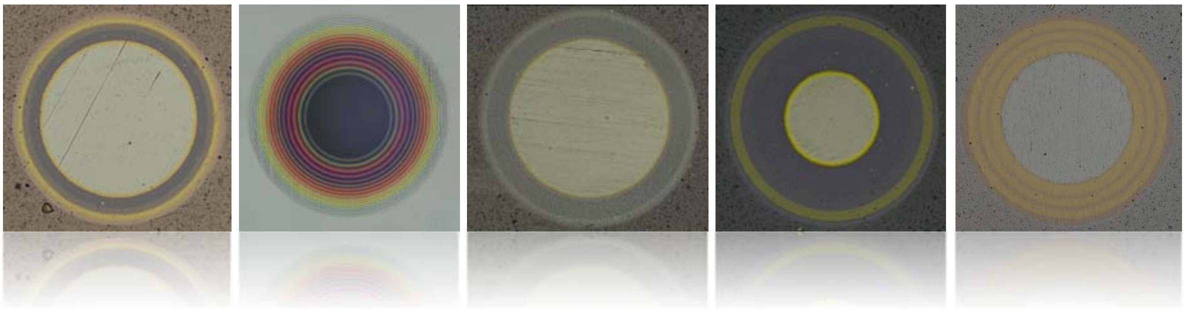

BAQ

Automatisierung und Qualitätssicherung

Coating thickness measurement with the calotte grinding method (Calotest)

Measuring principle:

With the coating thickness measurement instruments of the kaloMAX family, the coating thickness is determined by using the calotte grinding method. A hardened steel ball with an exact defined diameter, which lies loose between the driving shaft and the sample, is set into rotation by a motor-driven shaft (cf. schematic diagram).

Image 1: Measuring principle of the calotte grinding method

Therefore, the steel ball is used to carry an abrasive slurry, such as diamond suspension or diamond paste. Thereby a groove is ground into the sample – the so-called calotte. The grinding time varies depending on the coating type (its thickness and wear resistance) between a few seconds and several minutes. If the coating system of the clamped sample is ground right through (depth of grinding > coating thickness), every single layer can be seen under the microscope as a concentric ring or ellipse (cylindrical sample).

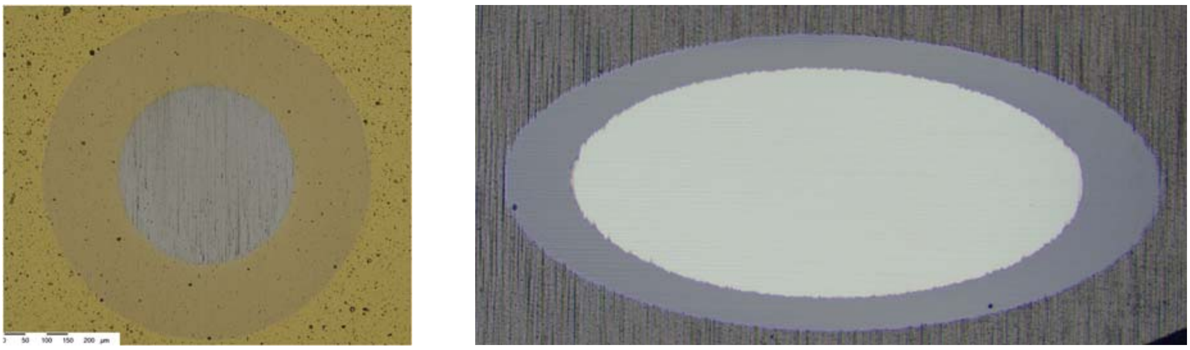

Image 2: Calottes on a flat (left) or cylindrical sample (right)

Using the calotte grinding method, single layers and layer systems can be analyzed. Since, compared to the coating thicknesses, the diameter of the hardened steel ball is very large, the layer system is ground in a very flat angle, which in a way widens the coating (the diameter of the single ring is typically 200 times higher as the coating thickness).

This is, besides the significant time saving, an important advantage of the calotte grinding method compared to the cross-section as the accuracy of the measurements is significantly improved by the coating widening and the analysis can be done under a normal reflecting microscope. Image 3 illustrates the principle of the method through a two-layer system.

