Vertical Machining Centers:

Increasing Shop Profitability Through Machine Choice and Deployment

MAKINO

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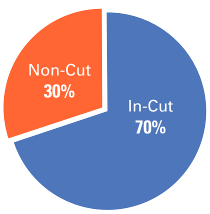
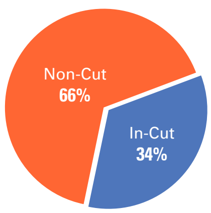
With metal-cutting machinery, on average, the spindle should be in-cut 70 percent of the available in-cycle time. However, based on a survey from more than 100 U.S. manufacturing plants (both small and large), the average Vertical Machining Center (VMC) spindle utilization during in-cut time is only 34 percent. Meaning that out of that 70 percent pie slice when the spindle should be utilized, 66 percent of the time the spindle is waiting or idle.



Expected Average



Actual Average

This low spindle utilization rate is due to the fact that manufacturers are experiencing much slower cutting results than what's realistically achievable with today's technology. Often this is caused by the limits of current operations, tooling or machines and, subsequently, manufacturers are spending the majority of "cutting" time doing anything but. The bulk of spindle utilization time is being consumed with setup, loading/unloading workpieces, cutting tool maintenance, chip clearing, etc.

Multiply the number of hours in a workday when the spindle is not being utilized by the average shop rate, and manufacturers can quantify how much reduced spindle utilization is cutting into profitability day after day, year after year.

The Economic Factor of Productivity

Any time the spindle is not spinning, productivity is reduced and profitability decreases. When production increases, it effectively lowers the cost per unit (CPU) of a product. With a lower CPU, the manufacturer can proceed in one of two ways:

1) Lower prices due to the reduced cost per part.

   Reducing consumer costs, in turn, permits the manufacturer to become more competitive in the market. When a manufacturer is able to sell more products at more competitive prices, it can increase market awareness and be in a better position to attract more customers; therefore, generating more sales and delivering healthier profits. With stiff competition in the marketplace between shops and manufacturers, a small boost in competitiveness can go a long way towards creating additional streams of revenue.

2) Increase margins while keeping consumer prices fixed.

   A lower cost per part, could allow the manufacturer to increase its margins if the consumer's price remained the same. This can provide a boost to the bottom line in situations where competition isn't as cutthroat or if the manufacturer has an existing stranglehold on the market.

Getting Back to Basics

It sounds simplistic but drilling down and analyzing fundamentals can allow manufacturers to outline steps for improvement. The basic premise that the entire purpose of machining is to remove metal, should serve as a litmus test for manufacturers to rate each step in their manufacturing process. Companies should score how efficiently each phase of production lends itself to achieving the goal of removing metal.

In order to excel at productivity, companies should strive to deliver a repeatable process, minimize the time needed to produce the part, streamline throughput, and maximize asset utilization.

The objective should be to meet customer expectations, meet cost expectations, and guarantee delivery. When a manufacturer performs these steps proficiently, the result should be improved production rates, minimized costs, and increased profitability.

However, for a business to truly excel in manufacturing, they must not only do everything as stated above; they must focus on the key factors that have the greatest impact on profitability.

The most prolific way to drill down on those factors is by examining two key fundamentals:

1. **Decrease cycle times:** Find ways to improve metal removal rates and reducing parasitic non-cutting time.

2. **Increase spindle utilization:** Determine how to eliminate unnecessary interruptions to production.

Three Vital Characteristics to Consider

By assessing the time that the spindle could potentially be running and measuring the spindle's true in-cut time, manufacturers can gauge the non-utilization rate and evaluate what changes could make the largest impact on productivity. Considering the fact that an average spindle should be cutting 70 percent of the time but is only in-cut 34 percent of the work day, finding ways to increase the in-cut time percentage is where manufacturers can experience the greatest improvement in productivity and profitability.

Since the prime function of a vertical machine is to remove metal, it's ideal to review three machine characteristics that can affect the rate of which metal is removed from a workpiece.

1. Horsepower (hp)

   The machine with the highest power capabilities is going to remove metal faster.

