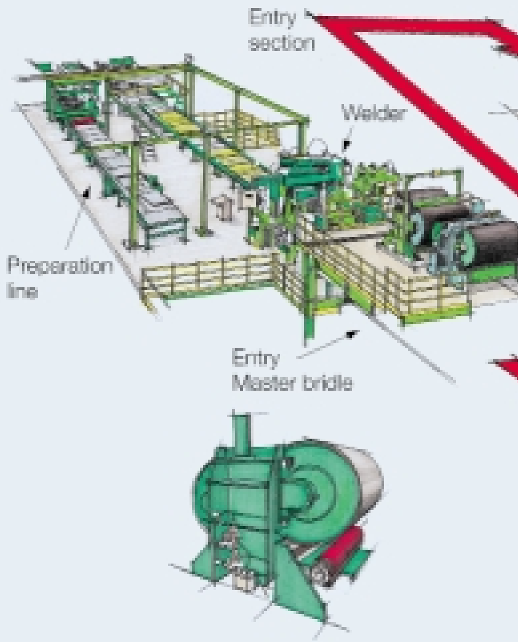
Control & automation of annealing and pickling lines

New developments in AC drive technology, including Direct Torque Control, are at the heart of advanced electrical systems developed by ABB for stainless steel treatment lines. Among the system features are operator stations for automated plant control and efficient management of the production data. Powerful software functions not only enable steel producers to control the quantity of produced material more precisely but also provide valuable information about the quality of the finished steel strip. ABB recently supplied all of the electrical and automation equipment for a new annealing and pickling line installed at Baoyong Special Steel in Ningbo, China.



Entry-to exit automation advanced electrical syst

In the cold-rolling area of an integrated steelworks

The demands made on the surface quality and thickness of steel strip have increased in recent years. At the same time, operators have had to concentrate on maintaining high annual production rates. To balance these needs, plants have to be equipped with advanced electrical systems featuring dedicated control functions.

One of the most important parts of an integrated steelworks is the cold rolling area, where the coils from the hot rolling mill are processed into steel strip. This area can be divided into two main sections **1**:

- Cold rolling mills for reducing the strip thickness
- Plants for the treatment of the structure/surface of the material and for changing the strip dimensions (*Table 1*)

The electrical equipment installed for the strip treatment plant has a large influence on the quality of the finished products. For example, the line control system has to ensure very precise movement of the strip. A standstill in the process section or uncontrolled strip tension can easily cause irreversible damage to the material or loss of production.

Main processing lines

Strip processing lines alter the characteristics, appearance and/or dimensions of flat-rolled products. Typical examples are the galvanizing line, which coats the steel with a layer of corrosion-resistant zinc, the colour coating line, which applies a layer of paint, and the slitting line, which cuts wide coils into narrow strips.

Except for those lines with a shearing section at the exit end, most coil processing lines can be described as continuous coil-to-coil operations. This means that coils of metal are brought to the line entry, uncoiled, fed continuously throughout the treatment process, and recoiled at the exit.

