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OIL LAYER MEASUREMENT IN ROLLING AND STAMPING PLANTS – ONLINE[1]

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Abstract

Oil is used in the production of steel strips for different purposes: as coolant and lubricant in the rolling mill, as corrosion and transport protection in storage and shipping and - most important - as lubricant in the forming/stamping processes. Industrial oiling systems have been improved considerably in the last 15 years – however uneven or out-of-tolerance oil coating results in high penalties in this value-added process. A continuous monitoring system is needed to ensure that the specified oiling parameters are maintained. A new system for measuring the oil layer on moving strips is presented. The OFM (Online Oil Film Measurement) is based on a spectroscopic approach. Using the absorption of characteristic wavelengths in the middle infrared, the system accurately calculates the oil film thickness as defined by the Lambert Beer Law. The paper will discuss alternative measurement methods such as gravimetry, back scatter and fluorescence. Practical installation examples in the steel and automotive industry are illustrated. Also, the paper will discuss typical oiling faults like dry stripes, uneven oiling and trough formation.
Key words: Oil film measurement; Oiling control; Lubrication monitoring.

MEDIÇÃO ONLINE DA CAMADA DE ÓLEO EM LAMINAÇÕES E ESTAMPARIAS

Resumo

Óleos especiais são utilizados na produção de tiras de aços por vários motivos: como refrigerante e lubrificante no laminador, como proteção contra a corrosão e proteção durante o transporte em geral e armazenamento e – mais importante – como lubrificante no processo de estampagem/conformação. Os sistemas de oleamento industriais melhoraram consideravelmente ao longo dos últimos 15 anos – entretanto um oleamento não uniforme ou fora de faixa resulta em sérias penalidades neste processo de valor agregado. Um sistema de monitoramento contínuo é necessário para assegurar que os parâmetros específicos do oleamento estejam sendo mantidos. Um novo sistema para a medição contínua da camada de óleo em tiras em movimento é assim apresentado aqui. O OFM (Online *Oil Film Measurement*) está baseado nos princípios da espectroscopia. Utilizando a absorção de comprimentos de onda característicos do infra-vermelho médio, o sistema calcula com precisão a espessura do filme de óleo aplicado, definida pela Lei de Lambert-Beer. Este trabalho visa comparar este novo sistema com os outros métodos alternativos de medição, tais como gravimetria, retro-espalhamento e fluorescência. São apresentados exemplos práticos de instalações na siderurgia e na indústria automotiva. Defeitos de oleamento típicos como faixas secas, distribuição não uniforme do óleo e áreas de acúmulo também são discutidos.
Palavras-chave: Espessura da camada de óleo; Medição do filme de óleo; Controle do oleamento; Monitoramento da lubrificação.

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1 INTRODUCTION

Optimizing of all parameters in the process chain is a continuous task for all producers and fabricators. Precondition for a safe process is the permanent monitoring and controlling of all quality relevant factors.
Today in the most rolling and stamping plants a continuous inspection of all key factors is not available. For testing purpose parts of the end or the beginning of the coil are separated and tested in laboratories outside the line. A time lag between production and test results is unavoidable – quality problems are detected too late.
This paper presents a new measuring system which is able to monitor an important quality factor - the oil film layer - during production process. Oil is used in different stages of the production and has to fulfill several tasks.
In the rolling mill oil is needed as coolant and lubricant. Mostly oil/water emulsions are used for this purpose.
When leaving the steel mill, the coil has to be protected against corrosion and transport damages. The oil layer should approximately correspond with the RA value. If the oil layer is lower, damages are possible. If the oil layer is too high, problems during the coiling process may result.
Till today several forming plants remove the transportation and anticorrosion oil in special washing/cleaning facilities, when having received the coil. Afterwards the metal sheet is re-oiled with special forming oil. Cleaning and re-oiling takes time, causes costs and pollutes the environment. In the supply chain this process step can be saved completely if the rolling mill directly appliques the planed forming oil. To fulfill these requirements the rolling plant has to monitor the oiling process. Otherwise oiling faults are not or to late detected and will in consequence cause damages during the forming process.
Industrial oiling systems have been improved considerably in the last 15 years – however uneven or out-of-tolerance oil coating results in high penalties in this value-added process. The oiling machine has to be able to deliver a homogenous oil layer under changing conditions like strip speed, temperature and oil type. Measuring the oil layer through a flow gauge on the oil pump is in most cases the practitioner method to check the oil flow. But this method only says that enough oil was transported. It guaranties not that the oil reached the sheet and that it is distributed homogenous.

