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Precision Thread Rolling: How it Works

Squeezing metal into jewel-like threads

High technology industries, including aerospace, defense, power generation, and motorsports, require threads with stronger physical characteristics, higher accuracy, and excellent surface finish.

Thread rolling is the preferred method for achieving these objectives. Outsourced thread rolling processes are more efficient and simply better than producing threads by cutting or grinding, especially on parts made from difficult metals.

In this "How It Works" note, we explain the thread rolling process, its advantages, and how we help customers engineer their parts to accommodate rolled threads.

Our focus is on precision thread rolling, which is a high-end niche within the broader fastener industry. It more closely resembles advanced manufacturing than ordinary manufacturing geared towards higher volume commercial industries.

You can find additional information on our homepage: www.threadrolling.com

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1. Introduction - What is Thread Rolling?

At HORST Engineering multi-axis CNC Swiss turning centers and multi-axis lathes pump out complete high precision machined components. They turn, they drill, they mill, and they thread. Yet, in our East Hartford, Connecticut factory, 80-year old thread rolling machines form external threads with a specialized, yet elegantly simple, secondary process. These machines are not antiques.

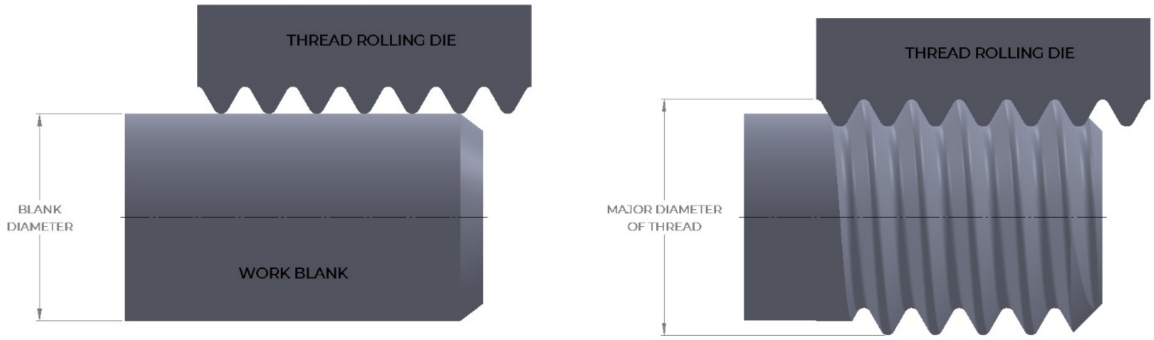
Much of the equipment has been rebuilt with modern controls and adapted to today's high tech CNC environment. Newer machines are mixed in with old, but the core technology behind this powerful process hasn't changed in more than 150 years. The method had its origins during the Industrial Revolution of the early 1800s and advanced later in that century. With improvements in materials, equipment, dies, and tooling, precision thread rolling became possible and by the 1940s, it was being used in a variety of modern industries including the emerging aircraft industry. HORST Engineering's founding dates back 75 years to 1946, and we have been rolling the highest quality threads for most of that time.

A variety of machine types and sizes to roll threads

It is remarkable that thread rolling is a process that has been around for more than a century. In what condition will CNC Swiss machines like our Citizen M32's be in 50 or 100 years from now? Far less sophisticated than a 13-axis Swiss screw machine, yet far more productive at its specialized task; a thread roller is good at one thing - squeezing metal.

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 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" cold forging (or forming) process. Every thread form, shape, and size has a unique set of dies which are typically ground from heat treated tool steel (Rc58-62). At HORST Engineering, our dies are procured from other suppliers, 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 Rc45 because die life would be seriously compromised. Like its sister process, centerless grinding, thread rolling can be done in-feed, or it can be thru-feed for parts that do not have "heads" such as studs and rods.

