22 State-of-the-Art, Noncontact Infrared, Laser and Microwave Intelligent Sensors and Systems for Steel Mills

Francois Reizine, Bingji Li, and John Nauman

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22.1 CURRENT SENSOR TECHNOLOGIES

Accuracy and reliability are very important in the harsh steel mill environment that is filled with steam, water, dust, scale, and heat. This environment leads to very high requirements for the sensors and systems used in detection, position of edges of steel products on the move, measurement of temperatures, levels, and dimensions. Therefore, in hot metal detectors and infrared scanners, automatic gain control, adjustable threshold, continuous monitoring of infrared energy, and Bluetooth wireless communication have been developed for ease of use, increased reliability, accuracy, safety and reduced wasted time, product, and maintenance. As a leader of sensors and systems providers in the world, ASC (American Sensors Corp. Pittsburgh, PA. USA) has applied those advanced technologies to its infrared, laser, and microwave, sensor, and systems technologies.

Infrared sensors include static and scanning detectors, edges positioning sensors and temperature /emissivity measurement sensors. Static hot metal detectors (ASC HMD-3000) have automatic gain control that allows the sensors to choose the best gain setting so that the energy of the signal is always between 3000 and 8000 mV. In other words, the sensors are never saturated (over 9969 mV) and never less than three times the threshold. The scanning and positioning sensors (ASC IS-3000) are non-contact sensors for loop control, width, and speed measurements of any hot and cold products. They provide analog and digital outputs, as well as serial Ethernet or Bluetooth wireless outputs. The temperature measurement sensors are the pyrometers, (ASC PM-3000/PM-500) which use one-, two-, and multiple- color (wavelength) pyrometry systems that allow the accurate measurement of emissivity and, consequently, the true temperature even in the presence of scale, slag, and fumes, and especially if the temperatures to be measured are as low as 200°C (390°F) and with targets that have low emissivity and variable roughness and surface conditions. Such sensors are being used in blast furnaces, Basic Oxygen Furnaces/Converters, continuous casters, hot rolling mill flat and long products, and galvanizing and galvanneal lines.
Laser-based sensors use different principles of physics, mainly time-of-flight, pulsed infrared laser meters for level measurement and dimensional length measurements; triangulation laser meters for width and thickness measurements; and laser Doppler velocimeters for velocity and length measurements, including mass flow, elongation, tension control, and cut-to-length applications. All of these measurements are non-contact (without slippage that causes inaccurate and non-repeatable measurements that reduce quality and causes more waste and accidents).

Microwave sensors are designed to measure the level of liquids, pastes, slurries, and solids through dust, smoke, steam, and particulate materials. The microwave sensors can be operated in storage, process ladles, and tanks, as well as in wells. The measuring systems consist of the electronic units with wave guides and cone-shaped antennas, all made of stainless steel. In the FMCW (Frequency Modulated Continuous Wave) (ASC MWS-3000) the frequency difference is transformed via a Fourier transformation into a frequency spectrum, and then the distance is calculated from the spectrum. Since measuring frequency is easier than measuring time, the measurement is more precise. However, pulse radar sensors are also available (ASC PR3000), and in both cases, the measurement is unaffected by environmental conditions such as dust, heat, vapor, or light.

These sensors and systems are based on state-of-the-art technical development to improve productivity and quality and to reduce maintenance and downtime. Table 22.1 shows the major applications of the sensor technologies in the production process of steel, including blast furnaces, mines, lime and pelletizing coke plants, melt shops, continuous casters, reheat furnaces, hot and cold rolling mills and processing lines.
TABLE 22.1
Applications of the Sensor Technology in the Flat Processing of the Steel Industry:

**Continuous Caster**
- Continuous Caster Optimization of Cut
  - LM-3000 Infrared time-of-flight Laser/
  - Auto-focus laser Doppler
- Width measurement of slab
  - LM-3000 Triangulation laser meters
- Snapshot or length measurement
  - HMD-3000-D Infrared sensor +
  - LM-3000-F laser sensor
- Temperature control
  - PM-500 two- or PM-3000 Multiwave Infrared pyrometers, with or without fiber optic cables and reimaging lens
- Positioning of the loop
  - MWS-3000 Microwave sensor or
  - IS-3000-LS infrared sensor
- Temperature profile along the width
  - PM-3000 multiwave length scanning pyrometer

