Force Measurement Basics

A quick introduction to force, load cells, measurement uncertainty, and risk. This guide is written for newcomers to force measurement. It explains, in plain terms, why a load cell reads the way it does and how to make sure the numbers you report can be trusted.

Force, Tension, and Compression

Force is simply a push or a pull. We measure it with a load cell, a sensor that converts force into an electrical signal that an indicator can read.

- **Compression** is a push. The load cell is squeezed between two surfaces.
- **Tension** is a pull. The load cell is stretched between two anchor points.

Load cells are not symmetrical. A cell calibrated in compression can read differently in tension, so a device used both ways must be calibrated both ways. A load cell is also only trustworthy across the range it was calibrated. A 10 000 lbf cell calibrated in 1 000 lbf steps has not been proven below 1 000 lbf, and you should not assume it is accurate there.

Figure 1. Compression — the load cell is pushed.

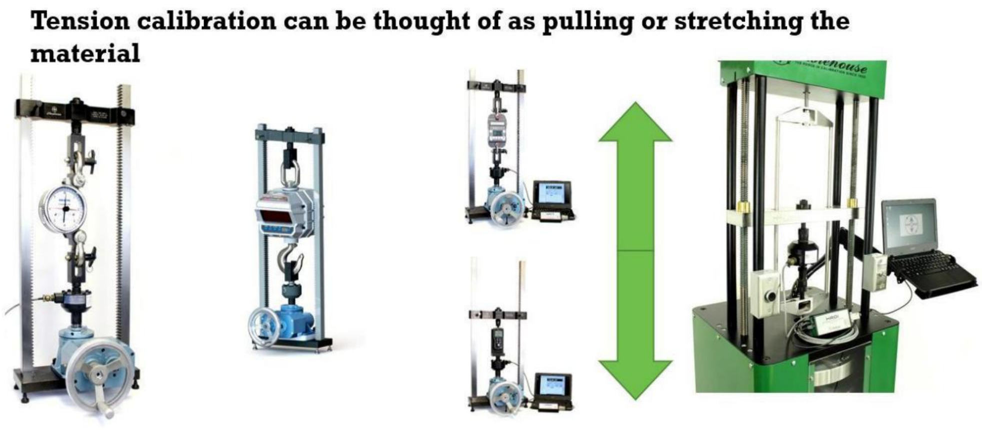

Figure 2. Tension — the load cell is pulled.

No Load Cell Is Perfect

A load cell does more than respond to a clean push or pull. Several mechanical interactions affect what it reads, and these are easy to overlook:

- **Side load** — off-axis force, the cell was not designed to measure.
- **Bending and eccentric loading** — force applied off-center instead of straight through the axis.
- **Torsion** — twisting introduced by the machine or the fixtures.

These interactions show up as measurement errors. A misalignment of only 0.1 % can create a measurable cosine error, and many cells carry a side-load sensitivity of about 0.1 % of rated output. In high-accuracy work, that is not negligible.

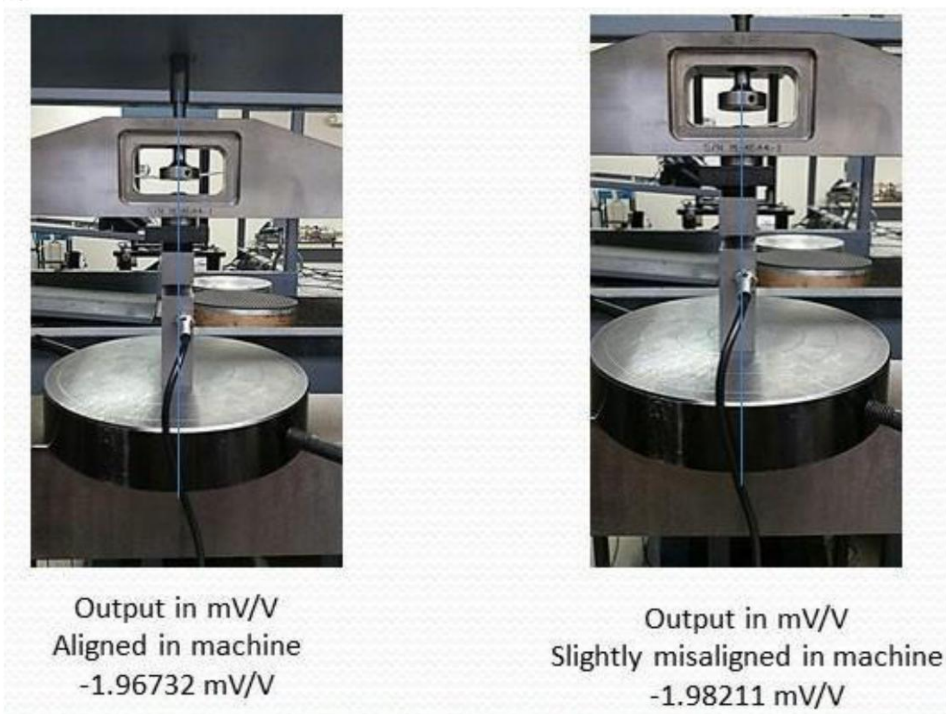

Figure 3. Same load cell and load. A slight misalignment in the machine shifted the output by 0.752 %.