2 MATERIAL AND METHODS

2.1 Methods to Measure an Oilfilm

Today the used oil values lie in a range between 0,5 g/m² to 2,0 g/m² in normal applications which is correspondent to a film thickness of 0,6 µm to 2,2 µm. Depending on the strip size the ratio oil weight to strip weight is between 0,001% and 0,03% - the oil film is razor-thin.
One measurement method frequently practised in the field to measure the thickness of the oil layer is gravimetric analysis. Thereby, circular or postcard sized pieces of metal are cut out of the sheet and weighed on a precision scales. Then the oil on the test sample is removed with a solvent and weighed again. When most precisely with high resolution scales executed, the oil layer can be ascertained by this method in g/m². However, this method provides no means to determine the distribution of the oil over the surface as well as between the top and bottom sides of the strip. Dry stripes

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cannot be detected. Another disadvantage of this method is that it makes the strips unusable and can only be carried out offline on already oiled metal strips, away from the production line. It is also very time-consuming.
Measurement of organic layers on metal sheet surfaces can also be carried out by comparing the absorption of radioactive emissions of the oiled strip against a non-oiled strip.[(1)] This method is known as the Beta Backscatter Method and is standardized according to ISO 3543. The sheet metal to be tested is charged with a weak nuclear radiation. The backscatter effect is dampened through the oil film. After an initial calibration, the amount of dampening is utilized as measurement for the layer thickness. This method has advantages over determining the oil film thickness through the gravimetric method: for example, samples do not need to be cut out of the strips and the oil film thickness can be ascertained much more quickly. Nevertheless, the utilization of even weak nuclear radiation in the framework of production is not without difficulties and requires strict safety and monitoring. This method does not provide absolute measurements, but only comparative measurements using previously calibrated strip samples.
A further method is the use of a gauging device that measures the thickness of the oil film by making use of infrared spectroscopy. It is available on the market in the form of a hand-held measurement device (Figure 1). With such a hand-held measurement device, the oil layer is measured on a spot with a diameter of approx. 15 mm. Irregularities can be ascertained in the surface distribution as well as differences in the oiling on the top and bottom sides. Measurements for an entire coil are theoretically possible but not practical in regular operation.

Figure 1. Hand-held measurement device for measuring oil layers.

Another method to accomplish this is to use the fluorescent effect caused by the illumination of the organic layer with ultraviolet light.[(2)] But beforehand a fluorescent substance must be mixed into the oil. Care must be taken with suitable methods to ensure that the fluorescent substance is uniformly distributed in the oil and does not de-mix over time. This system only provides relative distribution measurements of the oil layer. In order to provide absolute values, it must be coupled with the data of the quantity going through the oil pump. Based on fluorescent effect there exists also the LIF(t)[(3)] method. Problem is that fluorescence differs from oil to oil. Even in different charges of the same oil the fluorescence changes. In consequence a lot of calibration work has to be done, which is additionally influenced by temperature and surface reflection.
As follows, a spectroscopic method will be presented. This method is able to determine the oil film thickness without contact on moving strips. It has also been proven effective in practice in initial industrial applications.

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2.2 Spectroscopic Oil Film Measurement

Infrared spectroscopy is considered to be one of the most effective methods for the chemical analysis of organic substances. The measurement method presented here uses the principle of reflection photometry. To make measurements, the surface to be examined is illuminated with a broadband source of light (Figure 2). The light penetrates the oil film, is reflected by the metal surface underneath, passes through the oil film a second time and is then guided through the collector optics into a detector unit.

