AN INTRODUCTION TO LOCKING FASTENERS

INTRODUCTION

Fasteners in joints exposed to dynamic loads, stress reversals, shock, vibration, and radical atmospheric fluctuations are susceptible to loosening. When the design of the joint permits fastener tightening to high preload levels, the chances of fastener loosening in service are significantly reduced. However, in some applications the joint makeup — e.g. interposition of a soft gasket, accessibility, etc. — is such that preload alone is inadequate and an assisting anti-loosening measure must be employed. One such measure is use of locking fasteners.

Locking fasteners comprise a broad family of mechanical fasteners each having a designed-in capability to help resist loosening after the fastener is installed in its service application. Locking fasteners encompass both externally and internally threaded parts and there are literally dozens of designs from which to choose.

All can be broadly generalized into three basic categories — free-running, prevailing torque, and chemical reaction. Free-running locking fasteners assemble freely until seated and then gain their resistance to loosening through the presence of an accessory device or through development of a tensile load in the externally threaded component due to its tightening. Prevailing-torque locking fasteners have a self-contained feature which creates frictional interference between the threads of the mating components. Chemical reaction locking fasteners adhesively bond mating threads together through the application and reaction of chemicals.

The common design principle of all locking fasteners is to increase their break-loose torque. Most do it extremely well. The major disadvantage of the free-running types is that when the break-loose resistance is overcome, either through loss of fastener preload or ineffectiveness of the accessory device, further resistance to fastener loosening becomes essentially zero and eventual disengagement of the mating parts is a distinct possibility. In contrast, prevailing-torque locking fasteners retain a continuing resistance to removal rotation even after the fastener preload is fully dissipated. Chemical reaction locking fasteners are mainly suited to applications intended to be permanent; they have little, if any, re-use potential. For these reasons, prevailing-torque locking fasteners enjoy a degree of popularity beyond that of the other two types.

Definitions

Locking. Locking is a generic term used commercially to identify fasteners that have a capability to resist some magnitude of loosening. "Locking" is not intended to imply a permanency of fixity.

"All-metal" is a generic term which includes nuts that are all metal and those which have non-metallic patches, pellets or plugs located in their threads.

Prevailing Torque. Prevailing torque is the torque necessary to rotate a fastener relative to its mating component with the torque being measured while the fastener is in motion and with zero axial load in the assembly. Prevailing-on torque is the torque measured when the fastener is being advanced toward its seated position. Prevailing-off torque is the torque measured when the fastener is being removed. For free-running fasteners prevailing torque is zero.

Break-Loose Torque. Break-loose torque is the torque, applied in a removal direction, necessary to start the fastener in motion from its fully preloaded installed position. For most locking fasteners, break-loose torque is higher than installation (clamp load) torque.

Breakaway Torque. Breakaway torque is the torque necessary to start a fastener in motion after the axial load between the mating components has been reduced to zero. Breakaway torque for free-running fasteners is close to zero. For prevailing torque fasteners it can be substantial and is the measure for evaluating the effectiveness of any particular design.

FREE-RUNNING LOCKING FASTENERS.

ACCESSORY-DEPENDENT TYPES.

Jam Nuts.

One of the very first "locking" techniques was use of a jam nut in combination with a full thickness nut. To be effective the jam nut goes on first, is tightened, and then the thicker nut tightened against the jam nut. The disadvantages of this system are that preload development is

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limited to the strength of the jam nut, two nuts, extra bolt length, and added installation time.

Dimensional standards for jam nuts are given on pages D-4, D-5, D-13, and D-14. Strengths of jam nuts approximate 60 percent of those of full thickness nuts of the same size, style and grade as given in ASTM A563, page B-108.

Nuts With Cotter Pins.

A cotter pin fitted through nut slots aligned with a hole drilled through the shank of an externally threaded component effectively retains the nut in its originally tightened position. Until such time as the pin is removed or shears, the nut is permanently captive. The drawbacks of this system are the need to carefully locate the hole through the bolt shank, the extra component, reduced nut strength due to slotting, and added installation time. In many applications, a much more serious consideration is the sacrifice of "fine tuning" tightening to develop the desired preload. Slot/hole alignment occurs at 60 deg intervals and within such a relatively broad rotational range over or undertightening becomes a distinct possibility.

