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Optimising measurement cycle time

Abstract

The fundamental requirement of any probing cycle on a machine tool is acceptable and reliable metrology. In addition to this, the metrology must be achieved in an acceptable time. Optimising measurement cycle time is therefore an important part of building a metrology solution for production machining processes: it is necessary to understand the factors that affect measurement cycle time in order to be able to optimise it. The scope of this module is to introduce these factors and their effects.

As discussed in module TE412, One-touch versus two-touch probing strategies, the type of probing cycle has a significant effect on repeatability and cycle time. The module also introduced feed-rate, back-off and over-travel as other influential factors.

Feedrate

At the start of a probing cycle, the machine tool has to move the probe from a start position to the surface to be measured. It may be assumed that speeding up the cycle is simply a case of increasing the feedrate and reaching the surface sooner. However, as seen in module TE412, this has an effect on the accuracy of the metrology due to the response time of the machine tool controller to the probe trigger signal, introducing significant measurement uncertainty. It was also shown that for one-touch cycles, measurement uncertainty is directly proportional to gauging velocity. For a one-touch cycle, measurement uncertainty may be mitigated to an extent by a direct input to the CNC with a fast response time to the trigger signal.

For a machine tool controller with a longer scan time, say 4 ms, with a feedrate of 3000 mm/min, the uncertainty could be 0.2 mm. The machine tool has limited knowledge of the location of a surface to be measured and therefore cannot reliably slow the probing feedrate to a level which gives accurate metrology, possibly 30 mm/min, just before touching the surface. In this case a two-touch cycle is needed.

For a direct input controller with a scan time of 4 µs at a feedrate of 3000 mm/min, measurement uncertainty could be 0.2 µm. With such low uncertainty, the possibility that cycle optimisation could be achieved by increasing feedrate seems possible, but the acceleration characteristics of the machine tool are also significant and preclude this.

Acceleration and deceleration

The algorithms which determine the way in which machine tools accelerate and decelerate are set by control system manufacturers. Different manufacturers have their own particular logic schemes and calculations. However, machine tools do not typically accelerate at constant rates. For some, the rate of acceleration is calculated to arrive at the programmed feedrate in a set time as shown in figure 1. Consequently, the distance travelled by the axis to achieve the programmed feedrate increases linearly with feedrate:

$$2 \times \text{acceleration distance (mm)} = [\text{feedrate (mm/min)} \times \text{time constant N (s)}/60]$$

$$[2 \times \text{acceleration distance} = \text{acceleration distance} + \text{deceleration distance}]$$

With a typical time constant of say 0.06 seconds the total acceleration distance increases from 0.025 mm at 50 mm/min to 2.5 mm at 5000 mm/min. The deceleration distances are identical. Therefore the minimum move distance over which an axis will achieve the programmed feedrate will be 0.05 mm at 50 mm/min and 5 mm at 5000 mm/min.

