This is the published version of a paper presented at *Wire Association International, 83rd Annual Convention, Atlanta, 22-25/4 2013*.

Citation for the original published paper:


N.B. When citing this work, cite the original published paper.

Permanent link to this version:
http://urn.kb.se/resolve?urn=urn:nbn:se:oru:diva-34909
Monitoring of the wiredrawing process

By Joakim Larsson, Helena Johansson-Cider, and Magnus Jarl, Örebro University, Sweden

Abstract:
Manual monitoring for flaws, which is dependent on operator experience, is normal praxis during wiredrawing. This paper investigates different methods to monitor the drawing process. Force measurement and an optical method have been tested in plant experiments. Monitoring of the drawing force gives some information, but is not reliable. Optical methods are expensive and sensitive for variation in the lubricant layer.

Joakim Larsson is currently an R&D designer for Lämneå Bruk AB, Ljusfallshammar, Sweden. He previously worked as a research engineer at Örebro University, Örebro, Sweden, conducting wiredrawing research. He holds a bachelor's degree in mechanical engineering. Helena Johansson-Cider is a lecturer in environmental and energy technologies at Karlstad University, Karlstad, Sweden. She has worked with plastic forming of sheet metal at Morphic AB, and with wire technology at Örebro University, both positions mainly in the field of finite element modeling. She holds a master's of science degree in engineering physics from Karlstad. Magnus Jarl is a professor of mechanical engineering at Örebro. He joined the university in 2001. He previously was a senior researcher at MEFOS, Luleå, Sweden. He holds a Ph.D. degree in physical metallurgy from the Royal Institute of Technology in Stockholm, Sweden. He has worked with wire drawing for 12 years and published 14 papers in that subject.
Monitoring of the Wire-Drawing Process

Joakim Larsson*, Helena Johansson-Cider** and Magnus Jarl
Örebro University, *) Now at Lämneå Bruk AB, **)Now at Karlstad University

Introduction

Flaws with wire drawing are a troublesome problem. Surface flaws may be caused by galling; the galling may weld small particles of wire material to the die and cause scratching of the wire surface. Foreign particles may also scratch the wire. A small particle of wire material may increase or decrease. Sometimes problems encountered in the threading-up of the machine disappear after a short time.

Manual monitoring of the wire surface, which is dependent on the operator’s experience, is normal praxis. Operators often make an assessment of the lubrication from the wire brightness on the block. By experience they judge the risk of galling and scratches. Other methods are to touch one’s wire with a finger, to stop the drawing process and study the wire surface by a magnifying glass, or by rotating a discarded micrometer around the wire. Sometimes specimens are cut out and studied in stereo microscopes. When the operator judges that the risk for scratching is increased, he can take some measures such as reducing the drawing speed in order to avoid a flaw. An automatic system for flaw detection could be an advantage by providing more objective judgment and documentation of the wire quality. The need for manual work would also be reduced.

Optical methods

Optical methods may be used for direct detection of flaws, but also for monitoring of wire brightness as an indication of deterioration of the lubrication.

In co-operation with OptoNova three direct optical methods were discussed:

- Stroboscopic LED-light with fast area cameras
- 3D measurement with sheet-of-light-triangulation,
- Line-scan cameras

An area camera makes 500 pictures per seconds of 10 to 25 mm wire length. The flash light pulses have to be extremely short, 2-5 µs. This method is not able to measure the depth of defects. The second method is triangulation of a laser line projected on the wire surface. All three methods have to be adopted to cover the whole circumference of the wire. Line-scan and area camera may be designed circularly [11]. But triangulation should need four units to cover the whole circumference of the wire. The principle of triangulation is shown in Figure 1.
An experiment with laser triangulation was performed in a production plant. Only one unit was used and the whole circumference of the wire was not covered. The laser line was inclined. The wire speed was 1.5 m/s and the wire diameter 3.6 mm. The camera worked with a frequency of 4 kHz, which gave a resolution of 0.375 mm in length. The transversal resolution was 27 µm/pixel and the resolution in depth was 4 µm. A graphic processing was used to eliminate the vibrations in the wire and to flatten the cylindrical wire surface. The results showed noise corresponding to a depth of +/- 15 µm. A serious problem was that the lubricant remaining on the wire corrupted the measurements. (see Figure 2).

Pyrometer signal
A pyrometer was used for monitoring of the wire temperature. The spectral response was in the range 8-14 µm. The ratio distance to the measuring spot was 22:1. The pyrometer was aimed towards the lower windings of wire on the block. When the lubrication was deteriorated by water sprayed on the wire, the pyrometer signal was lowered (see Figure 3). The reason is the lower emissivity of a brighter wire surface.

A digital camera may be used to evaluate the wire brightness on the block. A simple arrangement with a fluorescent tube as a light source and a camera was tested. The intensities of pixels were evaluated with Matlab. The maximum intensity of the camera signal was 256 per channel. The three channels were added together and the maximum value became 768. Bar charts of block 1 and block 6 from a drawing machine are shown in Figure 4.

Figure 1. The principle of laser triangulation.