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Continuous operating lines

To ensure that the quality goals are achieved, the process sections have to

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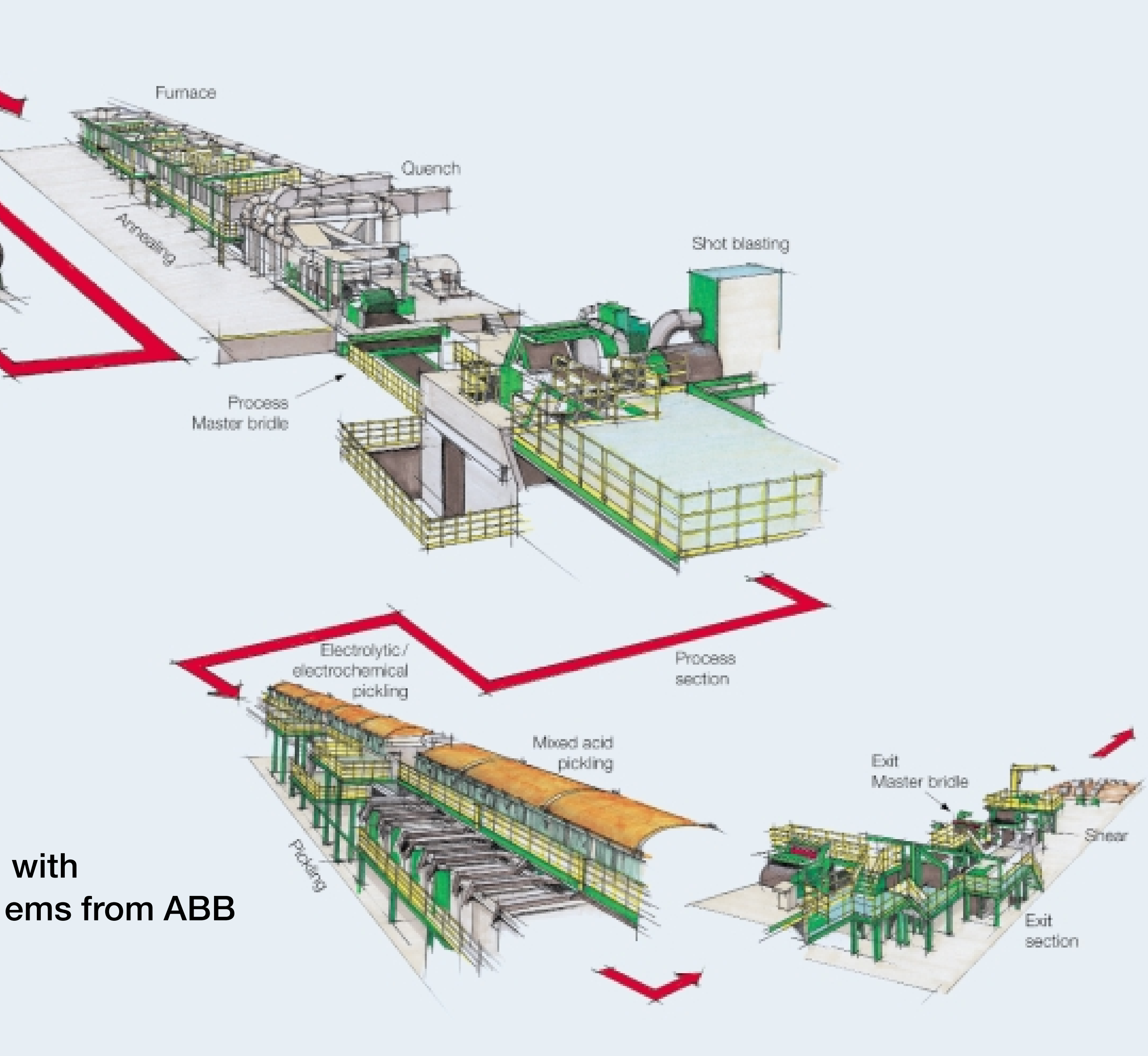


the coils received from the hot rolling mill are processed into strip, which is then passed through the treatment line. **1**

operate at constant speed and the process has to be supervised from beginning to end. After preparation of the coil, eg by removing any damaged outer wraps, the strip is fed into the line. One of the first operations to be performed is the welding of the incoming coil to the tail end of the coil being processed. This is a prerequisite for continuous operation, and requires a strip storage device known as the entry looper. The entry looper, in effect a buffer between the entry and the process area, stores enough strip to keep the processing section operating during the welding. As soon as the looper has emptied, the entry section accelerates to a preselected overspeed to provide more strip to refill it.

The main functions of the exit section are strip rewinding and coil discharging. These are made possible by another looper, which stores the strip coming from the processing section. Also, the exit section is capable of working at overspeed to compensate for the excess strip stored in the exit looper during stops in this section.

