By Scott Livingston

Precision Thread Rolling

Squeezing metal into jewel-like threads

Thread Rolling

At Horst Engineering & Manufacturing Co., one-year old multi-axis Citizen Swiss turning centers and Eurotech multi-axis lathes pump out complete high precision machined components. They turn, they drill, they mill, and they even thread. Yet, in the same small East Hartford, Connecticut factory, Horst Engineering's sister company, Thread Rolling Inc., uses fifty-year old Waterbury, Hartford, and Reed roll threaders to form external threads with a specialized, yet elegantly simple, secondary process. Not all of their machines are antiques. Much of the equipment has been refurbished, and newer machines are mixed in with old. So it is fitting that they make their home in the most historic section of the old factory, where a fifty-five year old wood block floor symbolizes the sixty-year old family business.

Above: Thread Rolling Inc. uses a variety of machine types and sizes to roll threads.

Photos by Alan Grant

Thread rolling is a process that has been around for more than one hundred years and there are machines in service that make the fifty-year old ones look young by comparison. Thread rollers come in a variety of types and sizes, but they all use a mechanism where hardened steel dies are matched and set to penetrate with force in order to reshape the material surface of a round diameter into a thread form. A cylindrical work piece or blank is fed into the machine (manually or automatically) and the dies rotate (cylindrical dies) or reciprocate (flat dies) in order to produce threads in a "chipless" forming process. Every thread form, shape, and size has a unique set of dies which are typically ground from heat treated tool steel (typically Rockwell C 58-62) and procured, rather than made in-house.

Thread rolling is primarily a cold forming process done at room temperature, but a niche does exist for hot rolling when materials are greater than

Above: A horizontal two die process is suitable for both in-feed and thru-feed rolling.

Right: A vertical three die process is often used when tight concentricity is important.

how it works

Rockwell C 45, because die life would be seriously compromised. Like centerless grinding, its sister process, the thread rolling process can be in-feed or thru-feed. Thread rolling is the method of choice for high-volume production threading applications. Planetary die roll threaders are capable of forming threads on tens of thousands of parts per hour. High speed vertical or inclined flat die reciprocating machines can also generate high production rates, and horizontal cylindrical two die machines can quickly produce thousands of feet of threaded rod.

A lot of the stuff you get at the local hardware store, like wood screws, lag bolts, and machine screws, were mass produced with the help of thread rolling machines. Acme, buttress, worm, square, and pipe threads are just a handful of unique forms which can be produced by thread rolling; however, machine screw type threads are the most familiar to people in the precision machining industry.

On one end of the spectrum, high-volume automated thread rolling is interesting because of the speed and dimensional stability of the process, but the production of commercial grade fasteners and parts is a relatively ordinary practice. On the other end of the spectrum, there is the very specialized niche of high precision thread rolling, primarily on small batches of parts. Some high technology industries, including aerospace and motorsports, require extremely tight tolerance threads with super surface finishes, and the extra strength inherent in parts made with the forming process. Thread Rolling Inc. uses a combination of vertical cylindrical three-die machines, horizontal flat die reciprocating machines, and horizontal cylindrical two-die machines to produce precision threads.

The focus is on producing the high precision variety of machine screw style threads, concentrating on the standard 60° unified and metric thread forms most common to the aerospace industry. The most common threads rolled here are Class 2A and Class 3A in UNF, UNC, UNJF, and UNJC forms. "J" form threads have a larger controlled root radius for added strength in the high stress area of a thread and are common to the aerospace industry. Dimensional inspection of high quality threads is different from the commercial variety. Specifications vary, but aerospace and military standards require that indicating type thread gauging be used to inspect the pitch diameter and associated dimensions.

Above: Flat die thread rolling is adaptable for both low and high volume requirements.

Inspection of pitch diameters are performed with both full form and single element indicating type gauges that are set with thread masters. Thread go/no go ring gages are used for reference only. Standard outside diameter micrometers are used for inspecting major diameters, and optical comparators are used to check minor diameters and root radii. With all of these gauges available on the shop floor, a thread rolling operator can monitor the process and make adjustments quickly. Die wear and other variables can affect the rolling process, but once a machine is set, the process is consistent and repeatable.

