8.36 Rolling Mill Controls


**Types of Drives:**
Eddy-current clutches, DC static converters, AC variable frequency

**Control Techniques:**
Analog, digital, programmable

**Partial List of Suppliers:**
Allen-Bradley; Avtek Systems; Eaton; General Electric; Louis Allis; Parametrics Div. of Zero-max Industries; Reliance Electric; Wer Industrial

**Suppliers of Services:**
ALSTOM Drives & Controls, engineering design, automation, and control systems
Brock Solutions, AC/DC Drive Systems Engineering, Industrial Control System (PLC, DCS, PC)
BWG Machinery, mill modernization, turnkey installation, commissioning and personnel training
Carlen Controls, feedback devices such as pulse tachometers, resolvers, strip speed sensors, and linear sensors
ContRolling Technology International, level-2 process control for hot strip mills, rolling mill simulations, multistand and multipass mills
Danielli Automation, USA, automation and process control systems for metals industry development, installation/start-up service
Danielli Corus, automation and control, and consulting services for rolling mill and processing line, environmental
Ferrex Engineering, rolling mill engineering, equipment supply
Mill Equipment & Engineering, engineering, process, and turnkey automation systems for all types of mill control
Morgan Construction, construction engineering services, mill audits, and field service programs for rolling mill plants
Siemens Energy & Automation, drives and automation systems for hot and cold rolling mills, profile rolling mills, plantwide automation, computer modeling, monitoring and data logging, AGCs, flatness measuring
SMS Demag rolling mill technology for the steel and nonferrous metals industries
Tippins rolling mill equipment and automation systems, hot strip mill modernization, and aluminum mills
VAI Automation, integrated control and information systems for rolling, complete hardware and software integration
Zumbach Electronics, laser-based instruments for noncontact dimensional gauging, including profiles or special shapes

**INTRODUCTION**

Because of the high processing speeds involved and the increasingly stringent product quality specifications, modern automation systems can have a considerable impact on the profitability of a rolling mill operation. The high value of the strip produced means that short payback periods are often possible.

Multiple-drive systems for process lines are available using both analog and digital control techniques and are
continually being advanced through the use of programmable digital hardware. These systems can use all available types of electrical drives and can be applied wherever speed is used for control of process variables.

Advanced mill setup models can generate actuator references for tandem and single-stand cold and temper mills rolling any combination of ferrous, aluminum, and brass alloys. The references calculated include interstand thickness and tensions, roll speeds, roll force, roll positions, work roll side shift, roll bending, and roll coolant flows. For continuous rolling mills, the model can calculate how to make a transition from the current coil conditions to those required for the new coil order.

Table 8.36a describes the features and characteristics of a typical rolling mill, which specification defines the equipment being controlled.

### Table 8.36a
Typical Rolling Mill Specification

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill type</td>
<td>1-2-3-4 reversing cold rolling mill</td>
</tr>
<tr>
<td>Material</td>
<td>Stainless steel, silicon steel, carton steel, nickel alloys</td>
</tr>
<tr>
<td>Strip width, maximum</td>
<td>18 in. (457 mm)</td>
</tr>
<tr>
<td>Strip width minimum</td>
<td>9 in. (230 mm)</td>
</tr>
<tr>
<td>Entry gauge maximum</td>
<td>0.60 in. (1.5 mm)</td>
</tr>
<tr>
<td>Exit gauge minimum</td>
<td>0.001 in. (0.025 mm)</td>
</tr>
<tr>
<td>Maximum coil size (winder)</td>
<td>16 in. (406 mm) I.D./37 in. (940 mm) O.D.</td>
</tr>
<tr>
<td>Absolute coil weight</td>
<td>4,000 lb (1,820 kg)</td>
</tr>
<tr>
<td>Specific weight</td>
<td>250 PIW (4.5 kg/mm)</td>
</tr>
<tr>
<td>Mill speed</td>
<td>0/250/500 FPM (0/76/152 MPM)</td>
</tr>
<tr>
<td>Mill rolls: work roll nominal diameter</td>
<td>1.125 in. (28.6 mm)</td>
</tr>
<tr>
<td>1st Intermediate roll nominal diameter</td>
<td>2.062 in. (52.4 mm)</td>
</tr>
<tr>
<td>2nd Intermediate roll nominal diameter</td>
<td>3.600 in. (91.4 mm)</td>
</tr>
<tr>
<td>Mill bearings: diameter</td>
<td>6.299 in. (160 mm)</td>
</tr>
<tr>
<td>Width</td>
<td>3.543 in. (90 mm)</td>
</tr>
<tr>
<td>Mill RSF</td>
<td>17,700 lb/in. (316 kg/mm)</td>
</tr>
<tr>
<td>Mill power</td>
<td>150 hp at 0/650/1500 rpm</td>
</tr>
<tr>
<td>Winder power</td>
<td>150 hp at 0/650/1500 rpm</td>
</tr>
<tr>
<td>Winder mandrel type</td>
<td>Solid block</td>
</tr>
<tr>
<td>Winder gearbox ratio</td>
<td>12.9:1</td>
</tr>
<tr>
<td>Winder tension maximum</td>
<td>9,000 lbs (4,050 kg) to 500 FPM (152 MPM)</td>
</tr>
<tr>
<td>Winder tension minimum</td>
<td>140 lbs (64 kg)</td>
</tr>
<tr>
<td>Payoff mandrel diameter</td>
<td>16 in. (406 mm) nominal</td>
</tr>
<tr>
<td>Payoff/wind-on speed</td>
<td>400 FPM (122 MPM) @ 37 in. (940 mm) O.D. coil</td>
</tr>
<tr>
<td>Rewinder mandrel diameter</td>
<td>16 in. (406 mm) nominal</td>
</tr>
<tr>
<td>Payoff/wind-on tension</td>
<td>3,000 lb (1,364 kg) max. @ 37 in. (940 mm) O.D. coil</td>
</tr>
<tr>
<td>Rewind payoff/rewinder speed</td>
<td>400 FPM (122 MPM) @ 37 in. (940 mm) O.D. coil</td>
</tr>
<tr>
<td>Rewind payoff/rewinder tension</td>
<td>1,100 lb (500 kg) max. @ 37 in. (940 mm) O.D. coil</td>
</tr>
<tr>
<td>Coolant system</td>
<td>Mineral oil</td>
</tr>
<tr>
<td>Mill direction</td>
<td>Left to right</td>
</tr>
</tbody>
</table>

