FASTENER MANUFACTURING EQUIPMENT- AN OVERVIEW

by Laurence Claus

It was over thirty years ago that I first walked through a fastener manufacturing plant. I was just completing a cooperative education program with General Motors and looking to complete my engineering education with another summer internship. As luck would have it I was invited to interview with a fastener manufacturer near my home.

That first introduction to manufacturing of fasteners would serve to begin a lifelong interest and appreciation for the way that fasteners are made and, more generally, with all manufacturing processes. I was particularly impressed with my first look at how fastener threads are formed. Never in a million years would I have expected that threads could be formed by squeezing and rolling parts between two, grooved flat plates.

This article is intended to be a primer for those that may have an interest in how fasteners are made, are new to the industry, or have served in a role that has never allowed them to experience the manufacturing environment. In reality, there are about as many different approaches to making fasteners as there are fasteners themselves. In an effort, therefore, to keep this article simple, I will only be addressing equipment that performs cold forming processes and thread rolling. Although I may mention a specific brand or two of equipment, this is not intended to be an endorsement, but rather recognition of first-hand experience with a particular machine or machine feature.

Cold Forming

To understand the equipment, one must first understand what the machine is doing. I have lost track of the number of times I have toured a loud manufacturing facility, witnessed a machine in full-scale operation, but been completely mystified about what it was actually doing.

The first significant process in the birth of a fastener is converting raw material into a formed blank. There are a variety of processes that accomplish this, including: cold forming, warm forming, hot forming, or screw machining. Although cold, warm and hot forming often employ similar equipment, I intend in this article to limit the discussion to cold forming only.

So, what is cold forming? In a nutshell, the cold forming process is one that exerts high levels of load on an ambient temperature, raw material blank while confined in a die or punch. The load causes the material to take the shape of the die or punch and transform the raw material blank into a near net shape or net shape part. Taking a bolt as an example, a small cylinder of round wire is transformed into a net shaped part that has all the features of a bolt except the threads.

The cold forming process is capable of three separate transformation processes, upsetting, extruding, and trimming. Upsetting, sometimes called heading, is the process of accumulating material into one location, for example, to create a head or collar. There are physical rules that a designer must abide by, and so only a limited amount of material can be moved with each strike of the machine. This will be important later on as it relates to why most cold heading equipment is designed to strike a part more than once. **Figure 1** shows an example of the upsetting process.

Figure 1: Example of Upset Head

The second cold heading process is extruding, or the pushing of material through a die, into a punch, or around a pin to generate a reduction of diameter or form a special shape. Extrusion is a little more complicated than upsetting because there are several methods for the designers to choose from. These will be determined by the desired end result and the capabilities of the existing equipment. Cold heading extrusion processes include forward extrusion and back extrusion.

Forward extrusion pushes material forward through a die or section of a die allowing the part shape to take the definition of the shape of the die it is being pushed through. Forward extrusion can take the form of what is referred to as "Open Extrusion" or "Trapped Extrusion". In a trapped extrusion, also referred to as an impact, the blank is totally confined within the die. This allows the designer greater latitude for reduction but limited degree of length. In fact, reductions of area of 75% or more are possible. **Figure 2** illustrates a trapped extrusion. One can see the significant diameter reduction, but also the limited length of the extended diameter relative to the entire length of the part. Open extrusions are not confined entirely in the die and, thus, can produce much longer extruded sections but at less reduction of area than trapped extrusions. A typical open extrusion is of the magnitude of 30-35%. **Figure 3** illustrates an open extrusion.

Figure 2: Example of Trapped Extrusion

Figure 3: Example of Open Extrusion

Figure 4: Example of Back Extruded Spark Plug Shell (Leaning on Raw Material Blank)

Backward extrusion occurs when material flows around a driven pin to fill out the space in a punch or die. This is generally how recesses, internal holes, and similar features are formed. **Figure 4** is an example of a spark plug shell blank. The entire internal cavity is formed by back extrusion.

The final process that occurs in cold forming is trimming or piercing. Unlike upsetting and extruding which simply redistribute the material without creating any waste, trimming and piercing generate a slug that gets scrapped. When an external feature is trimmed, it is normally pushed through a die that acts like a cookie cutter and shears away excess outside material to form the desired shape. For internal parts, a blunt pin is pushed into the interior of a part to shear away a web of material and pierce a through hole. **Figure 5** illustrates how a hex bolt head is trimmed in heading.

Figure 5: Example of Trimmed Hex Head (Left-Un-trimmed, Right-Trimmed)

Cold Forming Equipment

With this basic understanding of what is happening during the cold forming process, one can begin to appreciate the equipment required. Unfortunately it can get a little complicated because many industry segments have evolved their equipment to better address their particular needs, so that it is highly unlikely that a simple tutorial such as this one will capture everything. Following, however, are some of the features that help distinguish one piece of equipment from another.