Table 1
Plants determining the structure and surface of the material

Surface improvement	Surface treatment/ structural change	Strip dimensions
• Electrolytic tin/chrome lines • Electrolytic cleaning • Galvanizing and aluminizing lines • Coating lines	• Pickling lines • Continuous annealing lines • Combined annealing and pickling • Electrolytic strip degreasing	• Slitting lines • Shearing lines • Recoiling lines

Annealing and pickling line

The annealing and pickling line (APL) is one of the plants requiring a constant material processing time.

To remove the hardness caused by rolling, the strip is first run through the annealing section of the APL. During the annealing process the lattice of the steel is stress-relieved and its structure rearranged. Annealing can be performed in a continuous process in which the strip is passed through a furnace with different heating zones that raise it to an exactly defined temperature and afterwards through cooling zones that gradually cool it down to its exit temperature of about 80 °C (higher temperatures cause the line to be stopped to prevent possible damage to mechanical equipment further along). The temperatures in the heating zones are varied according to the type of steel being treated and the strip gauge and width.

After being annealed the strip is passed through the pickling section to give the material a clean, bright surface. This section consists of tanks containing electrolytic, electrochemical and mixed acid solutions.

Table 2 gives details, including the running speeds and annealing data, of a new APL installed recently by ABB at *Baoyong Special Steel* in Ningbo, China **2**.

Table 2
Specification of the new annealing and pickling line at Baoyong Special Steel in Ningbo, China

Product data	
Strip material	Hot and cold stainless steel (AISI 300–400)
Strip thickness	0.3 mm – 5.0 mm
Strip width	650 mm – 1350 mm
Coil weight	max 31 t
Running characteristics of line	
Threading speed	25 m/min
Entry/exit speed	90 m/min
Process speed	60 m/min
Entry/process/exit acc and dec	
Normal acceleration	$+0.13$ m/s^2
Normal deceleration	-0.13 m/s^2
Fast stoppage	-0.26 m/s^2
Annealing temperatures	
HR 300	1130 °C
CR 300	1090 °C
CR 400	840 °C

Drive control strategy

It is not possible to define a unique control strategy for a continuous processing line that will take account of all the different drive combinations in the various line configurations; this is particularly true in the case of the process section. Nevertheless, it can be done for some of the motor drives.

Normally, it is necessary to isolate the strip tensions in the various sections from each other in order to stop one section from influencing another. This is accomplished by means of speed-controlled bridle rolls. Each section has a master bridle which determines the reference speed; a speed pilot in the entry and exit sections controls the overspeed for the looper operation during stops (eg, for coil welding and finishing operations). When these operations have been completed the speed is adapted again to the process. Normally, there is one bridle operating in underspeed mode (feedbackward regulation) and another in overspeed mode (feedforward regulation), in each case referred to the master bridle of the process. This arrangement, known as indirect tension control, ensures that the required strip speed and tension are maintained. In other words, a bridle not assigned the function of a speed master acts as an indirect tension-controlled drive.

Very precise control of the strip tension is necessary to avoid strip breakage in critical areas. Direct tension control, with load cells mounted directly on the rolls **3**, guarantees this.

Pickling section of the annealing and pickling line at Baoyong Special Steel in Ningbo, China. The open tanks contain the rectifiers that generate the current flux used to clean the strip surface. **2**

Usually, the speed control of a master bridle is based on load sharing between the two drives of the bridle (*Table 3*). The advantage of this configuration over the solution with one drive as the speed master and the other speed-controlled is that the stability is better during acceleration and deceleration and differences in the roll diameter are compensated for at constant speed.

Indirect tension control with compensation of acceleration and losses is normally used for the coiler and looper. Thus, in the entry and exit section only one bridle is designated the speed master. If there is a side trimmer in the exit section it may have (with respect to the strip direction) one bridle before and one after the side trimmer, the latter acting as master so as to ensure constant speed at the side trimmer.

There is no particular rule for the process section. In general, the speed master should be behind the most critical part (eg, the furnace). If the line has only one process, the speed master will be next to the exit of the process. If there is a stretch leveller in the section, the leveller itself should be the master.