Dimensional standards for slotted nuts are given on pages D-6, D-10 and D-16, those of cotter pins on page L-37. Strengths of slotted nuts approximate 80 percent of those of full thickness nuts of the same size, style and grade as given in ASTM A563, page B-108.

Lock Wire.

Wire fed through holes in the heads of bolts and screws to "tie them together" has a modest degree of popularity, particularly in aerospace applications. The key to the effectiveness of this system is to route the wire through and between the fastener heads in a pattern such that if any fastener tries to move in a removal direction the tensioned wire tends to further tighten the adjacent fasteners. The system is generally limited to multi-fastener applications of externally threaded fasteners into tapped holes. Disadvantages are the need for drilled head fasteners, added installation time, and great care in the proper routing of the wire.

Dimensional standards for drilled fillister head machine screws are given on page I-32, those for drilled head socket cap screws on page G-9. Other types of headed fasteners can be drilled for lock wire applications but, before doing so, it may be prudent to examine the possibility of head strength reduction.

Lock Washers.

Lock washers of the two basic types — spring action and toothed — are popularly used accessories to assist against fastener loosening. The preponderance of their use is concentrated with small size screws, however some spring action types are available in sizes to 3 inches. Spring action lock washers — e.g. helical spring, belville, conical — placed under a screw head or nut compress during tightening and because their yield strength is not exceeded (lock washers are heat treated), they exert a spring-back reactive force which helps retain fastener tension and through it resistance to loosening. When fasteners assembled with toothed lock washers are tightened, the washer teeth bite into the fastener bearing surface and that of the work piece being joined creating a rachet-type resistance to removal. While catalogued in this presentation as accessory dependent types — which they are — fasteners with lock washers obviously cannot function without development of fastener preload.

The principal drawback of spring action lock washers is they flatten at relatively low loads compared to the preload level generally desired in the fastener. This means their reactive force comes into play only after a significant portion of the initial preload has been lost. The drawback of toothed lock washers is they scratch and mar surfaces. For fasteners and members with protective platings or coatings this becomes a genuine concern. A further drawback for all lock washers is the need to handle two pieces, and, in the case of belville and conical washers, the need to correctly orient their assembly on the threaded fastener.

For application data and dimensional standards of helical spring lock washers refer to page L-7, for toothed lock washers to page L-13, and for conical lock washers to SAE J773. There are no national standards for belville spring washers.

Sems.

Sems function exactly the same as screws with lock washers. The big difference is that during fastener manufacture the lock washer is assembled and held captive on the screw thus making the unit a "one-piece" fastener. This convenience coupled with reduced installation time and the assurance the lock washer is always present and correctly oriented definitely favors the economics of selecting sems as an alternative to the two-piece screw and lock washer combination. Nuts with preassembled lock washers are also commercially available.

Dimensional standards for sems are covered in ANSI/ASME B18.13, page J-8. There are no national standards for nuts with preassembled lock washers.

PRELOAD-DEPENDENT TYPES.

Serrated Tooth Fasteners.

An outgrowth of fasteners in combination with toothed lock washers is screws and nuts with serrated teeth formed integrally on their bearing surfaces. The teeth, located at the periphery or radially, are shaped and directed so that when the fastener is tightened they bite into the surface of the member being joined. Like the toothed lock washer this creates a rachet-type resistance to removal. Unfortunately, like their counterpart, serrated tooth fasteners also damage the surface against which they bear. However, the convenience of handling one item, with the assurance the locking feature is present, merits their consideration.

Designs of serrated tooth locking fasteners are proprietary and not covered in national standards.

Elastic Deformation.

A number of fastener designs with their locking ability based on elastic deformation principles have been introduced over the years. Some still enjoy modest popularity. In each design the bolt head or nut body is modified in some respect — slotting, dishing the head, recessing or concaving bearing surfaces, etc. — to improve the fastener's under-load flexibility or "springiness." When tightened the axial load developed in the fastener elastically distorts it and gives it an added capacity to absorb vibrating or pulsating externally applied loads. Additionally, in some nut designs the under-load compression against the nut bearing face translates into radial forces which squeeze the threads at the top of the nut into those of the mating component.

None of the elastic deformation fastener designs, either those now obsolescent or those still in demand, are covered in national standards.