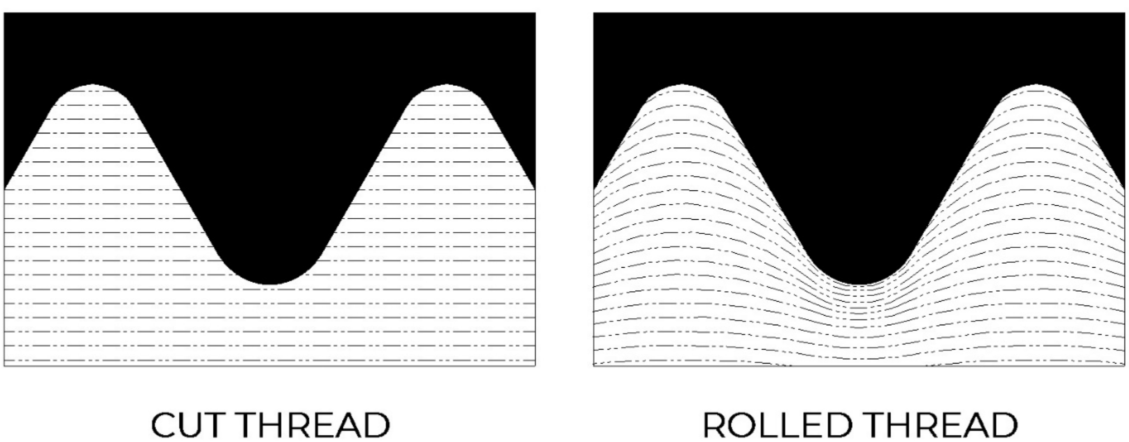


Thread rolling is the method of choice for high volume production threading applications. Planetary die thread rolling equipment is capable of forming threads on tens of thousands of parts per hour. High speed vertical or inclined flat die reciprocating machines can generate nearly as high production rates. Both methods require automatic feeding (i.e. vibratory bowl feeders). Horizontal cylindrical two-die machines can quickly produce thousands of feet of threaded rod in an hour.

These higher production methods are important, but they are not HORST Engineering's expertise. Our thread rolling is of a different sort. We focus on the lower volume, high precision work that is required for high technology industries.

2. Why Precision Rolled Threads?

HORST Engineering's thread rolling capability was developed for another purpose. While the process can be fast, use less material, and be suitable for high volume commercial hardware, the real benefits of rolled threads are their stronger physical characteristics, higher accuracy, and excellent surface finish. Rolled threads are simply better than cut or ground threads.



- **Physical Characteristics**
  - **Tensile Strength** – the cold forming process improves tensile strength by more than 10%.
  - **Shear Strength** – the compression of thread molecules (grains) and redirection of flowlines in the shape of the thread improve shear strength.

    - **Fatigue Resistance** – the compression that results from the rolling process leaves the surface of threads smooth and complete. Unlike a cutting or grinding process whose inherent weakness is that incomplete or partial grains remain at the surface, rolled threads are devoid of tool marks, chatter, or tears. Additionally, the dies create a burnishing action that smooths the surface of the threads particularly on the flanks and in the roots. The compacted grains are more dense and stronger. Parts with rolled threads assemble better resulting in less wear and tear. For all of these reasons, fatigue strength is more than 50% stronger and when the metal to be rolled is heat treated first, the fatigue strength can be more than 5X that of cut threads.

- **Accuracy**
    - The accuracy and consistency of rolled threads is much better than threads produced by other means.
    - When the process is properly set-up and under control, pitch diameters, major diameters, and minor diameters are the same from part to part during the length of a production run. When perfect blank diameters are created (typically by centerless grinding), pitch diameters can be held within .0005 consistently.
    - Other dimensional characteristics including thread angle, lead, drunkenness, and roundness are consistently better on rolled threads and particularly those made from super-precise blanks.

- **Uniformity** – as noted, with proper set-up and when operating under control, the consistency of thread rolling cannot be beat. The forming process is entirely different from cutting or grinding and uniform parts can be produced for long periods of time. As long as an operator monitors die wear and other factors, thread rolling can typically produce long production runs with little to no variation between parts.

- **Smooth Finish** – it was noted that the smooth finish created by the burnishing action of thread rolling dies contributes to the superior fatigue strength, but smooth finish has other benefits as well. Many aerospace specifications, and particularly those that require UNJ or "J" form threads, require a surface roughness (Ra or √) of 32√ or better. At worst, a proper thread rolling set-up will result in Ra32 for most metals. Many times, the finish can be as good as 16√, 8√, or even 4√. Threads with a finish that good shine like a mirror. Only thread grinding can come close to an 32√ or 16√ finish, and it is a much slower process. The more typical thread cutting process on a screw machine or lathe is challenged to generate an 32√

- **Speed** – even though HORST Engineering's focus is on the quality of threads, it should be noted that the speed of the thread rolling process is much better than other methods. Even when doing small batch high precision thread rolling, the value of a fast process benefits customers.

Aerospace drawing and specification requirements often require that threads be rolled. A secondary thread rolling process is the best method for getting the job done.

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

3. Different Types of Threads

Many of the fasteners you get at the hardware store were mass produced with the help of thread rolling machines. Wood screws, lag bolts, machine screws, it does not matter what type of thread is required; thread rolling is a suitable process. 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. Additionally, thread rolling equipment are well suited for producing high quality knurls (straight, diagonal, and diamond). HORST Engineering concentrates on machine screw threads and knurls.

We make the high precision variety of machine screw style threads. Our concentration is on standard 60° unified and metric thread forms that are highly utilized in the aerospace industry. The most common threads rolled are English standard Class 2A and Class 3A in UNF, UNC, UNJF, and UNJC forms. We also do metric threads to ISO and DIN standards. UNJ or “J” form threads have a larger controlled root radius for added strength. The root is the high stress area at the bottom of a thread and the J form is a very common requirement in the aerospace industry.