**Reheat Furnace**
- Width, taper measurement of slab at Entry
  - LM-3000/LM-500-LR7 Triangulation laser meters
- Snapshot and positioning length measurement at Entry
  - OB-3000-F Infrared sensor +
  - LM-3000-F laser distance sensor
- Automatic positioning at exit
  - LM-3000-F Laser distance sensors
- Product detection at exit of reheat furnace
  - OB-3000-F Retro reflective single sensor
  - LM-3000-F Laser distance meters

**Hot Rolling Mill**
- Coil diameter
  - LM-3000/LM-500-LR7 Triangulation laser meter
- Strip centering/camber and width measurement
  - IS-3000-HW Infrared sensor
- Crop shear optimization
  - Dual IS-3000-HW Scanners
- Snapshot or length measurement
  - IS-3000 Infrared sensor + OB-3000 laser optical barrier

**Cold Rolling Mill**
- Mass flow
  - LM-3000-F Laser sensor
- Cut to length at shear
  - LM-3000-F Laser sensor + OB-3000-F retro reflective single sensor
- Coil diameter
  - LM-3000/LM-500-LR7 Triangulation laser meter
- Strip centering/camber and width measurement
  - IS-3000 Infrared sensor + radiant bar
  - PHD-3000 Infrared sensor + radiant bar

**Processing Lines**
- Mass flow
  - LM-3000-F Laser meter
- Loop control
  - LM-3000-F Laser meter
- Coil diameter
  - LM-3000/LM-500 LR7 Triangulation laser meter
- Pin hole detection
  - IS-3000 Infrared sensor + radiant bar
- New control of ladle preheater
  - IS-3000 Infrared sensor
- Level of metal in pot
  - LM-3000/LM-500-LR7 Triangulation laser meter
22.2 PRINCIPLES OF SELECTED APPLICATIONS

22.2.1 CONTINUOUS CASTER OPTIMIZATION OF CUT

This application uses either two laser meters (ASC LM-3000-F), or one laser meter and one auto-focus laser Doppler Velocimeter (ASC LM-3000-LSV). The laser meter, which has a visible laser alignment capability in a mill-duty, water-cooled positive-pressure, air-purged housing. The laser meter, LM-3000-F is used to position the torch cut machine and the second laser meter, down the caster line (or the laser Doppler Velocimeter after the straightener segment and before the home-position of the torch cut machine) is positioning the head of the uncut slab. The top view of the application at the 3D overall caster is shown in Figure 22.1.

The principle of the application is that the first laser meter positions the front of the torch machine, and the second laser meter or laser Doppler positions the head of the slab. From the first laser (LM1), we get the distance L1. Since it is mounted in an angle \( \alpha \), the product of \( L1 \) and the cosine of this angle will give the perpendicular distance. The distance between the front edge of the slab and the torch machine \( L \) can be calculated as

\[
L = L_2 - L_1 \cos \alpha.
\]

(Note that \( L_1 \cos \alpha \) can be calculated in the laser meter itself)

Figure 22.1 Top view of caster application

There are four hot metal detectors (HMD-3000-D) mounted in different locations for self-calibration, first cut, and alarm if the cut slab is not moved away. The first HMD is mounted just before the torch-cut machine, and it is used for first cut. The second and third HMD are mounted between the torch-cutting machine and the minimum length. This is used for self-calibration of the system and for the generation of an alarm if systems fail. The fourth HMD is used to generate an alarm if the cut slab is not removed from the roller table.

All these sensors are controlled by a dedicated processor with integral display unit, called the MAB-3000, through which we give the precut and cut commands to the torch-cutting machine. The program in the MAB-3000 records all the data for analysis and also displays a user-friendly screen to see the online data, such as length from torch, velocity of slab, position of torch, speed of torch, precut command and cut command.

Figure 22.2 shows applications for sensors in a continuous caster.