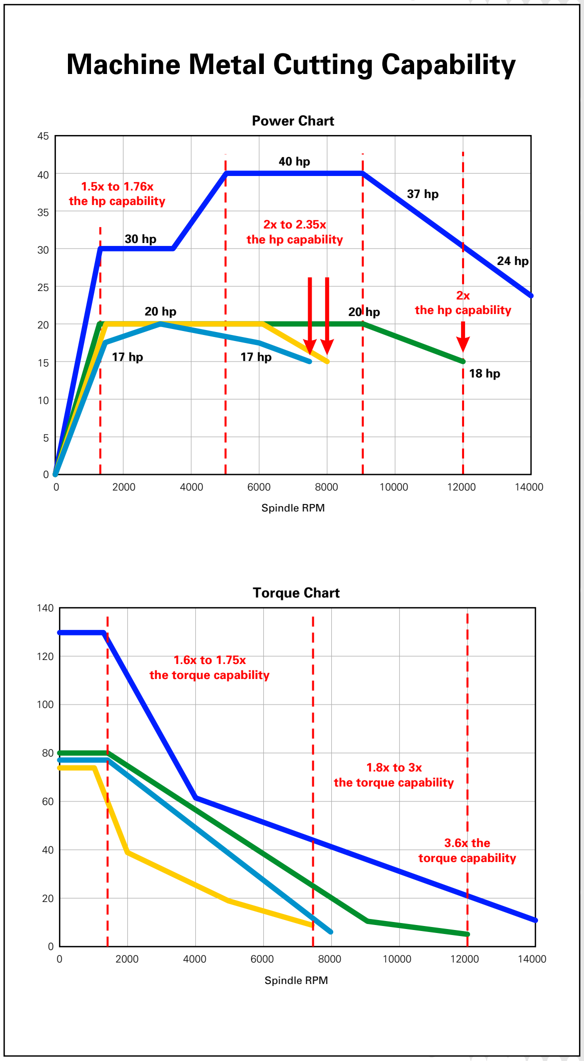
2. Torque

   The machine with more torque is going to be more productive than a machine with less torque.

3. RPM

   The higher the RPM, particularly in today's advanced tooling environment, the faster metal can be removed from the workpiece.

The chart below compares four different types of VMC milling machines, each with varying spindle characteristics. Since the prime function of a vertical milling center is to remove metal, it's best to select a machine with the most wide-ranging characteristics for horsepower, torque, and RPM. Doing so produces the shortest cutting time as well as the lowest cost per part.



Reduced cutting cycle time allows shops to make the same number of vertical milling machine parts on less machines or significantly shrink the number of production hours while using less machines. This can have a profound economic impact; freeing up floor space and decreasing production expense.

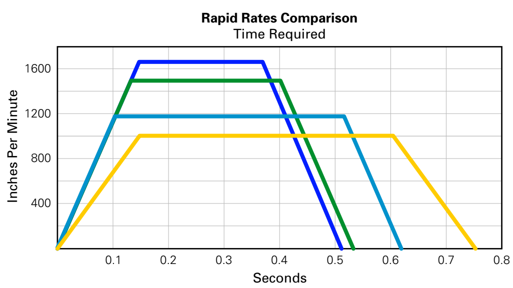
Lower production cost also can minimize WIP costs and carrying costs. Shops that can cut parts faster can reduce delivery times which allows them to be more responsive to customer needs, helping them gain a competitive foothold in the market.

More Efficient Machining

As previously mentioned, it's important to choose a machine that utilizes the greatest range of horsepower, torque, and RPM. However, with over 250 VMC full form machine builders to choose from, spec sheets often look very similar. It's highly advised that manufacturers drill down on a few major features that differentiate one machine from another. By thoroughly comparing this data, manufacturers can clearly separate the top performing machines from the lesser ones. The key features to closely examine are rapid rates and spindle horsepower, torque and RPM.

Rapid Rates

In-cycle non-cutting time is mainly comprised of rapid traverse moves and tool changes. The rapid rate is always on the spec sheet, but just as important is the axis acceleration/ deceleration rates because they determine how quickly max speed can be achieved. If moves are small, the real rapid rate may not matter at all. However, with larger moves (and larger parts) it can indeed be consequential.



