ELECTRIC POWER RESEARCH INSTITUTE

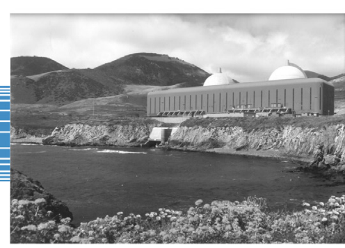
2018 TECHNICAL REPORT

Position Retention Devices Fundamentals

Plant Maintenance Support

Reduced Cost

Equipment Reliability



PORTIONS TRANSLATED

Position Retention Devices Fundamentals

All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

YES NO

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Product Description

This report focuses on position retention devices such as set screws, lock nuts, lock wires, cotter pins, thread locking compounds, and so forth.

Background

Over the years, the Electric Power Research Institute has published various reports that provide guidance on bolting usage.

Objective

The objectives of this study include the following:

- Reduce plant events caused by failure of position retention devices, materials, and methods.
- Provide background material and specific suggestions on methods to install position retention devices and materials.
- Provide methods of troubleshooting instances of failed position retention materials and methods.
- Make available information that should be incorporated into site maintenance procedures, work orders, and training to provide plant personnel with the knowledge to properly assemble position retention materials and methods.

Approach

The report reviews the fundamentals of position retention devices. Throughout the report, Key Points are highlighted, emphasizing the categories: Benchmarking, Cost, Human Performance, Information, Observation, Safety, and Technical. Appendices provide supplemental information, including torque tables.

Results

The report provides maintenance personnel (for example, mechanics, planners, and engineers) with the knowledge to reduce the instances of failures and to install these devices effectively and efficiently. Proper selection and usage guidance of position retention devices make them more effective in preventing loosening, and subsequent equipment reliability conditions.

Applications, Value, and Use

The information provided in the report will aid personnel in preventing and troubleshooting mechanical joint failures.

Position retention device failures are undesirable due to (1) failures creating personnel safety hazards (that is, when fatigue failures occur suddenly and without warning, which can cause direct risk to personnel in the vicinity of the failure) and (2) failures resulting in increased direct and indirect costs, including forced outages resulting from equipment degradation, extended refueling outages, and repair costs.

Keywords

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Product Title: Position Retention Devices Fundamentals

PRIMARY AUDIENCE: Maintenance personnel

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KEY RESEARCH QUESTIONS

What are the standards for anti-movement device materials and installation methods that reduce the instances of failures? How can the information available for anti-movement devices be presented in a format that will prevent future industry events?

RESEARCH OVERVIEW

This report supports the power generation industry by reviewing the events that have occurred and consolidating them into one location with the information and maintenance practices concerning the use of these devices.

An industry technical advisory group consisting of utility subject matter experts was used to guide the development of this research. Best practices from various sources, such as military, industrial, and manufacturing standards, were incorporated into the report.

KEY FINDINGS

- The anti-movement device effect on the Electric Power Research Institute (EPRI) members is greater than identified in a previous analysis of industry events and includes all craft disciplines.
- The risk due to improper practices affects more components than originally considered.
- Lubrication of position retention devices, such as set screws, should generally be avoided when using thread locking compounds.

WHY THIS MATTERS

Reliability of equipment important to safety and generation can be improved by properly securing fasteners, particularly on rotating equipment. Failure to prevent fastener loosening can cause poor reliability and excess unavailability.

HOW TO APPLY RESULTS

Guidance from this report should be incorporated into site maintenance procedures, work orders, and maintenance training (both initial training and continuing training) to improve personnel safety and equipment reliability.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- Besides EPRI members, organizations, such as the Institute of Nuclear Power Operations (INPO) and the World Association of Nuclear Operators (WANO), would be interested in this report as a reference for best practices.

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Section 1: Introduction

1.1 Background

Over the years, the Electric Power Research Institute (EPRI) has published various reports that provide guidance on bolting usage, including the following:

- *Bolted Joint Fundamentals* (1015336)
- *Assembling Bolted Connections Using Spiral-Wound Gaskets: Sealing Technology and Plant Leakage Reduction Series* (TR-111472)
- *Assembling Bolted Connections Using Sheet Gaskets: Sealing Technology and Plant Leakage Reduction Series* (1000922)
- *Assembling Gasketed Flanged Bolted Joints: Update of Report 1015337* (3002008061)

Although position retention devices were noted in the previously mentioned studies (especially 1015336), the technical advisory group (TAG) determined that additional guidance was needed in a separate report due to the following reasons:

- Recent operating experience indicated issues with these devices.
- Guidance for the use of thread locking adhesives was given very limited treatment in previous studies.
- Details concerning the use of improper set screw points needed to be expanded.
- Proper use of securing methods, such as staking and tack welding, was limited.
- Other position retention devices were also given limited treatment.
- There was too much reliance on "skill of the craft" knowledge for these tasks, considering the lack of experienced workers in the industry.

1.2 Report Description

This report provides fundamental information about position retention devices such as set screws, lock nuts, and lock washers used in mechanical joints and applications. It also provides several appendices, including torque tables.

The report applies to position retention devices used in electrical equipment such as limit switch arms, relay arms, switch knobs, flow control knobs, and backlash arms. However, the report does not cover electrical connections, which are the subject of the EPRI study *Electrical Connectors Application Guidelines* (1003471), which primarily addresses electrical conductor connections. A review of operating experience (see Section 6) revealed that position retention device problems affect mechanical, electrical, and instrument and control equipment.

1.3 Glossary of Terms

Rc (Hardness on Rockwell C scale). A hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. See ASTM-E18 (ASTM International [formerly the American Society for Testing and Materials]) for further details.

1.4 Acronyms

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	ASTM International (formerly, American Society for Testing and Materials)
CW	Cold worked
EPRI	Electric Power Research Institute
ICES®	INPO Consolidated Events Database
IER	Industry Event Report
INPO	Institute of Nuclear Power Operations
NAS	National Aerospace Standard
NASA	National Aeronautics and Space Administration
NMAC	Nuclear Maintenance Applications Center
Rc	Rockwell C scale
TAG	Technical advisory group
UNC	Unified National Coarse
UNF	Unified National Fine
WANO	World Association of Nuclear Operators

1.5 Highlighting of Key Points

Throughout the report, key information is summarized in “Key Points.” Key Points succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to take action for the benefit of their plant. The information included in the Key Points was selected by NMAC personnel, consultants, and utility personnel who prepared and reviewed the report.

The Key Points are organized according to seven categories: Benchmarking, Cost, Human Performance, Information, Observation, Safety, and Technical. Each category has an identifying icon to draw attention to it when quickly reviewing the report.

Appendix A Key Points contains a listing of all key information in each category. The listing restates each Key Point and provides a reference to its location in the body of the report. By reviewing this listing, readers can determine whether they have taken advantage of key information that the writers of the report believe would benefit their plants.

Section 2: Position Retention Fundamentals

2.1 Introduction

To properly select and use methods and products to maintain position retention, it is helpful to explore the reasons that fasteners loosen. Concepts such as friction, relative motion due to vibration, load directions, material properties, thermal expansion and contraction, and other concepts should be considered.

2.2 Why Fasteners Loosen

There are several theories as to why fasteners loosen, and it is believed that there is some validity to most of them. The report is not intended to explain all of them.

Fastener threads do not just "unscrew" unless a force is applied; a threaded fastener will not loosen unless the frictional forces that exist between the male and female threads are reduced or eliminated by some external force acting on the fastener and joint. The force causing friction between the threads is directly proportional to the fastener tension times the frictional coefficient between the threads. Some relaxation occurs after initial tightening, particularly in the first hour after initial tightening. For important applications, retightening after an hour can restore much of the initial bolt tension and resulting frictional force. Besides this phenomenon, most loosening occurs primarily due to relative motion between the threads.

Key Technical Point
Joints loaded in shear tend to loosen more than joints loaded in tension.

Joints loaded in shear tend to loosen more than joints loaded in tension because the shear loading is acting in the same plane as the frictional load resisting loosening. Forces such as vibration acting axially to the fastener may cause a reduction in tension of the fasteners causing loosening of the joint of 30%–40% over a long period of time but will not usually cause complete loosening. On the other hand, shear forces resulting from external forces (for example, vibration) acting normally to the fastener (in shear) may cause a complete loss of preload. Therefore, most position retention devices are intended to resist shear forces. (See Figures 2-1 and 2-2.)

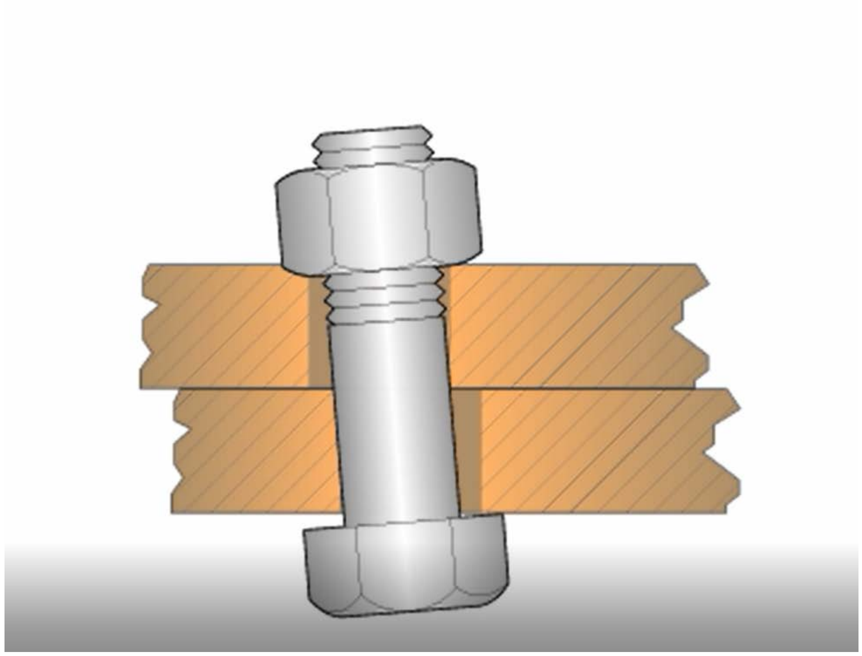


Figure 2-1
Example 1 of the process by which fasteners loosen

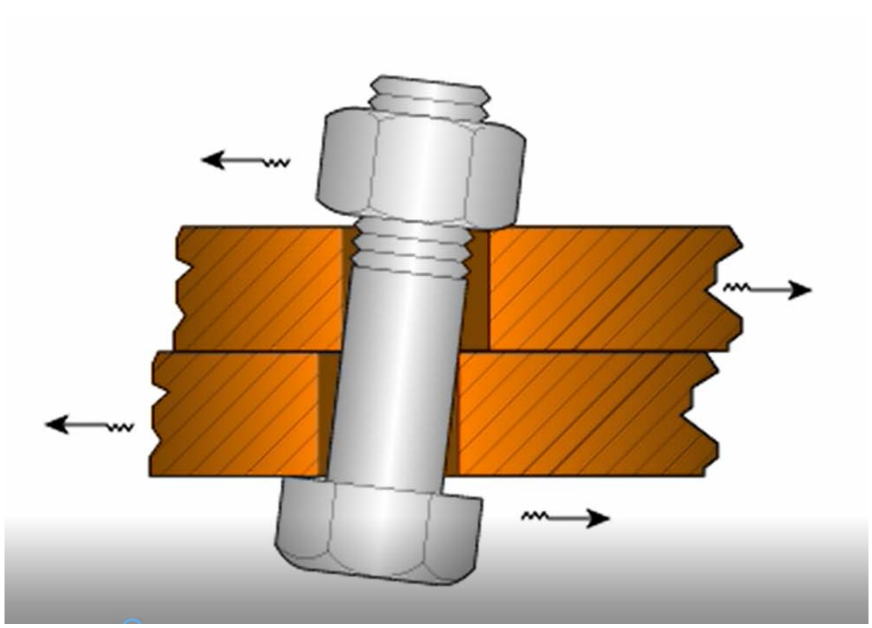


Figure 2-2
Example 2 of the process by which fasteners loosen

The standard threads typically encountered in fasteners (for example, Unified National Coarse [UNC], Unified National Fine [UNF], Metric) are designed so that some of the threads deform and come in contact to resist loosening, especially for relatively static joints. In cases where there is vibration or fluctuating loads, position retention devices are sometimes used to reduce the tendency to loosen.

When attempting to reduce loosening, it is helpful to know about the forces and environment that the equipment will experience. Parameters should be determined and discussed with vendors providing position retention devices or personnel specifying position retention methods. Such parameters include the following:

- Vibration direction (axial, torsional, radial)
- Vibration measures (frequency or frequencies, amplitude)
- Temperature absolutes and variations
- Relative motion between machine elements
- Material properties (hardness, finish, and so forth)
- Start–stop frequency

2.3 Principles Used to Prevent Loosening

2.3.1 Pressure-Retaining Joints

Key Technical Point
Lowering of fastener friction using lubrication is frequently used for fluid-retaining joints such as pipe flanges, valve bonnets, pump casings, and so forth, but can prevent thread locking compounds from working effectively; therefore, this method is not generally recommended for joints involving power transmission.

For pressure-retaining joints, the most common method to prevent loosening is to prevent loss of preload in the fastener (or fastener tension).

Fastener preload produces a high frictional force in the threads and nut faces, which prevent torque from transferring to the fastener tension. Methods such as lubrication are used to reduce friction allowing more torque to be transferred to the fastener tension.

Although using lubricants may prevent thread locking compounds from working effectively (see Section 4.2, Adhesives/Thread Locking Compounds), this method of preventing loosening is commonly used and usually recommended for pressure-retaining joints because this preload also produces gasket compressive load, which is important to good gasket performance.

2.3.2 Nonpressure-Retaining Joints

For nonpressure-retaining joints, particularly those subject to cyclic loads such as vibration, common methods to prevent loosening are as follows:

- Increase the coefficient of friction of thread or other surfaces by plating parts and avoiding lubricants. (See Section 3.1.11 for types of plating.)
- Introduce vibration damping by using nylon inserts in bolt or nut threads on prevailing torque lock nuts (for example, nylon nuts).

- Mechanically prevent losses of preload using products designed to do this.
- Counter the back-off torque. This is accomplished by such items as prevailing torque nuts or lock and toothed washers.
- Resist transverse slip by using joints designed to mechanically resist slip. Figure 2-3 illustrates effective designs to resist transverse slip. The bottom image in Figure 2-3 is a toothed shear washer.

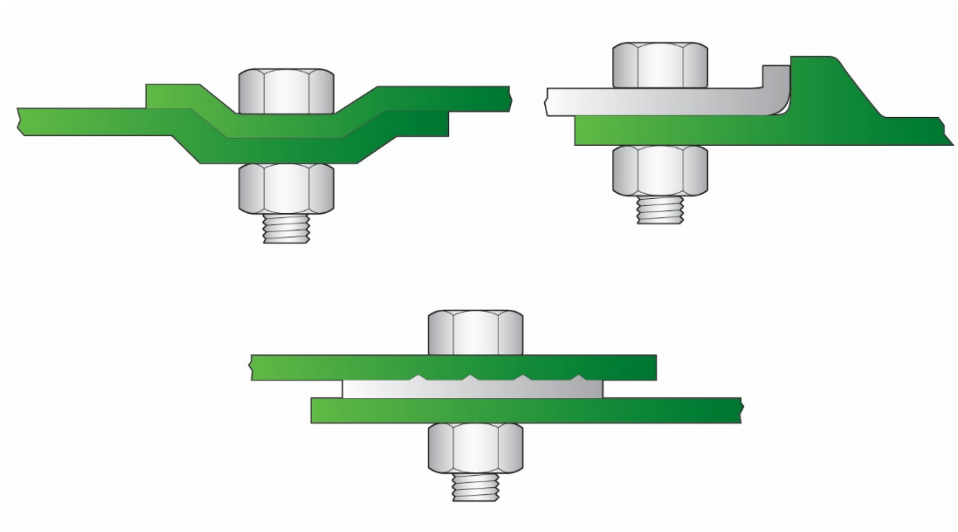


Figure 2-3
Resist transverse slip method

In his book, *An Introduction to the Design and Behavior of Bolted Joints* (1995), John Bickford provides a table of relative performance of various types of 0.375-in. (9.53-mm) – 16 locking fasteners, shown in Table 2-1.

