What makes a CNC-ready milling machine?

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In manual machining the operator provides a lot of **skill and finesse** (even artistic ability) to coax excess metal off the desired part. There is the familiar turning past the mark and returning to the correct position on the dial to make a cut at the desired position. Approaching the cut from the same direction, eliminates possible backlash and slop in the machine and with these techniques a machining expert can create a part that is more accurate than would be expected from the same machine run by an inexperienced operator.

Computer controlled machine tools (CNC-Computer Numerical Control) operate without requiring a human to turn the dials. Since there is no expert running the CNC machine, the differences between an expert and an inexperienced operator must be reduced or eliminated if a CNC machine is to produce acceptable parts. Once the differences are eliminated, the CNC machine can reliably make many copies of the same part with the same accuracy as the expert machinist. The CNC machine however will not get tired and make mistakes. There are no boredom or fatigue penalties.

The machine squareness, adjustment of gibs, and the fit of the ways should be common between the manual and CNC methods of machining. Either type of machining requires that the X-axis and Y-axis are perpendicular to each other and also to the Z-axis. The machine slides must be free moving over the length of travel and cannot bind or flex when cutting or when motion direction changes. Cutting flat surfaces requires linear slides with flat travel ranges. Lubricant applied to the ways and lead screws will not measurably affect the differences between the results of an expert and a novice. Lack of lubricant will affect the life of the machine, and may fatigue the machine operator, but will not make a marked difference in results between CNC and manual machining.

Two contributing mechanical factors, which can cause a big difference in the results achieved by an expert and a novice, are:

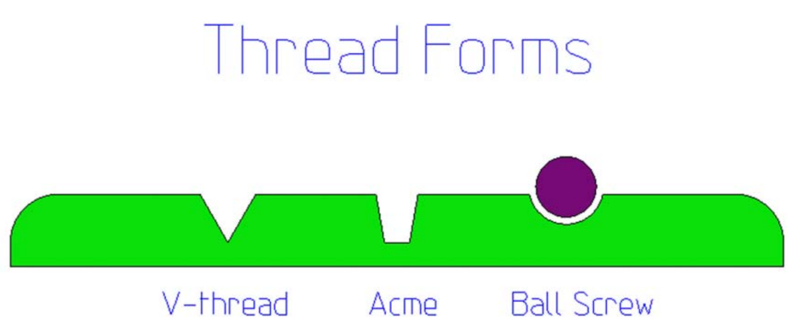
1) Endplay of the lead screw
2) Leadscrew nut slop

The expert makes extra motions to assure that the machine slides are positioned accurately before beginning to make a cut. He makes sure that all cutting forces push (conventional milling) in the desired direction, rather than pull (climb milling) so that the force of the cut does not affect the slide position. The novice is unaware of the need for this extra compensating motion. If these two mechanical factors are eliminated or minimized, the need for the extra motions is reduced or eliminated. This permits the novice and/or the CNC machine to make parts nearly as well as the expert.

Converting a manual mill to a CNC ready mill will address these two factors, and also add motor mounting brackets and motor shaft couplers.

Lead Screws convert the rotary motion of a machine handle or a motor into linear motion. They are precisely manufactured to move a predictable distance for each degree of rotational motion. Typical bench-top milling and routing machines will move .050 inch or .100 inch for each revolution of the handle or drive motor.

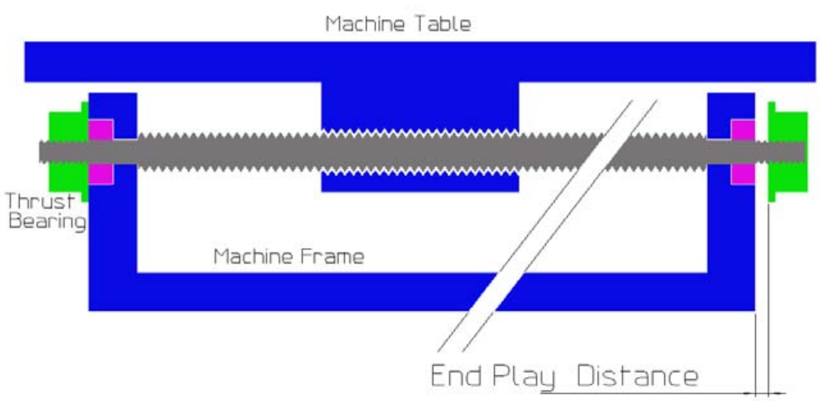
Lead Screw Types: Lead Screws are usually one of three types: 60° V thread, acme thread, and ball screw.