Load cell for direct tension measurement, mounted on the bridle at the entry of the process section **3**

Table 3
Typical drive control in a processing line

Motor	Power range (kW)	Control	Alternative control	Direct Torque Control (DTC)	Compensation
Bridle	20–60	Speed control with torque limitation	Torque control (direct or indirect tension control); option of load sharing and windows control	With pulse generator	Inertia and losses
Looper	80	Torque (tension control); strip tension remains constant during acceleration/deceleration and at constant speed	Speed control during jogging	With pulse generator	Inertia, losses and unbalanced weight
Winder Unwinder	150–400	Torque (indirect tension control) in normal run with coil diameter calculation (torque follows change of diameter value during coiling)	Speed control during threading, jogging, strip tail end positioning	With pulse generator	Inertia and losses
Support roll Squeeze roll Pinch roll	3–15	Window control (no slip between strip and roll: drive runs at deadband speed so that drive speed is always similar to material speed)		No pulse generator	Inertia and losses

Electrical solutions

When procuring electrical equipment for a plant, consideration needs to be given not only to the first-time cost of the equipment but also to the total cost over its lifetime. This has to take into account factors such as efficiency, energy consumption, spare parts and maintenance. The industry's preference in the past for adjustable-speed DC drives, which easily achieve a good torque and speed response, is giving way to a trend towards AC drives. This has come about as a result of modern electronic converters offering the same speed accuracy and fast torque response, but with the added plus that the AC motors allow a major cost saving due to their simpler construction and high reliability, even in harsh environments, and easier maintenance.

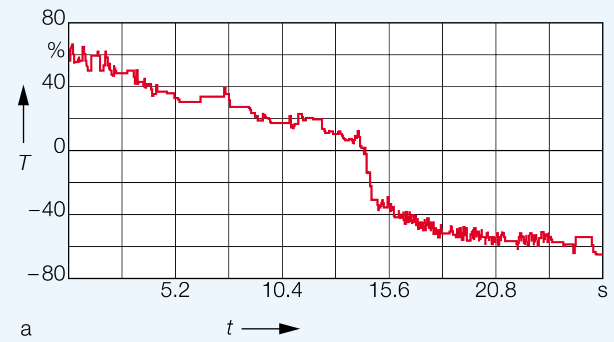
Table 4
Static and dynamic speed error achieved with DTC, scalar control and vector control

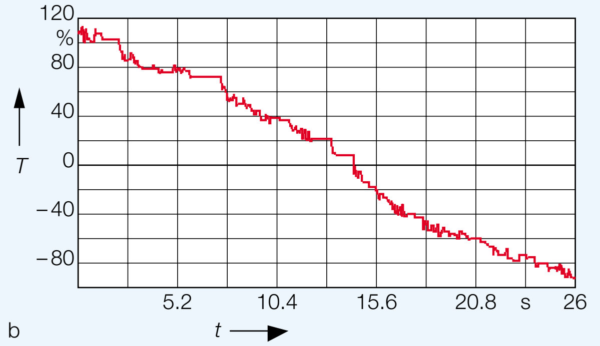
Speed error	Scalar control (no encoder)	Vector control (with encoder)	DTC (no encoder)	DTC (with encoder)
Static	± 1 to 3 %	± 0.01 %	± 0.1 to 0.5 %	± 0.01 %
Dynamic	3%	0.3%	0.4%	0.2%

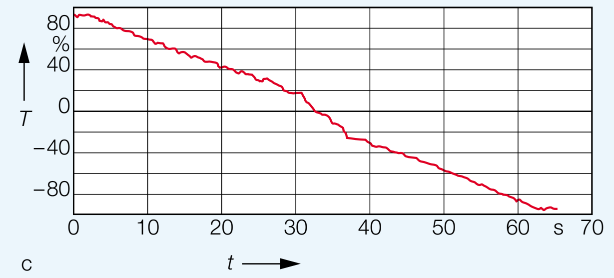
Direct torque control

Direct Torque Control (DTC) [1, 2, 3] is the motor control platform launched by ABB in 1994 as the universal solution for LV drive applications and recently adapted for MV applications. This technology is also used to control the induction motors delivered to the new annealing and pickling line of Baoyong Special Steel in Ningbo, China.

