High-speed profile measurement in the hot rolling mill

By **Christopher Burnett***

Aluminium, thanks to its lower density, is finding new markets for sheet applications across several industries, most notably in the area of transportation. Lighter weight vehicles consume less fuel, and where total loaded vehicle weights are concerned, allow higher volume shipments. These markets demand the tight tolerances for sheet thickness uniformity head to tail and edge to edge. Localised dimensional abnormalities can result in major issues in the downstream processing of the sheet, either in mechanical or aesthetic properties, ultimately impacting the end user.

This paper will describe a stereoscopic x-ray profile gauge with the ability to determine both the cross- thickness profile and the physical position of the strip in space as it exits the mill, throughout the entire sheet. By using a narrow x-ray fan beam to measure the strip, the system can record the height of each point of the strip in the time domain, the flatness, or shape, of the strip can be calculated, thus empowering process control engineers and mill managers to produce the highest quality sheet.

The consumption of fossil fuels used in personal automobiles, material shipments by rail or truck and all other aspects of transportation have been discussed scientist and politicians around the world. Reducing overall vehicle weight has been an active topic in those discussions. Aluminium producers have responded to this discussion with an array of products that help meet those goals. World-class aluminium producers rely on consistent mill processes to efficiently produce the highest quality sheet. However, even the most consistent mill requires independent measurement of critical product parameters.

Process variables in the hot aluminium rolling mill

There are dozens of instruments and measurement systems in a modern hot aluminium rolling mill. These sensors each contribute to the end goal of producing a coil with uniform mechanical and dimensional properties from head to tail and edge to edge. Advanced process control algorithms use hundreds of variables from various sensors and drives to maximise the prime quality yield from each ton rolled.

Starting with the mechanical properties of the alloy, strip tensions and temperatures are measured between every stand, pressure transducers measure reduction force and laser based velocimeters provide

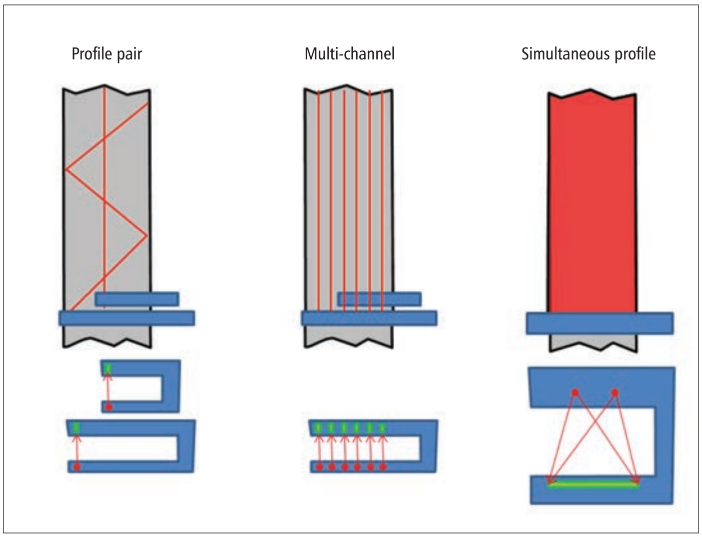

Fig 1. Measurement data from two single point style x-ray thickness gauges arranged in a Profile Pair and a multi-channel system compared to Thermo Scientific™ SIPRO