- The 60° V-thread is the least expensive and is the least efficient at converting the rotational forces into linear motion. These screws have typical efficiencies of 30%. On a large machine this can be a significant loss of power on the axis. For small bench-top machines, V-thread losses are a small portion of a small expenditure of energy. The thread flanks have large contact surfaces between the inside and outside threads. These threads are designed to be tightened and remain tight, not necessarily to transmit motion. Taps and nuts are readily available at economical prices.

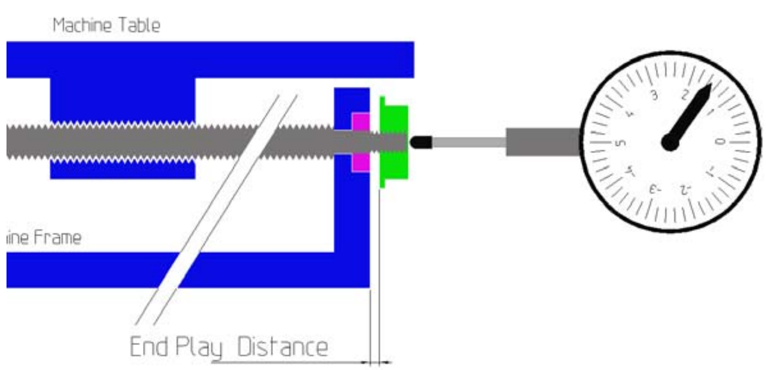
- Acme threads are better than 60° V-thread at transmitting rotational forces into linear motion. They will typically have about 60%-70% efficiency. The losses are also the result of friction between the sliding surfaces of the threads. These threads cost only slightly more than similarly sized 60° V-thread. They are designed for translating rotation into linear movement, but can develop excessive wear after extended usage. Compared to 60° V-thread, taps and nuts are much more expensive and form-turning tools are more complex to manufacture and use.
- Ball Screws are the most expensive and the most efficient. Adding a set of precision ball screws can triple the cost of a bench top machine, if the screws can even be found small enough to be used. Instead of sliding screw surfaces as found in the first two types of screws, ball screws substitute moving ball bearings in rolled or precision-ground, helical ball tracks. This results in a very low friction device and manufacturers typically specify their ball screws at 90% efficiency. Ball screws and nuts are not made with general purpose manufacturing equipment.

Endplay occurs if the lead-screw mounts permit motion of the lead-screw when direction changes.



Typically the ends of lead screws will be machined to a precision diameter with shoulders and placed in a sleeve or ball bearing (thrust bearings). If the machine design does not have thrust bearings, or adjustment for endplay, changes in direction will result in a rotation of the screw without any corresponding motion of the slide.

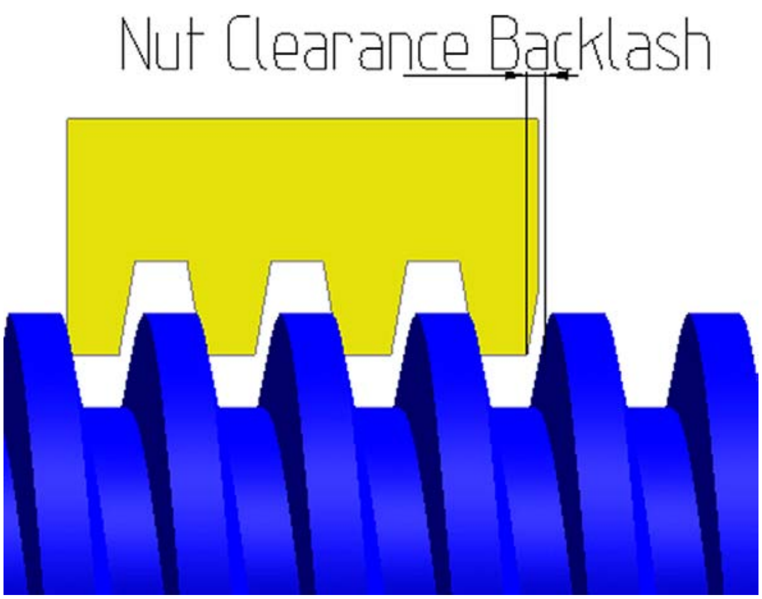
This can be easily measured by placing an indicator on the end of the screw. Under cutting loads, the indicator should remain steady during changes in direction of rotation of the lead screw.



