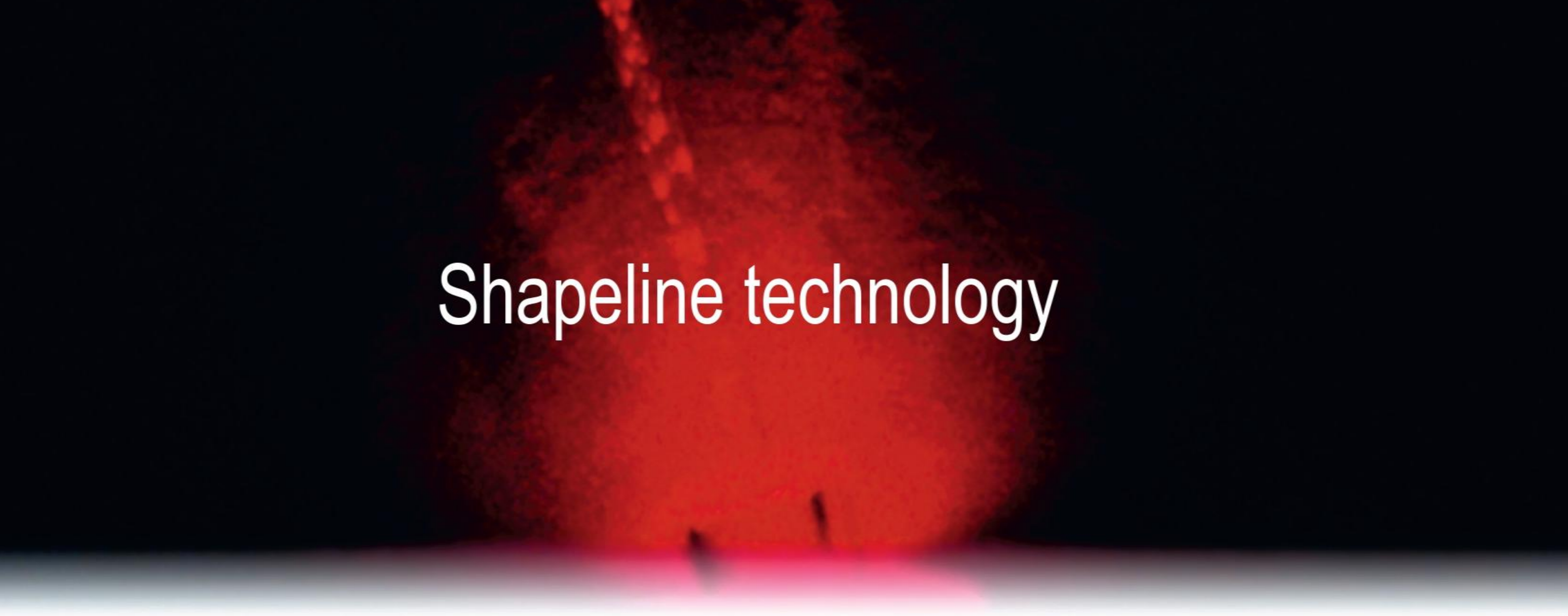


Shapeline technology

Since a flatness measurement system is usually installed in existing lines, the sensor must be flexible and adapted to handle the circumstances in the line. This can be limited space, bad environment, pass-line variations in various directions, specular surfaces and varying surface properties. In particular, unflat material in combination with normal transportation systems (such as rolls) introduces vibration and elastic material deformation. Our method deals with vibrations and the effects thereof in an efficient way by estimating the local normal vector of the material in every point by laser line triangulation, and not only compute the I-unit profile, but also retrieve the topography of the material to enable quality assurance.

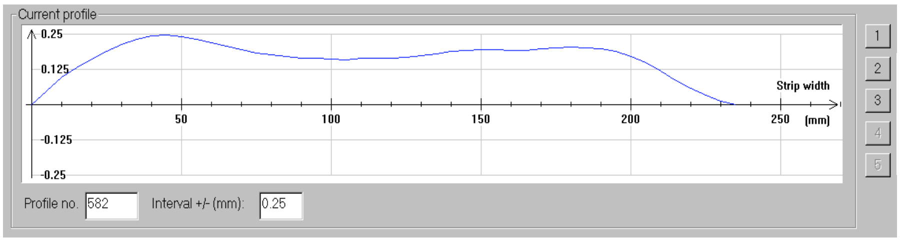
We use a laser line triangulation method for on-line measurement of manifested flatness based on a laser projector with two parallel lines. The double laser line approach permits local surface slope measurement in addition to 3D-position which can be used for material vibration compensation as well as elastic deformation compensation to some extent. The benefit is that manifested flatness can be measured with high resolution on material that is moving on roller tables or having severe vibrations in the lines.

