Quality Assurance
Related to Fastener Torque Requirements

Office of Quality Assurance Programs (EH-31)

Office of Environment, Safety and Health

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1. Summary

This paper presents a case in which improper torque applied to cap screws caused an incipient failure of a support stand for a nuclear safety-related device at a DOE weapons facility. Fortunately, operations personnel observed a symptom soon enough to avoid potential injuries to personnel, damage to the item being supported, or damage to other equipment.

Four additional examples at other DOE facilities and six at commercial Nuclear Power Plant (NPP) facilities are abstracted for cases where fastener torque has been a key subject of a reportable occurrence related to nuclear safety. Details of each of these cases can be read on the Internet by accessing the referenced DOE Occurrence Reporting and Processing System (ORPS) reports and NRC links.

One overall conclusion of these cases is that it is not unusual for root causes of errors to originate with design or engineering. Errors in field maintenance have also occurred but seem to be much less prevalent. In several cases, alertness of construction and maintenance personnel who have exercised a questioning attitude was the action that uncovered a mistaken torque requirement.

This paper points out the importance of the applicability of the QA requirements of DOE O 414.1C and 10CFR830 during design, fabrication, installation, and operation of safety-related equipment and components for the seemingly minor subject of specifying torque values and properly applying torque to fasteners. Additionally, the value of field work practice in accordance with the maintenance order, DOE O 433.1, has been demonstrated as many of these occurrences were uncovered during installation, first use, and maintenance.

2. Overall Lessons Learned

- *Root causes of errors related to fastener torque in many instances originate with design or engineering.*

  A key observation from this set of occurrences is that many of the primary root causes precede the conduct of work in the field. That is, they result from errors in design, engineering, or instructions provided to operators and maintenance workers. This points out that for torque requirements, particularly in the case of new or unique applications, diligence is required by all who are in the chain from initial concept to use in the field.

  Future avoidance of similar errors in design or engineering can be avoided by considering the following by the primary engineer and during design reviews required by QA:

  - **Explicit specification:** While skill of the craft may be sufficient in many designs, nuclear safety-related assemblies and installations should always have explicit torque specifications where loads, structural support, or fluid containing joints are part of the design.
  - **Use of generic drawings and tables:** Use of generic references vs. case-by-case specification can lead to oversights. Many fabrication and construction drawings refer to general reference drawings that have requirements that would be impractical to list on every drawing. Thus, it is important that worker training emphasize the importance of being aware when such reference drawings exist and to use them. A similar practice is providing tables of

torque values and relying on field personnel to interpret the tables. This is accepted practice. However, when the application is nuclear safety-related, regardless of whether the specifications are on a general drawing or in a generic table on the specific drawing, prudent practice would be for the engineer/designer to determine the specific torque requirements and explicitly state them on the drawing or in the procedure being addressed.

- **Translation errors:** Several of the errors in the reviewed examples are a result of improper translation of engineering or manufacturer's torque requirements into installation or assembly procedures. The basic cause has been both lack of understanding and lack of attention to detail. Where fastener torque is a design or procedure requirement, training of reviewers should emphasize that it is not sufficient to only verify that a torque value is present. The value should first be compared with the source document. In addition, if translation has been conducted from general references into a specific value in a procedure or on a drawing, the translation itself should be validated.

- *Errors in field maintenance related to improper fastener torque are less prevalent.*

  While some of the reviewed occurrences occurred in the field, they tended to be caused by subcontracted or new mechanics. This reinforces the need to be especially diligent when workers are new to the job or are not used to working in a safety-related environment and/or the need to be rigorous when safety is vulnerable to improper fastening of components.

  Of course the need to diligently train new workers applies to all field work as well as torquing of fasteners. Section 4.2 DOE G 433.1-1, the guide to the maintenance order, addresses training. Section 4.2.3.4, which discusses on-the-job training, may be particularly appropriate for temporary or subcontracted workers for non safety-related jobs.

