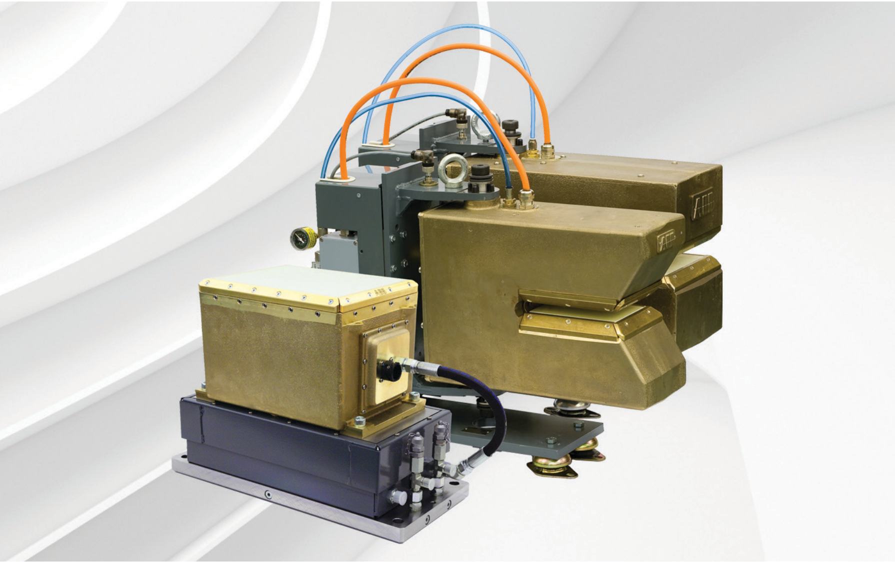
ABB MEASUREMENT & ANALYTICS | WHITE PAPER

Millmate thickness gauging systems
Calibration procedures for strip gauging



Accurate and traceable calibration plates are crucial for achieving the required thickness tolerances in metal strip production

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Measurement made easy

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Millmate thickness gauging systems

Introduction

Many strip producers struggle with the preparation and calibration of the large number of plates needed for radiometric gauges. This white paper discusses calibration plate preparation and provides an effective way to increase confidence in product tolerances.

Accurate calibration references for sensors

Accurate sensors are key components in industrial processes and are crucial for accurate process control. To stay accurate and to be traceable to national standards, sensors depend on accurate calibration references. Ideally, manufacturers would like the sensor to be ten times more accurate than the required product process tolerances. This level is often difficult to achieve; a commonly used minimum requirement is a sensor with three to four times more accuracy than required.

A similar relation of accuracies exists between the sensor and its calibration reference. The reference must be at least three to four times more accurate than the sensor. This means that the calibration reference should be at least ten times more accurate than the product tolerances.

Metal strip tolerances

Thickness tolerances for cold rolled metal strip have gradually tightened over time. Today they have reached challenging levels for strip producers. The total thickness tolerances depend on various factors in the rolling process, such as:

- the thickness profile across the strip that is set in the hot rolling mill. This is normally in the range of 0.5 to 1 % of the actual strip thickness, but could be more
- the static accuracy of the thickness gauge, related to the calibration accuracy
- measuring errors in the gauge related to mill conditions, alloy properties, and long-term drift
- imperfections in the rolling process, the mill equipment and in the Automatic Gauge Control

For tolerance levels of ±3 to 5 µm for can stock and other kinds of aluminium strip, typically the calibration accuracy for the gauge must be on the micrometer level. Consequently, the accuracy of the calibration plates must be in the range of 0.3 to 0.5 µm. Also, the influence on the gauge from the alloy properties and mill conditions must be minimized.