Figures 22.3 to 22.7 show applications using laser meters and laser Doppler Velocimeters in casters.
State-of-the-Art, Noncontact Infrared, Laser, and Microwave Intelligent Sensors and Systems for Steel Mills

Flat-Rolled Steel Processes: Advanced Technologies

References in casters include:
U.S. Steel-Gary, U.S.A.
ARCELOR, Mittal
VM Star, U.S.A
22.2.2 WIDTH MEASUREMENT OF SLAB

This application uses two Triangulation Laser meters (LM-3000-LR7D) to measure the width of the slab at slab caster or roller tables at entry of reheat furnaces. The system continuously measures and graphically displays the slab edge distance from the centerline of the machine and the overall width (profiling option available also). The system can interface with level 1 and 2 systems to position torches for cutting and control automatic width adjustments. The measurement principle used by the sensor is the one of the optical triangulation. The sensor emits a laser beam. The diode array R observes through focalization optics L the image of the impact A of the beam onto the surface to be measured. The distance OA is related in a one-to-one way to the address N of the enlightened control diode (Figure 22.8).

Figure 22.9 is a picture showing how the sensors are mounted. The minimum and maximum measuring distance and measurement range are described in Table 22.2.

Figures 22.10 and 22.11 show applications using the ASC LM-3000-LR7D for width and thickness measurement.

Table 22.3 describes the major application requirements, such as sample rate, background light elimination, sensitivity, and strongest and weakest signal for this application.

Table 22.4 describes the specifications and accuracy of the triangulation laser meter in this application.

Reference of width measurement of slab

Arcelor Mittal, AK Steel Mansfield, Allegheny Ludlum Steel (ATI)
TABLE 22.2
Minimum and Maximum Measuring Distances and Measurement Ranges

<table>
<thead>
<tr>
<th>Description</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum measuring distance (Dmin)</td>
<td>The distance from the front face of the sensor at which measurement can start</td>
</tr>
<tr>
<td>Maximum measuring distance (Dmax)</td>
<td>The distance from the front face at which measurement ends</td>
</tr>
<tr>
<td>Full scale span or working measurement range</td>
<td>Dmax - Dmin, the distance range over which the sensor will measure displacement</td>
</tr>
</tbody>
</table>

Table 22.3
Application Requirement

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Rate</td>
<td>The rate at which data samples are obtained from the sensor. The maximum attainable sample rate is determined by the operating mode chosen and the reflectance of the target</td>
</tr>
<tr>
<td>Background light elimination</td>
<td>A user-selected operating mode in which the sensor captures an image with the laser off and subtracts it from the subsequent image taken with the laser on. The maximum sample rates are lower, but performance in brightly-lit areas is improved</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>A measure of the relative ability to detect small amounts of reflected light. Since different models use different laser power levels and have differing distances to the target surface, sensitivity varies with the model. The better the sensitivity, the higher the attainable sample rate on surfaces such as clear glass, gloss black paint, or shiny plastic.</td>
</tr>
<tr>
<td>Strongest signal</td>
<td>The triangulation laser meter cannot be overloaded and measures accurately even when a mirror reflects the entire beam back into the detector.</td>
</tr>
<tr>
<td>Weakest signals</td>
<td>On surfaces of polished glass or water, almost the entire beam passes through or is reflected away. The LR7 can operate on the small remaining amount of scattered light</td>
</tr>
</tbody>
</table>
### Table 22.4
Optics and Accuracy Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>LR7-A</th>
<th>LR7-B</th>
<th>LM-500-</th>
<th>LR7-C</th>
<th>LR7-D</th>
<th>LR7-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dmin</td>
<td>13.0 in</td>
<td>325mm</td>
<td>26.0 in</td>
<td>650mm</td>
<td>30.0 in</td>
<td>750mm</td>
</tr>
<tr>
<td>Full Scale Span</td>
<td>8.0 in</td>
<td>200mm</td>
<td>32.0 in</td>
<td>800mm</td>
<td>40.0 in</td>
<td>1250mm</td>
</tr>
<tr>
<td>Dmax</td>
<td>21.0 in</td>
<td>525mm</td>
<td>58.0 in</td>
<td>1450 mm</td>
<td>80.0 in</td>
<td>2000mm</td>
</tr>
<tr>
<td>Laser Class</td>
<td>IIib</td>
<td>IIIb</td>
<td>IIib</td>
<td>IIIb</td>
<td>IIIb</td>
<td>IIIb</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±.008 in.20mm</td>
<td>±.02 in.50mm</td>
<td>±.032 in .81mm</td>
<td>±.050 in 1.27mm</td>
<td>±.016in .40mm</td>
<td></td>
</tr>
<tr>
<td>Target Standoff</td>
<td>17.0 in 432mm</td>
<td>48in 1220mm</td>
<td>42 in 1067mm</td>
<td>55 in 1397mm</td>
<td>19.5 in 495mm</td>
<td></td>
</tr>
<tr>
<td>Laser Spot Size (microns)</td>
<td>@ Span Center</td>
<td>120</td>
<td>275</td>
<td>250</td>
<td>300</td>
<td>150</td>
</tr>
</tbody>
</table>

