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Considerations in Torque Auditing and Residual Mode in Exacta Products

Torque auditing is one of the most challenging audits there is. It is an audit that does not fall neatly into the "destructive" versus "non-destructive" testing category. A torque audit changes the item being audited, just as indentation hardness testing or voltage checking does. At the same time, it is usually necessary to perform the audit without destroying the item (joint) being audited.

Torque auditing in also difficult to perform accurately because of the numerous factors that affect the force (torque), and the fact that there are interactions among the components in the joint and the forces involved.

In this paper we will discuss some of the factors that affect the torque that is retained in the joint by the initial tightening, and how they affect the audit and audit results. Note that this paper is not intended as a comprehensive discourse, nor is it in any way a substitute for performing torque audit experiments on the actual joints that you will be auditing.

Fastener Motion

To audit torque it is necessary to move the installed fastener. Traditionally, this has led to one of three methods of auditing.

- **Method 1 - First Motion in the Tightening Direction**
  In this method, a variable-reading type torque wrench (dial, beam, or digital) is used to apply force to the fastener in the tightening direction until motion is detected. The detected peak torque is regarded as and recorded as the residual torque.
- **Method 2 – First Motion in the Loosening Direction**
  In this method a variable-reading type torque wrench (dial, beam, or digital) is used to apply force to the fastener in the removal direction until motion is detected. The detected peak torque is regarded as and recorded as the residual torque.
- **Method 3 – Comparison of Rotation Endpoint**
  In this method the location of a point on the fastener in relation to an item in the grip of the fastener is marked. The fastener is then loosened, and the torque required to rotate the fastener back to that same point in relationship to the marked item in the grip is measured and recorded as the residual torque.

Each of these methods has numerous risks and sources of error. Method 1 is the most popular and most commonly-used method for a variety of reasons, and is the method we will examine the most here.

The fastener does not engage the torque wrench directly. There is a fastener engagement device attached to the torque wrench, and it is this device that connects the two. When this device is a socket, there is literally a "hidden" source of error in the measurement of the residual torque.

The socket usually covers the fastener head completely. When the fastener being audited is a nut that is on a bolt or stud, it is not possible to see the top of the nut because the nut is covered by the socket. As a result, it is common practice to mark the socket and the item(s) in the grip of the joint to assist in detecting motion of the nut. The auditor engages the torque wrench to the nut, marks the socket and grip item(s) with an almost continuous line, and starts applying torque. When the line on the socket begins to rotate in relationship to the line on the item(s) in the grip, first motion of the nut is visually detectable.

Unfortunately this tells us nothing of the relationship between the nut and the bolt or stud. It is the rotation of the nut in relationship to the bolt or stud that creates the clamping force that holds the joint together, and the nut can rotate in relationship to the items in the grip without rotating in relationship to the bolt or stud.

This disparity is possible partly because of something called “bolt windup”. Bolt windup is a twisting of the shank of the bolt itself. This phenomenon occurs in some, but not all joints. Whether it occurs or not is a function of a number of variables and their interactions. Research shows that the relationship between bolt diameter and bolt length is among the variables and interactions having the greatest effect. A short, large-diameter bolt will tend to “wind up” less than a long slender bolt.

If the bolt winds up during the torque audit, it is possible to rotate the nut in relationship to the item(s) in the grip without rotating the fastener in relationship to the bolt. When a socket is used on the nut, the auditor cannot tell whether the nut moved in relationship to the bolt/stud or grip item(s), or both.

Further compounding the error possible from this source is the possibility that the point at which bolt/stud windup occurs may fall inside the torque specification, rather than outside. This could lead to windup affecting some audit torque readings and not others.

Other factors that may affect windup include bolt hardness, thread pitch and coefficient of friction. We cannot address all of the possibilities here, but instead draw to your attention that this is a potential source of variation and torque audit error. If you wish more in-depth material, one source for such information would be An Introduction to the Design and Behavior of Bolted Joints, Third Edition, by John H. Bickford. It is available from Marcel Decker Press.

Perceived Motion and Human Response

When a joint torque audit is being conducted, the auditor may rely on a visual clue that the fastener has moved (see above), or the auditor may rely on feedback from the feel of the torque wrench, or both. In either case there is a dynamic of increasing pressure on the tool, a change in the fasteners to which the force is being applied, and a sensing of the change. The sensing of the change in the fastener from static to dynamic – from at rest to in motion – takes time to occur. During that time the auditor is sensing the change and responding to it by reducing or releasing pressure on the tool.

