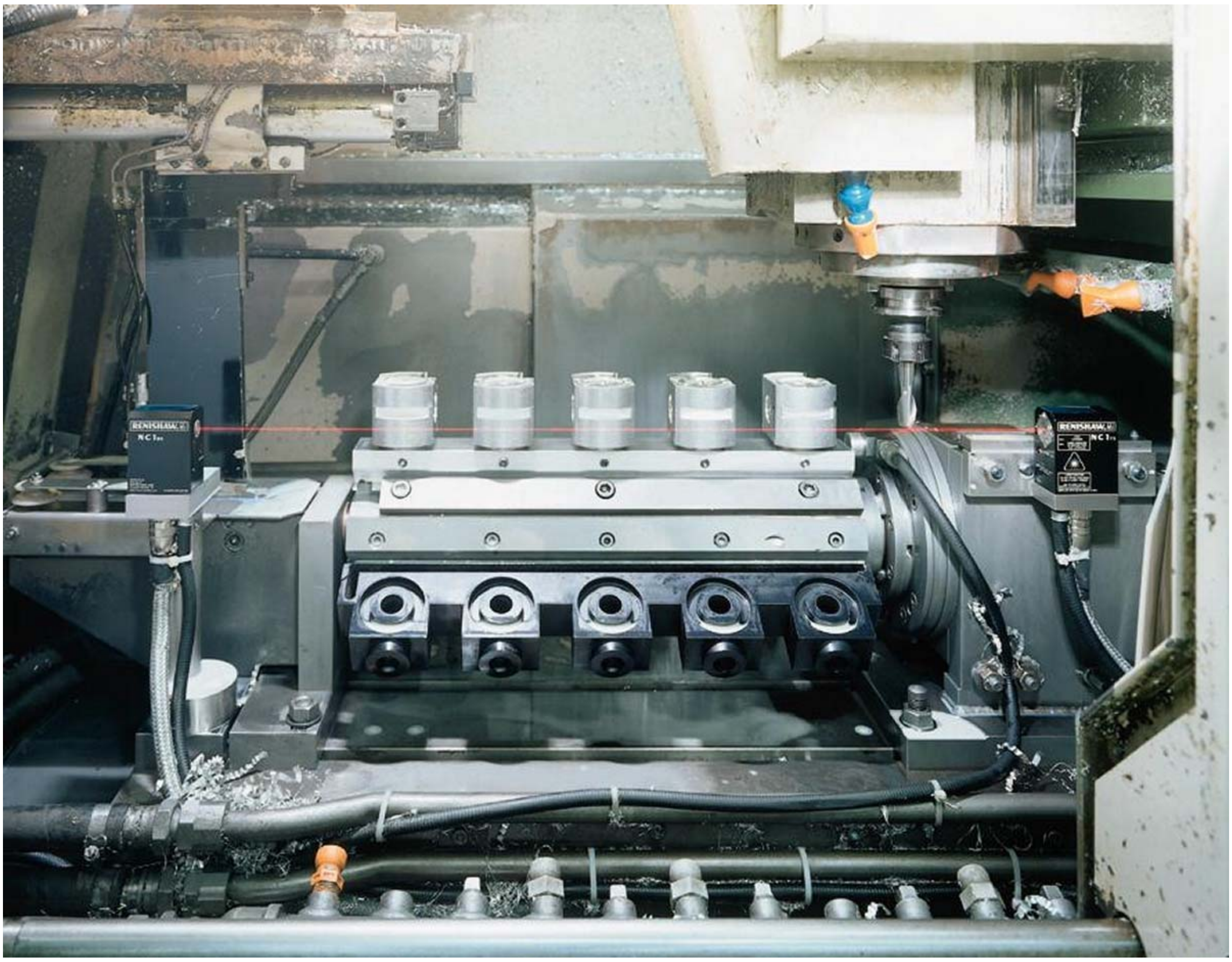
Understanding non-contact tool setting



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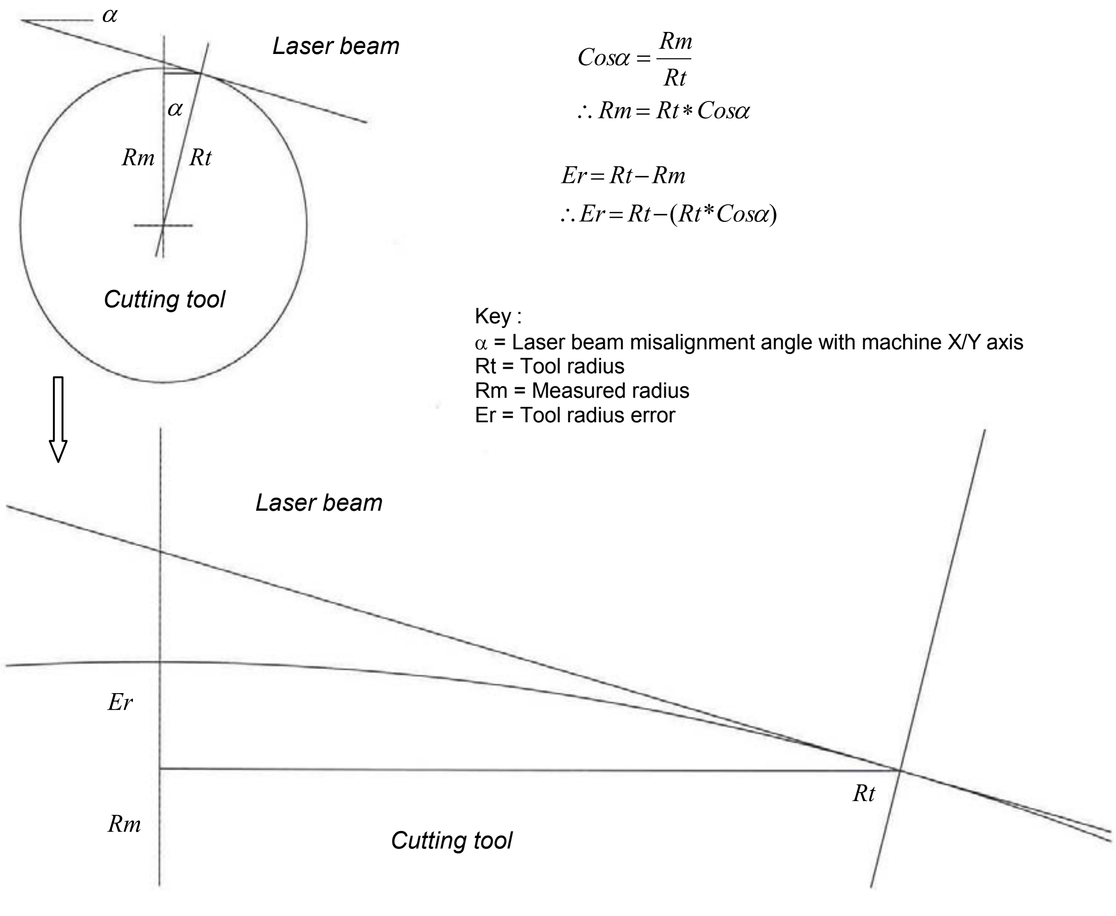
Contents

1 FACTORS AFFECTING ACCURACY

1.1 Alignment of the laser beam with the machine's axis

A poorly aligned system will result in measurement errors when setting tools. When considering a VMC, the error relative to the X/Y and Z-axes are of importance. The error relative to the X/Y-axis is of importance when measuring tools of different diameter. The error relative to the Z-axis is of importance when measuring the length of tools of different diameters on the tool's centreline. The following diagrams show how to estimate these errors.

1.1.1 X/Y-Axis Error



$$Cos\alpha = \frac{Rm}{Rt}$$

$$\therefore Rm = Rt * Cos\alpha$$

$$Er = Rt - Rm$$

$$\therefore Er = Rt - (Rt * Cos\alpha)$$

Key :
α = Laser beam misalignment angle with machine X/Y axis
Rt = Tool radius
Rm = Measured radius