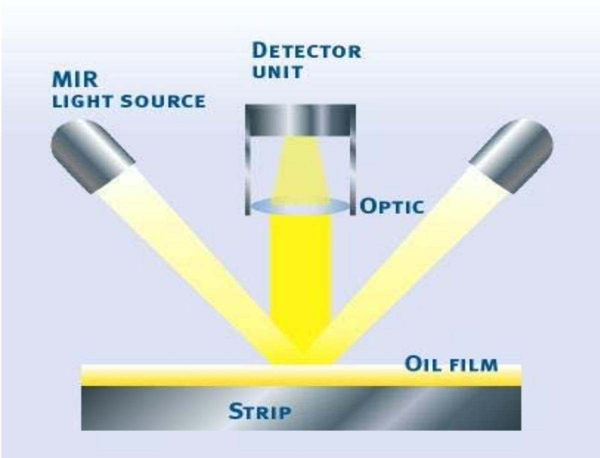

Figure 2. Design principle of a measurement system using infrared photometry.

Oils, such as those used in the steel industry as corrosion protection or for preforming, display virtually equal absorption characteristics in the middle infrared range of the electromagnetic spectrum. In a small range with wavelengths of between 3.6 µm and 4.5 µm (corresponds to a wave number of 2,800 cm^{-1} and 2,200 cm^{-1}) their absorption of the infrared light is intense. In contrast, in the contiguous spectral areas the radiation passes through almost unimpeded (Figure 3).

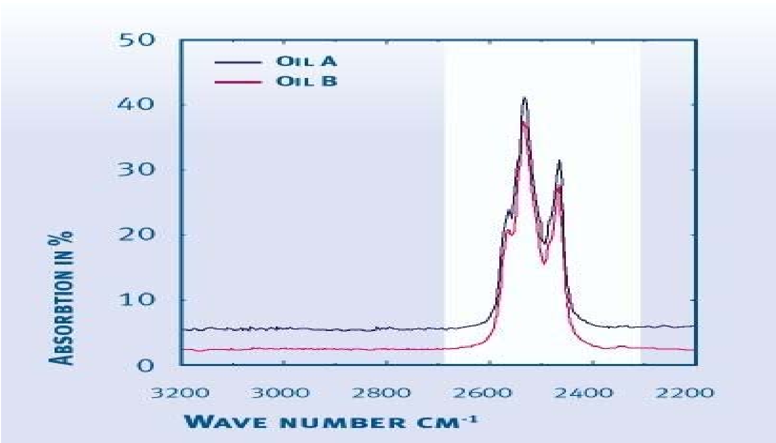

Figure 3. Characteristic absorption.

By means of the Lambert-Beer law, the extinction E(λ) (absorbency of the material for light of the wavelength λ) of oil with the typical wavelength in the median infrared results in:[(4)]

$$E_{(\lambda)} = \ln(\frac{I_0}{I_\lambda}) = C * d$$

After transformation, the layer thickness is calculated to:

$$d = \frac{1}{C} * \ln(\frac{I_0}{I_\lambda})$$

- d thickness of the oil layer;
- I_0 spectral intensity of wavelengths not influenced by oil;
- I_λ spectral intensity of wavelengths absorbed by oil;
- C constant;
- E_λ spectral extinction.

Different surface roughnesses exert influence on the light dispersion in absorbed as well as in unaffected wavelengths. The ratio (I_0/ $I_{(\lambda)}$) remains constant, and thus the system makes measurements independently of the surface roughness.
The spectral reflection behaviour of various surface-finishes varies. This must be taken into consideration through corresponding calibration when measuring the oil layer. For commonly used surfaces such as cold-rolled, galvanized, electro-galvanized, hot zinc, bonazinc, granocoat and others, calibration functions have been developed. These functions are already preset in the measurement system presented as follows.

2.3 Description of the Measurement Head

The measurement system consists of a measurement head which transversely passes over both the top and bottom sides of the strip. An attached computer evaluates and presents the measurement results. Figure 4 shows the measurement head.