A horizontal two die process is suitable for both infeed and thru-feed rolling.

4. Different Methods of Thread Rolling

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, HORST Engineering's focus is on the very specialized niche of high precision thread rolling, primarily for small batches of parts.

High technology industries, including aerospace, defense, power generation, and motorsports, require threads with superior characteristics including tight tolerances, excellent surface finishes, and high strength.

We use a combination of vertical cylindrical three-die machines, horizontal flat die reciprocating machines, and horizontal cylindrical two-die machines.

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

Attachments vs. Dedicated Equipment

Aerospace metals can be difficult to machine and form, so the common threading attachments used on screw machines and lathes, struggle to meet the quality requirements of precision threads. These attachments often have small dies, lack rigidity, and the screw machine or lathe lacks the force to make consistent threads. It is very common for us to help customers rework or repair their parts (when permitted) after a failed attempt to do their own thread rolling with an attachment.

Attachments have their place in the machining world for mild steels and other soft metals. They can work when set up properly, but for harder stainless steels and high temperature alloys, they are no match for a specialized thread rolling machine.

HORST Engineering has some attachments and we use them from time to time when the right opportunity to complete a part on a lathe or Swiss screw machine, comes along, but we only use them on small soft parts that don't have precision requirements. Attachments are no substitute for a dedicated secondary thread rolling process.

The force required to form threads on heat treated steel, Inconel, titanium, A-286, L-605, Waspaloy, Monel, Rene 41, or other high temperature alloys, cannot be achieved effectively without using dedicated equipment.

Thread Rolling vs. Cutting and Grinding Threads

Our equipment is geared towards smaller lots sizes, and high precision. The speed and efficiency of the secondary rolling process are advantages, and our customers often specify rolled threads for their superior characteristics, even when not required. When permitted to cut a thread, it often doesn't make sense. With the metals used for aerospace and other high technology industries, it is common to experience extreme tool wear and inconsistency when trying to cut threads. Thread grinding is a suitable alternative when tight concentricity requirements or super-precision are required (e.g. thread gage masters or set plugs), but it is a much slower and costly process and you don't get any of the high strength benefits.

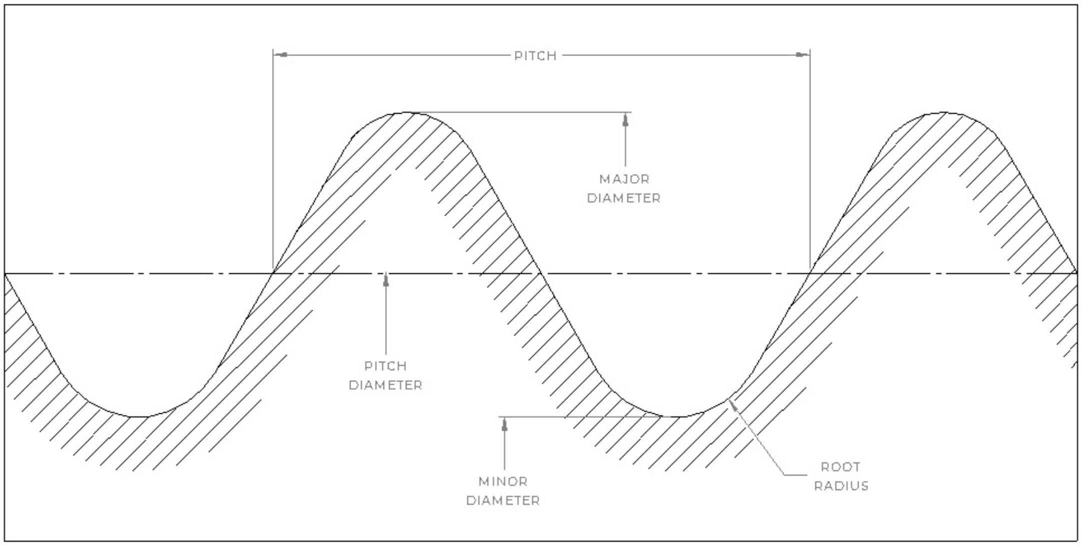
5. Thread Inspection

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.

At HORST Engineering, thread go/no go ring gages are used for reference only. Inspection of pitch diameters are performed with both full form (rolls or segments) and single element (rolls) indicating type gages that are set with thread masters. 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 on the fly. Die wear and other variables can affect the rolling process, but once a machine is set, and properly monitored, the process is consistent and repeatable.