Quality Matters, but How You Use the Load Cell Matters More

A higher-quality load cell gives you a better starting point: better repeatability, lower hysteresis, and more stability between calibrations. That quality sets the ceiling on how well you can measure.

It does not guarantee good results. A premium cell used with the wrong adapters, on a flimsy machine, or with force applied off axis will still give bad numbers. The instrument sets the ceiling; your setup decides whether you reach it.

The Key to Calibration: Replicate Use

The single most important principle in force calibration is to calibrate the way the cell will actually be used. The closer the calibration matches the application, the smaller the surprise when the cell goes to work.

- Use the same adapters, or adapters that replicate the real load path.
- Calibrate on a machine that is plumb, level, square, rigid, and low in torsion.
- Keep the line of force pure and centered through the cell.

Equipment that is not plumb, level, square, and rigid can produce a different output than was recorded at the time of calibration. If your calibration setup and your working setup do not match, the certificate describes a condition you never actually use.

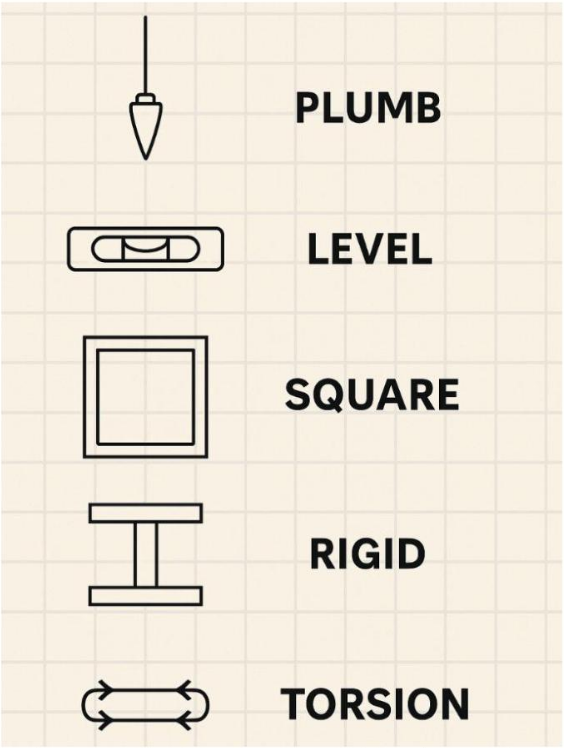

Figure 4. A calibrating machine should be plumb, level, square, rigid, and low in torsion.

Common Load Cell Setup Errors

Threaded adapters

Removing or changing a threaded adapter changes the reading. In Morehouse testing, a load cell showed an ASTM lower-limit factor (a measure of reproducibility) of 0.32 lbf with the threaded adapter installed, increasing to 0.553 lbf without it. The adapter is part of the measurement.

Adapter hardness

Using an adapter with a different hardness than the one used at calibration shifts the result. Surface hardness, flatness, and roughness all affect how force transfers into the cell.

Loading conditions

Off-center, side, and bending loads add error that pure tension or compression would not. Spherical seats, proper alignment, and centering adapters keep the force where it belongs.

Figure 5. Common Causes of Force Measurement Errors.

Alignment is Key

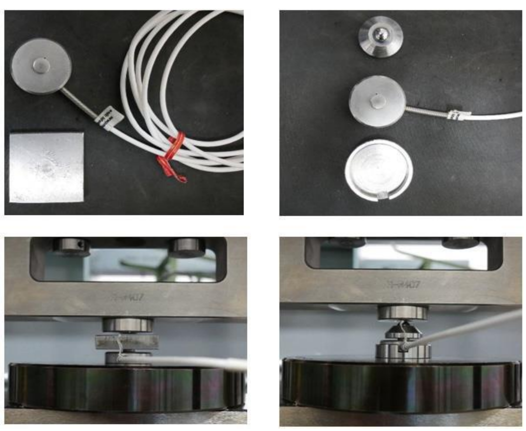

Figure 6. Button load cell setup: standard placement versus Morehouse centering adapters.

