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Precision styli

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Contents

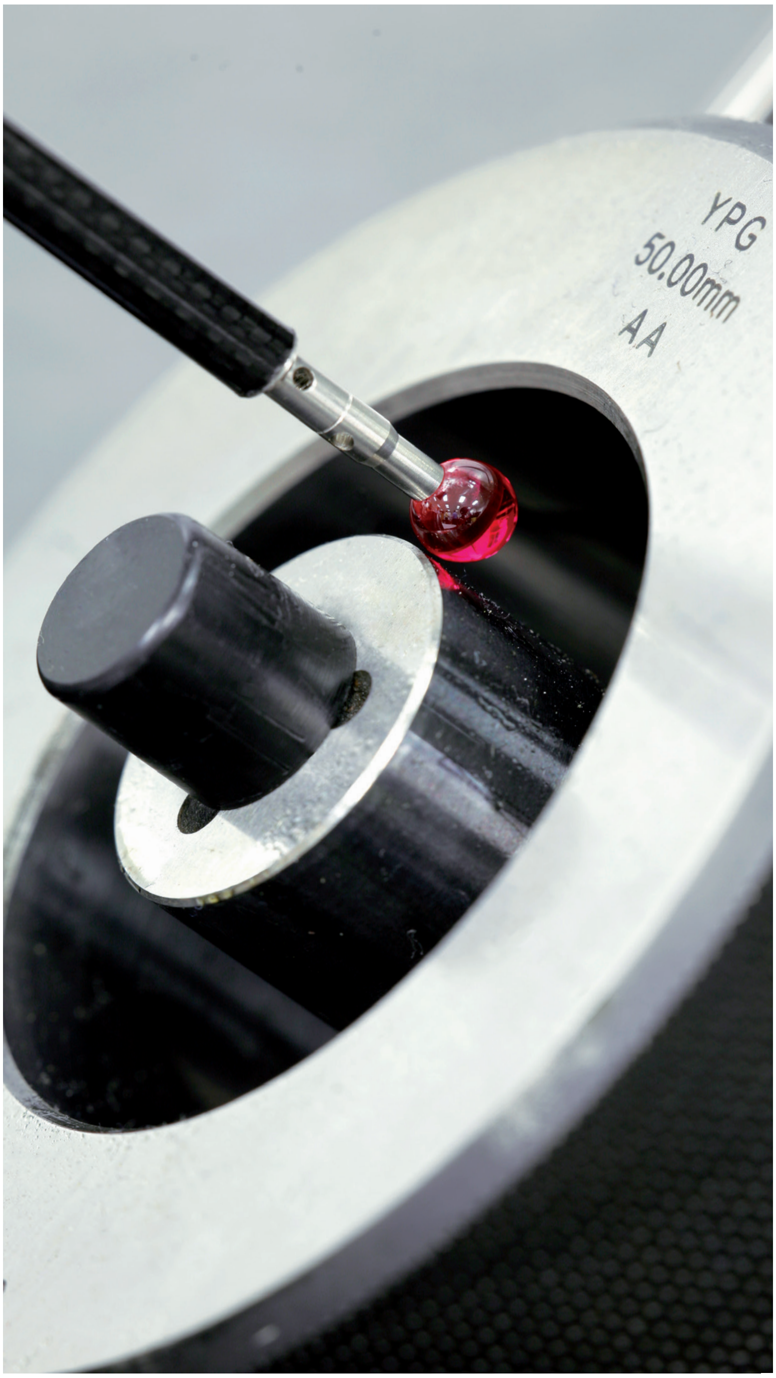
What is a stylus?

In principle, styli are the co-ordinate measuring machine's (CMM's) "tools", providing the same relationship that turning tools have with lathes, and milling and boring tools have with milling machines.

When measuring with a touch-trigger probe, the machine uses the stylus to take the data points on the surface of the workpiece.

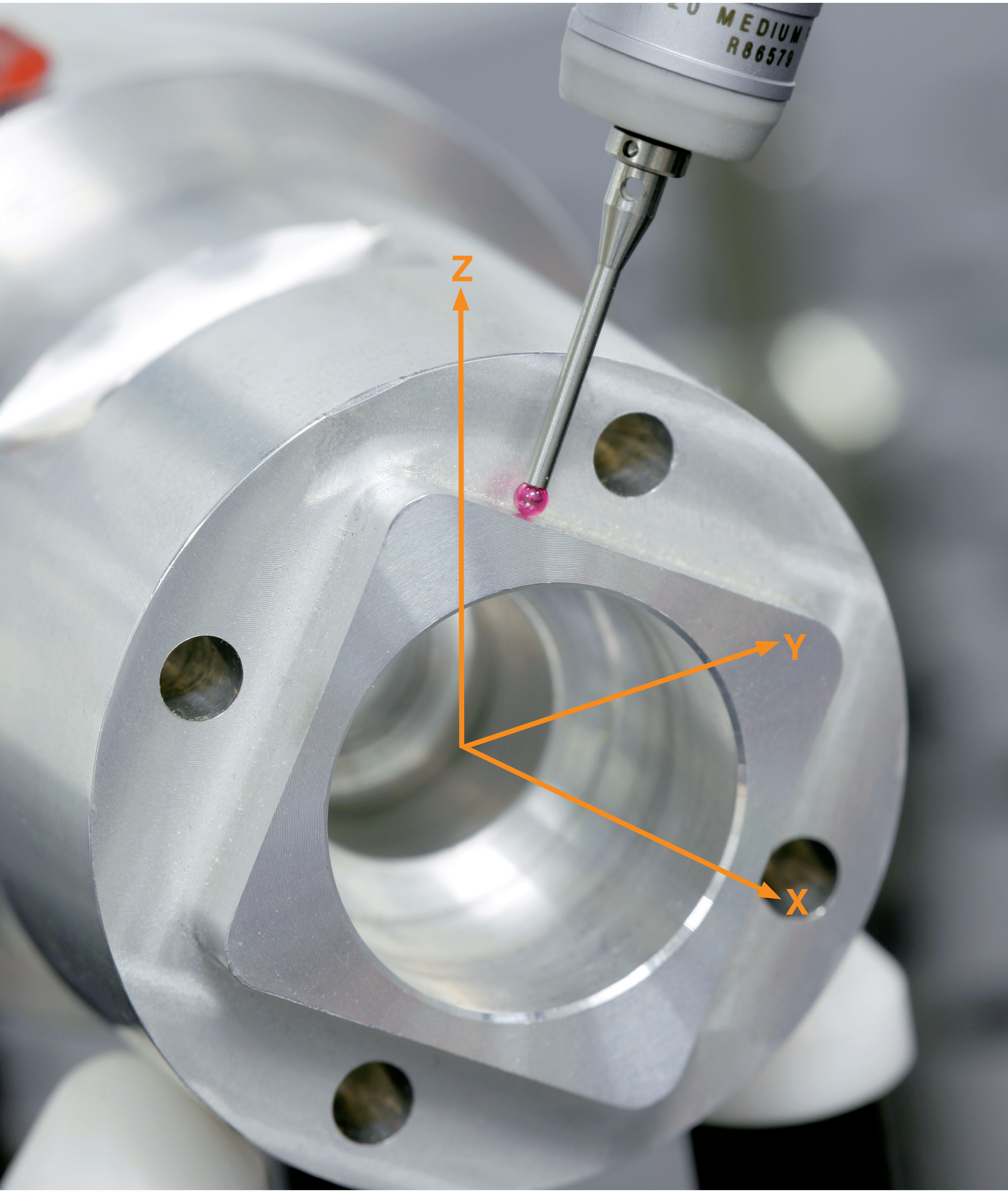
Each touch generates a point that is defined using co-ordinate values in X, Y and Z. Feature, size, form and position can then be computed from these points.

By contrast a scanning probe takes continuous readings along the surface of a work piece. Sophisticated software uses this data to compute the size, position and form of features on the component.



The stylus is the first link with the workpiece.

This is why it is vital that the stylus delivers the greatest possible accuracy at the point of contact.

