# The Importance of a Proper Hole

by Thomas Doppke

# 适当的孔之重要性

As many written articles have said, a joint is a complex and multi-sided thing. Dimensions, threads, strength, shape, all bear upon the performance of a joint. These are only a few of the numerous items which are considered by the designer and engineer in developing the attachment. One session of a group of engineers listed all the ways that a joint could be attached. They came up with some 150 ways of joining things. But the one often, almost always, overlooked facet of a secure joint is the hole that the fasteners insert into, tap, or pass through. What does the hole have to do with a secure and proper joint? Let's see.

First, very little is done in considering exactly what goes into a hole specification. There are standards that call out text book values. ISO 273 specifies clearance holes for bolts and screws. These are for general purpose use and have some mathematical basis for their diameters based upon bearing area. While they list three series of fits (normal, close, and loose) little discussion is given as to when each is to be used and users are left to their own devices as to which to pick. ASTM B18.2.3.1M Appendix III repeats the ISO specification including its vagaries. It does list several tables which show drill and hole sizes for tapping screws as well as clearance hole sizes for bolts. In addition, there are other standards, both industry and company specific, which detail hole sizes for various material and types of application. Some of these will be discussed below.

Bolts hold together the components of the joint. It is required that they pass through a hole and be fastened on the other side (by nut, tapped hole or other securing device. If the hole is too large the joint may slip with cyclic, sharp loads. What happens then? The hole may become enlarged, contributing to further enlargement and loss of clamping load. Loss of clamp load leads to fatigue, loosening and eventual joint failure. If the hole is too small another set of problems develop.

The areas of high stress in a fastened bolt have been plotted as the first lead threads, those at the edge of the fastened joint AND the underhead radius. This change in direction where the head is fastened to the shank is a particularly sensitive spot. Numerous failures have been seen where the head is broken off at this point. How does the hole figure in these failures?

Stack up between the various parts of the assembly may cause a 'give and take' on the true position of the bolt clearance hole. However, for maximum degree of security on critical joints it is recommended that a close tolerance hole be used. Too small an opening will lead to failure in the underhead shank to head fillet. Also the bolt may be angled due to hole lateral displacement. Even with a single tightness joint, the choice of a close tolerance hole, required for critical joints, no movement can be tolerated.

Looking at this example of a M10 bolt, note that the maximum diameter of the bolt at the radius run out is 11.2 maximum. The close tolerance specification for an M10 bolt is 10.5. This means that the bolt radius will impinge upon the hole edge, creating enough stress to act as a shear point for a head failure. The maximum run out diameter

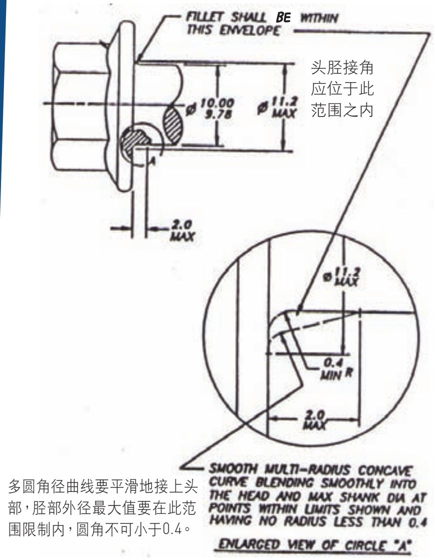
许多文章都曾写过，一个结合件是一个复杂且多面性的东西。尺寸、螺纹、强度、形状，都会影响结合件的功能。在开发一个结合件时，这些只是设计师和工程师会考虑的多项项目中之一些。一群工程师在某次会议中列出了可以结合一个结合件的所有方法。他们共列出了约150个结合东西的方法，但经常，几乎是始终，被忽略的牢固结合件的一个面向是，扣件要进入、攻入或经通的那个孔。那个孔与牢固、合适的结合件有何关系呢？让我们来看看吧。

