The A-B-C's of Self Drilling Screws
熟悉钻尾螺丝

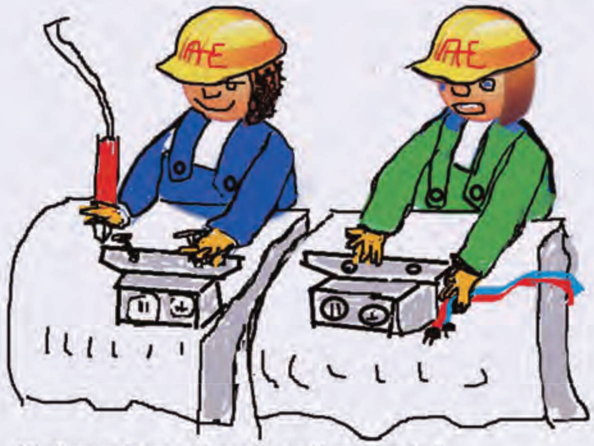
By Thomas Doppke

Tapping screws have long been considered the ideal fastener for thinner gauge metal. Inexpensive, easy to install, and requiring only the most basic tooling; they are used everywhere in the mechanical world. The one prerequisite is that they have a pilot hole to start into. While inventors have thought out the requirements and features needed for a tapping screw that could just be "pushed" into the metal, many design problems have retarded the development of such parts.

The advent of modern, high-speed assembly and mass production meant that vehicle assembly parts were made to fit all available options. No longer were vehicles "hand built", with each unit a created "one-of-a-kind". Instead, a basic unit was produced and accessories were 'added on' or 'left off', as ordered. That is, holes were punched out for all tapping screw locations (and other parts) in ALL of the metal bodies and when the option was not called out (no A/C, no cruise module, and so on) the hole was left in the metal. Since these had to be plugged (to meet regulations about gas leakage and vapor intrusion requirements) a costly problem was present. Every plugging option was expensive, the choices: use a plain screw and just screw it in as a plug, plug with some rubber-like sealer, or don't drill the hole in every part and drill as required "on line". The latter solution was tried but the time involved and the fact that line operators often could not reach the area (other installations partially obscuring the location) or put the part in a wrong location, was found to be expensive, time consuming, and made for a poor quality assembly.

The need for a "self-drilling" tapping screw became evident. Early prototypes included needle-like points that could be 'injected' into the base metal. The frictional heat generated by such points often melted the point, negating the intended outcome. Hardness variations of the sheet steel affected the point insertion while the heat-discolored area around the attachment was a cosmetic concern.

The solution that worked best was to make the screws with a drill point on the end. A factor about these that is both positive and negative is that the attached component can be used as a template to locate the screw. Conversely, the part can be mislocated, causing problems such as a location far enough beyond the specified point that will result in an insufficient



Misalignment in one station causes problems down the line

零件错置导致生产线出问题

自攻螺丝长久以来都被视为是用于薄金属的理想扣件。因为不贵、容易安装而且只需要最基本的工具便可操作，且只要有一个定位孔就可旋转锁进，所以普遍被采用于机械领域。虽然发明家们深思熟虑了能够单纯的将自攻螺丝「推入」金属所需的条件与特性，但是这类零件的开发还是因为许多设计问题而受到延迟。

现代、高速组装与大量生产的到来，意味着车辆组装零件的制造都是依照所有适用的选项装配好的。车辆不再是使用「独一无二」的零件「手工」打造而成的。而是先制造出基本构件，然后再依序将配件「添加上去」或是「除去」。也就是在所有的金属本体上都已经事先将所有自攻螺丝 (以及其他零件) 的位置冲孔完成，如果用不到(无A/C、没有定速组件等等)这些孔洞的时候就将它们留在上面。因为必须将这些孔洞塞住(为了符合气体泄漏规定与蒸气入侵要求)，所以就产生了成本升高的问题。每种堵塞方式都是昂贵的，包括以下几种方法：使用平螺丝锁入塞住、使用某些橡胶类密封料塞住或是不在每个零件上钻洞，而是依照要求在「生产线上」钻洞。经采用之后，发现最后这种方式是昂贵、耗时而且组装品质不良的，而且线上操作员时常找不到钻孔位置(其他安装上去的零件局部挡住了要钻孔的位置)或是将零件错置。

