Loose Square Drives, Not Lost Corrections: What Five Out-of-Tolerance Torque Transducers Revealed

SUMMARY

Learn how Morehouse metrologists investigated a set of six square-drive torque transducers after five were found out of tolerance as received, and how the pattern in the calibration data pointed to loose square drives rather than lost calibration corrections or failing transducers.

In this investigation, Morehouse:

- Showed that the as-received errors changed with loading direction and grew at low torque, the pattern of mechanical play and bending rather than a sensitivity shift
- Found loose square drives on every transducer, with the smallest cell the worst
- Found that the ±0.1 % of applied tolerance was equal to or smaller than one count of the indicator at the first test point on five of the six transducers
- Gave the customer practical next steps: drive verification, repeatability studies, and a better interim check standard

BACKGROUND

Morehouse Instrument Company has been in the force and torque calibration business for more than 100 years. Based in York, Pennsylvania, the company holds ISO/IEC 17025 accreditation and calibrates torque transducers with deadweights on a primary torque standard, vertically wherever the transducer allows. Loading vertically removes the side load and overturning moment that a horizontal moment arm puts on a transducer, so the calibration measures the transducer and not the fixture.

An aerospace and defense customer sent Morehouse six square-drive torque transducers ranging from 20 ozf·in to 811 lbf·ft. Each transducer pairs with a digital indicator that stores a five-point calibration table and applies corrections to the displayed torque. The customer specified ±0.1 % of applied torque from roughly 10 % to 100 % of capacity, clockwise (CW) and counter-clockwise (CCW).

Five of the six transducers were out of tolerance as received. Morehouse adjusted all five and returned them within tolerance. The customer's metrology lead then asked a fair question: was the transducer design unreliable, had operators over-torqued some of the units, or had the stored corrections somehow been removed before the as-received test?

CHALLENGES

An out-of-tolerance result on a reference transducer is expensive. Every tool it checked during the interval may need an impact assessment. Knowing the cause decides the fix: new transducers, operator training, a shorter calibration interval, or something else entirely.

The customer had already compared the results against the previous calibrations and found no obvious systemic offset between laboratories. The results looked scattered, which made the cause harder to see.

The lost-correction theory could be checked directly. For the as-received run, the Morehouse technician tared each indicator normally and left the stored five-point table alone. The temporary zero the indicator program allows was used only during adjustment. The data also argued against it. A lost or shifted table tends to produce a smooth error of similar size in both directions. That is not what these transducers showed.

INVESTIGATION

Reading the pattern

Morehouse Lab Manager Tim Wetzel and CEO Henry Zumbrun went through all six certificates. Table 1 summarizes the as-received results, and Figure 1 plots them.

Table 1. As-received error by cell and direction, as a percentage of applied torque. Tolerance ±0.1 % of applied. n = 6 transducers.

Cell	Capacity	CW as received	CCW as received	Result
A	20 ozf·in	+0.36 % to +3.5 %, erratic	+0.14 % to +3.5 %, erratic	Out of tolerance
B	10 lbf·in	−0.58 % rising to +0.17 %	Steady ≈ +0.2 %	Out of tolerance
C	106 lbf·in	−0.08 % to 0.00 %	−0.08 % to +0.08 %	In tolerance
D	620 lbf·in	+0.22 % at the two lowest points	Up to +0.11 %	Out of tolerance
E	300 lbf·ft	−0.02 % to −0.08 %	+0.23 % to +0.36 %	Out of tolerance
F	811 lbf·ft	+0.23 % to +0.47 %	≈ +0.1 %	Out of tolerance