Table 2-1
Relative performance of various types of 0.375-in. (9.53-mm) – 16 locking fasteners [1]

Type of Fastener	Percentage of Initial Load Retained
Serrated locking screw	85
Anaerobic adhesive	85
All-metal locking screw	50
Epoxy locking screw	45
Patch-type locking screw	30
Prevailing torque nut	30

Key Technical Point
Mechanically locked washers may be better than any of the vibration resistant nuts in this listing.

Bickford also provided a table of typical vibration performance of various types of vibration resistant nuts used as the basis for Table 2-2.

Table 2-2
Typical vibration performance of various types of vibration resistant nuts

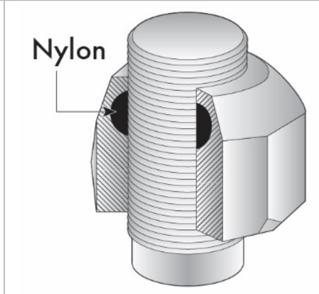
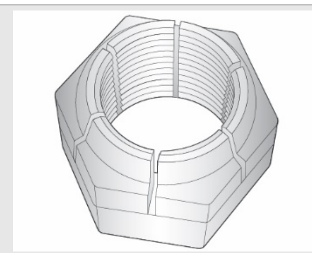
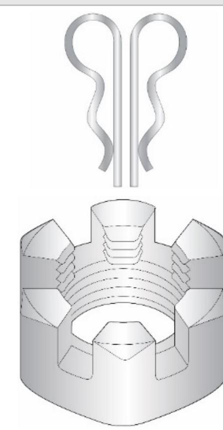
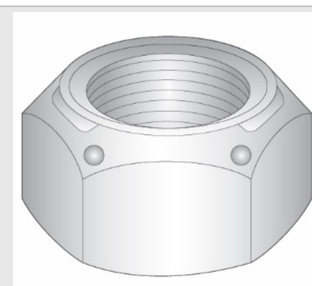
Type of Nut	Relative Number of Cycles Required to Shake a Nut from a Bolt	Figure
Nut with locking ring of nylon	100	
Beam-type self-locking nut, aircraft	53	
Castellated nut and spring key	38	
Distorted thread nut	19	

Table 2-2 (continued)
Typical vibration performance of various types of vibration resistant nuts

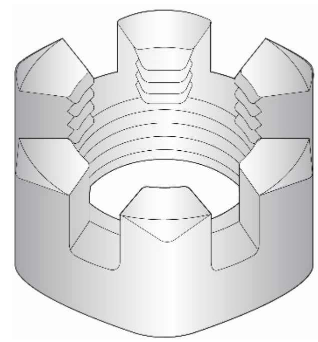
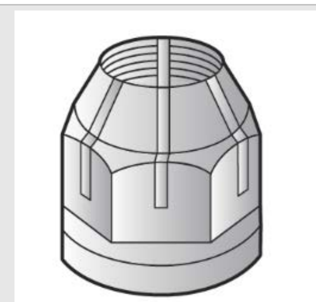
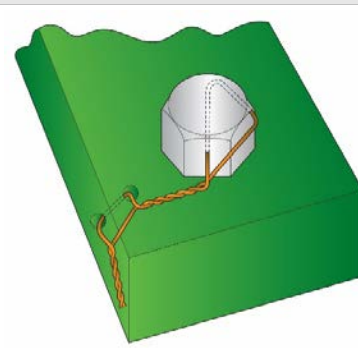
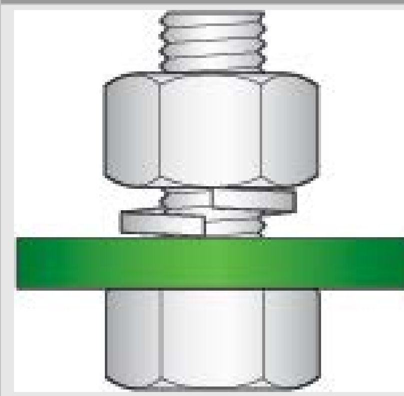
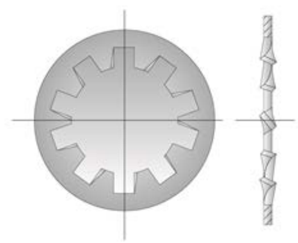
Type of Nut	Relative Number of Cycles Required to Shake a Nut from a Bolt	Figure
Castellated nut and cotter key	18	 
Beam-type self-locking nut, commercial	4-17	
Castellated nut and lock wire	8	

Table 2-2 (continued)
Typical vibration performance of various types of vibration resistant nuts

Type of Nut	Relative Number of Cycles Required to Shake a Nut from a Bolt	Figure
Plain nut and spring-type lock washer	5	
Plain nut, with or without tooth-type lock washer	1	

Note that, according to Bickford, the disc-lock nut discussed in Section 3.6.7, Mechanically Locked Washers, may be better than any of the vibration resistant nuts in this listing.

Other fundamental methods of locking fasteners are to use physical methods to prevent rotation such as lock wires, pins, and welding.

Section 3: Types of Position Retention Devices

3.1 Set Screws

A set screw is a fastener that is used to secure a device such as a collar, sleeve, or gear to a shaft. Note that this report will use the collar as the example in future text, unless otherwise indicated.

In contrast to other fastening devices, the set screw is primarily a device that provides a strong radial force to a shaft so that the frictional force between the set screw point and shaft is sufficient to prevent slippage. This is accomplished from either the set screw point deforming the shaft causing an interference fit—or, if using the dog or half-dog point, extending into a hole drilled into the shaft causing it to rotate with the shaft due to the shear strength of the set screw.

Set screws are usually made of alloy steel and case hardened to be able to penetrate materials as well as for longer life. Hardened set screws often leave a plastic deformation in the form of a circular or semicircular mark in the shaft that the screw sets against. This has both advantages and disadvantages. An advantage is that such deformation increases the holding power (torque resistance) of the joint as the screw is essentially “making its own detent” on a small but effective scale. A disadvantage is that, if the goal is to have a blemish-free cosmetic finish on the part being set against, actions must be taken to prevent the circular marks. However, in most set screw applications, this consideration is irrelevant. Another con is that this plastic deformation can cause corresponding high points in the shaft surrounding the circular mark. This can result in difficulties during disassembly if a bearing or other tightly tolerance part needs to slide past this area. Use of a flat mitigates this problem. (See Section 3.1.14, Other Considerations for Set Screws.)

Failures, such as collars spinning on shafts, are often caused by the improper selection, design, and application of set screws. The proper set screw for an application is selected and categorized based on the size, point style, and material (including hardness) that will provide the required holding power. Appendix B illustrates basic point styles for set screws. Selection is based on factors such as the type of driver used, dimensional and clearance constraints, weight savings, safety, and appearance.

3.1.1 Size Selection

Screw size selection is based on the holding power required for an application.

3.1.1.1 Joints Using Frictional Forces

Figure 3-1 is a typical shaft and collar assembly in which the force (F) developed by the cup face on the shaft because of tightening produces an equal, reactive force (F1). This clamping action results in two frictional forces, one between the shaft and the collar (F2) and the other between the shaft and the point (F3). These frictional forces provide most of the resistance to relative axial and torsional movements of the parts.

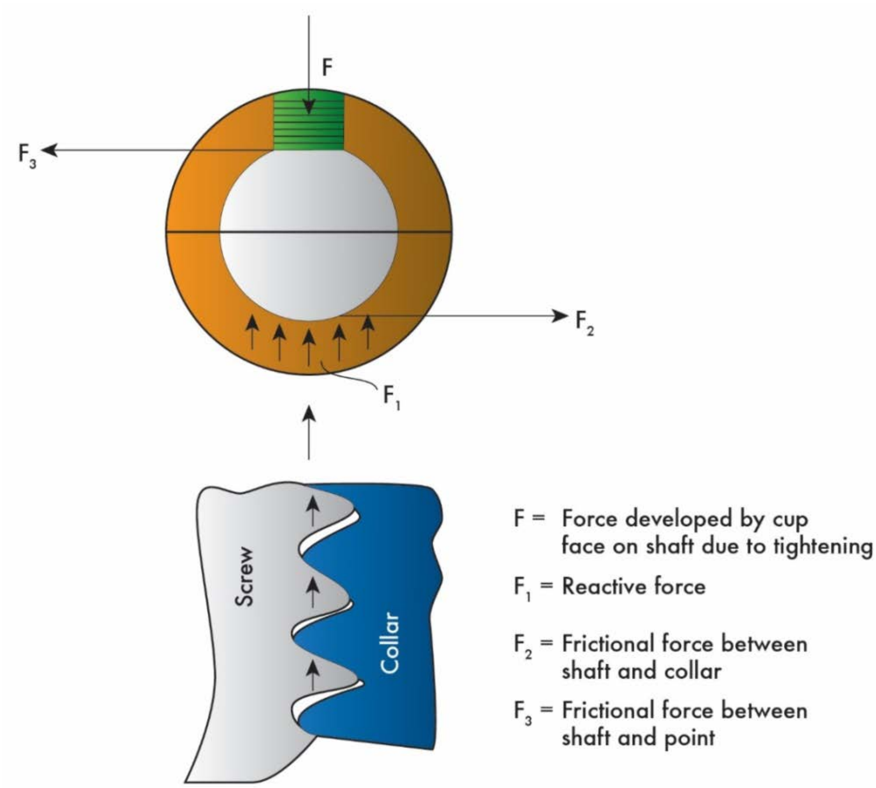


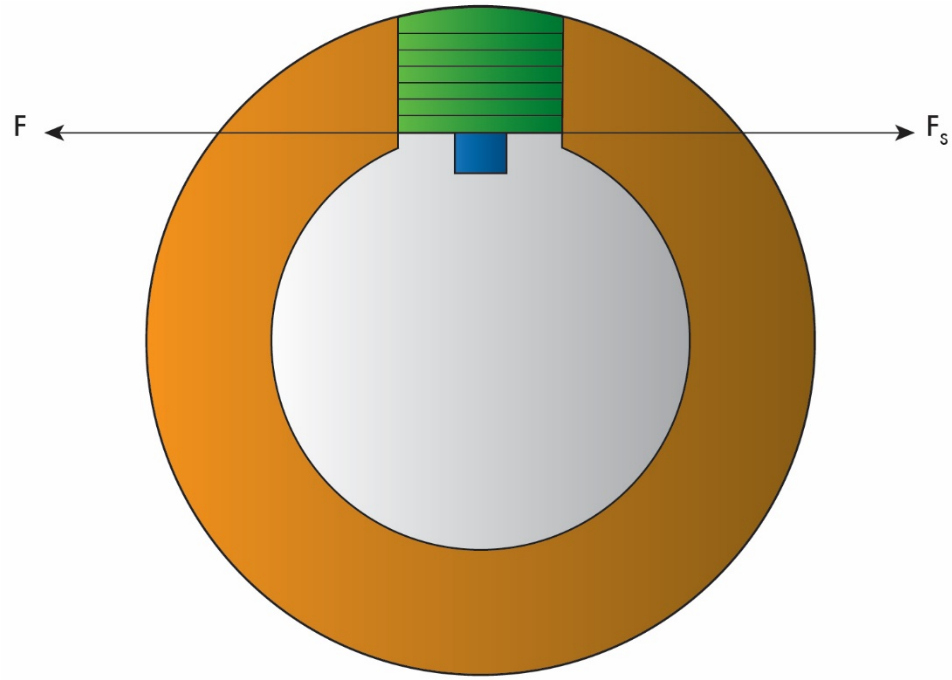
Figure 3-1
Shaft and collar assembly

The magnitude of the force is the principal factor in determining the axial holding power of the set screw or the resistance of the assembly to relative movement along the longitudinal axis of the shaft. Some additional load resistance is developed by the penetration of cone points into the shaft.

The torsional holding power of the set screw is determined by multiplying the axial holding power by the shaft radius.

3.1.1.2 Joints Using Shear Forces

For full dog or half dog set screws, the resistance to motion is due to the shear strength of the set screw. This is shown in Figure 3-2 below.



$F =$ Force by the Shaft Trying to Move the Collar

$F_s =$ Shear Force Developed by the Set Screw

$d =$ Diameter of Set Screw "dog"

$\tau =$ Shear Stress

$$\tau = \frac{4F}{\pi d^2}$$

Figure 3-2
Shear strength of a full dog or half dog set screw

Key Technical Point

Engineers often use a general rule that states that the diameter of a hollow set screw (hexagon, fluted, or spline socket) is equal to approximately one-quarter to one-half the diameter of the shaft. However, the range of usefulness of this rule is limited.

Engineers often use a general rule that states that the diameter of a hollow set screw (hexagon, fluted, or spline socket) is equal to approximately one-quarter to one-half the diameter of the shaft. However, the range of usefulness of this rule is limited. Appendix C (English units) and Appendix D (SI units), which were developed from experimental data for cup point set screws, provide guides for the proper sizing of set screws. Although they were developed for a specific set screw form and point style, the values given in the table can be modified to provide design data for many other forms and point styles of set screws using factors provided in Appendix B.

3.1.2 Load Type

A consideration for the size and point type of the set screw also depends on the type of loads expected to be encountered. The four major types of loads are as follows:

- **Minimal load.** The set screw is holding a collar that is not expected to see much load either axially or radially. An application of this type might be an idler pulley where there is no load transmitted by the shaft to the collar, but the set screw is merely trying to keep the pulley in the correct axial position. In some cases, an easy adjustment may be desired so a point type, such as the oval point, might be used because it causes minimal damage to the shaft and set screw and can be easily loosened and retightened.
- **Axial load.** There is a force trying to push the collar axially along the shaft. Loads such as these might be intentional to transmit motion or unintentional, which might be caused by a pulley on a belt drive that is not perfectly aligned.
- **Rotational load.** There is a force trying to transmit motion from a shaft to the collar. This is a very common load and might secure a drive pulley, bearing, fan hub, and so forth.
- **Combination load.** There may be a combination of the axial and rotational load that should be taken into consideration.

Also consider whether the load is shock loading (sudden starting and loading) or starts gradually. Shock loads create higher instantaneous loads and require a stronger joint.

Key Technical Point

The set screw material should be at least 10 Rockwell C scale points harder than the material that it is attempting to penetrate.

3.1.3 Material Selection

Shaft material and hardness are considerations when determining set screw material selection. The set screw should be harder than the shaft in cases where point penetration is desired, such as with cone point and cup point set screws. The set screw material hardness should be at least 10 Rockwell C scale points harder than the material that it is attempting to penetrate.

3.1.4 Seating Torque

Experiments have shown that torsional resistance power is approximately and directly proportional to the seating torques for cup, flat, and oval point set screws. Figure 3-3 illustrates torsional holding power as a function of seating torque for a 0.3125-in. (7.94-mm) diameter knurled cup point screw seated against a 1-in. (25.4-mm) diameter shaft with a hardness of RC15. A 50% increase in the seating torque increases the holding power of a set screw by 50%, within the strength limits of the assembly.