- *Alertness of construction and maintenance personnel who have exercised a questioning attitude was the action that uncovered a mistaken torque requirement.*

  In several of the cases examined, an error was discovered because of a questioning attitude by field personnel. The technically complex world of today calls for diligence in being alert to precursors to potential occurrences. Thus, an important lesson from the set of occurrences is that *workers should be challenged to have a questioning attitude when something unusual happens.*

  The concept of a questioning attitude when something does not look or feel right is one of the main themes of an excellent book, which is recommended reading for anyone interested in the safety challenges posed by technology. The book is entitled Inviting Disaster; Lessons from the Edge of Technology, by James R. Chiles; ISBN 0-06-662082-1, Harper Collins, Publisher (http://www.invitingdisaster.com). Examples from this publication can provide good case studies for training.

3. Featured Event of this Paper

ORPS Reference: NA-PS-BWXP-PANTEX-2004-0137

Workers had placed a critical, nuclear safety-related, heavy device into a special stand that rotates the device's position for a radiographic inspection procedure at a weapons program facility. As the technicians started to rotate the unit to a vertical position, they heard an unexpected "pop" after about ten degrees of rotation. After they returned the unit to the horizontal position, a check of the unit stand showed that there was a small amount of movement in a fork-shaped component that was attached with three socket head cap screws to the end of each support arm. The fork-shaped component holds the ends of the lifting and turning fixture firmly in place and supports the heavy device while it is being rotated between horizontal and vertical positions.

A twin unit of the initial stand was visually inspected and then used for the radiographic procedure. Subsequently, it too was found to also have considerable looseness. The three cap screws were found partially backed away from the fully seated position on the twin.

3.1 Investigation Results

At this facility, most of the engineering drawings for special tooling (such as this stand) refer to a general drawing that contains tables of standard torque specifications for various threaded fastener applications. The exceptions are specific cases where individual drawings contain fastener torque requirements and do not refer to the general drawing.

The Production Tooling Support Manager’s investigation found that most craft and inspection shop personnel did not understand that the general drawing should have been used for selecting and applying torque during assembly of tools and fixtures. Fasteners that did not have a listed torque value on the drawings for the special tooling were being tightened using standard hand tools (not torque wrenches) based on the judgment of the individual performing the work. The common practice had been to only use calibrated torque wrenches only when the tool or fixture drawing specified a torque value. There was a widespread lack of awareness that a general drawing was required when the torque value was not specified on a tool or fixture drawing. Consequently, it is safe to assume that fasteners were not properly torqued in many work activities.

In summary, the direct causes of this occurrence were the following:

- The attachment design of the fork component
- The use of skill of craft in tightening the fasteners using hand tools instead of a calibrated torque wrench
- Lack of proper training on the use of the general reference torque drawing by skilled crafts personnel and tooling warehouse personnel
- Failure to question the apparent lack of a specified torque value on the assembly drawing/procedure

3.2 Corrective Actions Taken

The following corrective actions were taken:

- Redesigned of the special stands to correct the reason for the cap screws’ loosening
- Assessed the applicability of the general drawing with torque requirements
- Trained appropriate personnel in the use of the general drawing
- Reviewed the entire special tooling process and all assessments performed over the last five years and provided corrective actions to address any identified concerns.

3.3 Quality Assurance and Integrated Safety Management (ISM) Implications

The occurrence described touches on at least four QA criteria in DOE O 414.1C and 10CFR830:

- Criterion 2 - Personnel Training and Qualification and ISM Principle #3, Competence Commensurate with Responsibility

  Training of personnel responsible for initial assembly and for maintenance of special fixtures and tools should have included the use of general reference drawings. The training requirements should include use of such drawings.

- Criterion 5 - Work Processes; and ISMS Core Function 4, Perform Work within Controls

  Assembly and maintenance procedures should directly include torque specifications when required and avoid the need for those conducting the procedures to search for a drawing or other reference. Prior to assembly of the special stand, craft should review the drawings, notes, and reference drawings; preferably an assembly procedure would exist for a critical component.

- Criterion 6 – Design

  It appears there may have been incompatibility in the mating materials, which if true, should have been discovered when the design was independently reviewed.