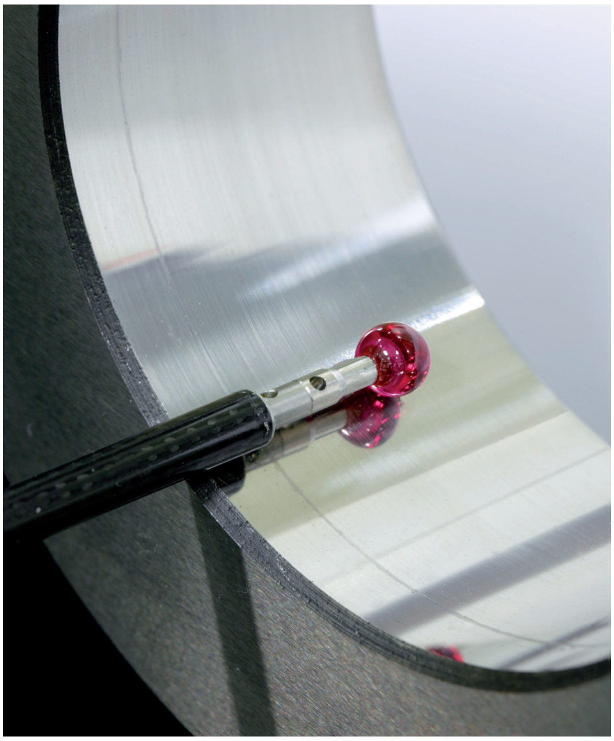

MEDIUM
R86579
Z
Y
X

The importance of styli for precision measurements

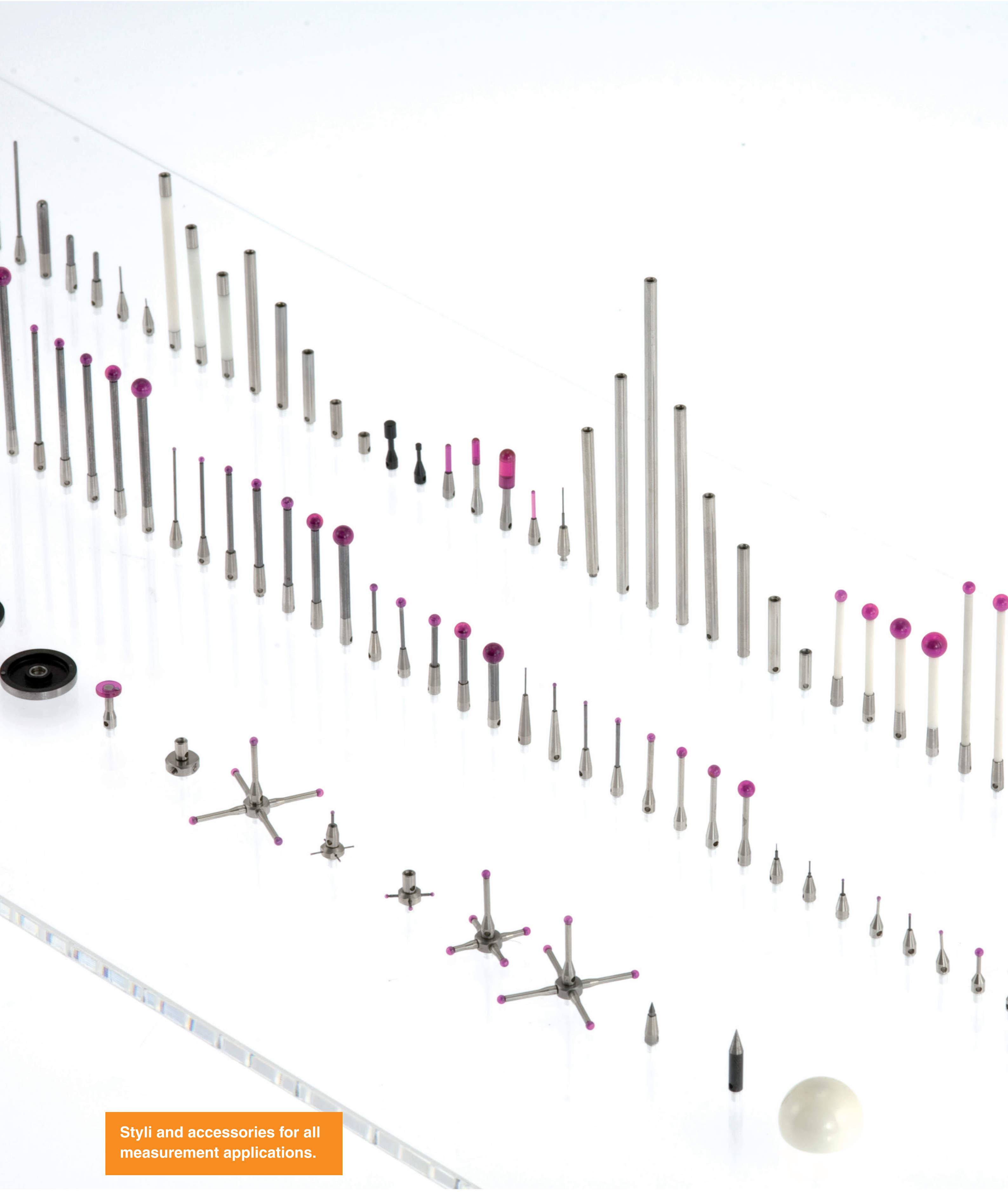
Quality assurance standards have increased dramatically in recent years. Companies can only remain competitive if they deliver top-class process stability and superior quality – and all as rapidly as possible. Quality assurance and co-ordinate measurement technology are playing a crucial role in these processes.

To stay competitive, manufacturers have been continually upgrading their co-ordinate measuring machines. CMMs are now being integrated directly into manufacturing as part of production processes and swift, high-performance scanning systems guarantee extremely precise measurements within the tightest timeframes.

Renishaw and its probing systems have always been at the forefront of these developments. The quality of styli and accessories plays a vital role in industrial measurement technology, which is why, in this guide, we have summarised key information on the subject for your benefit.



Renishaw offers a comprehensive range of precision engineered styli for metrology applications.



Styli and accessories for all measurement applications.

Selecting and using styli

Selecting the stylus that is best suited to your measurement application is very important. Here we describe the main types of styli and accessories, and the key parameters and material properties.

Connecting thread

- At a basic level, the choice of stylus always relates to the connecting thread on your co-ordinate measuring machine's sensor – usually M2, M3, M4 or M5.
- Renishaw sensors work with connecting threads.
- ZEISS sensors mainly work with M5 and M3 connecting threads.
- Styli can be used very flexibly with the help of thread adaptors. For example, you can use M2/M3/M4 styli on M5 sensor connecting threads.

M2

M3

M4

M5

When choosing a stylus, the connecting thread is the decisive factor

Renishaw has a large range of styli and accessories with all connecting threads to suit sensors and accessories from all manufacturers, as well as styli for CNC machine tool probes.

Thread adaptors can provide flexibility.

Workpiece geometry determines the choice of stylus component

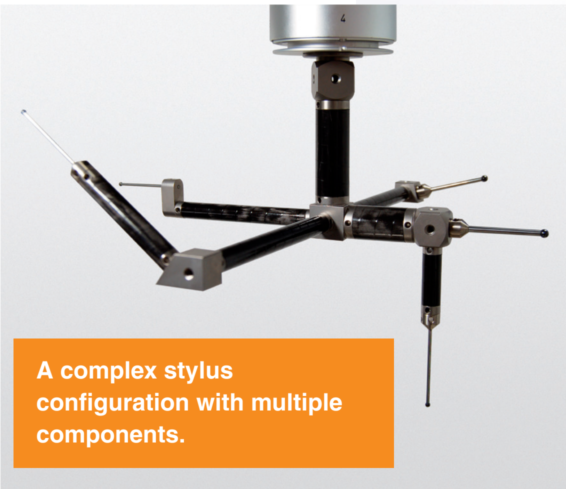
A stylus must be able to easily reach all of the workpiece's probing points. You need to be very careful when choosing your stylus components, so they provide the required inspection criteria and accessibility for each feature measured.

If you want to take all the measurements for a workpiece on a CMM equipped with a fixed sensor, you often need a number of styli, mounted in different orientations, requiring different shaped styli components, extensions and knuckles. The combination of all these components is known as a stylus configuration, which is mounted on an adaptor plate.

Renishaw produces stylus components in a range of materials, so you can assemble your stylus configurations to ideally suit the measurement application.

When assembling your stylus configuration, refer to the maximum mass that the sensor manufacturer has specified. The maximum mass can be up to 500 grams.

Stylus configuration, mounted on an adaptor plate.



A complex stylus configuration with multiple components.

Stylus types

Renishaw offers a wide range of stylus types and accessories so that you can carry out all your measurements successfully. All components, including stylus balls, are available in a range of materials.

Straight styli

Straight styli are the simplest and most frequently used type of stylus. Straight shouldered stems and tapered stems are available. Styli with tapered stems offer better rigidity when the workpiece is easily accessible.

Stylus balls are made from ruby, silicon nitride, zirconia, diamond coated, ceramic or tungsten carbide.

The holders and stems come in a range of materials – titanium, tungsten carbide, stainless steel, ceramic and carbon fibre.

