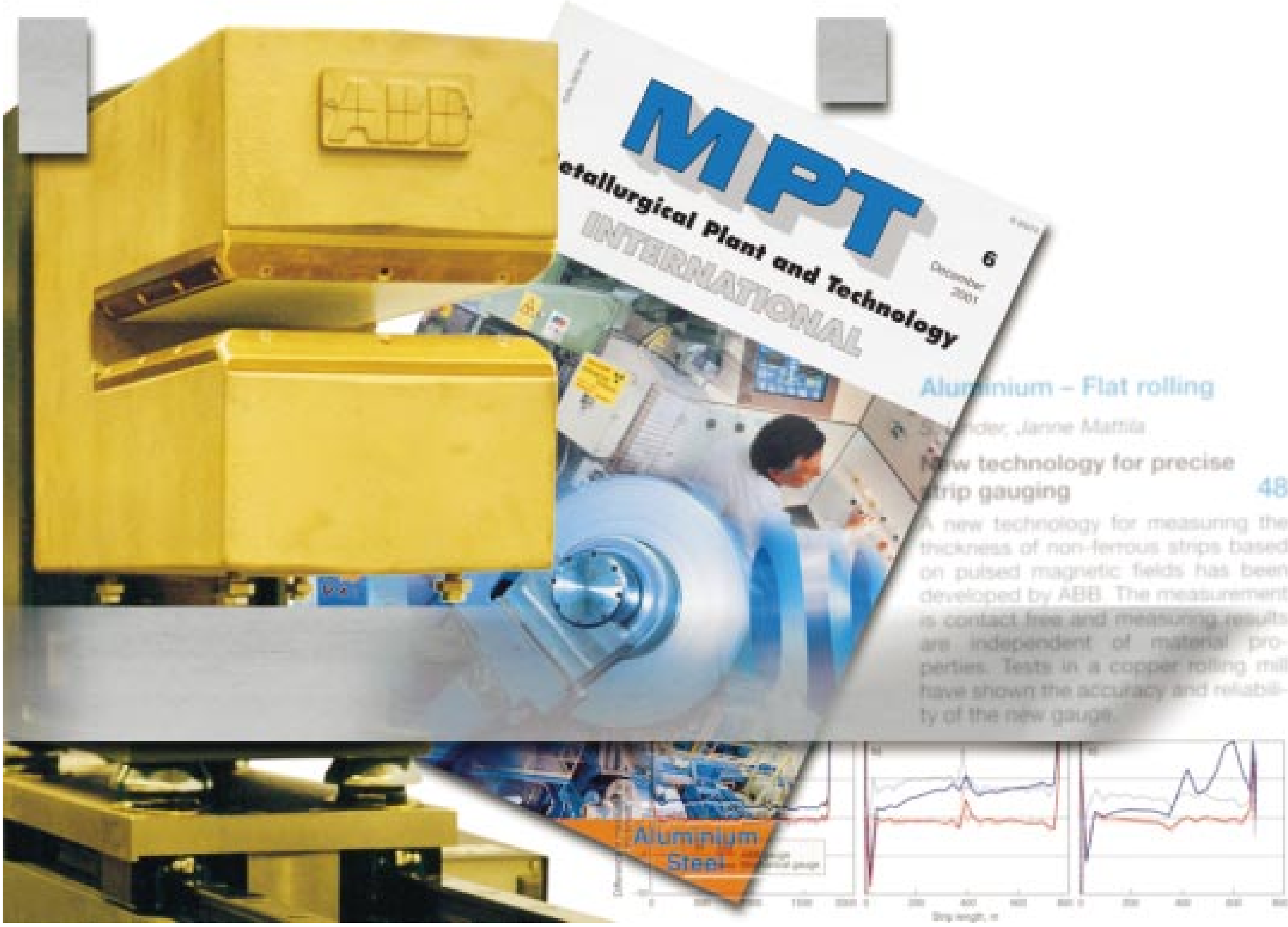

New technology for precise strip gauging

by Sten Linder & Janne Mattila

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ABB

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A new technology for measuring the thickness of non-ferrous metals strips has been developed by ABB. It is based on pulsed magnetic fields,and therefore features a unique combination, i.e. the measurement is contact free and measuring results are independent of material properties. Tests in a copper rolling mill have shown the accuracy and reliability of the new gauge. Rapid changes in thickness can be registered with great accuracy. Precision over the strip length was better than ±1 µm. Accuracy over long periods has been reduced to ±1 µm.