- Criterion 8 - Inspection and Acceptance Testing

  For fixtures that have nuclear safety importance, consideration should be given to procedurally requiring verification of critical fastener torque, thread engagement, or other appropriate measures in addition to visual inspection during initial assembly, during subsequent maintenance, and perhaps periodically during use.

3.4 Maintenance Order Implications

The causes of this occurrence are primarily in the areas of design and fabrication. Nevertheless, several aspects of the DOE maintenance order guide, DOE G 433.1-1, speak to this occurrence. Sections 4.5 and 4.6 address maintenance procedures and work management, and Section 4.7 address control of maintenance activities. Specifically applicable are Section 4.6.3.3, which deals with craft skills, and Section 4.6.3.5, which addresses work controls to ensure the operability of safety-related systems, structures, and components.

3.5 Lessons Learned from this Occurrence

The first question to be posed is why was the initial stand used with cap screws without having the correct tightening torque?

- It was assumed the special stand was fully functional because it had been used several times in the facility prior to the occurrence.

  There would have been no real fault by the technicians had the design and assembly been correct because the failure never would have occurred.

- Visual inspection by the QA technicians was all that was required prior to use of the tooling.

  The assembly and maintenance procedures/drawing should have specified torque verification for the cap screws. With regard to use after being turned over to operations, it is not expected that every fastener be checked for proper torque every time a special tool or fixture is used unless specifically called out by procedure. In this case, the operations staff was correct in assuming proper assembly without any other reason to suspect a problem with the first stand.

- Prior to issuing the special stand to the line, the only requirement was a visual comparison of the tool to the drawing to assure proper assembly. Torque or tightness of fasteners was not verified during assembly unless obvious looseness was detected.

  Assembly of nuclear-safety related tools and fixtures should be subjected to rigorous inspection and verification with appropriate hold points before proceeding or final release for field use.

The second question is why was the twin stand used before understanding the cause of the loose fasteners on the initial stand?

- A tooling field engineer and the QA technicians who utilized this tool performed a visual inspection, per the procedure, in which no obvious looseness of the fasteners was detected.

It is human nature to assume that the second stand would not have had a similar problem. Using the twin stand that turned out to also have loose cap screws was a result of not questioning the cause of the problem with the initial unit before using the twin. Therefore, it is important to strongly encourage a questioning attitude when something out of the ordinary happens.

4. Examples of Other Occurrences at DOE Facilities Related to Improper Torque

In addition to the above occurrence, four additional examples of occurrences related to improper fastener torque are abstracted from ORPS reports.

4.1 Mechanic's Failure to Follow Instruction Results in Broken Tie-Rods

ORPS Reference: EM-ORO-MK-WWWRAP-1999-019

Train 2 of the water treatment facility at Weldon Springs was shut down for repairs and modification. Upon startup, a vapor compressor was energized under routine startup procedures. The vapor compressor was then shut down after it was discovered that two tie rods (out of eight) had broken. The rods were found 10 to 30 feet from the compressor.

The direct cause of this event was the failure of a subcontractor mechanic to use a torque wrench for tightening the tie rods and therefore had no means of determining the torque being applied. The mechanic had been directed to torque the tie rod nuts to 80 ft-lbs. Actual field tests later proved the remaining tie rods had torque values from 175 to over 250 ft-lbs.

4.2 Error in Translating Manufacturer's Requirements to Design Drawings Results in Under-Torqued Lifting Rings

ORPS Reference: ORPS EM-RP-CHG-TankFarm-2001-0035

Prior to performing a critical lift on the cover plate of a pump pit, it was discovered that the swivel hoist rings on the cover were undertorqued during initial assembly. The site reference Hoisting and Rigging Manual specifies the bolts are to be tightened to the full torque loading per manufacturer's specification. The swivel hoist rings were actually torqued to 12 ft-lbs and not to the manufacturer's recommended 28 ft-lbs.

