# How Low Can My Load Cell Go?

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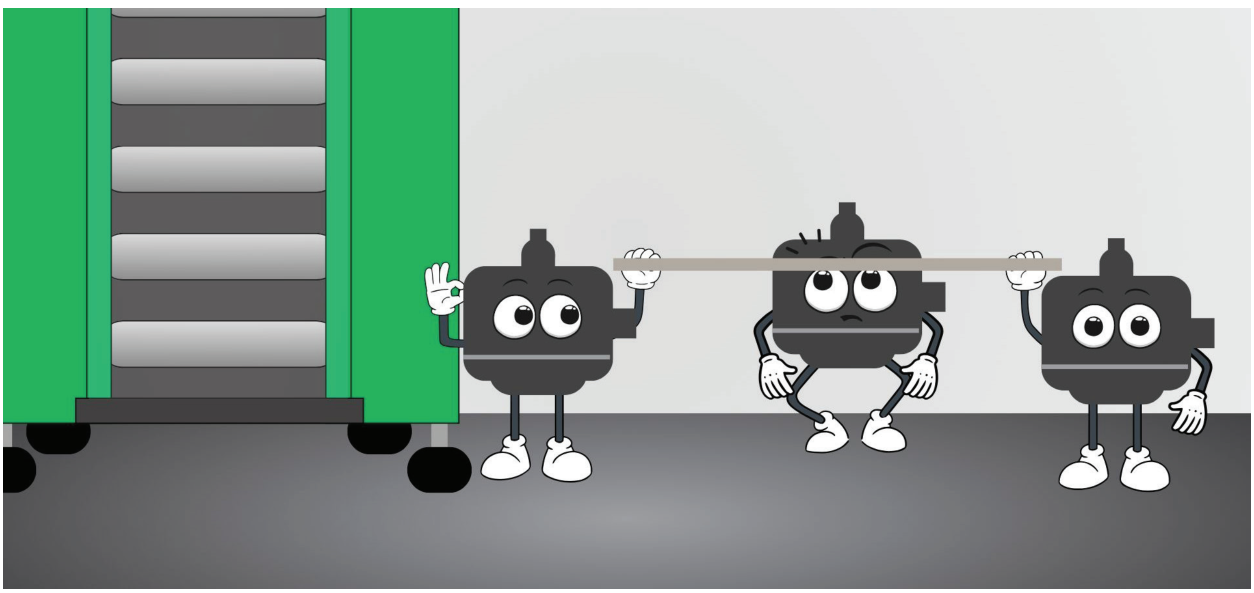
Load cells are subject to numerous factors that can affect their performance. Some factors include the design of the load cell, the readout used with the load cell, environmental conditions, cable length (if only a four-wire cable is used), overloading, adapters, stability, alignment, and the test method. There are enough load cell intricacies that impact measurement uncertainties to write a book strictly on that subject, which we have already done [1].

Management often wants to spend the least on equipment and push equipment such as load cells to their lowest operational level. Who can blame them as who would not want less equipment with better performance? Using equipment such as load cells below 5 – 10 % of their capacity or lower, such as 2 %, is a frequent practice that demands attention as it can significantly impact measurement uncertainty as a percentage of applied force. This article examines the impact on measurement uncertainty of using a load cell as low as 2 % of its rated capacity, compliance with ISO 376 and ASTM E74 lowest force point criteria, and how to uphold the reliability necessary to maintain a specific calibration interval. What holds for these standards can apply to any load cell.



## Introduction

Many customers ask, "How low can my load cell go?" We understand the potential benefits of using a load cell from 2 % to 100 % of its capacity.

Benefits like the lower your load cell can go to measure forces, the less equipment one would need to carry, and the fewer setups one would need to make; sometimes, fewer calibration costs would occur, and who would not want any of these things?

So, how low can your load cell go? Like the Limbo, everything has a point where going lower is impossible. In this article, we provide three things to consider in regards to measurement uncertainty when you ask how low my load cell can go.

We assume that one has communicated clearly with their calibration provider how they use the load cell so that the calibration lab can best replicate use. That means whatever readout is being used, adapters, cables, and standards or procedures being followed are sent in and communicated to the calibration laboratory.

## Consideration #1: What is the impact on measurement uncertainty for using a load cell as low as 2 % of its rated capacity?