Unlike traditional vector control, in which the parameters affecting the voltage and frequency (eg, the motor current and flux) are measured indirectly and a pulse encoder has to constantly provide new data to obtain a real degree of accuracy, DTC allows fast and flexible control of the machine without encoder feedback. Also, the variables used in flux vector control are controlled by a modulator, which delays the responsiveness of the motor to changes in torque and speed. DTC on







Measured shaft torque with different types of drive control (torque ramp from 100 % to −100 % at zero speed) **4**

a *Scalar control drive (PWM, no encoder)*
- *Control variables: frequency and voltage applied to stator windings*

b *Vector control drive (PWM, with encoder)*
- *Control variables: frequency and voltage controlled by modulator*

c *DTC drive*
- *Control variables: flux and torque controlled via fast DSP*
- *No modulator*

T *Shaft torque* *t* *Time*

the other hand uses advanced motor theory to calculate the torque directly without the need for a modulator; the control variables are the stator flux and the motor torque.

When DTC open-loop drives are installed, high dynamic performance (speed accuracy and torque control) is possible in many cases without having to use a tachometer. Where a higher accuracy is required, closed-loop DTC drives are employed, but the feedback device may be less accurate and therefore cheaper than the one used in traditional flux vector drives as the speed error and not the rotor position is known by the drive. In processing lines such as the APL described, the main motors used to transport material (in the bridles, loopers, uncoilers, coilers) are fitted with pulse generators.

The control variables in DTC are:

- Stator flux
- Torque, calculated on the basis of the flux and stator current
- Comparison of the flux amplitude and torque deviation with given references; the information this provides is sufficient to determine the optimum voltage vector at each instant

The high precision of the mathematical motor model makes speed feedback unnecessary.

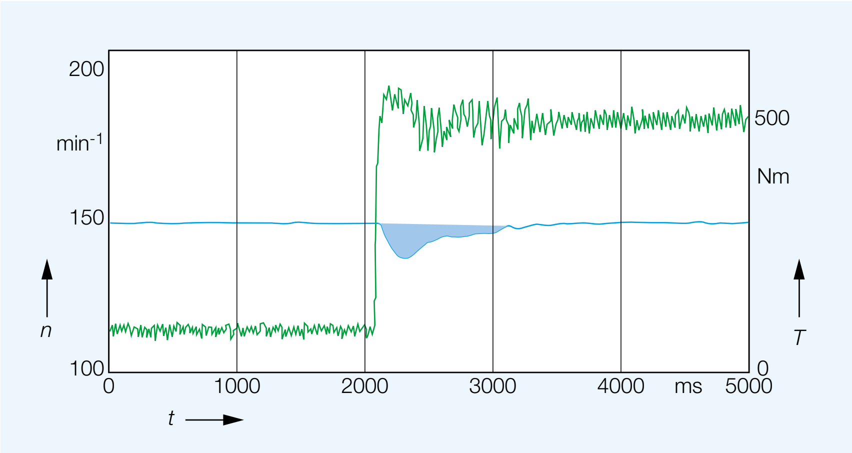
Combining high-speed signal processing with the advanced mathematical model has produced a 25 µs high-performance control loop that ensures accurate torque control and low oscillation levels. The resulting very fast torque response makes the DTC AC drive twice as fast as flux vector AC drives and at least ten times faster than open-loop AC drives with scalar control.

Other benefits in the torque control area include very precise torque control at low speeds, even down to zero, and full torque at zero speed. Measurements of shaft torque (with a torque ramp from 100% to −100 % at zero speed) for different drive controls are shown in **4**.

With DTC the dynamic speed accuracy is at least eight times better than with open-loop AC drives, and static speed control accuracy is twice as good as with the existing general-purpose AC drives (*Table 4*) **5**.

Automation systems

Modern automation systems based on an open system architecture provide user-friendly, reliable tools that support the operator in his daily work. Such systems feature a combination of field controls and higher-level information that makes it easy to interchange data between the Open Control System (OCS) and the Manufac-



Direct Torque Control (DTC) and dynamic accuracy **5**

n *Speed*
T *Torque*
t *Time*

Blue *Speed*
Green *Torque*

turing Execution System (MES) **6**. By combining these concepts, a plant automation system evolves with capabilities that extend from single motor control to overall plant control.