**Multiple Drives in Strip Manufacturing**

The simplest application of two drives in a speed-controlled system is a conveyor line in which more than one set of rollers must handle a common strip of material. This strip can be a belt or a web of product, such as paper, plastic film, or foil. Roll and motor speeds must be maintained either at identical levels or at a constant ratio to allow for gearing differences.

Many process lines require the ability to vary and control speed relationships between machine sections. This ability is a key part of the process, regulating such things as stretch ratios of calendaring systems, proportions of various ingredients in a product, and printing synchronization. Regulation of some process variables is accomplished through coordination of drive speed as well as of torque.
Multiple-drive systems are also used in advanced process control, in which speed is varied in response to changes in product properties, such as temperature or thickness. The refinement of process control computers has increased the potential applications of speed-controlled systems as effective control loops are developed for manufacturing lines.

**Electrical Drive Systems**

The techniques used for motor speed control in multiple systems include the eddy-current clutch, the DC static drive, and the AC variable-frequency drive.

**Eddy-Current Drive**

An eddy-current clutch drive applies variable voltage to a field coil, regulating the slip of an output rotor with respect to a constant-speed input rotor. The result is a smoothly operating unit with wide torque capability and simple, compact electronic controls. Its low efficiency, however, has limited its use to a few specialized applications.

**DC Static Drives**

The DC static converter is probably the most widely used speed control device. Because DC motor speed is proportional to voltage, and motor torque is proportional to current, the output of the system is easily regulated.

The available horsepower in these drives ranges from less than one to several thousand horsepower. Models currently on the market can give full output torque over the entire speed range with proper motor cooling. High efficiencies are obtained from the use of solid-state components, and speed regulation to 0.1% is available using conventional tachometers (for details on tachometers, refer to Section 7.19 in the first volume of this handbook).

The DC drive also lends itself to tension control because of its simple current-torque characteristic. It can also provide full negative, or braking, torque to a load when equipped with regenerative capability. One disadvantage of this type of drive is its poor power factor at low speeds. Installation of correction capacitors is sometimes required to avoid penalties from the utility. DC motors are also typically more expensive than corresponding induction motors (for details on tension and torque detectors, refer to Sections 7.21 and 7.25 in Chapter 7 in the first volume of this handbook).

**AC Variable-Frequency Drives**

AC variable-frequency drives are the beneficiary of many recent electronic advances. In these drives, the speed of the AC motor is proportional to the output frequency of the controller, with voltage varied in proportion. The development of power transistors and logic devices has enabled these drives to produce variable-frequency power compatible with virtually all AC motors up to 40 hp (30 kW).

In larger power ranges, silicon-controlled rectifier (SCR) choppers are used in place of transistors; efficiency deteriorates, however, because the power waveform is degraded. The AC transistorized drive has a high power factor (typically over 90%) and the ability to produce full motor torque over the entire speed range with proper motor cooling.

Variable-frequency drives are inherently self-regulating when used with synchronous motors. Speed regulation with induction motors depends on slip and is typically 20%. Closer regulation requires tachometer feedback.