Er = Tool radius error

Figure 1.1a

It is recommended that X/Y-axis alignment should be better than 1 mm per 100 mm.

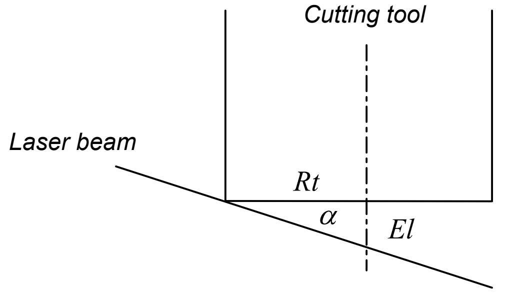
For example if the maximum tool diameter being used were 100 mm, the respective error would be:

$$Er = Rt - (Rt * Cos\alpha)$$

$$Er = 50 - (50 * Cos 0.573)$$

$$Er = 2.5\mu m$$

1.1.2 Z-Axis error – Measuring on the tool centreline



$$Tan\alpha = \frac{El}{Rt}$$
$$\therefore El = Rt * Tan\alpha$$

Key :
α = Laser beam misalignment angle with machine Z axis
Rt = Tool radius
El = length error

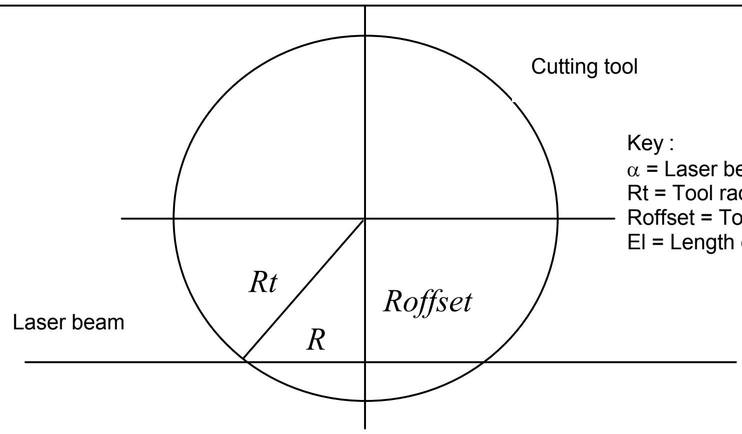
Figure 1.1b

It is recommended that Z-axis alignment should be better than 10 µm per 100 mm. For example if the maximum tool diameter being used were 100 mm, the respective error would be:

$$El = Rt * Tan\alpha$$
$$El = 50 * Tan0.006$$
$$El = 5\mu m$$

In reality both the X/Y & Z-axis errors are less than this due to the fact that the individual tool errors are relative to the calibration tool.