Formed threads are preferred for high strength and critical applications like those found in the aerospace industry. Threads that are rolled, especially on heat treated parts, have higher tension, shear, and fatigue strength. No material is removed during the rolling process, eliminating one of the inherent weaknesses of cut or ground threads. The cold formed properties include a higher density of material grains, or molecules, especially where they have been compacted along the lower flank of each thread pitch and in the root of the thread.

Aerospace metals can be difficult to machine and form, so the common threading attachments used on screw machines and lathes for higher volume work struggle to meet the quality requirements of precision threads. The force required to form threads on heat treated alloy steel or on exotic alloy parts made from Inconel® or Titanium cannot be achieved effectively without using dedicated equipment. Thread Rolling Inc. focuses on threads that are less than 1.500 inches in diameter, but rolled threads are produced on fasteners up to 5.00 inches and even larger. It takes serious force, up to thirty or forty tons of rolling pressure generated by very large machines, in order to move that much material. Some threads are deemed so critical that a destructive testing sampling process is required to microscopically examine each pitch of a thread at 500X.

Properly formed threads require that the dies are exactly lined up, or "matched." Whether the process uses two or three dies, they must track properly in order to avoid internal defects, such as overlaps, cracks, folds, seams, and craters. The destructive thread inspection method is used to identify internal defects and to verify that the proper material grainflow has been achieved. Representative samples are tested at the beginning of each new set up, and periodically during the course of a production run.

Above: Aerospace industry specifications require that indicating type gauges be used to measure threads.

The testing process requires that the threads are cut from the rest of the part, bisected longitudinally, mounted in an epoxy resin, ground and lapped to a three micron finish, etched to reveal the microstructure, and microscopically inspected. The whole process takes a little more than an hour, but requires specialized metallographic preparation and inspection equipment. Because production pauses for testing, a range of machines are required, so the machinists work on several jobs at the same time, alternating between grinding, threading, and testing processes.

Many times, parts are received for service in bulk packaging, but when they are returned with shiny precision threads, they are individually packaged with protectors to prevent damage during shipment. On one recent day, a clerk was packing up a single blue container that was lined with padded foam. The foam insert was die-cut for a single prototype shaft. This eighteen inch part was thread rolled on both ends. The part had been designed and engineered to accommodate rolled threads. That meant that the pre-roll thread diameters were properly chamfered and ground to the correct pitch diameter, a hypothetical diameter in between the major and minor diameters, which is used to determine thread size. This particular job did not require destructive testing, but set-up pieces were produced from similar material in order to get the machines set. With a one-piece lot size, there is no room for error, and the highly skilled machinists knew this.

Above: Metallographic thread specimens must be bi-sected, cleaned, hot mounted, ground, polished, and etched prior to inspection.

The highest quality rolled threads are produced from the best quality blanks. For that reason, most of the parts sent to Thread Rolling Inc. are left oversized so that the final sizing process can be controlled by centerless grinding. Once the correct size has been ground, typically by a threading associate and a grinding associate working together, the parts are ground to their final size within .0004 inch while holding roundness within .000050. Before thread rolling, the surface finish on the diameter is always better than 32 microinches. Thanks to the burnishing action of the dies, the finish after rolling, especially on the flanks, can be as good as 4 microinches, depending on the material and hardness. Finish is another reason for choosing rolling over other threading processes.

The lack of CNC controls on most equipment means that the process is not as user-friendly as screw machining, turning, or milling. It is difficult to explain to customers that the major diameter actually increases in size when rolled. Some do not want to believe that they can turn their blanks below the major diameter and that their parts will not be scrap. For example a .250-28 UNF-3A thread has a pitch diameter of .2268-.2243 and a major diameter of .2500-.2435. The blank size prior to roll threading will be near the maximum pitch diameter and the material displaced by the dies will form up to fall within the major diameter tolerance.

The folks at Thread Rolling Inc. frequently hear that customers have shied away from jobs requiring thread rolling because the process seems difficult, mysterious, or out of their control. The process is unique, but within the precision forming industry, there are many specialists at the craft. The process just cannot be done as easily as one might expect in today's environment where "do it all" multi-axis machines automatically perform their work. A lot of "feel" is necessary to be a successful thread rolling operator. High precision thread rolling is a hands-on niche process that is here to stay.

References:

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