由于这些因素，对于能够「自行钻孔」的自攻螺丝需求便浮现。初期的原型具有针状尖头让螺丝可以「注入」基底金属。但是这类尖头因为摩擦产生的热度，时常造成尖头熔化，而降低了预期的成效。钢板的硬度变化也会影响钻尖插入，且因为热度造成附着物周围区域颜色变化也会影响到外观。

对于这些问题的最佳解决方案就是就是在螺丝上打造出一个钻头。如此可以让组装上去的组件成为螺丝定位的样板，但是这样的设计有好有坏。负面结果是，零件位置安装错误造成问题，例如偏离

length of wiring to attach the next step (if required) or ducts and inlets not connectable, or space needed for other additional parts being used up by the mispositioning. On the plus side, the holes is always the correct size for the screw (one to one fit), there will be no paint and coating fill problems, or off size holes caused by worn punches.

On the minus side, the screws cost about US$0.01or more per part than non-drilling tapping screws (a typical automotive vehicle uses about 200-250 tapping screws, a cost increase of about US$2.00 to 2.50). Also, a load must be initially applied to the end of the screw to initiate the drilling action into the base sheet metal (this is often an ergonomics issue with today's assembly plants). More space is required on the backside to accommodate the increased length of the point. This facet increases the mass of the part, a small amount but still critical in today's weight conscious world. And finally to function effectively, drill screws must be installed at a faster rate than standard tapping screws.

This point is of significance when considering thread metrology. The most common screw used today is the 4.2 x 1.41 (#8-18) tapping screw. The standard pitch distance (distance between threads) is 1.41 mm (0.056"). Today's sheet metal has been reduced, in many applications, to 0.71mm (0.028") to save weight and reduce cost. This means that the tapping screw now taps into metal that is about ½ a thread pitch thick. While there are certain design features that can help, the use of a 2000RPM tool running into 0.71mm thick metal and running about 6 revolutions (approximately the standard run down) and stopping at a pre-set torque is a pretty amazing feat. A tool run is about 0.18 of a second and stops on the proverbial dime! It is a well-known fact that a tapping screw requires at least 1 thread pitch to develop any strength at all. One half a thread pitch is a disaster case waiting to happen.

One way that this has been slightly overcome is with the use of fine thread, self-extruding drilling screws. The finer thread is (in the case of 4.2mm) a 0.7 pitch, allowing for at least one thread pitch into the thin metal. The self-extruding feature pushes the metal outwards forming a cone rather than cutting a through hole. Whereas the standard tapping screw would cut off the cone, the extruding screw rolls the metal forming mating treads in a manner similar to the trilobular bolts in use elsewhere. In addition, the rolled up, formed cone adds another thread of two to the attachment thickness. Fine thread extruding drillers negatives are part size/length/head style availability, cost, the extra care to avoid off angled installations, an increase in end loading to start the screws, and the possibility of thread fill from the newer, thicker anti-corrosion finishes (See China Fastener World, number 36, On the Problems with Finishes).

The use of a stamped cone increases the engaged height by almost another pitch theoretically. Self-extruding trapping screws were the solution to the problem of thin metal but the cost and other factors led designers to look for a cheaper solution. When faced with the thin metal quandary, one solution suggested was to use a "spudded" hole. This is a hole that is formed in the stamping process with a die inset punch which forms a cone. It was thought that a cone would

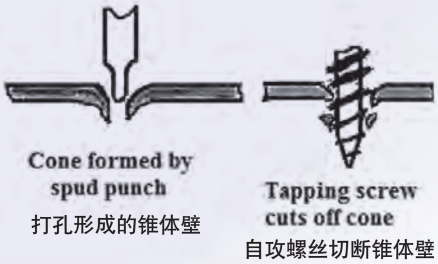
规定的位置太多，导致电线长度不足无法连接到下一个步骤，或是造成管道与接口无法相连，或是错装造成其他附加零件没有足够的安装空间。正面结果则是，孔洞的尺寸一定与螺丝相符，所以不会产生油漆与涂层堵塞问题或是冲孔错误造成的孔洞尺寸不符。