1.1.3 Z-Axis error – Measuring with a radial offset



Key :
α = Laser beam misalignment angle with machine Z axis, Fig 1.1b
Rt = Tool radius
Roffset = Tool radius offset relative to laser beam
El = Length error

Figure 1.1c

From earlier calculations, Ref Fig1.1b, the length error when measuring on centre was expressed as:

$$El = Rt * Tan\alpha$$

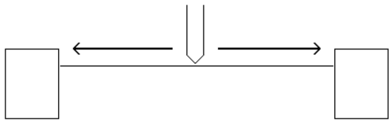
When using a radial offset, Rt is substituted for R, where: $R = \sqrt{Rt^2 - Roffset^2}$

Thus $El = Tan\alpha\sqrt{Rt^2 - Roffset^2}$

It can be seen that as Roffset tends to Rt, the error in length, El tends to zero. Therefore where possible tools to be measured for length should incorporate a radial offset. The radial offset should be slightly inside the tool tip radius. i.e. tool radius –1.0 mm

1.2 Measuring anywhere in the beam

A tool can be measured anywhere along the laser beam between the transmitter and receiver as the system is repeatable at any position. Accuracy will vary if tools are measured at positions other than at the point of calibration. This variation is due to diffraction of light as the tool obscures the laser beam.



It is recommended that the user should choose a position at which all measurements will be conducted, and then calibrate the system at this measurement point.

1.3 Effective beam diameter

Renishaw's non-contact tool setters use a MicroHole™ to provide continual protection to the optics and to control the profile / size of the laser beam. As the laser beam passes through the transmitter MicroHole™ the beam diverges slightly due to diffraction. The laser beam therefore progressively increases in size until it reaches the receiver MicroHole™. At this point a small section of the centre of the laser beam falls incident upon the receiver photodiode. For an NC1 system this is 0.4mm in diameter. Therefore the size of the laser beam that can be seen with the human eye is not representative of the part of the laser beam used to measure / detect the tool.

1.4 Minimum tool size

Precise calculation of this is complex and needs to consider the geometry of the tool as well as the convergence / divergence of the transmitter beam. There are two main factors that affect the minimum tool size that can be measured with Renishaw non-contact tools setting / detection systems.

The receiver will issue a trigger when its incident power drops by 50%. This can be achieved by a small tool either:

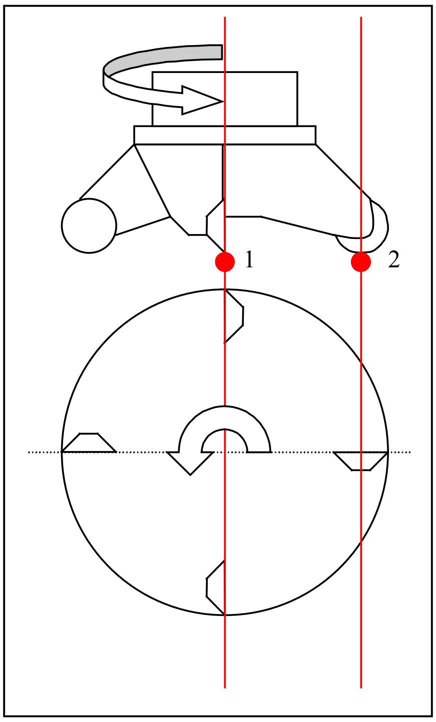
i) Close to the transmitter and obscuring 50% of the beam width, Or

ii) Close enough to the receiver to produce a crisp shadow 50% of the width of the receiver MicroHole™.

See Section 2.5 detailing the results of a case study determining the minimum tool size that can be measured / detected for different Renishaw non-contact systems and operating separations.

1.5 Spindle speed / speed of response

The electronics within non-contact tool setters have a finite speed of response. Large diameter tools being driven at high spindle speeds produce very high tip velocities. If the tool tip velocity is sufficiently high, it may not be ‘seen’ by the detecting electronics and hence the tool will need to travel further into the laser beam before it is detected.



The amount of time that a tip spends in the laser beam decreases as the spindle speed increases. Referring to figure 1.4a it can also be said that for a constant spindle speed, tools measured with a radial offset, i.e. position 2, spend longer in the beam than tools measured on centre, i.e. position 1. (Length measurement)

Figure 1.4b shows results from a VMC where an 80 mm face mill was measured for length at different spindle speeds. The tool was measured in position 1 and position 2.

As can be seen by measuring at position 2, i.e. off centre, spindle speed did not affect the length measurement.

For tool length, measure as far off-centre as possible but inside any tip radius that may exist.