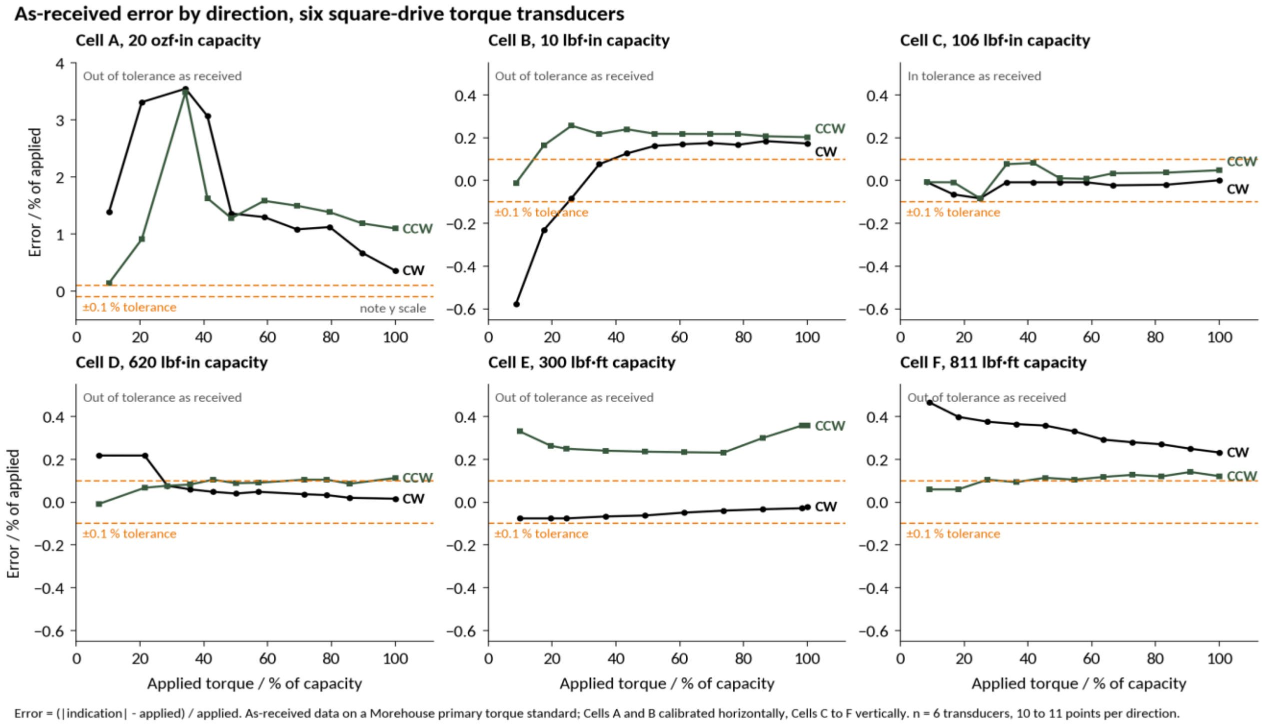

Figure 1. As-received error by direction for six square-drive torque transducers. Dashed lines mark the ±0.1 % of applied tolerance. Note the larger y scale on Cell A. n = 6 transducers, 10 to 11 points per direction.

Three features stand out. The error depends on direction: Cell E passed at every CW point and failed at every CCW point. The error is worst at the low end of the range on Cells B, D, and F. And on the smallest transducer, Cell A, the error jumps from point to point, reaching +3.3 % at 4.16 ozf·in and falling to +1.4 % at 9.86 ozf·in. Error that depends on direction, is worst at low torque, and is not smooth across the range is the signature of a loose drive, bending, or both. The largest low-end errors came from Cells A and B, the two smallest transducers, which were also the two calibrated horizontally.

The square drives

Every square drive in the set was loose. The smallest cell was the worst.

> *“Tim showed me the play in that drive, and I could not believe it,” Zumbrun says.*

A loose drive cannot transmit a clean torsional input. It transmits torque plus an off-axis contact force whose direction and size shift as the load changes, and slack in the coupling lets the effective moment-arm length move under load. The resulting error is not a fixed bias, so it does not repeat and no calibration can remove it. ASTM E2428 §X4.2.13 warns that square drives with a loose fit can introduce large measurement errors, and §X4.6.8 directs the laboratory to minimize slack in the coupling.

Figure 2 shows the difference. In a good-fit drive, the four faces keep the applied moment centered on the transducer’s torque measuring axis. In a worn drive, the shaft moves inside the socket. In a torque arm loading setup, this can change the length of the torque arm relative to the measuring axis. In a horizontal setup, it offsets the applied torque axis from the torque cell's measuring axis and creates unpredictable readings. Where the shaft settles changes from one loading to the next, so the error changes with it. Field experience shows these errors can be an order of magnitude larger than the entire Class A uncertainty budget.