This elapsed time typically takes several tenths of a second. Human nervous systems tend to average about 0.3 seconds for a relatively simple response such as this. This response time is a variable, and has all of the typical characteristics of a human variable. In addition to lot-to-lot variation (variation among auditors) there is within-lot variation (variation in response from a single individual). The length of time it takes an auditor to realize that the fastener has rotated and to stop increasing pressure on the wrench (and increasing the torque) leads to variation in the audit results.

Joint Hardness

Joint hardness refers to the rate at which tension rises as torque is applied. A “hard” joint is one in which very few degrees of fastener rotation are needed to go from 10% of the desired bolt preload (tension) to 100% of bolt preload. This would be typical of a joint in which two hard steel plates are bolted together. A “soft” joint is one in which it takes many degrees of rotation to move from 10% of the desired preload to 100% of the desired preload. An example of this would be a joint in which there was a thick soft gasket between two hard steel plates. The additional rotation is needed because the joint rate (slope of torque-tension line) is changed; the gasket material compresses and necessitates more fastener rotation.

How hard or soft the joint is interacts with the torque wrench and the auditor, combining in largely unpredictable manners.

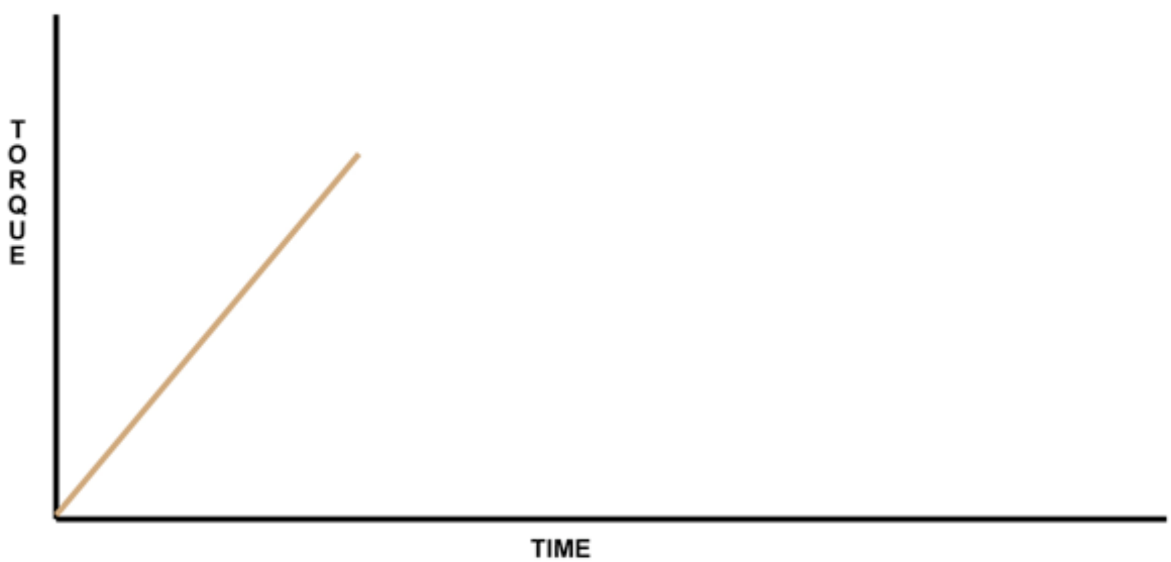
Dynamic Installation and Static Audit

The inertial difference between fastener tightening during installation and joint torque auditing is another source of variation in audit results.