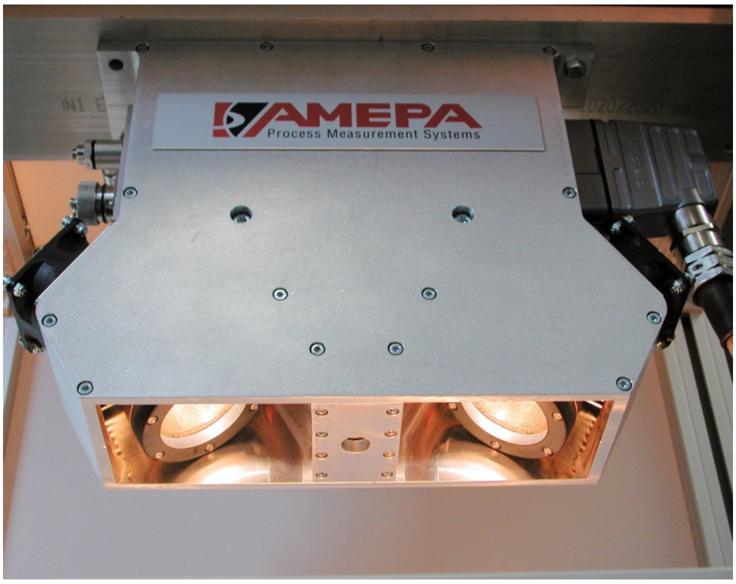

Figure 4. Measurement head.

Two lamps integrated in the measurement head illuminate the strip to be measured. The light is scattered back from the strip. A centrally aligned optical device separates the light spectrally. It is then fed to a low-interference cooled Pb-Se detector.

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Possible age-caused changes in the strength of illumination and thermal drift must be reliably compensated for. The measurement head has an internal reference unit. This compares the lamp power and the dark signal cyclically. So the measurement results are not influenced or affected during continuous measurement operations.
Dust and oil mist can cause the measurement unit to become dirty. The measurement head has an integrated blowing apparatus with aligned air nozzles that keeps the lamps and detector aperture clean.
The measurement spot has a diameter of approx. 15 mm. This makes it easy to recognize faulty oiling as in, for example, dry stripes. The measurement frequency is over 15 measurements per second and allows measurements on quickly moving strips.
The strip cannot be damaged because the measurement head works without contact.
The lamps have been positioned at a distance of approx. 120 mm away from the strip. The head tolerates variations of +/- 20 mm. Thus, strip fluctuations can be compensated for.
The measurement range begins at 0.1 g/m2 and ends at roughly 4.0 g/m2. Above 4.0 g - 5.0 g, the oil “swims” on the strip and absorbs so much light that a precise measurement is not possible anymore.
The head was conceived with the smallest possible design (currently 370 mm x 257 mm x 88 mm) to ensure optimal integration in very limited space on a production line.
No additional calibration is necessary for the various, standard commercial oils. The head can also measure the newly developed “hotmelt”.[(5)]

2.4 System Integration in a Production Line

The measurement head can be implemented for oil monitoring at various production levels. Initial technical experience has been collected at Salzgitter Flachstahl GmbH in an inspection line and in a hot dip galvanizing line. Both production lines are characterized by the fact that the electrostatic oiling apparatus is at the end of the line shortly before coiling. The space conditions for the integration of the measurement system into the line are very limited.
In order to receive area-wide information about the oil film condition of the metal strip, the head must be mounted on a traversing unit. Two measurement heads are needed in order to measure the oil film condition of both the top and bottom sides. Figures 5 and 6 shows the installation.

