How Tooling Effects Fastener Selection

工具安装如何影响紧固件选择

by Thomas Doppke

虽然典型设计师会挑选出他认为对其设计最理想的紧固件，他的选择还是可能因组装厂的考虑因素而被修改。精明的紧固件工程师在选择一个零件时，会考虑许多因素，包括工具与组装厂在组装时会采用的方法。

While the typical designer picks out what he thinks is the ideal fastener for his design, his choice will probably be modified by assembly plant considerations. Astute fastener engineers consider many factors when selecting a part, among which are the tooling and assembly plant methods that will be used during their installation.

Installation Factors

Among the obvious factors is **shape**. Hexagon head bolts have the maximum tool contact surface for torque tightening. Hexagon sockets are standard and inexpensive. Where cosmetic appearance is a requirement, a pan head or other decorative styles may be used but with caution. These types of parts can fall out of the drive sockets easily, the tool bit can jump out causing damage to surrounding paint and surfaces, and availability and commonization efforts to reduce complexity of parts are brought out at design/cost meetings. The use of steel as a material allows the bolts to be held by magnetic sockets as well as its higher strength although much aluminum is being used for corrosion resistance today in non-structural areas. Special bits (i.e. star and six lobe types) allow higher torque on pan head fasteners to be used with lessened chance of twist out and recess damage.

Of major consideration is **the direction of installation**. Often this factor is rarely thought of. If the screw/bolt is assembled in a direction which makes it prone to fall out of the socket or off the bit, special considerations are necessary. Ergonomics and Manufacturing for Design programs state that the best direction for an assembly is downward. However, this means that the bolt/screw has a great probability of falling out/off. Magnetic sockets and bits help but care should be exercised to avoid bumping the part when installing to prevent premature separation. Non-magnetic fasteners utilize “stick fit” sockets, that is, the sockets are slightly undersized so that the fasteners are jammed into it. This seems to work until the socket wears enough to loosen the fit or is too tight, causing difficulty in removing the socket from the bolt after installation.

Fastener length and diameter have always been “as required” factors. However, use of small diameter, short parts causes delays in assembly time. Operators often wear gloves and even bare hand operations have a problem with picking up and placing short and small diameter parts

安装关键

在一些明显因素中，**形状**是其中一项。六角头螺栓在扭距锁紧方面，有最大的工具接触面。内六角螺栓是标准品，价格不高，若必须具备美观外表时，可采用盘头或其他装饰型的，但必须小心。这类型产品容易掉出驱动套筒之外，工具钻头容易跳出，导致周围油漆与表面受到损伤。在设计与成本的会议里，零件的可获性与普通性常被提出，希望能减少零件复杂性。采用钢铁作为材料，除了使螺栓有较好强度，还可被有磁性的套筒吸夹，虽然为了抗腐蚀，今天在非结构性的地方已经使用许多铝材零件。特殊工具钻头（如星形与梅花形），可让盘头螺栓有较高的扭力，减少扭转脱出与内凹处损伤的风险。

安装方向是主要考虑项目，此因素常常被遗忘。如果螺丝或螺栓是被组装在一个容易弹出套筒或工具钻头的方向，那就必须有特殊考虑。人体工学与设计制造的规划谈到，最好的组装方向是向下的，然而这意味著螺栓或螺丝掉出来的可能性更大。虽然有磁性套筒与工具钻头可以协助，但仍须小心，安装时要避免碰撞到零件，以防零件过早脱落。没有磁性的紧固件，会使用「紧配」的套筒，

(Fig. 1). It has been found that about 6mm diameter and length are about the smallest dimensions that an operator can easily handle. Dropped parts increase production cost and may interfere with machinery if they fall into working parts of conveyors or other components being assembled.

Smaller and shorter parts also lead to longer assembly time as several attempts may be needed to install the parts. If smaller parts are an absolute necessary assembly, times should be adjusted accordingly. While tube-fed small screw assembly systems are common, the diameter to length ratios should be carefully considered. Too small a ratio may cause the screws to tumble and jam sideways within the tube, a further delay in assembly.

