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Society Study Group Mathematics with Industry 2012

Spotting damaged strips

How can you tell from a picture if a steel strip is pinched? This was Tata Steel's question for the Study Group Mathematics with Industry. The mathematicians found a surprisingly simple way to detect damaged strips.

Participants of the study group

Evgeniya Balmashnova (TU/e)
Mark Bruurmijn (TU/e)
Ranjan Dissanayake (Rajarata University)
Remco Duits (TU/e)
Leo Kampmeijer (Tata Steel)
Tycho van Noorden (Universität Erlangen-Nürnberg)

Glowing red hot strips of steel, shooting by with a speed of 70 km/h. This is daily business at the IJmuiden site of Europe's second largest steel producer Tata Steel. Their hot strip mill (see Figure 1) yearly produces 250.000 coils of steel. The steel enters the mill in slabs with a length of a few meters and a thickness of two centimeters. The slabs are heated up to a temperature of 1200 °C (which is around the temperature of magma) and step by step rolled into strips with a length of



Figure 1 The hot strip mill with glowing hot slab of steel.

up to two kilometers and a thickness of two millimeters. Then they are cooled down to 600 °C and coiled up generally in less than a minute.

During the final reduction step (see Figure 2) the steel can reach a speed of 70 km/h. This step is very critical. Any process error may lead to a defect in the shape of the strip. Especially at the tailing out of the strip such shape defects may make the steel pinch. This pinching is visible as ripples in the strip. The biggest problem is not that the strip is ruined, but that the machines might be damaged too. And stopping the machines is very expensive.

Leo Kampmeijer, researcher at Tata Steel, asked the study group to devise an algorithm that can automatically determine from a grey scale picture whether a strip is pinched at the tail. The main goal is to detect slight pinches before they cause any real damage. A second goal is a better understanding of what causes the pinches. This might be used to modify the process to prevent them altogether.

Detection

In the hot strip mill a camera already takes images of the steel strips and an automatic surface inspection system scans these pictures. This software is trained with categorized images and can spot simple defects. But pinching is very hard to detect automatically, partly because it can appear in different forms.

Mathematician Remco Duits specializes in image analysis and explains the limits of the available commercial software: "This system is trained to find small holes in the steel. It is highly specialized for this task and does this very well. But it cannot do other things,

it cannot even detect the end of the strip." Duits usually works on medical imaging. The problem reminded him of MRI scans of the human heart and he was curious to see whether his techniques from medical imaging would work for steel strips too. Leo Kampmeijer was cautiously optimistic at the beginning of the study group: "I am used to working with mathematicians and I know that a lot is possible mathematically. But I also know how hard it is to get something that works in the real world."

The study group decided to focus on two properties of pinched strips: their elongated tails and their ripples. Sometimes the medical background of the researchers shone through when they talked about the steel as if it were a patient: "In a healthy strip... I mean, a normal strip..."

On the tail

To automatically compare tails the mathematicians defined the tail length as the distance between the top point of the strip and the place where the strip first reaches its full width. See Figure 3. In the lower half of the image the width of the strip is almost constant

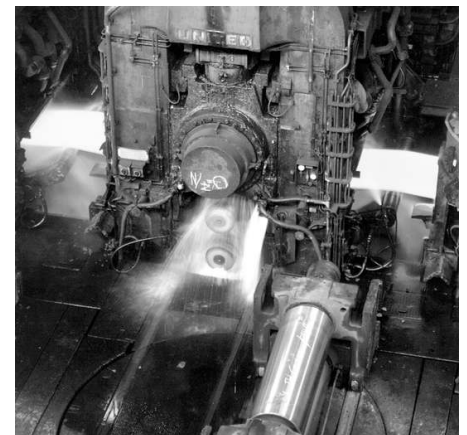


Figure 2 The final reduction step in the finishing mill.

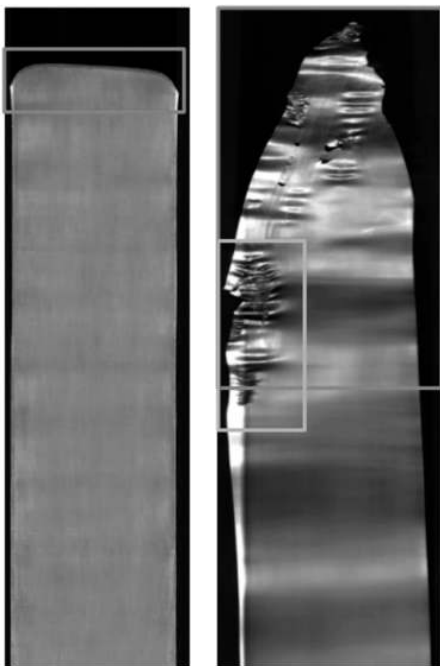


Figure 3 It is quite easy to spot the pinched strip with the naked eye. It has a long, irregular tail and ripples.

for both pinched and normal strips. Therefore the median width in this part is taken as the width of the strip. In practice this is done by counting the number of black background pixels in a horizontal line. As an example, if the image has a width of 200 pixels and the median number of black pixels in the lower half of the image is 30 in a line, then the width of the strip is taken as 170 pixels.