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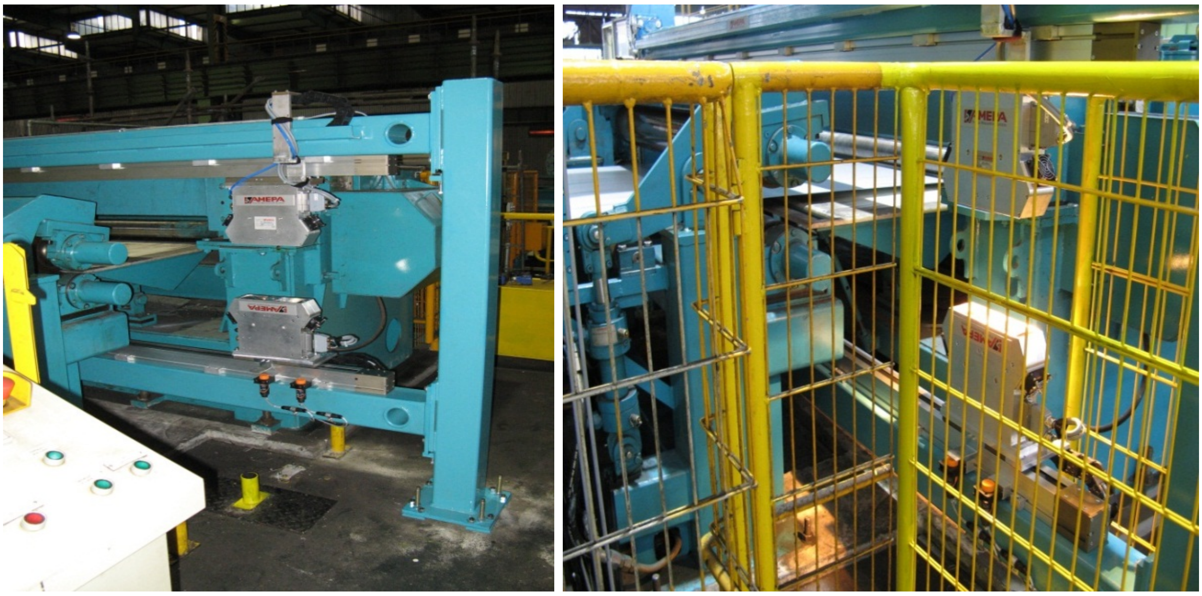

Figure 5. Installation of the oil thickness measurement system in an inspection line at Salzgitter Flachstahl GmbH.

Figure 6. Installation in a forming line of BMW.

The traversing speed can be freely adjusted within certain limitations. It must be ensured that there are no gaps in the measurements over the entire width of the strip. Taking a typical strip speed of 100 m/min to 600 m/min, a measurement spot of approx. 15 mm and a measurement rate of 15 measurements per second, an optimal traversing speed of approx. 180 mm/second to 250 mm/second is calculated.
The evaluation unit, with which the data is read from the measurement head and also with which the traversing unit is controlled, is found in a measurement cabinet that is placed next to the production line. The cabinet is dust protected and conditioned.
The evaluation unit receives the necessary data from the production line. It processes the data in order to evaluate the oil distribution in respect to area. Data is also required about the surface characteristics currently being worked. The measured data of the oil thickness is then integrated into one data file together with the strip speed, target oiling, target transfer value of the oil pump and then presented on a visualization screen.
Data transfer between the oil thickness measurement system and the production line can take place through all common field bus systems or network protocols.
The block diagram (Figure 7) shows an overview of the complete system.

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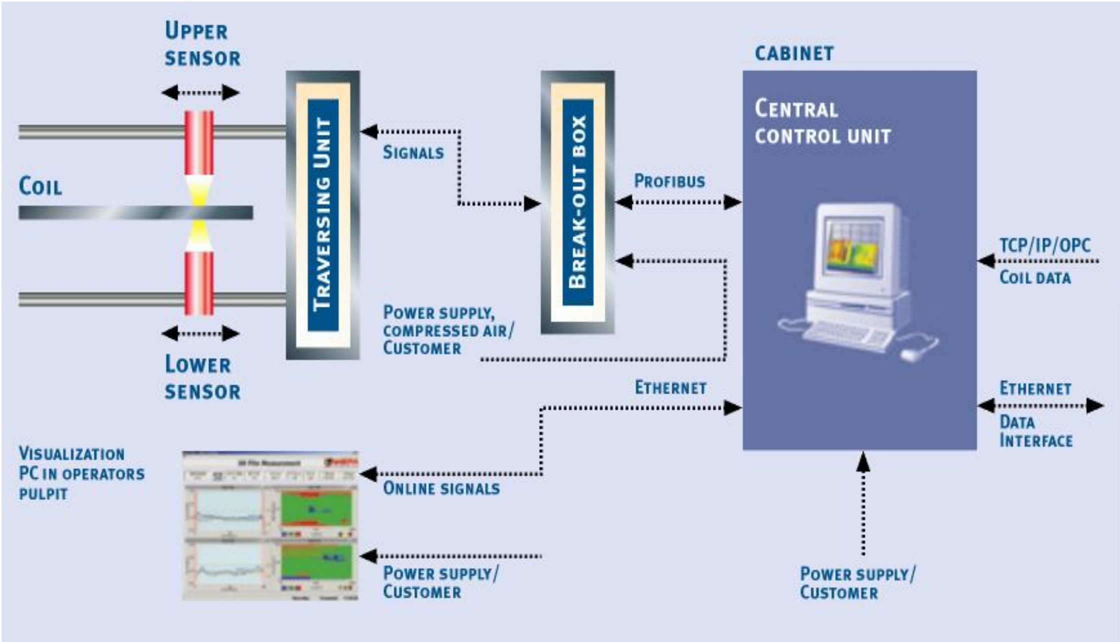