#### 22.2.2.1 Strip Centering/Camber and Width Measurement

This application uses infrared sensor (ASC IS-3000-HW) to detect strip centering/camber and width measurement.

The sensor is placed vertically or at an angle so that the scanner is perpendicular to the axis of the roller table. The sensor detects infrared radiation emitted by the work piece, and provides an analog output and serial outputs proportional to the angular position of hot products within its field of view.

Communication via HyperTerminal is used to send/receive data with the sensor. The sensor is linked to a computer via RS232 or RS485 duplex.

Figure 22.12 shows the IS-300-HW installed at ATI. Figure 22.13 is a typical application for the IS-3000-HW.

Strip Centering/Camber and Width measurement is currently being used at Alcoa, Alcan and ATI.
22.3 SENSOR SYSTEMS

22.3.1 SYSTEMS DEVELOPMENTS

Complimenting the improvements in the accuracy and reliability of noncontact sensors, the supporting electronic systems have expanded the use of the sensors. There have been advances in the resolution and speed of graphics, allowing sensor outputs to be more clearly and dynamically displayed in pulpits and to be coupled with other measurements and information. Databases have been implemented on level 1.5 and level 2 systems, so noncontact measurements are stored and searched rapid diagnosis of process failures and quality defects.

The most dramatic developments supporting noncontact sensors have been the use of analysis software to estimate conditions that cannot be measured for the data and the use of learning software for optimum productivity and quality. Some of these developments are discussed briefly, as they are in various stages of use, including some that are routinely used and others that have only been tested in production.

To simplify the integration of the sensors discussed in this article, into a customer’s existing control system, ASC provides an interface unit called the MAB-3000. This unit receives all of the sensor inputs associated with the application and provides a local visual display to allow for easy set-up and troubleshooting. The MAB-3000 provides local display of the application results and provides data storage of the various inputs and calculations. The MAB-3000 also provides output communication bus capability, in a number of standard formats, such as Ethernet, Profibus and Serial Link, as well as hard-wired analog and digital outputs, to feed the sensor data and application results to the customer control system.

22.3.2 SYSTEMS TECHNIQUES

In many installations, noncontact sensors are being protected from the environment of casters, rolling mills, and hot processing with wireless transmitters and receivers. This has involved the use of various types of technology to move data from the sensors to the analysis and display processors, including simple wireless connections (like Bluetooth) that are used to access the sensors and sensor database for diagnostics. The advantage of a wireless connection is its ability to avoid the damage to the connecting wires from water, heat, scale, and collision with metal products in the process environment.

Data from sensors are now routinely stored in structured files that comply with standard programming tools for searching, sorting, and displaying. Such databases were developed for business data, but have become robust and generally available where hard drives are installed. The standard software tools with these systems allow more complex and complete displays of the data at a minimal cost.

Graphic trending has become standardized in the form of real-time spreadsheets or similar tools. These graphics tools provide two- and three-dimensional displays of the output from the sensors. There are more colors, patterns, and methods of mixing the trend of variable with diagrams of the equipment, so the meaning of the displays is more evident.

The use of multivariable analysis is being applied to sensor systems so that conditions like crack potential or cleanliness ratings can be presented to the operators during the processing. These conditions are derived from historical and theoretical relationships between a desirable attribute and a measurable parameter. There are a number of statistical and theoretical methods used to develop these relationships, and they can be mathematically simple, like polynomials, or complex like simultaneous nonlinear differential equations.