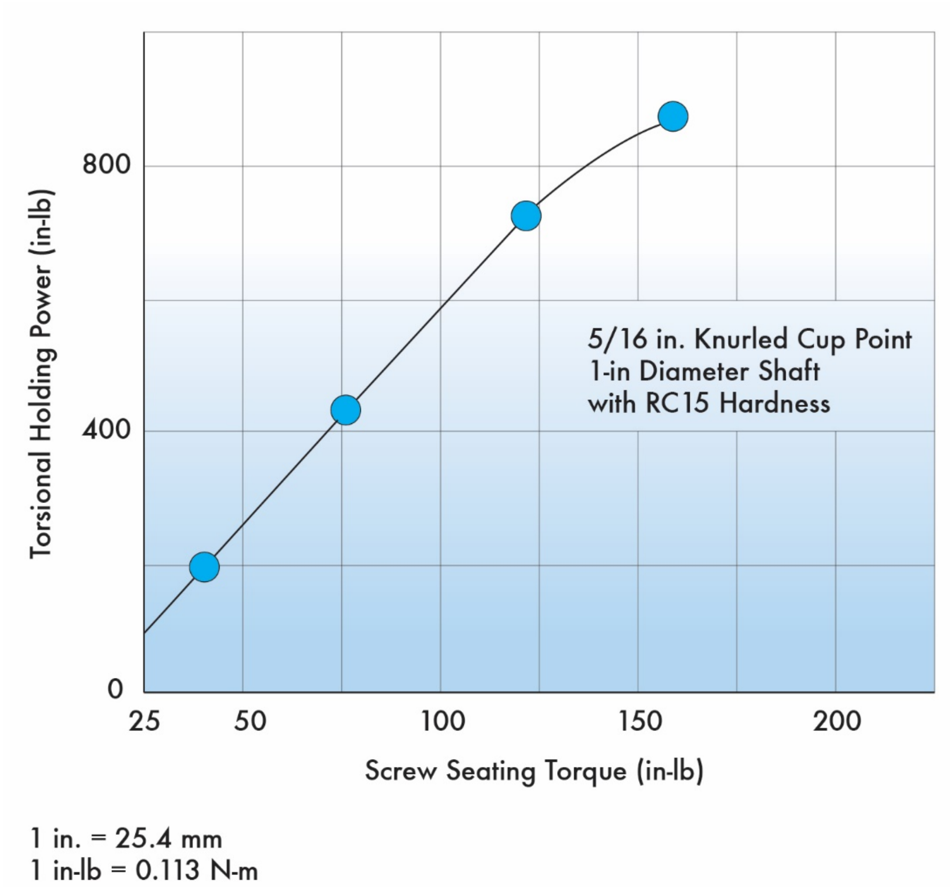
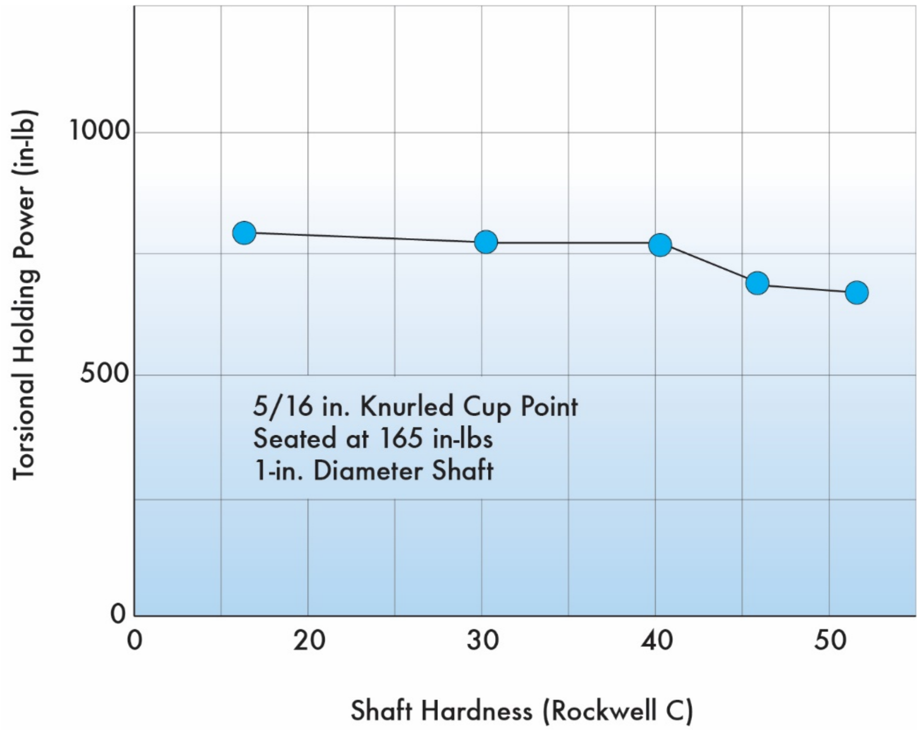


Figure 3-3
A screw seating torque/torsional holding power curve versus a torque curve [2]

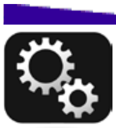
3.1.5 Relative Hardness

Figure 3-4 shows holding resistance as a function of shaft hardness using a hard (RC50) knurled cup point set screw seated at 165 in-lb (18.65 N-m). Notice that the holding resistance decreases as the shaft hardness approaches the screw hardness.



1 in. = 25.4 mm
1 in-lb = 0.113 N-m

Figure 3-4
A screw seating torque/torsional holding power curve versus a shaft hardness curve



Key Technical Point
Thread locking compounds that are resistant to lubricants should be considered in oily environments where fasteners might tend to develop slippage.

Corrosion-resistant materials or coatings should be considered in high moisture or corrosive environments.

Environmental impacts on torsional holding power that should be considered are as follows:

- Extreme temperature changes, which might cause dimensional changes between the elements being fastened.
- Oily environments in which fasteners might tend to develop slippage; consider thread locking compounds that are resistant to lubricants.
- High moisture environments, which might tend to lose material due to corrosion; consider corrosion-resistant materials or coatings.

3.1.6 Point Style Holding Power

The penetration of a hollow point set screw (such as a cup point) provides as much as 15% of the total holding power of the screw. The increased holding power of a cone point set screw, which contains neither a spotting hole nor a predrilled hole in the shaft, is a result of the point's deep penetration. The oval point set screw has less contact area; therefore, it provides a smaller increase in holding power.

The axial holding power data given in Appendix C (English units) and Appendix D (SI units) can be applied to various set screw point styles by multiplying the values given for cup point set screws in Appendix B.

The values given in Appendix C (English units) and Appendix D (SI units) were obtained based on the assumption that the point of the screw is not specially reset into the shaft and that the penetration results solely from tightening. For example, a dog point set screw that is seated in a hole drilled in a shaft acts as a pin only. Therefore, the holding power is not obtained from Appendix C (English units) or Appendix D (SI units); rather, it is determined by the shear strength of the screw material, for example, in Appendix B.

Figure 3-5 shows the impressions or “divots” left by various set screws in a laboratory experiment. On the far left is a divot left by a set screw that is too large for the shaft. Only minimal impressions appear at the top and the bottom of the picture because the set screw cannot dig in properly. This set screw will likely loosen easily.

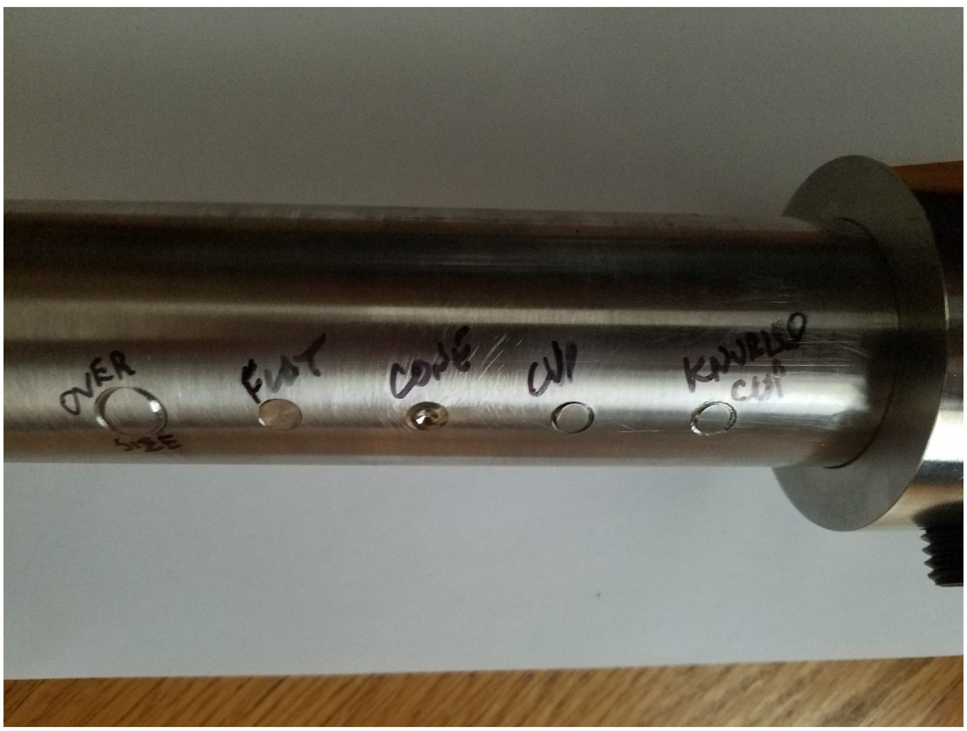


Figure 3-5
Comparison of impressions left by various set screws in a laboratory experiment

The remaining divots (from left to right) are for properly sized flat, cone, cup, and knurled cup point set screws. One should look for this type of divot indicating proper torquing of the screw.

3.1.7 Length of Thread Engagement

Key Technical Point
If sufficient engagement is available to prevent stripping in the tightening process, the length of the thread engagement has no noticeable effect on axial and torsional holding power.

If sufficient engagement is available to prevent stripping in the tightening process, the length of the thread engagement has no noticeable effect on axial and torsional holding power. The length of engagement depends on such factors as the amount of applied load, type of material, type of thread, and screw diameter. In most cases, the minimum recommended length of engagement is equal to the diameter of the set screw. If staking of the set screw is desired, the set screw length should be long enough to allow proper staking (see Section 4.4). This length typically permits the development of recommended seating torques without the danger of thread stripping. The tabulated values of seating torque in Appendix B and Figure 3-6 were developed under the assumption that the engagement length is sufficient to prevent stripping. Figure 3-6, which illustrates the standard set screw head styles, amplifies this concept. Each style is discussed.

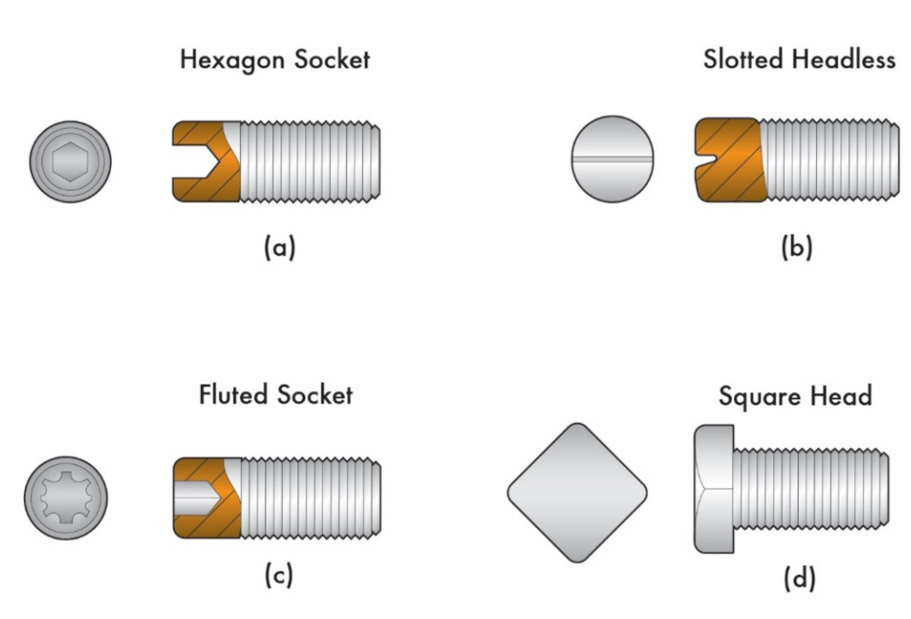


Figure 3-6
Set screw standard head styles

3.1.8 Thread Type

Experimental results indicate that coarse and fine threads of the same class of fit perform very similarly. Consequently, the values given in Appendix B apply to either thread type. If thread pitch were the only factor, to obtain the same "point loading," a fine thread would need a lower tightening torque than a coarse thread. However, the fastener loading is governed more by friction between the male and female threads and the friction between the nut/bolt head or set screw ends than the loading due to the inclined plane of the threads.

3.1.9 Type of Driver

The torsional holding power values given in Appendix B apply to socket-type set screws. However, the values also apply to all set screws, provided that the indicated seating torque is developed. Although the type of the tool used to drive the screw has no direct bearing on the holding power, it does influence the amount of seating torque that can be attained. The following example illustrates this concept.

For the slotted set screw, the maximum seating torque is that which can be developed by a screwdriver. Deformation of the screw slot occurs at a torque that is much less than the torque that will strip the threads.

Similarly, the maximum torque that can be applied to socket or head set screws is also lower than the torque that will strip the threads. However, it is higher than the torque that can be developed by a screwdriver. Consequently, the torque that can be applied is a function of the driver.

3.1.9.1 Hex Head Set Screws

Hex head set screws are the most common head types and are frequently encountered in machine elements. Hex keys are readily available in English and metric sizes. There is much variation in tool strength as discussed in Section 3.1.13.

3.1.9.2 Fluted (or Torx[1])

Fluted (or Torx) is often used due to its resistance to tool "stripping" of the head and tends to be more tamper-resistant due to the need for a more unusual tool. The tools are more expensive than standard screwdrivers, hex keys, and standard wrenches but are available in various sizes.

3.1.9.3 Slotted

Slotted heads are the least expensive to manufacture but are subject to stripping. Standard flat blade screwdrivers are used to tighten or loosen them.

[1]Torx is a registered trademark of the Camcar Corp. division of Textron Inds.

Key Technical Point
The maximum torque that can be applied is greater with square-head set screws because the screws can be tightened with a wrench more easily until the threads strip or the screw fails in torsional shear; therefore, caution is highly recommended with square heads.

3.1.9.4 Square-Head Set Screws

Square-head set screws can be tightened with a wrench more easily due to the ability to use a heavy wrench versus hex keys, screwdrivers, or Torx drivers. This can cause the threads to strip or the screw to fail in torsional shear. Table 3-1 lists typical maximum installation torques for square head set screws.

Table 3-1
Recommended maximum tightening torque for square-head set screws

Screw Size		Maximum Recommended Tightening Torques	
in.	**mm**	**in.-lb**	**N-m**
1/4	6.35	212	24
5/16	7.94	240	27
3/8	9.53	828	93
7/16	11.11	1344	152
1/2	12.70	2100	237
5/8	15.88	4248	480
3/4	19.05	7704	870

3.1.10 Number of Set Screws

Contrary to intuition, the holding power of two set screws is not maximized when the set screws are at 90° or 180°. The torsional and axial holding powers are increased by approximately 30% when a second set screw is installed diametrically opposed to the first screw. The holding powers are approximately doubled, however, when the second screw is installed in an axial line with the first screw.

Figure 3-7 illustrates the relationship of the angle between the two screws and the total holding power. The optimum displacement for two screws installed on the same circumferential line is 60˚. This displacement is recommended as a compromise between maximum holding power and minimum metal between tapped holes. A 60˚ displacement provides 1.75 times the holding power of a single screw.

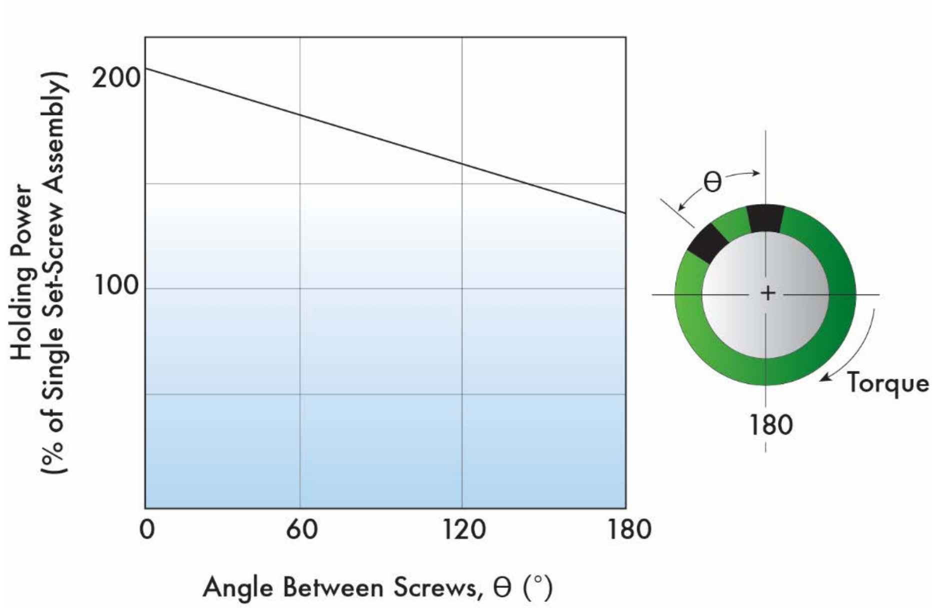


Figure 3-7
Angle between two screws and the total holding power

3.1.11 Type of Plating

A soft plating such as cadmium or zinc increases the holding power by 5%–10% for a given tightening torque. The plating acts as a lubricant, resulting in an increase in preload. A comparable increase can be achieved by using a thread lubricant, but lubricant is generally not recommended if using a thread locking compound. Set screws can also be plated to inhibit corrosion.