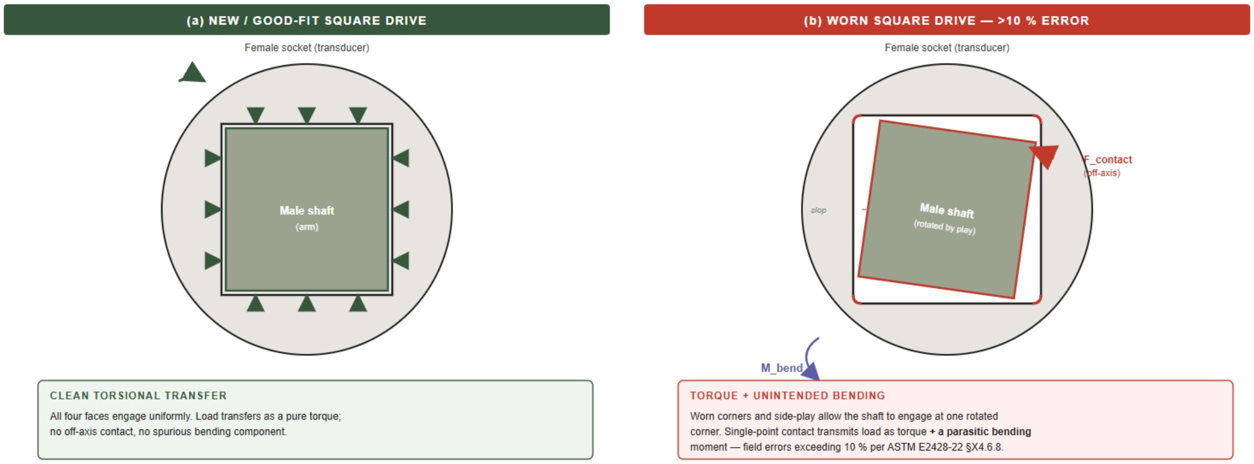

Figure 2. A good-fit square drive (a) engages on all four faces and transmits clean torque. In a worn drive, the shaft moves inside the socket. This can change the length of the torque arm relative to the measuring axis in a torque arm loading setup. In a horizontal setup, it offsets the applied torque axis from the torque cells' measuring axis to create unpredictable readings. Where the shaft settles changes from one loading to the next, so the error changes with it. Field experience shows these errors can be an order of magnitude larger than the entire ASTM E2428 Class A uncertainty budget.

This is why drive rigidity comes first. If the drive is worn, no correction or uncertainty budget entry will make the measurement repeatable; the coupling has to be fixed before anything else about the calibration can be trusted.

Morehouse adapters are made to US customary dimensions, which the transducer maker's published drive tolerance also appears to follow. The technician also tried a socket from a standard set to see whether the fit changed. Shimming the fit would likely make the results more repeatable, but that is not something an operator should have to do in daily use.

The adjustment

Adjustment confirmed the picture. The technician programmed the five-point tables, and on several cells the results still would not meet the specification. Points had to be edited more than once to reach the as-left results.

> *"A cell on a rigid drive that repeats well usually takes one pass, maybe a tweak at a point on occasion," Zumbrun says.*

Needing several passes told the team that reinstall-to-reinstall scatter was a real part of what the customer was seeing.

What overhung moment does

Overhung load is any load on the transducer that is not pure torque about its measurement axis. The most common source is the moment arm itself. A single-ended arm coupled directly to a transducer hangs its own weight on it as a side load, and that side load acts at a distance from the transducer's measurement plane, creating an overturning moment (Figure 3). A 5 ft single-ended arm weighing 35 lbf puts an overturning moment of roughly 87.5 lbf·ft on the transducer before a single calibration weight is added.

Figure 3. A single-ended unsupported torque arm on a torque cell. The weight of the arm acts at its center of gravity, producing a side load and an overturning moment about the transducer's measurement plane before any calibration weights are applied. From the Morehouse technical paper, Quantifying Overhung Load in Torque Calibration.

A strain-gage torque transducer is designed so that its bridge responds to shear strain and cancels bending. In practice, the cancellation is never perfect. Small differences in gauge placement, element machining, and bonding leave a residual, so part of any bending load shows up at the indicator as torque. The size of that residual varies from unit to unit and is almost never reported on a certificate. Shaft-style square-drive transducers, like the six in this set, typically have the least bending rejection.

