Contactless measurement for strip flatness in cold rolling mills

Siemens has developed SI-FLAT, an innovative contactless flatness measurement and control system that provides more precise control of tension stresses in cold rolled strip.

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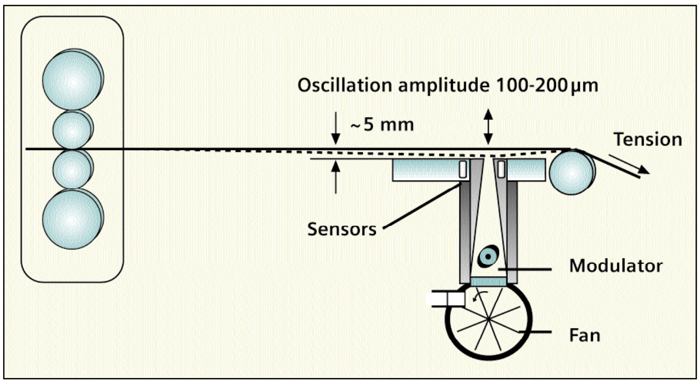
Poor control of flatness in cold rolling leads to non-uniform distribution of tension stresses across the strip width. Since this can cause the strip to break, it is essential to provide reliable measurement of the strip tension distribution (flatness), as a prerequisite for effective control. Siemens has developed a non-contact flatness measurement device and control package, SI-FLAT, for demanding requirements. The measurement principle and details from successful system installations are described.

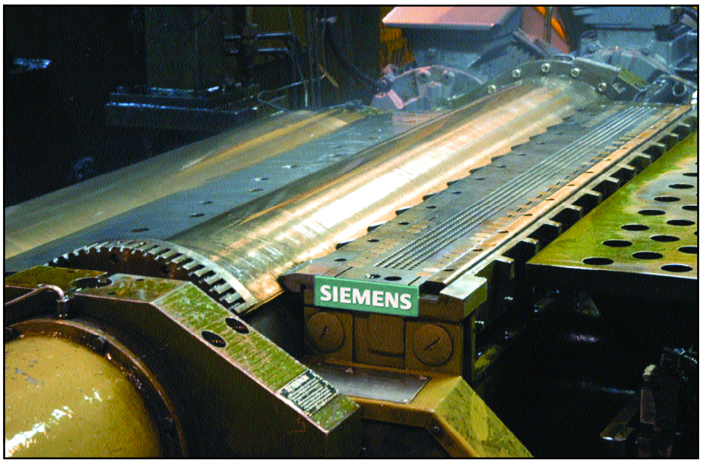
Measurement of strip flatness

In the last decade, there has been significant improvement in flatness measurement and control systems such that most rolling mills are now unable to operate effectively without them. These systems are all contact-based radial force measurement systems, using force transducers integrated in a deflector roll. However, the increasing demands on the strip surface, for example on bright-annealed stainless steel, has highlighted the weaknesses of contact-based measurement.

Interim solutions have been found by coating the rolls with chrome, rubber, or other materials. With these special coatings, scratches on the strip surface can be kept within specification, albeit at high investment and maintenance costs. Reversing cold mills for bright-annealed stainless steel are normally equipped with four flatness rolls: two are in operation at any given time, one is ready to be changed if the rubber coating gets damaged because of a strip break, and the fourth roll is in the grinding or re-coating process. New coatings are required approximately every three to six months, and extra calibration equipment is required, to reduce process downtime.