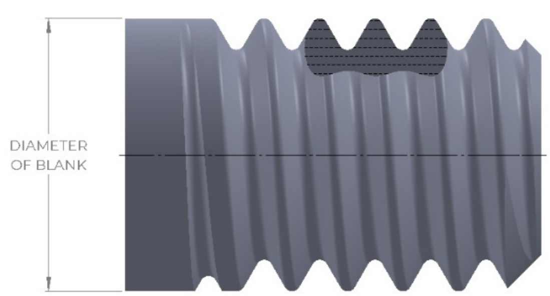
Aerospace industry specifications require that indicating type gauges be used to measure threads.

At HORST Engineering, we focus on threads that are 2.500 inches (63mm) or less in diameter, but rolled threads are produced on fasteners with diameters of 5.00 inches (127mm) and even larger. It takes significant force, up to thirty or forty tons of rolling pressure generated by very large machines, in order to make our threads. For larger parts, the force requirements are even greater. Some threads are deemed so critical, that a destructive testing sampling process is required to microscopically examine each pitch of a thread at 500X.



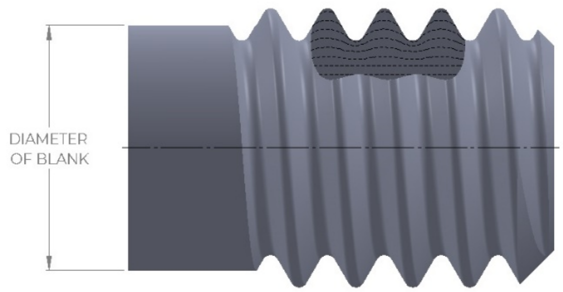
6. Thread Microstructure & Metallographic Examination

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.



CUT THREAD

The testing process requires that the threads be cut from the rest of the part, bisected longitudinally, mounted in an epoxy resin, rough ground, and then polished (lapped) to a three micron finish. The prepared specimen is etched to reveal the microstructure, and then it is microscopically inspected. The whole process takes a little more than an hour, but requires specialized metallographic preparation and inspection equipment. Because production is paused during the testing, a range of machines are required and the HORST Engineering's operators work on several jobs at the same time. We alternate between grinding, threading, and testing processes.



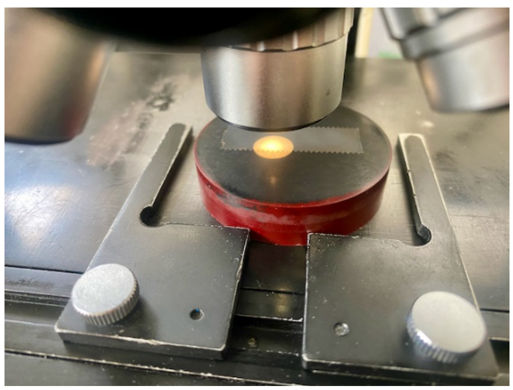
ROLLED THREAD

HORST Engineering makes complete fasteners, but we have an extensive value-added service business, doing work for a variety of customers, big and small, throughout the United States and Canada. A wide variety of part shapes and sizes are thread rolled. On any given day, bolts, rod ends, studs, setscrews, plugs, tie-rods, shafts, connectors, vanes, struts, and other specialized parts pass through the shop. It is fascinating to see the different types of parts that benefit from having their threads rolled. Many times, parts are received in bulk packaging, but when they are returned with shiny precision threads, they are individually packaged with protectors to prevent damage during shipment.

Metallographic specimens are bisected, cleaned, hot mounted, ground, and polished.

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 associates know this.

After polishing to a 3 micron finish, the specimens are etched to reveal the microstructure.



Each thread specimen is inspected at 200X for proper grain flow and 500X for internal defects.

7. Pre-Roll Thread Preparation

It has already been mentioned that the highest quality rolled threads are produced from the best quality blanks. When HORST Engineering produces complete parts, we frequently make a blank on a Swiss screw machine or lathe and leave the pre-roll thread diameter .003 inch over the max pitch diameter. Additionally, most customers are requested that for service work, they send in their parts in a similar condition. We ask them to leave the parts oversized so that the final sizing process can be controlled by centerless grinding. Once the correct size has been developed, 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 Ra32.

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 inch and a major diameter of .2500-.2435 inch. 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.

Customers entrust us with their parts and we take that responsibility seriously. We pride ourselves on helping our customers engineer their parts to accommodate rolled threads.

8. Summary

At HORST Engineering, we occasionally learn that prospective 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 can't be done as easily as one might expect in today's environment where "do it all" multi-axis machines automatically perform their work behind closed doors, but there are many great partners in the industry that can help. HORST Engineering is just one of those shops, but we have peers throughout the country and the world who have developed similar expertise. High precision thread rolling is a hands-on niche process that has existed for more than 140 years, and it is here to stay.

9. References

"Thread and Form Rolling", Clifford T. Appleton, *Tool Engineers Handbook*, 2nd edition, 1959, p. 46-62 to 46-77

"Threading", *Machinery's Handbook 25th Edition*, 1996, p. 1630-1854