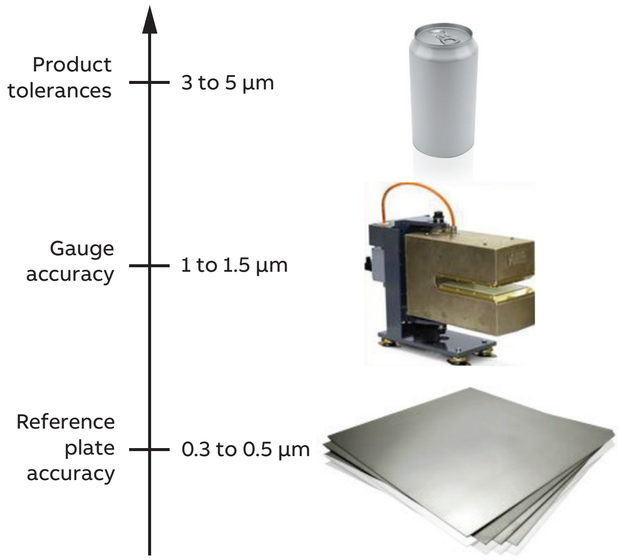

Figure 1 Accuracy levels in strip production

Creating accurate reference plates

Gauge blocks are the standard thickness and dimension references. They are widely used for calibration of mechanical measuring devices and for comparative measurements in mechanical measuring machines. In many respects they are close to perfect references. They consist of hard steel or a ceramic material. The surfaces are very smooth with a high degree of parallelism. The calibrated thickness is often accurate within ±0.05 µm or better. However, the area of a gauge block is relatively small, typically 30 x 9 mm. This is sufficient for a contact gauge, but not for a radiometric gauge or a gauge based on Pulsed Eddy Current technology (PEC).

Calibration plates used for calibration and verification of radiometric gauges or PEC gauges are cut out of rolled strip, often taken directly from the rolling mill. Considering the accuracy requirements for these plates, the strip material is far from perfect. The surface of rolled strip has a fairly large microscopic surface roughness. Typical Ra values for cold rolled aluminium strip are in the range of 0.2 to 0.5 µm, which corresponds to a peak-to-peak variation of 1 to 2 µm for each side of the plate.

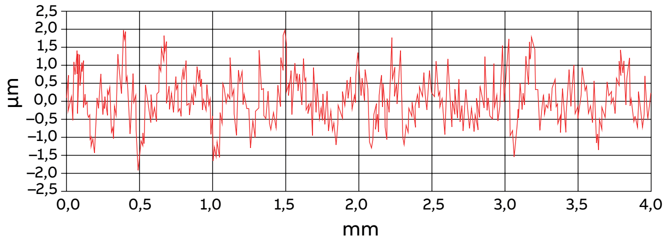

Figure 2 Measured surface roughness for a 0.7 mm aluminium plate

The plate calibration is normally based on mechanical measurements of the thickness between the peak levels of the plate surfaces. The radiometric gauges and also the PEC gauges will instead measure an average plate thickness that may be 1 to 2 µm lower than the mechanical measurement.

The influence from surface roughness can be reduced by grinding and polishing. Copper and steel alloys easily achieve Ra values of 0.05 µm or lower after polishing. Aluminium, however, is more difficult to grind and polish, requiring considerable effort to reach Ra values below 0.1 µm. Influence from surface roughness will remain an important uncertainty in plate calibration, even after polishing.

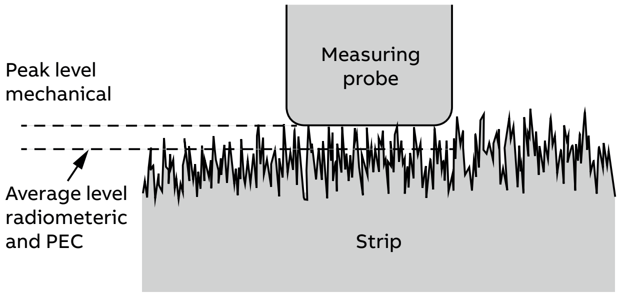

Figure 3 Difference between peak level and average level thickness

…Creating accurate reference plates

Rolled strip also has a macro structure, related to thickness variations both in the rolling direction and across the strip. The variation is typically 0.3 to 1 % peak-to-peak, measured over an area of 100 x 100 mm. This variation is in practice difficult to remove by polishing. The thickness variation can be reduced by preparing several similar plates and selecting the best one. Still, the thickness calibration of the plate must be made in a number of points and in such a way that it corresponds to the average thickness for the measuring area of the gauge.

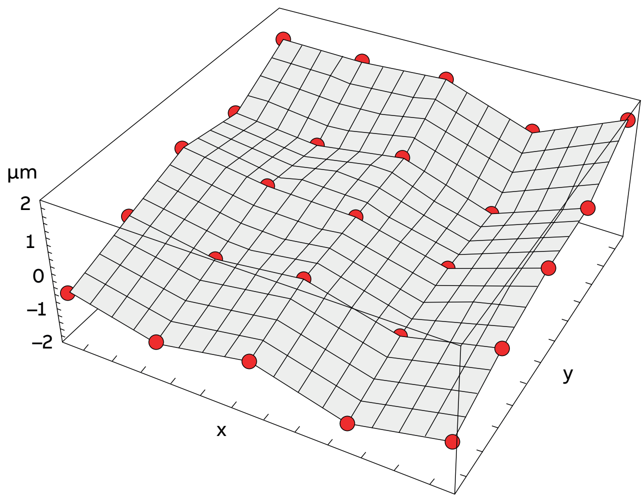

Figure 4 Macro structure for a 0.7 mm plate (over 100 x 100 mm)

