Potential measurement errors in force calibrations

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The measurement of force is performed so frequently and routinely that we tend to take these measurements for granted. Each force measurement disseminates from the top of the pyramid (Figure 1), the International Bureau of Weights and Measures (BIPM), to those performing material testing. Each level in the pyramid or measurement chain has an associated measurement uncertainty. This is referred to as Metrological Traceability.

Metrological Traceability is the 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.

When we begin to discuss force measurement error, we must understand the consequences these errors could have. These consequences may range from under-reported measurement uncertainties, leading to several financial implications. These errors are propagated from higher levels of the measurement pyramid and transferred down to those making field measurement.

A company could be failing a field measurement, when it is actually “in-tolerance,” costing a company additional expenses. This is commonly referred to as *producer’s risk*. If a company is passing a critical measurement, when it is actually “out of tolerance,” this is known as *consumer’s risk*. Consumer’s risk could lead to mass recalls and in serious cases, loss of human life.

Most force measurement errors can be avoided by taking the appropriate actions to make better measurements. To make better measurements, we must understand the sources of the force measurement error. In this article we will be discussing the following potential measurement errors: loading through the bottom threads in compression; four-wire versus six-wire cable; unbolting load cells; and not using the proper pin size when calibrating a tension link.

Potential measurement error—loading through bottom threads in compression

It is important to remember that not all calibration laboratories provide the same type of calibration service. For load cells calibrated in compression there may be a noticeable difference in output. The output is dependent on the calibration fixtures used at the time of calibration, the alignment of the unit under test (UUT), the hardness of the top adaptor used, etc. These are all potential topics for later articles. In this article, we are going to discuss how loading through the bottom threads in compression may affect the output on certain types of load cells.

For some labs, it is standard practice to load flat against the base, while other labs may load the cell through the threads. It is important for you, the end user, to know if your load cell was calibrated against a flat base or through the bottom threads; it could make a difference. At Morehouse, our standard procedure is to load a cell flat against the base, as seen in Figure 2 on the left. We are aware of other labs whose standard procedure is to load the cell through the bottom threads. For shear web type load cells there is a difference and we can put a number on the potential difference between these two calibration methods.

For the test detailed below and in Figure 2, we took a standard shear web style load cell and calibrated it using our dead weight force machine. We believe we can realize the unit of force with this machine to about 0.0015 percent or better. The results listed below show a difference of about 0.012 percent in output at full scale. This 0.012 percent difference is about four times larger than the original reported uncertainty.

If the compression calibration method is not listed on your certificate of calibration, I would suggest calling your calibration laboratory and asking how they calibrated your load cell in compression. We shot a video that shows a different test with similar results—it can be found at http://www.mhforce.com/force.

The test

Compression loading of load cells loading against the base of the load cell versus loading through the bottom threads: This test was done to show the potential difference in output by loading a shear web load cell against the base of the load cell, versus loading through the bottom threads (see Figure 2).

The test instrument used was a Morehouse ultra precision load cell and a Morehouse 4215 meter. The force was applied to the load cell using a Morehouse 120,000-pound dead weight machine, S/N M-7471. The weights in this machine were calibrated directly by NIST and are accurate to .0015 percent of applied force. An ASTM-E74 calibration was performed on the load cell and the uncertainty of the load cell was determined to be .798 LBF. For the purpose of this test, the load cell was kept at the same orientation; only the bottom adapters were changed.

Potential measurement error—four-wire versus six-wire

Cable shears or cables being pinched may affect your calibration, if you are using a system with a four-wire cable. Replacing a four-wire cable may cause a change in output, while a true six-wire setup with a meter capable of reading sense lines can eliminate the majority of the error associated with different cable length and gauge. To understand this error we conducted our own tests. We also filmed a video and posted the results to our website.

In understanding the errors associated with a four-wire cable, we must first understand why this error exists. In general, cable resistance is a function of temperature. The temperature change on a cable affects the thermal span characteristics of the load cell/cable system. On a four-wire cable this will affect thermal span performance.

Simply put, as the temperature changes, the resistance of the cable changes and can cause a voltage drop over the cable length. A four-wire setup simply cannot compensate for variations in lead resistance. Substituting a cable of a different gauge or a different length will produce additional errors.

A known example of this involves changing a 28-gauge or 22-gauge cables. On a 28-gauge cable there will be a loss of sensitivity of approximately 0.37 percent per 10 feet of 28-gauge cable. On a 22-gauge cable there will be a loss of sensitivity of around 0.09 percent per 10 feet of 22-gauge cable. The majority of this error can be eliminated if a six-wire cable is run to the end of the load cell cable or connector, and used with an indicator that has sense lead capability. With a six-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 temperature extremes.