3.1.12 Double Set Screw Use

It is common and accepted practice in the industry to install a set screw without a thread locker, and then install another set screw known as a “grub” screw with a thread locker on top of the top set screw (when space permits). The point of the grub screw is machined flat to prevent damage to the top (usually an Allen head) of the set screw. This is a very effective method of locking the bottom set screw, as shown in Figure 3-8.

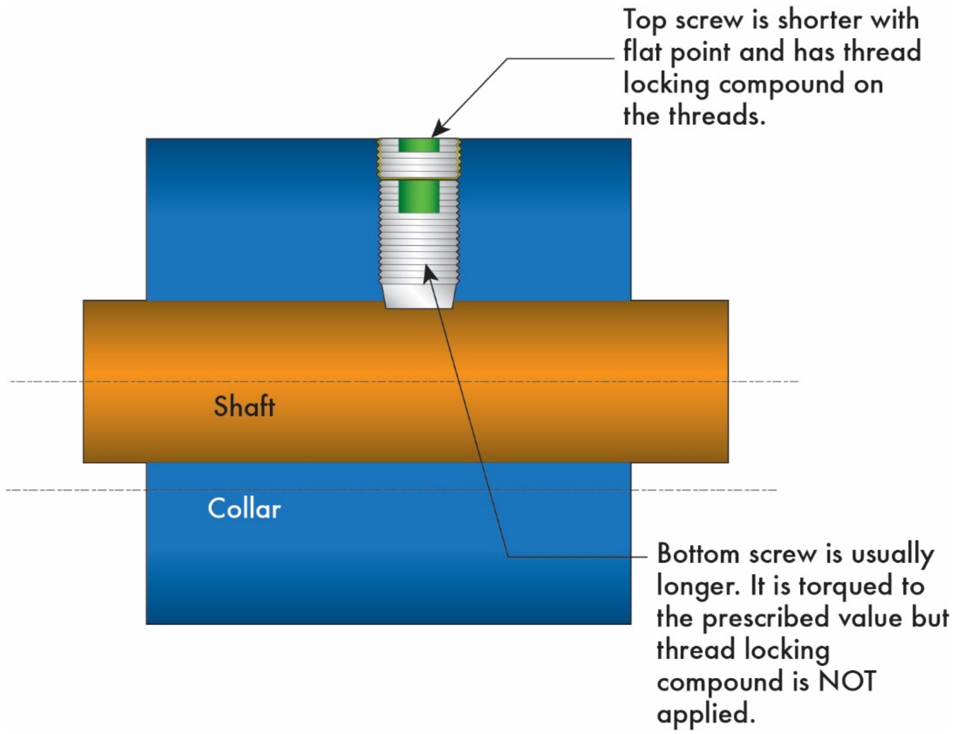


Figure 3-8
Grub screw and double set screw arrangement

3.1.13 Selection of Torque Values for Set Screws

Key Technical Point
Set screws may not have a specific identified torque value in many applications. If they are in a thin-walled piece or softer material that can be distorted by torquing to the value specified in the torque table, the softer piece must be considered and the set screws tightened so that there is acceptable distortion of the softer piece.

Set screws may not have a specific identified torque value in many applications. If the set screws are in a thin-walled piece or softer material that can be distorted by torquing to the value specified in the torque table, the softer piece must be considered and the set screws tightened so that there is acceptable distortion of the softer piece. In these cases, torquing in a four-step sequence can prevent excessive distortion. The torque value where distortion occurs should be recorded and provided as work order feedback so it can be used for future jobs.

Tables in Appendix C (English units) and Appendix D (SI units) provide reference use to give typical maximum torque values for ASTM F912 standard alloy steel set screws. Most stainless steel set screws are ASTM F880, condition cold worked (CW). Test torque values are significantly less (approximately 70%–75%) of allowed steel values.

In experiments conducted by EPRI, it was found that the maximum torque values using these tables cause distortion (permanent twisting) of standard "tool grade" hex keys (Figure 3-9).

Figure 3-9
Distortion and permanent twisting of a hex key

Upon investigating this phenomenon, it was found that there can be a rather large difference between different manufacturers of hex keys. For example, one manufacturer has information comparing its products and the associated physical properties such as Rockwell C hardness and tensile stress capacity to torque capacity. EPRI took one common size and noted the differences: a 1/4-in. (6.35-mm) hex key that would be used to torque a 1/2-in. (12.7-mm) diameter set screw. Notice that the recommended maximum torque of this set screw is greater than the capacity of several commonly supplied hex keys. Table 3-2 shows this for a 1/4-in. (6.35-mm) hex key.

Table 3-2
Comparison of torque capacities for different manufacturers' hex keys

Rockwell C Hardness	**Tensile Strength** (psi)	**Torque Capacity (1/4-in. Hex Key) Driving a 1/2-in. Diameter Set Screw** in.-lb	**Torque Capacity (~6-mm Hex Key) Driving an ~13-mm Diameter Set Screw** N-m	**Maximum Torque for 1/2-in. Diameter Screw Using a 1/4-in. Hex Key**
61	360,000	1125	127.1	820 in.-lb (92.3 N-m)
59	340,000	1063	120.1	
57	320,000	1000	113.0	
55	300,000	938	106.0	
53	280,000	875	98.9	
51	260,000	813	91.9	
49	240,000	750	84.7	
46	220,000	688	77.7	
43	200,000	625	70.6	
40	180,000	563	63.6	
37	160,000	500	56.5	

1 in. = 25.4 mm
1 psi = 0.00689 MPa

The yellow rows indicate hex keys that are manufactured that have insufficient capacity for the torque specified
(source: http://www.bondhus.com/features/protanium/body-4.htm).

Key Technical Point
Set screw torque values should be selected using the value recommended by the manufacturer of the end device as a starting point.

However, several sources of set screw torque values were examined for various couplings, bearings, hose manufacturers, and set screw manufacturers. The set screw manufacturers typically publish values in line with maximum ASTM values because the use is not known. Some manufacturers of devices will recommend set screws be tightened to values unique to their product, which may be less than values; some even caution against overtightening with no value given. Careful attention is advised if a caution is given about overtightening in the manufacturer's instructions.

With this in mind, set screw torque values should be selected using the value recommended by the manufacturer of the end device (for example, bearing, coupling, hose clamp) as a starting point.

Key Technical Point
A machined flat under that set screw can be used for additional 6%–10% holding power. This also allows for ease of disassembly with no raised edges in the material below. Staking of the top of the set screw can also be used to inhibit loosening.

3.1.14 Other Considerations for Set Screws

Additional considerations for set screws include the following:

- Apply a locking compound (see Section 4.2) in all set screw applications.
- A machined flat under that set screw can be used for additional 6%–10% holding power. This also allows for ease of disassembly with no raised edges in the material below. Staking of the top of the set screw can also be used to inhibit loosening.
- Do not reuse set screws. They are wear items, and their holding and penetrating ability is highest when using new set screws. When possible, always use new set screws.
- Do not allow a set screw to protrude from a rotating element. Protruding set screws can cause serious injuries.
- Using the incorrect set screw can cause unexpected movement, personal injury, equipment damage, and the inability to remove the assembly after tightening.
- Vendor guidance is preferred. Follow work instructions during installation, if provided.
- Use the longest set screw available for the application. The ideal set screw length should have one thread below the surface to allow for staking.
- Always clean the threads of the set screws and the threads of the device that the set screw is going into prior to the application of the thread locking compound.
- Ensure loading is optimized, as follows:
  - Inspect set screw and device threads for damage such as burrs, corrosion, and so forth, that would increase friction.
  - Run the set screw up and down the threaded hole to ensure that it moves freely but with no radial looseness (indicating the threads have excessive clearance).
  - If movement is restricted, clean threads or replace the set screw; or, if allowed by design, relocate the set screw hole.
  - If the threads are too loose, relocate the set screw; or, if allowed by design, use a larger hole/thread size.
- Always use the correct thread locking adhesive for the application. See Section 4.2 for additional discussion on thread locking compounds.

On most rotating equipment, the cup point set screw is the most common.

3.2 Prevailing Torque Lock Nuts

A prevailing torque nut is a nut that provides frictional resistance to rotation because of special features of the threads. The prevailing torque is defined as the torque required to run a vibration resistant nut down to the joint surface. This resistance to free turning of the threads provides the resistance to loosening. It is accomplished usually by distorting the threads on the nut so that they grip the bolt and prevent loosening. There are several variations of this type of nut (see Figure 3-10). One common property is that the length of the thread should be only minimally longer than the thickness of the nut because the distortion of the threads could damage many of the bolt threads and cause galling.

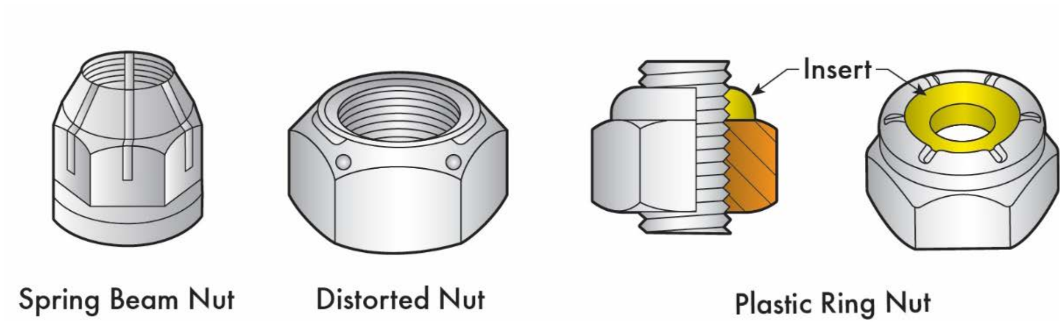


Figure 3-10
Prevailing torque lock nuts

Key Technical Point
Distorted collar nuts should not be used in applications where the nut must be threaded for a long area of the fastener due to thread damage of the fastener.

These nuts come in many styles, as follows:

- **Beam nut.** This uses an all metal nut with slots that allow the top of the nut to be compressed inward during manufacturing. When the nut is threaded on a bolt, these “beams” grip the bolt threads to resist loosening.
- **Distorted collar nut.** This uses an oval steel collar insert or a collar formed with a rounded triangular opening. There is also a type that has the top thread diameter smaller than the fastener size (sometimes referred to as “withdrawn”) so that this thread and the fastener thread deform to resist loosening. For any distorted collar nut, as the nut is threaded on, the bolt forces the nut or collar back into round, and the forces grip the threads to resist loosening. Distorted collar nuts often damage the threads of the fastener application. Therefore, they should not be used on fasteners where the nut will be rotated over many threads such as a long fastener. Due to thread damage, the fastener usually must be replaced when disassembled.
- **Plastic ring nut.** This uses a plastic collar that is distorted but does little damage to the metal bolt. The distortion allows gripping of the threads and resists loosening. Reuse of plastic ring nuts should be as recommended by the manufacturer.

3.3 Jam Nuts

A jam nut is a nut used in combination with another nut to prevent the bolt from loosening. The process is sometimes called *double-nutting*. The American National Standards Institute (ANSI) standard jam nut is thinner than the full-thickness nut. In the practice of locking a joint, either the standard jam nut or a full-thickness nut can be used as the jam nut.

The normal practice is to place the jam nut (full or thin) against the joint surface. The jam nut is torqued to seat only. The full-thickness nut is then assembled on top and torqued to the specified value while the installer holds the jam nut to prevent it from rotating. The understanding is that this action causes the jam nut threads to be pulled up and the full-thickness nut threads to be pulled down. This thread distortion causes an interference that creates the locking action.

The jam nut is of limited application. The use of the prevailing torque lock nut usually results in satisfactory service at a minimal cost. However, when assembly requires a long travel of the nut, the use of a jam nut might be more cost-effective.

3.4 Lock Washers

On bolts <0.25 in. (<6.35 mm), two styles of lock washers are common: spring-action helical washer and toothed washers. Lock washers should not be used on bolts >0.25 in. (>6.35 mm).

3.4.1 Spring-Action Helical Washers

ANSI/American Society of Mechanical Engineers (ASME) B18.21.1 lists the materials from which spring-action helical washers can be made. Most of these washers are fabricated of a hardened carbon steel. Because the washers are heat-treated, they are placed beneath the element that is turned, and they are compressed elastically during tightening. Spring-action helical washers exert a spring-back reaction force that helps retain bolt tension and resistance to loosening. A disadvantage of spring-action helical washers is that the spring flattens at relatively low loads compared to preload.

Spring-action helical washers are available in different thicknesses (regular, heavy, extra duty, and high-collar). The high-collar washers are used only with the 1960 series of socket-head cap screws. The spring-action helical washer (Figure 3-11) acts like a spring while the bolt is being tightened.

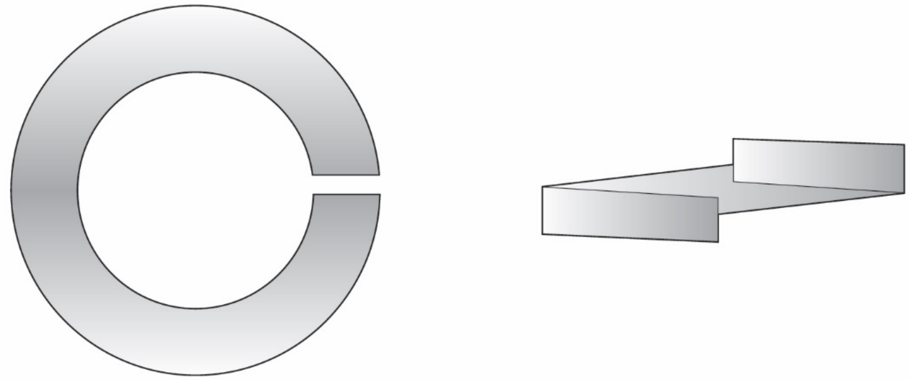


Figure 3-11
Spring-action helical washer

The use of lock washers is controversial. The evidence appears to indicate that the disadvantages outweigh the advantages.

One paragraph of the Naval Ships Technical Manual, Chapter 75 (NSTM 75), states the following:

> 075-5.6.2 The most frequently used lock washer is the helical spring (split) type. The helical spring lock washer is flattened when the bolt is torqued down. Once compressed, it acts as a flat washer, contributing normal friction between the nut or bolt and the bearing surface during tightening. If the fastener clamping load relaxes, the spring-action of the lock washer will maintain some load between the threads of the fastener, reducing the tendency of the fastener to rotate. Some helical spring lock washers have a sharp tooth on each end that bites into each bearing surface and prevents rotation. This type adds friction during tightening and will result in some reduction in [preload] because the helical spring lock washer diameter is small and it tends to dig.

However, another paragraph of NSTM 75 states the following:

> 075-2.5.4 Although lock washers might be encountered, using the flat washers with self-locking nuts, self-locking fasteners, self-locking inserts, or thread sealants such as MIL-S-22473 anaerobic compounds [are] preferable. Follow the procedures in paragraph 075-2.5.1 to identify replacement lock washers.

Key Cost Point
Spring-action helical lock washers flatten out when the bolt is fully torqued. Their value in preventing nut loosening is marginal, if not useless.

National Aeronautics and Space Administration (NASA) Reference Publication 1228 states the following:

> The lock washer serves as a spring while the bolt is being tightened. However, the washer is normally flat by the time the bolt is fully torqued. [Now] it is equivalent to a solid flat washer, and its locking ability is nonexistent. In summary, a lock washer of this type is useless for locking.

3.4.2 Toothed Lock Washers

Toothed washers are made from hardened carbon steel. The teeth on the washer dig into the bolt-bearing surface, therefore developing a greater resistance to loosening. However, the teeth can damage a bearing surface that has been treated with a protective coating. Figure 3-12 illustrates the internal and external toothed lock washers. These washers are ineffective without a reasonable preload. An external toothed lock washer is also available. However, the internal toothed washer is recommended for standardization.