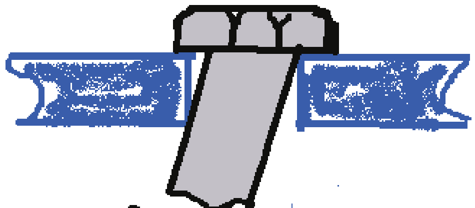
首先我们很少考虑到究竟该孔的规格要如何订定。有些标准采用了教科书的数据。ISO 273订定了螺栓与螺丝使用的配孔(clearance holes)，这些是供给一般用途的。它们对于根据承受面积而得到的外径有一些数学基础。它们列出三个系列的松紧配合度(正常、紧、松)，却几乎没有讨论到何时要用何者，而让使用者根据自己的器具去挑选。ASTM B18.2.3.1M附录IV重复说到ISO的规格，其中包括它自己的想法。它有列出若干表格，写出攻牙螺丝用的孔与其钻头的尺寸，与螺栓用的孔的尺寸。此外，还有其他的标准，工业用与商业用的，也有列出供不同的材料、不同的形式之用途的孔的尺寸。这其中有些会在下面讨论到。

螺栓将结合件的组件锁在一起， 它们必须穿透过一个孔，而后被(螺帽、有攻制螺纹的孔或其他固定用的器具)锁在另一边。如果这个孔太大，这个结合件会因循环、锐利的负荷而滑动。那么会发生什么事呢？这个孔会被扩大，导致更进一步的扩大而失掉锁紧的力量。失掉锁紧的力量会导致疲劳、松弛甚至最终的结合件失败。如果这个孔太小，会产生另外一组的问题。

锁紧的螺栓上之高压力的区域，一直被描述为是前面的引导螺纹，它们就在锁紧的结合件的边缘与螺栓头部底下的圆角处。螺栓头部与胫部连接处这种方向上的改变，是一个特别敏感的点。在许多的失败例子中，可见到头部就在此处断掉。孔在这些失败中是有何作用呢？

组装件中不同零组件间的堆迭，可能引起螺栓真正位置的「允许误差」现象。然而为了获取重要的结合件之最大程度之牢固性，我们建议要使用的孔，其公差密合度则高。孔的开口太小会导致螺栓头部底下接角处(fillet)之处的失败。而且螺栓也可能因为孔的横向移位而歪斜，即使是单一且密合度较高的结合件，若它是关键性的结合件，则建议密合程度较佳的孔，不能允许任何移动。



**With a 2° head offset the hole is too small for the bolt to pass through without interference at the underhead fillet**

有2度的头部偏差，要让螺栓穿过而不会与头底接角产生干涉，此孔是太小了。

(transition fillet diameter) for the radius is from 0.8mm greater than the nominal bolt diameter for an M6mm to 1.2mm for M8mm to 1.7mm for M12-16 sizes.

In addition to the potential problem with the radius run out there is the concern that the bolt head may not seat perpendicular to the shank surface. Standard heading practice allows a maximum angularity of 2° between bolt bearing face and shank. This means that the bolt will enter the hole at a slight angle.

What does this mean for our hole 'fit'? If we assume, for example's sake, that the attached material is 3mm thick, the amount that the shank of the bolt is out of perpendicular must be added to the maximum fillet circle to allow for non-interference and render a minimum hole size. For our 3mm work piece this value is 0.1048mm. From the hole size from standards below:

Recommended Clearance Hole Diameters 表1、建议孔的直径

| Diameter & Pitch 直径与节距 | Normal Clearance 正常孔径 | Close Clearance 紧的孔径 | Loose Clearance 松的孔径 |
|---|---|---|---|
| M5 x 0.0 | 5.5 | 5.3 | 5.8 |
| M6 x 1 | 6.6 | 6.4 | 7.0 |
| M8 x 1.25 | 9.0 | 8.4 | 10.0 |
| M10 x 1.5 | 11.0 | 10.5 | 12.0 |
| M12 x 1.75 | 13.5 | 13.0 | 14.5 |

We see that our M10 requires a hole diameter of 10.6048mm. The part may have a radius run out of 11.0 or a definite sharp edge that will be the locus for a head failure. It also approaches that maximum for a normal clearance hole. And this is for a grip range of only 3mm of stock!!