To wire a six-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 two wires are run to positive and negative sense. The six wires then feed into the meter with positive excitation

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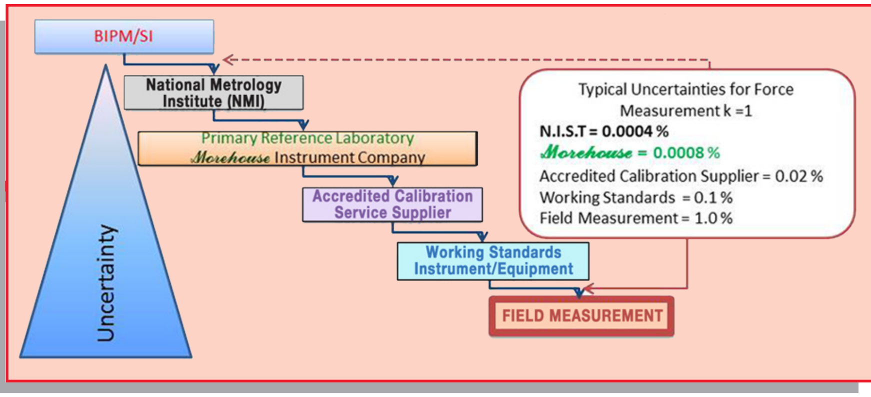

FIG. 1—Measurement uncertainty and the measurement hierarchy.

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
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20000	19994.0	19996.0
22000	21994.0	21996.5
25000	24994.0	24997.0

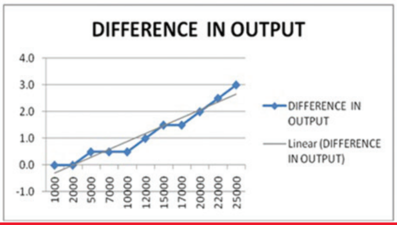

FIG. 2—Potential difference in output by loading a shear web load cell against the base of the load cell versus loading through the bottom threads.

and positive sense running to the meter, negative excitation and sense are run to the appropriate meter connections as well as positive and negative signal.

The results in Figure 3 demonstrate the difference cable length can make on output. It should be clear that a four-wire cannot be interchanged without requiring a recalibration of the entire system. A six-wire cable should be the desired choice if you intend to interchange cables or are operating in an uncontrolled environment.

On the video we posted we observed a difference of 0.106 percent between using two different-length, but same-gauge cables. The test described below shows a difference in output of around 0.05 percent by reducing the four-wire cable by about 40 inches.

The test

Four-lead versus six-lead wire with 114-inch versus 75-inch cable using interface 1000 LBF load cell:

In this HP test with 1000 LBF interface load cell loaded to 1000 LBF, the reading taken at the power supply was 10.0823; the load cell reading was 2.0575. The reading taken at sense loads was 10.0677; the load cell reading was 2.0605; the load cell signal was 20.745, The reading taken using a four-wire setup was 2.0577. The reading taken using a six-wire setup was 2.0605. The reading taken using 75-inch cable with a four-wire setup was 2.0586. The reading taken using 75-inch cable with a six-wire setup was 2.0605.

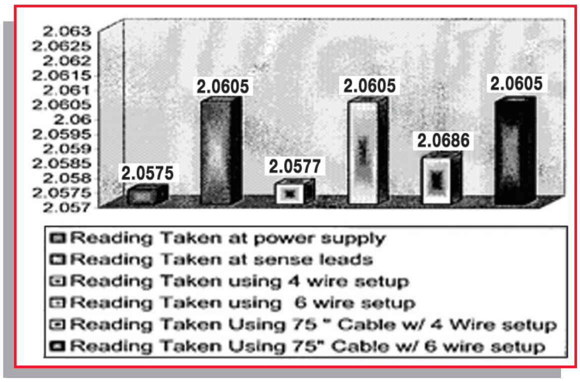

FIG. 3—Four-wire versus six-wire readings.

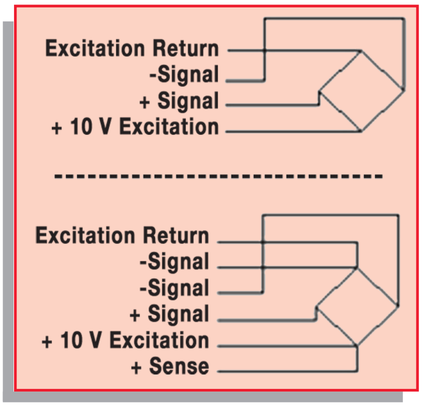

FIG. 4—Top: standard four-wire connection. Bottom: six-wire connection with sense tied into same pin as excitation on cell.

Potential measurement error—unbolting load cells may not produce repeatable results

If you are working to a standard such as ASTM E8 or another ASTM standard that references ASTM E4, then you must have your equipment calibrated in accordance with the ASTM E4 procedure. Annex A1, Verifying the Force Measuring System out of the Test Machine, in the ASTM E4 procedure lists the reasons to perform force measuring system verification out of the test machine.

