Abstract
This paper introduces the main devices and automation system configuration for high speed wire rod finishing mill line, and analyzes in detail the control principle and software implementation for critical devices.

1. Preface
With the rapid development of modern industrial technology and process automation, the demands on the steel grades, dimensional precision and quality performance of wire rod products are increased, and the rolling technology is now regarded as a measure of development of the nation’s steel industry.

2. Wire rod finishing mill line based on ABB 800xA platform
2.1 Main devices introduction
Main devices for wire rod finishing mill line includes: pinch roll, diverter, No.3 flying shear, crop shear, finishing mill, water boxes, pinch roll in front of the laying head, laying head. The finishing block comprises 8 stands which are driven by a synchronous motor. Due to the high power (6 800kW), high speed (base speed is 850rpm, maximum speed is 1600rpm) and precise static and dynamic characteristics, high demands are made on the design and manufacture of the motor and inverter. ABB’s AMZ synchronous motor and ACS6000 medium voltage drive system meet these requirements.

No.3 flying shear is continuous rotation type, driven by a DC motor powered by a ABB DCS800 drive. The cut is activated by the movement of the diverter in front of it. The diverter is driven by a servo motor powered by a servo drive controlled by a motion controller of type BALDOR NextMove ES. The communication protocol between motion controller and servo drive is CANopen. An incremental encoder, installed at the non-drive end of the shear motor, is used for the speed feedback to the DCS800 drive, and for position detection in the motion controller. A pulse multiplier (HUBNER type OM3-3A) is provided for this purpose.

The laying head and pinch roll are also driven by a DC motor powered by ABB DCS800 drives. The device layout and automation system configuration are shown in Figure 1.

2.2 Introduction to ABB 800xA automation platform
800xA, the latest automation platform from ABB, is used for the mill line control system. On the server-client side it comprises one aspect and connectivity server, one client and one engineering station; the controllers are AC450 with S800 remote I/O are used. Advant Fieldbus 100 (AF100) is used for communication between controllers and drives. 800xA has been used in diverse range of industries since its introduction in 2004 and its main features are:

1. Integrated system environment. In traditional control system, the operation, engineering and Information Management System (IMS) are separate, whereas these are integrated into a single environment in 800xA.
(2) The 800xA is backward compatible with almost all of ABB’s automation products which makes it possible for the old customers to upgrade their existing system in accordance with their needs and financial situation.

(3) Flexible architecture that allows for easy incremental addition of functions.

(4) Enhanced security. System wide security features support assigning different rights, such as read, write and operation, to different object, such as users and groups thereby ensuring safe, reliable operation.

(5) Extensive diagnostics. Comprehensive system-wide self diagnostic and reporting features enabling ease of maintenance and high system availability.

(6) Complete system management. Easy setup and maintenance to ensure safe, reliable operation.

3. Finishing mill control
3.1 Speed calculation
The outlet speed and product size of the finishing mill come from rolling schedule settings. The operator selects the working stands in the configuration display according to the product size, meanwhile the roll diameter and groove correction value of the first working stand are input by the operator. The maximum speed is calculated in the control program according to the following formula:

\[ V_{\text{max}} = \frac{\pi D_w n}{60000 Z} \]

\( D_w \) is the working diameter of the first working stand in mm, \( Z \) is its gear ratio, and \( n \) is the maximum speed of the motor in rpm. The working diameter \( D_w \) will be calculated according to the following formula:

\[ D_w = (1.05 \times D - \text{GR}) \]

\( D \) is the roll diameter and GR the groove correction value, both in mm.

3.2 R-factor calculation
R-factor stands for reduction factor which is equal to the speed ratio of the adjoining working stands. The total reduction in the finishing mill is divided into two parts: one is for its first working roll \( R_{\text{first}} \) which is used to control the speed of its upstream drives, and one is the total reduction downstream the first working roll \( R_{\text{remain}} \), which is used to calculate the speed reference of the finishing mill drive itself. The calculation is best illustrated by the following example.

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1 Device layout and automation system configuration
If the operator selects stands 3 to 6 as working rolls, then stand 3 is the first working roll, \( R_{\text{first}} = R3 \) and the reductions for the unselected rolls are 1.0.

\[
R_{\text{remain}} = R4 \cdot R5 \cdot R6 \cdot R7 \cdot R8 = R4 \cdot R5 \cdot R6,
\]
the total reduction factor \( R_{\text{total}} = R_{\text{first}} \cdot R_{\text{remain}} \).