Of additional consideration is the problem of the yield strength of the material being fastened. Too often the hole is opened up to allow a greater tolerance because of variation in hole location between the various pieces that make up the assembly. With too little bearing support the metal will pull into the hole (embedment) and loosening of the joint will occur. If the design absolutely requires a greater tolerance for fit, the use of a flat washer or bolt and washer assembly which will give a wider spread to the loading is a good idea.

The method used to manufacture the hole determines much of the joint's performance. Cleanly pierced holes offer little to interfere with assembly. Dirty punches, the use of spuds in place of proper punches, and dull drills will allow a slug or burr to hang on the edge. These pieces of dross will further offset the bolt placement and clearance allowance.

A major trend has been for the financial people in sheet metal areas to reduce the number of different punches that the plant has to stock. While this has some economic merit, the proper hole punch to allow for adequate clearance is often not among the 'selected 'sizes.

Not all holes are designed for through passage. Tapping screws require a pilot hole for installation. Too large a diameter pilot hole will allow the screw to either strip or will not engage enough metal for a secure attachment. The standard sheet metal tapping screw (Type AB) requires a hole that will form about 75% engagement in the requisite metal thickness ( minimum one thread pitch= 1.4mm). Too small a hole will cause jamming, be hard to drive and may even stall or break the screw. Unfortunately the hole size is very dependent upon the metal thickness into which it is being driven. As the metal thickness increases the hole size should also follow suit to prevent excessive friction but

我们来看一支M10螺栓的例子。这螺栓在圆角外缘处的最大直径是11.2。配这支M10螺栓的紧公差的规格是10.5。这意谓着该螺栓的圆角会侵犯到孔的边，造成足够的压力，变成头部失败的剪断点。该圆角其最大的外缘直径(转接角的外径)是比M6螺栓大0.8mm，比M8螺栓大1.2mm，到比M12~M16螺栓大1.7mm。

除了这个有关圆角外缘的潜在问题，也有一个顾虑，螺栓头部可能没有垂直于胫部表面。标准的头部制造，是允许螺栓承受面与胫部之间有最大 2 度的直角度。这意谓着螺栓可能稍微歪斜地进入孔中。

这对于我们孔的松紧配合度有什么意义呢？举例来说，若我们假设要结合的材料是3mm厚，螺栓胫部倾斜的量必须加在最大接角值上，以容许没有干涉，而产生最小的孔之尺寸。我们的工件3mm的话，这个值就是0.1048mm，**表1**列出这些标准螺丝及其孔的建议尺寸：

我们看到我们M10螺栓需要一个孔其直径为10.6048mm。这零件可能有一个圆角外缘11.0，或有一个尖锐的边缘，这可能会变成头部失败的地方。它也接近正常孔的最大值。而这是对只有3mm厚的零件的抓紧力范围！

另外一个顾虑是，被锁紧的材料的降伏强度的问题。常常这个孔会被放大，以容许更大的公差，因为组装产品其各种不同组件之间的孔的位置之差异。若承受支撑太小，金属会被拉入这个孔内，而发生结合件松弛。若设计绝对地要求松紧配合上更大的公差，则使用平华司或螺栓与华司组合的零件，如此会有更大的铺陈面积来承受该负荷。这也是一个好主意。

制造这个孔所使用的方法会大大影响该结合件的功能。一个较干净冲具在孔洞组装上较没有阻碍发生。不干净的

should never be so large as to reduce the thread engagement below 60-65%. The table below is for M4.2 x 1.41 (8-18) sheet metal standard tapping screws. Similar tables exist for the other sizes of tapping screws as well as for thread forming tapping screws (trilobular and generic thread forming types) and for the thread cutting types mentioned above.