Often the most significant contributions to MU (Measurement Uncertainty) would be the resolution, stability of the instrument, ASTM LLF (Lower Limit Factor) if applicable, and the reference standard uncertainty used to perform the calibration.

### *Resolution*

Resolution is the smallest change in the measured quantity that causes a detectable change in the corresponding indication. Resolution is found by taking the output of the load cell / by the indicated reading at capacity, and then that number is multiplied by the readability.

**Case # 1:** In mV/V At 25,000, a load cell typically has an output of 2 – 4 mV/V. Most meters will read up to the 5th decimal place. Thus, 25,000 / 4.00000 = 6250, which we multiply by the readability of 0.00001 = 0.0625.

**Case # 2:** In force units, a 25,000-load cell may count by 1; there would be 25,000/25,000 = 1, then multiply by 1 = 1.

Comparing Case # 1 at the 2 % force pt, our MU (Measurement Uncertainty) is 0.47 or 0.094 %, and in Case # 2, 0.74 or 0.149 % by only changing the reference resolution from 0.0625 to 1. More on the complete MU budget later.

### *Reference Standard Stability*

Typically, Reference Standard Stability is defined as the change from one calibration to the next. Morehouse wrote a paper on Load Cell Reliability that goes into much more detail on the reliability of load cells: https://mhforce.com/wp-content/uploads/2023/09/Morehouse-Load-Cell-Reliability-1.pdf.

The conclusion was that selecting the load cell and meter is pivotal, if someone wants to maintain an overall reliability of 95 % with 95 % confidence of 0.05 % or better.

In our sampling, we did not look at data below 10 % of a load cell capacity, as the population data showed the very best systems to have a 95 % confidence that the process was at least 89.33 % reliable at 10 % of capacity; the numbers would have been much worse below that number.

For our example, we will assume an exceptionally good load cell, like a shear web type with a base and threaded adapter installed, paired with a higher-end meter like the 4215 HS. Typical stability might be around 0.1 % at 1 % capacity and 0.05 % at 2 %.

### *ASTM Lower Limit Factor*

ASTM LLF, or Lower Limit Factor, is a statistical estimate of the error in forces computed from the calibration equation of a force-measuring instrument when the instrument is calibrated following ASTM E74 standard practice for calibration and verification for force-measuring instruments [2].

The ASTM LLF quantifies the Reproducibility Condition of the calibrated device by following the ASTM E74 standard. More information on the ASTM LLF can be found at https://mhforce.com/lower-limit-factor-improve-calibration-accuracy/.

For our example, the ASTM LLF is 0.209.

### *Reference Standard Uncertainty*

This is the uncertainty of the reference standard used to calibrate the load cell.

Note: If the calibration was not done following ASTM E74, one might use the load cell specifications or values from the calibration certificate, which could include non-linearity, repeatability, and, if making descending measurements, hysteresis.

**Case # 1:** Primary Standards (Deadweights) are used to calibrate the load cell within 0.0016 %.

In Case # 1, our MU cannot be less than the standard used to calibrate the device. Thus, our MU cannot be less than 0.0016 % of the applied force.

**Case # 2:** Secondary Standards (those calibrated by deadweight) are used to calibrate the load cell. The typical number for a secondary standard varies between 0.02 – 0.05 %; we will use 0.035 % for comparison.

In Case # 2, our MU cannot be less than the standard used to calibrate the device. Thus, our MU cannot be less than 0.035 % of the applied force.

Note: The deadweight primary standard provides the best possible calibration on How Low Can my Load Cell Go.

The following Measurement Uncertainty Budgets only include information available to Morehouse and are incomplete as environmental conditions during use, repeatability studies, repeatability and reproducibility between operators, resolution of the