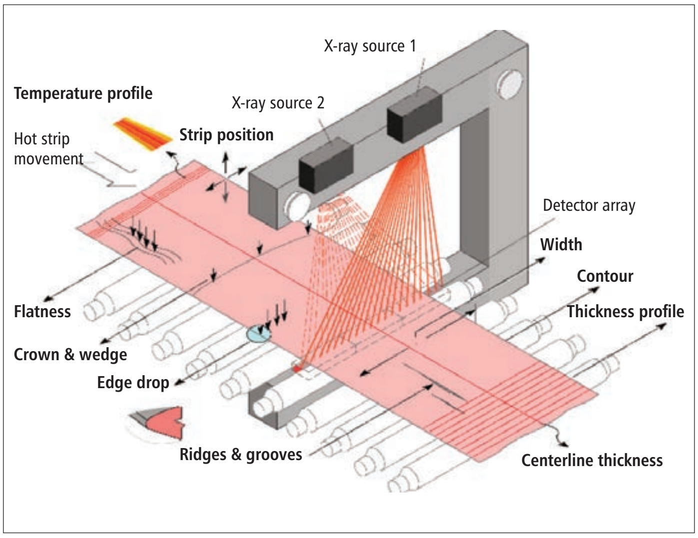

Fig 2. Dimensional measurements available from the stereoscopic SIPRO gauge

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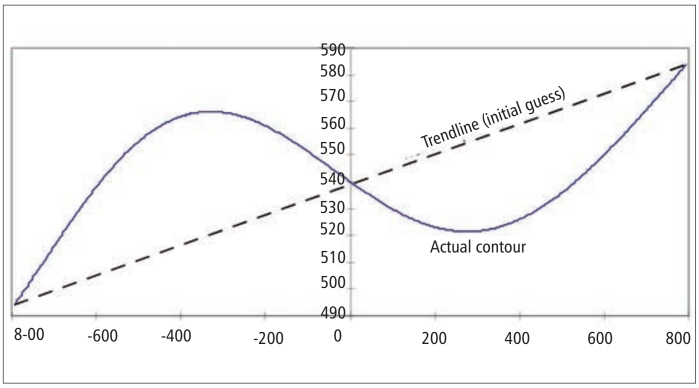

Fig 3. Contour measurement with trend line overlaid

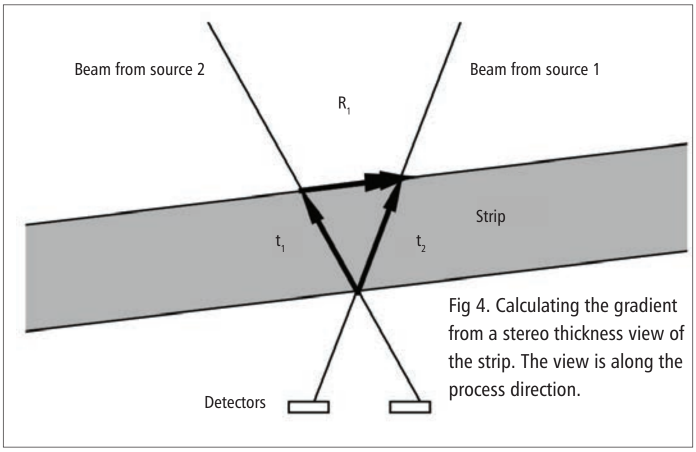

Fig 4. Calculating the gradient from a stereo thickness view of the strip. The view is along the process direction.

line speeds that monitor mass flow for use in feed-back and feed-forward control loops. At the end of the mill, prior to strip coiler, a simultaneous profile gauge is used to validate the strip produced meets the tight dimensional tolerances demanded in the market place.

While each sensor contributes to the overall strip quality, the operator and mill computer are responsible for digesting those inputs and producing the desired product. The profile gauge has the ultimate responsibility for validating the specifications are achieved. In the past, if coil quality was questioned, a chart recording of the gauge output might have been the only archived data to review. However, today, with high-speed data archiving, all of the previously mentioned variables and measurements can be recorded and reviewed by quality assurance, process engineers and plant management. Each discipline is able to mine the data for information critical to their areas of responsibility.

Simultaneous Profile Gauge (SIPRO)

In the last two decades, the evolution and miniaturisation of the integrated circuit has made high-speed radiation sensor arrays compact enough to fit into a robust frame for use in a hot strip mill. The first thickness gauges used large ion chamber or scintillator/photo-multiplier based detectors, which were only capable of providing a single measurement point averaged over several hundred square millimeter. To collect information about sheet thickness uniformity from edge-to-edge, multiple sensor packages had to be used. One of the first approaches to measure profile used a stationary sensor package in the center of the sheet, while a second sensor package mechanically traversed the sheet (see **Fig. 1**).

This arrangement provided a complete profile every 10-20 seconds depending on the speed of the traversing and strip width. The next step in profile measurement evolution was to install multiple sensor packages into one frame. While this increased the frequency of profile data, the physical size of the sources and detectors limited the resolution of the profile data, resulting in a small percentage of the cross profile actually being measured. Efforts to increase the resolution required offsetting the sensors in the rolling direction, which further complicated the issue of a discontinuous profile, but at their best, these profile systems still collected data on less than 30% of the total sheet width.

A modern detector array capable of simultaneously providing over 500 independent measurements across the strip has been developed, providing a quantum leap in the percentage of strip area measured. The miniature pixels are constructed using a special scintillator crystal mounted directly to a nearly continuous array of photo-diodes. The resulting measured profile is over 95% of the total sheet width when considering a single source above the strip.