Fig. 1 Dealing with Short and Small Diameter Parts with a Glove
图一 组装短小零件

For the same reason, handling **the finish on parts** should be reviewed. Oily and slippery finishes will cause dropped parts, even if they can be put into a magnetic holder. They must be loaded in the socket/bit first. Also the presence of an oily finish can be transmitted to surrounding areas and surfaces, upholstery being especially susceptible. Oily (sticky) finishes can also clog feed tubes.

Cross Threading

In former days assembly was a slow, hand operated process. The operator placed the bolt in the hole, added the nut and finger started it on. He lightly tightened it with a hand wrench, later with a torque wrench to specification for more accurate loading. Today time is of the essence. Production time study people measure assembly operations with stop watches to the nearest one hundredth of a second. Line speeds are such that a missed operation may occur in as little as a second. Today the operator places a bolt in the socket of a high speed assembly tool and rams it through the hole and into the nut WITH THE GUN RUNNING! Very efficient but it also leads to numerous incidences of cross threading. That is, where the bolt starts incorrectly into the mating thread. The usual consequences of cross threading are jammed parts, stripped parts and/or the lead thread being rounded off enough to prevent any further

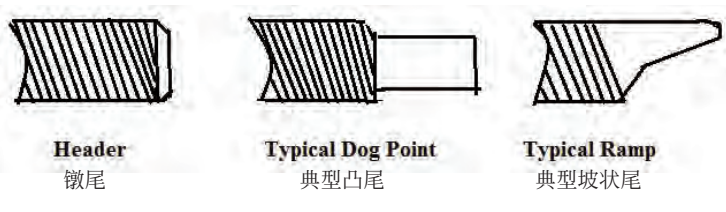


Fig. 2 Basic Point Styles
图二 基本尾端类型

也就是说，套筒的尺寸稍微小一点，方便让紧固件硬挤进去套筒里。这招似乎管用，但当套筒磨耗直到松弛，或是太紧，都会造成安装後套筒不易脱离螺栓。

紧固件的长度与直径一直是必要因素。然而，使用小直径且短的紧固件会造成组装时间之延缓。作业员通常要戴手套作业，即使不戴手套操作，要拿起和放下短而小直径的零件也不容易（**图一**）。我们发现直径和长度为 6mm 的紧固件，大约是作业员能够轻易操作的最小尺寸。零件掉落会增加生产成本，若掉入输送带或其他要组装之组件里，可能会阻碍机器运行。

较小较短的零件会造成组装时间变长，因为可能要尝试多次才能组装好这些零件。如果较小零件是绝对必要的，组装时间则要依此调整。虽然用送料管送出小螺丝的组装系统现在很普遍，但其外径与长度的比例仍要小心考虑。比例太小，会使螺丝在送料管内翻滚而横向卡住，造成更长时间的组装延缓。

同样的理由，**零件涂层的处理**也要检视。太油、太滑的涂层会造成零件掉落，即使零件可由具磁性的工具吸夹。这些零件必须先装填入套筒；有油的涂层会传送到周围的区域和表面，皮套披覆特别易受到损伤，有油（黏黏的）表层也会阻塞送料管。

螺纹交错

以前，组装是缓慢、手工作业的过程。作业员将螺栓放入孔内，加上螺帽，手指头开始将它旋转上去。其用扳手稍稍锁紧，之後再用扭力扳手锁到规定数值，以获得更正确的负荷。今日，时间是最重要的。生产时间研究人员用码表量测组装作业，精密到接近百分之一秒。装配线时间如此紧绷，一个失误作业可能在不到一秒的时间内发生。今

engagement. Of lesser consequence is the fact that several attempts to start the bolt may occur before completion of installation, a time factor which may cause a missed operation. While several standard points have been in use for years, they are, for the most part, inadequate for this assembly concern **(Fig. 2)**.

In an effort to overcome this problem, especially with the increased use of hydro-pulse tooling which can run as fast as several hundred to 2-3 thousand RPM, a series of patented **"anti-cross threading" points** have been invented, tried out, and sold. Not all are effective nor do all work in every condition.

Why do parts cross thread? What are the mechanisms and what can be done to lessen the effects? Just exactly how does a bolt enter an internal thread? These questions were studied closely in the attempt to come up with a solution.