就负面结果而言，自攻螺丝的单价比非自攻螺丝大约高出了0.01美元以上(一般汽车大约会用上200-250颗自攻螺丝，成本大概增加了美金2元到2.5元)。此外要让螺丝开始钻入基底金属板的起始动作也需要先在螺丝头施力(这常是现代组装厂所面对的一项人体工学问题)。组装需要更多的空间来容纳加长的螺丝尖尾，这样会增加零件的质量，虽然不多，但是在现今如此重视重量的产业领域里仍然是关键。最后就是为了有效的运行，钻尾螺丝的安装速度必须比标准自攻螺丝更快。

这点在考量螺纹尺寸时就是重要的。今日最常用的螺丝是4.2 x 1.41 (#8-18) 自攻螺丝，标准螺纹间距是1.41 mm (0.056")。在当今的许多应用中，金属板的厚度都被减少到0.71mm (0.028") 以减少重量与降低成本。这意味着现在的自攻螺丝锁入的金属板只有大约二分之一的螺纹间距厚。虽然有一些设计特性可以帮助组装，但是要使用2000RPM的工具将螺丝钻入到0.71mm厚的金属板而且要转六转(大概的标准运转停止数)并且在预设的扭力停住，实在是一项相当惊人的技艺。工具一秒大概会转动0.18，并且停的恰到好处。众所周知的，自攻螺丝至少要有一个螺纹间距才能够产生强度；只有二分之一的螺丝间距将会造成灾祸。

但是只要使用细螺纹、挤压成型钻尾螺丝就可以稍微克服此问题。4.2mm的例子中，0.7的细螺纹间距，至少可以让一道螺纹间距钻进薄金属板里。挤压成型的特性将金属往外推，形成一个锥体而不是切穿孔洞。标准自攻螺丝会将锥体切断，但是挤压成型螺丝会以类似于其他地方所用的三角螺栓的方式将金属卷起形成接合螺纹。此外，卷起成型的锥体也会在附着件上增加两个螺纹的厚度。细螺纹挤压钻孔机的缺点是，零件尺寸/长度/头部的可用性、成本、必须额外注意避免偏角安装、启动螺丝的末端负载增加以及螺纹被较新、较厚的抗腐蚀表面处理堵塞的可能性(请参考螺丝世界中国国际版第36期，＜后制表面处理所存在的问题＞)。

理论上使用冲压锥体几乎会增加一个螺纹的接合高度。挤压成型自攻螺丝是用于薄金属的解决方案，但是因为成本与其它因素使得设计师们去寻求较便宜的解决方案。在面对薄金属的窘境上，有一种解决方案被提出来，也就是使用「定位」孔。这是在冲压过程中使用一个锥体的模具插入冲压而成的孔洞。一般认为锥体会增加额外的高度，



give the additional height (increased engagement) and the problem would be resolved with a minimum of expense (spudded holes could be formed in the sheet metal stamping presses at little or no additional cost). Unfortunately the spud often forms a cone which is split or cracked (which opens up when a screw is installed). Also, the cone formed by a spud is actually thinner than the base thickness itself. Measuring the enlarged conical entrance area, the thinned down cone walls and the fact that the cone formed with a spud is only about 1/3 of the metal thickness, the idea of spudded holes was ruled out as a solution.

Before the self-drilling screw was finally accepted, several other solutions to the problem of attaching to thin metal were tried. Since the underlying problem was the thinness of the metal at the attachment point, any solution that increased that thickness was supposed to work. Extrusions formed during the stamping process with a properly designed extrusion punch (a better method than spudding); metal bent double to allow two thicknesses to be attached to; and the use of tapping plates and blocks (plain pieces of metal attached to the attachment points on the base sheet metal) were, and in some applications, are still used. Cost and extra labor impact negatively on some of these features.

