

Advanced Bolt Torque Audit Yields Bolt Tension Data

Torque-Angle Signature Analysis & M-Alpha Audit Method

By Ralph Shoberg



PCB *PIEZOTRONICS*

visit us online at www.pcb.com

Toll Free in USA 800-828-8840 • 716-684-0001

Advanced Bolt Torque Audit Yields Bolt Tension Data

Torque-Angle Signature Analysis & M-Alpha Audit Method

Auditing the performance of tightened bolted joints has long been a priority of quality and assembly personnel in the manufacturing and maintenance fields. There have been many methods developed over the past 40 years to determine the “residual torque” on a tightened fastener and this value is used as a measure of joint integrity. Each of these techniques is a practical method of determining the torque remaining in the joint or the capability of the installation tool; however the true object of tightening a fastener is to produce a clamping load in the joint that will create a reliable assembly. The object of tightening a fastener is to achieve a tension load on the fastener that clamps the bolted components with sufficient force to create a reliable assembly.

What is needed is **a method of estimating the “residual tension”** achieved by a fastener in a bolted assembly (not torque). RS Technologies (a division of PCB Load & Torque, Inc.) developed and patented an auditing method known as the **“M-Alpha Torque-Tension Audit”**, to estimate residual clamping load without having to rely on strain gaging a bolt, using ultrasonic methods, or using force washers. The ability to estimate both residual torque and residual tension on a bolted joint is the reason that the “M-Alpha” auditing process is considered to be a significant technological breakthrough for fastener tightness technology.

Because the M-Alpha audit method can permit the user to obtain bolt tension related measurements it represents a paradigm shift in the way “torque audits” can be conducted. Reliable bolted joints must have the proper clamp force holding the components together. Tension on the fastener is what is needed to be verified, not installation or “residual torque”.

Theory and Application of the M-Alpha Joint Auditing Method

The patented M-Alpha joint auditing method is a process of estimating the amount of clamp load on a threaded fastener using torque-angle signature analysis. The method is based on locating the “Elastic Origin” and analysis of the torque-angle signature to determine the elastic tightening angle of turn. The angular displacement (turn) of the fastener stretches the bolt and compresses the parts being clamped. The elastic clamping region of the torque-angle signature is the region where clamping force is directly proportional to the angle of turn from the “elastic origin”.

The elastic origin is located by projection of the straight-line portion of the signature curve backwards to zero torque, or the prevailing torque level in the case of thread locking interference type of applications.

This principal can be observed when viewing a clamp load-angle curve (see Figure 1). Once the curve becomes linear, the clamp load will increase at a consistent rate with each angle of rotation. This remains true until the curve stops being linear due to yielding of the fastener or the joint.

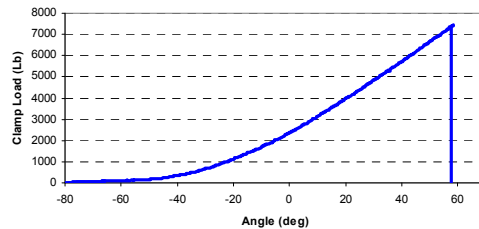


Figure 1: Clamp Load-Angle Plot

The amount of preload in the joint determines how well the joint will function when it experiences working loads. Insufficient preload is a major cause of fastener failures, leading to expensive machinery failures, tragic accidents, personal injuries and even loss of life.

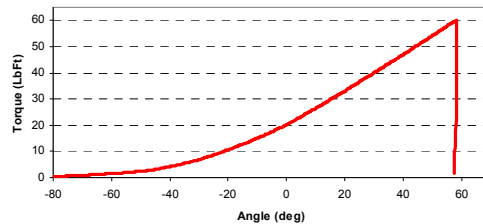


Figure 2: Torque Angle Plot

The torque-angle signature does not directly provide a measure of the fastener tension. However, it has been verified that for a given bolted joint, properly qualified, this signature can be used to directly estimate the clamping force on the bolt, as seen in Figure 2. For example, strain gages on a bolt or stud can be used to simultaneously measure the installation torque and the bolt tension. By scaling and plotting the measured torque and tension, shown in Figure 3, it is apparent that both are in direct proportion to each other.

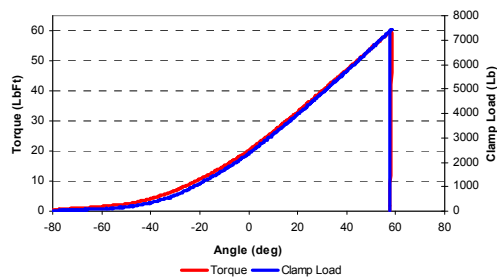


Figure 3: Torque-Tension Combined Scaled Plot

The torque and clamp load plots match up precisely when the ordinates are scaled. This relationship for the linear portion of the torque-angle curve can be used to directly calculate the clamp load in the joint. This is a fundamental characteristic of bolted joints tightened below the yield point of the bolt or components being clamped.