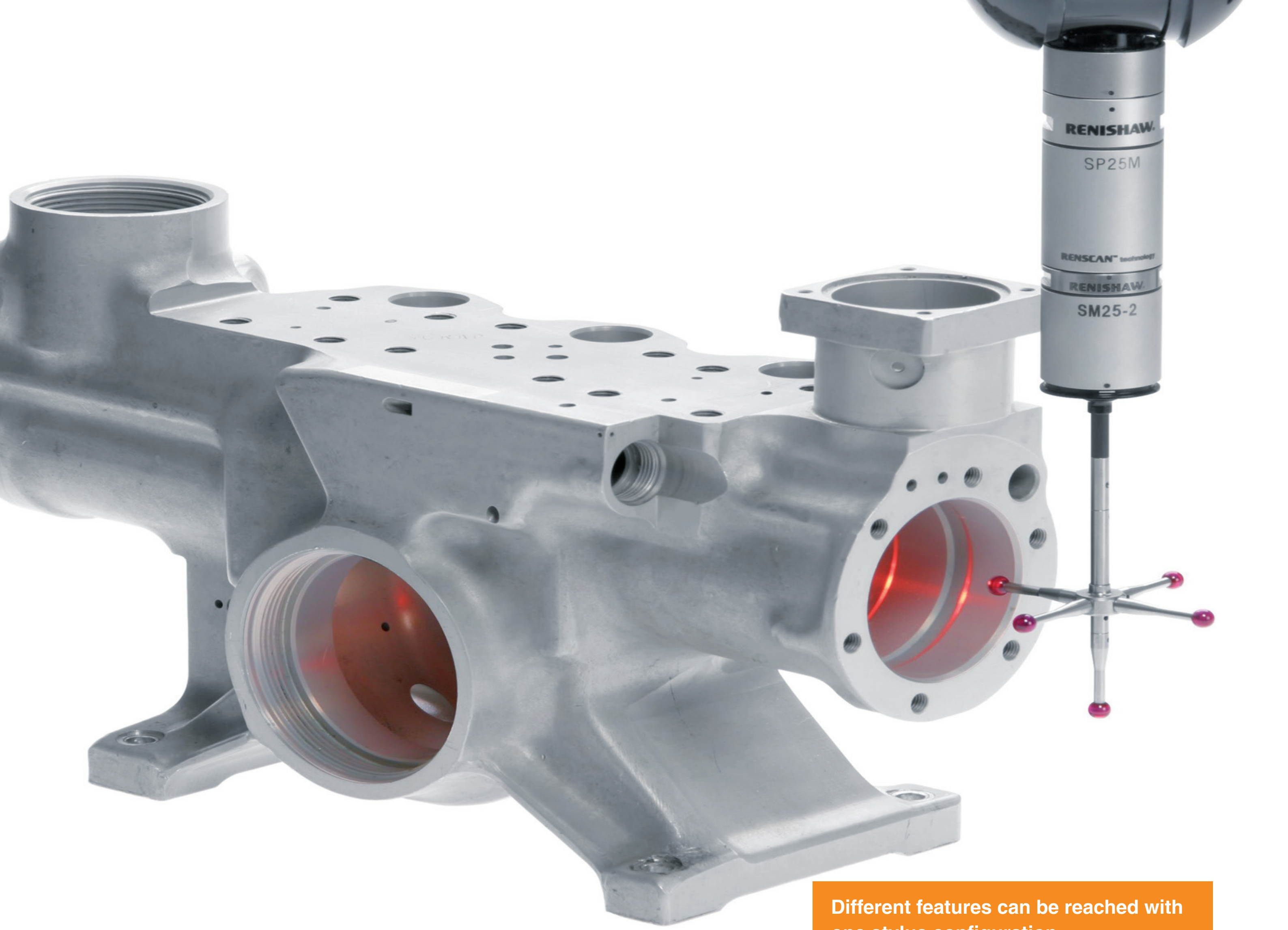
Main application

For simple features with which direct contact can be made.

The measuring travel direction should be near parallel to the co-ordinate axes and at right-angles to the surface of the workpiece. A wide range of accessories is available for aligning probes, e.g. for measuring angled holes.

To prevent stylus bending you should use the shortest stylus possible, particularly with touch trigger probe systems.

Straight stylus, right-angled to the workpiece surface.

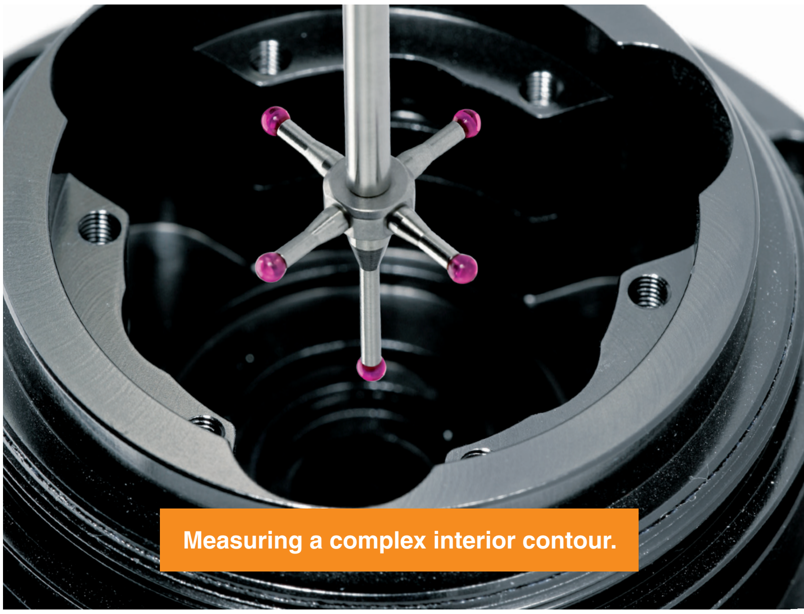


Different features can be reached with one stylus configuration.

Star styli

These are multi-tip stylus configurations with rigidly mounted styli. Balls are made from ruby, silicon nitride or zirconia. You can also configure your own star styli using stylus centres to mount up to five styli components.

Star stylus with five rigidly mounted styli.



Measuring a complex interior contour.

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Swivel styli

This is a clamping mechanism that can be used to adjust styli to the required angle.

Main application

For angled surfaces and angled holes, this configuration gives flexibility, enabling you to make contact with different features without changing the stylus.

Disc styli

These styli are ‘sections’ of highly spherical balls and are available in various diameters and thicknesses. Mounted on a threaded spigot, the discs are made from steel, ceramic or ruby. Full rotational adjustment and the ability to add a centre stylus are features of the range. This makes them particularly flexible and easy to use.

Main application

These styli are used to probe undercuts and grooves within bores, which may be inaccessible to star styli. Probing with the ‘spherical edge’ of a simple disc is effectively the same as probing on or about the equator of a large stylus ball. However, only a small area of this ball surface is available for contact and hence thinner discs require angular alignment in order to ensure correct contact with the feature being probed.

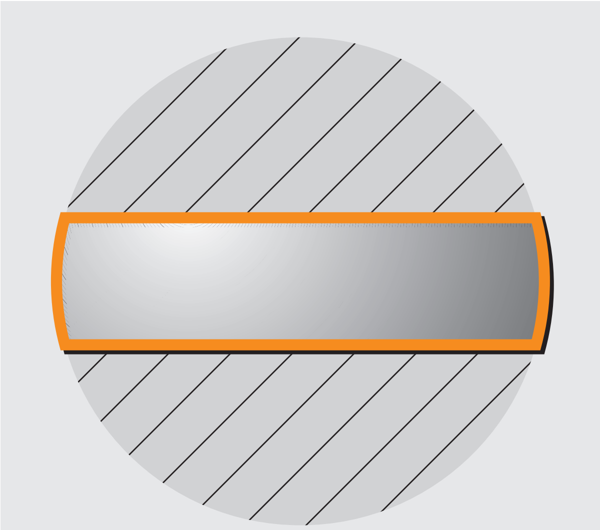
A simple disc requires datuming for only one diameter, but this limits effective probing to only X and Y directions. Adding a ‘radius end roller’ allows you to datum and hence probe in the Z direction, provided that the centre of the ‘radius end roller’ extends beyond the diameter of the probe. The ‘radius end roller’ can be datumed on a sphere or a slip gauge. Rotating and locking the disc about its centre axis allows the ‘radius end roller’ to be positioned to suit the application.

Semi-spherical disc styli

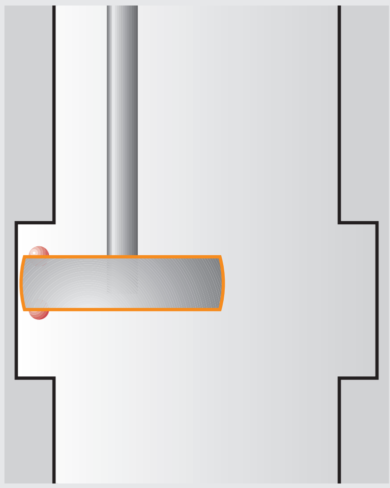
These styli have a half-ball, or roller, mounted on each face of the disc, both beneath and on top, which guarantees point contact in the Z direction.

Main application

Also for undercuts, stepped bores and grooves within bores. Using the hemispheres above and below you can also measure in the Z direction e.g. to measure the width of a groove.



The edges of all discs are curved, as though a section had been cut out of a sphere at its equator.



Measurement of diameter and width of the groove.

Cylinder styli

Cylinder styli are made from tungsten carbide, ruby or ceramic.

Main application

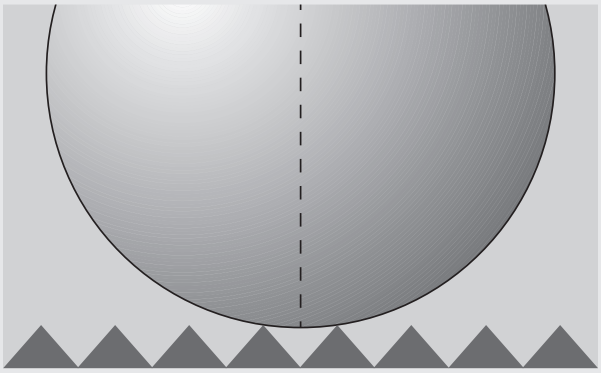
For measuring sheet metal, pressed components and thin work pieces with which proper contact cannot be guaranteed with ball styli. Ball-ended cylinder styli allow full datuming and probing in X,Y and Z directions, thus allowing surface inspection to be performed.

Ceramic hemispherical styli

Their advantage is that they have a large effective ball diameter with minimal weight.

Main application

For measuring deep features and bores. Also suitable for contact with rough surfaces, as the roughness is mechanically filtered out by the large diameter surface. In addition the outer diameter of various threaded features can be inspected using the same method.



Probing with such a large diameter ball can average out the effects of very rough surfaces.

Measurement of deep threaded bore.

Adaptor plates

If you need to measure certain features repeatedly, it is a good idea to set up the required styli configurations on adaptor plates.

You can store the assembled adaptor plates in styli cabinets, or racks on the CMM and use them when needed. Whenever you make a change, there is no need to recalibrate the probe so you can start measuring immediately. With a probe rack, even highly complex work pieces can be measured in CNC mode.

Adaptor plate for Renishaw SP80 probe head.