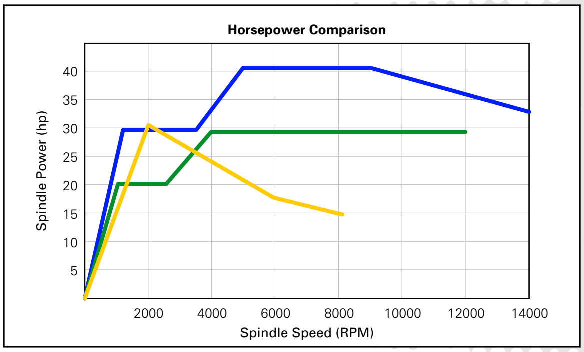
In the image above, the time required for a 10" move includes the profiles of four popular VMCs, all but one of which have similar published rapid rates. However, the top machine performed 30 percent faster than the slowest over just a 10-inch move. The longer the moves, and the more of them, the greater that difference becomes.

Likewise, rapid rates are reflected in tool change chip-to-chip time and can be equally important. Among the four machines in the comparison, the slowest machine takes 29 percent longer than two of the others.

Machine tool spec sheets seldom tell the real story about how a VMC will perform across a range of applications. Here are a few other performance indicators manufacturers need to consider:

Horsepower

HP is another widely misinterpreted spec, because what really matters is not the single top HP number on the spec sheet, but how much power the machine can generate and maintain across the entire speed range. In the horsepower comparison chart, there are horsepower profiles of three similar vertical milling machine centers. The yellow line represents a machine that claims a 30-HP rating – but, can only achieve that at a single point in its speed range. Not very useful. The green line depicts another 30-HP machine – but, one that can maintain that HP continuously across only a portion of its speed range. The blue line is the Makino PS-series of VMC machines, which maintains higher HP across the entire speed range than the other standard machines – but, also offers higher spindle speeds (i.e. rpm).



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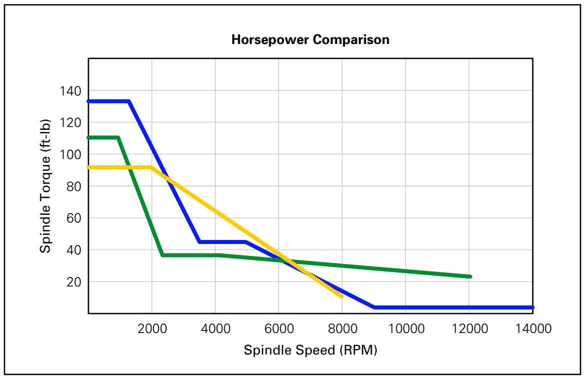
Torque

It's the same situation with torque. Available torque at slower spindle speeds makes a huge difference in achievable metal removal rates, particularly when hogging metal. Just like in a car, torque becomes less important as spindle speed increases. Here, the machine's ability to hold accuracy at higher feed rates becomes the critical factor.



Speed

The ability to cut at high spindle speeds isn't just about metal removal rates. It enables shops to take advantage of some of the enhanced cutting tools that have come out in recent years that are designed for high-speed machining. Moreover, combined with the ability to accurately execute high feed rates, high-speed cutting enables shops to more efficiently generate excellent quality 3D surfaces when required.

A machine's ability to perform well in all of these aspects—power, torque and speed—is especially critical to a job shop that cuts a wide variety of materials. The most efficient way to face off a steel part is to use as big a cutter as possible. However, a significant amount of torque is required. The next day, the goal could be hogging aluminum. Then later that week, the project is to move brass where speed is essential. The key is having a VMC capable of handling all of these requirements.

Profitability Impact

If drilling down on the differences in speed, torque, and horsepower seems like splitting hairs, manufacturers should take this calculation into consideration:

Consider a shop that runs roughly 2,000 hours of machine time in a single shift at a $100 shop rate. By decreasing non-cutting cycle time by 30 percent, that shop can return over $17,000 to the business in a year, and across a five-year lease, the return is over $88,000.

A manufacturer that uses today's technology alone has the potential to cut cycle times in half, especially compared to the way most shops run using more basic equipment.

Applying the same cost calculation as above, cutting the cycle time in half yields $70,000 worth of machining capacity per year.