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The new gauge

Existing technologies for precise strip thickness measurement are either contact-based technologies (mechanical gauges) or, if non-contact, dependent upon material properties (x-ray and isotope technologies).

A new technology developed by ABB is based on the interaction between pulsed magnetic fields and the metal strip. The measurement is completely insensitive to anything else but the strip. This means that the measured thickness values are not influenced by the strip material or by oil, dirt, water etc. Thus the new system will become a valuable new tool for accurate and reliable strip gauging in the non-ferrous metals industry.

The new *pulsed eddy current technology* has some similarity with earlier eddy current technologies, but those are based on AC voltage to generate the magnetic fields and measurements are influenced by the strip material.

Although pulsed eddy current is now for the first time used for strip thickness gauging, it has already been used earlier in other fields of the metals industry. The very first application, introduced about 10 years ago, was to measure the position and width of the strip in a cold rolling mill with the “Millmate Strip Scanner” [1]. Two years ago ABB introduced a further instrument to measure width, height and position of the red hot bar in profile rolling mills: the U-gauge in the ABB “Interstand Dimension Control” (IDC) concept [2] [3]. Although these applications were not so demanding as strip thickness gauging in terms of measuring accuracy, they have shown high reliability and durability, thus encouraging ABB to try the technology on strip gauging.

The new gauge based on the pulsed eddy current technology, called “*Millmate Thickness Gauge*”, is shown in figure 1. It can be used for any non-ferrous metal, i.e. copper, brass, aluminium etc. It is material independent to such an extent that all these metals can be measured without any setting of the instrument. Furthermore, no change in alloy or composition affects its accuracy.

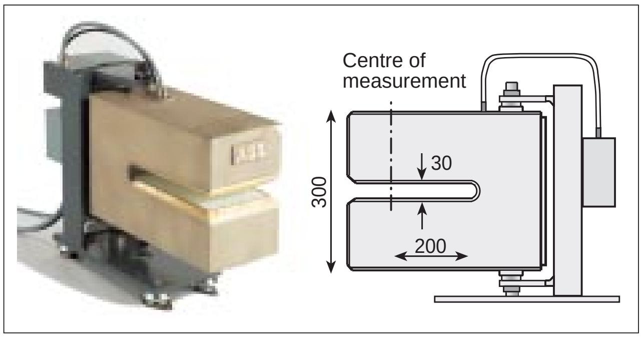

Figure 1. Millmate thickness gauge for non-ferrous strip 0.1–10.0 mm thick

The magnetic field used for the measurement penetrates any material except metal, without any influence of other parameters. Thus the measurement is completely insensitive to oil, dirt, water etc.

The gauge is designed for *heavy-duty operation* with a sturdy bronze housing and with exchangeable protection plates around the measuring gap. The gauge used for the test had functions to measure thickness, electrical conductivity, position of the strip in the gap, strip slope in the rolling direction and strip slope across the strip.

Field test conditions

The new ABB gauge has been tested in a *reversing cold rolling mill*. In this mill both copper strips (0.2–2.0 mm) and different Cu-Zn-Ni alloys (1.7–3.0 mm, coin material) were processed.

In the test the new gauge was installed adjacent to a *mechanical gauge*, which was intended to be used as a reference for judging its accuracy, figure 2. The two gauges were mounted on the same structure to enable them to move simultaneously back and forth. Thus both gauges were measuring continuously from the second pass of the mill to the last one, without any zero setting, etc.

On the reversing mill the strip *passes the gauges twice*, i.e. running out of the mill to the coiler and then back from the coiler into the mill; during this procedure the thickness remains the same, figure 3.

Except for the small deformation due to bending over the deflector roll and coiler, no change in thickness should occur. The comparison of the two measurements can be used as a *criterion for the stability of the thickness measurement*.

Using the mechanical gauge as reference it is important to point out the *difference* in what the two technologies are actually measuring (see figure 3). The mechanical gauge measures at a point 60 mm from the edge. The Millmate gauge measures the mean value over a surface with its centre 120 mm from the edge. Only when there is no thickness change across the strip will the two technologies measure the same thickness. Normally there are no large differences between the two positions but still a few micrometers must be expected.

The test was carried out during *two periods* of about 1 month each. During the first period the measured thickness from the new Millmate gauge was only compared with the reference value recorded by the mechanical gauge. During the second period an *automatic test plate* was also included in the test.