OCS operator stations

Advant OCS operator stations have direct access to a database in which all the data related to the processing line is stored. Located at the entry and exit pulpits of the line, the stations manage alarm reports and information arriving from each section, allowing the status of the plant to be kept under control. For example, the general starting conditions, motor torque and motor speed can be viewed and preset from these stations.

Strip tracking is one of the main functions provided by Advant OCS **7**. It assists the operator with routine work by keeping track of the coil welding so that the position of the strip inside the line and the amount of coil threaded in the entry section and rewound at the exit are always known.

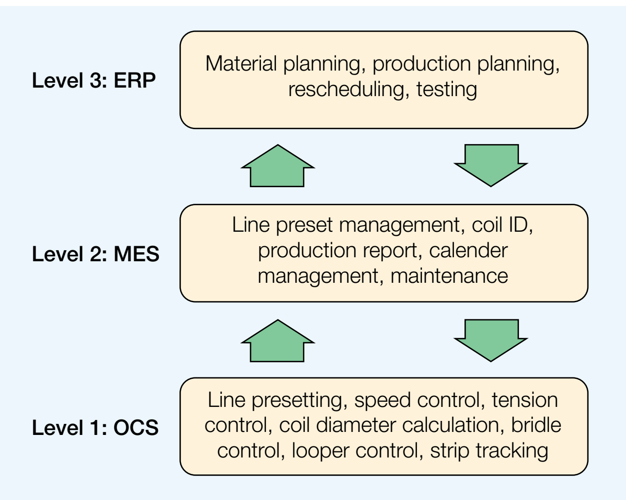
ABB Advant® Open Control System

With its Advant® Open Control System (OCS), ABB offers a standard, state-of-the-art platform with open system architecture for the automation of industrial processes. The system is characterized throughout by an object-oriented and distributed structure, high-performance operator stations, very high availability and ease of maintenance. All process and operator stations are linked by a systembus. The process control stations communicate with I/O units by means of field buses. Every stage in the industrial process can be controlled and monitored from each of the process operator stations.