Some benefits:

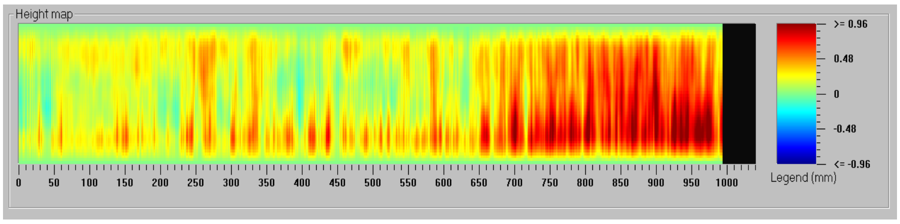
- The cameras are tuned to the same light wavelength as the lasers which effectively blocks out ambient stray light.
- The expected laser lifetime is long.
- The measurement is more or less surface independent. We measure on surfaces that are mirror-like as well as black surfaces and surfaces with scale, oil and moist.
- The sensor can be made compact for small space in existing lines

I-units and flatness profile

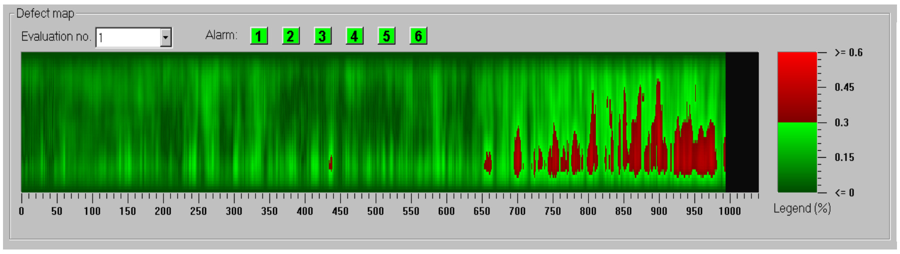
The I-unit is a powerful description of the fibre length distribution in the strip width direction. The definition is geometrical but the measurement is often indirect by measuring pressure on a tensiometer roll. For manifested flatness, the I-unit is computed as curve length difference per meter strip multiplied by 10-5. Usually the average curve length is set to zero and we get a graph a flatness profile that is centred around the x-axis. A flatness profile is useful for process control (rolling, levelling, quenching) as well as quality assurance and is therefore an important measurement property.



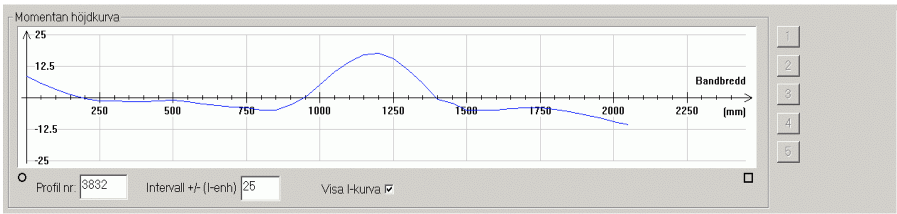
Crossbow. Updated when the material moves.



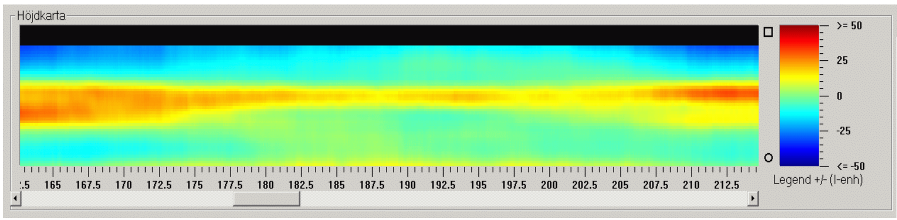
Color coded topography map. Shows the history of what has been measured.



Defect map. Shows which parts that do not fulfil the end-customer requirements.