Number of Blows

The practice of cold heading is subject to certain limitations as previously introduced in the discussions of upsetting and extrusion. Material is only capable of being pushed and deformed to a limited degree before cracking or breaking. When stressed above these limits, the material will catastrophically fail (crack or break) or perform in an unpredictable and unwanted manner. Therefore, cold heading equipment is first and foremost categorized by the number of blows that it is capable of striking the part with. Obviously, the more blows that a machine is capable of making, the more complex or unconventional a part it can produce. The simplest machines strike the parts at least twice, but machines are commercially available with as many as seven blows. The majority of all the equipment in service, however, has either two, three, four, or five blows.

Number of Dies

In addition to the number of blows that a part can receive, the number of dies in the machine is important. Not all machines are designed to provide a one-to-one ratio of dies to blows. In fact, the single most prevalent cold header is a single die machine with the capability to strike the part twice. This is known as a single-die- double-stroke (sdds) or one-die-two-blow (1d2b) header. These headers can either have a reciprocating or linear motion which allows the punch side of the machine to strike the part in the die twice. This same approach can be applied to equipment with two dies resulting in two- die- three- blow (2d3b) or two- die- four- blow (2d4b) headers depending on whether the first die is struck only once or twice.

As equipment increases to three dies or more, the die to blow ratio does become one-to-one. These machines are almost always laid out in a linear fashion so that the part starts on one side and is developed by progressively moving the part to each subsequent die across the machine's tool space. This style of machine starts with two dies and goes to seven dies. In fact, experimental equipment exists with more dies. Commercially, however, the most common and practical versions are the three, four, and five die machines. Machines with more than one die are most commonly referred to as "multiple die cold headers", "progressive headers", or "part formers".

Machine Size

Although machines are rated by tonnage, they are generally commonly referred to by diameter. For example, one might refer to a machine as the " 13mm or ½" machine" because that is the part size a machine was nominally designed for. In fact, because it really has to do with tonnage ratings, machines commonly are deployed by manufacturers to make parts that have larger or smaller diameters than what the machine name implies. However, when purchasing a machine, likely the manufacturer is using the nominal size implied to fill a niche within their product line. In other words, if the manufacturer is attempting to expand their product capability from say M10 to M14, they will seek out a header that is nominally sized for M14 diameter product.

Machine Stroke

The stroke of the machine is an important factor in determining if a part can be produced on a given machine. The stroke refers to how long a pin the machine can push and is the determining factor for die length and part size. Machines come in short, medium, and long stroke versions and as the labels suggest, they relate to part size. In other words, a long part is not going to be run on a short stroke machine. Parts such as nuts, hollow tubes, and shells are commonly run on short stroke machines, while screws, bolts, and other long products are run on medium and long stroke machines. Parts that are exceptionally long may exceed the capabilities of long-stroke machines and will need to be headed in open die headers or other types of equipment.

Transfer Mechanism

Although not much of a consideration on single die equipment, both flexibility and capability of transferring parts from one die to another on multiple die equipment is important. Everything must be timed right so that the part is clear of the die before the transfer begins to move it. The transfer, therefore, is often a very delicate balance of timing and ingenuity. Transfer mechanisms are one area that equipment has consistently continued to evolve and get better.

Transfer mechanisms can generally be classified into two different categories, linear and universal. A linear transfer is just as the word linear implies, a part is grasped as it comes out of one die and subsequently presented in the same orientation to the next die over. The part moves across the machine in a nearly linear fashion. A universal transfer, on the other hand, has the ability to move the part in a similar fashion to a linear transfer, i.e. from one die to the next in the same orientation, or to "swing" open like a screen door allowing the part to flip 180° and present the opposite side of the part to the die than was originally presented. In this way, full advantage can be taken of die or punch side in the forming strategy of the part. This normally only works for short parts, and is commonly employed on equipment for making nuts.

Equipment Types

The terms used for different equipment varies quite a bit from industry segment to industry segment. In some instances special equipment has been designed for specific industry segments, such as nut formers for nuts, rivet headers for rivets, and ball formers for ball bearings. Additionally, machines have been adapted to special uses such as spark plug shells and bolt makers. A bolt maker is a unique example because unlike most other examples, which only serve to make the formed part, a bolt maker combines heading (forming and trimming) with shaving a chamfer and rolling threads.

Many fastener manufacturers take a more general approach. Instead of having these very specific machines, they have heading departments that consist of a variety of machines ranging in size and number of blows. Therefore, they may have a combination of one-die-two-blow, two-die-three-blow, and multiple blow headers. In these cases, the heading department will form the blank and transfer it to another department for secondary operations and thread rolling.

Technology Advancements

Cold headers are one area that has not seen many radical advances in the last fifty years. Do not misunderstand me, equipment makers are continually improving things and machines have and continue to advance in technology. However, there has been little or no completely disruptive or radical technology in this time period. One of the most significant exceptions to this statement is a recent advancement from Nedschroef. Their newest development is a header that is a complete numerically controlled (NC) machine. They have decoupled the traditional mechanical systems on headers and replaced them with numerically controlled servo drivers. Their new machine is to cold heading what the CNC lathe was to mechanically driven screw machines. The advantage of this new concept is a machine that claims greater accuracy, flexibility, and speed than traditional equipment.