Figure 1.4a

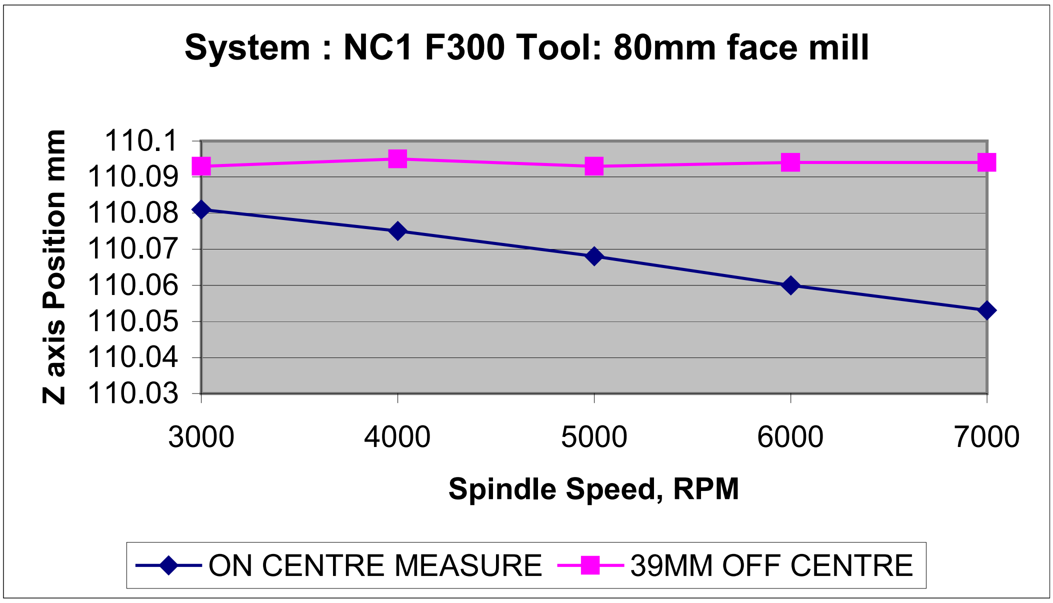


Figure 1.4b

It is therefore recommended that tools with cutting edges or inserts positioned off centre to the centreline of the spindle should be measured off-centre so that accuracy is not affected.

Factors such as spindle pull-up and tool tip geometry will also affect measurement accuracy. Guidance on how to determine individual tool accuracy, taking into account these factors, can be found in sections 1.10 & 2.2.

1.6 Tool profile

To cause a trigger, the light level at the receiver must fall below a set light level threshold. When measuring tools for length, flat-ended tools will cause a trigger as the bottom of the tool reaches the centreline of the laser beam (neglecting the diffraction of the laser beam as it interacts with the tool and assuming a trigger threshold of 50%).

If the effective tool end geometry is not flat then the threshold crossing will occur somewhere below the centreline. See Figure 1.5a / b.

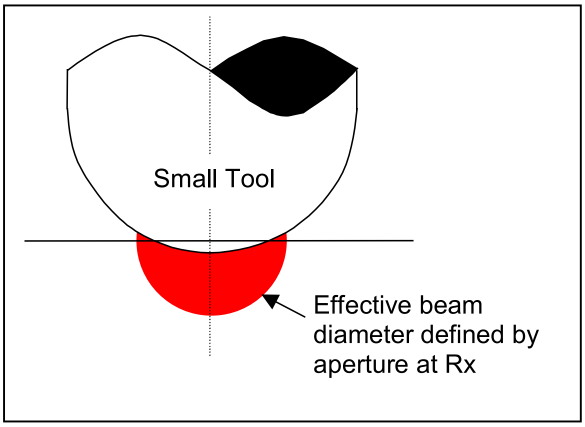


Figure 1.5a – Ballnose

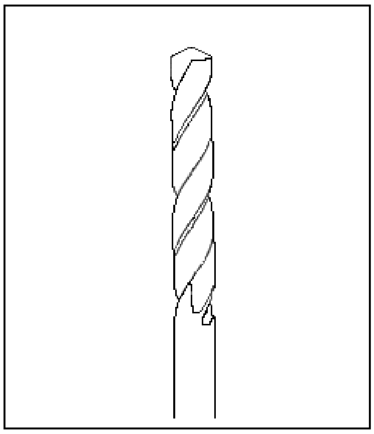


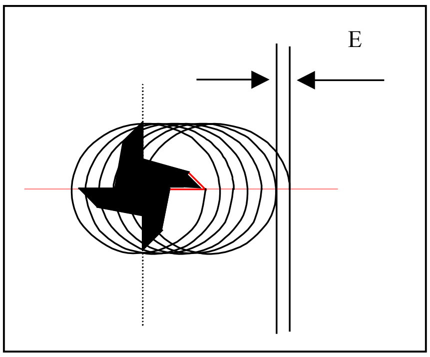
Figure 1.5b – Jobber Drill

If high tool accuracy is required for these types of tools, individual experience values will need to be established. These types of tools would obviously be measured for length with zero radial offset.

Note: See section 2.2 for description of experience values.

1.7 Feed per revolution

For rotating tool measurement an error is introduced that relates to the feed and the spindle speed.



The tool must rotate so that all teeth are presented to the beam inside the allowable error, as one tooth may be higher than the other teeth.

For example:

Allowable error (E):	0.001 mm
Spindle speed (S):	3,000 Min-1
Calculate feed (F):	F = E x S
	F = 0.001 x 3,000
	= 3 mm/min

Figure 1.6

Default speed in Renishaw software is 3000 RPM at a feedrate of 2µm per revolution.