I-unit profile. Computed from the topography. Used for quality assurance, leveller control or mill control.



I-unit map. Shows the flatness history for the strip

Laser line triangulation

Laser line triangulation is based on a (usually) red diode laser with a line producing optics. The line producing optics spreads the laser light in one dimension to make a fan of light (see Figure 1). Shapeline uses refractic optics that make the intensity even, thereby assuring an even measurement accuracy across the width. The line is focussed on the material and is clearly visible. If the surface is unflat, it may be observed with the naked human eye as a slight bending of the laser line.

To obtain the shape automatically and more precisely, the laser line is observed with a 2D matrix camera. The line is then projected in the camera image across the picture and the software can detect the line for every column in the picture. The usual way is to detect the centre of gravity of the line in every point with sub-pixel accuracy. This makes the measurement precise, but also independent of the actual intensity. The intensity itself is not important, only the position of the line.

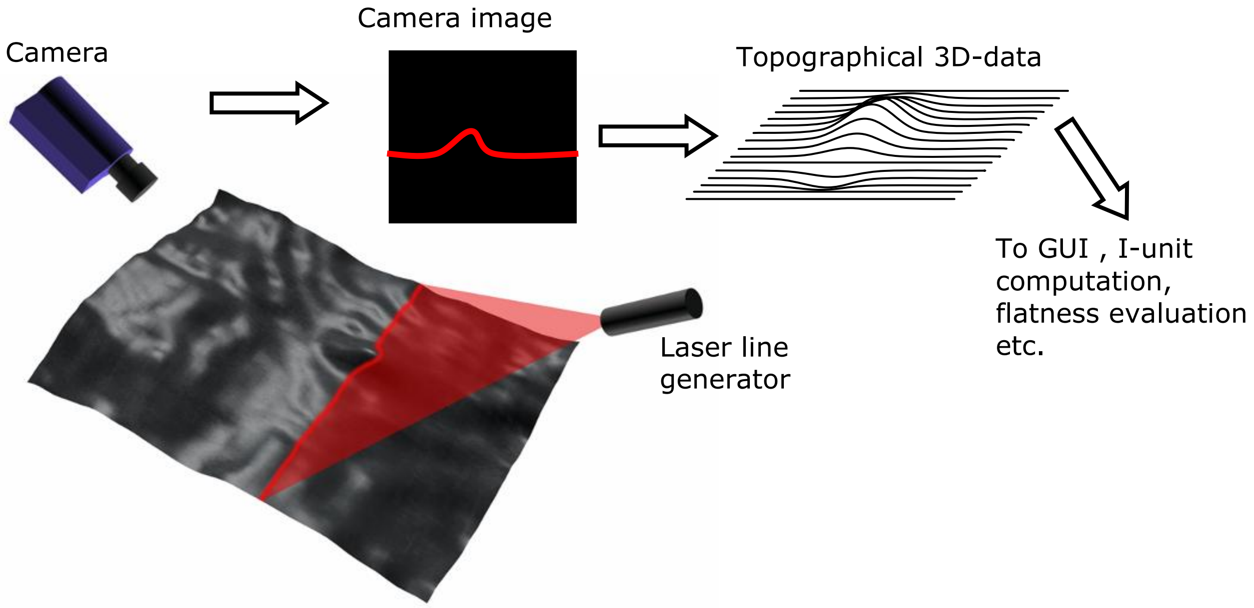
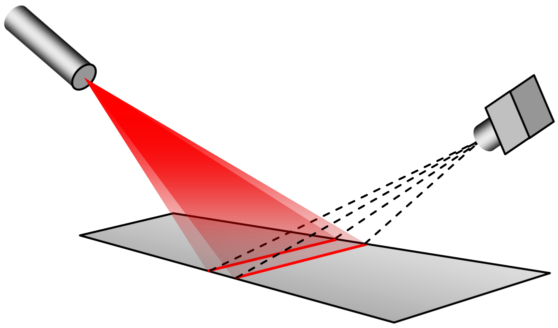


Figure 1. The principle of laser line triangulation

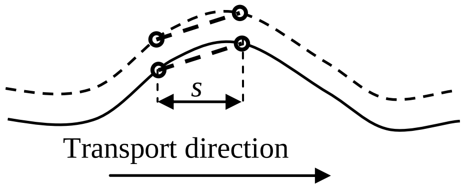
Since the camera may have several hundred columns, the number of measurement points is high. For instance, Shapeline can provide up to over 4000 points across the width by using several synchronized cameras. The measurement principle is accurate and robust. For each crossbow profile, the shape is "frozen" since all measurement points are acquired simultaneously. When the material is moved (normal line transportation), the profiles are measured continuously. The result is usually presented for the operators, used for line process control and utilized for production improvement and follow-up.