The reference design drawing stated that the swivel hoist rings should be installed with Locktite and torqued to 12 ft-lbs. Another reference drawing from vendor Information file contained the same general note as the reference design drawing. However, the manufacturer's specifications required a torque value of 28 ft-lbs. The drawings did not reflect the proper torque value for the installed swivel hoist rings.

The direct cause of this event was determined to be design error. Engineering processes failed to properly address installation of the swivel hoist rings and thus they were not installed using the manufacturer's specified torque.

4.3 Design Error Results in Loose Exhaust Ventilation Joints at a Beryllium Machining Facility

ORPS Reference: DPO-ALO-LA-LANL-SIGMA-2002-0003

A significant percentage of loose bolts were found on a beryllium facility's high velocity vacuum (HVV) process exhaust ventilation ducting system. After a machinist found a loose section of the HVV, subsequent inspection revealed that bolts on several flanges were loose, and further investigation determined that many bolts at the ducting/flange connections were finger loose at several pieces of equipment within the machine shop. It was later determined that approximately 70-80 percent of the flange bolts were hand loose on all small sections of ducting within the beryllium machine shop, and some had backed off to the point that notable gaps could be seen.

The HVV ducting consists of approximately 400-500 linear feet of various sizes of ducting (2-, 4-, and 6-inch ducting in the shops and a 20-inch header) with 40- 60 flanges throughout the facility that connect sections of ducting. Each flange has 4-6 bolts.

Detailed specifications for bolt torque, marking and patterns for torque were not included in the design drawings. The installers used the torque specifications provided by the manufacturer during installation, but there was no requirement to calibrate the torque wrenches, to mark bolts for use in torque to a pattern, or to use a specific pattern for tightening the bolts. Independent verification of bolt tightening was also not required. Acceptance testing was performed using a negative pressure leak test. After this inspection, several bolts along the ducting had to be tightened before the system was accepted as having passed the test.

The lack of a specific torque procedure may have contributed to the occurrence; however, the primary cause was concluded to be incorrect gasket material selection, which called out for the use of 1/8" thick and full-face flat face rubber gaskets per AWWA C110. Raised face flanges were used throughout the system as well as soft rubber gaskets. American Society of Mechanical Engineers (ASME) standard 313, paragraph f, 308.4 states that gasket material not subject to cold flow should be used with raised face flanges. Soft rubber gaskets are subject to cold flow. Some gaskets removed from the exhaust piping were noted to be cupped and creased, which would indicate cold flow.

The original design specifications did not require torque or a torque pattern. However, torque specification for flange connections had not been a standard requirement for this type of system. During the change control process for the modifications made to the exhaust system, reliance was placed on the subcontractor workers' skill of craft for installation detail and the subcontractor did not perform a review of the modifications at the level of detail that may have raised concerns about the lack of torque specifications.

Corrective actions directly on the system included a hand-over-hand inspection of all process exhaust flanges, replacement of all bolts and nuts (locking nuts), and replacement of gaskets with ones of more suitable material. A detailed installation procedure was written for the new materials being installed that required quality assurance checks on torque wrenches and calibration, torque specifications for the new gasket material, and a torque pattern. A quality control checklist was performed after installation of the new materials on 100% of the piping system to ensure bolt torque.

4.4 Incorrect Torque Procedure for Fissile Material Shipping Package

ORPS Reference: EM-SR-WSRC-FBLINE-2003-0006

A requirements review revealed that a procedure specifying torque values for 9975 shipping package closure bolts was incorrect. The procedure specified a torque value of 50 ft-lbs compared to the Safety Analysis Report for Packaging (SARP) requirement of 30 +/- 2 ft-lbs. A follow-up investigation revealed that the incorrect torque value had been applied to 19 packages.

The procedure had been prepared by marking up a similar procedure for DDF-1 containers, which are basically retrofitted 9975s for other uses. The torque value of 50 ft-lbs specified in the procedure for the closure of DDF-1 containers was included in the new procedure instead of the proper value specified in the SARP.