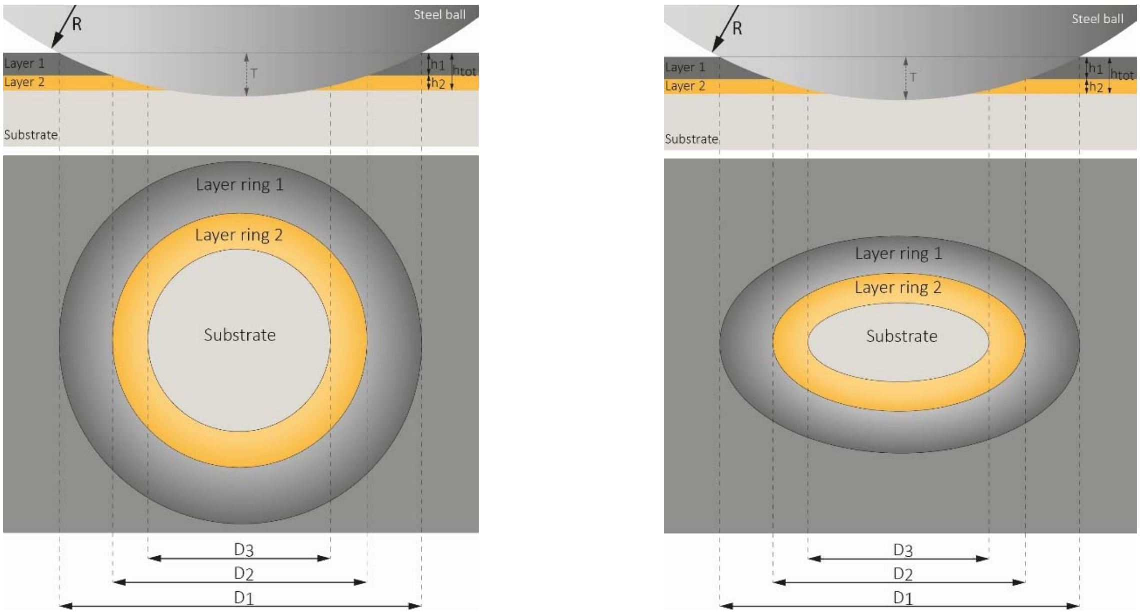

Image 3: Coating thickness measurement on a flat (left) or cylindrical sample (right)

As the diameter of the steel ball is exactly known, all layer thicknesses can be calculated by a simple geometric relation. Therefor only the diameters (flat sample) or the long diagonals (cylindric sample) have to be determined. Afterwards all existing layer thicknesses can be calculated according to the following formula:

$$h = \frac{(D^2 - d^2)}{8 \cdot R} \quad (1)$$

D: outer diameter (flat) or outer diagonal (cylindric)

d: inner diameter (flat) or inner diagonal (cylindric)

R: ball radius (normally 15 mm)

h: layer thickness

T: depth of grinding

Considering the measurement accuracy of the calotte grinding method

Basically, to achieve the best accuracy, an optimal rotation of the ball during the grinding is required. Radial runouts and lateral movements of the ball would change the size of the calotte and would have a false effect on the measuring results. This is why BAQ uses so-called traction rings as contact area for the ball. When completely assembled, the traction rings are ground during rotation at high-speed using a special grinding machine. Compared to a pure steel shaft, this reduces both radial runout and lateral movement of the ball to a minimum, so that this influence on the measurement result is negligible.

Furthermore, the measuring accuracy depends on the accuracy with which the diameters D and d can be determined (see equation 1). As the following image illustrates especially the surface roughness of the sample has an essential impact on the accuracy with which D and d can be determined by the user.