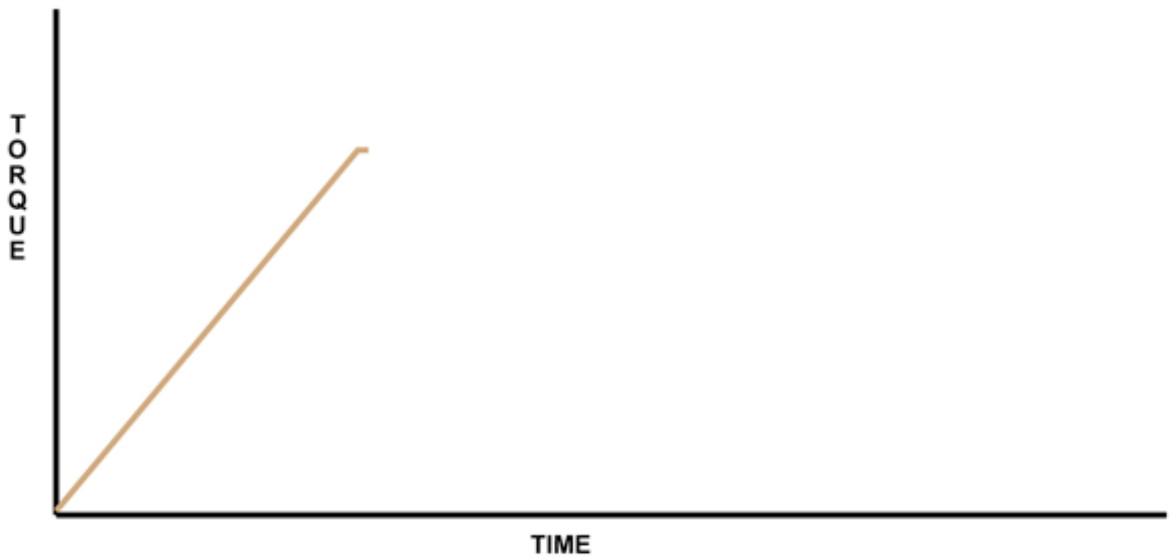
When a fastener is being tightened during installation, the torque is normally dynamic. Whether the installation tool is powered or manual, the fastener is being rotated until the torque control device stops rotating it. The opposite is true in a joint torque audit; the fastener is at rest and motion must be started in order for the torque to be measured.

The need to overcome inertia, to get the fastener to move, contributes to error both in the measurement and in the understanding of the results.

The first diagram here shows torque versus time during fastener installation. The vertical axis is torque and the horizontal axis is time. The first diagram shows the torque rising over time, as occurs during installation.



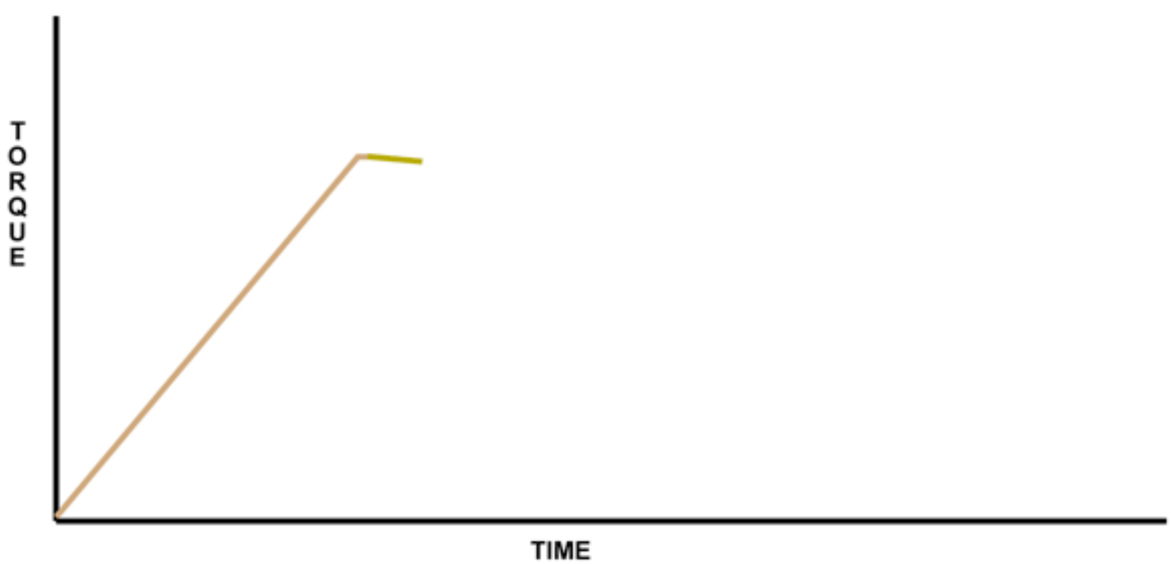
When the torque application tool has attained the specified torque, force stops being applied and the initial preloaded torque is present. This is shown in the diagram immediately below.