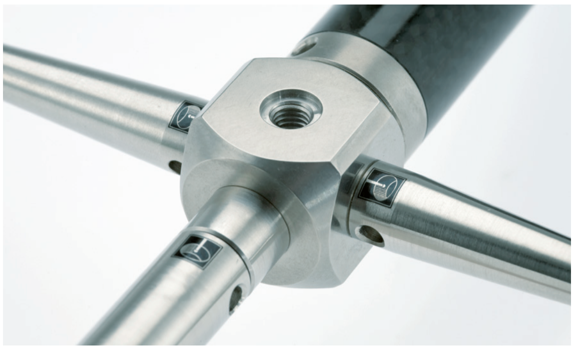
Adapter plates for ZEISS VAST probe heads.

Accessories

Accessories are useful for adapting probe components more precisely to specific measuring tasks. See our product catalogue for full details of our extensive range.

Bodies, cubes

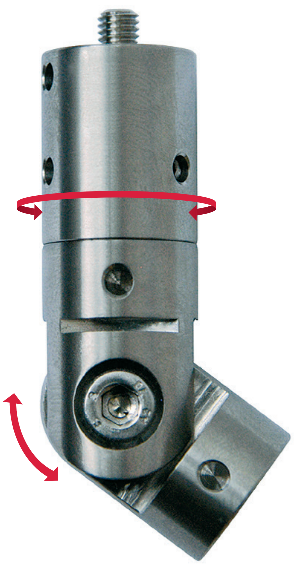
Combine to create specific styli configurations.



Knuckles must be extremely stable and precisely machined to ensure that the probing force does not alter the position of the stylus tip while measuring. Quality of design and materials is vital.

Knuckles

The angular alignment of the probe component for making vertical contact with angled workpiece surfaces or angled holes.

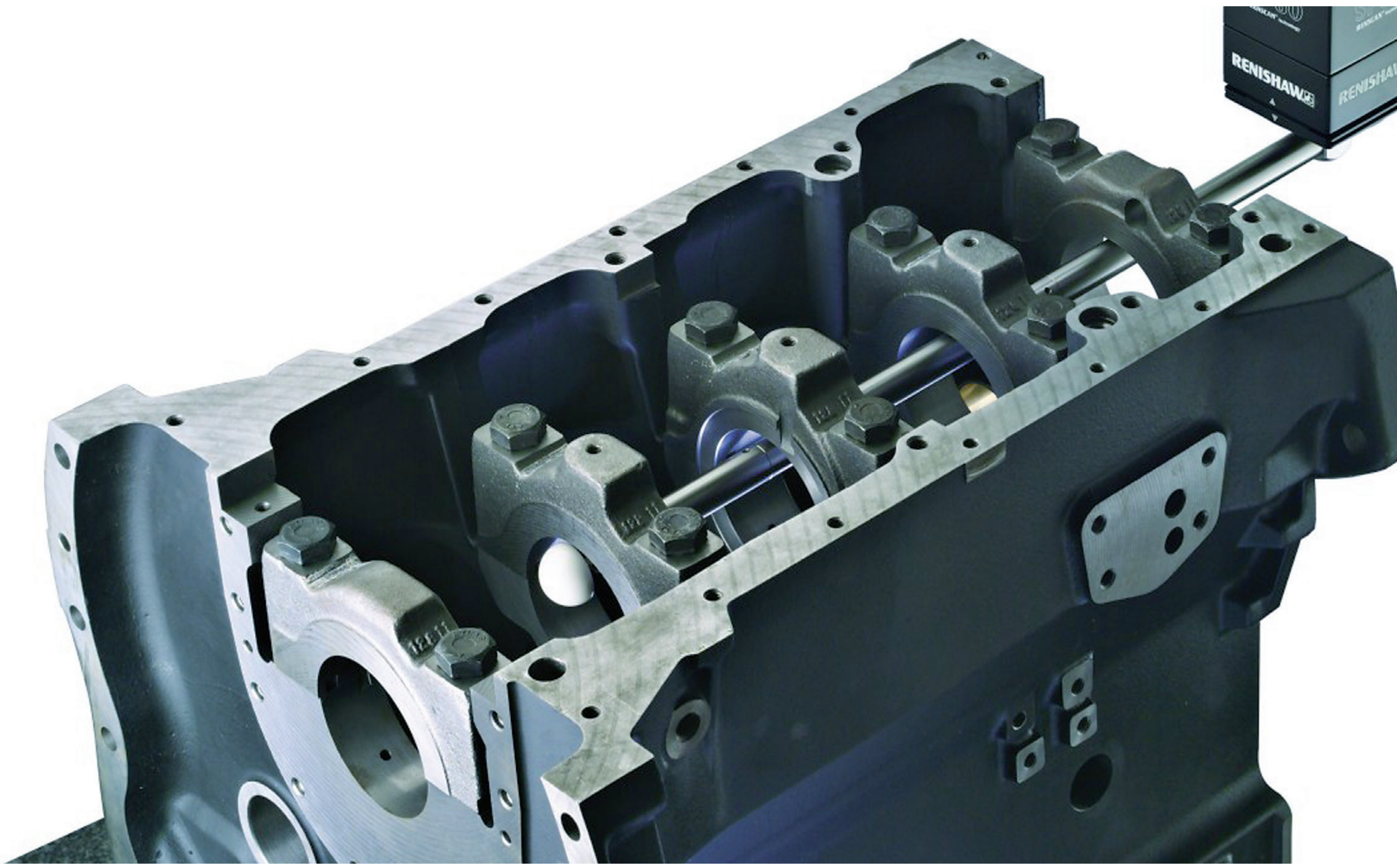


Extensions

Renishaw manufactures a wide range of extensions in different lengths and materials – steel, titanium, aluminium, ceramic and carbon fibre.

Main application

Extensions are used for measuring very deep features and bores, or probing points that are difficult to access.



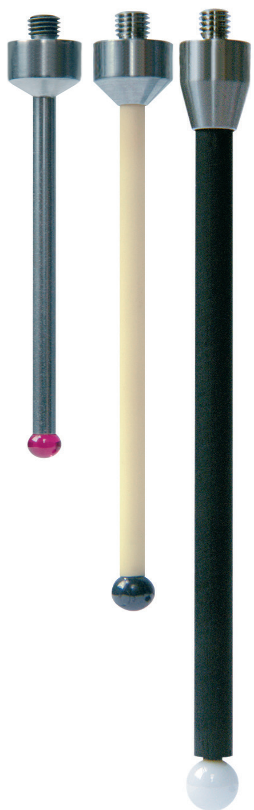
Materials used for Renishaw stylus components

Our product range caters for the widest range of material combinations.

All the materials used in metrology are described below.

Holders

The stylus stem is attached to a threaded holder. Steel and titanium are the ideal materials for holders. Titanium is best for saving weight on large M5 styli.



Stem

The stem must be designed for maximum rigidity to minimise bending during measurement.

Tungsten carbide

Provides exceptional rigidity, particularly with small stem diameters and shouldered probes.

With large stem diameters and long styli, weight must be considered. Ideally suited for most standard applications.

Ceramic

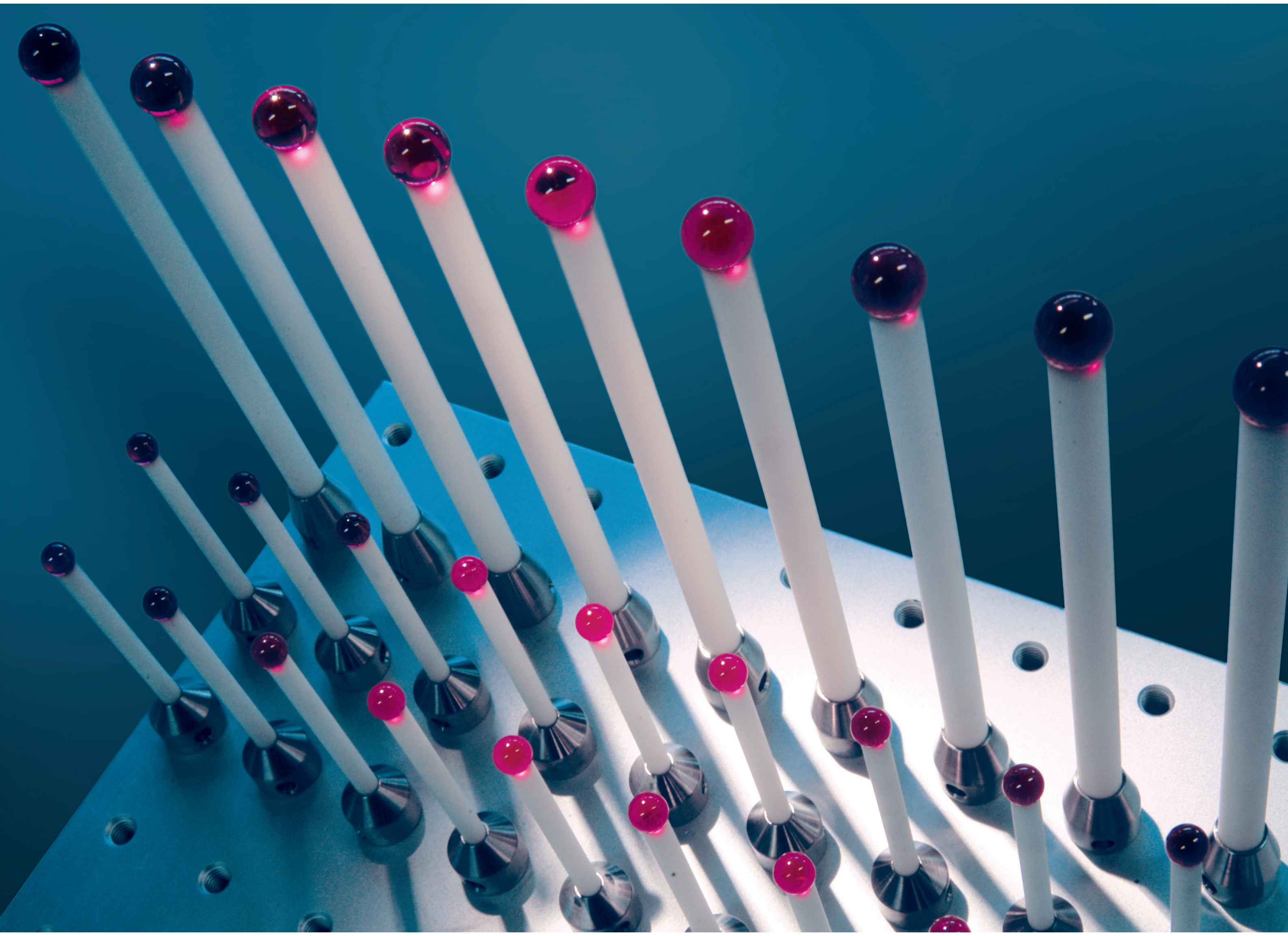
Due to its lightness, ceramic is mainly used for long styli. It is thermally stable, for production-related applications. It can also be used as break protection in machine tool applications.