1.8 Cleanliness of tool

If there is any debris or coolant on the end of the tool, measurement accuracy / repeatability can be affected. The difference in length between a dry and wet tool can vary up to 100 microns. This length variation is due to the coolant film on the tool itself. Diameter can also be affected.

Tools should be free of debris and dry prior to conducting a measuring routine. Standard Renishaw non-contact probing routines spin the tool prior to a probing cycle to reduce the chances of obtaining a false measurement. Some applications benefit from fitting an air blast to clean the tool prior to a probing routing.

1.9 Geometrical changes during operation

Thermal growth of the machine tool is an important factor when looking for consistency of measurements over a period of time. Consider the following:

- Environmental stability – Opening doors, windows or climatic changes will affect the stability of the system.
- Machine growth – Heat generated within the ball screws and spindle can affect the measurement accuracy and stability. Ensure that the machine has undergone a warm-up cycle prior to conducting measurements if it has been left idle for a while.
- Machine bed deflection – When clamping work pieces to the bed of the machine, deflections can occur due to the introduction of stresses.

Figure 1.8 shows how the z-axis position varied over a period of a couple of minutes, due to thermal growth of the spindle. A 10mm slot drill was measured for length on a VMC machine tool using a non-contact tool setter

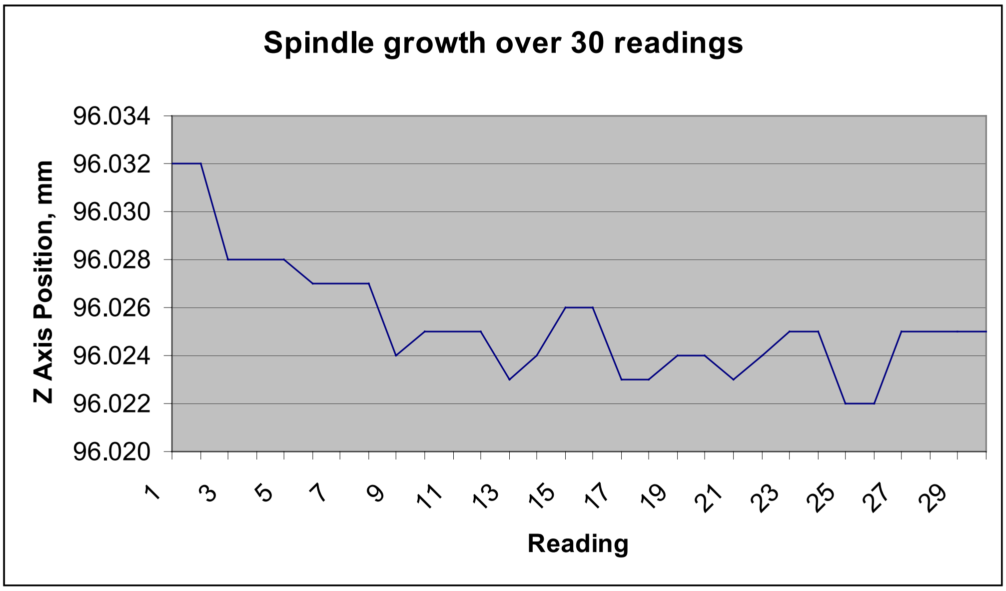


Figure 1.8

If diameter measurements are taken from both sides of the tool, the effects of any small movement is not seen. This assumes that both Y+ and Y- probing measurements move by the same amount resulting in the diameter staying constant.

1.10 Spindle pull-up

Certain spindle / shank designs are prone to an effect known as spindle pull-up. This effect is due to the centripetal forces affecting the position of the tool tip. I.e. At high spindle speeds the tool retracts further up into the spindle. There are two known reasons for this: firstly the ISO taper can expand and the forces from the pull stud cause the shank to move deeper into the spindle. The second is due to the spindle cartridge moving. Where possible the tool should be measured at a similar speed to that at which the tool will be used.

For tools being used at very high spindle speeds, the magnitude of spindle pull-up may require determining. As explained earlier, the speed of response should be considered when running at high spindle speeds. The following procedure may be adopted which determines the magnitude of pull-up:

- Load a solid, flat-bottomed pin into the spindle. The tool needs to be flat bottomed so that the speed of response is not a factor.
- Measure the length of the pin at the speed at which all tools will be measured by the non-contact tool setter, approx. 3000 RPM. Then measure the pin at the speed at which the tool will be used at when cutting material. I.e. higher than 3000 RPM.
- The difference in the two values is the amount of spindle pull-up, i.e. the difference in the Z axis position of the tool tip. This also includes factors such as tool tip geometry and speed of response of the system. Tools that are used at this cutting speed will need their experience values corrected by this amount.

Figure 1.9 shows the spindle Z movement for a particular VMC when calibrating using a solid tool over a range of spindle speeds. Both taper and face & taper tool locations are shown. Each machine will require characterising, do not use the values shown below.

