Comparing Preparation and Calibration Techniques for Ultrasonic Bolt Tension Measurement – *Part 1*

by:
Dave Archer, President
Archetype Joint, LLC
140 Engelwood Dr., Suite D
Orion, MI 48359 USA
www.archetypejoint.com

Preparation and calibration of bolts for ultrasonic measurement are components of measurement that have remained largely unchanged through the period of advancement in hardware and software.

The use of ultrasonics in determining bolt tension has increased in recent years due largely to improvements in application of the technology. Advances in user interfaces has improved ease of use and enabled traceability of settings and setup that were once established by knob twisting and then were lost or unverifiable. A main source of repeatability errors, differences in acoustic coupling each time a transducer is reapplied to a fastener, has been essentially eliminated in some systems by integrating or attaching the sensor to the fastener so only electrical connection is made on successive measurements. Many liquid-coupled systems are also addressing this issue through echo triggering designed to negate on/off errors. However, one component of measurement uncertainty has remained largely unchanged through this period of advancement in hardware and software: the preparation and calibration of bolts for ultrasonic measurement. This is usually the test practitioner's responsibility, and as such invokes discussion and debate as to best practices.

While all ultrasonic systems have the capability of measurement using database material constants, the vast majority of bolts used in ultrasonic measurement within critical joints are calibrated to more accurately correlate the relationship between applied load and resulting elongation. The procedure for performing that calibration and for preparing the bolt ends to ensure the maximum proportion of energy is reflected back to the sensor is not universally defined, either by independent specification or by general acceptance of preferred technique.

The purpose of this article series (two parts) is to provide quantitative guidance in addressing the most common questions test practitioners and their customers have regarding preparation and calibration. These questions are:

- Is it better to calibrate the bolt by directly tensioning it, or by elongating it by rotation relative to a mating nut member?
- How sensitive is calibration accuracy to the parallelism of the prepared bolt ends?
- How good a surface finish is required of the prepared bolt ends?
- Related to questions of required parallelism and finish, what are the best methods of preparing the ends of the fastener flat and parallel to one another?
- Is better accuracy achieved by measuring tension based on the individual calibration of each bolt or based on an average calibration of a subset of bolts?
- Does the bolt's grip length have an influence on the best calibration method to choose?

To provide the answers to these test objectives, the test plan summarized in **Table 1** was developed. The fastener used for all tests was an M10 x 1.5 property class 10.9 hex head cap screw, 50 mm long and threaded 26 mm with a phosphate/oil finish.

The basis of ultrasonic measurement is the **Micro Controls** MC900 transient recorder with ultrasonics option. The sensor used is a 3 x 3 x 0.1 mm thick 7.5 Mhz piezo ceramic chip bonded to the prepared bolt. A separate magnetic pickup and cable transfers the sensor signal to the transient recorder.

TABLE 1— TEST PLAN

Objective	Test ID	Cal Method	Grip	Finish	QTY
Effect of finish/angle	1	Tensile	med	fine	10
Calibration linearity	2	Tensile	med	extra fine	10
	3	Tensile	med	ground	10
Calibration linearity	4	Tensile	short	ground	5
	5	Tensile	long	ground	5
	6	Torque	short	ground	5
	7	Torque	long	ground	5
Tension accuracy	8	Tensile	short	extra fine	5
	9	Tensile	long	extra fine	5
Grip Lengths (mm) - Short: 23.4, Med: 31.4, Long: 39.4					

Test 1 - Finish and Parallelism

Two interrelated test objectives were the desire to provide guidance as to the effect of the finish and parallelism of the bolt ends on calibration and measurement accuracy, and what values different preparation methods might be expected to produce. Several preparation methods are used by practitioners; surface grinding, milling, turning and disk sanding. To contain the size of this test, only surface grinding and disk sanding were tested as they would be considered the two extremes of potential accuracy. The ground bolts were fixtured by threading them into a fixture block until the threads bottomed. The disk sanded bolts were clamped in a precision V-block and sanded from a pinned fence against first a 12" disk and then an 8" disk. Two finish levels were tested: Fine - 60 grit pass followed by 120 grit pass and Extra Fine - 60 grit pass followed by 120 grit pass. After the bolts were prepared, the surface finish of each was measured with a profiliometer with three readings taken on each bolt. A summary of the average of those three readings is shown in **Table 2**.