First, the problem of cross threading does not occur frequently or in great numbers. However, one cross threaded part can stop an assembly line (vehicle industry) and cost much time and money to repair. In small assemblies, a jammed or striped part may lead to scrapping of that particular individual piece (loss of production). Most of the bolts used today have a Header point on them. This is a chamfered point on a flat ended part. This works well in many situations and has been the standard for years. However, as mentioned before, power tools and the need for rapid assembly has led to new problems. In the study of how parts cross thread, it was found that an angular misalignment between the centerline of the bolt and the centerline of the internal thread (nuts were the primary concern) exceeded 5 degrees the probability of a cross threaded part increased dramatically. As **Fig. 3** shows, a header pointed bolt can be driven off angled enough to allow two threads to start on one side while only one thread engages on the other. Stripping, cross threading or jamming will occur. The presence of a wide countersink on the nut is a standard dimensional practice to allow for easier starting of the bolt (or so was the thinking). This has also contributed to the situation.

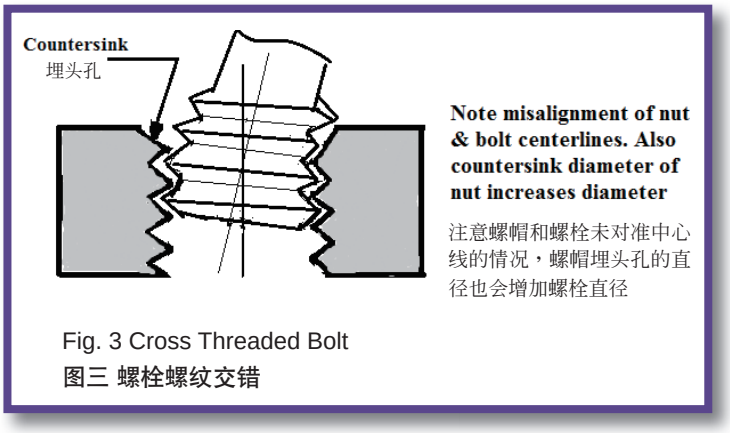


Fig. 3 Cross Threaded Bolt
图三 螺栓螺纹交错

天作业员把螺栓放入高速组装工具的套筒内，而後一边组装枪运作时，一边把螺栓推入孔内而进入螺帽里面。这种操作非常有效率，但也会造成许多螺纹交错事件，也就是说，螺栓开始不正确地锁入相配的螺纹。螺纹交错通常的後果是零件卡住、螺纹剥离或导程的螺纹被磨光，以致无法进一步嚙合。情况较轻的结果是锁紧螺栓前需要多次尝试，才能完成安装，而时间因素可能导致失误作业，虽然有一些标准螺栓尾端形式已实行多年，但大部分却是不适合组装的考量（**图二**）。

为了克服此问题，尤其随著可以达到几百至二、三千 RPM 的液压脉冲工具愈来愈常被使用，有一系列的专利「**反交错螺纹**」**尾端设计**问世、试用且发售，可是并非所有的都有效，也不是都适用於任何条件下。

为何零件会产生螺纹交错呢？这是什麼机制？我们能做什麼以减少这个结果呢？究竟螺栓是如何进入内螺纹呢？这些问题都被仔细研究过，企图能提出一个解决之道来。

首先，螺纹交错这问题并不常发生，发生数量也不多。然而，一个螺纹交错的零件可能使整条组装线（汽车产业）停顿，造成要花费许多时间与金钱来修复。在小组装作业时，一个卡住或剥离的零件可能导致该个别零件的报废（生产损失）。大部分现今使用的螺栓都有一个镦尾端（Header Point），这是一个平面端部上的倒角端点。在许多场合，此设计很管用，且已行之有年，然而，如前所述，电动工具的使用与快速组装的需求，导致新问题。在研究零件如何产生螺纹交错中，研究人员发现一个现象，即螺栓中心线与内螺纹（主要是螺帽）中心线之间若没对准，角度超过五度的话，螺纹交错的零件发生机率便急速升高。如**图三**所示，有镦尾端的螺栓可能被锁歪了，造成在一边有两个螺纹产生，而其中只有一个螺纹与另一个啮合，螺纹剥离、螺纹交错或卡住都将会发

