Two Systems for On-Line Oilfilm and Surface Roughness Measurement for Strip Steel Production

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1. INTRODUCTION

Rising demands of the automotive industry in quality of sheet surface make it necessary to control continuously the oilfilm quality and the roughness of strip steel. Moreover, the optimization of the deep drawing process requires sharp tolerances in the tribological behavior of the material to achieve higher production rates. High-strength steel and aluminum sheet can only be deformed without defect under optimized conditions. Thickness and homogeneity of the oil/lubricant layer and surface roughness are two important factors to reach the best product.

The on-line measurement of these parameters enables not only a complete documentation as expected by ISO 9000 but also a more economic production. The immediate availability allows the direct correction of process parameters if the quality of the oil film or surface roughness is out of its tolerance range. This avoids a cost and time intensive second oiling or milling of the product.

Both systems presented here for the on-line measurement of oil layer and surface roughness are based on approved measurement techniques. The new aspect is the adaptation of these techniques for on-line measurements under the rough conditions of a cold rolling mill.

2. NON-CONTACT ON-LINE-MEASUREMENT OF THE OIL LAYER

2.1 Measuring principle

For the non-contact online measurement of the oil layer on strip steel several optical methods can be used.

The AMEPA-OFM measuring principle presented here works after the principle of the diffuse reflectance spectroscopy (Fig. 2.1). For the measurement the surface to be examined is spotlighted by an illuminant. The light penetrates the oil layer on the sheet, is then reflected by the sheet base and passes the oil layer for a second time. Part of the reflected light is caught and examined by an AMEPA-OFM sensor.

Using this method, no further aid is needed – like for example fluorescence substances. The measurement can be done at the installation location independently from the operation of the plant. For attributing the measured values of the individual points on the strips, benchmark values such as strip speed and nominal oil value are read in. The measuring range of the system measuring the oil layer is from 0.2 to 5 g/m².

Mineral oils typically used by the steel industry as corrosion protection or preforming oils feature an only narrow range in their spectrum within which they strongly absorb infrared light. Within the bordering ranges the oil lets pass the radiation nearly unhindered.

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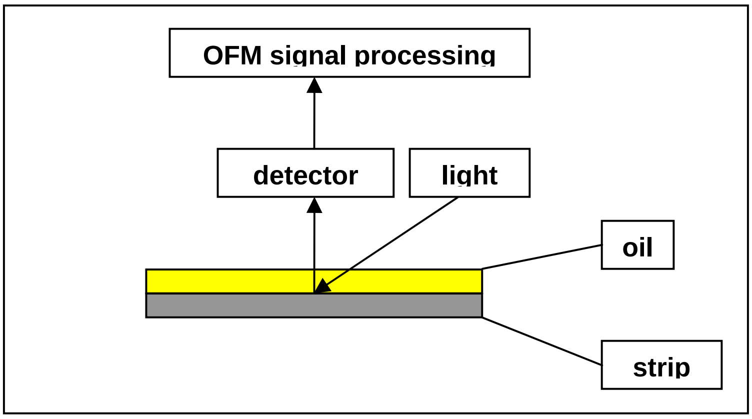

Fig 2.1: Plan of the AMEPA-OFM sensor of the oil layer thickness

By means of the Beer-Lambert law the extinction of the oil with the typical wave-length in the median infrared results in:

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

after transformation the layer thickness is calculated to:

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

d layer thickness of the oil layer
I_0 spectral intensity with wave-lengths not influenced by the oil
$I_{(\lambda)}$ spectral intensity with wave-lengths absorbed by the oil
C constant
$E_{(\lambda)}$ spectral extinction

Different surface roughnesses exert influence on the light dispersion in absorbing as well as in uninfluenced wave-lengths. The ratio ($I_0/I_{(\lambda)}$) remains constant, and thus the system measures independently from the surface roughness.

Measurements of the thickness of the oil layer are carried out on different finished surfaces. Here it has to be taken into account that the spectral reflectivity $\rho_{(\lambda)}$ changes depending on the material. This is accounted for with corresponding calibration of the measuring head. Up to now, calibrations for the following surfaces are available: “cold roll“, “hot-dip galvanized“, “elo-galvanized“ with and without phosphate coating and “Granocoat®“.