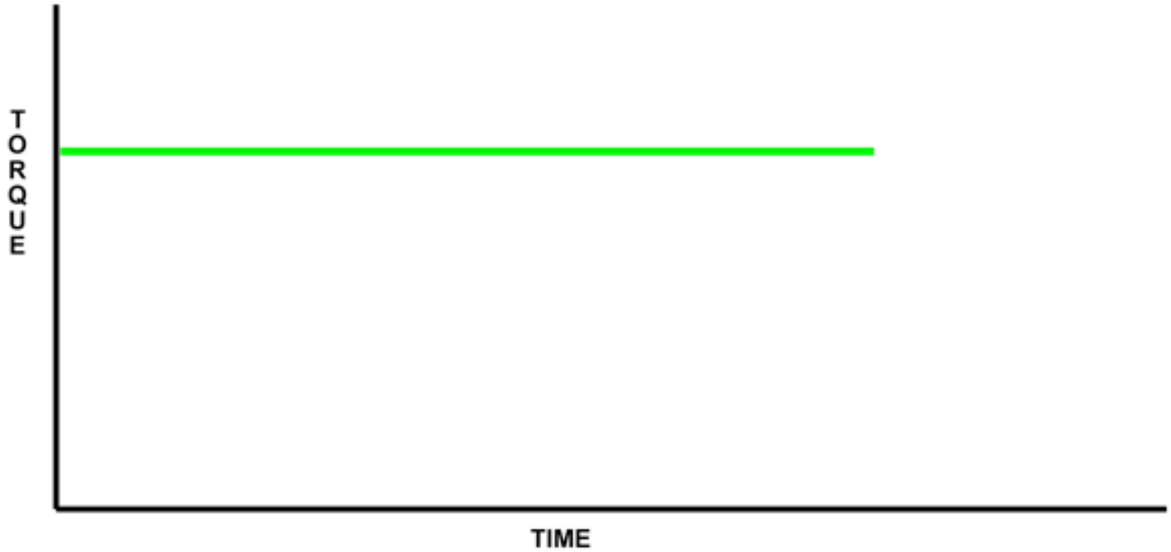
Once force is no longer applied, any joint settling that will occur can begin. The joint settling may be occasioned by any of a number of factors that include, but are not limited to: bolt windup, flow of paint or gasket materials, unevenness of mating surfaces, surface finish of mating surfaces, perpendicularity of bolt/stud shank to underside of bolt/stud head, perpendicularity of grip item(s) to underhead of bolt, bolt/stud installation seating or perpendicularity error.

Joint settling takes time. Even though it may begin immediately (or later, or not at all), the amount of time between the installation and the audit means that inconsistent time between installation and audit may contribute to variation in the joint torque audit results.

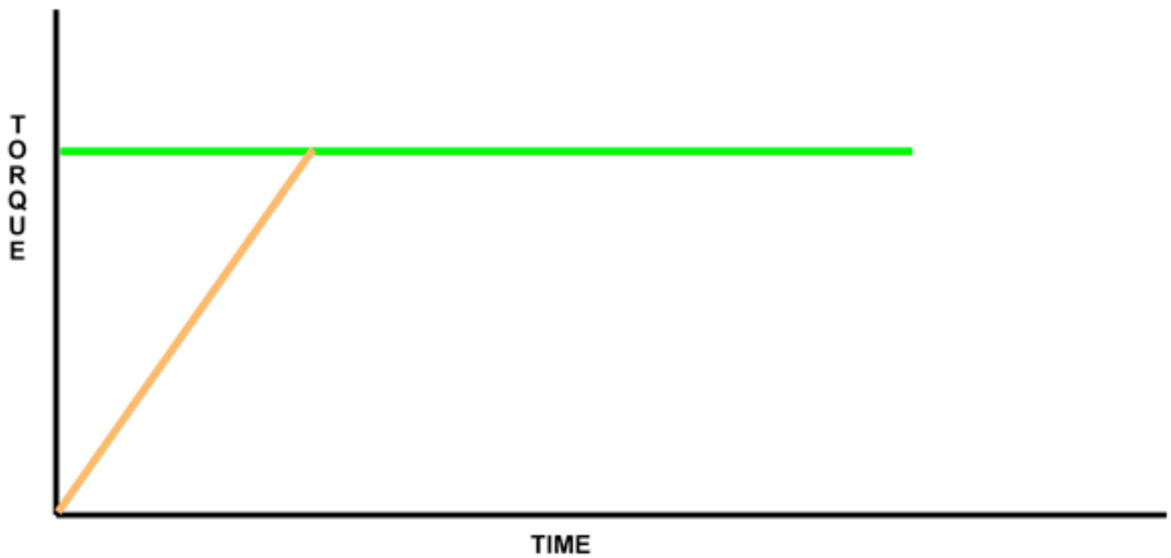
The diagram below shows a slight amount of settling having occurred after installation. This leaves the actual residual torque slightly below the installation torque.