The manufacture of a pilot hole also affects the joint security. Many plants, again to save money, reduce the number of drills, punches and other hole making devices as an economy move. Thinner metal, popular in today's market, presents an additional problem. Much of the sheet metal in vehicles today is less than a thread pitch in thickness, leaving little engagement for the tapping thread to firmly hold the attachment. This has been addressed somewhat by forming extrusions in the metal. The only problem is that these extrusions, especially in the thin metal, are so thin that the tapping screw cuts the extrusion off, leaving even less metal engagement than before. Further, the manufacturing plants like the use of a spud instead of a proper punch. The spud is a 'nail- like' tool that basically punches a hole in the metal, extruding a cone-like form on the back side. This cone is often cracked, burred and irregular. When the screw is inserted the cone opens like a flower rather than taps as it was meant to.

Plastic fasteners play a large part in today's assembly processes. Trees, grommets, push pins all function in retaining grilles, moldings and trim to metal and other plastics. These pars are very sensitive to hole size and variations in tolerance of the hole will greatly affect their performance. "Loose," "easily pulled out," "won't retain" are the symptoms of too large of a hole while small holes will cause failure to install and breakage. While there has been much work done on standardization of hole sizes for these types of parts, the tendency of the sheet metal people is to still try to use their standard and common size punches. Often they will list a "make do" size and the part will not perform as expected.

Rivets are a popular and cheap attaching device. They are easy to install, quick, tidy and a low tech fastener. However, they are very hole size sensitive. Narrow tolerances and specific hole sizes are necessary if they are to function properly. Since they are a shear fastener, they work

冲具，或用小尖铲代替合适的冲具，与钝的钻子都会留下赘屑或毛边挂在边缘。这些赘料会抵消螺栓的安装与孔洞的配差。

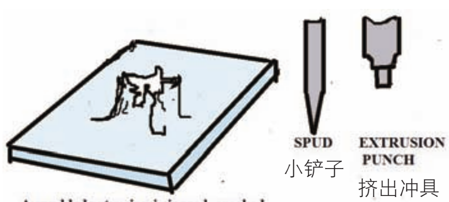
现在的主要趋势是，金属板业界的财务人员要降低工厂库存的不同冲具的数目。这虽然有经济上的优点，可是适合的配差的孔的冲具，常常不在所「选定」的规格内。

并非所有的孔都是设计要穿透的。攻牙螺丝需要有个预先制造的预钻孔来安装。预钻孔直径太大，将容许该螺丝剥离螺纹，或无法与足够的金属啮合来达成一个牢固的结合。标准的钣金攻牙螺丝(AB型)需要一个孔，来在所要的金属厚度上成型约75%的啮合，(最少一个螺纹节径=1.4mm)。孔太小会造成咬死，不易驱动，且可能停滞不前或折断该螺丝。不幸的是，该孔的尺寸很依赖螺丝要驱入的金属厚度而定。随着金属厚度增加，该孔尺寸亦随着增加，以防止过多的摩擦，但绝不可大到会减少螺纹啮合低于60~65%。**表2**是针对M4.2 × 1.41(8 - 18)标准钣金攻牙螺丝，还有针对其他尺寸的攻牙螺丝与成型螺纹的攻牙螺丝(三角螺纹与一般成型螺纹之类)与前面提到的切削螺纹之类的类似表格存在。

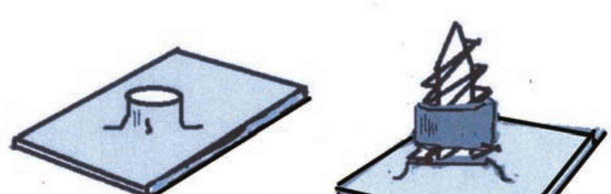
表2. 攻牙螺丝与其建议孔径
Table 2.

| Metal Thickness 金属厚度 | Drill No. 钻头编号 | Probable Hole Dia. 可能的孔径 | Approx. % Thread 约%螺纹 |
|---|---|---|---|
| 0.65mm | #32 | 3.01mm | 100 |
| 0.80 | 32 | 3.01 | 100 |
| 1.00 | 31 | 3.12 | 99 |
| 1.30 | 30 | 3.32 | 96 |
| 1.65 | 29 | 3.53 | 85 |
| 2.05 | 28 | 3.64 | 76 |
| 2.60 | 26 | 3.82 | 60 |
| 3.17 | 26 | 3.82 | 60 |
| 4.00 | 25 | 3.88 | 50 |