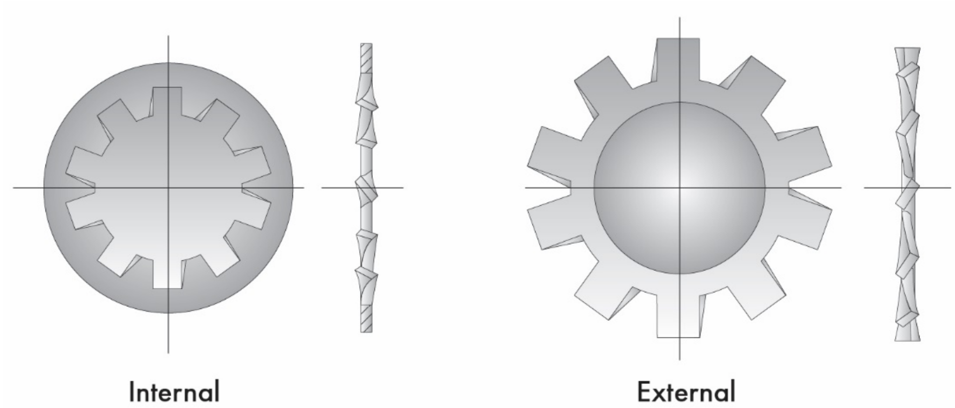


Figure 3-12
Toothed lock washers

3.4.3 Belleville Washers

Although not technically a locking device, Belleville spring or conical washers are available for a variety of applications. Their primary use is to lower the stiffness of the fastener assembly, therefore providing a load if the bolt tries to loosen due to such factors as thermal elongation. Figure 3-13 illustrates the cross-section of a Belleville washer.

Figure 3-13
Belleville sprint or conical washers

3.4.4 Mechanically Locked Washers

Disc-lock washers use two-piece multi-toothed cams with ridges to resist loosening, as shown in Figure 3-14.

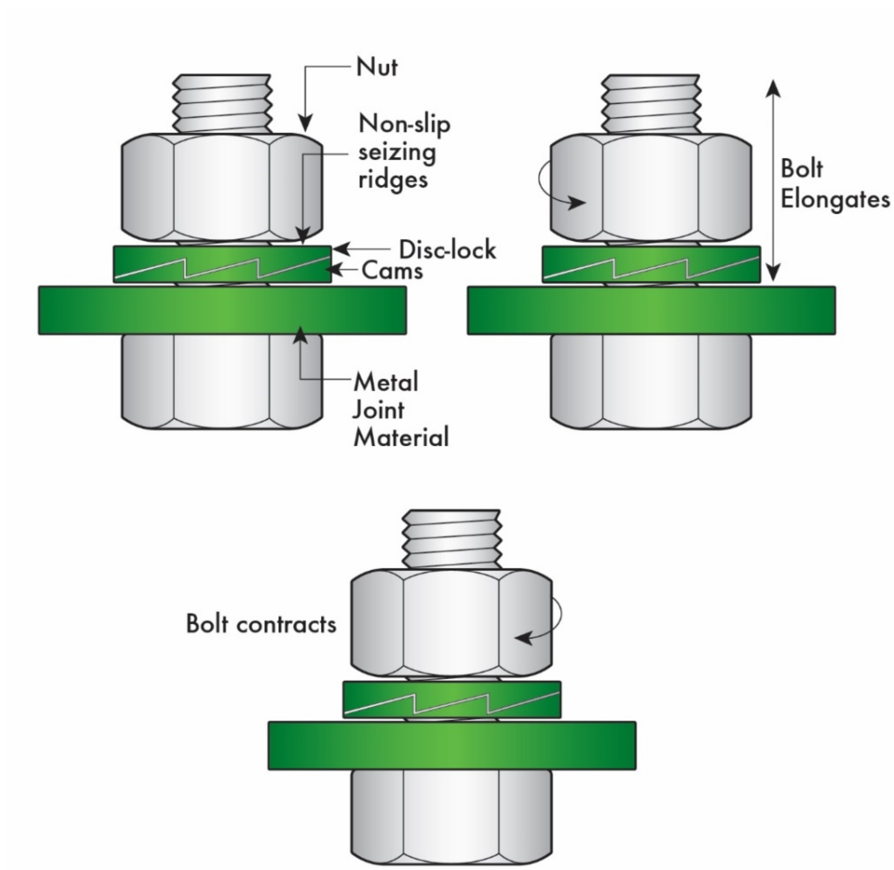


Figure 3-14
Disc-lock wedge locking washers

3.4.5 Pantleg Washers

Pantleg washers are relatively simple devices that can be used in some configurations. One leg is bent over the flange of the fastener configuration and the other over the nut, preventing nut rotation. Figure 3-15 shows the configuration for right hand threads. If the nut loosens counterclockwise, the tabs resist rotation.

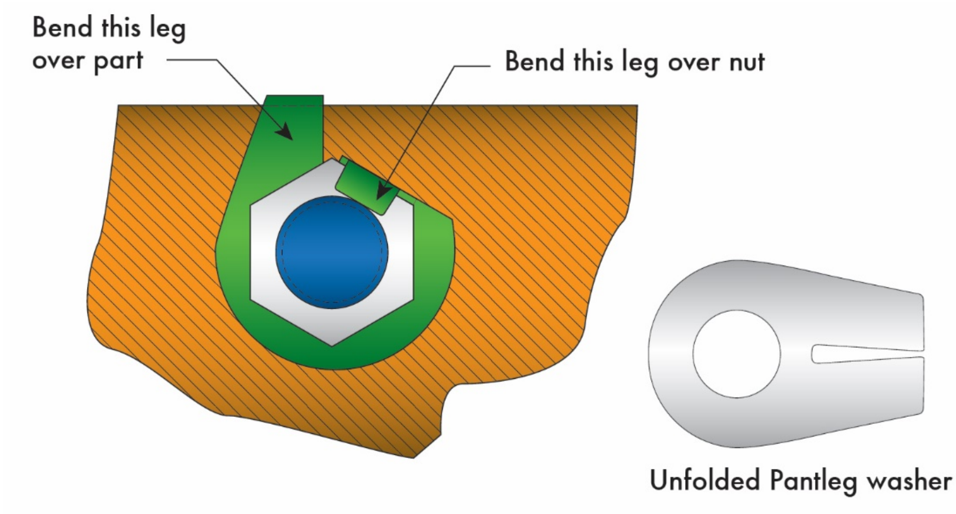


Figure 3-15
Correct pantleg washer assembly with right hand threads

3.5 Other Locking Methods

3.5.1 Lock Wire/Safety Wire

Lock wire is useful in multi-bolt applications. The wire is fed through holes in the heads of the bolts and screws, therefore tying the bolts together as illustrated in Figure 3-16. The key to the effectiveness of lock wire is routing the wire through the bolt heads. The wire should be routed so that if a bolt moves in the direction of removal, the tensioned wire tightens the adjacent bolts. Using lock wire to prevent loosening requires increased installation time, drilled head bolts, and proper routing of the wire.

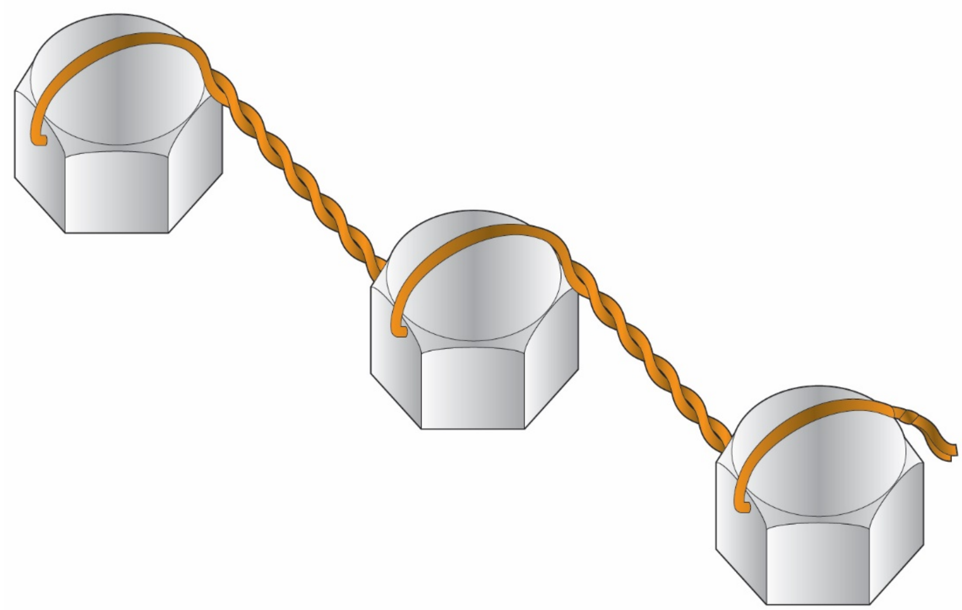


Figure 3-16
Lock wire

The National Aerospace Standard (NAS M33540), "*Safety Wiring, Safety Cabling, Cotter Pinning, General Practices For*" provides very specific guidance for the materials and methods for safety wiring, safety cabling, and the use of cotter pins. Materials and sizes for these types should be in accordance with the manufacturer recommendations or this standard if no manufacturer guidance exists. This standard is recommended for more detail if questions regarding lock wiring arise. Key insights from this standard relative to methods are provided in Table 3-3.

Table 3-3
Recommendations for lock wire/safety wire

Application	Method	Recommended Limitations or Precautions
Closely spaced (<2 in.) between centers or closed geometrical patterns	Single wire method	No more than 24 in. of wire used
Shear and seal wiring applications so it can be broken when required in an emergency	Single wire method	
Fasteners 2 in.–4 in. apart	Double wire method	
Fasteners 4 in.–6 in. apart	Double wire method	No more than three fasteners safety wired together
Fasteners >6 in. apart	Double wire method	No fasteners safety wired together unless tie points are provided on adjacent parts so the span is less than 6 in.

1 in. = 25.4 mm

Methods of lock wiring include the (1) single wire method (Figure 3-17) with no twisting except where the two ends of the wire meet and (2) double wire method (Figure 3-18), which the most common method of lock wiring is the double-twist method where one twist is twisting two strands of wire through an arc of 180° (one-half turn).

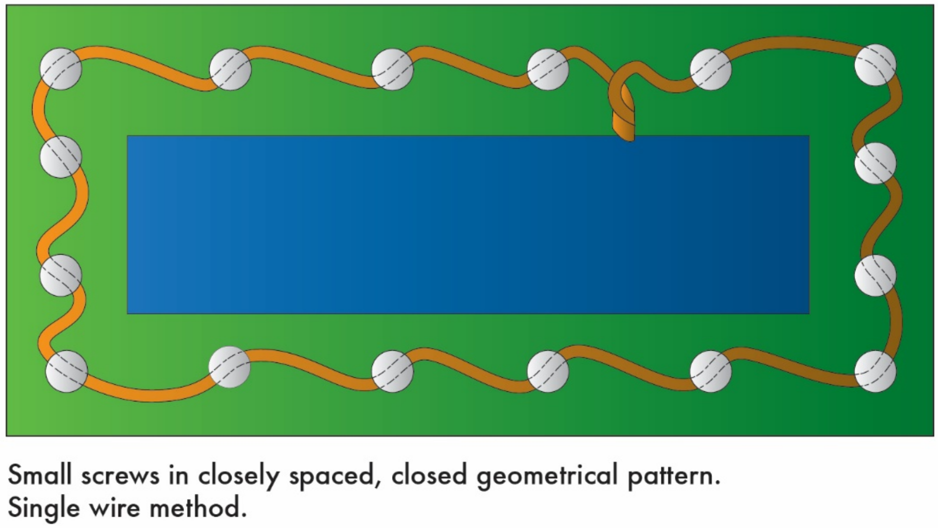


Figure 3-17
Single wire method of lock wiring

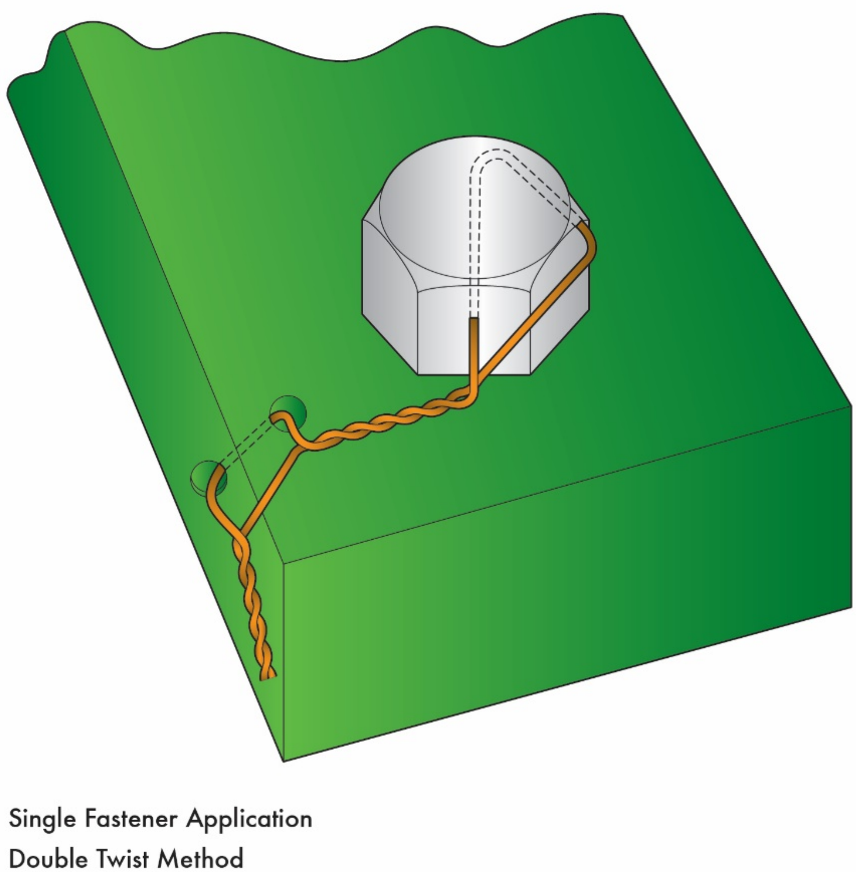


Figure 3-18
Double-twist method of lock wiring

Key Technical Point
Use new safety wire upon each application because it weakens when twisted.

For both methods, a pigtail of 0.25 in. (6.35 mm) to 0.50 in. (12.7 mm), usually three to five twists, should be made at the end of the wiring and bent back or under to prevent snagging. Also, using new safety wire upon each application is recommended because it weakens when twisted.

Key points regarding lock wiring are as follows:

- Do not over twist the wire so that it is excessively weakened. This varies depending on the type and size of wire.
- Ensure that the wire is wrapped in a direction around the fastener that resists loosening. Although most bolts turn clockwise to tighten and counterclockwise to loosen, make sure that they are not reverse threaded.
- Follow manufacturer's guidance for lock wiring, if provided.

Additional information on lock wiring from a manufacturer's website is provided in Appendix E.

3.5.2 Castellated Nuts with Cotter or Spring Pins

Cotter pins are used with castellated nuts whose strength is approximately 80% of that of full-thickness nuts. To install cotter pins, align the nut slots with the holes drilled through the shank of an externally threaded bolt. This installation and the resulting deformation are critical to the performance of cotter pins. Difficulties in using cotter pins can result from locating the hole in the bolt shank and from a reduction in the nut strength because of slotting, as illustrated in Figure 3-19.

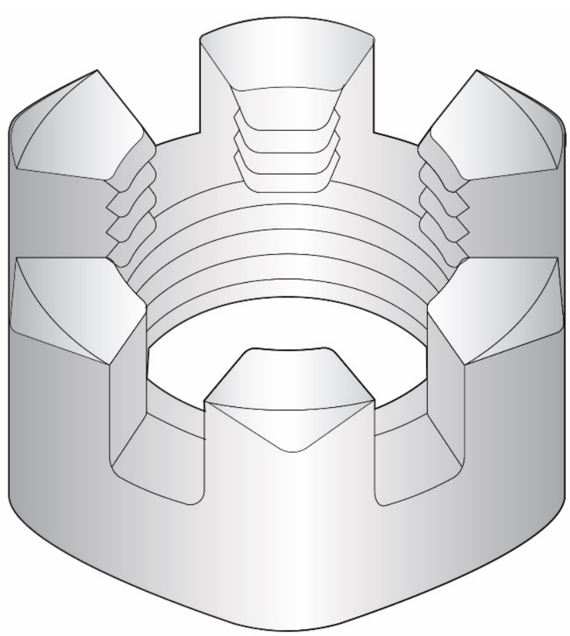


Figure 3-19
Excessive slotting of a castellated nut

Section 4: Thread Locking Methods

4.1 Introduction

In addition to the devices in Section 3, there often needs to be additional methods to prevent threads from loosening.