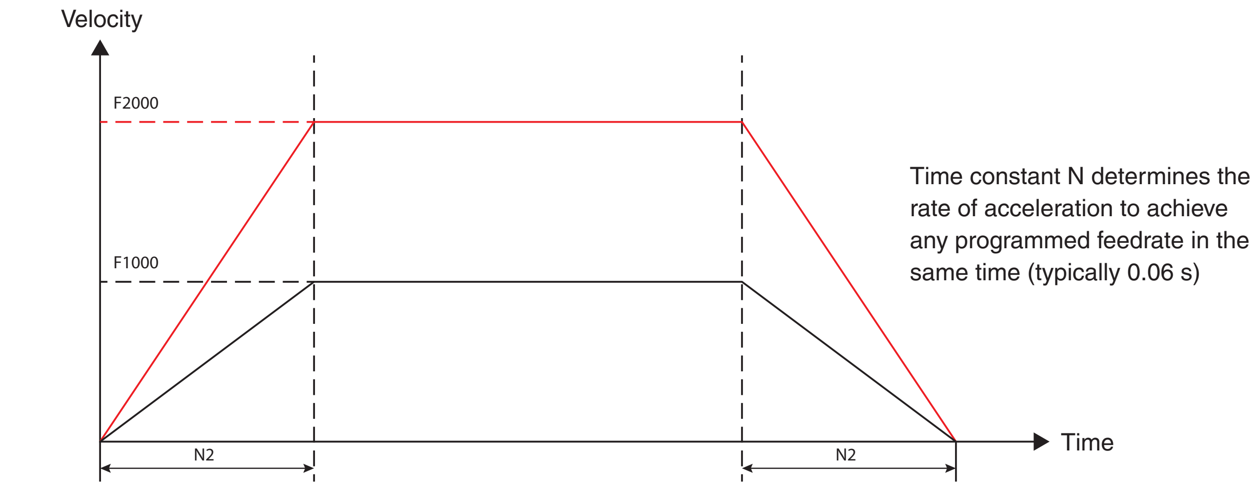

Figure 1: Machine accelerates over a set period of time, making the rate of acceleration dependent on the feedrate required.

Once a probe trigger signal has been acknowledged by the CNC, the probe will continue to travel towards the part whilst the stylus deflects. As probing speeds increase, the distance travelled beyond the trigger point during the deceleration phase of the probing move is increased. This increases the distance needed to travel back to the start point on the return move.

Consider this on a machine with a time constant of 0.06 s:

A return move at 5000 mm/min to a point 2.5 mm clear of the surface following a probing move at 30 mm/min would require a move of 2.52 mm and take 0.085 s.

The same return move after a probing move at 5000 mm/min instead of 30 mm/min would be 5.833 mm and take 0.13 s.

This is extremely significant in determining the duration of probing cycles and eliminates many perceived benefits of probing at feedrates above 2000 mm/min.

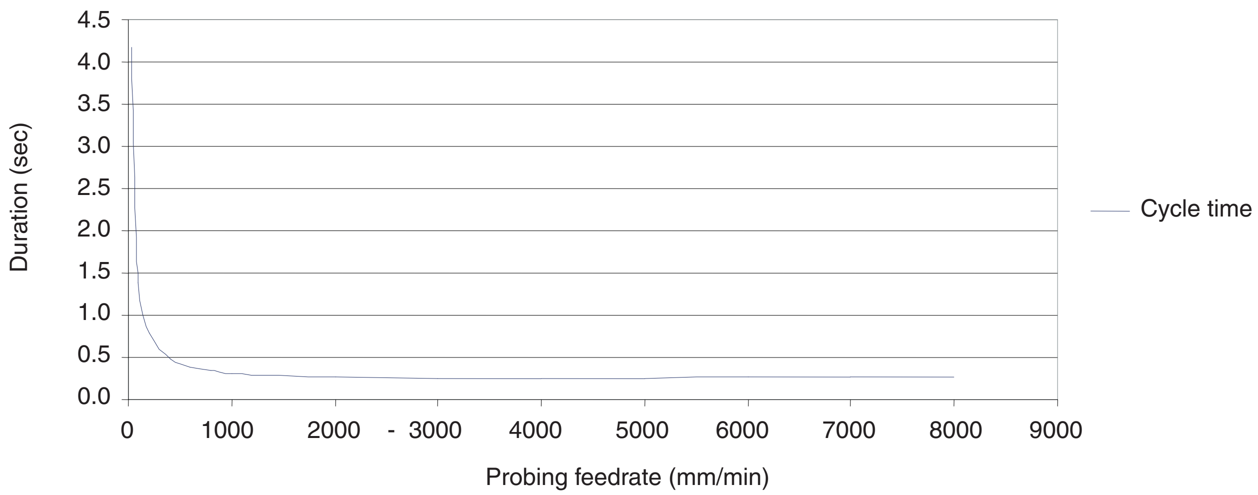

Figure 2: One touch cycle time

Figure 2 shows how improvements in cycle time accrue as feedrate increases up to 2000 mm/min, after which no further improvement is seen. The increase in post trigger deceleration distance at higher feedrates prevents further reductions in cycle time. This distance has to be retraced to return to the start position after the probe has triggered.

There is also a risk of damage to the probe and stylus at very high feedrates. The extra distance travelled when the probe is still in contact with the component may approach the over-travel limit of the device, particularly in the Z-axis or other axes when using short styli. There is also a risk when probing inside small features that the stylus may become jammed and bend if an inappropriately high feedrate is used.