For discussing the test results, the analysis is divided into three parts:

Rapid thickness changes (short-time precision). For a strip thickness gauge it is very important that it measures rapid thickness changes both with high precision and without time delay. This is the basis for a gauge to be useful in a closed loop thickness control. A rapid and precise gauge provides possibilities for optimum control and thus for closer thickness tolerances.

Thickness changes over the strip length (medium-time precision). Stability over the strip length is a very important factor when considering a thickness measurement technology. No drift or sudden erroneous 'jumps' are allowed if highest tolerance is needed.

Long-time accuracy. This test looks at the long-time accuracy over a month and then compares the thickness of all processed material.

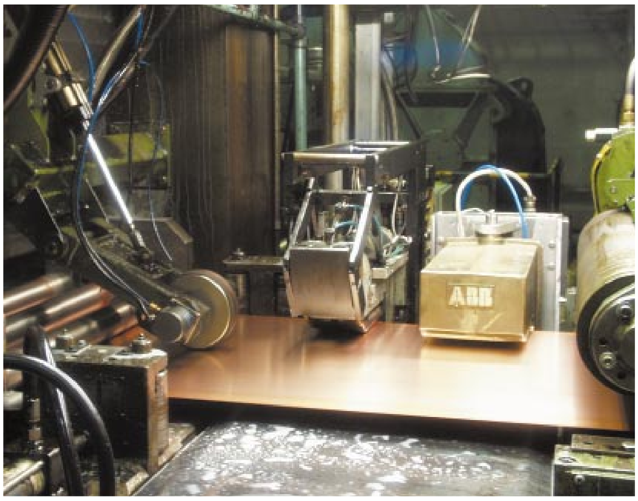

Figure 2. Test set-up with the new gauge parallel to a mechanical gauge

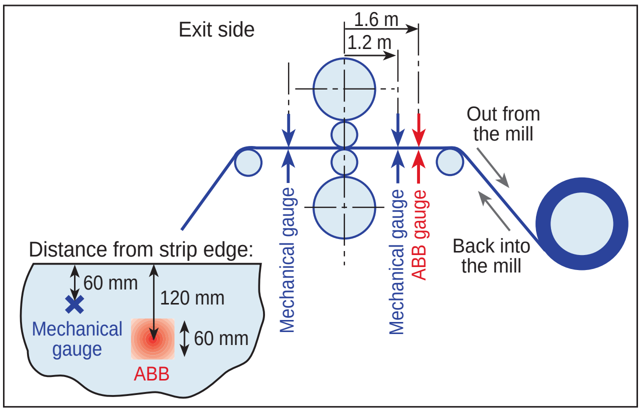

Figure 3. Test set-up at the reversing mill

Precision measuring of rapid thickness changes

The short-time performance of the new technology has been studied by comparing the signals from the Millmate gauge and those from the mechanical gauge. In principle the two technologies should show exactly the same thickness at any given moment. However, as mentioned before,

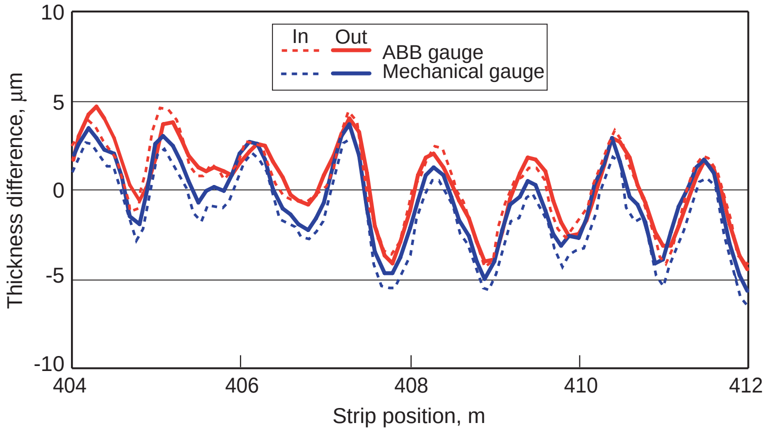

Figure 4. Example of rapid registration of signals (Cu, thickness 1.6 mm; rolling speed 150 m/min)