| Measurement Uncertainty Budget Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Laboratory | Morehouse | | | | | | | |
| Parameter | FORCE | Range | 25000 | Sub-Range | 2 % Force Point | | | |
| Technician | HZ | Standards Used | SAMPLE LOAD CELL FOR HOW LOW CAN MY LOAD CELL GO | | | | | |
| Date | 12.28.2023 | | | | | | | |
| Uncertainty Contributor | Magnitude | Type | Distribution | Divisor | df | Std. Uncert | Variance (Std. Uncert^2) | % Contribution |
| ASTM E74 LLF | 87.0833E-3 | A | Normal | 1.000 | 32 | 87.08E-3 | 7.58E-3 | 13.85% |
| Environmental Conditions | 7.5000E-3 | B | Rectangular | 1.732 | 200 | 4.33E-3 | 18.75E-6 | 0.03% |
| Stability of Ref Standard | 375.0000E-3 | B | Rectangular | 1.732 | 200 | 216.51E-3 | 46.88E-3 | 85.58% |
| Ref Standard Resolution | 58.0000E-3 | B | Resolution | 3.464 | 200 | 16.74E-3 | 280.33E-6 | 0.51% |
| Morehouse CMC (Ref Lab) | 8.0000E-3 | B | Expanded (95.45% k=2) | 2.000 | | 4.00E-3 | 16.00E-6 | 0.03% |
| | | | Combined Uncertainty ($u_c$)= | | | 234.04E-3 | 54.77E-3 | 100.00% |
| | | | Effective Degrees of Freedom | | | 234 | | |
| | | | Coverage Factor (k), Confidence Interval = | | 95.45% | 2.01 | | |
| | | | Expanded Uncertainty (U) K = | | | 0.47 | 0.09412% | |

Figure 1. How Low Can My Load Cell Go 2 % of Capacity Incomplete MU Budget.

best existing device, and other error sources are not included.

For the sake of this article, these examples would be the absolute best one could achieve using the Welch-Satterthwaite equation, and their overall MU would be much higher with more contributions to MU than shown here.

When we look at the overall measurement uncertainty of the 2 % force point at the time of calibration, the dominant contribution is the stability of the reference standard in this example.

We typically see either the ASTM LLF or the reference standard stability as a dominant contributor to the overall MU. Occasionally, one will set the resolution too coarse, and that will become dominant. When we look at the overall measurement uncertainty of the 1 % force point at the time of calibration, the dominant contribution is the stability of the reference standard in this example.

Note: We use some best-case scenarios for stability and the ASTM LLF.

On how low my load cell will go, the comparison between a 2 % and 1 % force point percentage-wise shows that at the 1 % force point, the overall MU is 0.136 % versus 0.094 % of applied force at the 2 % point.

If the ASTM LLF factor was dominant, there are options such as having the load cell calibrated using its normal range and then calibrating a separate low range. The ASTM LLF is often lower at a low-range calibration when compared to the normal calibration.

The stability, resolution, and reference standard uncertainty typically remain constant; thus, only certain load cells can be used with multiple ranges. In some cases, a second range from 1 % - 10 % of capacity might work, some 2 % - 20 % of capacity might work, and in others, a second range would have minimum benefit, if any. To know what may work, contact your calibration provider.

| Measurement Uncertainty Budget Worksheet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Laboratory | Morehouse | | | | | | | |
| Parameter | FORCE | Range | 25000 | Sub-Range | 1 % Force Point | | | |
| Technician | HZ | Standards Used | SAMPLE LOAD CELL FOR HOW LOW CAN MY LOAD CELL GO | | | | | |
| Date | 12.28.2023 | | | | | | | |
| Uncertainty Contributor | Magnitude | Type | Distribution | Divisor | df | Std. Uncert | Variance (Std. Uncert^2) | % Contribution |
| ASTM E74 LLF | 87.0833E-3 | A | Normal | 1.000 | 32 | 87.08E-3 | 7.58E-3 | 26.42% |
| Resolution of UUT | 000.0000E+0 | B | Resolution | 3.464 | 200 | 000.00E+0 | 000.00E+0 | 0.00% |
| Environmental Conditions | 3.7500E-3 | B | Rectangular | 1.732 | 200 | 2.17E-3 | 4.69E-6 | 0.02% |
| Stability of Ref Standard | 250.0000E-3 | B | Rectangular | 1.732 | 200 | 144.34E-3 | 20.83E-3 | 72.58% |
| Ref Standard Resolution | 58.0000E-3 | B | Resolution | 3.464 | 200 | 16.74E-3 | 280.33E-6 | 0.98% |
| Morehouse CMC (Ref Lab) | 4.0000E-3 | B | Expanded (95.45% k=2) | 2.000 | 200 | 2.00E-3 | 4.00E-6 | 0.01% |
| | | | Combined Uncertainty ($u_c$)= | | | 169.43E-3 | 28.71E-3 | 100.00% |
| | | | Effective Degrees of Freedom | | | 207 | | |
| | | | Coverage Factor (k), Confidence Interval = | | 95.45% | 2.01 | | |
| | | | Expanded Uncertainty (U) K = | | | 0.34 | 0.13637% | |

Figure 2. How Low Can My Load Cell Go 1 % of Capacity Incomplete MU Budget.