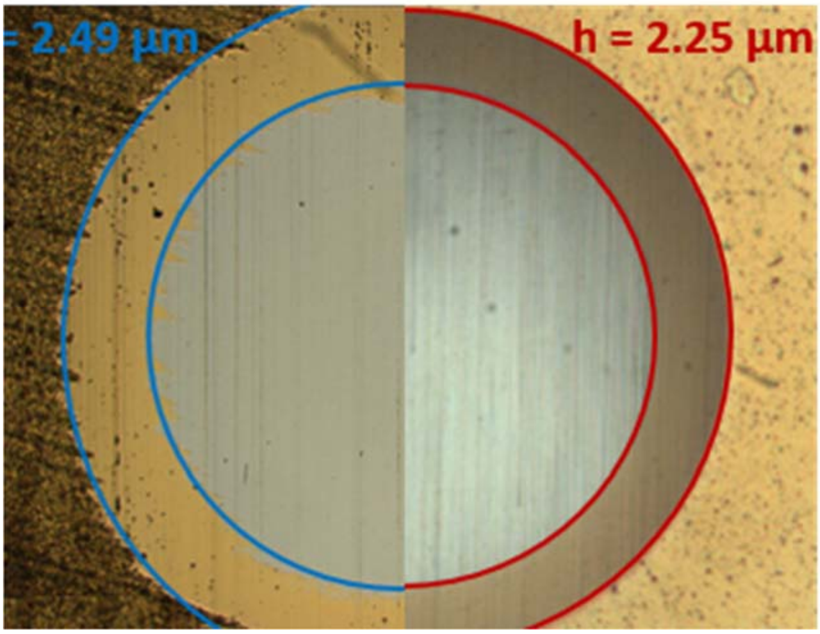

Image 4: Impact of the surface roughness

As with all measurement methods for coating thickness measurement, the following also applies to the calotte grinding method: the lower the surface roughness of the sample, the better the measurement accuracy. But the advantage of the calotte grinding method compared to other methods is, that the user can directly see how the measuring result is obtained and therefore evaluate it very well. According to DIN EN ISO 26423, the surface roughness of the coating and/or substrate should not exceed 20 % of the coating thickness.

With surface roughnesses typical for this application, the accuracy in determining the diameters is approx. ± 10 µm. Besides the accurate measurement of the diameter, the depth of grinding is also very important. This becomes clear illustrated by the following example, for which the below assumptions are made:

Assumption 1: Regardless of the depth of grinding, the diameters D and d can be determined with an accuracy of ± 10 µm.

Assumption 2: The actual coating thickness is 2.25 µm.

Case 1: Grinding depth is too large

The calotte has been ground so deep, that the corresponding diameters are D = 1400 µm and d = 1300 µm. The actual coating thickness is therefore:

$$\frac{1400^2-1300^2}{8\cdot 15000} = 2.25\ \mu m \qquad \text{(cf. assumption 2)}$$

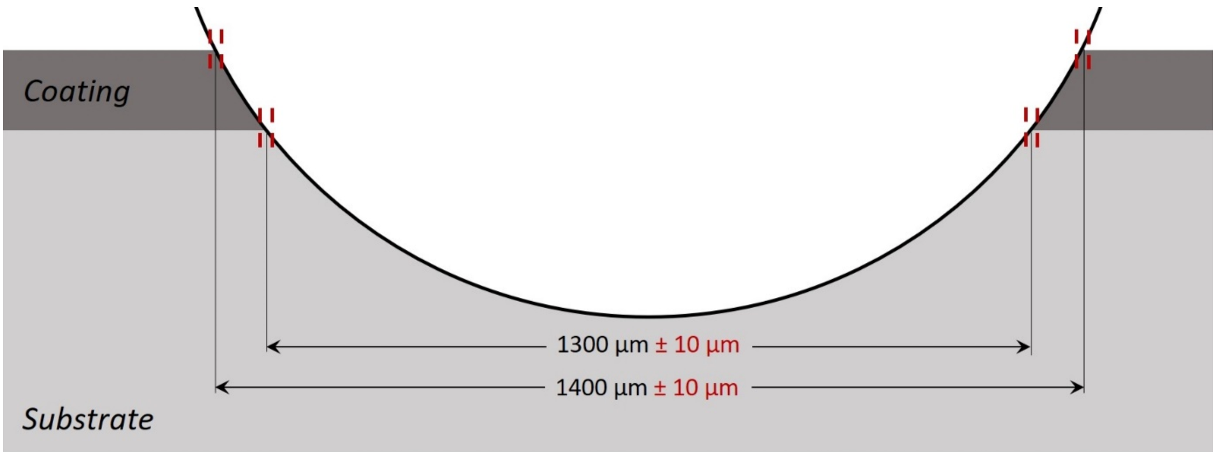

Image 5: grinding depth too large

Since the diameters D or d can, according to assumption 1, be determined with an accuracy of ± 10 µm, the coating thickness measured by the user may be within the following ranges:

Minimum value: $$\frac{(1400-10)^2-(1300+10)^2}{8\cdot 15000} = 1.80\ \mu m$$

Maximum value: $$\frac{(1400+10)^2-(1300-10)^2}{8\cdot 15000} = 2.70\ \mu m$$

In this case the measuring accuracy is ± 0.45 µm.