The type and size of the probe in the measuring machine are critical factors. Narrow tips will be less sensitive to a non-perpendicular measuring angle. On the other hand they may be more susceptible to an error from probe depression in the material. A large flat measuring probe will not have any influence from depression, but will be extremely sensitive to the measuring angle. In fact, flat probes with moderate measuring areas (d = 2 to 3 mm) are also very sensitive. The best compromise is a probe with a spherical contact surface of large equivalent diameter, such as 50 to 80 mm. This probe will have a small depression that is easily compensated. A perpendicular measuring direction will still be a necessary part of the measuring procedure, but small angle deviations will not significantly influence the accuracy.

Figure 5 Spherical measuring probe

ABB´s reference plate calibration

The Millmate Thickness Gauges (MTG) from ABB are based on PEC technology and measure the thickness of a metal strip with very high accuracy. The thickness measurement is contact-free, using magnetic fields. This technique yields a robust measurement that is virtually insensitive to dirt and other environmental factors. Also the measurement does not depend on material properties, eliminating the need for customer-specific calibration plates. An MTG set of 12 site calibration plates constitutes a system delivery. These are the only plates needed to maintain the traceability and high accuracy of the gauge measuring electronics by calibration and adjustment at site.

The calibration process for the MTG Site calibration plates involves two steps. First is the calibration of reference plates kept at ABB. Second is the calibration of the site calibration plates included in the MTG system delivery.

The primary references used at ABB for the reference plates are gauge blocks calibrated with traceability to national standard labs like NIST, PTG or NMIJ. This calibration takes place in an accurate mechanical measuring machine. The measuring machine, based on a Mitutoyo Laser Hologage, has been developed and designed by ABB to achieve the best possible accuracy.

In the second step, the site calibration plates are calibrated by direct comparison with the reference plates. This comparison is done in a standard MTG gauge.

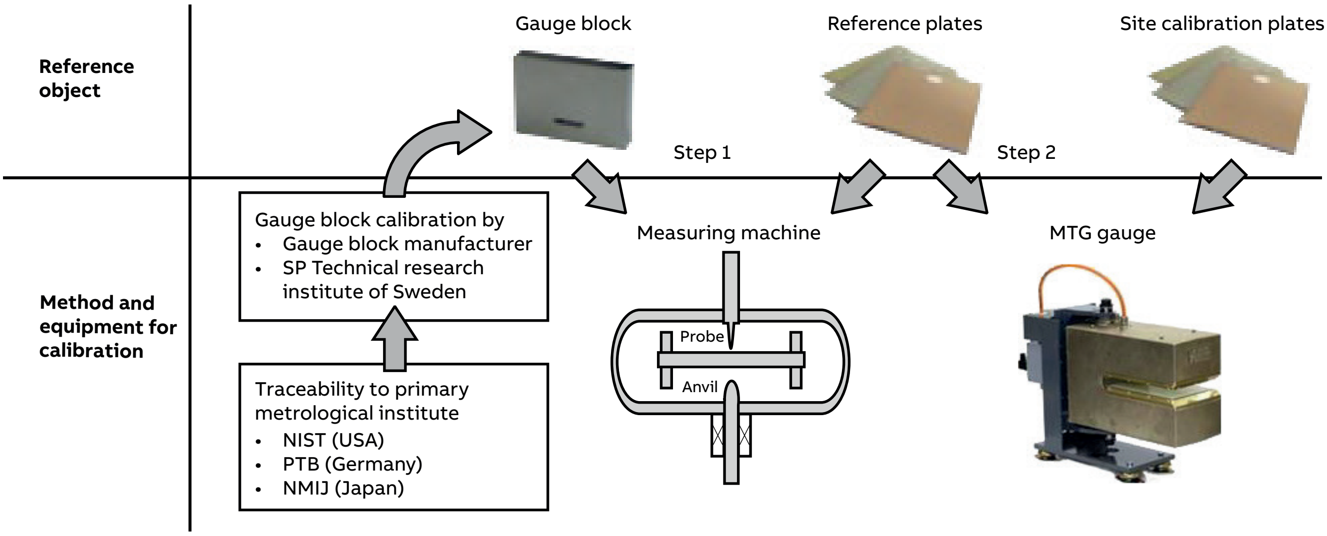

Figure 6 **MTG Site plate calibration process**

The mechanical measuring machine

The ABB reference measurement is performed between the probe of the Laser Hologage and the lower anvil. The Laser Hologage mounts on a frame joined to the lower anvil. To achieve high temperature stability, the frame and the anvil are manufactured from Invar alloy having a very small coefficient of thermal expansion (near 1 ppm/K). The whole set sits on an air bushing and can move vertically without friction.