● **Figure 1** ***Schematic cross section of the system***

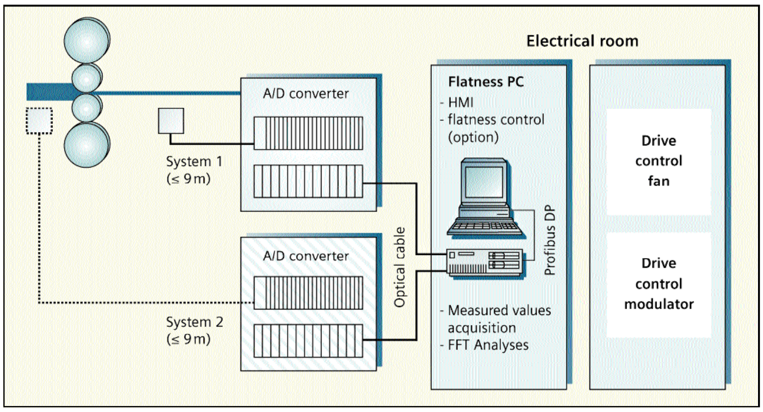


● **Figure 2** ***Close-up of SI-FLAT in mill line***

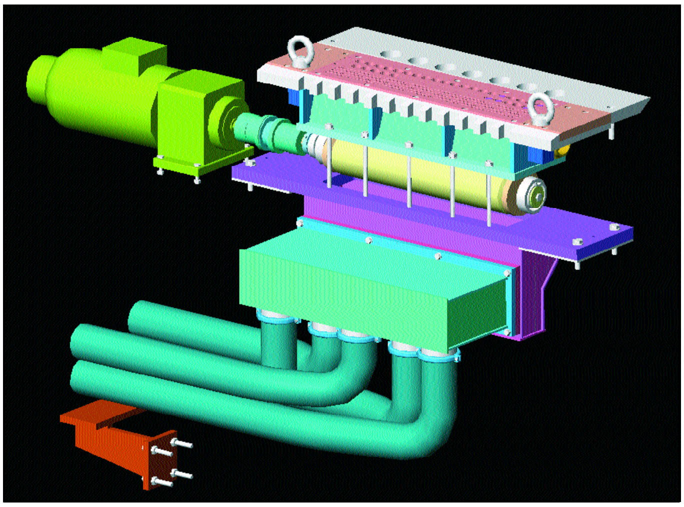
Out of these drawbacks arose the need for a non-contact flatness measurement system. The SI-FLAT development, which began in 1998, was handled by the Siemens Research Centre in Munich in cooperation with the Cold Rolling Technologies department in Erlangen.

Principle behind SI-FLAT

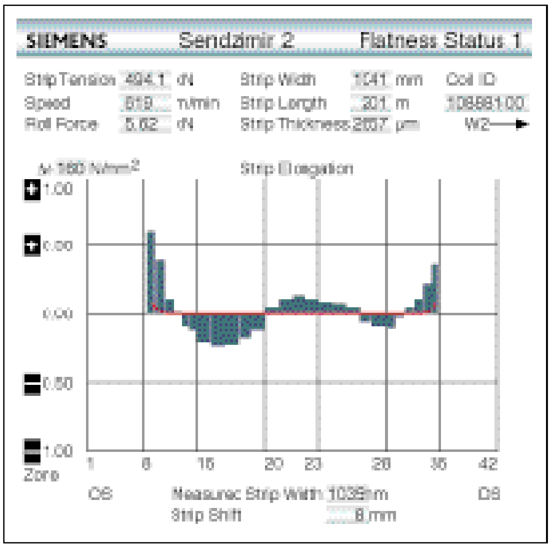
The solution, embodied in SI-FLAT, was found in a periodic excitation of the strip followed by measurement of the excitation amplitudes across the strip width, which indicate strip tension distribution. The excitation force is applied by creating a vacuum between the strip and a sensor plate which is located approximately 5mm below the pass line of the mill



● **Figure 4** ***Signal processing***



● **Figure 3** ***3D construction model of the device***



● **Figure 5** ***Typical data presentation***

stand (see *Figures 1* & *2*). An air shaft is opened and closed periodically by a modulator to achieve a periodic excitation of the air between the strip and sensor plate. A schematic 3-D model is shown in *Figure 3*.
The SI-FLAT measurement device comprises:

- A fan to create the vacuum
- Air pipes from fan to the pressure balance container
- A speed-controlled modulator
- A sensor plate containing the holes for the air flow and the sensors for the measurement of excitation amplitudes
- Electrical equipment for the electronic evaluation and drive controls

The speed of the modulator is controlled to adjust the applied frequency, which must be below the natural frequency of the strip under tension, and the excitation amplitude of the strip is measured with non-contact eddy current sensors and filtered online by Fast Fourier Transformation (FFT) analysis. Vibrations in the strip thus have no impact on the measurement result. The applied average amplitude of approximately 0.15mm is constant, irrespective of strip gauge and width, and automatically adjusted by controlling the fan speed.

Signals from the individual sensors are guided to an analog-digital conversion unit installed close to the mill line. From there the pre-processed data are transmitted to the evaluation unit, which is typically a PC. The PC enables the measured values to be visualised and makes them available to other systems (see *Figure 4*). As an option, a standalone flatness control system can also be implemented.

The sensors are connected to the sensor electronics by coaxial cables with a maximum length of 9m. Measurement signals from the sensors are converted into digital form, transferred to an electrical room via fibre optic cable, and processed there with the measurement acquisition PC. The drive control for modulator and fan is also located in the electrical room. Neural networks are used to adapt the effectiveness of actuators.

The crucial advantage of the non-contact measurement principle over other devices lies in the fact that it dramatically reduces the risk of damage to the strip surface and causes no wear of the measurement device, so reducing maintenance costs.

Benefits of SI-FLAT

Speed independence Conventional flatness measuring rolls depend on the rolling speed (typically one measurement per revolution). Thus, at

Year order	Material	Mill type	Thickness min-max [mm]	Width max. [mm]	No. of devices
2000	Stainless steel	Sendzimir	0.30–6.5	1,320	2
2000	Non-ferrous	4-high	0.20–2.5	470	2
2000	Carbon steel	6-high	0.15–4.0	830	2
2002	Titanzinc	Tandem 4-high	0.40–2.0	1,250	1
2003	Carbon steel	6-high	0.20–3.0	1,100	1
2003	Carbon steel	6-high	0.20–3.0	1,100	1
2003	Carbon steel	Tandem 6-high	0.30–2.5	2,080	1

● **Table 1** ***Cold reversing mills used to pilot the SI-FLAT system***

the beginning of the pass, due to the low rolling speed, the measurement rate is very low, say one measurement every three seconds. Because SI-FLAT measurement is time-based, the sampling rate is independent of the rolling speed and so it enables the system to measure even when the mill is stopped. SI-FLAT measures up to 10 times per second for all speeds and this faster response time enables the control system to correct critical flatness errors immediately and so leads to significantly reduced 'off-lengths'. This is a big advantage, especially for reversing cold mills and temper mills, because the biggest flatness errors normally appear immediately after starting a pass.