4.2 Adhesives/Thread Locking Compounds

Adhesive/thread locking compounds are available, which are effective in providing resistance to loosening. These compounds work by filling in the space between the male threads on the fastener and the female threads on its mating part (for example, nut). They are described in the following sections.

Information for both products is available on websites for Loctite[2] at http://na.henkel-adhesives.com/industrial/threadlocker-loctite-13445.htm (North American site; other international sites may be selected at www.loctite.com and selecting the country), and Vibra-TITE[3] at www.vibratite.com.

4.2.1 Anaerobic Compounds

Anaerobic compounds harden in the absence of air. Typically, they come in various strengths. The two manufacturers most used in the United States are Loctite and Vibra-TITE. Both companies provide anaerobic products in low, medium, and high strength compounds. Currently, they color code their products as purple (low strength), blue (medium strength), and red (high strength). A "wicking" grade is provided for fasteners that are already assembled. Descriptions of the various products are as follows:

- Low strength formulas are often used for very small fasteners (<1/4 in.) or for installations where frequent adjustment is needed and loosening would not be absolutely critical.
- Medium strength formulas are the most widely used for fasteners in the 1/4-in. to 3/4-in. (6.35-mm to 19.05-mm) range where adjustment is not necessarily frequent and disassembly is needed for maintenance and it is desired to break the fasteners loose with hand tools.
- High strength formulas are used where disassembly is expected to be infrequent, loads are high, and consequences of loosening might be catastrophic or require high maintenance costs (for example, the impeller

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[2] *Loctite* is a registered trademark of Henkel AG & Company KGaA.

[3] *Vibra-TITE* is a registered trademark of ND Industries, Inc.

fasteners of a large pump). When high strength compounds are used, heat is generally required to break the fastener loose.

- Wicking grade formulas are also marketed by both companies, which can be used on fasteners after assembly. These formulas have a green color code for both companies.

Products are available in different forms such as liquid, gels, stick, and paste. In some cases, primers are needed, particularly if the metals involved are nonactive.

Generally, fasteners should be free of lubricants unless the product specifications specifically allow them for use in oil environments such as inside a gear box. Cleaners are often marketed for these applications. Loctite provides a medium strength compound (Loctite 2432) that is low sulfur/halogen for nuclear applications where stress corrosion cracking might be a concern.

4.2.2 Vibra-TITE

Vibra-TITE offers a product that is not an anaerobic compound, marketed as VC-3. It uses a blend of acrylic resins to resist loosening. One advantage described by Vibra-TITE is that fasteners can be adjusted, removed, and reused. At least one of the industry TAG members reported good results with this product.

4.3 Tack Welding

Tack welding can be used for carbon steel nuts, but it is not recommended for low-alloy materials such as A194-2H without close attention to pre- and post-weld heat treatment.

Permanent damage may be caused from weld splatter, cracking, and so forth. Grounding of the components being welding can cause damage due to arcing. In general, tack welding should be used on parts that are seldom disassembled and not on rotating machinery.

Common uses are to secure equipment or safeguards that must be in place for security reasons (for example, grating to plant drainage systems) or some internal parts such as bolting or internal valve parts such as check valve hinge fasteners.

4.4 Staking of Threads

Staking of threads with a center punch is another effective locking method. The major disadvantage of this technique is that the threads become damaged, making disassembly more difficult. When used, the “stake” must often be freed by drilling the location where the parts were punched. If the parts would not suffer irreparable damage or are very inexpensive to replace, this can be a good solution. In general, this method is specified by the manufacturer.

4.4.1 Staking Set Screws

Staking helps keep the set screw from backing out. To properly stake a set screw, the following process should be used:

1. The top of the set screw should be approximately one thread below the surface.
2. Using a center punch and hammer, position the point of the set screw approximately 1/16 in. to 1/8 in. (1.59 mm to 3.18 mm) from the threaded hole with the punch head angled slightly away to facilitate pushing the metal toward the set screw.
3. Strike lightly with the hammer until the top threads are clearly distorted into the path of the set screw.
4. It is recommended to stake a set screw in two places (Figure 4-1).

Figure 4-1
Staked screw set

4.4.2 Removing the Stake

When disassembly of a staked thread is required, typical removal involves drilling into the stake with a drill bit slightly bigger than the staked divot at a depth approximately the same as the divot. The fastener can then usually be removed with normal tools.

Section 5: Position Retention Device Troubleshooting

5.1 Introduction

Table 5-1 is intended to provide a list of some of the possible issues that might be encountered when troubleshooting the failure of a position retention device. As with most all troubleshooting, careful attention to the physical condition of the parts during disassembly is paramount to determining the causes of failures and subsequent corrective actions. Photographs are very useful during disassembly to help diagnose causes. Physical testing or metallurgical examination and testing may be needed and should be considered.

Table 5-1
Troubleshooting guide for a position retention device

Condition	Possible Explanation	Corrective Action
Evidence of sudden load over and above what device should be expected to resist (such as sudden bearing failure causing excessive load)	May not be anything wrong with device	Repair problem causing excessive loading
Marks on component not as expected	Set screw – wrong point type used	Replace set screw with proper type and correct torque
	Set screw – insufficient torque	Replace set screw using correct torque
	Set screw – wrong material used	Replace set screw using correct material and torque
	Set screw – marginal "bite" into shaft	Consider putting a "flat" on the shaft to increase "bite"
Set screw loosening	Staking not performed as specified or improperly performed	Stake properly

Table 5-1 (continued)
Troubleshooting guide for a position retention device

Condition	Possible Explanation	Corrective Action
	Need further resistance to loosening	Use locking compound (see below) Consider use of grub screw assembly Consider use of staking
No thread locking compound	No thread locking compound	Use proper thread locking compound and change work instructions or procedures as necessary
Lock wire/cotter pin broken	Possible overload.	Repair overload condition
	Over twisting of lock wire	Correct over twisting using new lock wire and change work instructions or procedures as necessary
	Wrong lock wire material	Use correct lock wire material and tighten properly
	Reuse of lock wire	Use new lock wire and tighten properly
Lock wire untwisted	Lock wire twisted or installed in wrong direction	Twist lock wire so it is tensioned upon fastener loosening
Self-locking (for example, beam or nyloc) nut loosened	Reuse of tension nuts	Use new tension nuts and change work instructions or procedures as necessary
	Wrong type of tension nut	Use new and correct tension nuts and change work instructions or procedures as necessary

Table 5-1 (continued)
Troubleshooting guide for a position retention device

Condition	Possible Explanation	Corrective Action
Failure of locking washers	Wrong type of lock washer used	Use correct lock washer; tension lock washers are rarely effective
	Lock washer used improperly (especially pantleg washers)	Install washer properly
Jam nut loosening	Insufficient tightening of jam nut	Tighten jam nut
	Thread locking compound not used	Use thread locking compound

Section 6: Operating Experience

6.1 Summary of Findings

The following findings were from a search of the INPO ICES database from January 1, 2014 to February 8, 2018 using keywords "set screw," "locking," and "anti-rotation" in exact and any word containing search fields with different combinations or individual searches (Appendix F). The resulting findings were then reviewed for specific applicability and to the components and practices discussed in this report. Thirty-six events were noted. The details of the findings are provided in the following texts and illustrated in Figure 6-1.

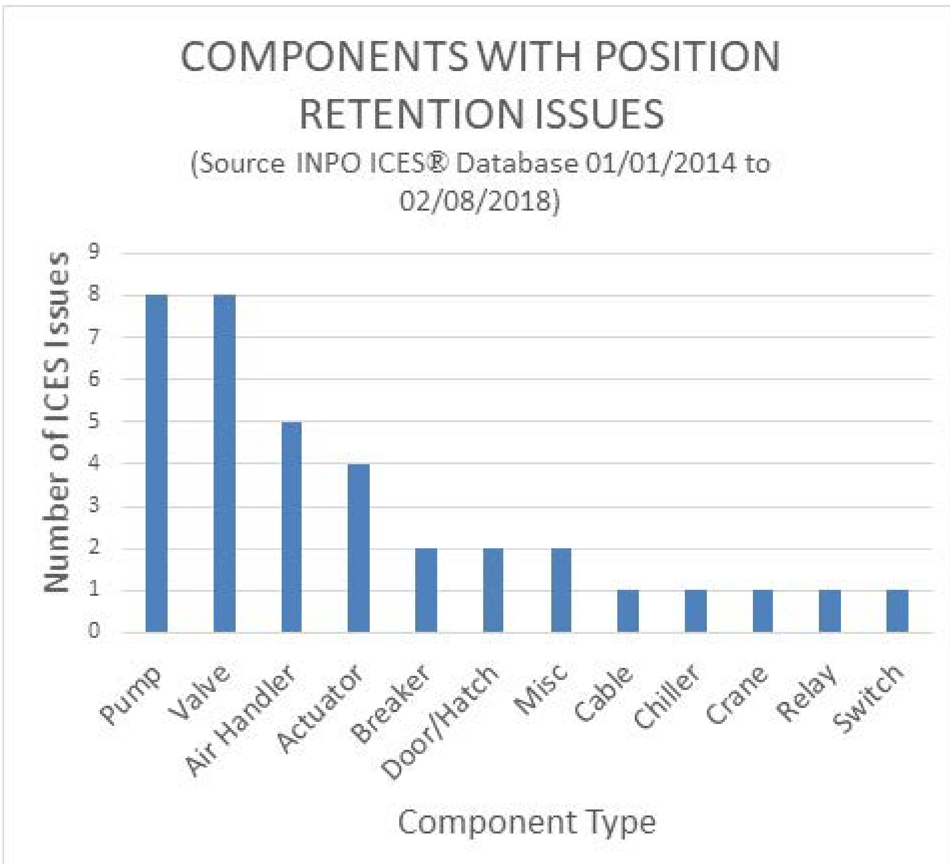

Table 6-1
Operating experience

Key Information Point

Anti-movement device learnings should be considered for all maintenance.

The mechanical events have been published in the Industry Event Report (IER) 17-9, *Weaknesses in Maintenance Technical Fundamental Skills Adversely Affecting Plant Operations*. The search also noted several additional events not noted in the IER affecting electrical and instrument and controls as well as mechanical. The implications of the operating experience search are that anti-movement device learnings should be considered for all maintenance.

Appendix F contains the data to support the previous findings and relates the most likely skills disciplines impacted.

Section 7: References

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Appendix A: Key Points Listing

A.1 Key Cost Point

Section	Key Point
3.4.1	Spring-action helical lock washers flatten out when the bolt is fully torqued. Their value in preventing nut loosening is marginal, if not useless.

A.2 Key Information Point

Section	Key Point
6.1	Anti-movement device learnings should be considered for all maintenance.

A.3 Key Technical Point

Section	Key Point
2.2	Joints loaded in shear tend to loosen more than joints loaded in tension.
2.3.1	Lowering of fastener friction using lubrication is frequently used for fluid retaining joints such as pipe flanges, valve bonnets, pump casings, and so forth, but can prevent thread locking compounds from working effectively; therefore, this method is not generally recommended for joints involving power transmission.
2.3.2	Mechanically locked washers may be better than any of the vibration resistant nuts in this listing. (Table 2-2)
3.1.1.2	Engineers often use a general rule that states that the diameter of a hollow set screw (hexagon, fluted, or spline socket) is equal to approximately one-quarter to one-half the diameter of the shaft. However, the range of usefulness of this rule is limited.

A.4 Key Technical Point

Section	Key Point
3.1.3	The set screw material should be at least 10 Rockwell C scale points harder than the material that they are attempting to penetrate.
3.1.5	Thread locking compounds that are resistant to lubricants should be considered in oily environments where fasteners might tend to develop slippage. Corrosion resistant materials or coatings should be considered in high moisture or corrosive environments.
3.1.7	If sufficient engagement is available to prevent stripping in the tightening process, the length of the thread engagement has no noticeable effect on axial and torsional holding power.
3.1.9.4	The maximum torque that can be applied is greater with square-head set screws because the screws can be tightened with a wrench more easily until the threads strip or the screw fails in torsional shear; therefore, caution is highly recommended with square heads.
3.1.13	Set screws may not have a specific identified torque value in many applications. If they are in a thin-walled piece or softer material that can be distorted by torquing to the value specified in the torque table, the softer piece must be considered and the set screws tightened so that there is acceptable distortion of the softer piece.
	Set screw torque values should be selected using the value recommended by the manufacturer of the end device as a starting point.
3.1.14	A machined flat under that set screw can be used for additional 6%–10% holding power. This also allows for ease of disassembly with no raised edges in the material below. Staking of the top of the set screw can also be used to inhibit loosening.
3.2	Distorted collar nuts should not be used in applications where the nut must be threaded for a long area of the fastener due to thread damage of the fastener.
3.5.1	Use new safety wire upon each application because it weakens when twisted.

Appendix B: Typical Set Screw Point Styles Table

Table B-1
Typical set screw point styles

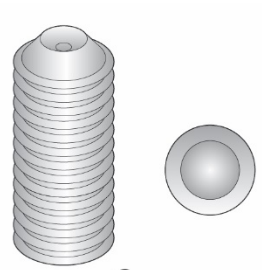
Point Type	Use/Typical Applications	Holding Strength	Precautions	Tips
 Cup	The most commonly used set screws on rotating machinery. Cup points penetrate less and cover a wider area compared to cone points, but penetration is more compared to flat or oval points. Cup points require less torque, which helps minimize distortion in case of thin-walled components such as bearing race or sleeves. <u>Typical applications</u> – Semi-permanent location of gears, collars, pulleys, or knobs on shafts. Most widely used point type. Can be used on hardened shafts, in softer castings, and materials where high tightening torques are impractical.	1.00	For a curved surface such as a shaft, cup points may not penetrate uniformly all the way around. In most cases, achieved penetration may provide adequate holding power without any shaft surface preparation.	Holding power can be improved by milling a flat spot (slightly larger than the point diameter) under the point to help uniform penetration. This also helps with any shaft material flaring, which could interfere with component removal when needed.

Table B-1 (continued)
Typical set screw point styles

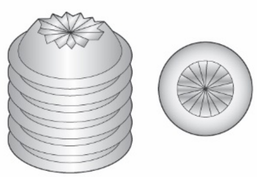
Point Type	Use/Typical Applications	Holding Strength	Precautions	Tips
 Knurled Cup	Offers the added advantage over cup point of a locking action that prevents the screws from working loose in high vibration applications. Typical applications – Similar to cup points but with different precautions. Semi-permanent, location of gears, collars, pulleys, or knobs on shafts. Counterclockwise locking knurls resist screw loosening, even in poorly tapped holes. Resists most severe vibration.	1.00+	Knurled cup point set screws require a higher torque to properly penetrate the shaft and should not be used in thin-walled or soft material sleeve-type applications due to concerns over deforming the sleeve. They should not be used on very soft surfaces or those harder than Rockwell hardness 30Rc. As soon as they are removed, the cutting edges of the knurls are torn and no longer have full strength to resist unscrewing. For this reason, never reuse a knurled cup point set screw.	Same as cup

Table B-1 (continued)
Typical set screw point styles

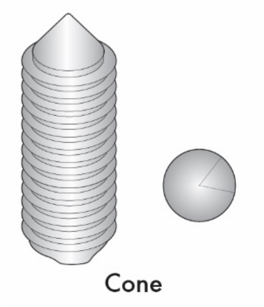
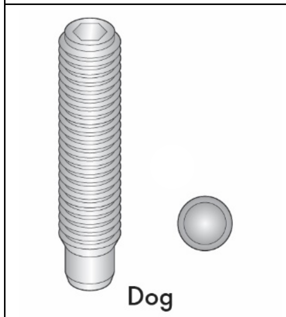
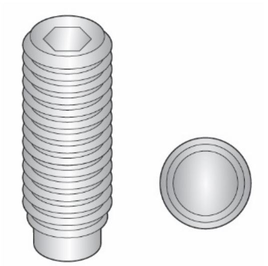
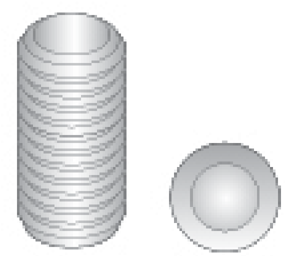
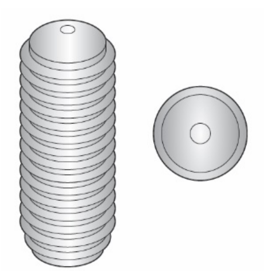
Point Type	Use/Typical Applications	Holding Strength	Precautions	Tips
	Offers the most penetration but requires increased tightening torque to properly secure them. Cone-point set screws do not require any surface preparation. Their use is preferred where adjustments/removal of the component may not be needed. <u>Typical application</u> – Where permanent location of part is needed; where disassembly requirement is expected to be very infrequent.	1.07	Create more damage to shaft. Their penetrating characteristics cause displacement of the securing material and can prevent disassembly.	Disassembly can be enhanced by spotting the securing material below with a drill, end mill, or abrasive.
	Usually located in a hole (slightly larger than the point diameter and height) drilled into the shaft surface directly under the point. If used without a hole, they are essentially a flat point. <u>Typical application</u> – Where part to be retained is generally located at the same place every time because the shaft is drilled or slotted to receive it. Can be used where high torques are expected due to dependence on shear strength.	Depends on size and material of set screw because most of the strength is in shear. If used without a hole or groove, 0.92.	Needs blind hole or groove to function properly.	These can be used by locating into a groove under the point to allow for positional adjustment as well. This allows dog point to function as a dowel pin, relying on holding power and shear strength of the dog point to resist slippage.