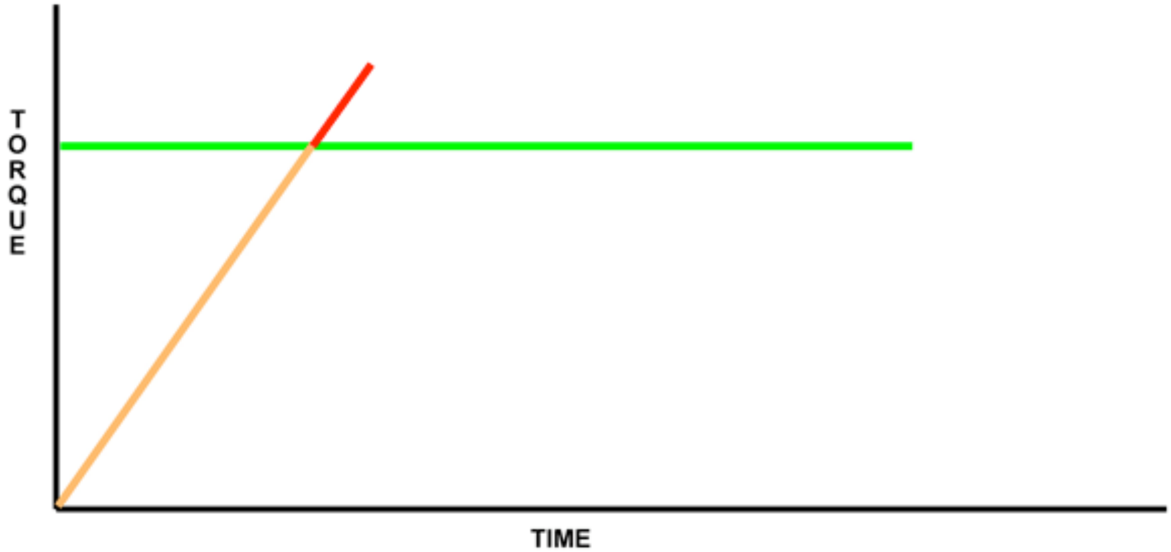
Having established what the actual torque is at the time of the audit, we can now look at what happens during the audit process and some of how measurement error occurs. The diagram immediately below establishes where the actual torque is in the joint with a green horizontal line.



The diagram below shows the beginning of the joint torque audit. Using a standard variable reading torque wrench that detects, or is set to detect, the peak torque. As the auditor begins applying force, the torque reported by the tool rises. The auditor continues applying torque until the actual torque is achieved as shown in this diagram.