Special Screw Threads.

Some externally threaded fasteners have specially designed threads which, when axially loaded, provide a locking action. In each design the screw thread profile is modified in such a way to allow free assembly, but at seating and tightening, the threads ride into or against the mating threads to create a jamming action. One of the first designs was the Dardelet thread which, prior to the maturing of high strength bolt technology, enjoyed some popularity in structural applications. Other locking thread designs have since been developed and offered commercially. Most are proprietary, none are covered in national standards.

PREVAILING-TORQUE LOCKING FASTENERS.

Prevailing-torque locking fasteners gain their locking action through frictional resistance induced between mating threads. The interference is intentional. This means that during first, or any subsequent installation, there is a positive resistance to assembly which continues through fastener seating and tightening. However, most importantly, a high residual resistance remains so that, even though fastener preload is lost entirely, disassembly is difficult and full disengagement in service unlikely.

Prevailing-torque locking fasteners encompass both internally and externally threaded fasteners and, in any joint design, the engineer must decide which of the mating components should be the locking fastener. In tapped hole applications the answer is obvious. However, in bolt/nut combinations the prevailing-torque feature can be in either and the system will function effectively. At the present time prevailing-torque nuts are the more popular for the reasons one nut can accommodate several styles, types and lengths of bolts and screws, properties of nuts are more fully standardized, there are many proven designs from which to choose, most are commercially stocked items. Conversely, prevailing-torque bolts and screws are essentially one-application parts due to the need to locate or position the locking feature on each length.

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Prevailing-torque characteristics are gained through various means with all falling within two generalized categories — all-metal fasteners with their threads modified in some manner and fasteners with a non-metallic element added or fused into their threads. Each has its advantages and its limitations.

For all-metal fasteners physical shape and manufacturing methods dictate the manner of thread modification. Externally threaded fasteners are solid, not easily deformed, and their threads are usually formed by thread rolling. Consequently, it is easiest to produce them with modified or asymmetric thread profiles. In contrast, nuts are hollow and lend themselves to distortion through top or side applied pressure thus introducing localized deformation of thread form. It is possible, of course, to tap nuts with special threads. But, tapping is for full nut thickness which makes thread start during assembly extremely awkward.

Non-metallic elements for bolts and screws are usually plastic strips or patches in their threads located at least 2 to 3 threads from the point (to allow free-running thread start) and close to the anticipated mid-point engagement with the internal thread. Non-metallic elements in nuts are full collars or rings at the top, patches fused in the threads, or plugs through the nut wall at nut mid-thickness. Nylon is most frequently used because of its rigidity and superior memory properties. However, it has temperature and certain environmental and chemical exposure limitations. Teflon has some use because it can survive higher temperatures but its lower rigidity and higher lubricity adversely affect its prevailing-off torque performance.

All-metal prevailing-torque fasteners have fewer temperature and environmental limitations but they exhibit less resiliency, have a higher susceptibility to thread galling, and are not suited for long run-on assemblies. Also, their deformed threads risk damage to mating threads (or to their own, depending on the relative hardnesses of mating parts) which may reduce their reuse potential. Non-metallic element fasteners can tolerate longer run-ons, mating threads are not damaged, reusability is improved.

A great number of different designs of prevailing-torque locking fasteners are currently being marketed. Practically all are proprietary and tradenamed, most carry manufacturer claims of unique capabilities beyond those of competing products. It would be impractical for any consumer to fully test and comparatively evaluate all designs in search of the one best suited for a particular application. Consequently, as an assist, IFI many years ago published "plateau" standards for prevailing-torque fasteners. IFI 100/107, page F-6, details the dimensional envelopes, strength grades, and prevailing-torque values for hex and hex flange prevailing-torque nuts. IFI-124, page F-18, establishes prevailing-torque requirements for lock screws. While this latter standard was originally written for non-metallic insert type screws, it applies equally to any all-metal design which meets its test requirements. The two standards define basic requirements, in effect plateau levels of properties, which all product designs within the family must meet. This then frees the consumer to turn his attention to an evaluation of other properties of importance to the application.

What are some of these other considerations?