Back-off distance

During a two-touch probing cycle, the approach feedrate for the first touch is relatively high and used simply to find the surface quickly. After backing off, the probe is brought in at a gauging velocity slow enough to provide low measurement uncertainty (as discussed in module TE412). The significant parameter that can be used to optimise this part of the cycle is the back-off distance. Since the gauging velocity is low, in the region of 30 mm/min, with a back-off distance from the surface of, for example, 2 mm, the gauging approach would take 4 s to complete: a significant period of time. To optimise the cycle time it is necessary to reduce the back-off distance to a minimum.

Probing software has a default back-off distance value which should be sufficient for the probe to withdraw far enough to reseat the stylus on most machine tools. This parameter defines the back-off distance from the point where the probe halts during its first touch on the fast approach, not from the measured surface. Due to a number of factors which will be described in the next section the probe halts at a certain time - and therefore distance - after it has contacted the measured surface: an effect known as over-travel. In order to optimise the back-off settings for a measuring cycle, the machine characteristics must be taken into account. The back-off parameter should be set for the machine's usual over-travel at fast approach speed plus the minimum distance from the surface required to allow the probe to reseat.

Over-travel

Over-travel is the distance from the measured surface to the point at which an inspection probe halts after probing the measured surface. Three phases of the trigger sequence contribute to this distance, as can be seen in figure 3.

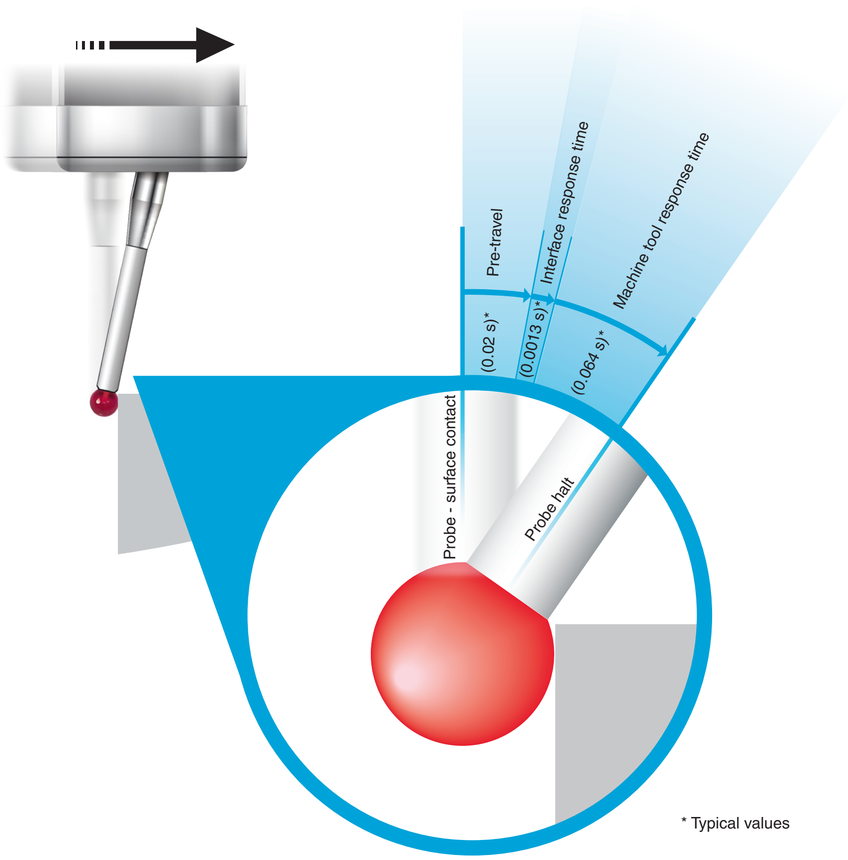

Figure 3: Probe trigger sequence and signal transmission

The probe trigger sequence can be broken down into three distinct time phases:

- Phase 1 - Surface contact up to the probe triggering mechanically, ‘mechanical pre-travel’
- Phase 2 - Mechanical trigger up to the trigger signal being transmitted to the CNC controller, ‘interface response time’
- Phase 3 - Trigger signal transmission up to CNC response, ‘machine tool response time’

Phase 1 - Mechanical pre-travel

Mechanical pre-travel is the distance of travel required between the point of contact with a given surface and the probe sensing threshold being achieved. Pre-travel is probe hardware dependent; it does not vary with the probing speed and can be calibrated out with appropriate calibration and application software.