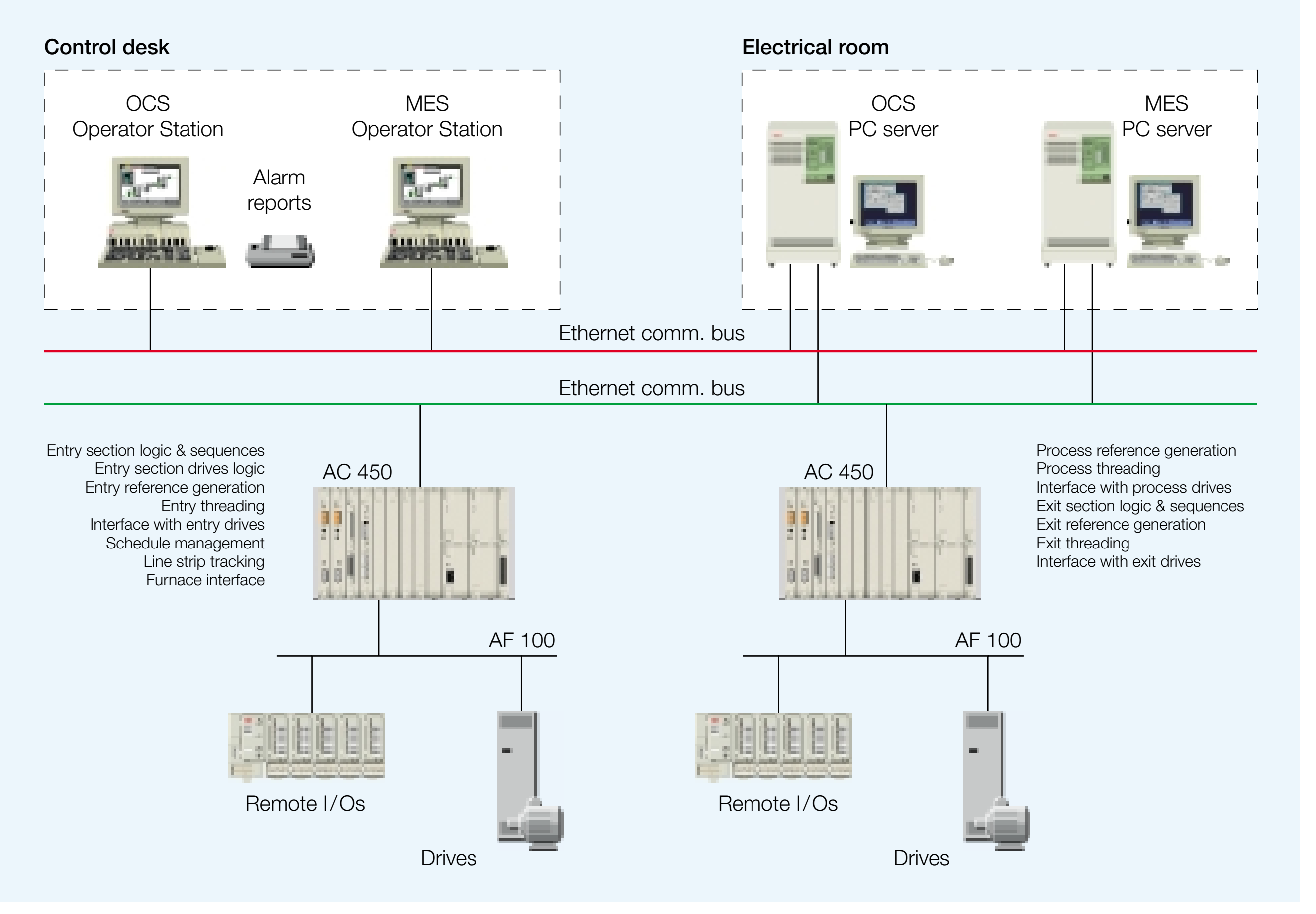
Standard ABB solution

Programmable logic controllers manage the exchange of signals between the different process sections. The current

Main functions performed by the Open Control System (OCS), Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) system **6**



OCS: strip tracking display showing the reference and actual values of speed and tension in different sections of the line. Also shown is information on the incoming and outgoing coils (eg, the coil ID and remaining strip length). **7**



Automation layout with two multi-CPU PLCs in control of the whole line. From the control desk it is possible to view all the operations taking place in the line. **8**

standard ABB solution for a strip processing line consists of two PLCs (AC450 RMC) **8** dedicated to applications in the metallurgical sector. A wide choice of standardized functions and ready-made software modules makes it easy to find reliable solutions that meet customers' needs.

The first multi-CPU AC450 controls the entry section, the tracking and the presetting functions, while the second PLC interfaces with the process and exit sections. To relieve the CPU load of the PLCs some functions are implemented on the motor drives; these incorporate the majority of the application software for motor control. The large drive systems are, in fact, linked through a fast, dedicated fieldbus (AF100) via a control unit called the Application Controller (APC). Software running on the APC includes modules for speed control, current control and tension control. Remote I/O devices communicate through the AF100 with the overriding control CPU.

The standard overall control system function covers the generation of all sequences, velocity and acceleration references for the drives, and the signals for starting and stopping the line. Application-specific modifications are made according to the project requirements.