Case 2: optimized grinding depth

The calotte is ground so deep, that the external diameter D is twice as large as the inner diameter d. With a coating thickness of 2.25 µm is D = 600 µm resp. d = 300 µm:

$$\frac{600^2-300^2}{8 \cdot 15000} = 2.25\ \mu m \qquad \text{(cf. assumption 2)}$$

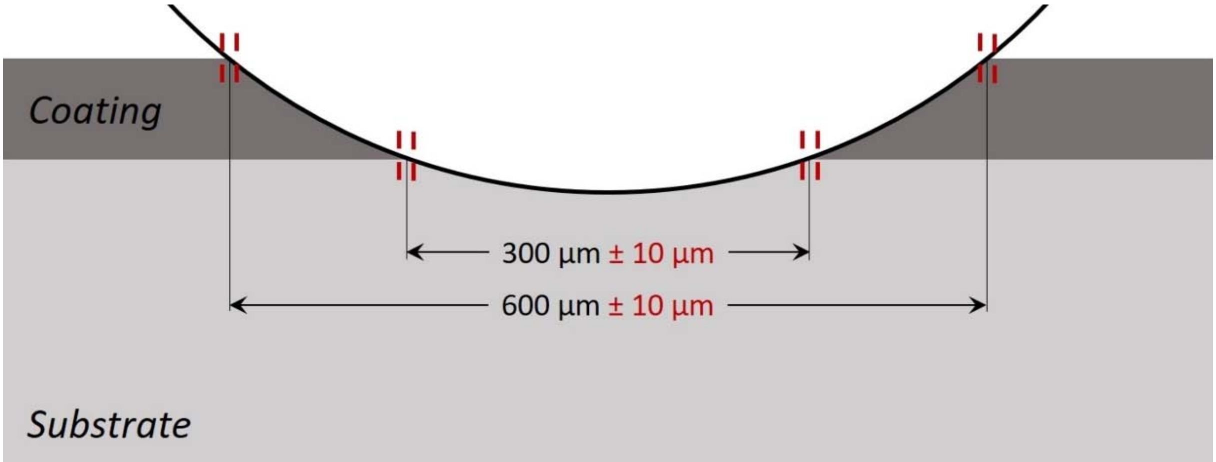

Image 6: optimized grinding depth

As the diameters D or d can be determined according to assumption 1 with an accuracy of ± 10 µm, the coating thickness measured by the user can be theoretically be within the following ranges:

Minimum value: $$\frac{(600-10)^2-(300+10)^2}{8 \cdot 15000} = 2.10\ \mu m$$

Maximum value: $$\frac{(600+10)^2-(300-10)^2}{8 \cdot 15000} = 2.40\ \mu m$$

The measuring accuracy is in that case at ± 0.15 µm. Only by reducing the grinding depth, the measuring accuracy has been improved by the factor 3.

➔ We recommend to select the grinding depth, so that D ≈ 2 · d.

Advantage:

▪ **very simple**	no specialized stuff needed
▪ **quick**	no sample preparation necessary; measuring results are available within a couple of minutes
▪ **multi-purpose**	measurement of single layers and layer systems
▪ **high accuracy**	„layer widening“
▪ **material independent**	in principle suitable for all substrate/coating combinations
▪ **geometry independent**	results independent of sample shapes (flat, cylindrical, spherical and ellipsoidal)
▪ **traceability**	through direct measurements the user can see how the results occurred

Appliction areas:

- PVD coatings
- CVD coatings
- metal coatings
- galvanic coatings
- chemical coatings
- polymer coatings
- paint coatings (hardened)
- decorative coatings
- oxide coatings
- and several more

Standards:

- DIN EN ISO 26423
- DIN EN ISO 1071-2 (withdrawn)
- VDI 3198 (withdrawn)