That development is quite recent, but in the last ten to twenty years, there also has been significant advancement in cut-off quality, transfer mechanisms and actions (for example, National Machinery's Formax Plus® transfer which has modest ability to rotate up-and-out so that it can extract a part from the die before it moves it laterally over), and wire feeding. Additionally, designers have become more enlightened with tooling and more parts than ever are being formed on segmented (or collapsible) tooling. This gives capability to form grooves or double upsets because the die can split open allowing such a configuration to be pushed out of the die.

Thread Rolling

For externally threaded parts, one of the operations after forming is thread rolling. Like cold heading this process is normally performed at ambient temperature and is a displacement process. In other words, in the same way that cold heading redistributes material to form the net shape of the part, thread rolling displaces material to form the threads. This displacement action "disrupts" the material's grain alignment making the formed threads significantly stronger than cut versions (See **Figure 6**). In fact, some

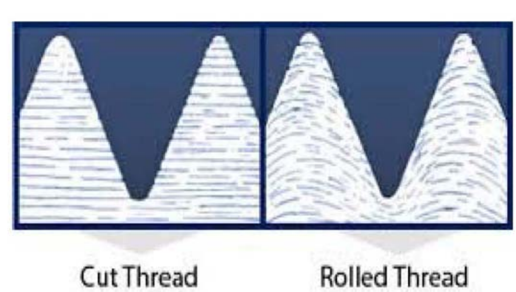

Figure 6: Rolled Versus Cut Threads- Grain Pattern

industry segments may actually roll the threads on heat treated blanks to take advantage of this strengthening mechanism and to provide for improved fatigue performance.

The process is referred to as “rolling” because regardless of the process utilized, the blank is simultaneously turned and squeezed between two or three dies. In this way, it must “roll” or rotate to successfully form the threads.

There are three process variations that are employed to roll threads on fasteners. These are flat die rolling, cylindrical rolling, and planetary rolling. By far, flat die rolling is more prevalent than either of the other two methods, but each method has its advantages, and thus, industry users and proponents.

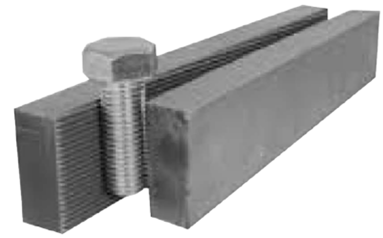

Figure 7:
Example of Flat Thread Roll Dies

Figure 8:
Example of Cylindrical Roller Dies

Flat Die Rolling

Flat die rolling is the most predominant method of thread rolling. **Figure 7** illustrates how the process works. The roll dies are two flat, matched plates with grooves that develop into the desired thread profile running lengthwise along them. At first glance it may appear that these grooves are horizontal lines, but closer inspection reveals that they are angled. The angle is the desired helix angle, or how steeply the threads will spiral up the blank. When fitted in the machine one die remains stationary and the other is on a moving ram. The unthreaded blank is introduced to the dies when the moving ram is at the back of its motion. As it comes forward, the part rotates and squeezes between the dies. By the time it reaches the end, the thread is fully formed.

Flat die rolling, when properly set-up produces good quality threads. It is relatively fast, rolling in some cases, as many as 300 parts per minute. Again, assuming a good set-up and standard operating variables, die life can be very good.

Cylindrical Rolling

The second most common rolling method is cylindrical rolling. This is when parts are rotated between either two or three spinning dies (See **Figure 8**). Cylindrical rolling is much slower than flat die rolling but maintains far better run-out results and excellent thread quality. For these reasons, this method is often used on critical fasteners where shank to thread concentricity and run-out quality is important. It is often a common method for rolling threads on long parts, large diameter parts, and parts that have internal holes with thin walls.

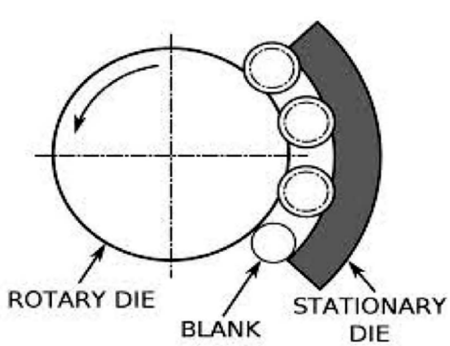

Figure 9:
Example of Planetary Roll Die System

Planetary Rolling

Figure 9 illustrates a diagram of a planetary roller. In this case there is a fixed hemispherical outer die and an inner rotating cylindrical die. Parts are introduced to the dies and the inner rotating die rotates, moving the part along the face of the long hemispherical die. Although these machines can be a little tricky to set-up, once set they have tremendous throughput because the die can have more than one part in it at a time. In fact, it may have many parts in it at one time, so that this type of roller produces the best throughput of all the roller types. To be most effective though, they require high volume work, where the machine can be set-up and dedicated to a single or only a couple of jobs.

Conclusion

The processes and equipment used to manufacture fasteners are quite ingenious and fascinating. Even though there haven’t been that many advances in technology, these methods are tried and true and have made billions of fasteners over the years. They are likely to continue to make billions more in the years to come. For everyone invested in the industry having a fundamental knowledge of how these machines work and what they do is valuable knowledge.