RPM	Taper only	Error, mm	Face & Taper	Error, mm
3000	137.292	N/A	137.293	N/A
5000	137.289	-0.003	137.290	-0.003
7000	137.287	-0.004	137.290	-0.003
9000	137.287	-0.005	137.287	-0.006
11000	137.282	-0.010	137.287	-0.006
13000	137.277	-0.015	137.286	-0.007
15000	137.276	-0.016	137.288	-0.005
17000	137.268	-0.024	137.288	-0.005
19000	137.265	-0.027	137.287	-0.006

Figure 1.9

1.11 Turbulence within the laser beam

Excess turbulence within the laser beam can affect the repeatability of the tool setter. Any air blasts should be directed perpendicular to the laser beam and not along the length of the beam. The air exiting the transmitter and receiver units should be allowed to escape freely and not directed back into the path of the laser.

2 BEST PRACTICES TO REDUCE MEASUREMENT ERRORS

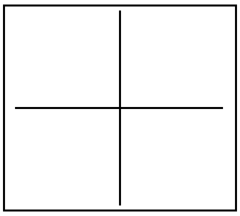
2.1 System alignment – separate systems

A poorly aligned system will not give optimum results. The following method should be employed when aligning a separate system:

1. Loosely mount the transmitter and receiver units on the machine and set the non-contact system into “set-up” mode.

2. Prepare a paper target marked up with crosshairs, see drawing

3. Using blu-tack or tape, fix a paper target onto a tool with the cross hairs facing the transmitter

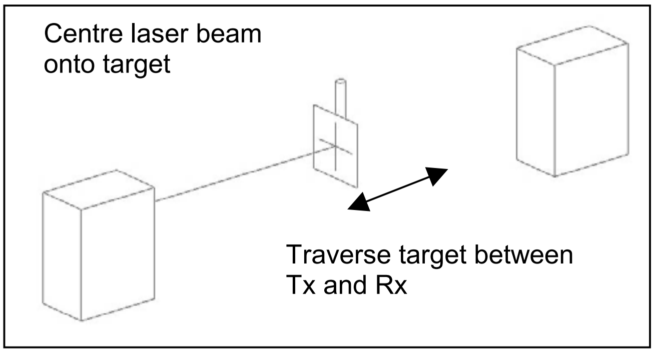


Example Target

4. Starting as close to the transmitter as possible, centre the target with the centre of the laser beam.

5. Move the target towards the receiver.

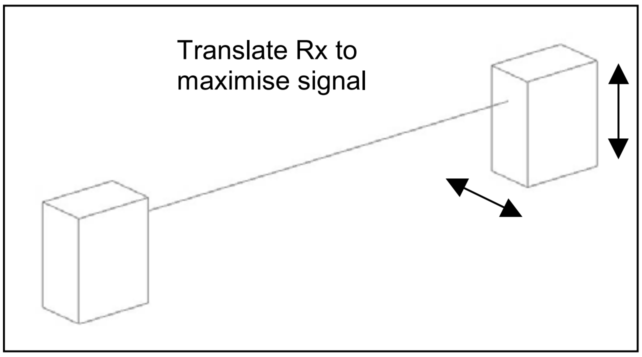
6. Correct the laser beam by pivoting the laser in both the vertical and horizontal axis, and repeat the procedure until the laser spot stays on the centre of the target as it traverses along the measuring gap. Finally lock the transmitter in place.



7. If possible, clock the top and side of the receiver unit so that the front face is perpendicular to the laser beam. A mirror mounted flat against the front of the receiver unit can also be used. Pivot the receiver unit until the laser spot projects back onto the middle of the transmitter air cap. Remove mirror.

8. Translate the receiver unit vertically and horizontally such that the laser spot is in the centre of the MircoHole™ / air cap and the maximum signal strength is achieved. Lock the unit in position.

9. Set system into “normal” operation mode.



10. Run the Renishaw beam alignment macro and check the results against the limits calculated as in chapter 1.1.

    If any slight adjustments were required, then calculate the required correction move based on the output of the alignment cycle and the system separation. Start with moving the receiver because this defines the effective beam path. A dial indicator on the receiver housing can be used to control the correction.

    Put the system into “set-up” mode and check the signal strength. Re-adjust the transmitter to the maximum signal strength as before. Return to step 9.

2.2 Optimal method of achieving machining accuracy

The best method of achieving tool setting accuracy is to measure the tool and a representative piece of material to obtain the individual experience value for that specific tool.

The experience value is the difference between the measured size (length or diameter) of the tool and the effective cutting size. Broadly speaking, it can be equated to the accuracy error and is used to refine the measured size, based on previous experience of how the effective cutting size differs from the measured size when the tool is being used. One or more of the factors that are detailed in this report could contribute to the difference as well as other factors such as material type / condition, spindle speed, feed rate, spindle loading, tool type etc.

Use the following method

1. Install the laser tool setter on the machine and align the laser beam with the axis of the machine, checking with the Renishaw beam alignment macro. Alignment should be within 10 µm per 100 mm in the z-axis and within 1 mm per 100 mm in the X/Y-axes (axes based on VMC configuration). The alignment macro should ideally be used with a solid, flat-bottomed, cylinder-type calibration tool having minimal run-out. The approximate setting length and diameter of this tool must be known.