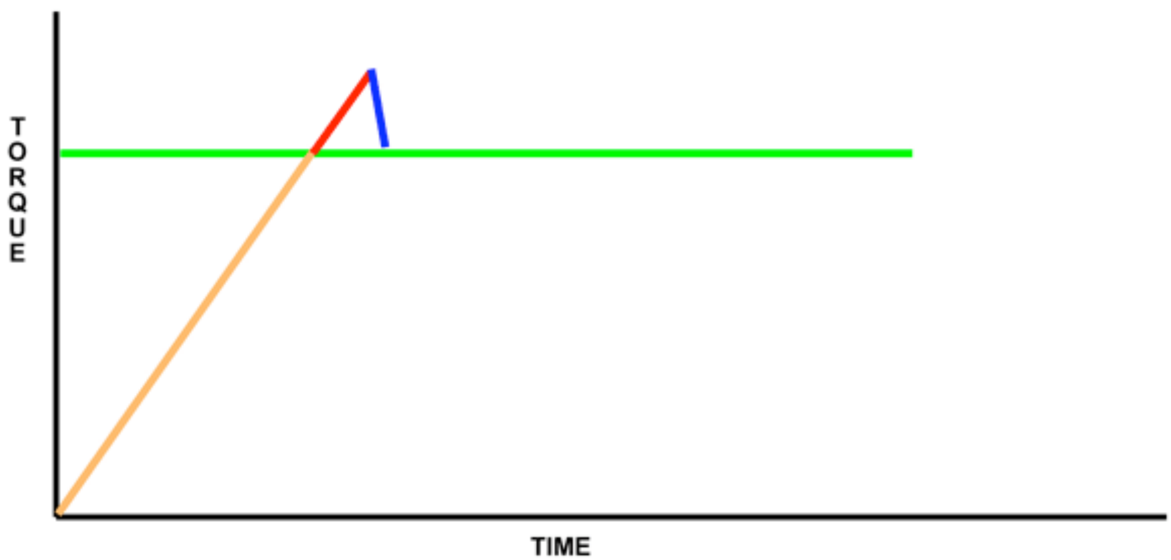


Even though the actual torque has been reached, the force required to overcome inertia – to make the fastener rotate – has not been achieved. This requires additional force – additional torque. This is shown in the next diagram immediately below.

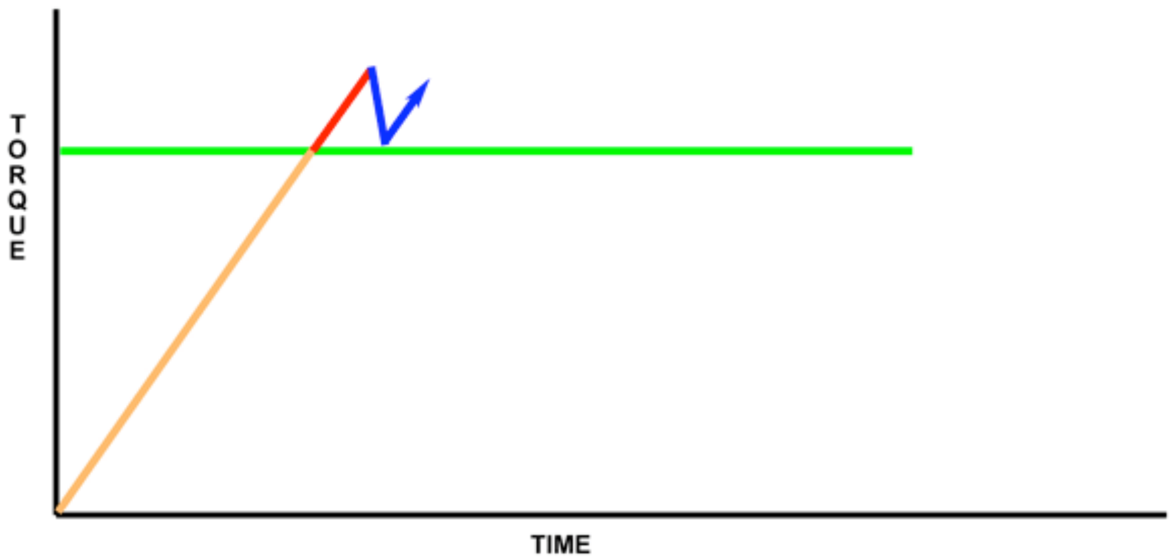


This torque is not the actual torque, but it is the peak torque that will be measured and recorded by the torque wrench during audit IF no other errors enter the process. But it is not what the real torque is. It is the sum of the actual torque and the torque required to overcome inertia – to go from static torque to dynamic torque.

In the transition to dynamic torque the torque actually drops to, or extremely close to, the actual torque. This transition is shown by the blue section of the torque line in the graph below.



If we assume the operator senses the fastener motion and reacts to it very quickly, the installed torque will still be changed by some amount. This is a rise in torque shown by the second blue segment below, and assumes the operator stopped quickly enough that the peak reported by the tool (peak torque finger, pointer, or digits) did not change.



In the scenario just depicted, there is a zone of error that is equal to the difference between the peak torque reported by the torque tool and the actual torque on the joint when the audit was conducted. This error can be substantial and misleading.

In this example we assumed that the operator stopped applying force very quickly when the fastener moved. Yet we know that the auditor's response is a variable, and that the variation can result in an even higher reported value.