Steel

For styli with superior rigidity in standard applications where weight is not an issue.

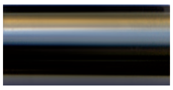
Carbon fibre (thermally stable)

Also ideally suited for long styli as carbon fibre styli only weigh around 20% of tungsten carbide styli. Its thermal stability delivers huge benefits, particularly with very long styli and this makes it suitable for use in a production environment.



Parameters for materials for extensions/ plate extensions

The parameters are similar to those for the stylus stem.



Tungsten carbide

Deflection-resistant carbide stems for all standard applications at stable ambient temperatures; primarily for the use within a controlled environment.

Steel

Extension with superior rigidity; for standard applications where weight is not an issue.

Aluminium

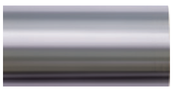
Very light; ideally suited for extensions, but only in a stable air-conditioned environment due to thermal growth.

Ceramic

Light, solid and thermally stable; for use in production-related applications.

Carbon fibre

Thermally stable with low mass; ideal for long extensions subject to temperature fluctuations.



Titanium

Very light and thermally stable with good flexural rigidity compared with aluminium; suitable for long extensions.

Materials for connecting components

Titanium

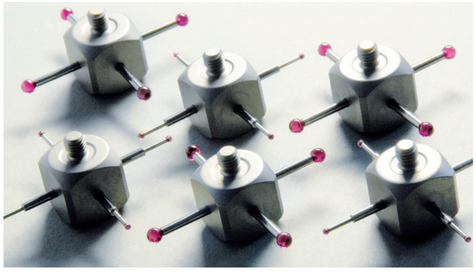
We supply the larger M5 accessories, such as knuckles and cubes, in titanium to keep the products very light.

13 g

11.2 g

Steel

The smaller products are usually made from stainless steel.



The materials shown here influence the product's price. However, when choosing your styli and associated components, you should always give priority to the measuring application and the ambient conditions. Erroneous measurements waste time and money!

Choice of material for styli components and accessories

The key criteria when choosing a material are:

- ambient conditions
- length/flexural rigidity
- the permitted masses specified by the probe manufacturer

Fluctuations in temperature can cause serious measurement errors.

If you are operating your CMM in an air-conditioned area at a stable 20°C, this effect does not generally occur (except for extreme extensions). Otherwise, fluctuations in temperature always cause significant thermal expansion and changes in the length of the probe component or extension, and so lead to measurement errors, unless compensated for.

Minor differences in temperature, can cause measurement errors. You can minimise such errors by choosing the right material for the stylus stem or the extension.

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Very long extension, made of carbon fibre.

Calculating changes in length

Changes in length depend on the change in temperature, the length of the stylus shank being used and the expansion behaviour of the material.

The change in length is calculated by

$\Delta L = L \times \alpha \times \Delta t$

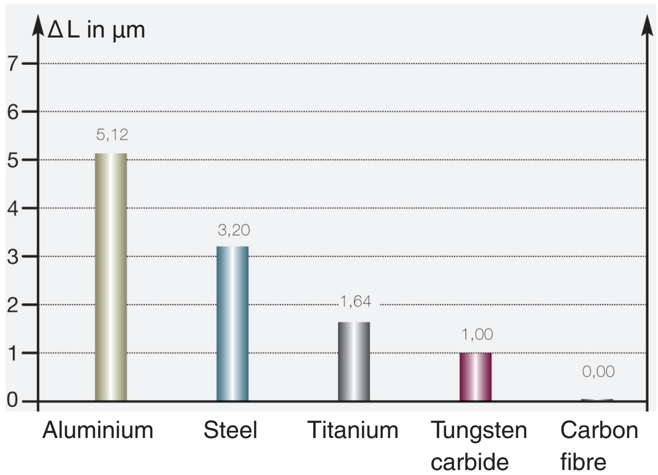
ΔL = change in length

L = probe length

α = expansion coefficient

Δt = difference in temperature

Thermal length increase in µm with a 200 mm probe extension and a temperature difference of 1 K.

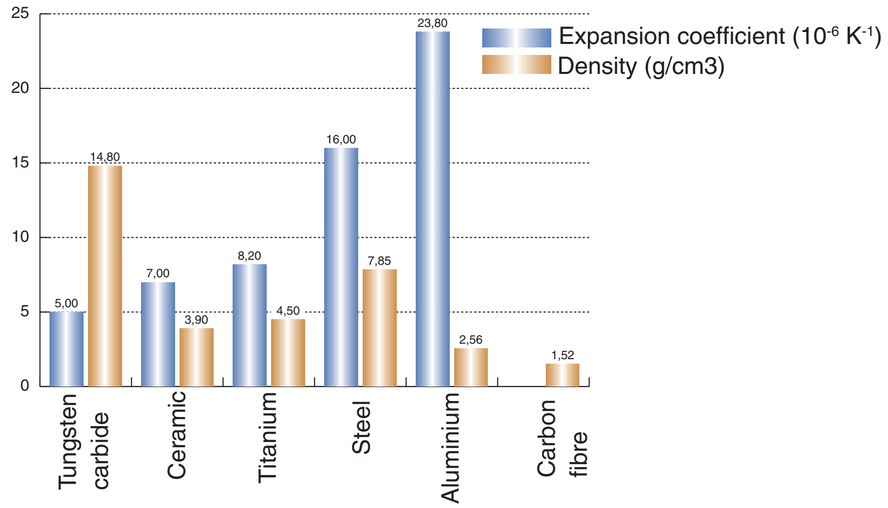


Remember that you are measuring in the µm range!

Comparison of materials Heat coefficient/Mass

Material	Thermal expansion	Density (g/cm³)
Tungsten carbide	5.0×10^{-6} K^{-1}	14.8
Ceramic	7.0×10^{-6} K^{-1}	3.9
Titanium	5.5×10^{-6} K^{-1}	4.5
Steel	16.0×10^{-6} K^{-1}	7.85
Aluminium	23.8×10^{-6} K^{-1}	2.56
Carbon fibre	~ 0,4 $\times 10^{-6}$ K^{-1}	1.52

Thermal length increase in µm with a 200 mm probe extension and a temperature difference of 1 K.



There are major variations in terms of both thermal expansion and weight between the different materials.

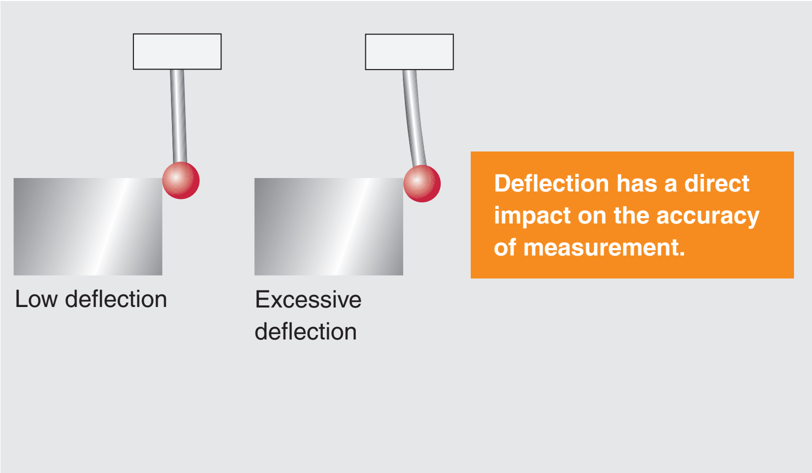
Carbon fibre offers the ideal combination of minimal mass and greatest temperature stability.

> You should always use carbon fibre for very long extensions, as in these cases even tiny temperature differences could otherwise cause major measurement errors.

Flexural rigidity

The stylus stem must be designed for maximum rigidity. During probing, measuring forces occur that must not cause the stylus to bend excessively, as this can directly impact on the machine's measurement uncertainty; particularly with dynamic measurements (scanning) that simultaneously probe in all spatial directions.

The bottom line: styli should be as stiff as possible.



Materials flexural rigidity compared

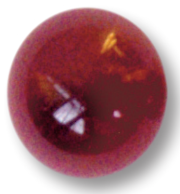
In materials technology, the elastic modulus is a material characteristic that describes the relationship between tension and expansion when a solid body is deformed. As the value of the elastic modulus increases the more resistance a material presents to being deformed. So a material with a high elastic modulus is rigid, while a material with a low elastic modulus is flexible.