Performing the M-Alpha Joint Auditing Method

The objective of the M-Alpha Audit process is to **determine the “Elastic Tightening Angle”** for a preciously tightened fastener. The amount of clamping load in the joint is directly proportional to the elastic tightening angle. The process of the torque-angle curve analysis is shown in Figures 7 through 10 to illustrate the concepts of the “Elastic Origin” and how the “Elastic Tightening Angle” is determined for a given bolted joint.

Step 1: Tighten the fastener with the specified torque (as seen in Figure 2, previously) stopping in the elastic clamping region.

Step 2: Locate two points on the linear section of the torque-angle signature curve (Figure 4).

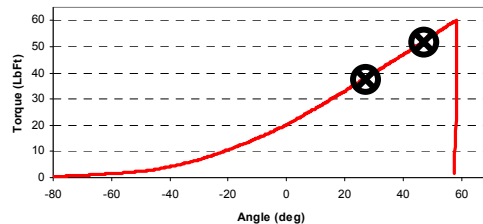


Figure 4: M-Alpha Tightening Torque –Angle Signature

Step 3: Project a line through the two points to the zero torque level, locating the Elastic Origin, as depicted in Figure 5.

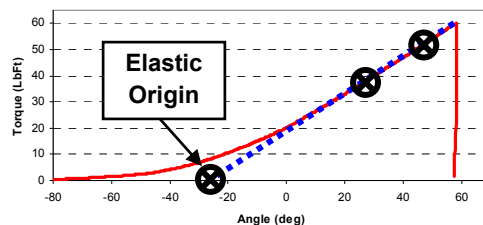


Figure 5: Locate the Elastic Origin

Step 4: Determine the Elastic Clamping Angle, measured from the Elastic Origin, as in Figure 6.

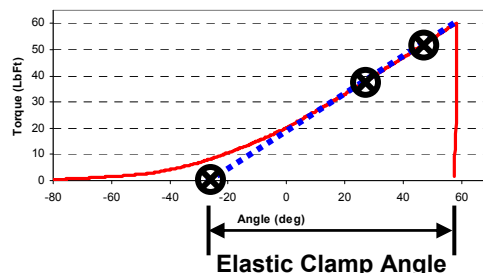


Figure 6: Determine the Elastic Clamping Angle

Measure the Elastic Clamp Angle from the Elastic Origin to obtain the final torque value. The clamping force achieved by the fastener is directly proportional to the measured Elastic Clamping Angle. Knowing how the torque-angle signature looks when tightening a fastener helps to understand the M-Alpha Audit method.

M-Alpha Torque-Tension Audits

Torque audits typically involve tightening a pre-assembled joint a small additional angle, usually as little as 5 degrees or less and rarely more than 10 degrees.

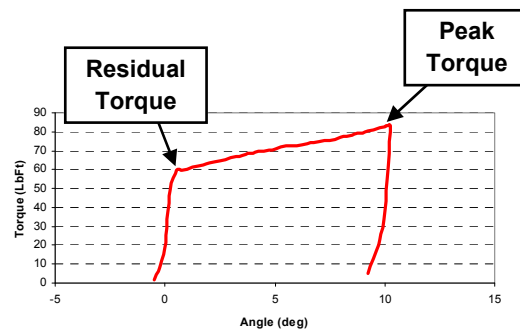


Figure 7: "Traditional" Breakaway Tightening Audit Signature

Traditional audits simply measured the peak torque values or used a calculation algorithm to more accurately locate a residual torque value as a measure of the joint integrity. The M-Alpha method allows the residual torque value to be measured, as shown in Figure 7. More importantly, a paradigm concept, the M-Alpha audit can provide an accurate estimate of the residual clamping load on the tightened fastener.

To illustrate the M-Alpha Audit, overlay the audit signature (Figure 7) with the installation signature (Figure 2) as shown in Figure 8.

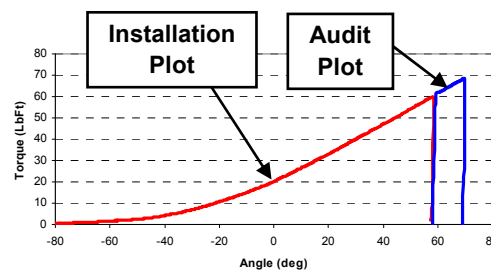


Figure 8: Installation & Audit Plots

The audit signature created by advancing (tightening) the fastener a few degrees will simply be a continuation of the torque angle curve on the same linear slope in the elastic tightening region.