A further assumption related to the auditor and audit – a hidden assumption - is that the force was applied steadily so that no torque spike affected the peak torque. An erratic force application, particularly at or very near the point where the static torque transitions to dynamic torque and fastener movement, can increase the error in the reported torque.

We also assumed a minimal amount of joint settling occurred between the time the dynamic torque ceased being applied in the installation process and the audit began was very little. The greater the amount of joint settling, the lower the reported joint audit torque will be. It is entirely possible to have a lower reported audit torque than was actually applied to the joint during assembly. The softer the joint and the more variation in the components within it, the more likely this is to occur.

The Exacta Residual Mode

The existence of the above problems in joint torque auditing led to the development of the Residual Mode for the Exacta line of digital torque wrenches.

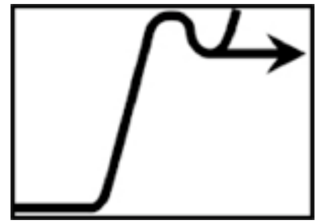
The question posed was straightforward: "Can we reduce the zone of error in joint torque auditing for most of the joints our customers encounter in their assembly operations?"

The answer to this question is a qualified "Yes".

In the Exacta line we use high-speed processors to measure the torque. These processors look at the analog output from the torque transducer many thousands of times per second. Since we know the dynamic of the joint torque audit we were able to develop an algorithm that looks at a string of torque values and compares them to the known pattern of torque for a static joint torque audit after installation.

The residual mode is an algorithm that looks for an increase in torque followed by a rapid dropoff that is followed by a similar rate of increase in torque as occurred prior to the dropoff. It then reports as the residual torque the torque at the bottom of the dropoff before the second rise in torque.

This mode is represented by a symbol that depicts quite well the principle applied to obtain the residual torque value. The symbol is shown to the right.



The reported residual torque value is reported as the value that corresponds to the line with the arrow; the "valley" created by the resumption of dynamic torque in moving the fastener.

The actual algorithm used will not capture the exact residual torque on any joint, except by pure chance. It will, however, reduce the "zone of error" in the joint torque auditing of many or most of the joints our customers audit. The amount of reduction can be quite significant in many audit applications.

It is not possible to store an infinite variety of algorithms on the tool. In fact, we can only keep, store, and use exactly one algorithm. Since most of the joints our customer base audits are hard or fairly hard joints, the algorithm is designed to work best with joints of high hardness (fairly few degrees of rotation to move from 10% to 100% of desired preload).

Even with an algorithm designed primarily for this type of joint, perfect torque detection is not possible. There will still be a small discrepancy between the reported torque and the peak dynamic torque applied during installation.

Joint settling that occurs after the installation process and before the audit process will still affect the audit results. Where a great deal of settling has occurred, the discrepancy between the reported residual torque and the installed dynamic torque can be large enough to cause concern. As a rule of thumb, the softer the joint the more settling is likely to take place and the greater the discrepancy is likely to be.

Another source of variation still lies with the operator. Even though the electronics can sense, measure, compare, and report the torque many times faster than a human being with a different torque wrench can, there are still limits to the capabilities of the tool, and these capabilities can be overwhelmed by incorrect or erratic audit technique.

Erratic force application during the audit will create a rise/fall/rise pattern such as the algorithm uses to determine the residual torque. When this occurs, the tool will report exactly the torque it found, even though the cause was erratic force application instead of fastener movement.

Note that softer joints, such as those including painted components or gasket materials in the grip can also cause this rise/fall/rise pattern to occur when flow of the softer material takes place during the audit. Even a set of components with a rough surface finish can flow or reflow to some degree when the torque rises during the audit process. This is particularly true as the applied torque approaches the actual torque.

It is possible for either the joint or the operator to introduce a discrepancy between the installed torque and the audited torque.

Recommendations

1. Conduct experiments on the actual joints to be audited to determine how closely the Residual Mode will come to the reported dynamic torque from the installation process.
2. Insure the experiments take into account the variables discussed here, particularly those pertinent to joint hardness and joint settling or relaxation.
3. Use the results of the experiments to refine the joint audit process. This may include such refinements as auditor training, audit time windows for the elapsed time between assembly torque application and conducting the audit, and other changes as your data indicates will be beneficial.

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