However, when the detector array are positioned below two x-ray sources arranged in such a way to provide a stereoscopic view of the full strip width, the Thermo Scientific™ SIPRO gauge is capable of stitching together the two views to provide a high resolution thickness profile measurement based on 100 percent of the cross strip area.

Within the detector array housed in the lower arm of a stainless steel C-frame, individual detector pixels are positioned every 6mm across the width of the strip.(see **Fig 2**). When translated up to the level of the roller table, the resulting measurements are provided at a resolution of 5mm of strip width. This high resolution provides mill operators information on ridges and grooves, unlike lower resolution sensors.

The two-x-ray sources of the SIPRO are positioned above the strip and are arranged to view the strip from different angles. A unique rotating shutter design exposes the aluminium sheet to one source at a time. Data from the detector array is collected every 5 milliseconds and is synchronised with the rotation of the shutter. At a strip speed of 15 m/s, this 5-millisecond update equates to a measurement value every 75mm of strip length. Profile systems based on scanning or oscillating sensors require much more time and are 200 to 2000 times slower.

The positioning and synchronised data collection from the different sources also provides information on the physical position of the strip in space. In the event the strip is bouncing above the roll table surface, the profile thickness, width and all other measurements are not degraded.

Flatness measurement

Additionally, a flatness value can be calculated from the position, or height data. The measurement of flatness is essentially a two-stage process. First, the contour is measured. Then a history of the contour in the process direction is built up and the flatness calculated.

The contour calculation itself follows a number of stages:

1. Selection of a series of points across the strip - for which it is necessary to "locate" the strip.

2. Calculation of the transverse gradient at these points.

3. Integration of the gradient to give a relative height profile (contour).

4. Further iterations carried out, as necessary.

The flatness calculation stages include:

1. Collection of the height data along a set of "threads"

2. For each thread calculation of the length of the thread and the horizontal distance between ends.

3. Calculation of the flatness.

Locating the strip

The locations of the edges of the strip are calculated from the stereo thickness view - both the horizontal and vertical positions are known very accurately (See **Fig 3**). At this stage, because of the assumption that the strip has out-of-flatness, the vertical positions of points on the strip between the edges are not known. Initially however, the vertical position of each point on the strip can be estimated from the "trendline" - an imaginary line between the edges of the strip.

It is possible to make a calculation of the contour using these points. If the thickness of a point on the strip is measured from two directions, there will be a difference in measured thickness, which is dependent upon the gradient of the strip. The gradient can be calculated from the two thickness values as the vector diagram in **Figure 4** shows. R_1 is the resultant of the vectors t_1 and t_2 and its direction is the gradient of the strip. The directions of t_1 and t_2 are calculated from the positions of the detectors at which they are measured relative to the sources.

These directions are fixed from the outset, since there is no movement of either source or detectors.

This method of measurement assumes that both surfaces of the strip are parallel - i.e. the thickness is not changing. Additionally it assumes that the gradient of the strip is not changing. In both cases, the distance between detector elements becomes very important.

When detector elements are 25mm or further apart, there will be an error in the gradient. Therefore, it is essential that the transverse measurement resolution is as small as possible, so that the effects of changes in either thickness or gradient are minimised.

The operator will want to examine the flatness at a number of predetermined points across the strip. These points extend in the process direction along ribbons or threads. The positions of the threads can be configurable and each time the contour is evaluated the heights are calculated for each of them. For each thread, the height data is built up over time and can be related to the longitudinal position on the strip. The latter is calculated from the velocity of the strip and the time since the head of the strip was detected.

Summary

The two source stereoscopic geometry, coupled with a highly specialised detector results in a profile measurement that is capable of simultaneously measuring six essential hot rolling parameters:

- Centerline thickness for automatic gauge control (AGC)
- Instantaneous cross profile thickness
- True sheet width, regardless of strip contour or height
- Crown and Wedge data
- Edge drop measurement
- Sheet wander (relative to mill centreline)
- Flatness or Shape

For hot sheet aluminium producers, this wealth of data provides insight to the rolling process and how it can be tuned to provide uniform sheet dimensions for the end user. The end user, in turn is assured to have a consistent supply of material to meet not only their current demands, but also the needs of future applications where aluminium sheet can be used to light weight other modes of transportation. ■

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