Figure 7. Block diagram.

3 RESULTS

Depending on strip length (commonly 2,000 m - 3,000 m) and speed (commonly 20 m/min - 600 m/min), approximately 3,000 to 10,000 measurement values are created per coil at a measurement frequency of 15 Hz. The best method to evaluate and display the measurement values is a graphic visualization. The design of this visualization screen was implemented in close consultation with the client (Figure 8).

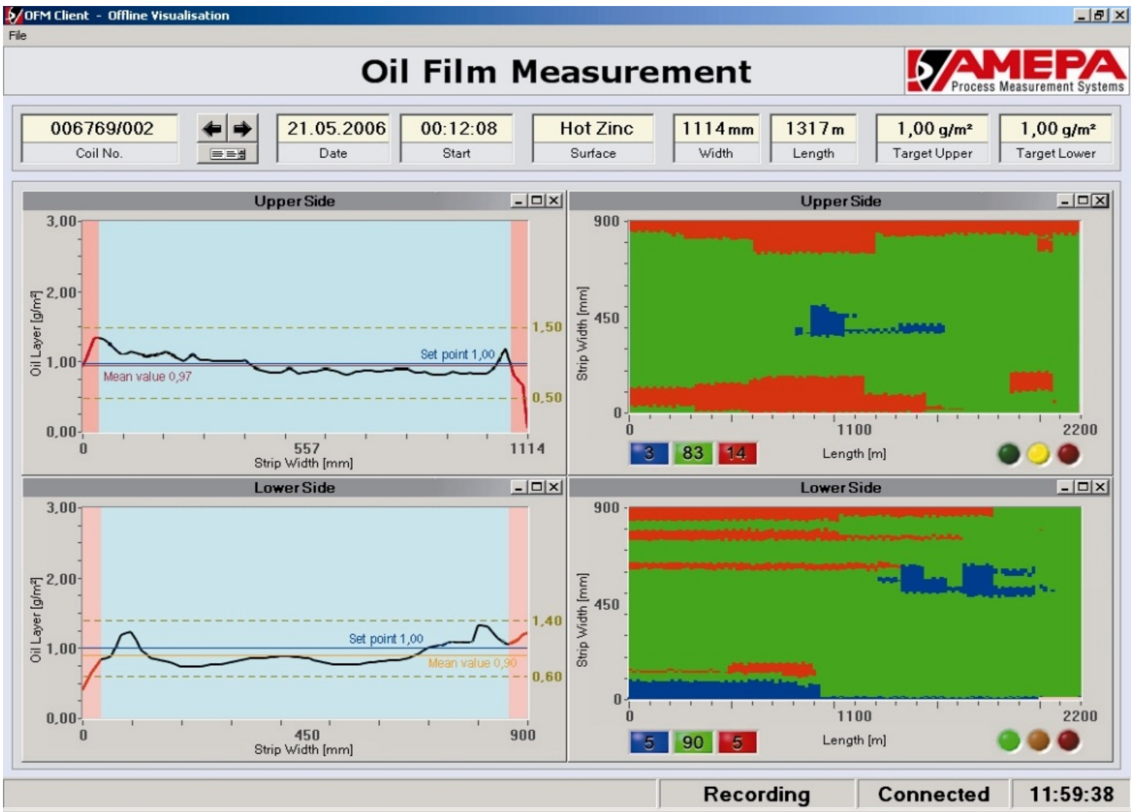

Figure 8. Visualization screen.