Material	E modulus in kN/mm^2
Tungsten carbide	620
Steel	200
Aluminium	70
Titanium	150
Ceramic	300 – 400
Carbon fibre	≥ 450

Selecting and using styli

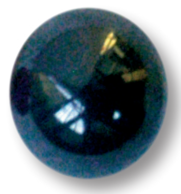
The choice of the ball material depends on the measuring strategy and the work piece material. Bear in mind the ball‘s quality rating – Renishaw only use balls in the top precision category, grade 3 to grade 5.

Ruby



The industry standard and the ideal stylus ball material for the vast majority of measurement applications. Ruby is one of the hardest known materials. Very few applications exist where ruby is not the preferred ball material.

Silicon nitride



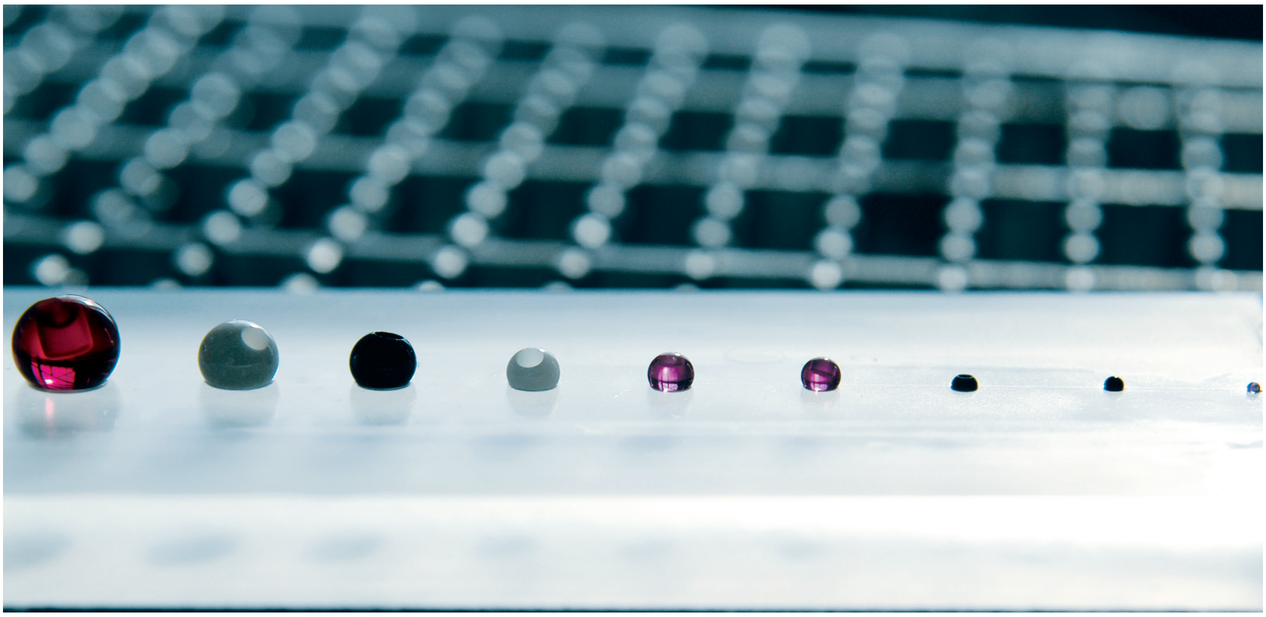
A very hard and wear-resistant ceramic which can be machined into high precision spheres. It can also be polished to an extremely smooth surface finish. Its applications are best confined to aluminium.

Zirconia

A particularly tough ceramic material with hardness and wear characteristics approaching those of ruby. Its surface properties make it an ideal material for aggressive scanning applications on cast iron components.

OPTiMUM™ diamond

Ceramic balls are diamond coated to a thickness of approximately 0.015 mm and the balls are then polished in a highly complex process. The diamond coated spheres maintain their roundness and do not suffer material build-up or premature wear when scanning a part.



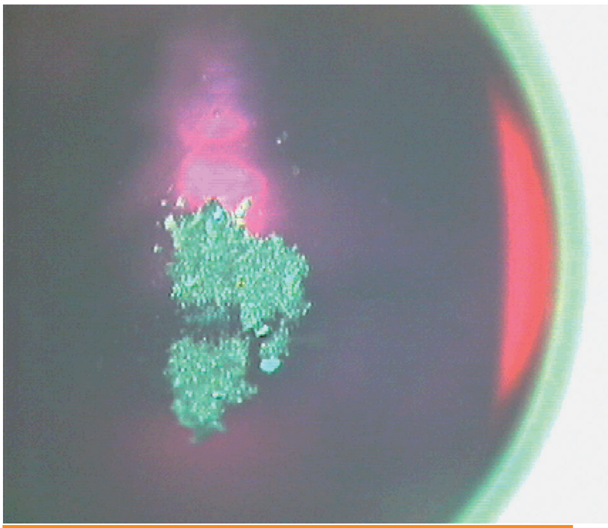
Notes on scanning

With point measurements, the ball only comes into contact with the component's surface for a very short time. Scanning is different as the ball slides along the surface of the workpiece, making continuous contact.

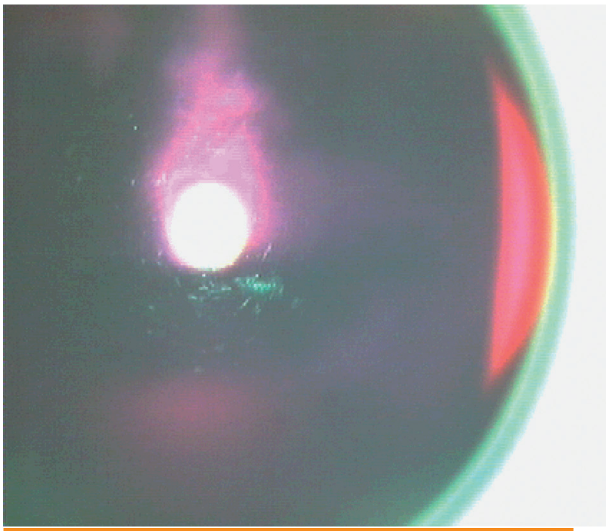
Ball stylus wear and tear and ball stylus deposits left by scanning can affect measurements.

Impurities

All the tests with ball materials have shown that materials are deposited on ball surfaces. Between inspections, it is recommended that the balls are cleaned with a dry, lint-free cloth so that no residue is left.



Typical coating of impurity on a ruby ball after 350 m of scanning.

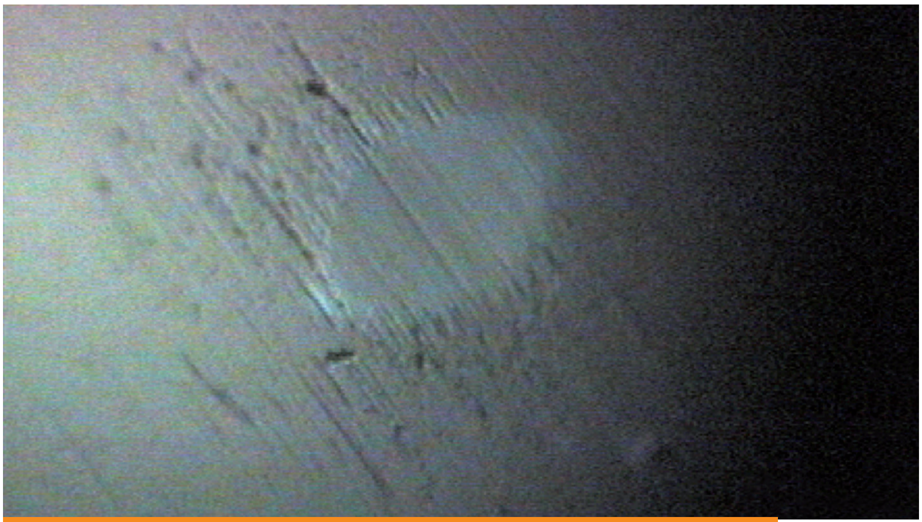


The same ball after being cleaned with a dry, lint-free cloth.

Abrasive wear

Scanning abrasive materials

If, for example, components made from cast iron are being measured, both the ball stylus and the surface of the workpiece can suffer wear from abrasion. Minute particles of residue can cause fine scratches on the ball stylus and the surface of the workpiece. We recommend zirconia ball styli for this type of application to minimise this effect.