Standard Setup versus Morehouse Adapters in Morehouse Deadweight			
Manually Aligned	**Data**	**Aligned with Adapter.**	**Data**
0 degree	2011	0 degree	2008
120 degree	1997	120 degree	2006
240 degree	2018	240 degree	2010
Average	2008.66667	Average	2008
Standard Deviation	10.6926766	Standard Deviation	2
Max Deviation	21	Max Deviation	4
% Error	1.045%	% Error	0.199%

Figure 7. The same button cell read 1.045 % error with manual alignment and 0.199 % with Morehouse adapters.

Getting these details right pays off. Properly centered adapters produced a 525 % improvement in reproducibility in Morehouse testing on a button load cell, and adding a load-ball compression adapter improved reproducibility by 30 – 40 %.

Cable and indicator

Use the same load cell cable and indicator that were used at calibration. The cell, cable, and meter are calibrated together as a system, and swapping any part of that chain can change the reading.

Measurement Uncertainty in Plain Terms

No measurement is exact. Measurement uncertainty is the honest range around a reading where the true value most likely sits. A good uncertainty estimate is built to capture the real-world errors described above: adapters, alignment, loading conditions, and the machine itself.

There is an important limit to keep in mind: the calibration laboratory's reported uncertainty does not include your in-use factors. Treat the certificate as a baseline. To get a realistic total uncertainty, you must add the conditions specific to how and where you use the device.

Capturing Real Errors in Your Uncertainty

When the size of these setup errors is not yet known, there are two practical ways to find and account for them:

- **Compare two load cells** calibrated against deadweight primary standards. The difference between two independently traceable cells exposes an error you would otherwise miss.
- **Build control charts and vary the loading conditions** on purpose. Change adapters, alignment, and orientation, then watch how the readings move. Monitoring reference standards over time with control charts, such as a periodic force verification check, turns hidden setup errors into numbers you can include in your uncertainty budget.

The Calibration Lab's Uncertainty Matters

Uncertainty accumulates at every step away from the primary standard. As a rough picture of the force chain: NIST primary standards are near 0.0008 – 0.0010 %, Morehouse is about 0.0016 %, accredited calibration suppliers commonly fall between 0.025 % and 0.05 %, working standards near 0.1 %, and field measurements near 1.0 %.

This is why the choice of calibration provider belongs in your analysis. If you need a device to be within ±0.02 %, a lab whose stated uncertainty is ±0.04 % cannot mathematically meet that need. Always verify a lab's accredited scope before assuming its capability fits your requirements.

Risk: Calling Good "Bad" and Bad "Good"

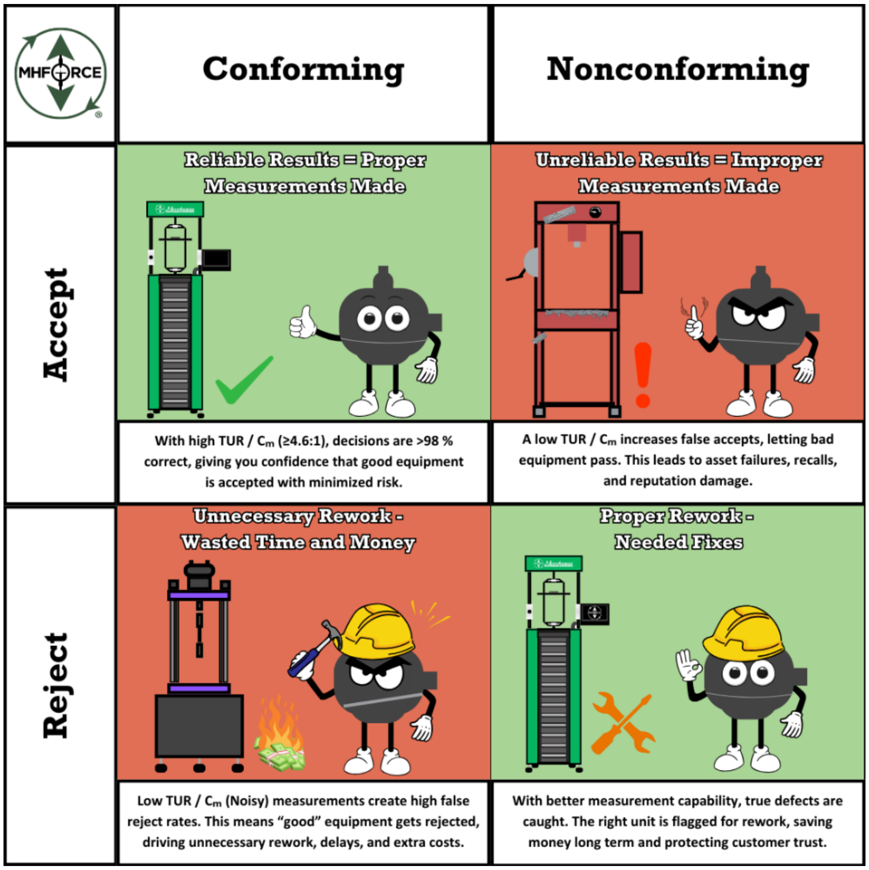

Figure 8. Decision outcomes by test uncertainty ratio. A high TUR (≥ 4.6:1) keeps accept and reject calls reliable; a low TUR drives false accepts and false rejects.