Table B-1 (continued)
Typical set screw point styles

Point Type	Use/Typical Applications	Holding Strength	Precautions	Tips
 1/2 Dog	Same as full dog but shorter. If used without a hole, they are essentially a flat point. <u>Typical application</u> – Same as full dog. May be used where set screw length is limited to get adequate thread engagement.	Same as full dog.	Same as full dog.	Same as full dog.
 Flat	Used when something does not require significant holding force and needs to be able to be adjusted without damaging the surface. They can be used against thin-walled materials. <u>Typical application</u> – Thin-walled materials.	0.92	Less holding power than cup points.	They fit well into locating grooves and onto machined flats.
 Oval	Used when something does not require significant holding force and needs to be adjusted (usually frequently) without damaging the surface. Often used where the oval point will contact a groove or *v*-shaped slot, such as a tool holder, where frequent adjustment or removal is needed. <u>Typical application</u> – Tool holders.	0.90	Less holding power than cup points.	They fit well into locating grooves and onto machined flats.

Appendix C: Torsional Holding Power (in.-lb) for Cup Point Screws (English Units) Table

Table C-1
Torsional holding power (in.-lb) for cup point screws (English units)

Shaft Diam. (in.)	**Nominal Screw Size (in.)**																		
	#0	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#8**	**#10**	**0.25**	**0.31**	**0.38**	**0.44**	**0.50**	**0.56**	**0.63**	**0.75**	**0.88**	**1.00**
	Seating Torque (in.-lb)																		
	1	**1.8**	**1.8**	**5**	**5**	**10**	**10**	**20**	**30**	**87**	**165**	**280**	**430**	**820**	**820**	**1325**	**2400**	**5200**	**7200**
	Axial Holding Power (lb) (see *Note*)																		
	50	**65**	**85**	**120**	**160**	**200**	**250**	**385**	**540**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**5000**	**6000**	**7000**
0.06	2	2	3	4															
0.09	2	3	4	6	8														
0.13	3	4	5	8	10	13													
0.16	4	5	7	9	13	16	20	30			**in.-**	**lb**							
0.19	5	6	8	11	15	19	23	36	51										
0.22	5	7	9	13	18	22	27	42	59										
0.25	6	8	11	15	20	25	31	48	68	125									
0.31		10	13	19	25	31	39	60	84	156	234								
0.38			16	23	30	38	47	72	101	188	281	375							
0.44				26	35	44	55	84	118	219	328	438	547						
0.50					40	50	63	96	135	250	375	500	625	750					
0.56						56	70	108	152	281	422	563	703	844	984				

Table C-1 (continued)
Torsional holding power (in.-lb) for cup point screws (English units)

0.63						63	78	120	169	313	469	625	781	938	1094	1250			
0.75							94	144	203	375	563	750	938	1125	1313	1500	1875		
0.88							109	168	236	438	656	875	1094	1313	1531	1750	2188	2625	
1.00									270	500	750	1000	1250	1500	1750	2000	2500	3000	3500
1.25									338	625	938	1250	1563	1875	2188	2500	3125	3750	4375
1.50										750	1125	1500	1875	2250	2625	3000	3750	4500	5250
1.75											1313	1750	2188	2625	3063	3500	4375	5250	6125
2.00						**in.-lb**					1500	2000	2500	3000	3500	4000	5000	6000	7000
2.50													3125	3750	4375	5000	6250	7500	8750
3.00														4500	5250	6000	7500	9000	10500
3.50															6125	7000	8750	10500	12250
4.00																8000	10000	12000	14000

1 in.-lb = 0.113 N-m

Note: The holding resistance values listed in Appendix C and Appendix D are based on ultimate strengths. Safety factors appropriate to the given application and load conditions should be applied to the axial holding power and torque values presented. Values divided by a safety factor of 1.5 to 2.0 under static load conditions and 4.0 to 8.0 under dynamic conditions should provide adequate results. See Section 3.1.14, Other Considerations for Set Screws, for additional factors to consider.

Appendix D: Torsional Holding Power (N-cm, N-m) for Cup Point Screws (SI Units) Table

Table D-1
Torsional holding power (N-cm, N-m) for cup point screws (SI units)

Shaft Diam. (mm)	Nominal Screw Size (mm)															
	1.60	**2.00**	**2.50**	**3.00**	**3.50**	**4.00**	**5.00**	**6.00**	**8.00**	**10.00**	**12.00**	**14.00**	**16.00**	**20.00**	**22.00**	**24.00**
	Seating Torque (N-cm)								**Seating Torque (N-m)**							
	13	**17**	**58**	**98**	**115**	**191**	**353**	**826**	**20**	**38**	**81**	**88**	**152**	**302**	**575**	**720**
	Axial Holding Power (N) (see *Note*)								**Axial Holding Power (kN) (see *Note*)**							
	215	**346**	**555**	**817**	**1133**	**1504**	**2415**	**3958**	**6.8**	**9.6**	**12.4**	**15.2**	**18.0**	**23.6**	**26.4**	**29.2**
2	22															
3	32	52	83													
4	43	69	111	163				N-cm<	>N-m							
5	54	86	139	204	283	376										
6	65	104	166	245	340	451	725									
7	75	121	194	286	397	526	845									
8	86	138	222	327	453	602	966	1583								
9	97	156	250	368	510	677	1087	1781								
10		173	277	409	567	752	1208	1979	34							
11			305	449	623	827	1328	2177	37	53						
12				490	680	903	1449	2375	41	57	74					

Table D-1 (continued)
Torsional holding power (N-cm, N-m) for cup point screws (SI units)

13				531	737	978	1570	2572	44	62	80	99				
14				572	793	1053	1691	2770	47	67	87	106	126			
15					850	1128	1811	2968	51	72	93	114	135	177		
20					1133	1504	2415	3958	68	96	124	152	180	236	264	
25							3019	4947	84	120	155	190	225	295	330	365
30							3623	5937	101	143	185	227	270	354	396	438
40								7915	135	191	247	303	359	471	527	583
50									169	239	309	379	449	589	659	729
60									203	287	371	455	539	707	791	875
70										335	433	531	629	825	923	1021
80											495	607	719	943	1055	1167
90								**N-cm<**	**>N-m**			682	809	1061	1187	1313
100													898	1179	1319	1459

Note: The holding resistance values listed in Appendix C and Appendix D are based on ultimate strengths. Safety factors appropriate to the given application and load conditions should be applied to the axial holding power and torque values presented. Values divided by a safety factor of 1.5 to 2.0 under static load conditions and 4.0 to 8.0 under dynamic conditions should provide adequate results. See Section 3.1.14, Other Considerations for Set Screws, for additional factors to consider.

Appendix E: Additional Lock Wire/ Safety Wire Guidance

SAFETY WIRE TYING

In aviation there are three things that you can't be without; velcro, duct tape and SAFETY WIRE. This article is about Safety Wire.

It comes in several different thickness and alloys for different applications. It is very light, corrosion resistant, strong, and easy to install.

Wire .020 inch diameter is very thin, not very strong, but you can bend it around just about anything. You use tie wire on light bolts or fittings where you need to bend the wire around a lot of corners and where the wire does not have a lot of pull on it.

Wire .032 inch diameter is easier to work with, and reasonably strong and should work on anything you might need safety wire in aviation.

Wire .041 inch diameter is extremely strong, because it is twice as thick and is very stiff and difficult to work with. It doesn't bend easily and will not tighten around a tight radius; when using it on wide turns, extra strength will be needed to use the safety wire.

While there are different materials used to make safety wire; like Copper, Brass and Aluminum, we don't recommend them. The type we recommend is 302/304 soft temper stainless steel.

With the thicker wires a safety wire tool makes the job a lot faster and easier. There are several different tools ranging from a unit that looks like a screw driver, wire winder tool and safety wire pliers. These tools make a beautiful finished job, with the right tightness and strength.

They are easy to use. You wrap the safety wire around whatever it is you are securing, bring both ends back into the pliers mouth, close the mouth down on the wires, lock it (it has a little spring loaded locking mechanism) then pull a round knob in the middle of the handle back. When you pull on the knob of the pliers the handles turn and the wire wraps around itself.

Areas where you might use safety wire include around bolt heads, or nuts where there is no means of locking them. Areas of special concern are propeller bolts, control system linkages, areas of movement, Aircraft Engines or vibration. Another area of use is on turnbuckles to prevent them from backing off in flight.

A bolt that is properly safety wired like that in the examples just doesn't hold the fastener in place; it serves to pull it tighter. Each bolt holds the other and actually tightens the other if it starts to come loose.

HOW TO PROPERLY INSTALL SAFETY WIRE

There are a couple of basic rules to follow when safety wiring something.

They are:

1. If you are safety wiring a nut or bolt FIRST torque the nut or bolt to its proper torque. Where possible align the holes that are going to be used to safety wire the units in place. BUT DON'T OVER TORQUE or UNDER TORQUE them to achieve this!
2. After installation the safety wire should be tight! So as not to allow the unit(s) to move.
3. Safety wire should always be installed so as to make the nut or bolt "TIGHTEN" itself when the safety wire has been installed. That is the safety wire should come around the top of head of the bolt/nut and back onto the securing unit so that the safety wire PULL is in a tightening direction!
4. NEVER over stress the safety wire. This weakens it, which could cause it to break under vibration or load. This is generally caused when you "over wind" the safety wire. Safety wire should never be nicked, or kinked.
5. When cutting the safety wire always leave 4 to 6 turns after the loop. REMEMBER always bring the safety wire AROUND the head of the bolt/nut in a tightening direction, in as small a contour to the bolt/nut as you can get.

A guide to using safety wire pliers!

After you have wrapped the safety wire around the object, grip both ends of the wire in the jaws of the safety wire pliers and slide the outer sleeve down with your thumb to lock the handles.

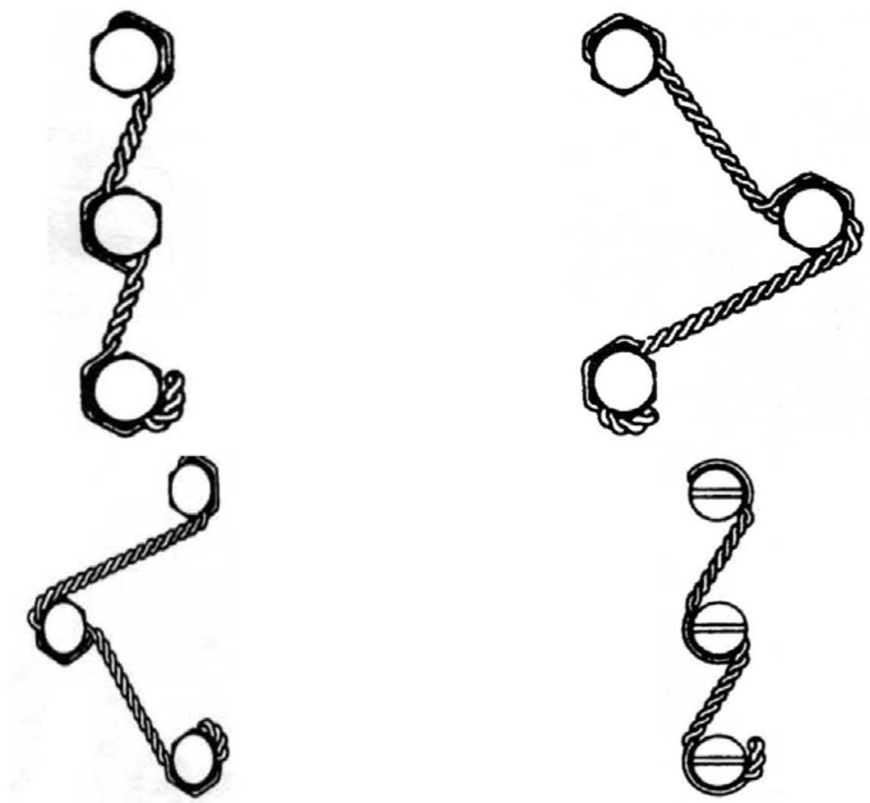
Now grasp the knob located in the middle of the pliers and gently pull out. This will cause the pliers handles to turn, twisting the safety wire!

When you have the amount of twists required, grasp the handles and squeeze. This will release the safety wire from the jaws of the pliers.

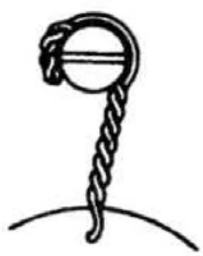
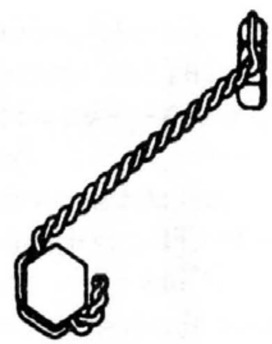
Use the cutters in the jaws to cut the safety wire to the proper length and then bend the end of the wires over so that you don't poke yourself on them the next time you reach into work on something.

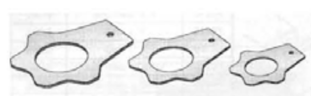
See next pages for examples

HERE ARE SOME EXAMPLES OF PROPER SAFETY WIRE TECHNIQUES







These units are used where a nut or bolt does not have a hole for safety wire. You install them under the nut/bolt bend the tabs over the side of the nut/bolt and then safety wire the tab with the hole in it.

Source: http://www.bobmartinco.com/pdf/safety_tying_wire.pdf

Appendix F: Industry Events and Skills Disciplines Impacted

This appendix provides the details of applicable findings from INPO ICES database review from January 1, 2014 to February 8, 2018 and most likely the skills disciplines impacted. Key search words were "set screw," "locking," and "anti-rotation." The URL links are available to those with an INPO ICES access through the INPO website.