Vibration compensation

A normal laser line triangulation system has the limitation that vibrations and unflatness cannot be properly separated. However, by projecting two laser lines one after the other in the transport direction, we are able to measure local surface gradient. A shape defect always gives a change in the local gradient, whereas a vibration does not. In fact, also an elastic deformation gives little or no gradient change unless the material reshapes (the buckles move). Therefore, the method also significantly compensates for elastic deformation.



Two laser lines are projected and viewed by the camera.



In each width position, two points are measured giving a local slope or gradient. Even if there is a vibration, the gradient is the same.

Figure 2. The double laser line triangulation principle

The reconstruction of the topographical data is complex. For instance, the following factors have been taken into account:

- Calibration. Shapeline utilizes a patented calibration procedure that has now been used for several years.
- Drift. The system geometry and the distance between the laser lines are not constant, but change over time. This has to be compensated for continuously.
- Sampling density. The gradient is only an approximation of the real surface gradient since it is only sampled in two points. This has to be compensated for, especially for short wavelengths.
- Random walk error introduced in the integration of topographical data.
- Camera and laser overlap and boundary effects.
- Material speed variations.
- Material position variations (pass-line as well as sideways).

The software handles these issues both for strips and plates.

Use of the method in real life situation

The system has been tested by comparisons between stone table measurements and measurements on a roller table.

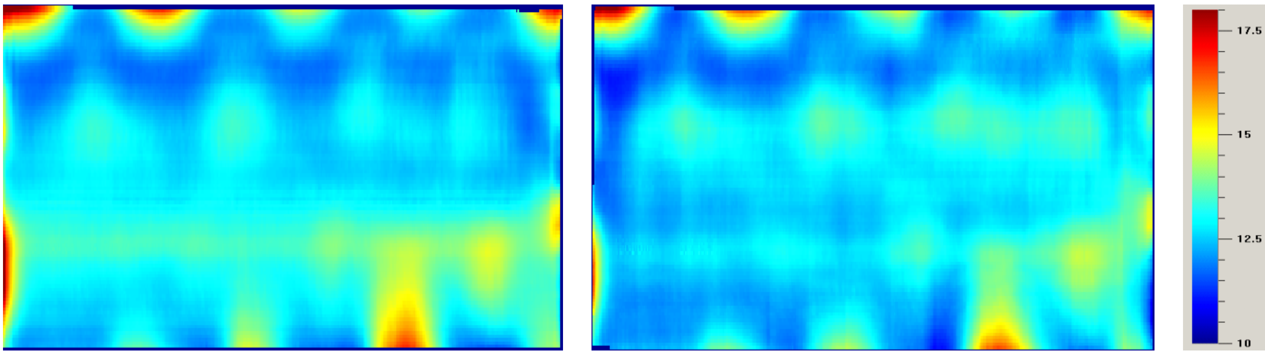
Adjustment of the roller table

The roller table was improved by adding smaller wheels between the normal rolls. The reason is that we want to prevent plate hang-down, strip head collisions with rolls and wave locking for thin material.

The result is a transportation that has a low content of elastic deformation, but the vibrations are still prominent, especially for thin, unflat plates. For plates showing a U-shape, elastic edge deformations (swinging) also still exist.

Measurement results

To test the algorithms, a number of plates were measured both on a roller table and on a stone table. The measurements gave consistent results, and an example is shown in the figure below.



The same plate measured on a stone table (left picture) and on a roller table (right picture)

A large number of plates have been measured and compared. In general, the measurement difference is less than one mm with some exceptions for the head and tail of the plate.

Summary

The principle is based on double laser line triangulation which gives an accurate, compact and durable solution both for strips and plates. The measurements compensate for vibration and delivers flatness, crossbow, flatness compensated width and topography. The method is robust due to its architecture and technology. Very little maintenance can be expected. Data can be visualised in numerous ways, also in real-time.