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The headline displays the data provided from the plant, coil number, production date, measurement start time, surface type, strip width, strip length, as well as oil target values for both the top and bottom sides.
The graphic is divided into two sections to display the upper and under side of the strip. On the left side the measurement values of a transverse pass are compared to target oil value. The target oil value is displayed as a horizontal line. On the right the sum of all transverse passes is depicted as map of the total strip width and length. The green colour signifies that the application of oil lies inside the tolerance specified by quality assurance. Red means that the oil application exceeds the acceptable value. Blue means that the oil application is below the acceptable value. An evaluation of the blue, green and red areas in terms of per cent is displayed under the colour map. The adjacent ‘traffic-light’ indicator displays whether the strip is well oiled, must be tested again or has to be rejected.
In addition to the visualization of the results on the measurement-evaluation computer, the visualization can also be seen on a remote computer. Furthermore, all measurement values can be integrated into available documentation systems over a field bus or network protocols (such as OPC for example).
The online visualization makes it possible for operators to react immediately to problems in oiling. The visualization can also be configured as a three-dimensional oil thickness map. A few special oiling situations are presented as follows. Some of them have been created by us for test purposes:

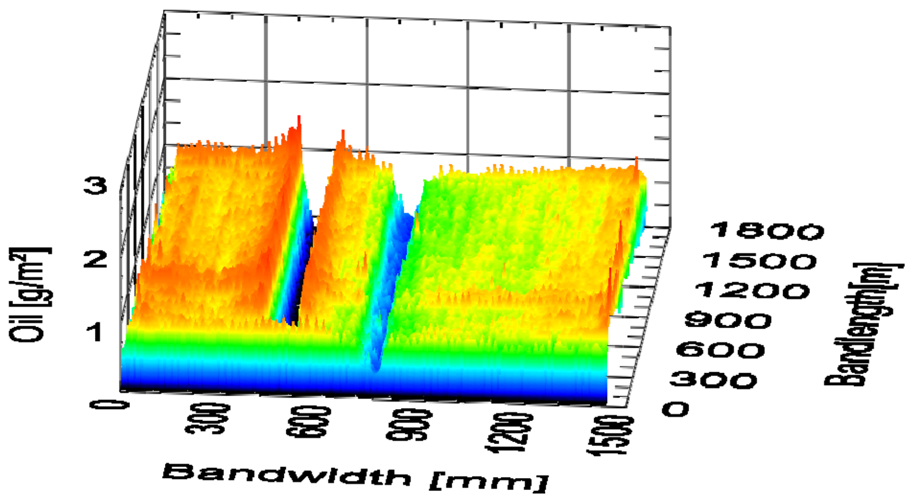

Figure 9. Dry stripe.

Figure 9 seems to show a strip with two dry stripes. In reality there is only one dry stripe at bandwidth 400. The seeming dry stripe at bandwidth 750 is caused by the splitting of the strip in the middle. Dry stripes are caused by clotted or soiled sections in the oiling bar. The figure shows that the surplus oil is distributed on the sides of the dry stripe and conducts to a sectional over-oiling.

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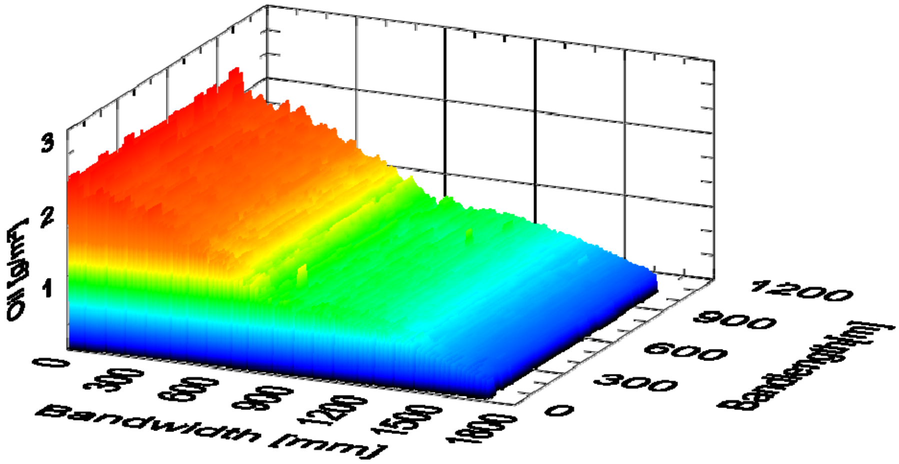

Figure 10. Sloped oiling.