Because every reading carries uncertainty, a pass or fail decision can be wrong in two directions:

- **False reject** — calling a good instrument bad. This wastes time on adjustments, rework, and downtime that were never needed.
- **False accept** — calling a bad instrument good. This is the dangerous one, because an out-of-tolerance device stays in service.

To protect against false accepts, laboratories guard-band, shrinking the acceptance window by an amount tied to the measurement uncertainty. The lab's own uncertainty drives how much guard-banding is required.

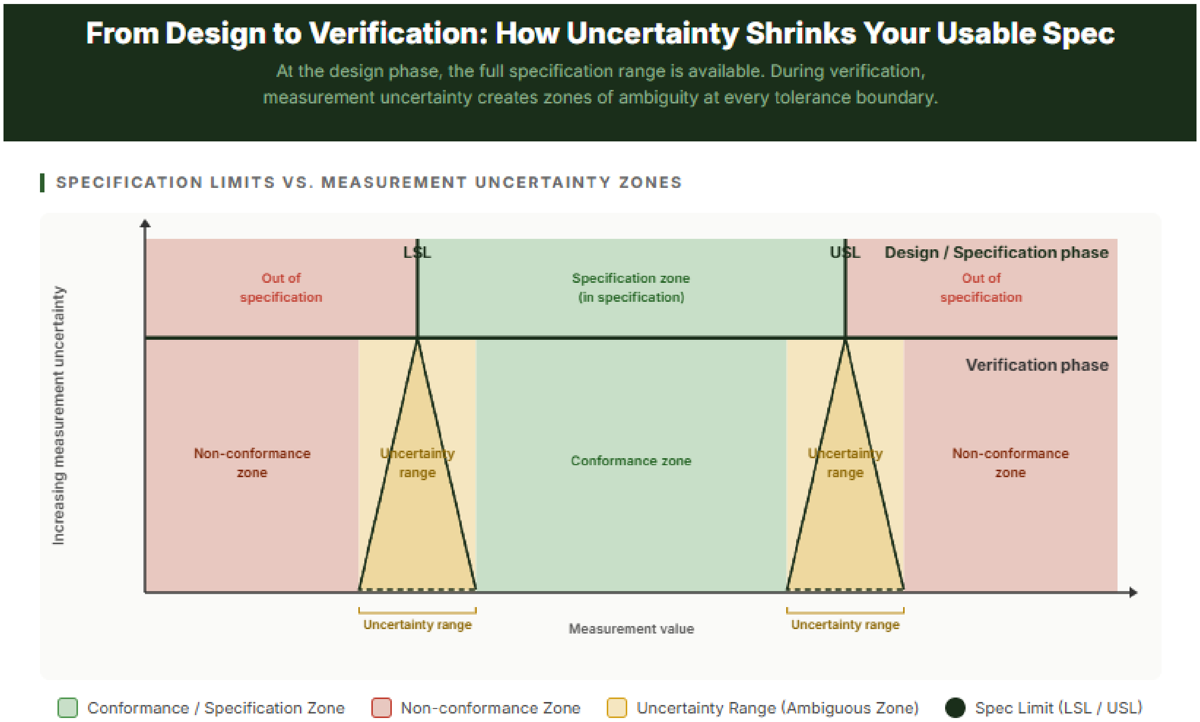

Figure 9. Measurement uncertainty creates zones of ambiguity at each tolerance limit, which shrinks the usable specification.

Consider a 10 000 lbf system with a ±5 lbf tolerance (0.05 % of full scale). With low-uncertainty primary standards, the acceptance window can run from 9 995.170 lbf to 10 004.825 lbf — wide and fair. With uncertainty about 10 times larger, that window tightens to roughly 9 996.7 lbf to 10 003.3 lbf. With uncertainty about 20 times larger, it shrinks to roughly 9 998.4 lbf to 10 001.6 lbf, and good devices begin to fail. Lower lab uncertainty means fewer false accepts and fewer false rejects, and a fairer call either way.

Key Points to Remember

- Force is push (compression) and pull (tension), and load cells treat the two differently.
- No load cell is perfect, and setup errors are often larger than the cell's own error.
- Replicate use: same or equivalent adapters, on a plumb, level, square, rigid, low-torsion machine.
- Build uncertainty that captures these errors, and treat the calibration certificate as a baseline, not the whole picture.
- Lower lab uncertainty leads to fairer pass and fail decisions and protects against both false accepts and false rejects.