2. Determine the position along the laser beam at which all calibrated measurement cycles will be conducted. Using the Renishaw calibrating macro, calibrate the positions of the beam in the X, Y and Z-axes. The calibration tool could be the same as the one used in step 1 above. Where possible calibrate at the cutting speed.

3. Closely inspect and ensure that all tools are free of debris and dry.

4. Clamp a piece of material that is representative of a typical part on the machine bed.

5. Renishaw non-contact software allow a number of parameters to be varied to optimise probing cycles. The following bracketed numbers are typical only. Please refer to the appropriate programming manual. Set the scatter tolerance (5), sample size (5), number of re-tries (3) and feed per rev (2 µm per rev) to low values. Run the machine through a warm-up cycle to reduce thermal drift.

6. Choose a master or base tool, then measure the tool on the non-contact tool setter. Note, where possible always measure tools for length, off-centre.

7. Cut a datum surface on the material to establish a reference surface at the same speeds and feeds to which the tool will be used.

8. Taking each tool in turn:
   - Machine a feature into the datum surface
   - Measure the feature (spindle probe, gauges, CMM, etc)
   - Update the experience value of the tool – Refer to next section for guidance

9. The non-contact tool setter is now calibrated and ready for use.

Experience values

Once the experience value has been determined, it must be entered into the appropriate tool setting macro. When the tool is measured by the non-contact system, the experience value will be added to the measured value and the effective cutting tool size will be written into the tool offset register.

Fanuc - a typical input in a Renishaw macro for a Fanuc control, in this case tool length setting, is as follows:

G65P9862 B1. H.5 J0.036 M1. Q5. S2500. T20. Y3.

(In this example J is the experience value input.)

For more details refer to the Renishaw non-contact Programming guide (Fanuc) H-2000-6187.

Siemens - a typical input in a Renishaw subroutine for a Siemens 810D / 840D control, in this case tool length setting, is as follows:

R02=1. R11=0.5 R05=0.0036 R13=1. R14=2. R17=5. R19=2500 R25=3.
L9862

(In this example R05 is the experience value input.)

For more details refer to the Renishaw non-contact Programming guide (Siemens 810D / 840D) H-2000-6199.

Heidenhain – to input the experience value for tool length into a Heidenhain iTNC530 control, the following sequence is used:

a) Call the tool that is to be measured using a TOOL CALL.

b) Select cycle **503**, which is situated below the **RENISHAW** soft key within the **Touch Probe** menu.

c) Enter the prompted Q parameters (Q366 is the parameter for experience value) and tool table data.

A similar sequence is followed for the experience value for tool radius. For more details refer to the Renishaw non-contact Programming guide (Heidenhain iTNC 530) H-2000-6247.

2.3 Setting tools using single standard reference

This method uses a single reference or calibration master such as a plain flat-ended pin. The tool measurement errors and minimum tool that can be measured / detected is dependant upon the non-contact system used and separation distance between the transmitter and receiver units.

Use the following method

1. Install the laser tool setter on the machine and align the laser beam with the axis of the machine using the Renishaw beam alignment macro. Alignment should be within 10 µm per 100 mm in the z-axis and within 1 mm per 100 mm in the X/Y axes (axis based on VMC configuration). The alignment macro should ideally be used with a solid, flat-bottomed, cylinder-type calibration tool having minimal run-out. The approximate setting length and diameter of this tool must be known.

2. Determine the position along the laser beam at which all calibrated measurement cycles will be conducted. Using the Renishaw calibrating macro, calibrate the positions of the beam in the X, Y and Z-axes. The calibration tool could be the same one as used in step 1 above, however at this point the actual size and length must be known. This data is used to establish the calibration of the laser.

3. The non-contact tool setter is now calibrated and ready for use.

2.4 Establishing the length of a calibration tool

In order to use the non-contact tool setter to measure tool lengths and diameters it is necessary to provide some form of master or calibrated tool. The selection of tool should be based on the target accuracy expected of the system.

Whilst it is the case that in certain applications, absolute accuracy is not required, Renishaw recommends establishing the actual calibration tool dimensions.

This can be achieved in a number of ways:

Traditional Methods	Other Methods
Slip gauge between tool and table	Off line tool pre-setter
Slip gauge between tool and work piece	Contact table probe
	Dial Test Indicator
	CMM

Calibration tool examples

- Dedicated master complete with calibration certificate such as master arbour for ISO 230 measurement.
- A cutting tool mounted into a tool holder that has been measured as above providing length and diameter information.
- Purpose made pin of known diameter, mounted into a tool holder that has been measured as above providing length information.

2.5 Case study

The following section details results obtained from a machine tool fitted with the following non-contact tool setting systems: NC1, NC3 and NC4. The machine used was a Bridgeport $VMC1000_{22}$ Digital with Heidenhain controller running standard Renishaw non-contact software. The calibration tool used was a 6 mm diameter ground pin with a flat bottom. The results do not include factors such as tool push-off, spindle pull-up, etc. All measurements were conducted in the middle of the system separation, i.e. mid way between the transmitter and receiver units. **Note:** This study was conducted using the single standard reference as detailed in Section 2.3. Tool experience values are not included

The tooling suite consisted of the following

• 6 mm Calibration Pin	• 3, 6 & 10 mm Ballnose
• 0.03 to 0.9 mm Micro Drills	• 3, 6, 10 & 25 mm Slot
• 1, 3, 6 & 10 mm Jobber Drills	• 80 mm Face Mill

The absolute length of each tool was determined using a slip gauge on the bed of the machine. The micro drills were measured for length using an optical camera providing a magnification factor of approximately X180.