To find the tail length we start by scanning the image line by line, starting from the top row. In the first few rows there will be no strip visible, so here the number of black pixels will be 200. As soon as the number of black pixels drops below 200, we have found the beginning of the tail. We remember this as the first line number. Now we keep going until we find a line where the strip first reaches full width. In our example we would continue until we have a line with 30 black pixels, this is the second line number. The tail length is the difference between the second and first line number.

Shadowy figures

There is a small problem with the described method: shadows in the image might be seen as background pixels. In that case the estimation for the tail length will be off. Therefore the mathematicians developed a second approach in which the width of each row is computed (by taking the distance between the first and last non-black pixel). Then the mean of these values is used and a more accurate tail length is found.

The images from the factory do not have too many shadows and in most cases the first and second approach yield exactly the same tail length. If the two results differ, this indicates that there is something wrong with the image. It could be a shadow, or a hole in the strip. So using two different methods of finding the tail length and comparing the results can be useful for detecting holes.

Ripples

Strips that are pinched, have vertical ripples. They show up in the images as fast changing, periodic changes of grey values. A common strategy for finding such distortions is using the Fourier transform. Unfortunately, the ripples have local frequencies and Fourier only detects global ones. Luckily, the related Gabor transformation could do the job. This transformation filters the images and gives more weight to the higher frequencies. In the end the transformation yields just one number that measures how rippled a strip is. A *rippleness* of 0 is a perfectly flat strip, a rippleness of 10.000 is the worst possible.

Classifying

For each image of the strip this results in two numbers: one for the tail length and one for the rippleness. A scatter plot shows how these two numbers are distributed for pinched and normal strips. See Figure 4. A line separates the normal strips from the pinched ones.

This criterion correctly identifies all of the pinched strips. Of the normal strips 96.3 percent is correctly seen as good, less than 4 per-

cent is wrongfully seen as pinched. In most cases this seems to be caused by a problem in the lighting.

Future work

Remco Duits is happy with the results, but emphasizes that the classification can go much faster: "We cut some corners and did everything rather roughly. The goal of the study group was to make it work, to get some first results within a week. Things could look much better, there is a huge mathematical framework behind all this." At the end of their paper the mathematicians list the possibilities for further research. The pinches can be classified based on severity and other types of defects might be detected with similar methods.

Leo Kampmeijer from Tata Steel is already very pleased with the results: "We could start using these methods tomorrow. As soon as I have time, I will do more tests to see which of the methods is most workable." He was surprised that it was possible to detect pinched strips from just the tail length and rippleness: "I thought that you would need more properties of the strip." The mathematicians also suggested more future applications than Kampmeijer expected when he prepared the questions: "So I hope to stay in touch".

This is a brief report on the Study Group Mathematics with Industry, held from 30 January to 3 February 2012 at Eindhoven University of Technology. The scientific proceedings are available on www.eurandum.nl/events/workshops/2012/SWI.2012.

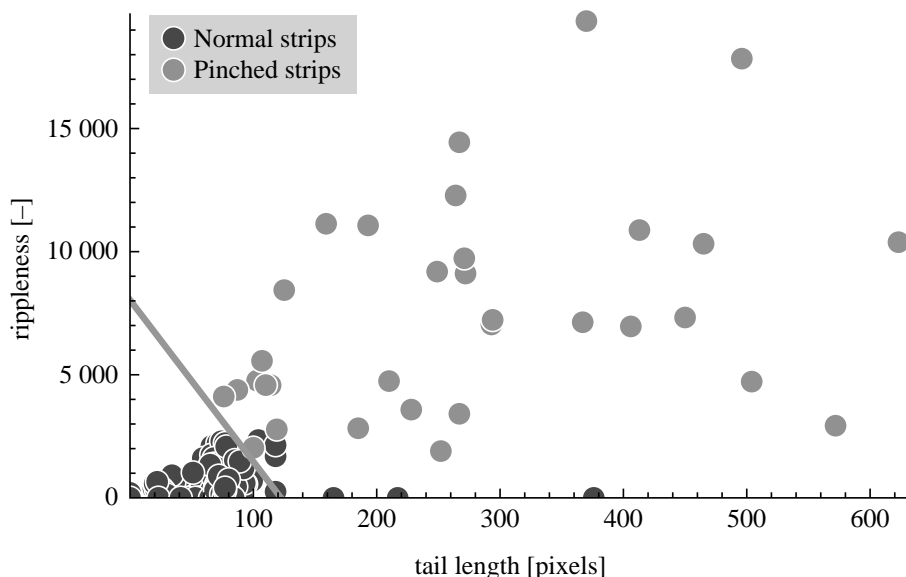


Figure 4 The tail-length is on the horizontal axis, the rippleness on the vertical axis. Most normal strips are in the lower left corner. The line indicates the criterion for classifying strips.