2.2 Measuring setup

At Salzgitter Flachstahl GmbH (SZFG) the measuring head as described above was installed in a inspection line. The installation location is situated ca. 2000 mm behind the lubrication machine. Between lubrication machine and sensor a roll is looped by the strip with an angle of about 5°. This roll is necessary to close the oil film, which was applied in the form of finest drops, before the sensor. The sensor is mounted on to a linear axis and is moved across the strip width of a maximum of 1830 mm with about 250 mm/s. The measuring distance between strip and bottom edge of the sensor is 120 mm. Strip deviations of ±20 mm are admissible. The strip speeds of this installation can reach 500 m/min.

The sensor is connected to a processor that enables the evaluation and output of the measured values. Due to a link-up with the control system of the processor of the inspection line allocation data such as coil number, type of surface, required lubrication etc. and status data such as strip speed and current strip length are transferred. This link-up can be carried out via OPC or field bus.

2.3 Display

The combination of installation data and determined measurement values results in a lubrication chart of the entire coil. The distribution of the oil is shown on-line on a display in the control pulpit of the inspection line. The operators can always see the lubrication of the strip currently running and they are thus able to intervene directly in the process in case that inhomogeneities show up with the lubrication.

Figure 2.2 shows the current user interface of the OFM oil thickness monitoring system. The upper line shows all the data related to the coil while the two diagrams show the lubrication.

The diagram to the left indicates the oil thickness over the strip width with the blue line representing the nominal value. The yellow line stands for the average value of the oil thickness measured during the last traversing of the sensor and indicates the numerical value. The upper and the lower limit for oil thickness can be assigned by the operator and are displayed in the picture. In case the limits are exceeded this is shown to the operator by coloring the measured value of the oil thickness, which is normally black.

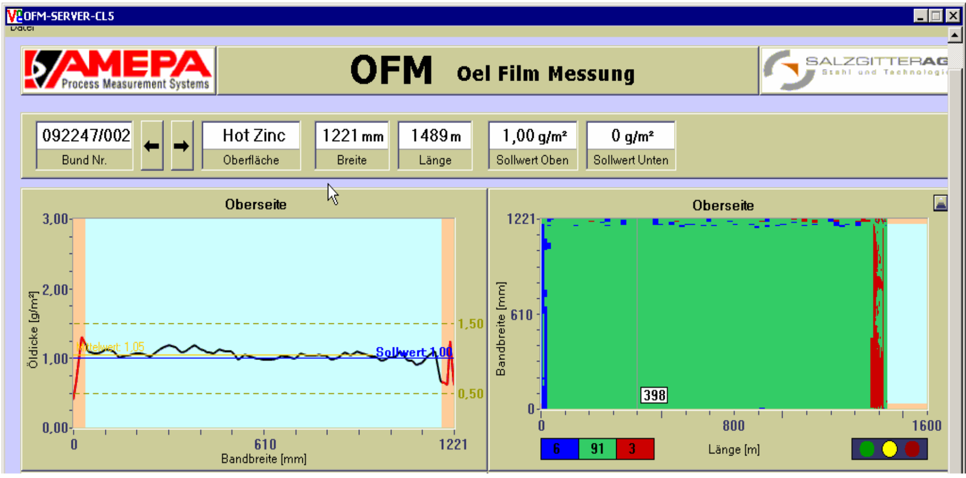

Fig. 2.2: Screen surface of the OFM system in the control station of the SZFG with perfect lubrication

Shown in the diagram to the right is the distribution of the lubrication over the strip surface. Green areas stand for measured values within the tolerance limit, blue areas for values below the limit and red areas show that too much oil has been applied. The small case left below the diagram shows the proportion of the individual areas in the entire area (in percentage). Next to it, by means of the stoplights, the operator is given some guidance in whether to release or block. On the basis of the area proportions, the operator parameterizes the threshold values for the change between red, yellow and green. The example in figure 2.2 shows a strip which is lubricated rather uniformly.