**7.3 Minimum force**

Taking into consideration the accuracy with which the deflection of the instrument can be read during calibration or during its subsequent use for verifying machines, the minimum force applied to a force-proving instrument shall comply with the two following condition:

a) the minimum force shall be greater than or equal to:

- 4 000 x $r$ for class 00;
- 2 000 x $r$ for class 0,5;
- 1 000 x $r$ for class 1;
- 500 x $r$ for class 2.

b) the minimum force shall be greater than or equal to 0,02 $F_f$ .

Figure 3. How Low Can My Load Cell Go ISO 376 Requirements [3].

## Consideration #2: ISO 376 and ASTM E74 lowest force point criteria.

Using a load cell below 2 % of its capacity is not recommended. ISO 376 and ASTM E74 have different criteria for establishing the first usable force point.

ISO 376 section 7.3 requires the minimum force to be greater than or equal to 2 %.

Listed below are ASTM Sections referencing the lowest possible applied force:

- Section 8.6.3.2 Class A—For force-measuring instruments used to verify testing machines in accordance with Practices E4, or similar applications, the LLF of the force-measuring instrument shall not exceed 0.25 % of force. The lower force limit for use over the Class A verified range of forces is 400 times the LLF in force units obtained from the calibration data.
- ASTM E74 Note 8 states, "It is recommended that the lower force limit be not less than 2 % (1/50) of the capacity of the force-measuring instrument [4]."

## Consideration #3: ASTM E74 on Calibration Due Dates

One of the main reasons we would advise against using a load cell below 5 % or 2 % is found in section 11.2.1 of the ASTM E74 standard, which states, "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 [4]."

Notice we are not considering 1 % as the likelihood of meeting the criteria is low. Some load cells may meet the criteria, though almost any shift in output would cause the instrument not to meet the criteria outlined in section 11.2.1, and the result would be the user no longer being able to have a calibration interval of two years, which would increase downtime and calibration costs.

## Conclusion

The question "How low can my load cell go?" involves intricate considerations to maintain a low measurement uncertainty and maintain the reliability one needs to maintain a specific calibration interval.

The assessment of measurement uncertainty, including factors such as resolution, reference standard stability, ASTM LLF or other specifications, when applicable, and the uncertainty of the calibration standard, is vital for understanding the limitations and precision of a load cell at lower force levels. Moreover, adherence to industry standards, such as ASTM E74 and ISO 376, provides clear guidelines and recommendations on the minimum force points for load cell usage.

The implications of calibration due dates, as outlined in ASTM E74, further emphasize the practical challenges associated with using load cells at extremely low force levels.

Meeting calibration criteria becomes critical for maintaining calibration intervals and avoiding increased downtime and calibration costs.

Like people doing the Limbo, each load cell is different—some will be able to go lower than others, and some will fail early.

If you buy great equipment, the chances of maintaining a usable range of 2 % or better with a Measurement uncertainty of under 0.1 % of applied is possible, though not typical.

The decision on how low a load cell can go should be a careful balance between the application's specific requirements, adherence to the appropriate standard, and the practical constraints imposed by calibration considerations.

## References

[1] Zumbrun, Henry. *Force Calibration for Technicians and Quality Managers: Top Conditions, Methods, and Systems that Impact Force Calibration Results*, 2022. Available online at https://mhforce.com/force-calibration-for-technicians-ebook-2022-edition/

[2] ASTM E74 *Standard Practices for Calibration and Verification for Force-Measuring Instruments*, Section 8. Available online at https://www.astm.org/e0074-18e01.html

[3] ISO 376:2011 *Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines*, Section 7. Available online at https://www.iso.org/standard/44661.html

[4] ASTM E74 *Standard Practices for Calibration and Verification for Force-Measuring Instruments*, Section 11. Available online at https://www.astm.org/e0074-18e01.html

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