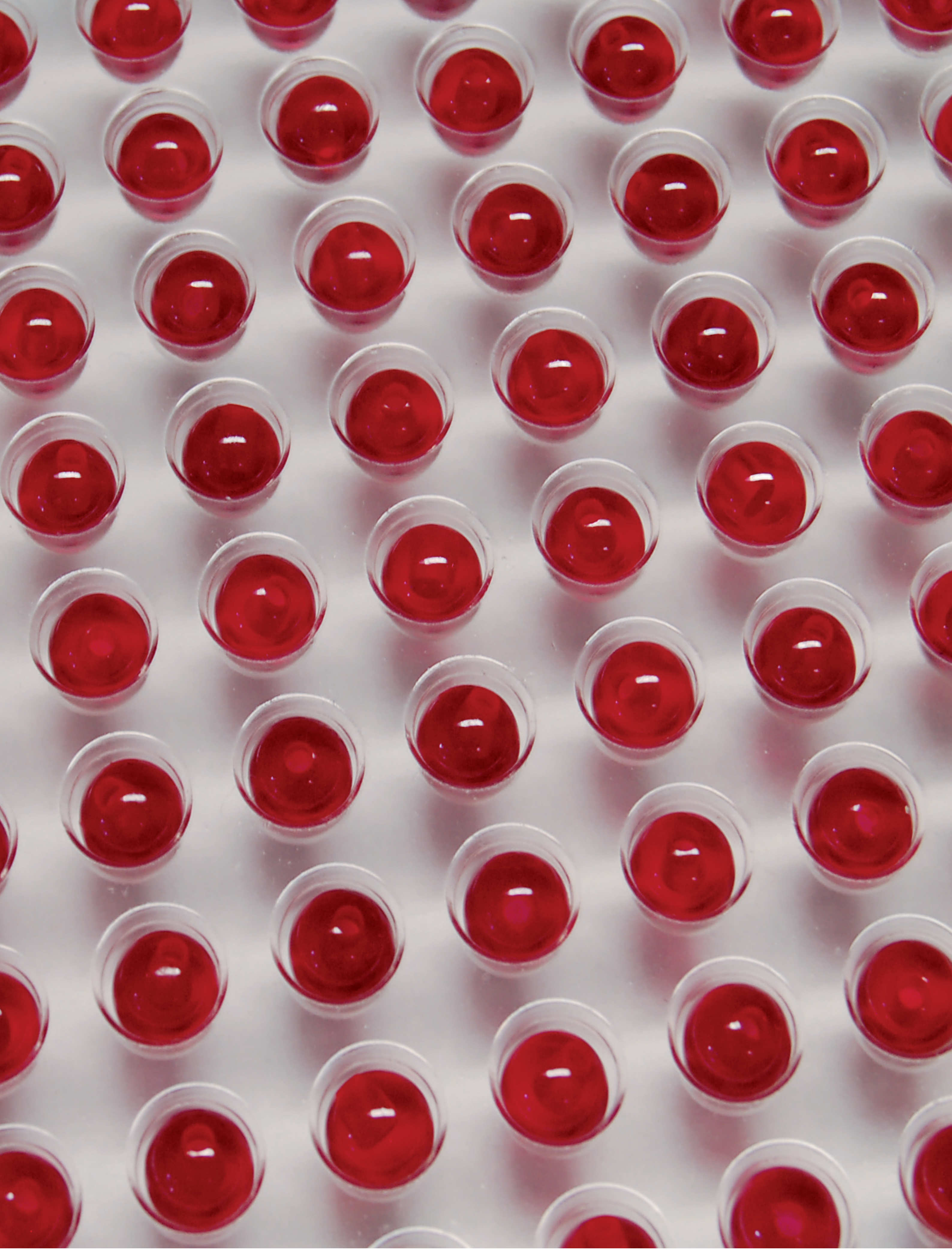
The scratches on the surface of this ruby ball are clearly visible.

Adhesive wear

Scanning aluminium parts

When a ruby ball is used to scan an aluminium surface, the two materials attract one another. The material is usually passed from the softer surface to the harder surface. This means that aluminium is deposited on the surface of the ball and the coating of aluminium can be seen clearly after only 100 m of continuous measurement using a single contact patch on the stylus ball. We recommend ball styli made from silicon nitride for this type of application.

A coating of aluminium is clearly visible on this ruby ball.

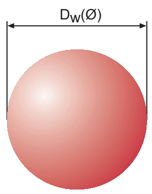


Ball precision (grade)

Ball grade is a rating that describes the precision class of the ball used. Precision classes range from grade 48 (the lowest precision class) to grade 3 (the highest). Renishaw use grade 3 and grade 5 balls.

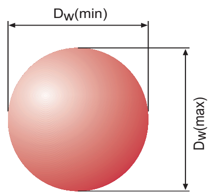
Table of precision classes

Grade	ø deviation	Roundness
20	± 0.50 µm	0.50 µm
16	± 0.40 µm	0.40 µm
10	± 0.25 µm	0.25 µm
5	± 0.13 µm	0.13 µm
3	± 0.08 µm	0.08 µm



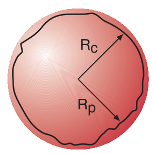
Nominal ball diameter D_W

The diameter value used to identify the ball size.



Ø Deviation

The difference between the largest and smallest diameters of one ball.

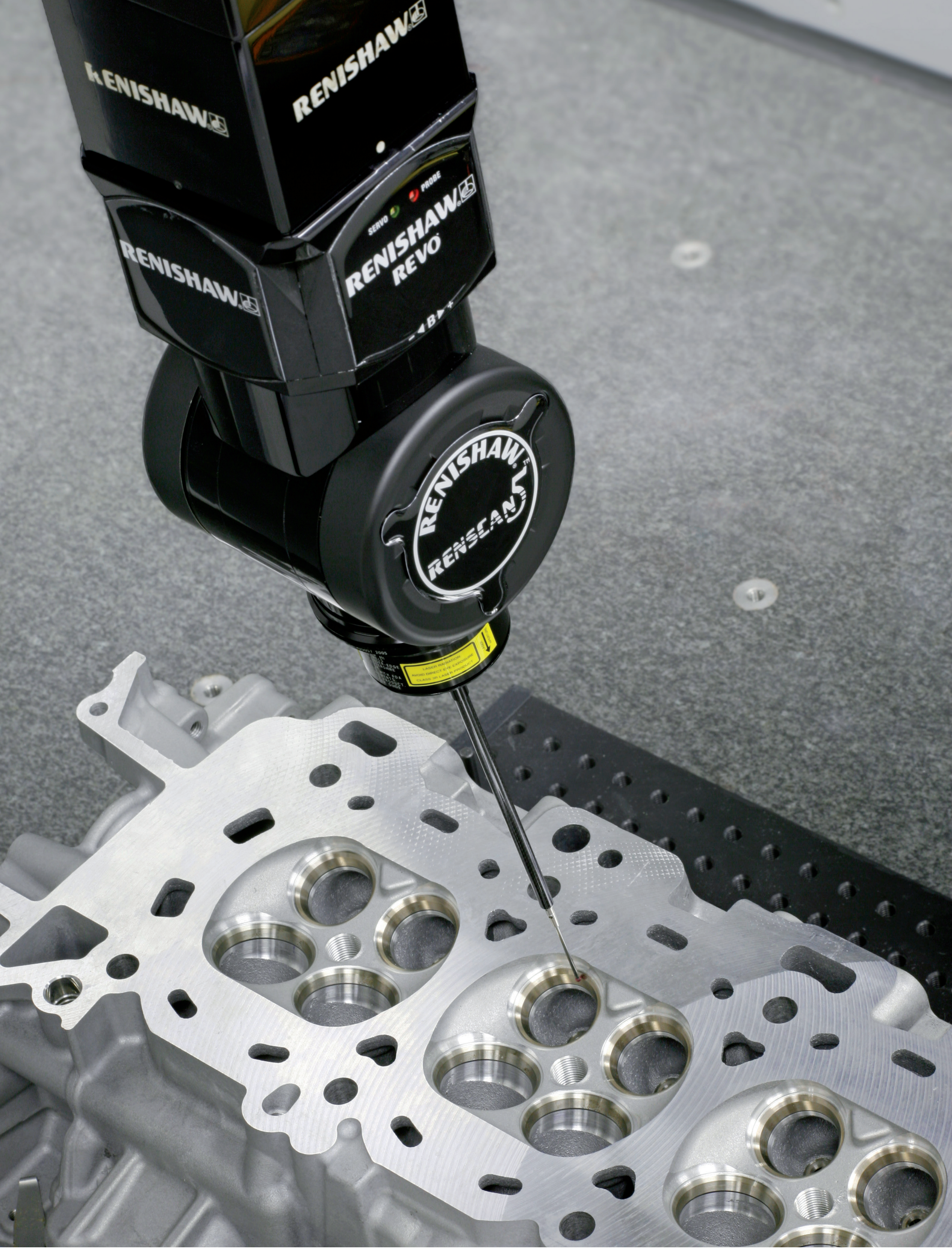


Deviation Roundness

The greatest radial distance in any radial plane between a sphere circumscribed around the ball surface and any point on the ball surface.

The roundness deviation (the ball's form defect) directly impacts on measurements.

Diameter tolerances are almost insignificant for 3D metrology because the effective ball stylus centre and diameter are established during the calibration process.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SERVO
PROBE
RENISHAW
REVO
RENISHAW
RENISHAW
RENSCAN

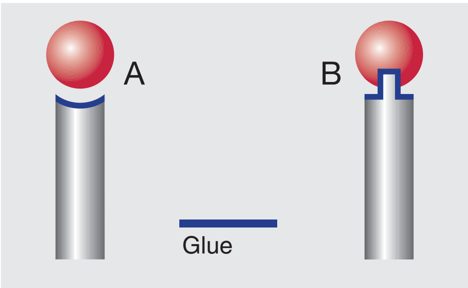
Cup or spigot ball assembly

There are two options for connecting the stem to the ball – a cup connection or a spigot connection.

The majority of Renishaw styli are manufactured using the spigot mounted design. This means that we drill holes in the balls down to 0.5 mm diameter, grind spigots on the shafts and bond the balls to the spigot.

The advantage is clear – the bond is technically superior in engineering terms and, particularly with slim stems, there is a greater gluing area. Particularly with slim stems, because of the limited gluing area, conventional bonding methods can result in the ball quickly separating from the stem when even a minimum amount of force is exerted.

Our Grade 3 (0.08 µm spherical form deviation) ball styli are constructed using an undrilled ball bonded into a spherical cup. Investigations into the effect of the design and construction of styli using such a highly specified ball have indicated that the form of the ball can be degraded by both machining a hole in it and through distortion from gluing it onto a spigot. Measurements taken before and after assembly have shown that the form of the ball remains well within specification throughout the process. Due to limits of measurement capability and bond strength, Grade 3 ball styli are available with a minimum diameter of 1 mm.