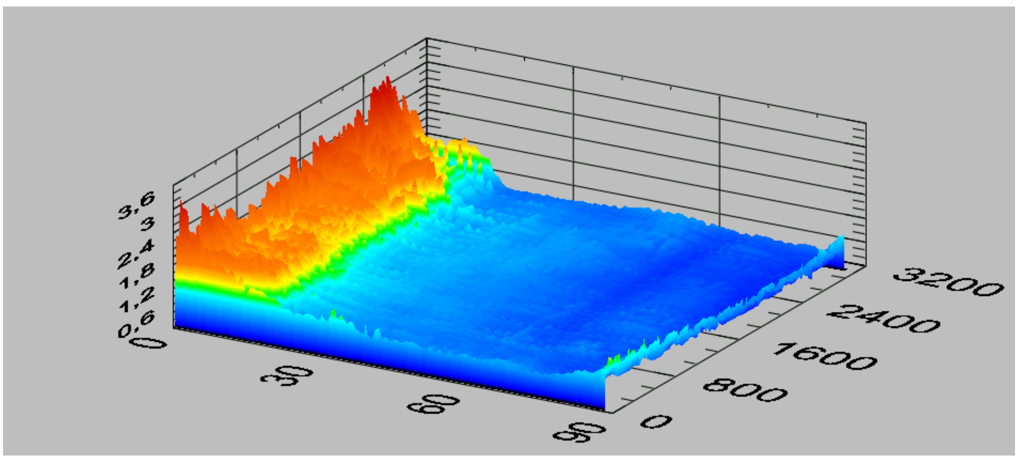

Fig.2.3: A difference in the lubrication between the left and the right of the strip

Figure 2.3 shows a 3-dimensional plot of the lubrication of a coil with a length of about 3000 m and a width of 0,8 m. The thickness of the film is plotted in the vertical direction. Again the three colors green, blue and red represent areas where the lubrication is within, below or above the tolerance limits. On this coil a difference in the lubrication of the right and the left side of the strip is shown.

If strips, which have already been lubricated in another installation, are processed in the inspection line, the current lubrication status can also be determined with the OFM system. The example in figure 2.4 describes the lubrication distribution of a pre-lubricated strip, which was reworked in the inspection line. Due to the preceding storage the oil was squeezed outwards.

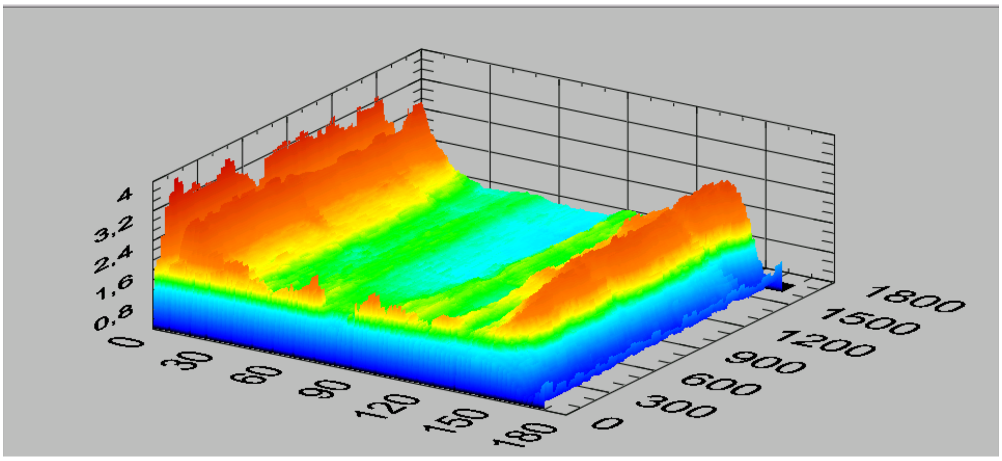

Fig. 2.4: Strip reworked in the coil line. Due to the preceding storage the oil was squeezed outwards.

2.4 Outlook

With the online system, SZFG will be able to check the correct function of the lubrication machine during lubrication of the strips and to increase the reliability of the installation. The OFM system also allows to measure pre-lubricated strips of other installations during processing and, in case of irregular lubrication, to take the necessary actions. The continuous recording of coil related oil data into databases of the quality assurance will help not only to supervise and improve the condition of the installation but also to handle reclamations.

3. ON-LINE SURFACE ROUGHNESS MEASUREMENT ON STRIP STEEL

Today the roughness is measured on samples taken from head or tail of the coil. This measurement does not give a representative value for the roughness distribution over the length of the coil because rolling force and speed are reduced when the welding passes the skin pass.