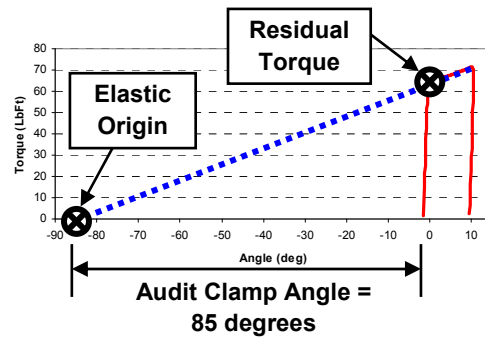


Figure 9: M-Alpha Audit

The M-Alpha Audit is accomplished by advancing the fastener in the tightening direction, projecting a tangent line to the audit signature to locate the elastic origin, and measuring the angle from elastic origin to the residual torque point. The residual tension on the fastener is proportional to the elastic clamping angle determined by the audit. Multiply the Audit Clamp Angle by the Angle-Tension Coefficient to estimate the actual tension on the fastener, as seen in Figure 9 above.

The M-Alpha method can be used to estimate the **relative clamp load** in a tightened joint. For this application the exact elastic tightening angle of clamp force coefficient does not need to be known. An example of this application would be to determine the relative clamping forces on the five lug nuts on a single automotive wheel, or all twenty lug nuts on the four wheels.

To get an **accurate estimate of clamping force** on a bolted joint being audited, the relationship between torque, clamp load and angle must be experimentally determined or calculated. A clamp load/degree coefficient can be determined experimentally using stain gaged bolts, force washers, elongation measurement, or ultrasonic elongation equipment. Calculations are easily done using the SR1 Bolted Joint Design/Analysis program. (Note: For more information, please visit www.pcbloadtorque.com)







With the M-Alpha Audit, engineers and technicians have a powerful tool to use in their quest to assure reliable bolted joints on machinery, steam turbines, gas turbines, compressors, pumps, electric motors, wind energy towers, highway signs, bridges, and more.

What are the divisions of PCB?

PCB Piezotronics, a member of the PCB Group families of companies, has five major divisions, all of which offer targeted sensor technologies. These divisions are supported by an active outside direct sales force of Field Application Engineers, as well as international direct sales offices throughout the world. Individual PCB Piezotronics divisions, locations and their primary product specialties include:

		Depew, NY, USA - www.pcb.com – Piezoelectric, ICP®, piezoresistive & capacitive pressure, acoustic, force, torque, load, strain, shock & vibration sensors.
		Depew, NY, USA - www.pcb.com/aerospace – Sensors & Instrumentation for aerospace & defense applications, including air and spacecraft testing.
		Novi, MI, USA - www.pcb.com/auto – Sensors & Instrumentation for automotive testing, including modal analysis; NVH; component durability; powertrain testing; vehicle dynamics; safety and regulatory testing.
		Depew, NY, USA - www.imi-sensors.com – Industrial vibration sensors, bearing fault detectors, mechanical vibration switches, panel meters, cables & accessories for predictive maintenance and equipment protection.
		Depew, NY & Provo, UT, USA www.larsondavis.com – Precision microphones, sound level meters, noise dosimeters, audiometric calibration systems.
		San Clemente, CA, USA - www.pcb.com – Research & development engineering center for special technologies. Seattle, WA, USA - www.pcb.com – Process development and fabrication of MEMS sensors.

PCB Group Companies

		Farmington Hills, MI, USA - www.pcbloadtorque.com – Designs and manufactures high quality, precision load cells, wheel force transducers, torque transducers, telemetry systems, and fastener torque-tension test systems.
		Cincinnati, OH, USA www.modalshop.com – Global leader in dynamic calibration offering a complete line of automated calibration systems and recalibration services to support dynamic vibration, pressure and force sensors in applications such as: national standards, commercial labs, government/military research, consultancies, and industrial/plant floor operations.
		Rochester, NY, USA - www.sti-tech.com – Mechanical engineering consulting firm specializing infinite element analysis, advance analytical techniques, experimentation, technology development, & design optimization for turbo machinery, industrial machine systems & mechanical structures.

A PCB GROUP CO.



Toll-Free in USA 800-828-8840 ■ 24-hour SensorLineSM 716-684-0001
 E-mail info@pcb.com ■ Website www.pcb.com
 ISO 9001 Certified ■ AS9100 Certified ■ A2LA Accredited to ISO 17025