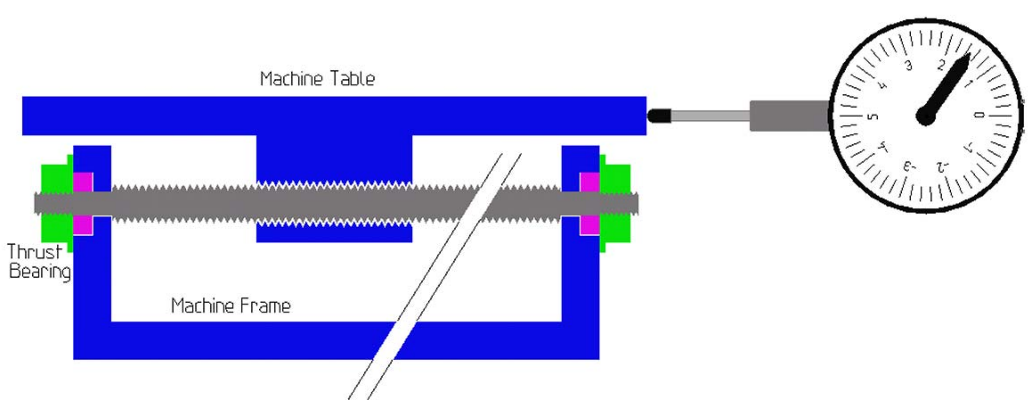
CNC ready desktop mills from manufacturers such as Taig and Sherline have thrust bearings to prevent endplay.

Endplay can be eliminated for the most part by a slight preloading of the thrust bearings. Take care not to preload the bearings too much as that may cause excessive drag, heating and premature wear of the thrust bearings. Motor shaft bearings should not be used as a substitute for thrust bearings, as they have no method to adjust for endplay.

Lead Screw Nut Slop is the result of a loose fit between the machine axis lead screw and the table drive nut. Commercial grade V-threads and acme threads have clearances that permit rotation of the screw within the nut. Even a precision ground ball screw will have some small clearance between the nut and the screw. When rotation direction changes, this clearance permits a slight rotation of the lead screw, before the machine slide starts to move in the new direction. Usually this is the main component of backlash because the endplay will remain small on a well-designed and maintained milling machine.



The Nut-clearance backlash can be measured once the endplay has been eliminated. Place an indicator against the end of the machine table, or mount it to the table and contact a moving part of the machine such as the spindle. If your machine has graduated dials, note the reading when the dial is rotated clockwise to move the indicator dial off zero. Then rotate the handle counter-clockwise until the indicator dial has moved at least .001 inch. The nut slop backlash is the change in the hand wheel reading minus .001 inch.



The same measurement can be made on a CNC machine by using the incremental jog, set to .001 inch increments. Jog the machine in a plus direction to move the indicator off zero. Then jog in the opposite direction until the indicator moves .001 inch. The nut clearance backlash will be equal to the distance jogged minus .001. If the CNC controller supports backlash compensation, this is the number to use for that parameter. Entering the backlash compensation into a controller will NOT in any way eliminate backlash, but may make drilled hole locations a bit more accurate.

In order to take the expert out of machining, we need to mechanically eliminate backlash. Three methods are commonly used to accomplish this.

1) Use a single nut with a small or zero backlash. Examples of this kind of solution are 1) a cast lubricious nut (moglice) that can be lapped to fit the lead screw, 2) machined or molded, solid plastic materials such as acetal (delrin) that have small or zero clearance, relying on the plastic to “stretch”.
2) Dual nuts held in opposition on the lead screw can also be used to minimize backlash. These can be used on all three types of thread form. The nuts are preloaded against opposite flanks of the threads, and sometimes held apart with stiff springs. Generally dual nut solutions on V-thread and acme forms will use a material softer than the lead screw to prevent degradation of the thread accuracy. The lead screw determines the machine accuracy and so machines are designed to wear the nut rather than the screw. Lubrication is always needed with dual nut solutions.
3) Spring-loaded, split nuts can be used on acme threads. The spring forces a split nut to press on both sides of the thread, and thus adjusts for wear with a constant spring pressure. These are usually made of a slippery plastic such as acetal.

Adding mechanical backlash control to a milling machine permits the machine to reliably position as good as an expert machinist, turning manual cranks. There are still a few other tricks that the expert machinist uses to make good parts, but much of what at one time was thought of as art is now reduced to practical science with the addition of a few anti-backlash nuts.