INTRODUCTION

Steadily rising demands on the strip surface quality force mill operators to increased efforts. This applies for steel mills as well as for aluminium and other non-ferrous metals strip producers. The course of these efforts brought up more and more the weak points of flatness rolls and its contact based measuring principle with a non uniform surface of the rolls. Solutions therefore have been found by coating the rolls with chrome, rubber or other materials. The new generation of measurement rolls tries to solve this problem by closed solenoid roll bodies. But this leads to more impact of force-flow to neighbourhood sensors, and this makes it difficult to get a correct interpretation of the measured force especially in the strip edge area.

This situation was the challenge for the development of a flatness measurement system that overcomes the well-known problems. This development was done by the Siemens Research Centre, Munich in co-operation with the cold rolling mills technologies department of Siemens in Erlangen, Germany. The result of this development was a flatness measurement device is working on a contact-free principle. Since its introduction in 2002, installations for almost all types of rolling mills and different materials to be rolled have proven the functionality and benefits in daily operation in industrial application.

FUNCTIONAL PRINCIPLE OF THE SYSTEM

The basis of the SIROLL\textsuperscript{CIS}SIFLAT (SIFLAT) principle bases on a periodical excitation of the strip. The different excitation amplitudes across the strip width are measured and represent a measure for the strip tension distribution.

The excitation force is applied to the strip by sucking the air under the bottom side of the strip through a perforated base plate which is located approximately 5mm below the pass line of the mill stand. A modulator opens and closes periodically an air shaft, thus achieving a periodical excitation of the air stream between strip and sensor plate, which consequentially is applied to the strip. The modulator speed is controlled to adjust the applied frequency which has to be below the natural frequency of the strip under tension.

![Figure 1: Functional principle of SIFLAT](image)

The applied average amplitude of the strip is approximately 0,15mm, and it is kept constant over all dimensions, tensions and qualities of the rolled material. Therefore the power of the air stream is adjusted to the strip properties by controlling the fan speed.

The excitation amplitude of the strip is measured by eddy current sensors which are embedded in the base plate. The signal generated by each sensor is filtered on-line by a FFT (Fast Fourier Transformation) analysis and taken as one
measurement value of the flatness. The FFT analysis ensures that disturbances - e.g. vibrations in the strip - do not influence to the result of the measurement.

![Figure 2: Installation in a Cold Reversing Mill](image)

The signals from the individual sensors are then guided to an analogue - digital conversion unit. From there, the pre-processed data are transmitted to the evaluation process, which is typically a PC based system. From there, the measured values are visualized, and are available for the flatness control system.

![Figure 3: Easy Access to the Measurement Unit](image)

### MAIN ADVANTAGES OF THE SIFLAT SYSTEM

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Description</th>
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<tr>
<td>Contactless</td>
<td>No strip damages, wear free, low rate of maintenance</td>
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<td>Strip speed independent measurement</td>
<td>Significant reduced off-length</td>
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<td>Consistent data acquisition</td>
<td>Solid data set, no influence of short time tension variations</td>
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<td>Excitation amplitudes controlled by</td>
<td>Sensors are always in optimum range for all the fan power dimensions and the complete range of tension</td>
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<td>No disturbance forces due to contactless measurement</td>
<td>Less sensible to disturbance forces</td>
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<td>Integrated strip edge detection available</td>
<td>Economical and reliable solution</td>
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<td>Sensor diameter 18 mm</td>
<td>Best possible resolution even on the strip edges</td>
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<td>Very simple calibration of the sensors</td>
<td>Time-saving calibration</td>
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<td>No need of spare roll and special calibration Device</td>
<td>Reduction of investment and maintenance cost</td>
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<td>Reduced wear and quicker maintenance</td>
<td>High availability</td>
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<td>No sensors or electronic parts are rotating</td>
<td>Simple maintenance, no transfer of the data from the rotating part to the fixed part necessary</td>
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### INSTALLATIONS AND RESULTS

The first installation of the new developed system was for a stainless steel cold reversing mill. Since this a lot of other installations in both existing as well as new build rolling mills have been executed. The applications are proven in different types of rolling mills, and for different kinds and sizes of materials.
The working range covers strip widths up to 2080 mm (until now), and strip thicknesses from 0.08 mm to 4.5 mm. Operational strip tensions are up to 500 kN with strip speeds of 1200 m/min, and strip temperatures of up to 180 °C.

Figure 4: SIFLAT in different applications

In some of the first installations, SIFLAT was operated in parallel to roll-based measurement systems. This gave an excellent opportunity to compare both measurement systems.

Figure 5: Screen shots, comparison SIFLAT with roll based measurement

Prior to the first industrial installation in the Aluminum industry, the SIFLAT measurements had to be verified on a laser based plane table. SIFLAT passed these tests and thus proved the reliability of the measurement for Aluminum, too. The latest orders for two Aluminum Cold Rolling Mills in China are designed for a strip width of up to 1800 mm, and strip thicknesses from 0.15 mm to 4.5 mm.

Figure 6: Comparison SIFLAT measurement with Laser based offline measurement / material = Aluminum

One of the advantages of SIFLAT is the speed independence of the measurement method. This leads especially on cold reversing mills to significant reductions of the off-length on the strip head and tail-end.

Figure 7: Measured flatness accuracy on a 6-high Reversing Cold Mill

**FLATNESS CONTROL**

The flatness control system within SIFLAT determines the deviation of the measured strip tension stress distribution from the selected set-point curve. The created curve of control deviation is analysed with the aid of a mathematical algorithm and allocated to the available actuators according to their efficiency factors. Each actuator takes over a component of the control difference according to its "actuator efficiency". The actuator efficiencies are determined on-line by a neural network based model specially developed by Siemens. The
analysis is based on the control deviations, a least square analysis and on the actuator efficiencies. The flatness control procedure then combines the actuator settings so as to ensure, even during the alteration, a coordinated interaction between the actuators. In this way undesirable tension distributions during the actuator setting are avoided. In addition the effect of roll force changes on the gap profile is compensated by a feed-forward control operating on the other gap actuators (roll bending, shifting, tilting) whose characteristics are also determined using a neural network.

The variable combination of the actuator movements, together with the self-learning function for the estimation of the actuator efficiency and the feed forward characteristics allow the application of the control principle for any actuator or stand type. The control system adapts itself automatically to achieve the best performance for any combination of the available actuators.

**OUTLOOK**

Already the first test installation in 1999 confirmed the expectations of the SIFLAT concept. The experience gathered from the installations since then led to constructional improvements of the original design in terms of longtime behaviour and maintenance friendliness of the device. In all applications, the measurement results fully met and even exceeded the expectations of both, supplier and (even) customer. All projects were completed in schedule and the final acceptance of the customer is issued typically after 3 to 4 weeks operation.

The installations, now working partly for more than 5 years, show an outstanding good longtime availability that confirms the statements that have been made earlier. Today, the system is fully accepted in the market, the market awareness is very high. With SIFLAT, Siemens once more has proven its commitment to the Metals Industry and its role as a innovative company.