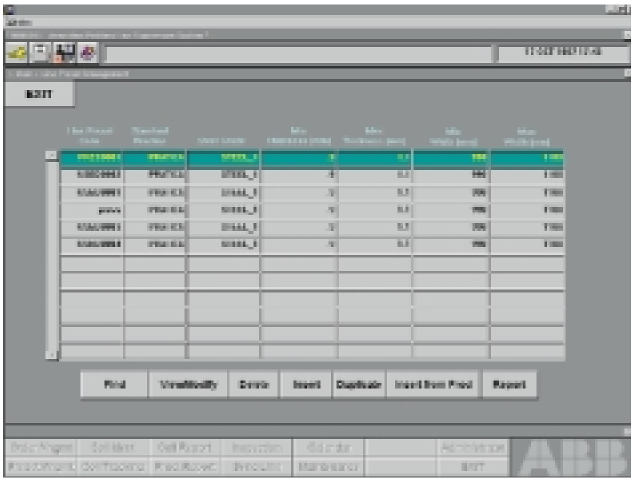
Manufacturing Execution System

Quality control depends not only on accurate control of the technological parameters of the strip but also on overall control of the production process. The necessary coordination is achieved by means of Manufacturing Execution System (MES) functions, being divided into operator functions and process functions.

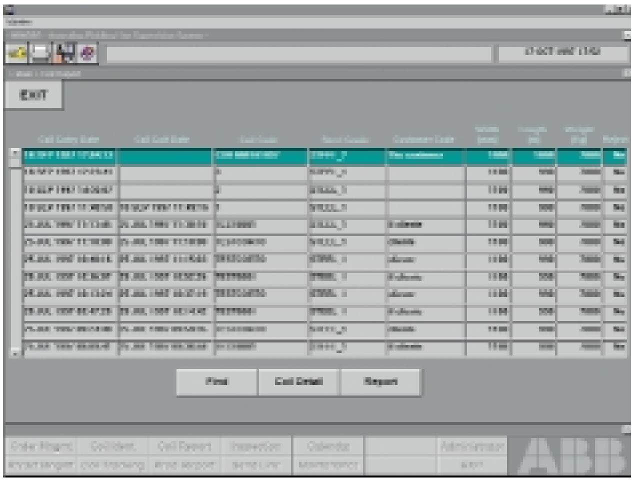
Operator functions

These functions are as follows:

- *Order management*, giving the list of coils to be worked and detailing for each coil its dimensional data, main characteristics (coil code, steel grade identification for furnace and pickling, customer code) and required final characteristics.
- *Line preset management* **9**, comprising a set of data used to set the line up before starting production; preparations for all the electrical and mechani-



MES: line preset management. All the data for line set-up are entered here. **9**



MES: coil report. This provides information on the technological parameters and quality of the produced strip. **10**

cal devices are based on the order data. Coil data given by the order management and line preset functions assigned to the coil constitute the preset data sent to the OCS for correct coil processing.

- *Coil reporting* **10**, with displays and print-outs of data on worked coils. The main displays are the quality product report (thickness, flatness, elongation data) and the technological product report (furnace, pickling, thickness, flatness, elongation distribution data for the process technology engineer).
- *Production reporting*, showing the number of coils produced and the work shifts in the plant (production reports can be displayed on a shift, daily and monthly basis). Reporting of the plant time distribution (how long the plant has been in operation and how long at standstill) and the pickling consumption is also possible.
- *Maintenance reporting*, showing the actual operating time of the mechanical and electrical equipment.

Process functions

These functions are automatically activated by the system whenever a message is received or something occurs in the plant.

- *Material tracking*, allowing monitoring of the position of the coil in each section of the line.
- *Data acquisition*, for collecting information from the OCS about the uncoiler and recoiler, tension and process sections, as well as for archiving in the system database.

APL automation systems normally make use of mathematical models that control the processing area with high precision and have a direct effect on the overall strip quality. In the case of the furnace, for example, the mathematical model uses the line speed, type of steel, strip width and thickness as information when converting the annealing curve characteristics into working parameters. A model may also be provided for the pickling area, for example to precisely control the acid dosing needed to obtain a clean, bright surface.

Conclusions

Adjustable-speed AC drives featuring advanced DTC technology and flexible control systems are destined to make a significant contribution to process line developments in the metallurgical industry. Steel producers benefit from the use of such powerful tools not only by being able to control more precisely the quantity of produced material but also due to the important information they provide about the quality of the finished strip.

Reference

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[3] P. Vas: Sensorless Vector and Direct Torque Control, 551–559. Oxford University Press, 1998.

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