CADEM
effiCNC

Maximizing spindle power usage

And thereby reducing machining time by up to 50 %

Understanding the spindle motor

The machine spindle is just a distant acquaintance that we normally don't bother to understand. It however is the heart of the machine, and can improve productivity dramatically if you make friends with it, understand it, know its eccentricities.

The spindle power is defined in two ways in a machine's brochure.

1. The short term (e.g., 10 min./15 min./half hour) and continuous ratings.
2. The power- torque diagram.

Short term and continuous ratings

When a motor runs, heat is generated because of the I squared R losses in its winding. The higher the load on the motor (i.e., the power generated), the higher the current in its windings and the more the heat generated.

The insulation in the windings - ground insulation, magnet wire, tapes, sleeves - is rated for a certain temperature, typically between 105 and 180 °C.If this temperature is exceeded, the insulation breaks down, the windings short, and the motor breaks down. This is what we mean when we say “the motor got burnt”.

The current generation of CNC machines have inbuilt safety mechanisms that prevent motor damage. The machine will sound an alarm and shut down if the temperature exceeds the limitt.

The trick in machining is to load the motor to the maximum extent without its internals reaching the maximum allowed temperature.

Continuous rating: This is the maximum load at which the motor can run continuously, 24 hours. At this power, the heat generated is equal to the heat dissipated into the atmosphere, and the temperature is stable.

Short term rating: This is the maximum load at which the motor can run for a specified short term - half an hour, 15 minutes, 10 miuntes, etc. At this load, the temperature is continuously rising, and reaches the maximum allowed after the specified time. E.g., if the short term rating is for half an hour, after half an hour the temperature rises beyond the safe level. For smaller machines, the 10 or 15 minute rating may be specified instead of half hour. This is because large machines have long machining times. On a smaller machine the cycle time will be less than 10 or 15 minutes, and you will never continuously cut for more than this time. E.g., if you are turning a 4m. long shaft at 200 m/min, 0.5 mm./rev, a single cut would take an hour.

Examples of specs:

SPINDLE DRIVE		
AC motor rated power (cont./ 30 min. rating)	kW	18.5/22
Spindle speed (Max.)**	rpm	3000 (2000)
Full power range (For 3000rpm)	rpm	440 - 2630

Spindle drive		
Spindle motor rated power (Continuous / 15 min. rating)	kW	5.5 / 7.5
Speed range (inf. variable)	rpm	50 4000
Full power range	rpm	1000 3000

The Ace LT-25 spec on the left means that if you want to run the motor continuously, you can load it to 18.5 kW max., and at 22 kW load you can run it for half an hour at the most.

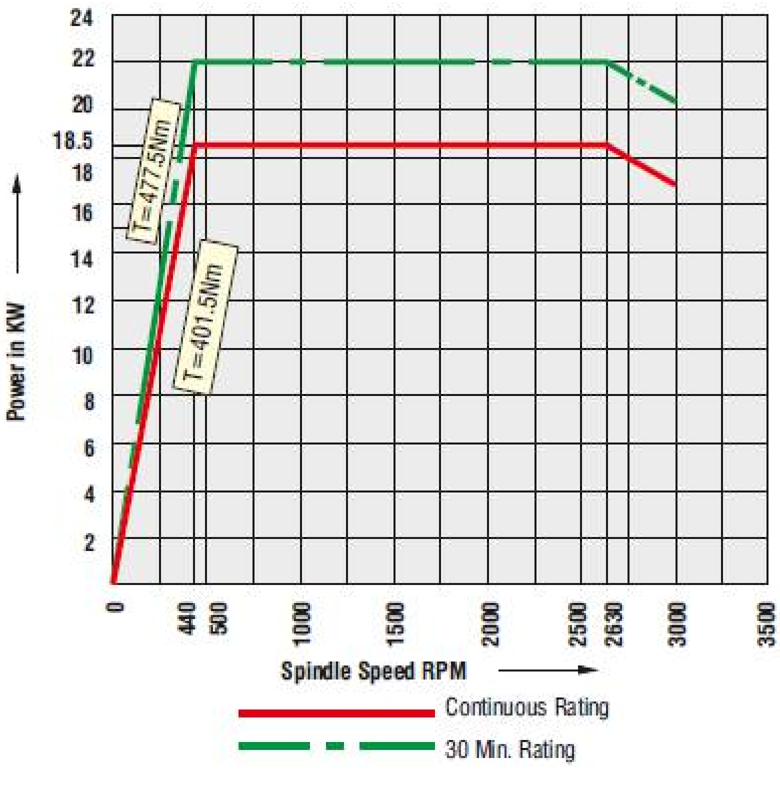
In the Ace Jobber-Jr spec on the right, the higher number is the 15 minute rating.

The spindle power required at the motor is more than the cutting power required at the chuck, because of mechanical losses in spindle bearings and belt, and power required to rotate the spindle itself. The mechanical losses will typically be about 20 % for most machines, which means the spindle motor power is 1.2 times the cutting power. Mechanical losses can even as high as 40 % for some poorly built machines.

The power-torque diagram

This diagram shows how much power and torque are available at various spindle speeds.
If you exceed the torque available, the motor will stall, just stop rotating. If you exceed the rated power or time, the motor will burn. In newer CNC machines the temperature sensor will cause an alarm and the machine will shut down, to prevent motor damage.