Why two laboratories can disagree

Morehouse calibrated the four larger transducers (Cells C to F) vertically, so they saw no overhung load here. The two smallest, Cells A and B, were calibrated horizontally, so arm loading may be part of their results, and a loose drive makes that loading less predictable. A laboratory or in-house check that uses a single-ended moment arm puts the weight of the arm and the deadweights on the transducer as a side load and an overturning moment. Real transducers are never perfectly balanced against bending, so part of that load reads as torque. Because the bending load changes little with applied torque while the torque signal scales with the weights, the error as a percentage of reading is largest at the bottom of the range. Each unit's bending sensitivity is different, so the offset also varies from cell to cell.

Morehouse has measured this directly. In a worked example from its technical paper on overhung load, a square-drive torque cell on a 5 ft single-ended arm read 0.169 % high at 1 000 N·m compared with the Morehouse primary torque standard. After the bending contribution was quantified with a CW/CCW comparison, the residual difference was 0.010 %. The 2007 UK torque intercomparison found the same effect across ten laboratories: on the 100 N·m transducer, deviations of several tenths of a percent were common at the low end. Two laboratories can disagree by that much without either being wrong about the torque applied.

Loose drives make this worse. A CW/CCW comparison on a loose coupling measures slop rather than transducer bending, so the drive has to be rigid before bending can be characterized at all.

The tolerance

The ±0.1 % of applied specification is hard to support at the bottom of these ranges. On five of the six transducers, one count of the indicator is equal to or larger than the tolerance at the first test point (Figure 4). Cell F reads to 0.1 lbf·ft against a tolerance of ±0.074 lbf·ft at 73.8 lbf·ft. Cell B reads to 0.001 lbf·in against ±0.000 89 lbf·in. Test uncertainty ratios at those points ran from 1.3:1 to 1.6:1. Add drive play, and a small change reads as a failure.

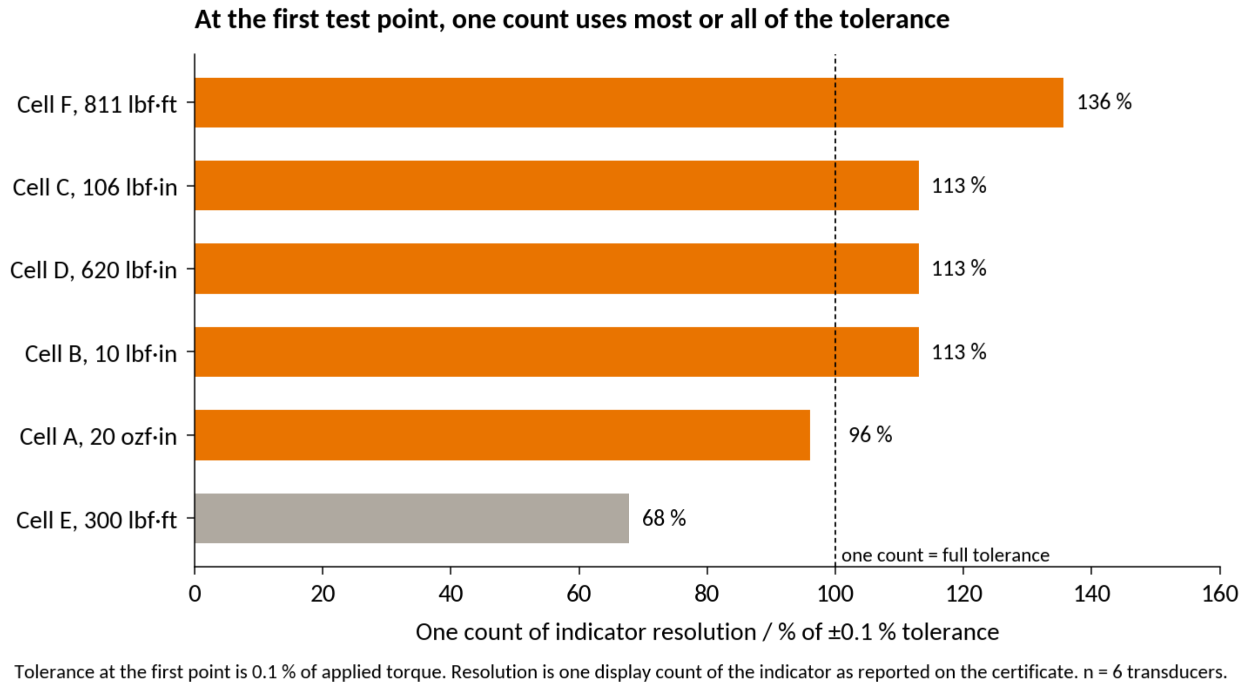

Figure 4. One display count of the indicator as a percentage of the ±0.1 % of applied tolerance at the first test point. Bars at or above 100 % mean a single count uses the whole tolerance. n = 6 transducers.