One change in plant "culture" was that the usual plant tooling was too slow for effective drilling. This meant that parts performed slowly (try drilling a hole with a brace and bit if you want to experience poor performance). Also the formation of the point affects the drilling efficiency. The main methods of point formation are via milling the point on the screw blank or by heading or forging the point. While the latter methods are cheaper and faster, a study by a major OEM concluded that milled edge points vastly outperformed the other two types in terms of speed, ease of drilling, clogging and dulling during usage. The use of highly corrosion resistant coatings on screws (which are usually harder and/or thicker) have a tendency to deposit on the cutting edges and tips of the drill portion, causing a duller edge where a sharp cutting surface is required. Electroplating is especially famous for preferentially covering edges and tips.

The extent of the constant corrections to each problem that arose from each new additional feature on the drilling screws has increased the cost and made the product a patched up fastener, band aide upon band aide. One company dipped the points in a plastic compound to protect them from the coating application. The plastic breaks off during installation; leaving an uncoated surface to rust and the pieces of plastic to possibly infest other functions. Another company designed the flutes of the drill manufactured with a burr on the trailing edge. This would break off easily upon the initiation of installation, exposing sharp edge. However, the burrs often were broken off during handling, heat-treating and plating. The variations of fix upon fix seemed endless. One design was made without flutes. A very heavy end load forced the needle–like point

因此可以用最少的花费解决这个问题，因定位孔可以在冲压过程中在金属板上成型，只需少许或是不需要额外的成本。不幸的是，在这个过程中形成的锥体时常会在螺丝锁入时产生裂缝或是破裂。而且这样的锥体是比基底金属本身还薄的。测量扩大的圆锥入口区时，发现锥体壁已经变薄而且以此方式成型的锥体厚度大概只有金属厚度的1/3，所以此解决方案就被排除了。

在钻尾螺丝终于被采用之前，还有其他几个针对连结薄金属问题的解决方案也被试过。因为根本的问题就是金属板接合点的厚度太薄，所以只要是能够增加厚度的解决方案都被设定为可行的。这些方案包括，在冲压过程中使用正确设计的挤压冲头制造的挤压成型(优于钻孔法)、将金属双重弯曲形成两个连接厚度，以及使用在某些应用中目前仍被使用的开孔板与开孔块(连接到基底金属板连接点上的金属板)。但这些方法中有些会增加成本与劳力。

工厂「文化」产生了一种变化，那就是过去常见的工厂工具加工速度太慢，以至于无法进行有效的钻孔，而这意味着零件完成的速度是很缓慢的(如果你想体验这种不佳的绩效，试着使用手摇曲柄钻钻孔)。钻头构成也会影响到钻孔效率。钻头构成的主要方法是将螺丝胚料铣削出尖头或是透过打头或锻造而成。后面这两种方法更便宜与快速，一份由主要的OEM所做的研究，显示出铣削刀刃在速度、钻孔容易度、使用期间发生堵塞与变钝上的表现都远优于另外两种方法。在螺丝上涂布高抗腐蚀涂料(通常是更硬或是更厚)容易在刀刃以及钻头造成沉积，导制刀刃变钝无法符合需要锐利切割表面的需求。电镀是一种常被优先使用来包复刀刃与尖端的方法。

针对钻尾螺丝上每个新的附加功能所产生的问题所持续修正的程度，已经导致成本增加并且让螺丝变成贴贴补补式的补丁扣件。有一家公司将螺丝尾端浸入塑胶复合物免去涂层的需要，但是塑胶复合物会在安装期间破裂，导制表面失去保护而生锈，而且塑胶碎片也可能会影响到其他功能。另外一家公司则是将钻头的凹槽设计成有毛刺，但是这样的设计在一开始安装时就很容易破裂，裸露出尖锐的边缘。而且这些毛刺常常在搬运、热处理与电镀时断裂。这样不断的变化与修正似乎是无止境的。还有一种设计是没有凹槽的，必须使用很强的力量将针状尖头压入金属里面，在压入的过程中通常会造成燃烧与熔化现象，其所造成的负面结果是很容易想像到的。

钻尾螺丝有各种不同的长度，但是每转动一次，锁进的深度都是固定的。钻头制造商改善了凹槽轮廓使其能够发挥最佳的效能，并且仔细控

into the metal, often burning and melting its way in (a throwback to the original concept ideas). The negatives of this are easily imagined.