Figure 2. Wire surface and signal along white line. Blue areas; difference in lubricant layer.

Figure 3. Force and pyrometer signal, water spray deteriorates the lubrication.
A problem encountered was that the windings are not always even. Sometimes gaps between wire windings were formed (see Figure 6). These gaps may corrupt a simple measurement of brightness on the block.

Figure 6. Gaps between wire windings.

Force measurement
Different configurations of load cells were used in these experiments. In the first experiments in a two-block machine KIS load cells were used. These could be built in without stresses. In the following experiments in continuous machines these cells could not be used due to lack of space. An arrangement with Z-load cells was used. An example is shown in Figure 7.

Figure 7. Arrangement of load cells for force measurements. The lubricant box is held by Z-load cells. The die holder with cooling shall be attached to the right in the lubricant box.

The force signal was updated with a frequency of 300 Hz and sampled with a frequency of 1000
Hz. The first trials were promising. An example is shown in Figure 3. The force signal was strongly affected by deterioration of the lubrication. Different methods to analyze the force signal were tested, e.g. Fourier’s analysis, the ratio between maximum and minimum signal in a time span, and the median force in a time span.

Figure 8 to 10 shows the ratio between maximum to median force during the time spans of one second. The measurements are made in the 10th draw. Normal production parameters are used in Figure 8. The lubricant was removed from box 8 and 9, and the speed was increased from 3.5 to 6 m/s. The wire surface was still OK (see Figure 9). Afterwards the wire was wet with water and dish detergent in box 9, and the speed was increased from 3.5 to 5 m/s. The wire surface was scratched. The ratio of maximum to median force was increased compared to the normal wire drawing (see Figure 10).

Evaluation of the force signal with Fourier transform showed that the largest changes occurred in low frequencies. The frequency of the electrical current was 50 Hz and should be excluded. The intensities in the range 3 to 46 Hz were summed up and expressed in Figure 11 and 12. These Figures show the same experiments as Figure 8 and 10.

However, manual inspection of wire coils after drawing revealed scratches on of the wire. These
Scratches were not detected by the force measurement nor indicated by the operator.

![Figure 11. Fourier transform, sum of intensities 3-46 Hz, time span 1 second. Drawing speed 3.5 m/s. Normal production parameters.](image1)

![Figure 12. Fourier transform sum of intensities 3-46 Hz, time span 1 second. Lubricant removed from box 8 and 9. Drawing speed increased to 5 m/s. The wire was wet by water and dish detergent in box 9. Scratches on the wire surface.](image2)

**Eddy Current**

Eddy current had been tested in-line at one of the participating companies. A combination of a rotating probe after the first draw in the machine and a through-type coil after the last draw was used. The rotating probe can detect long surface scratches and the through-type coil short flaws. The flaw signal from the rotating probe stopped the line, but the flaw signal from the through-type coil activated a painting system for marking of defects. The line worked but it was difficult to get all equipment to work together. However, the non-operative time was increased. The arrangement could not detect long scratches arising after the first draw. The lubricant did not affect the measurements, but accumulation of lubricant in the rotating probe once caused a breakdown.

The “minicoil” is marketed by Foerster. This through-type coil rides on the wire and designed for use in drawing machines. This method is used for short defects, but long defects such as scratches are hard to detect.

**Discussion and conclusions**

Supervision of wire surface quality has been an issue for a long time. Direct and indirect methods may be used. The indirect methods are e.g. measurements of resistance between die and wire, temperature, vibrations, forces, wire brightness etc. Direct methods are optical and EC methods.

Several of these methods are probably too sensitive in the drawing plant. The operators are not used to handling sensitive equipment and the environment with dust from carriers and lubricants is harsh. This is a drawback for all optical methods and as well as methods such as resistance measurement between die and wire and temperature measurements with thermocouples welded on the nibs. The measurement of resistance between die and wire may be sensitive to small iron particles rubbed off the wire surface.

There are both pros and cons of indirect methods. They indicate the risk for flaws, which may make it possible to avoid the flaw. However if flaws occur without indication, it is not possible to relay on the method.

Direct methods are EC testing and optical supervision of the wire surface. EC-methods for short defects are on the market. They may give documentation of the wire surface quality. But the risk is that an enlarging scratch will not be found. Moreover, they will give no warning of
risk for flaws and, thus, no possibility to take countermeasures. The EC device should be calibrated to indicate a certain depth of defect. The method with triangulation of a laser line may be calibrated to indicate a depth of a defect. It is especially suitable for long defects as scratches.

Pros and cons for array and area cameras are that they inspect the surface, but they are not possible to calibrate for a depth of a defect. This may result in erroneous flaw indications. They also need a demanding light source and the high speed area cameras are extremely expensive.

Acknowledgment
This work was part of “Steel Research Program for Sweden” founded by Vinnova in cooperation with The Swedish Steel Producer’s Association. The participating companies supporting the work were Hörle Wire AB, Fagersta-Stainless AB, FNsteel Hjulsbro AB, AB Sandvik Materials Technology and Suzuki Garphyttan AB.

References