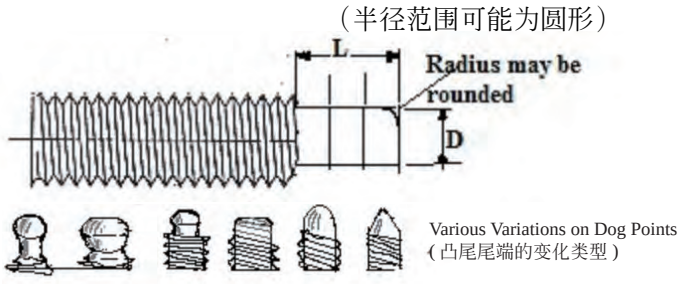


Fig. 4 Some Typical Dog Point Styles
图四 凸尾尾端类型

One of the first suggestions was to use a dog point bolt. It was thought that if the bolt would start in at an angle normal to the face, it would to allow correct address to the nut before thread engagement. Keeping the bolt at this 90 degree angle would be accomplished by a dog point which aligned the bolt before thread engagement. Unfortunately, it was found that many dog point styles were too short and the same situation existed still. Lengthening the dog point was a slight improvement but problems persisted.

The orientation of the starting thread of both parts with respect to each other was a source of cross threading. It was found that if the female thread was angularly misaligned and the start was such that the male thread could pick it up upon initial engagement, the incidence of cross threading would be greatly reduced. However, if the female thread was 180 degrees away, cross threading would occur. This factor was found to contribute to about 32% of the problems encountered. Since power driving could not control how the screw/bolt addressed the female thread, this was considered to be an unresolvable problem.

It was found that interactions between the orientation of the starting thread and the design of the point contributed to about 25% of the problems. Further, the point style of the parts used contributed to about 20% of the problems. The point styles were standard dog point, header point, AC pointed parts and one special ramped point. Various combinations of interactions without any singular variable contributed to the remaining 24%.

The outcome of the study was that modifications to point style to fit each particular condition were one solution. The development of a special, patented point which is much like a longer dog point with special radii and diameter looked as if it had much greater usage potential. Ramp-like points also had some success.

The Solution

The perceived solution to the problem of cross threading is the use of a cross thread prevention feature on the bolt. **There are two main classes of features available today (either patented or non-**

生。螺帽有大埋头孔是标准的规格条件，这是为了使螺栓容易开始（或者想法是如此）运作，但也因此造成这种情况。

首先建议使用有凸端（dog point）的螺栓，因为如果螺栓可用垂直于其面的角度开始安装，则在螺纹嗡合之前，就可以正确地趋近螺帽，同时利用凸端保持该螺栓于九十度角，如此在螺纹嗡合之前，就可使螺栓对准。不幸的是，许多凸端太短了，问题仍然没有解决。将凸端加长，稍有改善，但问题还是存在。

两个零件的起始螺纹方向，是螺纹交错的出发点。如果阴螺纹是斜角未对准的状态，而阳螺纹在开始啮合时就锁上去，螺纹交错事件就会大大减少。然而，若阴螺纹是一百八十度的分开，交错螺纹就会发生。此因素约占所发生问题的 35%。由於电动工具趋进无法控制螺栓或螺丝靠近阴螺纹的方式，所以这就被视为无法解决之问题。

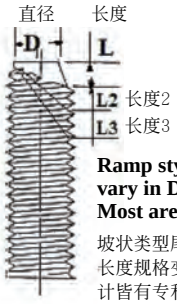
我们发现起始螺纹方向与尾端设计之间的相互作动，大约占了这些问题的 25%，且该零件尾端型式占了这些问题的 20%。尾端型式有标准的凸端尾端、镦尾端、AC 尾端与特殊的坡状尾端（ramped point）。组装时不同的互动组合，不具任何单一变数，占了这问题其馀的 24%。

研究结果显示，更改尾端型式来配合每个个案是一解决途径。有一个特殊、有专利的尾端设计，像加长的凸端尾端，同时具有特殊的半径与直径，也似乎有较大的使用潜力。坡状尾端也有成功的例子。