**Analog Multiple-Drive Systems**

A conventional analog drive is speed-regulated through the comparison of a desired speed, represented by a reference voltage, with the actual speed, represented by a tachometer-generated voltage. The difference between the two speeds is the error used to raise or lower the actual drive power output to the proper level.

Speed coordination between two drives is easily implemented using the wide variety of amplifiers, multipliers, and meters developed for use with analog voltages. The techniques described here can be used with any of the basic drive types and are widely available.

**Speed Control**

A typical speed control system is shown in Figure 8.36b. Here, the regulation of a metal foil rolling mill is illustrated, where one set of draw rolls are operating at a differential but constant speed ratio to the speed of another, prior set of rolls.

In the analog controls shown, the voltage used as a reference for the first, or lead, drive is fed into a potentiometer. The reference for the second drive is taken from the wiper of the pot, giving a reference that will vary with both the reference of the first drive and the wiper position. The ratio will be constant between the two drives for a given position. An amplifier is often used between the two drives to give the second drive the ability to go faster than the first as well as to prevent interaction between drives.

Additional amplifiers and control potentiometers enable the coordination of any number of drives. The system described in Figure 8.36b will maintain the desired speed ratios of the three sets of draw rolls as the process speed is changed. A variation often seen is a speed-follower system, in which the actual speed of a lead motor becomes the reference for the next drive or set of drives. This actual speed is generated by the lead motor tachometer.

Motor-operated reference potentiometers, acceleration control amplifiers, and upper and lower limit settings are usually incorporated into multiple-drive systems to give total control of reference voltages. The components used in these systems typically give accuracies of 5-0.1%, depending on their quality and complexity.

**Dancer Tension and Speed Controls**

Winding and unwinding of a web of material, such as paper, is a common application of
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multiple drives. These systems often use movable rolls, called dancers, which accumulate a certain length of material and hold a preset tension on it. The dancer assembly is located between a constant-speed output roll and a roll of material being wound, as in Figure 8.36b.

As the diameter of the roll being wound increases, its rotational speed must decrease in order to maintain a constant surface speed. If the input speed to the assembly from the draw rolls has not changed, a gradual surface speed increase in the winder will pull the dancer down. Therefore, the dancer motion mechanically drives a feedback potentiometer, producing a voltage that is integrated and used to correct winder speed to the proper level.

Dancer systems can also be used in the same way between two machine rolls to maintain speed synchronization in a system with otherwise low accuracy. Slight changes in the speed of one section will raise or lower the dancer, which will produce a voltage correcting the speed error.

**Thickness Control** Analog systems can also be used for more complex process control. The foil thickness control loop shown in Figure 8.36b is an example of the control of two process variables in an interrelated system.

Figure 8.36c describes the operation of a linear variable differential transformer (LVDT)-type thickness gauge, while Table 8.36d provides a summary of the capabilities of a number of thickness detectors.

**Digital Control Techniques**

The availability of sophisticated and cost-effective digital equipment has greatly expanded the capability of process control systems. In many applications, digital signals are superior to analog signals, because of their precision and high noise immunity. Their processing by high-speed computers can also provide the basis of model-based advanced controls.

A digitally regulated drive and motor will typically be provided with a pulse generator as a feedback device. The pulse generator is driven by the motor and produces a frequency proportional to the motor speed. The speed reference for such a drive will be either a precision frequency or a numerical value. Systems using a frequency reference often include a phase-locked loop for comparison of the reference and actual speeds. These systems can also use up–down counters to detect any build-up in speed error.

Systems using a numerical reference compare the desired speed with the number of pulses generated by the feedback device in a given period; this allows numerical treatment of any speed error and great flexibility in processing the correction. Digital systems typically operate with zero average
speed error, meaning that no speed difference is allowed to accumulate.

Two or more motor drives are easily coordinated with digital references. Analog components (which are less accurate) are replaced by thumbwheel switches and microprocessor-based computation, as illustrated in Figure 8.36. Numerical speed ratios can be set and used precisely, and synchronization is held exactly, because no pulses are lost. The history of the

\[
t = k (e_m - e_{ref})
\]

where:

- \(t\) = Thickness (mm)
- \(k\) = Calibration constant (mm/Volt)
- \(e_m\) = Output of measuring LVDT (Volt)
- \(e_{ref}\) = Output of reference LVDT (Volt)