The optical on-line roughness measurement provides a measurement over a significant part of each coil and could be used for a more complete documentation of this important product property according to ISO 9000. The on-line measurement could not only be used for sharper production tolerances but it could also be used as tool for a more precise trigger for the change of the texturing rolls.

Here we will present the development, laboratory results and on-line measurements of the industrialized version by Amepa based on the original development by the Center for Research in Metallurgy (CRM) in Liège /1/.

3.1 Measuring Principle

The presented roughness measurement system uses the two-dimensional triangulation, also known as light-section measurement. The CRM has refined this principle for the on-line roughness measurement on strip steel. Successful tests were done at Arcelor Flat Carbon Steel, Gent /1/.

For the roughness measurement a laser line is projected under a certain angle onto the surface. Due to the surface profile this line is distorted if it is observed not under the same angle than the projection. This distortion allows a direct calculation of the surface profile and hence the surface roughness. A more detailed description can be found in /1/.

On-line roughness measurement principles that use a laser spot for the roughness measurement depend on the movement of the strip to achieve data in the second dimension. Therefore these devices are only able to measure parallel to the rolling direction. The light section principle allows an arbitrary orientation of the line and so roughness can be measured perpendicular or under 45° to the rolling direction as SEP 1940 /3/ demands.

3.2 System Design

The sensor consists of a laser system for line projection and of a microscope with a high resolution CCD-camera for the observation of the distorted line. An additional laser is used for background illumination enabling a direct inspection of the microscopic image of the strip surface which can be done normally only in laboratory.

The main difference to the CRM prototype is the usage of diode lasers instead of a solid state Nd:Yag laser. The advance of the diode lasers is the more compact construction of the sensor and the more flexible installation of the system because the lasers can be placed direct into the sensor head. The higher wavelength of the diode laser system leads to a decreased resolution which is mainly compensated by a high aperture microscope objective.

For the necessary adjustments of the optical system fully motorized stages are used. This means the settings for installation or corrections can be changed whenever necessary. No production stop is required. An installation at nearly inaccessible locations is possible as well. These properties guarantee a high availability and a flexible operation.

3.3 Laboratory results

The laboratory results can be divided in three sections. The most important are the comparative measurements with the stylus on different textures and surface qualities over a wide range of roughness. Optical roughness measurements on roughness standards used for the calibration of stylus systems are also presented. These two groups allow a comparison of the optical measured statistic roughness values with the results of a stylus and with the values of the calibration standards. For a qualitative measurement the optical sensor was also used in a scanning mode – which is only possible in laboratory – to get a three dimensional image of the surface. The plausibility of the measurement principle can be shown better than with the analysis of the statistical values.

The stylus measurement requires a measurement length of 12.5 mm. Therefore we used the average value of 24 optical measurements with a laser line length of 530µm each.

The results of the optical measurements on roughness standards are listed in table 3.1. The standards were chosen to cover the roughness range important for strip steel production.

Table 3.1: Optical measurement on roughness calibration standards

Roughness Standard	nominal Ra [µm]	optical measured Ra [µm]
Halle KNT 2058/2	0.45	0.49
Halle KNT 2058/2	1.1	1.07
Mitutoyo Specimen No 178-601	2.97	2.91

The results of laboratory measurements with the stylus and the optical system show a very good agreement (Fig. 3.1). The investigated samples cover a wide range of roughness, but also stochastic and deterministic textures (EDT, Pretex, EBT) and different surface qualities (cold rolled, annealed, galvanized) as well.

Only for roughness values smaller than 0.8µm the deviation is higher than 10%. For most samples the deviation was less than 5% which is in the same order than the deviation of stylus measurements done by different operators with different stylus systems /4/.

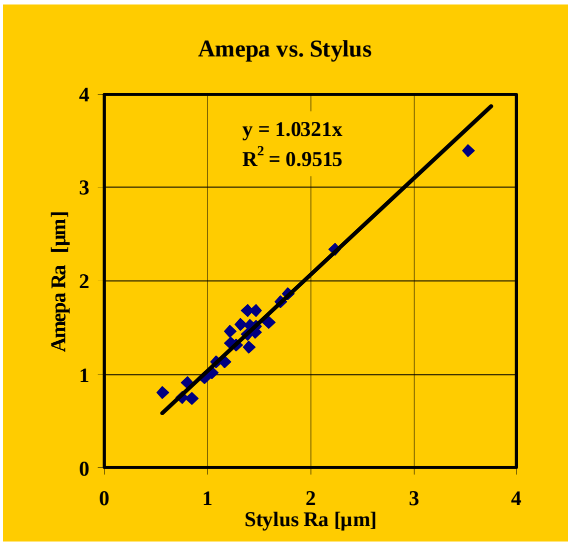

Fig. 3.1: Comparison of the optical roughness measurement with stylus on different sheet samples with different textures and surface qualities