Cost Calculator

2,000 hours of machine time (1 shift)
x **30%** hours average non-cutting time

= **600** hours of non-cutting time
29.4% non-cutting time reduction

= **176.4** hours recovered
x **$100** shop rate

= **$17,640 potential savings**

That's $350,000 over the course of a five-year lease.

Increase Spindle Utilization for More Production and Profitability

Automation can help manufacturers increase spindle utilization. However, there are other aspects of machine design that also impact spindle run time.

Tooling Support and Capacity

On some VMCs, there is no direct access to the automatic tool changer (ATC), requiring tooling to be loaded through the spindle. When machines are designed in this fashion, no tools can be loaded while the spindle is cutting. With this type of design, the operator cannot unload, check, or reconfigure tools either. Obviously, this design kills productivity since the spindle needs to be stopped in order to reconfigure the tool magazine or standard tool maintenance. Ultimately, this lack of spindle utilization increases costs and limits profits.

However, selecting a VMC that allows for tool support and access while the spindle is in use, provides the operator the ability to perform regular tool maintenance such as replacing worn tools, loading tools for the next job, and so on with minimal disruption to the machining cycle. Considering how often and long machines are typically down for these tasks, those minutes add up. Even at just one hour per week, that's worth $5,200 in a year. Manufacturers should consider that cost over the total life of the machine, as it will greatly impact a shop's productivity and profitability.

Greater tool capacity can also reduce setup and changeover time as well as time spent loading redundant tools, in order to eliminate a machine stop when a worn tool must be replaced. Some VMCs limit tool capacity to only 20 or 24 tools. This can stifle flexibility and variety needed to machine efficiently. Choosing a VMC with a larger capacity, such as an ATC with a 60-tool capacity, will also enable the use of larger tools without sacrifice. It also provides enough capacity to keep adjacent pockets empty.

Many VMCs limit tool weight. Often, the larger, longer and heavier tools are the most efficient way to machine and reduce cutting time. Limiting the use of these tools can increase production time and increase the cost per part. Higher tool weight capacity is helpful for using heavier and/or more versatile tool combinations. A higher tool capacity can help mitigate tool weight and tool number limitations, helping to maximize production and profits.

Chip and Coolant Management

For a machine to be productive, not only should it have increased speed, power, torque, RPM, and appropriate tool capacity, but it should have efficient chip removal as well.

Stopping the machining cycle in order to clear chips off the workpiece or to sweep chips down into the chip auger is time when the spindle could be running. When the chip basket isn't large enough to accommodate chips or if the coolant tank capacity is not sufficient to support production, spindle utilization is halted. If the flood, part wash or TSC capabilities are subpar, then the machine isn't capable of supporting production requirements and the spindle must stop for the operator to refill. Halting spindle operation is inefficient and kills productivity.

At a $50 per hour shop rate, if an operator spends only 30 minutes per eight-hour shift clearing chips or waiting for the coolant tank to refill, that's $6,250 in chip/coolant management expense in one year. Over fifteen years, that adds up to $93,750 in unnecessary parasitic costs per machine.

VMCs should have robust coolant systems capable of flushing and moving large amounts of chips. This not only improves production rates, but it can also support longer tool life. A highly integrated internal chip evacuation as well as an external lift-up chip conveyor (LUCC) is essential for efficient chip removal from the work zone.

By combining properly designed sloped interior surfaces with an overhead flood coolant system, the need for manual chip management inside the machine is reduced. Outside the machine, a lift-up chip conveyor allows chips to flow directly into drums or other receptacles. That's important when changing over from one material to another.

In order to maximize profitability, manufacturers need to plan appropriately to accommodate the spindle's continuous cutting. Chip and coolant management need to be robust enough for the VMC's intended use.

User-Friendly Ergonomics

The ease with which an operator can perform daily or frequent tasks can have a major impact on how much work gets done over the course of a shift. This can include opportunities for improvements such as: shorter distance to table for setup, overhead access to permit the use of a crane for heavy part or fixture loading, easier access to the tool changer for tool maintenance and exchange.