The procedure went through a number of reviews which included Operations, Criticality, Engineering, Material Control and Accountability, and Radiological Control Operations to ensure the technical content was correct. The procedure was also reviewed by shipping and transportation engineering to ensure Department of Transportation requirements were met. Finally, the procedure was routed to members of the Site Packaging Review Committee and the Closure Business Unit Transportation Representative to review 9975 and onsite transfer requirements prior to approval. However, these reviews failed to recognize the fact that the new procedure specified a nominal torque value of 50 ft-lbs as opposed to the

SARP which specifies a torque value of 30 +/- 2 ft-lbs for the closure of 9975 material packaging containers.

5. Examples of QA Issues Related to Improper Torque at Nuclear Power Plants (NPP)

Improper torque has been identified as a basic cause in a variety of safety-related occurrences outside of the DOE. Abstracts of six examples are included here to indicate the wide variety of situations. These accounts have been abstracted and paraphrased from the originals for purposes of this bulletin.

5.1 Main Steam Isolation Valve Failure Caused by Failure to Implement a Known Design Correction

Ref: http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/2003/200300500.html

On November 11, 2002, a boiling water reactor NPP was at 100 percent power. A main steam isolation valve (MSIV) disc separated from its stem allowing the disc/piston assembly to drop into the valve seat. This led to the rapid loss of flow in the "B" Main Steam Line resulting in a steam pressure transient. As a result of increasing reactor pressure, the reactor tripped due to a “Reactor Pressure High” signal. After the reactor trip, all MSIVs automatically closed.

The cause of the event was a deficient MSIV design that did not ensure the proper stem-disc thread loading. Contributors to the failure were marginal thread dimensions and inadequate torque specifications during assembly. Five of eight MSIVS had been modified incorporating an improved design. The failed MSIV had not been modified.

The corrective action taken was the incorporation of a modified stem-to-disc connection on the three remaining unmodified valves.

5.2 Control Rod Drive (CRD) System Inoperable Due To Incorrectly Specified Design Torque Value

Ref: http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/1996/1996841.html

With an NPP in a refueling outage, the plant operator identified that the torque values specified by the vendor for the 3/8-inch hold down bolts for the CRD hydraulic control units (HCUs) exceeded the minimum yield strength of the bolt material. This caused the CRD HCUs to be inoperable because the torque value did not meet seismic qualification requirements for restraining the HCUs during a design basis earthquake. The error was initially recognized by field maintenance staff who questioned why two different bolt diameters had the same torque specification (see root cause below).

There are seven 3/8-inch bolts in each of the 145 CRD HCUs for a total of 1015 bolts. These bolts attach the vendor supplied HCUs to structural steel supports in the containment building which were architect/engineer (A/E) designed.

The reason for the improper torque value was an engineering error in assigning the specification for 1/2-inch hold-down bolts to the 3/8-inch bolts in the same application. The root cause of the occurrence was attributed to a lack of questioning attitude and attention to detail by the A/E when determining the proper bolt torque. Initially questioned by field maintenance staff as to why two different bolt sizes have the same torque specification, the error continued to be present through three subsequent reviews by the A/E and vendor until finally corrected.

5.3 NPP Emergency Diesel Generator Leaking Fuel Line Assembly Due to Lack of a Design Torque Value

Ref: http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/1996/1996712.html

In 1996 a leaking fuel line assembly occurred on the emergency diesel generator at two separate nuclear power plants. It was determined that the leak was caused by the fuel line sleeve coming loose. The diesel generators at both stations were provided by the same vendor.

There were no unusual engine noises, temperature changes, or cylinder firing pressure changes noted prior to the fuel line leak. The operator discovered significant fuel spray emitting from the fuel pump. A root cause investigation determined that the cause was inadequate crimping of the ferrule sleeve onto the fuel line during assembly. In order to establish corrective action, tests were conducted at the owner's metallurgical laboratory to evaluate different torque and tightening values to achieve optimum "crimping" of the ferrule sleeve. It was concluded that the fuel line nut should be tightened 1 1/8-1 1/4 turns past hand tight or 150 ft-lbs of torque to achieve optimum ferrule sleeve crimping. A procedure was revised to incorporate specific tightening values and inspection criteria to ensure proper crimping of the sleeve.