You will see this diagram in brochures of CNC machines. At least, you should, but most machine builders' brochures don't have it because most users (and possibly most machine builders) do not know its significance. It describes the spindle's behaviour.



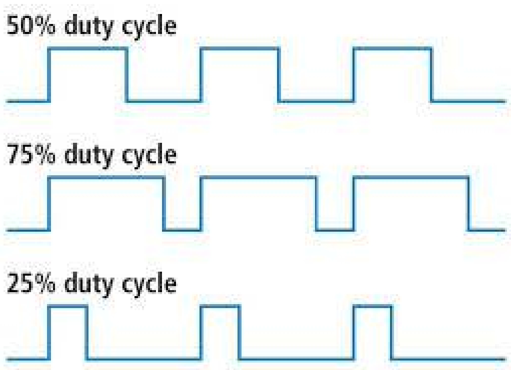
In this graph, the red curve is the continuous rating, and the green one is the half hour rating.
The power and torque available are not constant – they depend on the RPM at which the spindle is running. If we want to cut for more than half an hour continuously, we look at the red line. Otherwise we look at the green line.

Let's assume we are cutting that 4 m. long shaft that takes 1 hour for a single cut, so we'll look at the red line. Beween 0 and 440 RPM the power available rises linearly. At 200 RPM the available power is 10 kW. Between 440 and 2630 RPM we get the full power of 18.5 kW. Beyond 2630 RPM the power available drops

again.
The torque is constant at 401.5 Nm till 440 RPM, and then drops. You can calculate the torque available at any RPM using the power-torque-speed equation that you've learnt in college.

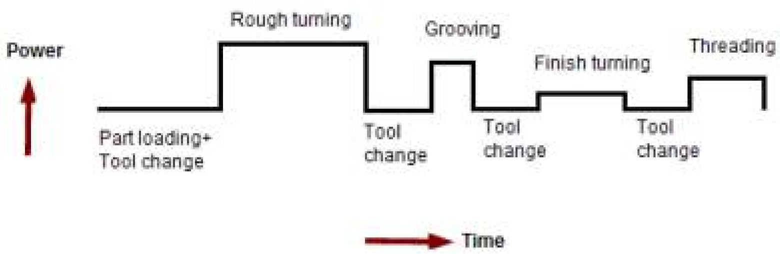
Duty cycle

How much the motor gets heated depends on the Duty Cycle, the pattern of loading of the motor. While a part is being machined, the motor is not continuously running. E.g., It is idle during tool change, idle again during rapid approach to the part, loaded when taking a cut, idle during rapid retract for the next cut, etc. The diagram below shows examples of duty cycles.



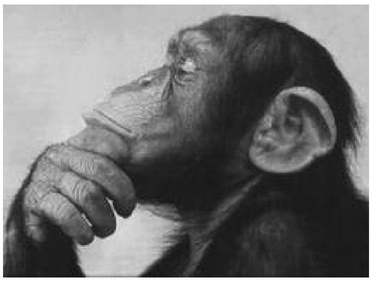
In the fist graph, the motor is loaded for some time, then is idle for an equal amount of time, then again loaded for an equal amount of time, etc. It is effectively loaded only 50 % of the time, and high heat generation occurs only 50 % of the time.
So even if the spindle power meter graph shows 100 % during these cutting periods, the heat generation is less. When power varies like this, we take the root mean squared (RMS) value as the the equivalent uniform power. For 25, 50 and 75 % duty cycles, the RMS power is roughly 45 %, 70 % and 86 % respectively of the peak power consumption.

These duty cycles are just illustrative, and an actual duty cycle while turning a part would look something like this one, below.



The duty cycle is always less than 100 %, and in most parts with less than 15 minutes cycle time it is between 60 and 70 %. In very large parts (like a 4 m. long shaft) the duty cycle may be close to 100 %.

So what do I do with all this gyan ?



You can use this to dramatically reduce the machining time, by up to 50 %.
Here's how:

1. Identify the operation that involves the maximum amount of material removal, and hence will take the most time. This will typically be a roughing operation, like rough turning.
2. Determine the minimum and maximum spindle speed in an operation.
3. From the machine's power-torque curve, determine the minimum power and torque available at these spindle speeds.
4. Increase the depth of cut to the maximum possible value that the insert will allow, without exceeding the power and torque determined in the previous step. Calculate the cutting power using equations or on-line power calculators in the web sites of cutting tool manufacturers. Increase this by 20 % to determine motor power (assuming mechanical losses of 20 %).
5. If you have increased the depth of cut to the maximum possible value and still want to reduce the cycle time, increase the feedrate to the maximum allowed on the insert, then increase the cutting speed. Remember that increasing the cutting parameters reduces the tool life. The depth of cut has the least effect on the tool life. The feed rate has a greater effect, while cutting speed has the greatest effect. This is why it makes sense to first increase the depth of cut.
6. Repeat steps 1 to 5 for all operations.

You cannot play around much with the cutting parameters in finishing operations. There is no depth of cut because there is a single cut. You can only increase the feed rate and cutting speed. Increasing the feed rate will worsen surface finish, and increasing cutting speed will reduce tool life.

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