Consistent data acquisition A consistent measurement set is taken from all sensors at one time, compared to a distributed sampling over one revolution of the roll with some of the conventional systems. This leads to a higher quality measured value, which is unaffected by short-term tension variations. *Figure 5* illustrates a typical data output.

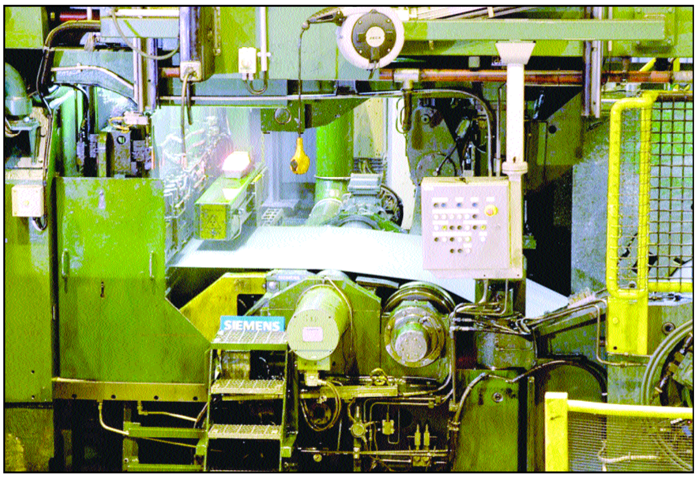
Higher resolution The design principle and the type of sensor selected allows for a shorter arrangement of the sensors than with a conventional measurement roll. While other systems have a sensor diameter of more than 25mm, the SI-FLAT sensor diameter is 18mm, with a typical inter-sensor distance of 15 mm. This enables higher resolution of the measured flatness, which is especially important on the strip edges. The sensor arrangement can be selected individually for each plant.

Wide measurement range Conventional flatness rolls have to be equipped with force sensors that are designed to measure the maximum force (maximum strip tension). For the thinnest gauges, rolled with minimum strip tension, the force on the sensor is much lower, with resultant loss of accuracy SI-FLAT works with the same excitation amplitude for all strip dimensions, and through the whole range of strip tension. This is reached by automatically adapting the excitation force to the process via the fan speed, hence the sensors are always working with optimum stroke.

Less susceptible to disturbance Conventional flatness rolls must contend with several disturbance forces arising from the bending of the flatness roll under tension, bending of strip over the roll, and forces due to strip shift (especially by rolling an asymmetric strip profile). Because SI-FLAT has no contact with the strip, it cannot be influenced by such disturbance forces.

Strip edge detection As an option, SI-FLAT can also be delivered with strip-edge detection integrated into the system. Additional sensors in the edge area of the device enable a higher resolution and provide accurate edge detection.

Ease of maintenance The device does not have to be removed from the mill line for calibration. A calibration plate, covering all sensors, is simply placed on the device and all sensors are quickly calibrated in parallel with simple pushbutton actions, and without the need for a separate calibration stand. Additionally, compared to conventional systems, SI-FLAT features a significantly longer service life due to reduced wear and faster maintenance. The sensor surfaces are covered by plates to protect them against damage by scratches of rolling material during threading-in or threading-out (see *Figure* 2). The sensors are monitored electrically, so that a defective sensor can be automatically marked and removed from the measurement. As sensors can be individually and easily replaced directly in the mill, a complete spare measuring device is not required, so minimising investment and maintenance costs.



● **Figure 6** ***Installation in mill line***

Plant installations

During the pilot phase, SI-FLAT underwent several design modifications. Today, all requirements for safe installation and operation have been satisfied, including working under challenging environmental conditions involving emulsion and rolling oil. A test system was temporarily installed in the downstream side of a reversing rolling mill for copper and copper alloys. The results from this implementation were very promising and formed the basis for the acquisition of first pilot projects on a number of cold reversing mills (see *Table 1*).

The pilot devices were built to fit actual mill conditions (see *Figure 6*) and, despite the extremely narrow spaces, installation took place without major problems. In some cases, the new device was installed in parallel to conventional flatness rolls, enabling comparison of different methods to be made.

The test installation showed the functionality of the new concept and, during operation of the pilot installations, the measurement results fully confirmed the expectations of both the supplier and customer.

After three years of operation in three pilot installations, all expectations have been fulfilled. In one installation, where SI-FLAT was installed beside conventional flatness rolls, the old system is now out of operation.

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