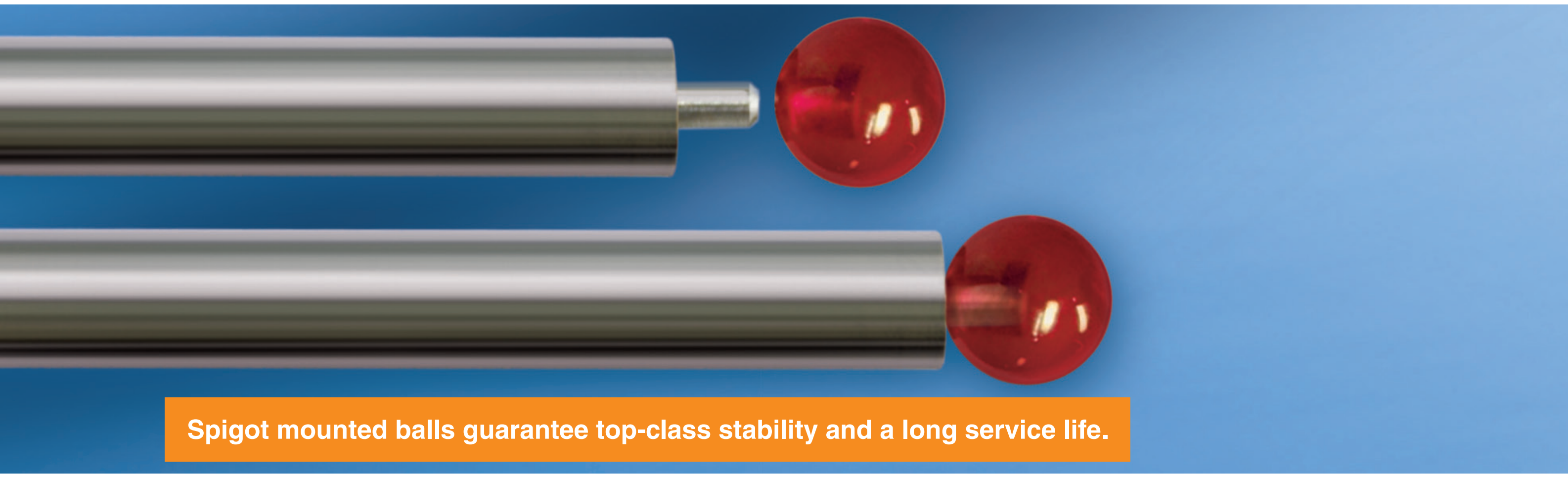
A: Cup connection, less gluing area

B: Spigot connection, greater gluing area and safety due to spigot.

It is important that a manufacturer ensures that spigot lengths and bore depths match. If the hole is too deep, air gets captured and the balls come loose very quickly when measuring in Z directions.

If the spigot is too long, the bottom of the bore becomes conical or round, causing air pockets to occur and cause a lack of stability.

Spigot mounted styli.



Spigot mounted balls guarantee top-class stability and a long service life.

Calibrating styli

Before you begin taking measurements, it is crucial that you calibrate the probe precisely for all your measurement procedures. The effective dimensions of the probe components have to be established if accurate results are to be obtained. These values are stored in the CMM's data processor.

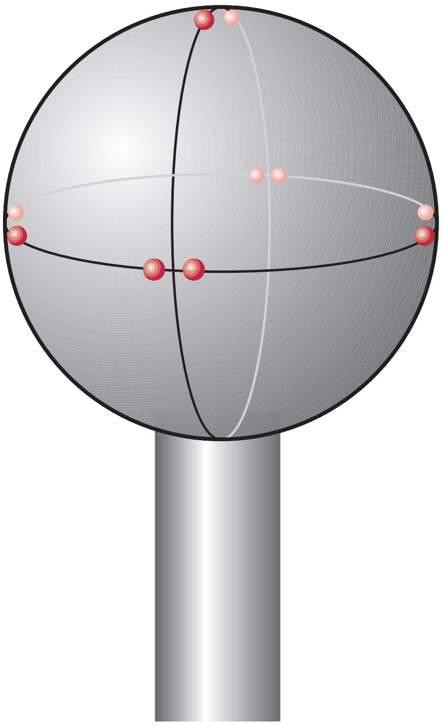
How it works

The position of the individual ball styli and their diameters are established using a special probe calibration programme (see the machine manufacturer's user manual).

You contact a reference point with all the styli to be used, one after the other. The reference used is usually an extremely precise, manufactured ball with a known diameter. The exact dimensions of the ball being calibrated are input to the measuring software.

If the styli are to be used for measuring separate points, the stylus is calibrated using a number of points on the reference ball's cardinal points (see image).

A far greater number of points are taken for scanning systems. The machine manufacturer's user manual will describe the precise probing strategy for calibrating the styli.



Ensure that you use the calibrated ball whose values have been input to the software, particularly if you are using more than one CMM.

Outcome

The probe calibration procedure establishes the stylus tip's effective diameters when measuring, and their positions in relation to one another and to the machine's co-ordinate system.

A special analysis program and the known diameter of the calibrated ball are used to establish the unknown diameters of the stylus tip.

The co-ordinates of the centre of the first stylus ball calibrated are stored in the CMM's data processor as reference co-ordinates. All the remaining tip positions are established by generating differences with the first one, and then also stored as ball centre co-ordinates.

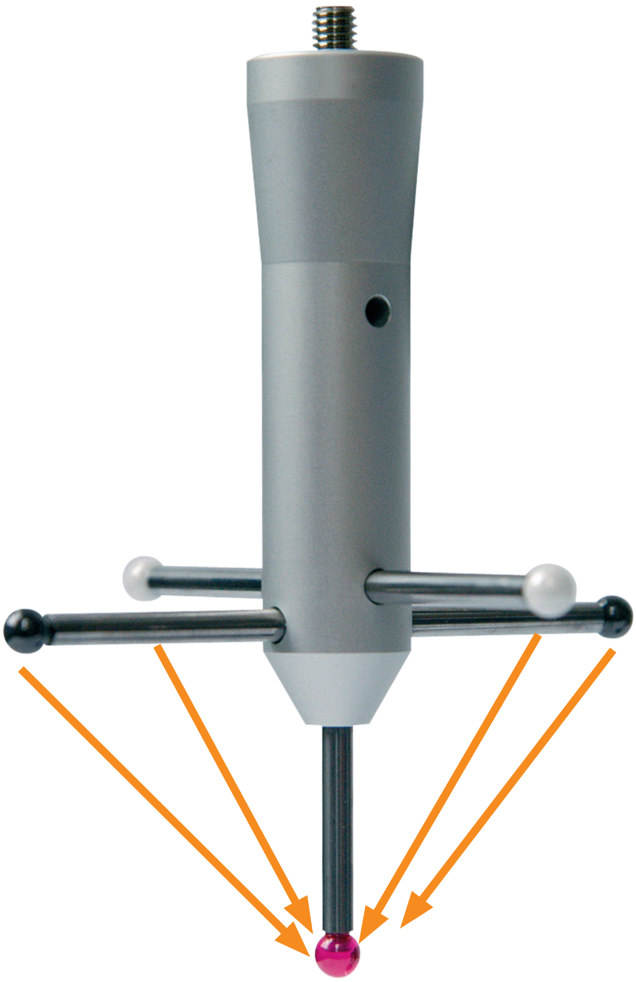
Once the various tips of a stylus configuration have been calibrated, their centre points are compensated for by the CMM software, so that measurements with all the styli appear as though they had been taken with just a single stylus.

This means that whichever stylus you use to probe a point, you always get the same result.

When taking measurements, the CMM compensates for the stylus position and tip dimensions. This leaves just the form of the stylus tip as the only factor influencing the measurements.

Calibrating other shaped components

Apart from reference balls, stylus calibration can also be done using other references such as end gauges, ring gauges and pin gauges. Typical examples are with cylinder and disc styli. The basic principle does not alter. The machine manufacturer's user manuals will describe the routines for these types of calibration.



Summary of key criteria for using probe components

In the CMM sector, all the equipment manufacturers invest heavily in keeping measurement uncertainty to a minimum. This is also often reflected in the high cost of investing in CMMs.

The performance of your gauging can easily be degraded if you use a stylus with poor ball roundness, poor ball location, bad thread fit or a compromised design that allows excessive bending during measurement. To ensure the integrity of the data you gather, make certain that you specify and use a stylus from the comprehensive range of genuine Renishaw styli.

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Checklist

- Always use styli that are as short and stable as possible.
- With long styli components, ensure that they have the required stability.
- Check that the styli you use have no defects, particularly on the thread and the seating area. This will ensure that the mount is very secure.
- Variations? Check that the probe component is firmly attached.
- Replace worn styli.
- Are you using components that are thermally stable? Bear in mind the ambient conditions.
- When putting together stylus configurations, refer to the permitted masses as specified by the sensor manufacturer.
- Avoid too many or superfluous thread connections. Use the lowest possible number of separate components.
- Do you have scanning applications.
- Take advantage of the benefits offered by silicon nitride balls when scanning aluminium.
- Use the largest possible ball.
- Large ball styli act as mechanical filters on the surface of the workpiece. The fine structures on the surface of the workpiece are scarcely recorded with large balls, which prevents random measurement variations (flyers).
- Ensure that the measuring force and dynamics suit the stylus components. With small ball styli with a slim stem, you should reduce these values when necessary.

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