Drill screws come in several point lengths but can only advance so deep with each revolution. Drill makers have designed in optimum efficiency into the flute contours, and carefully control the rake, chisel and point angles to allow the fastest and easiest drilling. Coupled with web thickness and flute depth, the dimensions dictate the amount of metal removed with each revolution. In the case of the M4.2 x1.41 (#8-18) drill screw, this is 0.10mm (0.004") per revolution. However, when the screw has drilled its hole and the tapping begins, the screw advances 1.41mm (0.0056") per turn. This is not a problem if the drilling point is clear of the metal before the tapping process begins. The problem occurs when drilling into a thicker stack up. Several thicknesses or gaps between the sheets can cause jamming, stalling, or even break the screw when this advancement differential occurs.

To solve this concern, drill screws come in at least 5 drill point lengths (special lengths are available for unique applications). The negatives are increased mass, added space needed of backside for clearance, cost, and availability. Longer screws are harder to control and start. Often a dimple is placed in the sheet metal surface as a starter point.

The chart below is a recommendation of ranges for each drill point length.

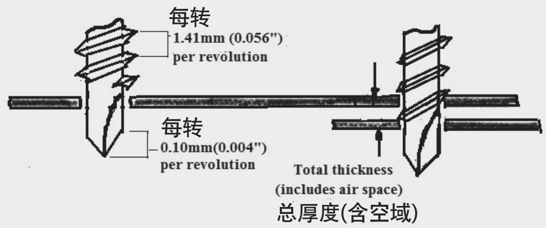
Recommended Thickness per Drill Point Type (M4.1 x 1.41 [#8-18] size screw) **每种钻头类型建议厚度** (螺丝尺寸M4.1 x 1.41 [#8-18])

Type 类型	Thickness Range 厚度范围
1	<0.89mm (0.035")
2	0.89-2.54mm (0.035-0.10")
3	2.54-3.56mm (0.10-0.14")
4	3.56-6.35mm (0.14-0.25")
5	Up to 12.7mm (0.50")

Drilling screws face many of the problems that standard tapping screws face. The need for a washer under the head, point sealer compounds on the end and threads to seal out gas and liquid intrusions, and some fixes for the speed-strip out conditions caused by rapid installation speeds. The usual solution for this is to form raised "nibs" or ridge-like protrusions under the head of the screw. These, when contacting the mating surfaces, act as a retarding devise to use up the tool installation speed and excess torque.

Drill screws are sometimes seen with wings attached to the shank, above the drill flutes and below the threaded portion. These ream a clearance hole to allow for threading without the possibility of jamming or breaking of the screw. This is especially useful when drilling through wood or other softer material before tapping into metal substrate or multi-layer stackups.

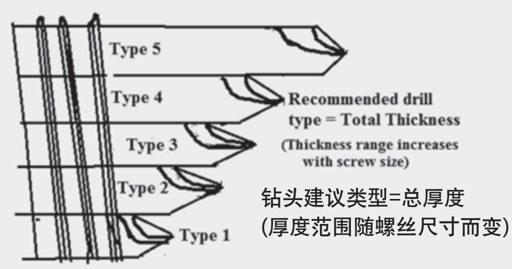
制了架子、凿子与尖头角度，让钻孔更快更容易。加上网状厚度与凹槽深度的尺寸控制了每一转去除掉的金属量，使用M4.2 x1.41 (#8-18)钻尾螺丝时，每一转是0.10mm(0.004")。但是当螺丝钻孔完成开始进行锁紧程序后，每一转可前进1.41mm (0.0056") 。如果在锁紧程序开始之前钻头上都没有金属，那就不会有问题；但是当钻入到比较厚的迭板时问题就产生了。在钻入数层金属板或是金属板之间有间隙时，若发生级差的情况就会导制卡住、停止转动甚至造成螺丝断裂。