To prove the plausibility of the detected lines we used this system to scan over sheet surfaces. Using a step width of 0.5 µm complete three-dimensional data sets of different surfaces were acquired. One example of such a data set is presented in Fig. 3.2. The lateral resolution is 0.5µm and the resolution of the height profile is approximately 0.1µm which is of course less than can be obtained with interferometric systems /2/.

Due to the high reflectivity of galvanized surfaces they are very interesting for a system which analyses the scattered light. In Fig. 3.2 the 3d-measurement on a galvanized EBT sample is shown. The image on the right shows the microscopic image of the surface. The color-coded 3d-scan shows, that 95% of the strip surface is detected. Only in the dark-red and dark-blue zones no value for the height level was measured because the light was nearly completely reflected so that the scattered portion was too weak. These missing data can be interpolated in the on-line roughness measurement because they represent parts of the surface which are very flat. The clearly visible fine structure gives a good impression of the resolution of the system.

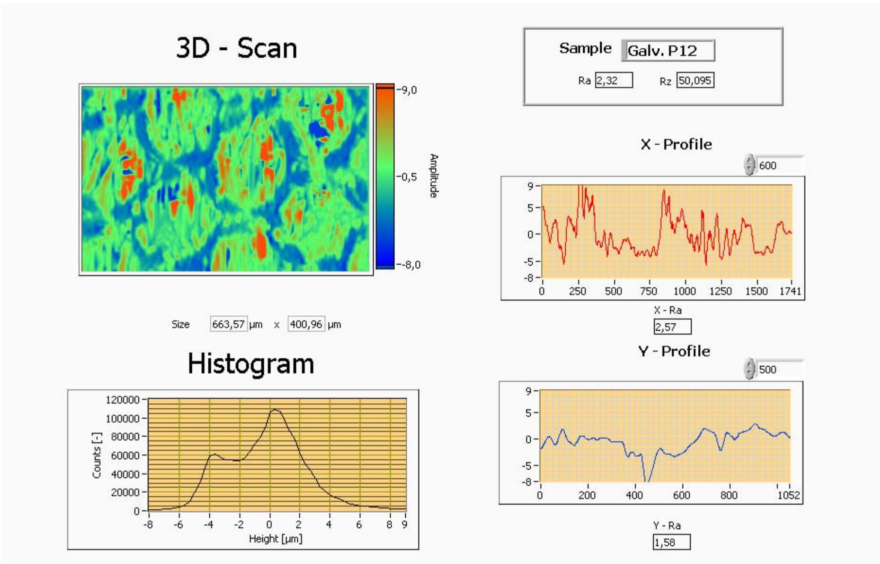

Fig. 3.2: On-line sensor moved in steps of 0.5 µm over a galvanized EBT surface to collect a 3d-data set. The unfiltered raw data are shown (dark-red and dark–blue are regions where no signal was detected). A microscopic image of the analyzed region is shown on the left.

3.4 On-line Measurements

For on-line measurements the system was installed at Arcelor Flat Carbon Steel, Gent. These online measurements were overseen by the Rolling Annealing Finishing (RAF) group of Arcelor Research. The Amepa system was tested on different production lines. In the beginning the sensor was installed after the skin-pass at the exit of the continuous annealing line (CAPL). To test its performance on polluted surfaces the sensor was installed at the entrance of the CAPL. In spring 2006 the system was installed at the exit of the galvanizing line at Sidmar.