Quality models or quality engines are being developed in software to predict key quality properties from the sensors, and then the predicted properties are used in real time to recommend manual or automatic adjustments to process speed, guidance, temperature, and other parameters. These models are largely theoretical and involve element mathematics to estimate stress, grain size, porosity, and phase structure of the metal. These models seek to control cracking, inclusions, pores, chemical segregation, and dimensional deviations in the processing of flat rolling products.

In some systems, statistical models of parameters are derived from least square error analysis of the sensor data to set up target conditions to minimize quality problems and to operate at the highest possible speeds. Programming methods are automatically applied in systems to support quality objectives.
Expert systems or neural-network models are used to establish limits and optimum settings of process parameters. Expert systems use a set of rules that are automatically adjusted from the measurements, even if the measurements are taken long after the parameters have been applied. For example, noncontact temperatures are measured along the surface of a cast slab and then related to spray water settings in the secondary spray area on future casts. The rules that are evolved from these measurements can be used to change or limit the operation of the water sprays. Neural networks operate in a similar fashion, but instead of mathematical rules, neural networks use equations that simulate the operation of biological neurons that are automatically adjusting to the feedback from the sensors.

22.3.3 SYSTEM EXAMPLES IN SLAB CASTING

The slab caster has many examples of systems with noncontact sensors in hot rolled product. The level of liquid in the mold involves several sensors and complex systems analysis. The objective of the most of these complex systems is to control the cracking and uniformity of the four surfaces of the slab in the mold. Multivariable analysis has been applied to the laser scanning of the exposed surface in the mold and has been tied to the speed, the submerged nozzle condition, and observations of the surface by experienced inspectors. This analysis was used in real time to set casting speed and the rates of lubrication on the surface in the mold.

There are several complex systems involved in the use of noncontact level measurements, like the radioactive isotope and eddy current sensors that track the movement of the liquid in the mold. Expert systems and simulation models are used to predict the level from the weight of the tundish, the weight of the ladle, the conditions of the submerged nozzle, and the casting speed. The noncontact sensors are then used to calibrate those models, so the level can be controlled to follow a series of ramping and holding steps, which improve the quality and reliability of the startup, the changes in the width, or the changes in the tundish. These models are quite complex and involve level 1 and level 2 systems.

Another control system with noncontact sensors involves the measurement of width and thickness to optimize the shape of the slab. Because the slab thickness is dynamically changing with hydraulic cylinders in the segments, the slab thickness needs to be measured and modeled for thermal shrinkage, cooling and compression with the hydraulic cylinders, speed, and water cooling. The measurement of the thicknesses and the width are supplemented by models predicting the bulging and guttering of the surfaces, which are displayed to alert the operators and to feedback to the cooling system. Multivariable analysis and finite element models are used to tie these variables together to establish a basis to minimize changes in slab shape.

The estimation of the weight from the length and width of the cut slabs has evolved in sensor systems. The weight of the slab is critical to the yield of flat-rolled products, and noncontact velocity measurements are beginning to be preferred to gain confidence in the length of the slab over the contact sensors which often slip. The noncontact velocity measurements involve tracking surface features that require special algorithms and learning systems. Once the velocity is determined from the data, the weight of the slab is estimated from the width and thickness measurements. These measurements are adjusted for the expected shape of the cross-section, which is never perfectly rectangular, and learning systems are used to estimate the cross-section from the noncontact measurements, history of the type of slab, and the prior measurements of weight.

In other systems, there is a control of internal quality with the use of the noncontact measurement of speed and dimension. The slab caster uses a soft reduction in thickness of 5% to 10% just before the last liquid solidifies at the center, and the location of this reduction is determined with an estimation of the liquid present throughout the caster, which involves finite element models and feedback from the speed and dimensions. Expert-system rules are often involved in the final setting of the strategy for control, once a history of the center porosity and chemical segregation has been determined.