因应之道

对於螺纹交错问题的解决之道，是在螺栓上赋予一个防止螺纹交错发生的特性。今天可见到的包括两种主要特性（不论有无专利），**第一种就是我们常见到的引导尾端（piloted end point），包括像凸端的尾端，**

patented). They are the familiar piloted end point which may consist of a dog point-like end, modified to be either cylindrical or rounded in shape, shorter, longer, wider, bulb shaped or whatever the particular patent has defined (if patented) (Fig. 4). Some types are not patented and are available to any manufacturer without license requirements. They operate by keeping the threads from engaging until the axis of both members is aligned. Humorously, the ideal dog point, which would be a 100% anti-cross thread part, would have to be about 200mm long but it would obviously never see usage. Various modifications have been tried; bulbs on the end, incomplete threads for several pitches, cones, and so on. All with little general success. The longer dog point seems to be the answer for this type.



Ramp style Points vary in D & L dimensions. Most are patented

坡状类型尾端随直径和长度规格变化，多数设计皆有专利

Fig. 5 Ramp Style Point
图五 坡状类型尾端

The second class consists of a formed shape on the end of the bolt. The one most commonly seen is ramp-like in appearance and there are several patented variations being currently offered for sale **(Fig. 5)**.

These parts usually have a radiused section which allows for rapid entry and prevents the pilot edges from mating into the internal threads. This section leads into a full thread diameter. The tapered ramp does not allow the part to wobble or engagement to occur until the axis is in perfect alignment. This type functions by having the bolt "kick" back out if engagement is not achieved at first penetration. The bolt jumps out and attempts tore-engaged. This happens again and again until engagement occurs. The length of the shaved ramp varies by patent from short pieces to one almost one diameter long.

At last count, there are more than sixteen point styles on the market (some are proprietary, some not) and each with their arguments as to why their particular one is the best. Which one is best suited for a particular installation needs to be determined by actual application. Only a few styles have shown promise in general situations. Before a cross thread point is specified, some examination of the cross threading situation should be done. Sometimes the problem is not a fastener problem at all.

Other Factors

Among the several process factors that contribute to cross threading problems are:

Operator factors: Some observed problems that were found were caused by actual physical differences between assemblers. As mentioned

经改善为圆柱形或圆角形、较短形、较长形、较宽形，球茎形，或任何有专利定义的类型（图四）。有些类型没有专利，任何制造商都可使用，不需授权。这些类型的作用是让螺纹在两个相配零件的轴线对准之前不会啮合。好玩的是，理想的凸端尾端，一个百分之百的螺纹反交错产品，却需要大约 200mm 的长度，所以从未有人使用过它。其他各种的变动都有人试过，像端部球茎形、有几圈非完整螺纹及圆锥形等，然而很少有全面成功的案例。较长的凸端尾端似乎是这类型的答案；第二种则是在螺栓尾端有一个成型的形状，最常见的是外观像斜坡形状，现在有很多获有专利的样式在贩售（**图五**）。

这些产品都有一个圆角部分，可容许快速进入，且防止引导边缘（pilot edges）锁进内螺纹。此部分带到一个全螺纹直径，这个削尖的坡状处不允许零件摇晃或啮合，直到轴线完美地对准才行。如果第一次未能啮合，螺栓会被「踢退」，螺栓会跳出，啮合就分开。到啮合完成前，此状况会重复发生。坡状处长度因专利有所不同，从短的到几乎一个直径长度的都有。

最後要说的是，市面上有超过十六种的尾端形式（有些有专利认证，有些没有），每一种都号称自己最好。何种最适合某一个别安装需求，必须由实际应用来判定。只有少数几种形式显示在一般情况下是管用的。在指定某一种螺纹交错的尾端之前，必须进行螺纹交错的检查。有时问题并不只限於紧固件问题而已。

螺纹交错的其他因素

若干程序因素也会造成螺纹交错的问题：

作业员因素：观察中发现，有些问题源自於组装人员身材的差异。如前所述，螺栓趋近阴螺纹的角度是极重要的。曾经有一个情况是组装线一边的作业员比另一边的还矮很多，当组装该紧固件时，其持该紧固件的角度不

before, that angle of address of the bolt to the internal thread is critical. One situation that was seen was where the operator on one side of the line was much shorter than the opposite person. When assembling the fastener, he would present that fastener at a different angle, causing a higher percentage of stripped parts.