The end of the mechanical pre-travel phase of the trigger sequence is not the point at which the probing system issues a trigger to the CNC, but the point at which the interface recognises that a mechanical trigger has occurred and begins a response. Pre-travel and pre-travel variation are fundamentally important characteristics of the mechanical probing device and are very significant factors in determining the quality of the metrology.

Mechanical pre-travel distance (µm)	Speed 30 mm/min	Speed 1000 mm/min
	Pre-travel duration (s)	**Pre-travel duration (s)**
2	0.004	0.0001
10	0.02	0.0006
50	0.1	0.003

Table 1: Pre-travel effect on cycle time

From table 1 it can be seen that pre-travel does have an effect on cycle time, but that it will only be of significance where devices with high pre-travel are used in conjunction with low measurement speeds.

Phase 2 - Interface response time

The interface response time is the difference in the point at which the probe mechanism triggers and the point at which that trigger is transmitted to the CNC controller (as discussed in module TE412). The interface continuously monitors the status of the probe and transmits the trigger signal to the machine on contact with a surface. This is not a factor that can be changed to optimise cycle time, but must be taken into account when selecting other parameters.

Phase 3 - Machine tool response time

Machine tool response time is controller response time plus the period of deceleration. Controller response time is determined by the process through which the machine recognises and acts on the probe trigger input. This is completely outside the control of the probing hardware supplier and has a direct bearing on the metrology performance of the probing system, although only a marginal effect on cycle time. The interface transmits the trigger signal to the CNC controller. What happens next depends entirely on the capability of the machine tool controller and the way the trigger signal has been interfaced. The time delay between the interface transmitting a probe trigger and the control system acting on that signal could be as little as 4 µs or as much as 4 ms dependent on controller specification and purchased options, again as discussed in module TE412.

It can therefore be seen that on contact with the surface of the component, these three phases cause a short delay before the trigger signal is acknowledged. Phases 1 and 2 have no effect on the integrity of the metrology because the time delays they cause are consistent and can be calibrated for, as long as the same dynamic conditions are used during calibration and measurement cycles

In Phase 3 however, the controller response time will be indeterminate and potentially have a significant effect on the metrology performance.

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Conclusions

There are a number of factors which determine the duration of probing cycles on CNC machine tools.

Some of these are due to the probing hardware such as pre-travel and interface response time which can, in general, be accounted for with calibration routines and ensuring all measurement takes place under the same dynamic conditions. More influential however, are the acceleration and deceleration rates set by the machine tool builder, the choice and set-up of the control system, the inspection strategy in use, and the optimisation of the probing system to a particular machine tool. Some generalisations can be made:

- The machine tool characteristics of controller response time and acceleration rate have a more significant effect on the achievable optimised probing cycle time than the choice of probing hardware.
- If the back-off distance has been optimised within the probing software, the cycle time difference between two-touch and one-touch measurement strategies is marginal.
- There is likely to be no cycle time benefit to probing at speeds above 2000 mm/min using either a one-touch or a two-touch measurement strategy, in addition to the negative effect on metrology, when using touch-trigger probes.
- As the machine tool plays the major role in determining the duration of any given probing cycle independently from the choice of sensing device, there is no legitimacy for any probing manufacturer to claim superiority over another on the basis of speed.
- Uncertainty about the position of the probed surface can have a direct affect on probing cycle time.
  With 'known part' probing, i.e. a just machined surface, the initial clearance move can be very close to the machined surface. Feedrates and back off distances can be optimised to allow minimal probing time. With 'unknown part' measurement, the probe needs to be positioned conservatively to allow for the uncertainty associated with the part surface. Typical applications are part set-up where fixturing is not precise, or where input material exhibits variation (castings etc.)

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