预钻孔的制造也影响该结合件的牢固。为了节省金钱，许多工厂降低了钻头、冲具与其他制造孔的工具的数目，作为一种经济运动。薄钣金在今日的市场很受欢迎，而这也代表着另一个问题。今天汽车上的钣金，很多是厚度少于一个螺纹的节径，使得攻制的螺纹只有很少的啮合要来牢牢地锁住结合物。这问题已经利用在金属上成型出一个凸出物来解决。唯一的问题是，这些凸出物，特别在薄金属上是如此的薄，以致攻牙螺丝会把它们切掉，剩下比之前更少的金属啮合。更甚者，制造工厂喜欢使用小铲子而不是合适的冲具。这小铲子是像铁钉的工具，基本上可在金属上打出一个孔，在背边挤出一个锥形的形体。此锥形体常会龟裂，有毛边，不规则。当螺丝嵌入时，这圆锥体会像花朵一样开放开来，而不是如我们所期许地像个栓子般。




A spudded extrusion is jagged, cracked and will open up before tapping correctly
用小铲子挤出的形体不平、易裂，在适当攻牙之前就散开来了。



Even a proper extrusion can be cut off with standard tapping screws leaving less than 1/2 pitch engagement
适当的挤出型体也可能被标准攻牙螺丝切掉，剩下不到1/2的咬合。

塑胶扣件在今日的组装制程，扮演着大角色。树状零件、孔环、压销等在保持栅格、模铸品与饰条于金属与塑胶上，都有其功能。这些零件对孔的尺寸很敏感，而且孔的公差的变异会大大地影响其功能。「松的」，容易被拉出，孔太大会保留不住，孔太小会导致安装失败与断掉。虽然对这些零件的孔的尺寸，在标准化上已经做了许多工作，钣金业者的趋势仍然是努力要用他们的标准与常用规格的冲具。他们常常会列出一个「可行」的尺寸，结果是该零件的表现不如预期。

by the expansion of the rivet body inside the hole, forming a 'plug' which makes the joint a solid section. Too large a hole will cause failure by the inadequate expansion inside the hole cavity, not filling the cavity entirely. In some cases of very large holes the rivet may buckle sideways inside the hole or push out between the various layers being riveted together. Too small a hole will make for a hard to install part; in cases where the metal has been finished or painted before installation, the paint in the small hole may make the rivet impossible to install at all.

Some rivet facts relative to holes are: 1-the hole size for a solid rivet should be 107% of the rivet diameter. 2-The diameter of the required rivet is related to the thickness of the thickest plate being held together. The formula for this is $d=1.4\sqrt{T}$, but never any larger than three times the thinnest plate. 3- The rivet hole should be located a minimum of two times the rivet diameter or one and one-half times the thinnest plate thickness from the edge. The maximum distance from the edge should not exceed eight times the thinnest plate thickness. 4- The clearance between rivet holes should be no less than three times rivet diameter and not more than 24 times to keep plates from separating. And obviously holes should not be located too near bends and radii.

Some fasteners require special holes to function. Besides the obvious hex hole for a hex body rivetnut to function as an anti-rotation fastener (which is often negated by the sheet metal people in favor of a round hole [economy] and therefore doesn't really function), some parts need a special hole. With the increased use of thin metal, the use of push in metal nuts of various types requires square holes. The attaching screw threads into the metal impression, generating pressure by expansion of the metal nut against the hole walls, and generates a much more secure attachment than would a single tapping screw into the thin metal. These types of parts require precision holes, close tolerances and, at the very least, the right shape.

Once again the sheet metal stampers have not kept up with the requirements. Holes are easier to stamp when the corners are rounded. A tautology exists here, that being the part designer designs a part with a square installation hole needed. The metal people stamp a hole with a rounded corner. The part doesn't fit, or fits poorly, causing less than expected performance and everyone blames each other. Consideration of the problems of stamping a square hole needs to be thought out early in the design process. Sharp, square corners do indeed rip and are fatigue starting point. A radius needs to be added but, holes are often seen with much more radiused corners than they have to be.