The plate to be measured is moved horizontally along the two horizontal axes by computer controlled stepper motors until the measurement point is above the anvil. To perform the measurement, the frame is raised slowly, and the lower anvil is brought into contact with the plate by means of a friction-free pneumatic actuator. Then the probe of the Hologage is carefully lowered. The plate is then tilted around the two horizontal axes by computer controlled stepper motors until the minimum thickness is detected.

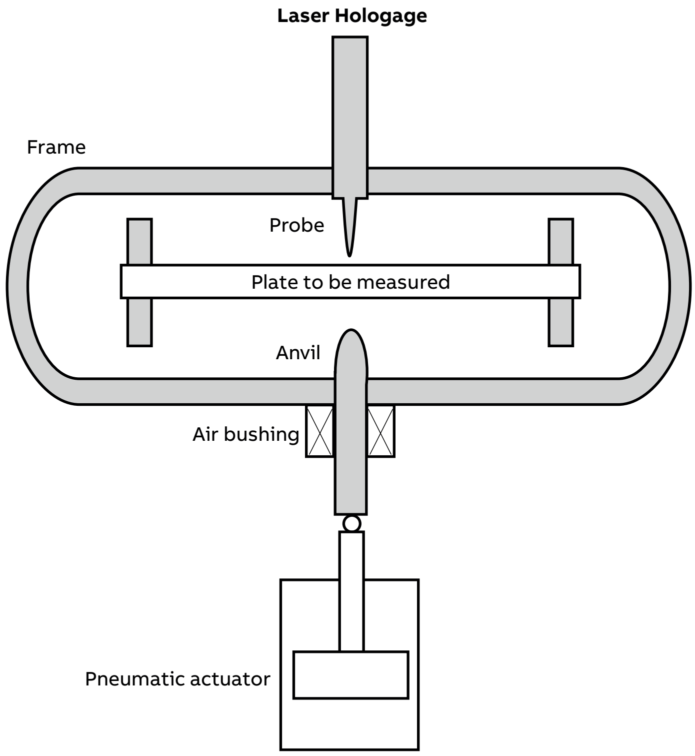

Figure 7 Mechanical measuring machine designed by ABB

Minimizing uncertainties

To achieve a total calibration uncertainty of a few tenths of a micrometer, the sources of uncertainty must be on the level of 0.01 µm. The following sources have been addressed in the MTG Site plate calibration at ABB:

- The primary references are gauge blocks with a traceable accuracy of 0.03 µm.
- The two-dimensional plate tilting procedure ensures that the minimum thickness is measured in each measuring point independent of non-flatness and other imperfections of the plate.
- The Invar frame has very high temperature stability and by design the mechanical loads on the system are identical for measurements on a gauge block and a plate.
- The measurement takes advantage of the premium version of the Mitutoyo Laser Hologage since it is the best position sensor on the market, having a maximum non-linearity of 0.03 µm per mm.
- Measuring forces are selected so as not to create any plastic deformation. However, they will create small elastic depressions that need to be accounted for. The depressions in the gauge block and in the plate will differ, since the modulus of elasticity of the plate differs from that of the gauge block. The system accurately compensates for probe depression based on material property information and active contact force measurement.
- Compensation for temperature expansion of the gauge block and the plate is done to get a calibrated thickness that corresponds to 20 °C.
- The reference plates are ground and polished to create a smooth surface. The remaining surface roughness is measured and the mechanical measurement is compensated to achieve a thickness value that corresponds to the average plate thickness. Theoretical analysis and comparison with density measurements indicate that 3.5 x Ra is a suitable average compensation for the surface roughness.
- The MTG site calibration plates are calibrated in an MTG gauge by direct comparison with the ABB Reference plates of similar thickness and material properties. The measuring procedure is insensitive to differences in surface roughness and macro structure of the plates. The comparison accuracy of the measurement depends mainly on the repeatability in the measurement.

Conclusion

Thanks to careful consideration of all potential sources of uncertainty, a calibration accuracy of 0.3 to 0.5 µm has been reached for the MTG Site calibration plates. Since these 12 plates will secure an accurate calibration for the full measuring range of the MTG gauge, no other plates are needed. Thus, the MTG user will not have any concerns about time-consuming preparation of customer-specific plates or for frequent calibration procedures.

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