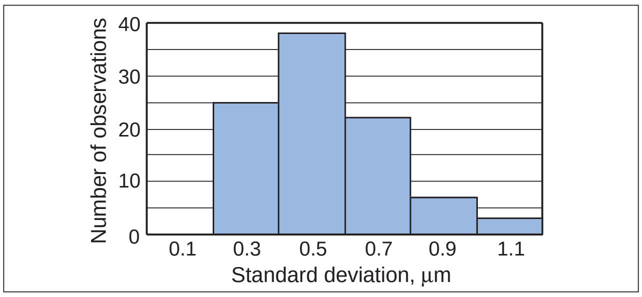

Figure 5. Differences between the thickness measurements of the Millmate gauge and the mechanical gauge (Cu, thickness 0.3–1.5 mm)

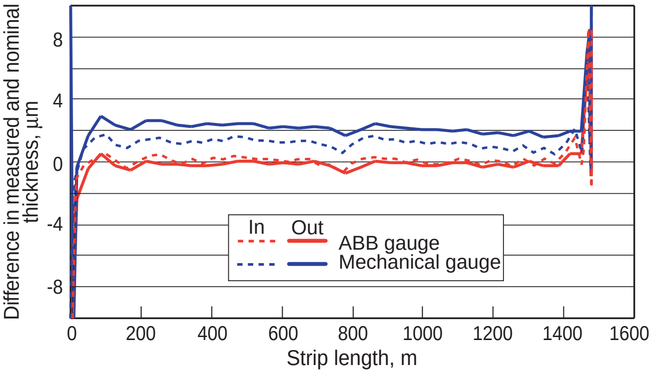

Figure 6. Thickness recording along the strip (Cu, thickness 0.70 mm; mean value registrations)

the two systems measured at different positions in relation to the edge and over different areas.

Figure 4 shows an example of the very good *correspondence* of the thicknesses measured with the Millmate gauge and with the mechanical gauge. All four curves indicate the same thickness trend. The ABB gauge shows more or less the same strip thickness changes for the strip running out of and into the mill. The mechanical gauge shows the same changes, but with a small static difference between running out and in. There are some small differences in the signals from the Millmate gauge and the reference gauge, but they do not exceed the values explainable from the difference in measurement position. In general, the example shown is a very typical curve for *rapid thickness recording*.

Figure 5 shows the *standard deviation of these differences between the two technologies*. They can, most likely, be explained by the differences in measurement position in relation to the strip edge and by errors in synchronizing the signals from the two technologies.

Another important observation regarding precision over short periods is that thickness control was equally good with both technologies used as the master system.

As a result it can be noted that the new Millmate gauge measures rapid thickness changes correctly, at a level better than 1 µm. There are no indications that at this time scale the gauges do not provide perfect measurements of thicknesses.

Measurement stability over the strip length

A typical example of *measurements over a strip length* is shown in figure 6. In this case the mill was run with the Millmate gauge as master for the control and the thick red line shows mean values (over 5 s) provided by the ABB gauge for outgoing strip. The thick blue line shows the values for the same measurement by the mechanical reference gauge. Except for a constant off-set of 2 µm, the two systems show the same curve, i.e. no change in thickness along the strip. The Millmate gauge showed the same thickness for the strip running back into the mill, but the mechanical reference gauge recorded a somewhat thinner strip.

Figure 6 shows typical curves for copper rolling. The new ABB gauge always showed the same thickness for the outgoing and incoming strip.

Also for *the mechanical gauge* the curve shown in figure 6 is typical. However, quite often the differences between the two strip directions are larger. Three types of behaviour were observed, as illustrated in figure 7:

- a sudden signal change when the direction changed or a weld passed, figure 7a.
- slow changes during rolling of the first pass when the gauges are turned on, figure 7b, and
- sudden changes in the middle of the strip, figure 7c.

It seems likely that the thickness measurements by the Millmate gauge, which are identical for the two strip directions, are more reliable than those by the mechanical gauge, which provides different values for the two directions. Own calculations have shown that thickness changes can only occur with really thick material > 3 mm. But the strip can only become thinner, not thicker!