Results

The following table details the tool length errors that can be expected for different systems and separations when using a single standard reference.

Range of tool length errors 80mm face mill measured with radial offset down to 1mm drill			
Separation, m	NC1	NC4	NC3
0.09	-	-	0.012
0.5	0.019	0.019	-
1.0	0.033	0.019	-
2.0	0.031	0.025	-
3.0	0.031	0.037	-
4.0	0.036	0.036	-
5.0	-	0.042	-

Table 2.5a

The following two tables detail the minimum tool that can be measured / detected for different systems and separations

Min tool – Measure (mm)			
Separation, m	NC1	NC4	NC3
0.04	0.15	0.05	-
0.09	0.20	0.10	0.20
0.19	0.20	0.15	-
0.5	0.40	0.30	-
1.0	0.60	0.40	-
2.0	0.60	0.50	-
3.0	1.00	0.60	-
4.0	1.00	1.00	-
5.0	-	1.00	-

Table 2.5b

Min tool – Detect (mm)			
Separation, m	NC1	NC4	NC3
0.04	0.10	0.03	-
0.09	0.10	0.05	0.10
0.19	0.10	0.10	-
0.5	0.20	0.10	-
1.0	0.20	0.20	-
2.0	0.30	0.20	-
3.0	0.30	0.30	-
4.0	0.30	0.30	-
5.0	-	0.30	-

Table 2.5c

The figures detailed in Table 2.5b are based upon being able to measure the tool with length error of less than 50 µm from the calibration pin.

The figures detailed in Table 2.5c are based upon being able to measure the tool with a length error of less than 3 times the tool diameter. Tools of smaller diameter may be detected but will have unknown measurement error.

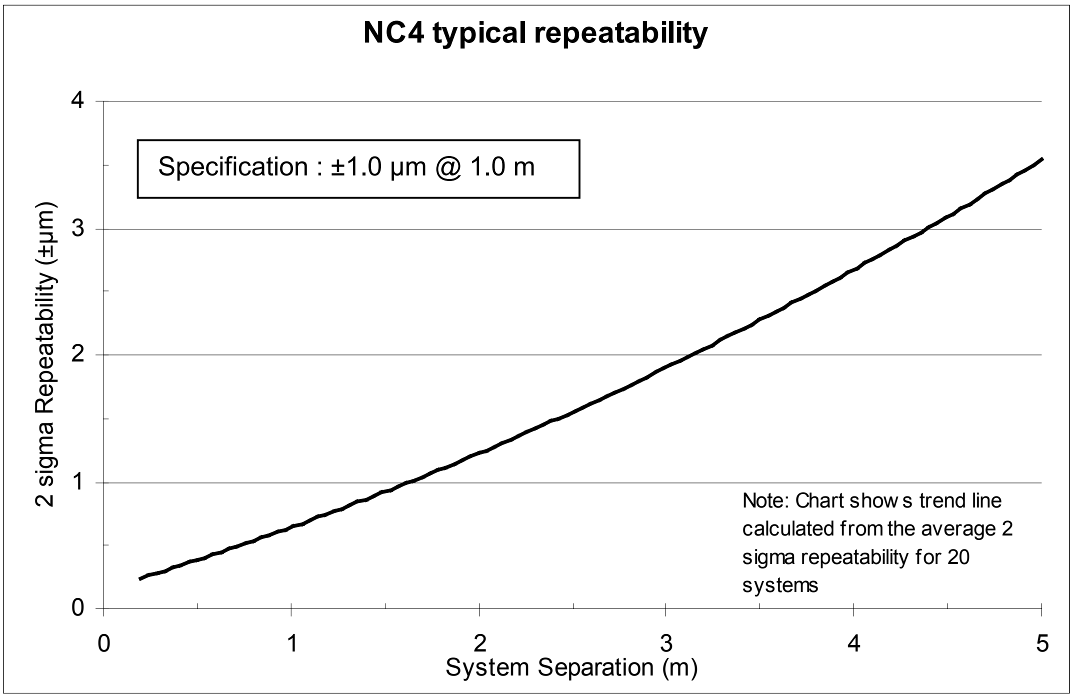
2.6 Product Performance

This section provides typical repeatability values that can be expected from NC1, NC3 and NC4 probes under ideal conditions. Values are based upon an average 2 sigma repeatability for a sample of results taken from the NC1, NC3 and NC4 production test rigs. These rigs pass a solid pin of known diameter through the laser beam a set number of times. A trigger is issued as the pin passes into the laser beam and an average 2 sigma result recorded.

Repeatability specification figures for each system are also shown.

NC1		2 Sigma edge repeatability, ±µm	
System		Typical	Specification
Fixed	F150, F200, F300	0.5	1.0
Separate	S700	0.6	2.0
	S1000	0.9	
	S1400	1.0	
	S2000	1.2	

NC3	2 Sigma edge repeatability, ±µm	
	Typical	Specification
	0.07	0.15



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