Drilling Stackup-M4.2 x 1.41 (#8-18) drill screw
叠层钻孔--M4.2 x 1.41 (#8-18)螺钻

要解决这种顾虑，钻尾螺丝至少要有五种钻头长度(特殊应用时也有特殊长度可用)。这样的缺点是会增加质量、增加后方清除所需的空间、成本与可用性。较长的螺丝更难控制与起动。通常在金属板的表面会有个凹点做为钻孔起始点。

左表是每种钻头长度的建议范围。



钻尾螺丝跟标准自攻螺丝一样，面对许多的问题。例如螺丝头下方必须有垫圈、尾端与螺牙必须涂上黏着剂防止气体与液体入侵。一般要解决这种问题就是要在螺丝头下面塑造出一个凸起或是脊状突出。因此当与接合面接触时，可以产生缓冲作用耗尽工具安装速度与过多的扭力。

有些钻尾螺丝会在钻头凹槽的上面以及螺牙下的螺丝杆上有翼状设计。这样可以扩大孔隙，让螺丝旋进时不会卡住或是断裂。这尤其适用于钻孔穿过木头或是其它较软材质，然后再锁紧到金属基底或是多层的情况。

虽然钢制、经过硬化与热处理的材料最适合钻尾螺丝，但是也有不锈钢(级别400与300)、铝合金等材质的螺丝应用于软式施工，若有需要

While steel, hardened and tempered, is the best material for self-drilling screws, they are available in stainless (grades 400 and 300), aluminum for soft applications, and other special materials upon request. Stainless 300 series (Ni-Cr 18-8 grades) are not hardenable and are not capable of drilling into sheet steel in any but the thinnest gauges, making their usage a moot point. One unique application was a 300 series stainless steel screw body with a steel drill point. The point could drill through the sheet metal and the stainless steel body protected the application from rust and corrosion. Needless to say, these are very expensive and the usage was limited to a unique application. (400 series screws will form reddish rust after exposure but not the heavy deposits that steel will. They are heat-treatable and are often chrome plated.)

In summary, drilling screws are used when assembly labor costs are high; when hole alignment is difficult and the attached component part can be used as a template; where large clearance holes, slots and washers cannot be tolerated due to fit or location; and when there are hole interference conditions caused by paint or other finishing coatings.

The negatives, for there are always negatives to every solution, are the higher cost and lower availability of a specific type, size and length screw with the correct and desired coating. The increased length which requires more backside clearance, increased weight, and the possibility of operator injury from a sharp point protruding farther out from the joint. Higher speed tooling adds to the cost as well as probable ergonomic problems from the increased end loading required to start the parts.

也可以用其他特殊材质制造。300系列不锈钢(Ni-Cr 18-8级)无法加硬处理也不能钻入钢板，只能用于最薄的尺度，所以没什么用处。唯一的用途是300系列不锈钢螺丝本体搭配上钢制钻头。这样子钻头可以穿透板金而不锈钢本体则不会造成生锈与腐蚀。毫无疑问的，这样的螺丝设计是非常昂贵且用途有限。(400系列螺丝在暴露到空气后会产生红锈，但不像钢制螺丝会产生大量沉积，它们是可以接受热处理的而且通常会镀上铬。)

总之，钻尾螺丝适用于下列情况：当组装人工成本高、孔洞很难校直而且连接组件可被当做样板使用、由于安装或是位置要求不可以有大孔隙、狭槽与垫圈，以及因为漆料或是其他修整涂层造成的孔洞干扰情况。

至于缺点呢，每个解决方案一定都会有缺点，例子如下：成本较高而且具有正确与要求涂层的特定类型、尺寸与长度的螺丝可用性较低；加长的长度需要配合更大的背后间隙、重量也会增加；而且作业员可能因为螺丝穿透接合处而被锐利的尖头刺伤，因为较高速的工具以及起动零件所需而增加末端荷载，产生的人体工学也都会增加成本 。