To Automate or Not Automate

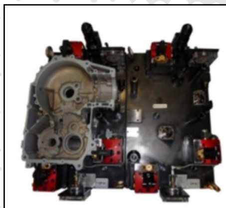
With the spindle utilization occurring only 34 percent of in-cycle time, the most important function—the cutting of metal and the generation of revenue—is only happening one-third of the time as well. Therefore, it is imperative that manufacturers evaluate their need for automation and the impact it will have on their production and profits.

Automation can increase efficiency, increase spindle time, and increase profitability. Every year for a one-shift operation, 2,640 production hours are lost to part loading/unloading time, changing the setup, securing the right program, etc. At a $50 shop hour rate, that equates to $66,000 in lost spindle utilization annually. Multiply the annual $66,000 cost over 15 years, and that's $990,000 in lost revenue per machine. When a manufacturer sees a spindle sitting idle, that should immediately serve as a warning sign to calculate the long-term cost of lost spindle utilization in their operation.

Another functional way to add automation to VMCs in order to increase productivity and reduce non-cut time is by decoupling the loading and unloading function from the spindle so that it can run simultaneously, building a queue of work waiting for the spindle, or quickly exchanging completed work for waiting workpieces.

Creative Fixturing

Machining a single part one-by-one in a vice may be needed infrequently, but that method crushes productivity with high-production work. With creative fixturing there are a myriad of ways to get more out of each machining cycle.



OP10

OP20

For example, the transmission housing pictured above requires two operations, both of which are set up on the same baseplate. Both parts are machined in a single cycle, after which the OP 10 piece is transferred directly to the OP 20 station. Aside from quickly transferring parts, it eliminates tool changes because a single tool can be applied to both parts before changing to the next. Moreover, each machining cycle yields one completed part.

Add a Fourth Axis

A standard rotary table is of limited value on a VMC because it typically won't provide access to multiple sides of a part. However, a vertical rotary indexer with a tailstock provides a variety of opportunities to machine multiple sides of a part or multiple parts, all in a single setup.

The indexer provides angular access to holes and other features, much in the same way that a 3+2 five-axis VMC machine does. Being able to machine multiple features on multiple parts in a single setup improves quality, reduces parasitic time, and most certainly improves machine productivity.

While this may sound like a part programming nightmare, multi-part machining functionality is now very common in CAM systems. Moreover, the fixture location only needs to be established in the VMC's workpiece offsets one time, which subsequently covers every part in the setup.

Consider a Pallet Changer

One of the major reasons horizontal machining centers are so productive is that workpiece loading/unloading is external to the process except for the few seconds it takes to index from one pallet to the other. Manufacturers can reap the same benefit with a vertical mill, as well as all the advantages of multiple part machining if the VMC is adaptable to this form of automation.

Third-party pallet changers can be procured from companies such as Midaco, which makes manual and automatic versions, or Erowa, which is aimed more at smaller, more complex parts such as EDM electrodes.

Naturally, this form of automation is going to require additional investment, typically between $20,000 to $40,000. However, by eliminating the vast majority of working load/unload time, as well as permitting the ability to run completely unattended, the cost of this technology can easily justify itself for the right kinds of work.

Conclusions

Manufacturers determined to extract the greatest amount of productivity and profit need to re-evaluate their VMC machine specifications and weigh how much non-cutting time is occurring when the spindle should be in cut.

- Focusing not only on refining process improvement—like the latest technology tooling, but machine-enabled process improvement as well, will help decrease cycle times and maximize spindle utilization which provides a lower cost per part and greater profitability.
- Machine choice greatly impacts VMC productivity. Scrutinizing spindle HP, Torque, RPM and rapid rate capabilities while comparing different machine models, allows manufacturers to make an informed decision on what is best for production needs.
- Any phase in the machining process which halts or decreases spindle utilization should be carefully inspected in order to analyze the time/cost benefit and whether they warrant upgrades or process changes.
- In order to maximize productivity and profitability, manufacturers must calculate how the in-cycle parasitic time is affecting spindle utilization with machine metal cutting capability, tooling support and capacity, chip and coolant management, unique fixturing, automation, and ergonomics categories.

By examining production fundamentals, manufacturers can determine what steps are necessary to improve productivity and, in turn, unlock tens- to hundred-of-thousands in potential savings and profits over the lifetime of the machine