Another critical internal quality issue is cracks. Similar to the soft reduction control, cracks are estimated from the measured speed and dimensions, using multivariate analysis and models with finite element simulations that calculate the strain on the solidifying surfaces inside the slab, as they are bent and supported through the machine. The casting speed and the distribution of water in the various zones are adjusted with these of models, and in some installations, an optimum speed and a water flow is recommended from these models to minimize the potential for internal cracking. This recommendation is used dynamically as the noncontact sensors for velocity and thickness update the models.

There are systems being tested that use noncontact optical devices to improve the surface quality of the slab. Pattern recognition software is being applied to the data from lasers or cameras directed at the surface of the slab. The severity of the oscillation marks is estimated, and the oscillation pattern is being modified.
in real time. With the use of hydraulic oscillators, it is possible to change the frequency, the positive amplitude, and negative amplitude of the oscillation, which have different effects for different steel grades. The adaptive software, like expert systems and neural networks, has been applied to this problem, and different noncontact sensors have been evaluated, including eddy current and infrared sensors.

Another problem that is being tackled by advances in systems with noncontact sensors is the slip of the drive rolls. In the past, the driven rolls controlling the speed of the slab have been allowed to slip or fail to drive the slab at all. The noncontact sensors tracking the velocity of the rough surface can be now used in combination with the infrared temperatures and the position of the tundish nozzle to determine the severity of the slip. As needed, the hydraulic pressure on the drive rolls is increased to reduce the slip or the operator is alerted to take other action. Early action can mitigate the sticking of the slab in the caster.

Comparison between the target velocity and the noncontact velocity can be used to alert the operator to the blockage of the submerged nozzle in the tundish or the slide gate on the ladle. Action can be taken to increase argon shrouding or change the nozzles before the cast must be aborted. The criteria for these control actions have been developed from the historical data of the noncontact sensors for particular grades and sizes. Various methods of analysis of the data have been used to determine and adapt the criteria.

Many applications on the slab caster have been proposed to utilize surface inspection devices that are also noncontact. In general, the pilot studies with digital cameras and associated software have not provided confident identification of defects, such as cracks, excessive mold powder, or pinholes. The state of the pattern recognition software is considered one of the weaknesses of these devices, and as better software is developed, it is believed the digital cameras will be used to help control the surface quality.

Current systems to protect the machine from breakout of the liquid metal in the mold are becoming more complex and effective. These systems rely primarily on contact thermocouples in the mold, but they are being improved by adding the signals from noncontact infrared pyrometers in the secondary spray system. The systems now include models to estimate the shell thickness. The expected temperature in the spray area is compared to the signal from the pyrometer for automatically determining if the caster needs to be slowed down to avoid a thin-shell breakout.

### 22.3.4 SYSTEM EXAMPLES IN HOT ROLLING

In the next processing step for flat rolled products, the slab moves into the reheat furnace to be prepared for hot rolling. The systems that control the firing of these furnaces now utilize noncontact measuring devices for width, thickness, and length to position the slabs and select zone temperatures. These systems utilize thermal models of the heat flow in the slabs to estimate the temperatures along the length and width. The models are particularly critical when slabs with different thicknesses are charged into the furnace together. The feedback from the infrared pyrometers at the exit of the furnace is used to adapt the models for each type of steel and its associated surface conditions.

At the hot mill, a number of systems are being used to improve the use of noncontact sensors. Analysis of laser velocity and position sensors has provided width measurement at the mill and estimations of camber and surface flatness. Even the amplitude of the waves on the edge or the center of the rolled product are determined and fed back to the operator for adjusting the roll bending or roll gap. The analysis for these applications involves Fourier transforms and digital filters in the systems.

There are also pattern and shape analysis systems for the head end of the products as it emerges from the rolling mill. The objective of these systems is to determine the severity of turn up or turn down on the head end. Severe changes in shape of the head can lead to damage to the equipment or cobbling of the product in the mill. Laser and noncontact devices are used to measure the position of the head, and pattern software is used to classify the shape for the system. The shape of the head is also used in systems that control the threading of coiling furnaces and the automated cropping of the ends. These systems often include adaptive functions for the tuning and input from the operator manual offset.

Noncontact lasers and other devices are used to measure the eccentricity and vibration around the rolling mill. These are coupled to analysis systems that determine eccentricity of the rolls, or problems with the mechanical system, such as chatter or slip. The eccentricity analysis is used in real time to regular the gap between the rolls for control of the product thickness. Vibration analysis systems are used to alert maintenance personnel to the need to perform further work on the mill.