Table F-1
Industry events and skills disciplines impacted

View URL	Component Involved	Discipline (M = Mechanical) (E = Electrical) (H = HVAC) (IC = I&C)
https://apps.inpo.org/xIces/ICESReport/313121	Actuator	M/E
https://apps.inpo.org/xIces/ICESReport/313907	Actuator	M/E
https://apps.inpo.org/xIces/ICESReport/407770	Actuator	M/E
https://apps.inpo.org/xIces/ICESReport/407888	Actuator	M/E
https://apps.inpo.org/xIces/ICESReport/313713	Air handler	M/H
https://apps.inpo.org/xIces/ICESReport/318156	Air handler	M/H
https://apps.inpo.org/xIces/ICESReport/324305	Air handler	M/H
https://apps.inpo.org/xIces/ICESReport/324108	Air handler	M/H
https://apps.inpo.org/xIces/ICESReport/322111	Air handler	M/H
https://apps.inpo.org/xIces/ICESReport/316361	Breaker	E
https://apps.inpo.org/xIces/ICESReport/420306	Breaker	E
https://apps.inpo.org/xIces/ICESReport/316423	Cable	E

Table F-1 (continued)
Industry events and skills disciplines impacted

View URL	Component Involved	Discipline (M = Mechanical) (E = Electrical) (H = HVAC) (IC = I&C)
https://apps.inpo.org/xIces/ICESReport/321210	Chiller	M/H
https://apps.inpo.org/xIces/ICESReport/324611	Crane	M
https://apps.inpo.org/xIces/ICESReport/318301	Door/hatch	M
https://apps.inpo.org/xIces/ICESReport/426843	Door/hatch	M
https://apps.inpo.org/xIces/ICESReport/313712	Misc.	M
https://apps.inpo.org/xIces/ICESReport/321911	Misc.	M
https://apps.inpo.org/xIces/ICESReport/312708	Pump	M
https://apps.inpo.org/xIces/ICESReport/316281	Pump	M
https://apps.inpo.org/xIces/ICESReport/317279	Pump	M
https://apps.inpo.org/xIces/ICESReport/422729	Pump	M
https://apps.inpo.org/xIces/ICESReport/407748	Pump	M
https://apps.inpo.org/xIces/ICESReport/324342	Pump	M
https://apps.inpo.org/xIces/ICESReport/324784	Pump	M
https://apps.inpo.org/xIces/ICESReport/314970	Pump	M
https://apps.inpo.org/xIces/ICESReport/407503	Relay	IC
https://apps.inpo.org/xIces/ICESReport/311187	Switch	E
https://apps.inpo.org/xIces/ICESReport/312613	Valve	M
https://apps.inpo.org/xIces/ICESReport/313666	Valve	M
https://apps.inpo.org/xIces/ICESReport/316492	Valve	M
https://apps.inpo.org/xIces/ICESReport/320150	Valve	M
https://apps.inpo.org/xIces/ICESReport/321380	Valve	M
https://apps.inpo.org/xIces/ICESReport/408015	Valve	M
https://apps.inpo.org/xIces/ICESReport/407349	Valve	M
https://apps.inpo.org/xIces/ICESReport/325494	Valve	M

Appendix G: Translated Table of Contents

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位置固定装置的基础知识

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最终报告，2018 年 10 月

产品说明

本报告重点介绍如紧定螺钉、锁紧螺母、安全锁线、开口销、防松螺纹油等位置固定装置。

背景
多年来，美国电力研究院发表了各种报告，为螺栓连接的使用提供了指导。

目的
本研究的目的如下：

- 减少由位置固定装置、材料和方法失效引起的核电站事故。
- 为位置固定装置的安装方法和材料提供背景资料和具体建议。
- 为发生失效的位置固定材料和方法提供故障排除方法实例。
- 提供应纳入现场维护程序、工作指令和培训的信息，向核电站人员提供正确组装位置固定材料和方法方面的知识。

方法
本报告回顾了位置固定装置的基础知识。整篇报告着重介绍了以下几个方面的关键点：基准测试、成本、人力绩效、信息、观察、安全和技术。附录提供包括扭矩表等补充信息。

结果
本报告为维护人员（如机械师、规划人员和工程师）提供了减少失效实例以及有效、高效安装这些装置的知识。位置固定装置的正确选择和使用指南使其更有效地防止松动，保证后期设备的可靠性条件。

应用场合、价值与使用
本报告中提供的信息将有助于维修人员预防和排除机械连接故障。

位置固定装置故障是不利的，因为（1）故障会造成人员安全隐患（即，当疲劳失效突然发生且没有预警时，可能对故障附近的人员造成直接风险）（2）故障会导致直接和间接成本增加，包括因设备退化、长时间的换料停电和维修费用而导致的强迫停运。

关键词
螺栓连接
维护
位置固定
紧定螺钉
扭矩

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Principaux fondamentaux sur les dispositifs de maintien de position

La totalité ou une partie des exigences du programme d'assurance qualité nucléaire EPRI (EPRI Nuclear Quality Assurance Program) s'appliquent à ce produit.

YES NO

Chef de projet EPRI
G. Boles

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3002012803
Rapport final, octobre 2018

Description du produit

Le présent rapport porte sur les dispositifs de maintien de position, tels que les vis de fixation, les écrous de blocage, les fils à freiner, les clavettes, le frein filet et ainsi de suite.

Contexte
Au fil des années, l'Electric Power Research Institute a publié plusieurs rapports sur l'utilisation des éléments de boulonnage.

Objectif
Les objectifs de la présente étude sont les suivants :

- Réduire les événements de centrale causés par des défaillances des dispositifs, des matériaux et des méthodes de maintien de position.
- Fournir des informations générales et des suggestions pratiques sur les méthodes permettant d'installer les dispositifs et les matériaux de maintien de position.
- Fournir des méthodes de dépannage des incidents liés aux matériaux et aux méthodes de maintien de position.
- Mettre à disposition des informations à intégrer aux procédures d'entretien sur site, aux ordres de travail et aux formations afin que le personnel des centrales sache comment utiliser les matériaux et les méthodes de maintien de position.

Approche
Le rapport passe en revue quelques principaux fondamentaux sur les dispositifs de maintien de position. Différents points clés sont présentés dans le rapport, notamment dans les catégories suivantes : valeurs de référence, coûts, performance humaine, information, observation, sécurité et aspect technique. Les annexes fournissent des renseignements complémentaires et des tableaux de couple de serrage.

Résultats

Le rapport fournit aux équipes chargées de l'entretien (par exemple aux mécaniciens, aux planificateurs et aux ingénieurs) des connaissances qui leur permettront de réduire les défaillances et d'installer ces dispositifs de façon efficace et efficiente. La sélection et l'utilisation judicieuses des dispositifs de maintien de position optimisent leur efficacité, évitent que les pièces connectées se détachent et améliorent donc la fiabilité des équipements correspondants.

Applications, valeur et utilisation

Les informations fournies dans le rapport aideront les membres du personnel à éviter et résoudre les défaillances de joints mécaniques.

Il convient d'éviter toute défaillance d'un dispositif de maintien de position du fait que (1) ces défaillances mettent en danger la sécurité du personnel (c'est-à-dire lorsque les défaillances de fatigue se produisent soudainement et sans avertissement, ce qui entraîne un risque direct pour les membres du personnel se trouvant à proximité) et (2) ces défaillances donnent lieu à des frais directs et indirects, y compris en cas d'arrêt forcé pour panne d'équipement, d'arrêt de ravitaillement en combustible et lorsque des frais de réparation sont encourus.

Mots-clés

Boulonnage
Entretien
Maintien de position
Vis de serrage
Couple de serrage

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位置保持装置の基礎

本成果物には、EPRI 原子力品質保証プログラム (Nuclear Quality Assurance Program) の要件の全てまたは一部が適用される。

YES NO

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成果物記述書

本報告書では、止めねじ、ロックナット、ロックワイヤ、割ピン、ねじロック剤などの位置保持装置に焦点を当てる。

背景
長年にわたり、Electric Power Research Institute (電力研究所)は、ボルト締めの使用法に関する指針を提供するさまざまな報告書を発行してきた。

目的
本調査の目的は次のとおりである。

- 位置保持装置、材料、および方法の不具合によって引き起こされる発電所事象を減らす。
- 位置保持装置および材料の設置方法に関する参考資料と具体的な提案を提供する。
- 不具合のある位置保持材料および方法についてトラブルシューティングを行う際の方法を示す。
- 現場の保全手順、作業指示、および訓練に組み込むべき情報を利用可能にして、発電所作業員に位置保持材料および方法を適切に組み込むための知識を提供する。

取り組み方
本報告書は位置保持装置の基礎を精査するものである。報告書全体を通して、重要ポイントを強調し、次のカテゴリーに焦点を当てている。ベンチマーキング、費用、ヒューマンパフォーマンス、情報、観察、安全性、および技術。補遺は、トルク表を含む補足情報を示す。

結果
本報告書は、保全担当者（メカニック、プランナー、エンジニアなど）に対して、不具合の発生を減らし、これらの装置を効果的かつ効率的に設置するための知識を提供する。位置保持装置を適切に選択して使用するための指針により、緩み防止とそれに続く機器信頼性に関する状況にとってより効果的である。

適用、価値、および使用
本報告書に記載されている情報は、機械接合部の不具合を防止し、トラブルシューティングを行うために役立つ。

位置保持装置の不具合は、(1) 作業員の安全性の問題を招く不具合 (つまり、疲労不具合が突然警告なしに発生すると、不具合の発生場所付近の作業員に直接の危険をもたらす可能性がある) および (2) 機器の劣化に起因する強制停止、燃料交換時停止の長期化、補修費用など、直接的・間接的な費用の増加をもたらす不具合となるため、好ましくない。

キーワード
ボルト締め
保全
位置保持
止めねじ
トルク

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위치 고정 장치의 기본 원리

본 제품에는 EPRI 원자력 품질 보증 프로그램의
요건이 전부 또는 일부 적용되었다.

YES NO

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최종 보고서, 2018년 10월

제품 설명

본 보고서에서는 고정 나사, 잠금 너트, 잠금 와이어, 코터 핀, 회전나사 잠금 장치 같은 위치 고정 장치에 대해 중점적으로 다룹니다.

배경
EPRI(미국전력연구소)는 오래 전부터 볼트 고정법에 대한 지침을 제공하는 다양한 보고서를 발표해 왔습니다.

목적
본 연구의 목적:

- 위치 고정 장치, 고정재, 방법상의 문제로 인해 발생하는 발전소 사고를 줄임
- 위치 고정 장치 및 고정재 설치 방법과 관련된 배경 자료와 구체적인 의견을 제시함
- 위치 고정재 및 방법에 문제가 생길 경우 해결할 수 있는 방법을 제시함
- 현장 유지 보수 절차, 작업 순서, 교육 과정에 통합시켜야 하는 정보를 제공해, 발전소 직원들이 위치 고정재와 방법을 올바르게 활용할 수 있는 지식을 갖추도록 함

접근법
본 보고서에서는 위치 고정 장치의 기본 원리를 검토합니다. 보고서 전체에 걸쳐 벤치마킹과 비용, 인적 성과, 정보, 관찰, 안전성, 기술 등을 자세히 살펴보고 핵심 포인트를 강조합니다. 부록에서는 토크 표를 비롯한 추가적인 정보를 제공합니다.

결과
본 보고서는 유지보수 담당자들(정비사, 설계자, 엔지니어 등)에게 장치 고장을 줄이고 해당 장치를 보다 효과적, 효율적으로 설치할 수 있는 지식을 제공합니다. 적절한 위치 고정 장치를 선택하고 사용 지침을 따르면 고정이 풀리거나 그로 인해 발생하는 장치 신뢰성 문제에 보다 효과적으로 대처할 수 있습니다.

활용, 가치, 이용 방법

본 보고서에서 제공하는 정보는 직원들이 기계 접합부의 고장을 예방하고 해결하는 데 도움이 될 것입니다.

위치 고정 장치가 고장 나면 (1) 직원의 안전이 위험해지고(아무 경고도 없이 갑자기 피로 파괴가 발생하면 고장 난 장비 주변에 있던 직원에게 직접적인 위험이 발생), (2) 장비 성능 저하로 인한 고장 정지, 장시간 동안의 연료 보급 중단, 수리 비용 등 직간접적인 비용이 증가하므로 바람직하지 않습니다.

키워드

볼트 고정
유지관리
위치 고정
고정 나사
토킹

목차

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Fundamentos de dispositivos de retenção de posição

Os requisitos do Programa de Garantia de Qualidade Nuclear do EPRI se aplicam a este produto total ou parcialmente.

YES NO

Gerente de projeto EPRI
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Descrição do produto

Este relatório trata de dispositivos de retenção de posição tais como parafusos de fixação, contraporcas, arame de lacre, contrapinos, pasta de fixação de roscas, entre outros.

Panorama
Há anos o Electric Power Research Institute publica vários relatórios para orientação sobre o uso de aparafusamento.

Objetivo
Os objetivos deste estudo incluem:

- Redução de ocorrência nas usinas causadas por falhas nos dispositivos, materiais e métodos de retenção de posição.
- Apresentar material de contextualização e sugestões específicas sobre os métodos de instalação dos dispositivos e materiais de retenção de posição.
- Apresentar métodos para solução rápida de problemas ou para tratar falhas nos materiais e métodos de retenção de posição.
- Disponibilizar informações que devem ser incorporadas aos procedimentos de manutenção do site, às ordens de serviço, e aos treinamentos, para oferecer à equipe da usina o conhecimento necessário em relação aos métodos e à montagem de materiais de retenção de posição adequadamente.

Abordagem
O relatório analisa os fundamentos dos dispositivos de retenção de posição. Em todo o relatório, os pontos-chave são destacados, com ênfase nas categorias: benchmarking, preço, desempenho humano, informação, observação, segurança e técnica. Os apêndices apresentam informações complementares, incluindo tabelas de torque.

Resultados

O relatório oferece, às equipes de manutenção (por exemplo, mecânicos, planejadores e engenheiros), o conhecimento necessário para reduzir os eventos de falha e para instalar esses dispositivos de maneira eficiente e eficaz. Orientações sobre a seleção e o uso apropriado dos dispositivos de retenção de posição fazem com que eles sejam mais eficazes na prevenção de afrouxamento, e nas condições subsequentes de confiabilidade do equipamento.

Aplicações, valor e uso

As informações apresentadas no relatório ajudarão a equipe a evitar e resolver de forma rápida falhas de conexão mecânica.

As falhas em dispositivos de retenção de posição são indesejáveis pois (1) criam riscos à segurança da equipe (ou seja, falhas de fadiga, que ocorrem de repente e sem aviso, podem causar risco direto à equipe nas proximidades da falha), e (2) falhas que resultam em aumento dos custos diretos e indiretos, incluindo paradas forçadas causadas pela degradação do equipamento, paradas longas para abastecimento, e despesas com reparos.

Palavras-chave

Aparafusamento
Manutenção
Retenção de posição
Parafusos de fixação
Torqueamento

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Fundamentos de los equipos de retención de la posición

Este producto está sujeto a la totalidad o a parte de los requisitos del Programa de garantía de calidad nuclear de EPRI.

YES NO

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Descripción del producto

Este informe se centra en los equipos de retención de la posición tales como tornillos prisionero, tuercas de bloqueo, cables de seguridad, pasadores de chaveta, compuestos de bloqueo de roscas, etc.

Antecedentes

A lo largo de los años, Electric Power Research Institute ha publicado varios informes que ofrecen orientación sobre el uso de la tornillería.

Objetivo

Los objetivos de este estudio incluyen los siguientes:

- Reducir los eventos de las centrales causados por un fallo en los equipos, los materiales y los métodos de retención de la posición.
- Proporcionar materiales de apoyo y recomendaciones específicas sobre los métodos de instalación de equipos y materiales de retención de la posición.
- Proporcionar métodos para la resolución de problemas en caso de fallos en los materiales y en los métodos de retención de la posición.
- Poner a disposición información que debe incluirse en los procedimientos de mantenimiento, órdenes de trabajo y formación del lugar, para ofrecer al personal de la central los conocimientos necesarios para instalar adecuadamente los materiales de retención de la posición y sus métodos.

Planteamiento

El informe analiza los fundamentos de los equipos de retención de la posición. En el informe, se destacan los principales aspectos y se hace hincapié en las categorías: análisis comparativo, costes, rendimiento del personal, información, observación, seguridad y aspectos técnicos. Los apéndices proporcionan información adicional, incluidas las tablas de par de torsión.

Resultados

El informe proporciona al personal de mantenimiento (por ejemplo, mecánicos, responsables de la planificación e ingenieros) los conocimientos necesarios para reducir el número de casos de fallos y para instalar estos equipos con eficacia y eficiencia. La adecuada selección y orientación sobre el uso de los equipos de retención de la posición los hacen más eficaces a la hora de evitar que se aflojen y respecto a las correspondientes condiciones de fiabilidad de los equipos.

Aplicaciones, valor y uso

La información incluida en el informe ayudará al personal a evitar y solucionar los problemas de averías en las uniones mecánicas.

Deben evitarse las averías en los equipos de retención de la posición, ya que estas (1) crean riesgos para la seguridad del personal (es decir, cuando se producen fallos súbitos por fatiga y sin previo aviso que pueden generar riesgos directos para el personal en las proximidades de la avería) y (2) originan mayores costes directos e indirectos, como paradas obligatorias derivadas del deterioro de los equipos, paradas prolongadas por repostaje y costes de reparación.

Palabras clave

Tornillería
Mantenimiento
Retención de la posición
Tornillos prisionero
Par de torsión

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