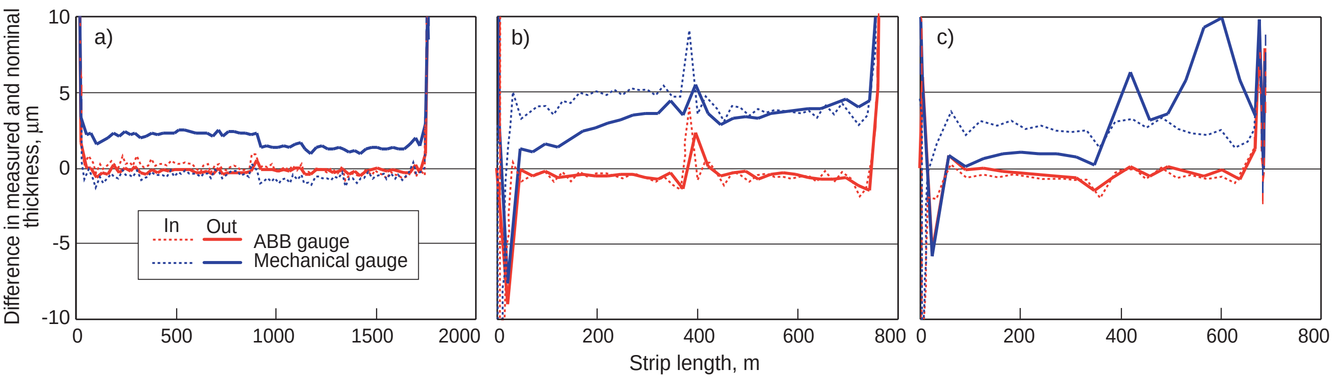

Figure 7. Thickness recordings with irregular measurements of the mechanical gauge (Cu, mean value registrations)
a.) Sudden signal change at a weld (thickness 0.63 mm)
b.) Slow change during rolling of the first pass (thickness 1.45 mm)
c.) Sudden change in the middle of the strip (thickness 1.50 mm)

In order to illustrate the *stability over a longer period* all measurement differences over the test period of 24 days are summarised in figure 8. Here the largest difference between outgoing and incoming strip thicknesses have been plotted. With the Millmate gauge most recordings are within ± 1 µm, with the mechanical gauge within ± 2.5 µm. However, there are some recordings by the mechanical gauge where the difference is indeed large.

From this we draw the conclusion that the mechanical gauge is not reliable enough to be used as a reference when judging the medium-time stability of the Millmate gauge. The best technique is to use the assumption that the thickness of the outgoing strip is the same as that of the incoming strip. Based on this assumption the medium-time precision of the new ABB gauge over the length of a strip is around ± 1 µm. The new technology is very reliable in this respect.

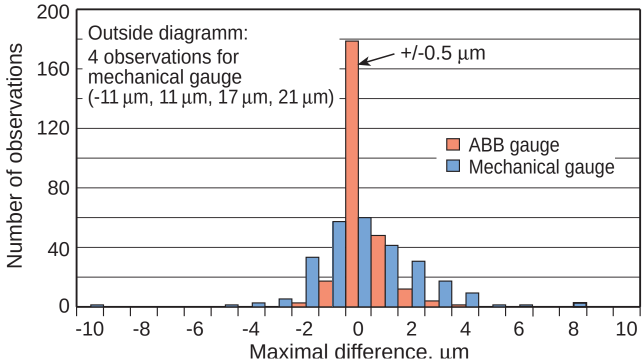

Figure 8. Maximum differences in registrations of strip running out of and running into the mill (material: Cu)

Long-time accuracy

In order to check if the new technology features sufficient long-time stability, two separate tests, over one month each, were carried out. The thickness measured with the new Millmate gauge was compared with that measured by the mechanical gauge. However, due to the problems observed earlier with the mechanical gauge, a continuous measurement on a test plate was included in the second test, this being an objective way to judge the stability of the instrument.

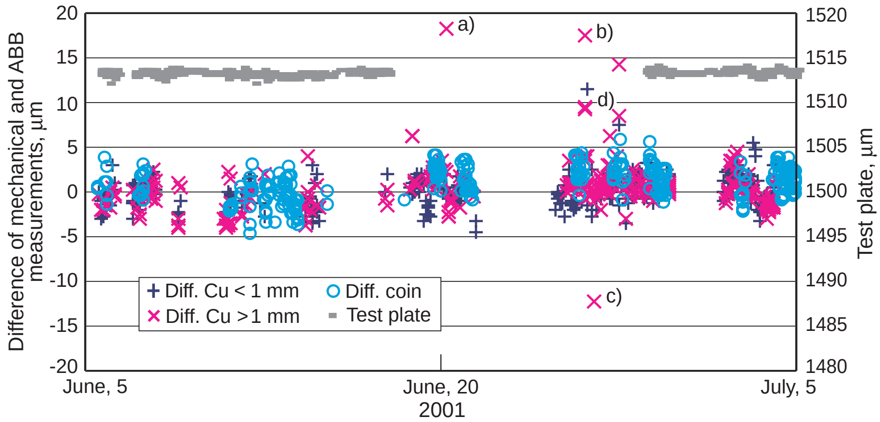

Figure 9. Differences between the thickness measurements of the Millmate gauge and the mechanical gauge over the test period

Figure 9 shows the results from this test. Here the *differences* between the thicknesses measured with the mechanical gauge and the thicknesses measured with the Millmate gauge are shown as a function of time over the test period. In order to obtain measurements of maximum reliability from the mechanical gauge, the values were taken as soon as possible after the rolling had become stable, i.e. after some 50–100 m of strip.