RESULTS

The investigation answered the customer's question. The stored corrections were not lost, and the data does not point to a transducer design problem in the usual sense. It points to the mechanical interface, mainly the square drives, combined with a tolerance that leaves no room at the low end.

Morehouse recommended the following:

1. **Verify the square drives.** Check each drive against the manufacturer's tolerance and replace worn drives before recalibrating.
2. **Run repeatability studies.** Load the same point several times, removing and reinstalling the transducer and rotating the drive 90° between runs, as ASTM E2428 §6.5.6 does with its four square-drive positions. If the spread approaches 0.1 %, the tolerance cannot hold in service no matter who calibrates the transducer.
3. **Use a better interim check.** Shunt calibration checks the bridge and electronics, not the mechanical path, so it will not catch this problem, and it is even less useful on small cells. A small weight stack on a simple arm gives a known, repeatable torque and makes a better check standard than torque tools.
4. **Confirm the indicator units.** Verify that each indicator displays US customary units and that the stored points were entered in the same units. The applied points were metric nominals converted to US customary (811.3184 lbf·ft is 1 100 N·m), so a mismatch between the display and the table would be easy to miss.
5. **Review the low-end tolerance.** A tiered or percent-of-full-scale tolerance at the bottom of the range would reflect what the indicator can resolve.

Morehouse also offered to short-cycle two or more of the transducers to see whether they hold tolerance, and to work with the customer on a better calibration method for the small cells.

Lessons for any torque laboratory

- A rigid drive coupling is a prerequisite for any torque measurement, not a line item in the uncertainty budget.
- The shape of the error tells you where to look. Direction-dependent error that grows at low torque points to the mechanical path.
- Laboratories that use single-ended arms should characterize bending on each transducer, rotate through four orientations, and consider a bearing-supported arm or a torque transfer machine for new work.
- A tolerance tighter than one count of resolution at the low end will produce failures that say more about the specification than the transducer.

The most effective fix for overhung load is in the fixture, not the budget. Supporting the arm with a bearing carries its weight independently of the transducer and removes the bending contribution entirely (Figure 5). Bearing friction becomes the new, generally smaller, contributor. In the worked uncertainty budgets in the Morehouse technical paper, either a bearing-supported arm or a bending-compensated transducer cut the expanded uncertainty by a factor of three to five without changing anything else.

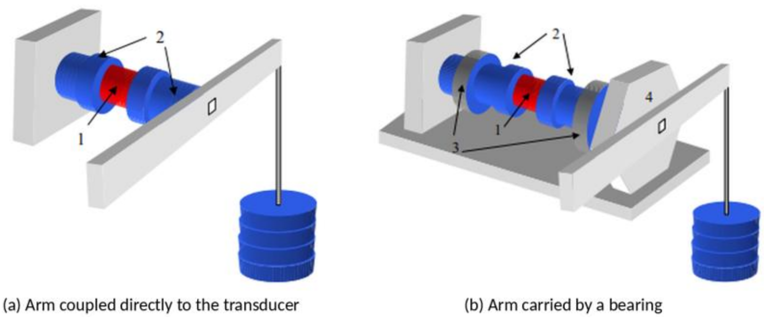

Figure 5. Isolating the transducer from the arm weight. With the arm coupled directly (a), the transducer carries the arm as a side load. With the arm carried by a bearing (b), the bending contribution is eliminated and bearing friction must be characterized instead. From the Morehouse technical paper Quantifying Overhung Load in Torque Calibration.

Morehouse's technical paper, Quantifying Overhung Load in Torque Calibration, covers the CW/CCW method, worked uncertainty budgets, and mitigation options in detail.