In the strip portrayed in Figure 10, the oiling bar was inclined downwards on one side. This resulted in an over-oiling on the left side of the strip and an under-oiling on the right side.

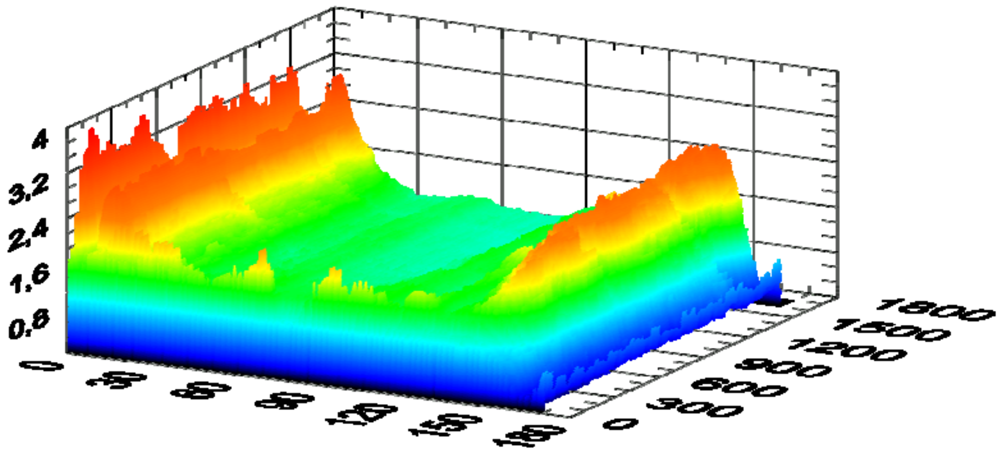

Figure 11. Trough formation.

A trough formation as shown in Figure 11 is often found when the strip has been in storage for extended periods of time. The oil is pressed away from the middle of the strip towards the outer edges, especially with strongly oiled sheets, through the pressure exerted in coiling. This is recognizable at the coil storage where oil can be seen coming out from the sides of the coils.
Trough formation is reduced through further developed corrosion protection/transformation oils – so-called prelubes – which contain thixotropy builders and a transformation additive(6) and are characterized by very good flow attributes in warm or high pressure conditions. In a cooled condition, they are highly viscous and unmovable and thus maintain their position on the strip. Relatively newly developed hotmelt(5) have since also come into use, which exhibit wax-like characteristics in a cold state. Even after storage for a longer period of time, their distribution remains homogeneous.

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4 DISCUSSION AND CONCLUSION

An online measurement system is currently the only way to monitor the oil layer on the entire coil. Oiling problems can be recognized on time, and corrected. With the availability of a safeguarded, documented oil application, in many cases, a further oiling can be avoided. This makes it possible to reduce costs in the framework of the value-added chain. Practical experience at steel and automotive companies proves the feasibility of the industrial application. Other applications directly before the forming or the lacquering process are also possible.

REFERENCES

1 HELMUT FISCHER GMBH, Instruction manual Betascope.
2 DR. REISINGER, BRUCKNER, In-line quantification of oil films on metal surfaces, MPT International 3/2000.
3 STAHL UND EISEN HEFT NR. 6/2011 Inlineschichtdickenmessung.
4 J.W. NIEMANDSVERDRIET, Spectroscopy in Catalysis, ISBN 3-527-28729-4 and WERNER SCHMIDT, Optische Spektroskopie, ISBN 3-527-29828-2.
5 VERBAND DER AUTOMOBILINDUSTRIE E.V., VDA-Prüfblatt 230-202, Hotmelt-Hilfsstoffe für die Produktion-Prüfverfahren (10/2004).
6 VERBAND DER AUTOMOBILINDUSTRIE E.V., VDA-Prüfblatt 230-201, Prelubes-Hilfsstoffe für die Produktion- Prüfverfahren (05/2003).