TABLE 2: COMPARISON OF SURFACE FINISH BY PREPARATION METHOD

	Surface Finish, Ra (µm)			
	Ave	**Min**	**Max**	**Std Dev**
Disk - Fine	2.63	2.00	3.73	0.50
Disk - Extra Fine	1.71	1.33	2.67	0.38
Surface Ground	0.82	0.58	0.97	0.12

After surface finish readings were taken, each bolt was placed shank down on a surface plate and two pairs of measurements taken 90° apart were taken at the perimeter of the head with a 0.001 mm (0.00005") resolution gage head and amplifier (**Figure 1**). The angle of the head surface relative to the surface plate as defined by the readings at the 0° and 180° position were calculated, as was the angle relative to the 90° and 270° line. The averages of those angles for the 10 bolts in each group are summarized in **Table 3**.

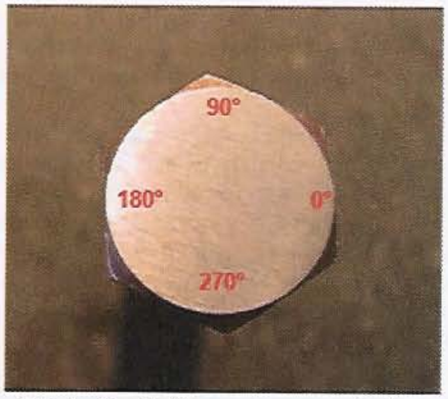

Fig. 1– Parallelism measurement setup.

TABLE 3 – ANGULARITY BETWEEN BOLT HEAD AND SHANK, DEGREES			
	0°- 180°	**90°- 270°**	**Ave**
Disk - Fine	0.108	0.114	0.111
Disk - Extra Fine	0.121	0.049	0.085
Surface Ground	0.043	0.065	0.054

Viewed independently, the data in **Tables 2** and **3** is of limited value. The impact of these differences will be better illustrated through their effect on calibration linearity and on bolt tension measurement error.

Comments on Test Results

- As this test was based on only a single bolt style and sample sizes that are smaller than ideal, the applicability of results should be viewed narrowly and as guidance only.
- Considered independent of parallelism and based on experience in addition to this test, surface finish readings greater than approximately 2.0 µm (79 µin) Ra are not desirable, primarily because the amplitude of the signal is diminished. The gain required to maintain given amplitude with the Fine Sanded group was approximating 20% greater than the Extra Fine sanded group (2.63 µm vs. 1.71µm Ra). With bolts that don't require much gain to achieve good amplitude this may not be a problem, but high-gain applications increase signal noise. Finishes finer that approximatly 1.0 µm (39 µin) Ra don't appear to add any additional value and may decrease sensor bond strength. Note that these comments may not translate precisely to liquid-coupled ultrasonic systems as the sensor-to-bolt interface is fundamentally different.
- The affect of parallelism is a continuous spectrum rather than the more bounded "sweet spot" of finish. All incremental improvements in parallelism and flatness provide incremental improvements in accuracy, albeit getting smaller as control gets greater. As such it is hard to state a cut-off value. The angular error of the extra fine sanded bolts was about 50% greater than the ground bolts, but as will be shown in Part 2 of this article, the measurement error of the three groups prepped with this method were essentially equal to the five groups that were surface ground. While this could be a case of small sample sizes or narrow application, additional experience indicates that the disk sanding method can be used with good results and is particularly beneficial when bolt quantities are small. This method is more operator-dependant than other methods and is at least as sensitive to setup quality as others so it should be used after gaining experience and with a means to check the result. Flatness/parallelism generated from milling and turning tends to fall in the middle, although surface finish should be monitored because it can be worse than any of the methods tested here.

Part 2 of this article will be published in the December 2007 issue of *Fastener Technology International,* discussing the effect of these preparation techniques on calibration and measurement accuracy. FTI

Company Profile:

Archetype Joint, LLC*, provides joint design, test and validation services for OEMs and suppliers of assembly equipment and fasteners. Located in Orion, MI, USA, the company has a complete independent test lab accredited to ISO 17025 by* ***A2LA****. Archetype Joint takes pride in utilizing the diversity of its professional experience and its customer base to provide clients with interpretation and recommendations, not just test data.*

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About the Author...

David Archer *is President and founder of Archetype Joint, LLC. He started Archetype Joint after over 20 years of broad experience in design, manufacturing and consulting, focusing on enhancing product value through reducing design and process complexity. The realization that joint design was the most widely ignored barrier to achieving product cost, performance and quality goals was the genesis for Archetype Joint.*

Archer holds a Bachelor of Science Degree in Mechanical Engineering and Applied Mechanics (1980) and an Master of Science degree in Manufacturing Engineering (1990) from the ***University of Rhode Island****.*