These reasons include: Inadequate spacing within the testing application load train to allow placement of the force standard; physically impossible to apply a primary dead-weight force in the compression mode without removal of the force measuring system (note: the force measuring system includes the indicator); and test rigs that do not have a reaction frame. When you send a load cell that requires bolting, you should not expect the calibration results to be valid for your testing needs (Figure 5).

If you are not testing the load cell in the machine in which it is being used, and not working to a standard that references ASTM E4 or ISO 7500, you will need to account for additional errors due to the following: mounting considerations, variation between different bolts; material in the base; surface finish on the base; hardness, stiffness, alignment, flatness, bending and variations from using different bolting sequences that may contribute to the uncertainty. The torque wrench that may or may not be accurate to four percent of applied torque that was used to torque the bolts must also be considered. This assumes a torque wrench was even used.

FIG. 5.

Even if all of these potential errors are quantified, a Repeatability and Reproducibility (R & R) study has to be performed between

Potential force calibration errors *(continued)*

the technicians installing the load cell in the machine, and the technicians in the laboratory performing the calibration. Is there a significant difference between these technicians? My assumptions are that any lab going to these great lengths to quantify all of these errors, has already realized that there is probably a better way to ensure more repeatable results.

Morehouse is always going to suggest purchasing the proper equipment that will allow for calibration of the load cells in the machines they are being used. There are two very good standards that will give you the detailed instructions on how to use a load cell system to calibrate these load cells in place. These standards are ASTM E4 and ISO 7500.

If you are working to ASTM standards that references ASTM E4 as a calibration requirement, it is important to note that the entire system needs to be calibrated, if removed. When equipment is not available to allow for in-place calibrations, please remember to account for the various uncertainty contributors listed above in addition to environmental conditions, the uncertainty of the reference standards used to perform the calibration, the resolution of the device, the stability of the instrumentation and the reproducibility and repeatability of the measurement process. It is important to remember that most load cell manufacturers will not warranty a cell that has been removed from the base.

Potential measurement error—using different adaptors on tension links

You are out in the field with a tension link, load link, or some type of digital dynamometer to use for a weighing application (Figure 6). You need pins to engage into the unit. What can you use? Slings? Maybe one size pin with one diameter on one end and another pin with a different diameter on the other end. As long as the fixtures are safe to hold the load it shouldn't matter, should it?

Here at Morehouse, we have done testing with this issue in mind. Forged pins, for example, can differ by small amounts in diameter from pin to pin. Depending on the Scale manufacturer, we have seen differences up to 1.7 percent between different sets of pins (Figures 6 and 7 demonstrate this). ***If your instrument has an accuracy of 0.1 percent, your error could be 17 times greater by substituting pins.***

Calibration should be performed with the same load pins the end user is using with the device. Some links exhibit very high errors when substituting different types of pins (Figures 8 and 9).

Okay, I have my pins. I will always use the same ones, so now I am set. Is there anything else to worry about? Maybe. If you are using forged pins and they are not aligned in the same position they were calibrated in, there could be additional random measurement error.

In our Lab, we have notes on each instrument and the way the loading pins should be aligned so we can duplicate calibrations. We reference the pin diameter used on all our certificates and will put notes in with the instrument explaining the loading procedure.

Attention: It is important to position any forged loading pins through the shackles the same way that we had the pins positioned during our calibration. There can be variation in the surface of the pins from one pin to the next. This variation may affect your ability to reproduce the calibration results.

We have a standard practice to label the pins. Standard practice is to label the TOP PIN, BOTTOM PIN and mark the direction of each pin with an up arrow at the 12:00 position. This helps the end user eliminate as much variation as possible, allowing for reproducible measurements.

Tension links—good measurement practice:

- Using correctly sized pins is critical;
- Do not use pins that are worn or bent;
- If links are damaged, highly used, or worn, decrease the time between calibrations;
- The same size and style of shackle and pin used during operation should be used for calibration;
- Maintaining pin orientation is best practice.

To continue this discussion with Henry Zumbrun,
***go to* www.testmagazine.biz/info.php/15on000**

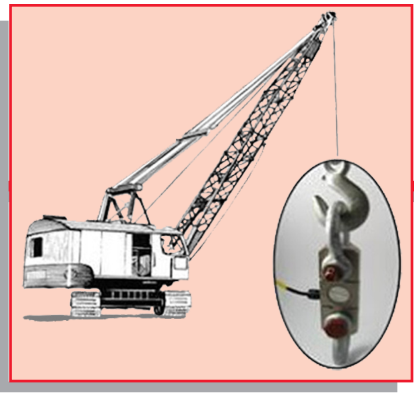

FIG. 6—Tension links—are your measurements accurate?

FIG. 7—Pin size is critical.

FIG. 8—Loaded without the proper pin size.

FIG. 9—Tension link loaded with proper pin size.