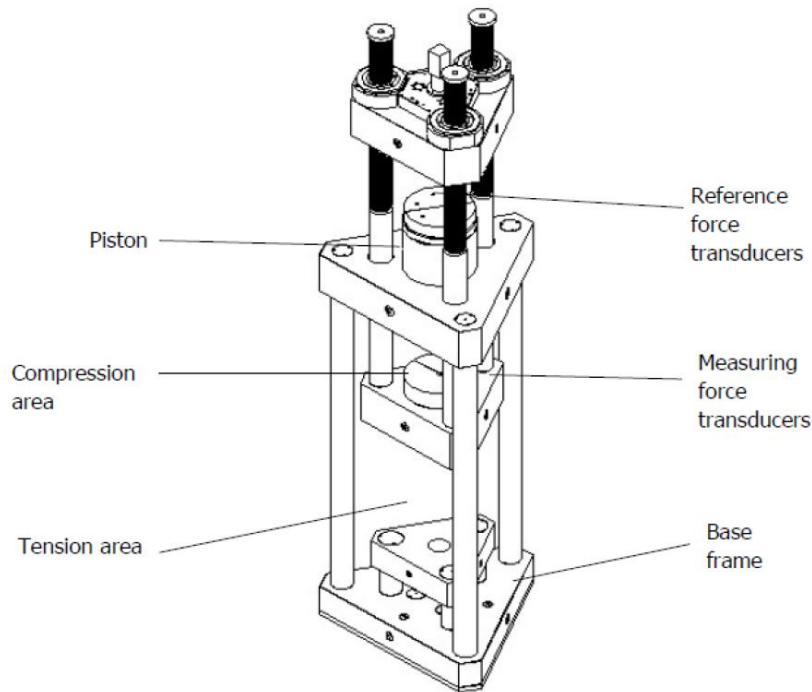


Figure 24: Example of a Typical FSM Type Machine

Morehouse Calibrating Machines (FSMs)

If the machine purchased through Morehouse is a Calibrating machine (FSM). Note the figure above shows distinct areas for compression and tension calibration. Other manufacturers may try to combine the compression and tension area. This is not shown in Euramet cg-4 as these machines do not replicate how the equipment is typically used in the field. Some may question why the Morehouse machine only has two bars. We had built a three-bar machine and ran tests to see if there was a difference. It turns out our two-bar machine has a lighter tare weight and performed just as well as a three-bar machine. To learn more about our tests and two versus three-bar, we have a paper linked at the end of this section.

To determine the uncertainty of the Morehouse (FSM), the Euramet recommends these 5 steps.

Step 1 - Determination of the uncertainty of the force generated by the SI-FSM (Reference Standard Used for Calibration, hopefully, Morehouse Deadweight Machine)

Step 2 - Determination of the calibration uncertainty of the transfer standard in the SI-FSM (Use the Morehouse Deadweight to Calibrate the Load Cell. Rotate the load cell and take several readings. This is where ASTM E74 data or ISO 376 reproducibility can be used)

Step 3 - Determination of the uncertainty of the transfer standard's reference value (This step deals with stability of the reference load cells over a short period of time)

Step 4 - Determination of the uncertainty of force generation in the FSM (Here a comparison is made between the machine using an additional set of transfer standards calibrating in the SI-FSM)

Step 5 - Determination of the FSM's CMC (Calibration Uncertainty of the Reference Load Cell, and Long-Term instability)

Note: Morehouse has observed various ways to calculate the uncertainty of the FSM and reference standards; we believe an alternative method described in our uncertainty guidance meets most accreditation guidelines. If you are unsure, please check with your accreditation body to determine what method is required.

Morehouse 3 Bar Versus 2 Bar Universal Calibrating Machines Comparison Test [Paper](#)

Summary

The Morehouse Universal Calibrating Machine simplifies force calibration by reducing rework, errors from misalignment, and problematic setups. The machine ranks among the most versatile and cost-effective solutions to calibrate all types of force instruments. The operator can replicate how the force instruments are used in the field by using different setups for tension and compression and proper adapters recommended by several standards, including ISO 376. The UCM will help you improve measurement accuracy and grow your business.

Force measurement can be hard, Morehouse has additional spreadsheets, tools, and guidance to simplify the process.

Additional Information

Visit www.mhforce.com for additional guidance on adapters, uncertainty, calibration techniques, and more.

Your time is valuable. Morehouse thanks you for taking the time to read this document. We wish you the absolute best and are always here to help!

About Morehouse Instrument Company

Our purpose is to create a safer world by helping companies improve their force and torque measurements. We have several other technical papers, guidance documents, and blogs that can add to your knowledge base. To learn more and stay up to date on future documents and training, subscribe to our newsletter and follow us on social media.

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Contact Morehouse at info@mhforce.com or 717-843-0081.

References

ISO 376 <https://www.iso.org/standard/44661.html>

ASTM E74-18(2026) Standard Practices for Calibration and Verification for Force-Measuring Instruments
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