— Installation method, manual or automated. Prevailing-torque nuts with their locking feature located at the top surface can be installed in one direction only. Nuts with their locking feature at nut mid-height are non-directional or "two-way." Directional nuts have a longer thread start than two-way nuts.

— Reusability. Prevailing-off torque values tend to decline with each installation. Rate of decline varies with different product designs. If frequent in-service disassembly is expected, a design with a slower drop off of its prevailing-off torque capacity might be considered. If the assembly is viewed as permanent, then a fastener with a high first prevailing-off torque, but not necessarily continuing at a high level, might be given first consideration.

— Sealing against entry or loss of fluids or gases. Non-metallic elements mold themselves to mating threads and effectively seal escape routes along the thread helix. But, before making a final decision, it may be prudent to examine the possibility of a reaction between the plastic element and the chemical it's sealing.

— Environmental conditions. What is the expected temperature? Will the assembly be exposed to chemicals or in a corrosion inducing atmosphere?

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— Reliability and uniformity. In assembly line applications it is usually desirable to establish a tightening torque, set the tightening tools accordingly, and then over a period of production time expect some measure of consistency from one installation to the next. Some prevailing-torque fastener designs exhibit a close uniformity product to product. Others tend to range more widely. What is an acceptable scatter for the application?

Prevailing-torque nuts are the only family of industrial fasteners with standardized torque-tension requirements. IFI-101, page F-16, details such values for steel, cadmium and waxed hex and hex flange nuts, in sizes 1/4 through 1 in. and in the two strength grades normally combined with heat treated bolts and screws. IFI-101 requires that the nut develop a specified tensile load in a mating screw or bolt with the application of a tightening torque falling within a specified range. The range approximates plus or minus 15 percent from the mean, which, for threaded fasteners, is quite narrow. A further narrowing is possible through judicious selection of the prevailing-torque fastener and its lubrication. Lubrication reduces the needed installation torque, narrows the torque-tension scatter band, and helps fight galling. But, lubrication drastically influences torque-tension relationships. It is vitally important to conduct some preliminary testing of the fastener in its application to establish the "correct" tightening torque.

In closing, there are two joint design considerations worth comment.

When deformed threads are assembled with standard form threads there is a possibility that one or both may be damaged. Consequently, it is important that a strength grade of prevailing-torque fastener be selected that properly matches that of the mating component. Damage is minimized when fasteners of compatible strength grades are combined. Damage is greatest when the mating fasteners have widely different hardnesses, for example combining a heat treated nut with a non-heat treated low carbon steel bolt or screw. IFI 100/107 gives guidance on strength grade compatibilities.

Prevailing-torque locking fasteners function properly only when the locking feature engages full form threads. Most externally threaded parts are pointed which means that their first one or two threads are truncated and of imperfect form. Consequently, when using prevailing-torque nuts of any design, and most particularly of "top lock" designs, it is important to arrange for an adequate protrusion of bolt or screw end beyond the top of nut to insure effective locking.

CHEMICAL REACTION LOCKING FASTENERS.

Use of chemicals to form a more permanent bond between mating fasteners is a relatively recent development. Most frequently used are an epoxy resin coupled with a hardening agent which, when mixed, react and harden into an adhesive bond.

There are two application systems. In the first, pre-mixed chemicals are applied to the fastener threads by the user at the time of fastener installation. In the second, the resin and hardener are encapsulated separately, usually in the threads, during manufacture. On assembly the capsules rupture, the chemicals mix, and react to form the adhesive bond. This latter system is the more convenient to use and assures the correct mix of chemicals. However, because of the additional processing during fastener manufacture, it's more expensive.

Adhesive bonding is an extremely effective fastener locking technique. Following installation, fasteners are difficult to remove and fastener reuse is usually impractical. For these reasons use of chemicals is advisable only for permanent one-time applications.

During assembly, the installation torque for fasteners with the chemicals added at that time is essentially zero. For fasteners with preapplied chemicals some installation torque is necessary to rupture the capsules. However, and much more importantly, if in service the bond is broken, both systems provide a significant measure of prevailing-off torque because of the continuing presence of the set chemicals between the threads causing interference and resistance to disassembly.

IFI-125, page F-22, covers requirements for lock screws with chemical additives, both preapplied and at-time-of-installation. The requirements are presented in the form of a performance test to permit comparative evaluation.