Tool factors: The tool used for the process should be as compatible to the installation process as possible. If an assembler is required to bend over to install a part with a side angle tool, for example, it will probably lead to a number of off angle installations. Designing for installations at unusual angles and awkward directions is sure way to increase the number of misapplied fasteners.

Process factors: Many cited cross threaded examples have been found to have non-dimensional causes. Weld splatter, dross and other dragged in material (paint, chips, etc.) can effectively strip threads and jam parts during assembly installation of the fastener and are usually not discernible as the primary cause. The largest single process error found has been the fact that there is often metal misalignment. Because of variation in stamping, holes may not line up correctly. A bolt being inserted thorough several thicknesses may get off angled by metal overlap of the clearance holes. Welded nuts and pre-installed nuts and studs are the biggest offenders. Plants have always been partial to asking for AC points (the cone shaped point found on many bolts and screws). They use the bolt as a pry lever to bend the overlapping sheet metal aside somewhat. They then start the bolt although it will probably be jammed (cross threaded). They go to a larger powered tool to drive the bolt the rest of the way even through it is off center. An often forgotten process factor is socket wear. Sockets are not changed often and wear will allow the nut or bolt head wobble, making for an off center drive of the part.

Conclusion

The selection of a fastener depends upon many things. Even after a thorough review of all the considerations, tooling is often overlooked. An exemplar test, using plant type tooling, may show if there may be a problem with how the plants actually assemble the product. If it appears that there may be a cross threading problem or other concern with the actual part as handled by the assembly line, the use of a special point may be the solution. Other considerations not mentioned are the lack of sizes in a special point, and the need for a certain amount of backside clearance to accommodate the longer point. Increased mass and added cost if the part is a proprietary design along with procurement difficulties may also influence the use of this solution. Ergonomics of assembly (size, direction, tooling size needed to install) all will have to be considered.

同，导致零件剥离可能性较高。

工具因素：程序中使用的工具必须尽可能与组装过程相容。例如，若组装人员必须弯下身用单边角度工具以安装一个零件，这可能会导致许多歪斜的安装。须从不寻常与不顺手的角度来安装之设计，必定会增加紧固件使用不良的数目。

程序因素：我们发现许多被引用的螺纹交错例子和尺寸规格的因素并无关系。焊接飞溅、浮渣与其他材料之滴涎（油漆、碎屑等），都会在紧固件组装过程中使螺纹剥离与卡住零件，而且不易被察觉出是主要原因。我们发现最大之个别程序错误，常常是由於金属未对准。由於冲压误差，孔可能对不准，一支螺栓如果需穿透几层零件，可能由於预留孔的金属重叠而歪掉。焊接螺帽、预先组装的螺帽与螺钉是最大的出错案例。工厂常常偏爱 AC 尾端（许多螺栓与螺丝上具有此种圆锥形的尾端），他们利用此种螺栓作为杠杆，微幅朝侧边弄弯重叠的钣金，之後再开始锁紧螺栓，即使可能会卡住（螺纹已交错），他们会去拿动力更大的工具来驱进螺栓，使其走完剩馀的安装距离，即使其已经偏离中心了。另一项常被遗忘的程序因素就是套筒磨耗。套筒并不常更换，而其磨耗後会使螺帽或螺栓头摇晃，造成零件偏心驱进。

结论

紧固件选择有赖於许多因素，即使彻底检视了所有顾虑，还是常常会忽略了工具。利用工厂的工具做样品测试，可显现工厂实际组装该产品时是否会有问题。如果看起来可能会发生螺纹交错，或对於组装线处理的实际作业有顾虑，则改用特殊的尾端型式也许是一解决方式。其他没有提到的考虑事项包括某特殊尾端尺寸不全，以及零件背面需要留有某个量的空隙配合较长的尾端。如果该零件是有专利权设计且采购有困难度，产量和成本的增加都会影响采用此解决方案之决定。组装的人体工学（尺寸、方向、安装所需工具的大小），都要考虑到。