Too Much? Too Little?
孔太大、太小？

The photo above shows a failed hole which caused the loss of a part which held a critical component to the sheet metal. If this hole was more square cornered, as designed, the clip would not have come off and some expense to the customer could have been saved (not to mention the loss of a good deal of good will). By closing up the radius and some modification to the edges of this particular metal push in nut this problem was resolved and no further action was needed.

Proper holes, while usually not given much thought during any phase of engineering, can contribute to a sound and long lived joint or they can cause hard to resolve field problems. Many engineering changes are made during development of a product and often holes are changed because of fit problems, tolerance difficulties, etc. The most commonly heard statement is "What? It's only a hole. It doesn't have anything to do with fasteners !! It doesn't, does it? It's only a hole!"

铆钉是常见且便宜的结合器具。它们容易安装、快速、整洁，是低技术的扣件。可是它们对孔的大小非常敏感。若要它们表现适当，窄的公差与明确的孔的尺寸是必须的。因为它们是一种剪断扣件，它们借着在孔内扩大铆钉本体，形成一个「塞子」来让这结合件变成一个牢固的断面，来发挥作用。孔太大会造成在孔内不当的扩大而失败，无法完全将孔穴填满。在某些非常大的孔的例子里，该铆钉在孔内会横向卷曲，或在不同的迭层间被推出。孔太小会变成不易安装零件。若金属有表饰层或安装前有上漆，在小孔里漆会导致铆钉无法安装。

以下是一些铆钉与孔有关的事实：(1)实心铆钉的孔应是铆钉直径的107%。(2)所需之铆钉的直径与欲锁固的最厚钣金的厚度有关。(3)铆钉的孔应该位于离边缘两倍的铆钉直径之最小值，或者1.5倍之最薄钣金的厚度之距离。离边缘最远的距离不应超过最薄钣金厚度的8倍。(4)铆钉孔互相之间的间隔应该不小于3倍的铆钉直径，不大于24倍，以防止零件分离。很明显地，孔不应位于太靠近弯曲处与圆角处。

有些扣件需要特殊的孔才能发挥功用。除了六角体的拉帽明显地需要六角的孔以发挥功用，来防止旋转外，有些零件需要特殊的孔，钣金业者常常否定它而基于经济考量偏爱圆孔，因此实际上无法发挥功用。随着薄金属的使用增加，各种不同的按入式金属螺帽的使用则需要四方形的孔。锁紧用的螺丝会将螺纹切入金属上，利用金属螺帽的扩张对孔壁产生压力，而变成比使用单一攻牙螺丝锁入薄金属，还更牢固的结合产品。这些型式的零件需要精确的孔，紧公差，而且形状要正确。

金属钣金冲压业者一直没有跟上需求。孔是圆角的话，较容易冲压。相同的事情在此重复发生。零件设计师设计一个零件，需要一个四方形的孔来安装。金属业者则冲压出一个圆角的孔。这零件就不适配，或适配不当，导致比预期差的功用，而后大家互相指责。要冲压一个四方形的孔的考虑，要早在设计阶段就想好。尖锐的，四方形的角落确实会撕裂，且是疲劳的始点。必须要加以圆角，可是我们常看到孔的角落圆角得太多了。

上图显示一个失败的孔，它造成了锁着关键组件于钣金上的零件不见了。如果这孔是更四方形角落的话，该金属丝夹就不会掉落，客户的花费就可节省下来，更不用提商誉的损失了。把圆角做小一点，与修改一下该金属压入螺帽的边缘，就可以解决这问题，而不需进一步的动作了。

虽然工程设计阶段常常不多加思考这个孔，但适当的孔可以有利于造成一个完整而长寿的结合件，否则会产生不易解决的现场问题。许多工程设计的变更，都是在产品开发的时候做的，孔常常更改是因为松紧配合问题、公差困难等等。最常听到的说词是"什么？它只是一个孔。它跟扣件没什么关系！它没关系，不是吗？它只是一个孔呀！"