In most cases the two technologies show about the same thickness, with a spread of about ± 2–3 µm; but sometimes the differences between the two technologies are larger, up to 20 µm (12 such points are marked with letters in the figure and will be discussed later). The figure also shows the results of the measurements made on the test plate with the Millmate gauge. Here the thickness should of course be the same throughout the measurements, which indeed was observed. The standard deviation was only ± 0.25 µm. (Due to a registration problem in the computer, test plate data was not collected during an 11-day period.)

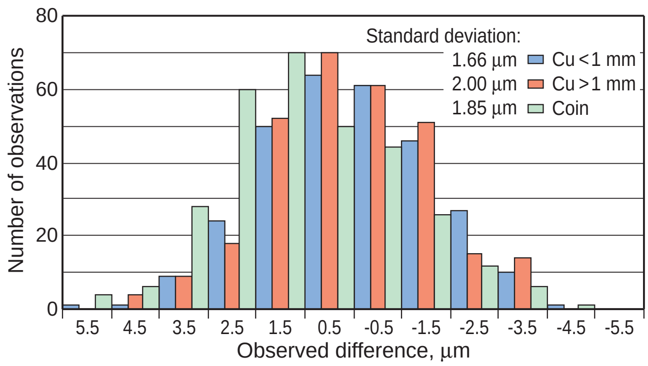

Figure 10. Distribution of measured values according to figure 9

The spread in figure 9 is shown as a *distribution plot* in figure 10. The normal spread is around 2 µm and it is independent of the strip material and thickness.

The points in figure 9 with a difference larger than 4 µm have been in-

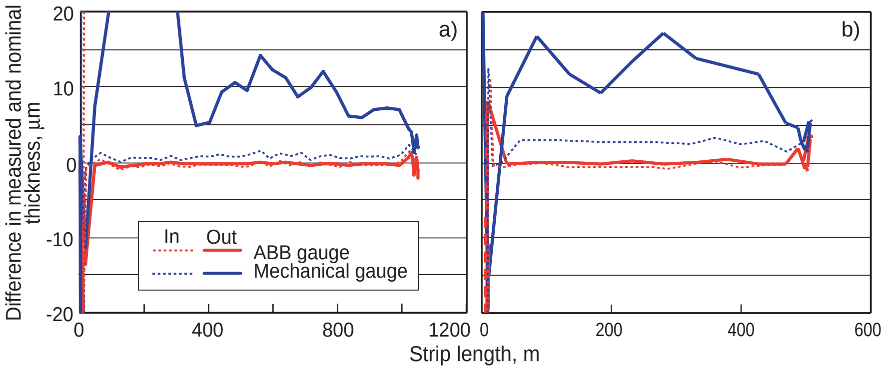

Figure 11. Recordings with irregular measurements of the mechanical gauge as shown in figure 9
a.) Point a: Cu, 1.62 mm thick b.) Point b: Cu, 1.20 mm thick

vestigated separately. Diagrams for the points a) and b) in figure 9 are shown in figure 11. Again, the strip should have the same thickness running out of the mill and back into the mill. This is more or less true for the Millmate gauge, but not for the mechanical gauge. This might lead to the conclusion that in these examples the *mechanical gauge* shows an *erroneous behaviour*. The same applies to the other points outside the normal spread of ±4 µm.

Generally, the difference between the two systems was around ±3 µm across all materials. It is likely that some of the difference is due to measurement errors by the mechanical gauge, i.e. an error of at least 1–2 µm. Additionally, the profile of the strip might result in a thickness difference of at least ±1 µm between the two measuring points. The test results thus indicate that the new gauge has an accuracy of about ±1 µm. The new gauge delivers reliable measurements at all the times.

The stability of the new gauge was tested on a test plate and was found to be almost perfect, i.e. less than 0.5 µm change over the test period. ■

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