5.4 Incorrect Torque Value in a Procedure and Incorrect Bolting Materials Caused a Mechanical Seal Failure on a River Water Pump

Ref: http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/BV1/bv1_pim.html (look for the third event under "Mitigating Systems")

A maintenance procedure that did not contain appropriate quantitative acceptance criteria (i.e., torque values) for installation of mechanical seals led to seal failure and shaft damage to the one of the river water pumps at an NPP. The failure was caused by incorrect bolting material installed on the mechanical seal package, contrary to approved instructions and drawings, and incorrect torque values that were specified in the work instructions.

This finding is significant because it reduced the availability and reliability of a safety-related pump. Specifically, the seal failure and shaft damage resulted in the unplanned unavailability of the river water pump until repairs were completed. Further, from a reliability perspective, the degraded seal increased the likelihood of failure when the pump would be required to perform its safety function during design basis events, confirmed by its ultimate failure when the pump was placed in service.

5.5 Potential Non Operability of High Amperage Circuit Breaker Due to Over Torquing

Ref: http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/1999/1999511.html

This issue concerned the potential for the malfunction of large circuit breakers at an NPP due to the application of incorrect torque values. This deficiency was identified and determined to be of a chronic reportable nature in approximately October 1999.

The maintenance guidance for this model circuit breaker originally published by the supplier of the circuit breakers contained incorrect torque specifications for circuit breaker arc chute mounting bolts. Specifically, the guidance as originally published was in error by a factor of at least two regarding the DS 206 and by a factor of at least three for the DS 416 when compared to the torque values in procedures used by the OEM factory during fabrication.

The arc chute shields the circuit breaker's components from the electric arc when opened under load. The failure of the arc chute case to maintain its design integrity due to cracking, the potential for the total separation of pieces during a seismic event or normal operation, and their subsequent infiltration of the breaker operating assembly could cause the failure of the breaker. Likewise, failure of an O-ring integral to the bolting assembly could cause the same result.

Contract maintenance and inspection personnel observed the results of this over-torquing during Class I E breaker reconditioning. Multiple instances of longitudinal cracks were observed in the mounting bolt block portion of the arc chute case. In addition, the O-rings used as a capture device for the arc chute mounting bolts were damaged. Pieces of the O-rings were found inside of circuit breakers.

It was recommended that a thorough inspection be conducted with the arc chutes properly torqued into place on this type circuit breakers provided by the same supplier. To be noted was that the cracks may not be visible once the arc chutes have been removed from the breaker. An inspection of the O-rings should also be conducted when removing the arc chute.

5.6 Violation of ANSI Standard Procedure Requirement for UF6 Cylinders Valve Installation Leads to Deviation from the Design Basis Torque

Ref: http://www.nrc.gov/reading-rm/doc-collections/event-status/event/2005/20051027en.html (look for the event for a fuel cycle facility).

This event relates to a failure to follow procedure related to the installation of valves in Uranium Hexafluoride (UF6) cylinders at a facility that provides fuel feed stock for NPP fuel. Torque values were based on assembly per a requisite standard. However, thread engagement when the specified torque was used could have been incorrect as a result of not explicitly following the required standard.

ANSI N14-1 (2001), Uranium Hexafluoride Packaging for Transport, Section 6.14.6 states, "No material of any kind other than the specified solder shall be used on the threads to facilitate installation [of cylinder valves into the UH6 type 48Y cylinders]." Contrary to that standard, maintenance personnel used Teflon spray to facilitate the installation of cylinder valves into type 48Y cylinders. Use of a thread lubricant, such as Teflon, can be expected to *increase the degree the valve threads are engaged for a given torque*. This was discovered when the receiving inspectors at a UF6 conversion facility noted white residue around cylinder valves. Analysis of the residue showed it was Teflon. Interviews with maintenance workers disclosed that Teflon had been used when some cylinder valves were replaced.