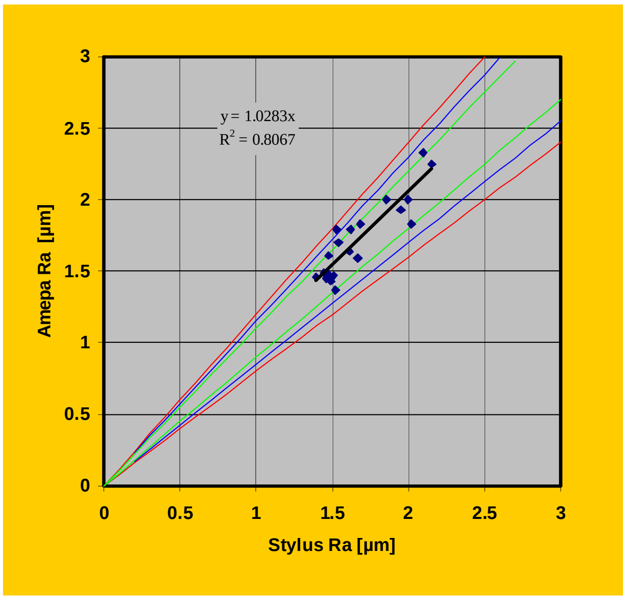

Fig. 3.3: On-line results of one production shift at the continuous annealing line at Sidmar, Gent (green +/- 10%, blue +/-15%, red +/-20%).

At first the on-line roughness measurement system was installed at the exit of the continuous annealing line after the skin pass mill. In Fig. 3.3 the mechanical off-line and optical on-line roughness measurements of one production day are shown. For the mechanical roughness three stylus measurements were done at the end of each coil at the strip position where the optical sensor was installed. The optical measurements were saved in the Sidmar database and the mean value of the last 10% of the coil was calculated for the comparison with the stylus results.

To test whether this system could also be used on polluted surfaces the sensor was installed at the entrance of the continuous annealing line where the surface of the coils is still contaminated from the milling process. The result of one of these tests is shown in Fig. 3.4, where a coil was produced in the tandem mill with increasing rolling forces. Afterwards the roughness was measured in the inspection line with the stylus and than this coil was sent through the continuous annealing line where the optical on-line measurement was done.

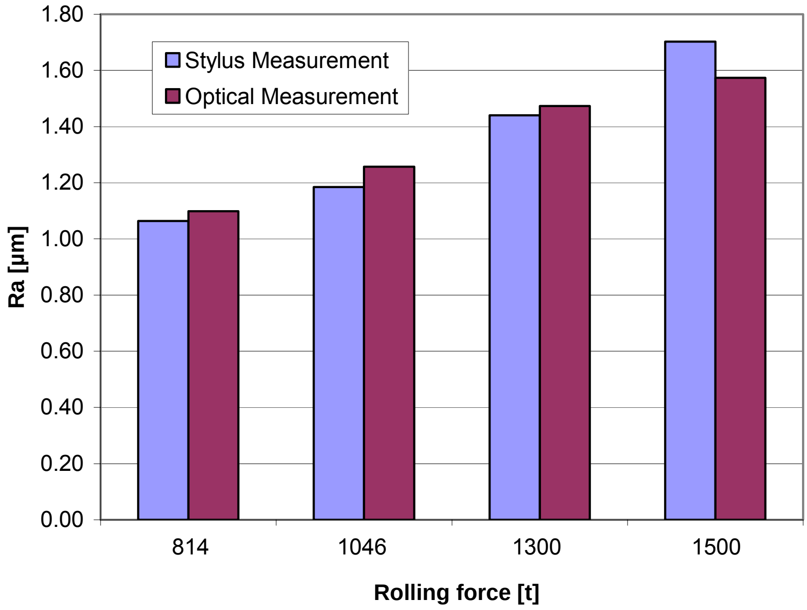

Fig. 3.4: EBT Surface, rolled with different rolling forces in the tandem mill: comparison of optical and mechanical roughness measurement on polluted surface at the entrance of the continuous annealing line.

3.5 Conclusion

Amepa has developed, based on the CRM prototype, an on-line roughness measurement system. This system has a similar performance than the CRM system and its results show a good agreement with the stylus measurements in laboratory and in on-line trials as well. It delivers roughness information over the complete length of the coil. This opens the possibility of process optimization during cold rolling and a complete documentation of this product property.

The here described measuring principle enables a roughness measurement perpendicular or under 45° to the rolling direction (SEP 1940) unlike optical systems which calculate the roughness out of a series of punctual measurements measuring always in rolling direction. The Amepa system works independent of the investigated surface, of its roughness, coating or texture, therefore no calibration is required. For a verification of the system it is possible to use the roughness standards used for stylus systems as well.

4. References

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