There have been limited trials on using noncontact measuring devices to automatically steer the flat products through the mill. Differential forces using contact measuring across the width of the rolls has been used with some success, but now the additions of...
the laser measurements of edge position, velocity, and thickness across the width may allow these systems to provide automatic steering and decrease camber and hook. It also appears that these systems may be improved by adaptive software to deal with the changing friction and temperature in the mills. Historical data and different models may need to be utilized before automatic steering becomes a reality.

Infrared temperature sensors continue to be used in more and more sophisticated control systems at the hot rolling mill. The feedback from the sensor is used in systems to predict forces in the mill. The relationship between the hardness of the metal and the temperature is modeled in the controls for setting the gap between the rolls, and the measured temperature is used with the models of heat transfer to estimate the temperature inside the steel. Various methods are used by different systems to adapt and learn the temperatures and hardness under different conditions and products.

The infrared sensors are critical for the systems that regulate the quenching of the product after rolling. Heat transfer models are combined with the sensors to estimate temperature inside the product and to estimate on the effectiveness of the quench headers on the top and bottom. Some effort is being made to use this feedback to estimate the size of the grains in the metal and the metallurgical phases that are present. The sensors are being expanded to scan the entire width, and this data is stored in databases to be used for the quenching and for control of thickness. Metallurgical models are proposed for these systems as the data and the devices become more reliable.

Noncontact sensors are routinely used to determine the true velocity and shape of the products coming through the hot mill. These devices can be used to estimate the mass flow by the control systems with the proper models and adjustments. Mass Flow control is critical to the control of tensions and thickness in a tandem mill with multiple stands. Width control is also dependent on the complex analysis of the width sensors combined with the models for the roll gap and the edge rolling. A number of elastic and plastic effects for different alloys are considered in these systems before the sensor measurements can be used to tune the width control.

The signals from the noncontact measurements of velocity can be used to determine the slip of the product in the mill. This is critical for accurate control of the thickness, width, and flatness from the level 1 and level 2 systems. The signals are also used in the diagnoses of chatter and lubrication with the appropriate models in the systems.

Systems are being evaluated to use noncontact eddy current, laser, and ultrasonic sensors to estimate the quality of the product coming out the mill. With effective software, these systems appear to indicate the porosity, grain size, and phases present in the steel. These systems are in the early stages of evaluation in rolling mills.

Noncontact optical systems are also being used in the rolling mills to inspect the surface for cracks, porosity, roll marks, and scale. As the software and the adaptive approaches in these systems improve, the effectiveness of the inspection will improve.

22.3.5 SYSTEM EXAMPLES IN FINISHING

Cold mills have complimentary systems that use the non-contact sensors for velocity and dimensional control. The use of noncontact devices in systems for controlling the flatness and the roll gap are the most mature. There are also optical inspection systems used in these mills. Between and after rolling, many steel products are annealed and cleaned, where noncontact infrared and optical inspection devices are used. There are systems that estimate the temperature, where it cannot be accurately measured, with existing infrared devices and heat transfer models.

There are loop controllers and steering systems in the annealing and cleaning operations that use position, hole-detection, or infrared sensors. Most of these systems employ dynamic models of mass flow, and compensate for thermal expansion and alloy properties to accurately control the movement of the flat rolled product. Where automated welding is required to complete the processing, the sensors are provided with heat transfer models to complete the control and tuning of the welding operation.

Finally, there are systems that use noncontact devices in the tracking of flat rolled products, such as coils, stacked plate, and sheet. These tracking systems use mapping and dynamic simulation software to estimate where each piece is located and are coupled to the noncontact sensors that confirm the positions. Of course, bar codes and other identifying tags are used, when possible, but otherwise, complex software is coupled to position sensors to improve the reliability of the tracking with pattern recognitions and learning.

APPLICATION REFERENCE
1. U.S. Steel-Gary,
2. ARCELOR, Mittal
3. AK Steel (Armco) Mansfield
4. VM Star, U.S.A
5. ALCOA
6. ALCAN
7. ATI