**FIG. 8.36e**
Left, differential roller gauge with LVDT; right, LVDT schematic.

**TABLE 8.36d**
Thickness Measurements

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Type*</th>
<th>Sensitivity**</th>
<th>Application****</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micrometer caliper</td>
<td>C</td>
<td>0.0001 in.</td>
<td>Sampling, quality control, calibration, foils, web, sheet, film materials (N)</td>
</tr>
<tr>
<td>Interferometry gauge</td>
<td>NC</td>
<td>1% of reading</td>
<td>Measures thin-film deposition layer thickness and uniformity of semiconductors and dielectric layers (Y)</td>
</tr>
<tr>
<td>Optical micrometer</td>
<td>NC</td>
<td>0.1 µm</td>
<td>Provides thickness monitoring for silicone wafers (Y)</td>
</tr>
<tr>
<td>Laser gauge</td>
<td>NC</td>
<td>0.05 in.</td>
<td>Mounted directly on production line and is used to alarm on any out-of-tolerance condition (Y)</td>
</tr>
<tr>
<td>Differential roller gauge</td>
<td>C</td>
<td>20 µin.</td>
<td>Low-speed continuous foils, web, sheet, film materials, calibration, sampling (Y)</td>
</tr>
<tr>
<td>Sonic and ultrasonic gauges</td>
<td>C</td>
<td>0.01 in.</td>
<td>Rigid, relatively thick sheets, or pipe walls accessible from one side only (Y)</td>
</tr>
<tr>
<td>Capacitance gauge</td>
<td>NC</td>
<td>0.001 in.</td>
<td>Insulating sheets, films (Y)</td>
</tr>
<tr>
<td>Radiation gauge</td>
<td>NC</td>
<td>50 mg/cm***</td>
<td>Metal foils and plastic films (Y)</td>
</tr>
</tbody>
</table>

* C = contacting; NC = noncontacting.
** 1 in. = 25.4 mm; 1 µin. = 2.54 × 10^{-5} mm.
*** Actual sensitivity depends on the specified value for a given instrument divided by its density (g/cm^3).
**** Whether a device is suitable for continuous process instrumentation is indicated by N (no) or Y (yes).
speed of the machine is always available for subsequent correction.

**Thickness Controls** The computation capability of a digital system allows complex functions to be easily implemented. An example is the control of the thickness of a strip of metal being drawn to a given gauge between sets of rollers, shown in Figure 8.36e. A thickness-measuring device outputs a number representing the actual gauge of the product, which is then compared with the desired gauge, and in case of an error, a correction signal is fed to the speed control of the draw rolls.

An increase in the speed of the last roll will reduce the thickness of the product foil, because the input rate has not changed; a decrease in the speed of the last roll will increase its thickness. Limits are set upon the maximum and minimum speeds and their rates of change. Tuning of the control system is simplified for the operator by the parameters being entered numerically.

**Advanced Thickness Control** In more advanced control systems, the noninteractive tension and thickness/extension and tension controls ensure the consistently high performance for any combination of mill type, product range, and operating practice.

A variation of feedback and feedforward control algorithms in combination with a variety of thickness gauges and mass flow thickness controls can optimize the performance of the available mill actuators.

Roll eccentricity compensation (REC) and different tension control strategies can be employed for threading and rolling in conventional tandem mills. The controls can also utilize speed-dependent actuator references generated by the setup calculation. The control systems usually include current overload protection, rounding of acceleration ramps and separate speed ramps for threading and tailout. A dynamic order change function is usually also available for continuous rolling mills.

**Advanced Modeling** An advanced mill setup model includes comprehensive sequences of calculations that involve the derivation of actuator references and schedule-dependent control system gains appropriate for the particular application.

One application might involve a thick product where the mill setup may aim to achieve the correct thickness on the coil head end as it is threaded with minimal out-of-tolerance lengths. In this case, the setup calculation can be made to achieve the target thickness on the coil head end and at thread speed with minimal yield losses.

In another case, it might not be possible to roll the head end to the target thickness until tension is established on each side of the stands. In such a case, two separate sets of
mill actuator references are required for the threading operation. First, a short length of strip will be rolled that is thicker than desired due to the lack of front tension while the head end is produced, even with increased back tension. Once the head end is coiled, the mill can achieve target thickness at thread speed with acceptable flatness. For this situation, the threading setup calculation must sacrifice a controlled length of out-of-tolerance material until tension is established and then the correct thread speed, roll gap, and roll bending references are applied to achieve the desired thickness reduction on each stand.

**Operator Interfaces** State-of-the-art digital control systems also improve the operator access to the system, because changes can be initiated directly through a keyboard or a video display using easily learned commands. Operator interfaces include mimic displays, performance monitoring, diagnostics, alarms, and screens to interact with the setup functions and dynamic controls.

Operator interfaces can be implemented on PCs using Windows NT and connected via an Ethernet TCP/IP network. The screens usually update rapidly, and the package is sufficiently flexible that the client’s engineering staff can reconfigure screens where that becomes necessary.

**Management Support** Digital techniques in speed control also allow the monitoring of all other functions of a production process. As shown in Figure 8.36e, the information gathered about speed and thickness can be stored and used to generate reports. This can be used to inform both the equipment operators and management of the quantity and quality of the foil being produced.

The precise control of motor speed has thus led to accurate information that is vital to production management.

**Bibliography**