### 3.3 Material elongation calculation

Material tracking for devices after the mill need to be started before the finishing mill due to the high output speed of the material leaving the mill (15-120 m/s), and an accurate material tracking is only possible if the material elongation in the finishing block is known. The elongation is calculated as a finishing mill length in final material dimension. The formula is as follow:

\[
L_{\text{total}} = L_r \cdot [(R_8 \cdot R_7 \cdot \ldots \cdot R_2) + (R_8 \cdot R_7 \cdot \ldots \cdot R_3) + \ldots + (R_8 \cdot R_7) + R_8]
\]

Where \( R_N \) (output speed)/(input speed) for roll \( N \),

\( L_r \) distance between roll \( N \) and \( (N-1) \) in mm.

### 4. Water boxes control

The purpose of water boxes is to cool the process section exiting the previous stand and to control the rod temperature entering the Bar Reducing / Sizing mill or laying head. The water boxes control system utilizes both closed-loop flow PID and closed-loop temperature PID algorithms. If the latter is chosen, the former acts as the inner loop, and both algorithm control the rod temperature by regulating the cooling water valves. Taking into account the fast material speed, all the related signals must be connect the fast I/O channels of the system.

The parameters set by the operator on the display include: the length of dry head and tail, water flow, temperature control enable, temperature reference and so on, the actual rod temperature and flow and pressure of the cooling water are also shown in real-time. The calculation of the water valve activation timing is very critical for the control of the water box; it may cause cobbles if the valve is open before the rod head reaches the water box; or the valve isn’t closed in time after the tail passing it before the next rod head arrives. The hot metal detector (HMD) signal at the entry of the water box is used for the time calculation.

\[
t_{\text{open}} = \frac{L_1 + L_{\text{head}}}{v_{\text{head}}} - (t_h + t_r)
\]

\[
t_{\text{close}} = \frac{L_1 - L_{\text{tail}}}{v_{\text{tail}}} - (t_h + t_r)
\]

where \( L_1 \) length between the HMD and the water box entry 

\( L_{\text{head}} \) dry head length 

\( L_{\text{tail}} \) dry tail length 

\( t_h \) time hysteresis for the signal scanning in the control program 

\( t_r \) valve response time(approx. 0.2s)

Obviously that \( L_1 \) must be long enough to guarantee reasonable dry head and tail length.

### 5. Control of the pinch roll

#### 5.1 Rotation control

The pinch roll unit consists of an upper and a lower roll which are driven through an integral speed increaser by a speed regulated DC motor. The upper roll is closed by pneumatic cylinder with force controlled by a pressure regulator. There are three operator selectable automatic operating modes for the pinch roll unit: tail pinching, head and tail pinching and continuous pinching.

The pinch roll is used to apply a constant tension force to the rod to prevent flopping of the rod in the water boxes during body of coil, so torque control algorithm is used. It can also helps maintain good coil shape for the rod tail, which is implemented by switching from torque control to accurate speed control after tail of rod exits last rolling stand.

A pressure sensor detects the actual pressure of the two rolls, after tail of rod exits last rolling stand, the high pressure is chosen to avoid the tail end whiplashing.

#### 5.2 Open and close control

There are three automatic closing modes, head closing, tail closing and force closing. If head pinching or continuous pinching is selected, time calculation is started when the rod arrives the HMD at the entry of the finishing mill,

\[
t_{\text{head close}} = \frac{L_2}{v_{\text{head}}} - (t_h + t_r)
\]

where \( L_2 \) is the distance between the HMD and pinch roll 

\( t_h \) time hysteresis for the signal scanning in the control program 

\( t_r \) valve response time(approx. 0.2s)

If tail pinching is selected, time calculation is started when the tail of rod leaves HMD in front of no.3 pinch roll,

\[
t_{\text{tail close}} = \frac{L_2 - L_{\text{tail}}}{v_{\text{tail}}} - (t_h + t_r)
\]
where $L_3$, distance between HMD and pinch roll

- $L_{cut}$, tail length cut by No.3 flying shear
- $L_{tail}$, tail pinching length given by the operator

The pinch roll will be forced to close when the snap shear in front of the finishing mill closes, or the chopping shear starts cobbble-cutting.

Pinch roll opening is handled in a manner similar to closing with corresponding three automatic opening modes, head opening, tail opening and force opening. If head pinching is chosen, the time calculation is started when the rod arrives the HMD at the entry of the finishing block,

$$t_{head\_open} = \frac{L_2 + L_{head} - (t_h + t_r)}{v_{head}}$$

where $L_{head}$, head pinching length, is set by the operator. If tail pinching or continuous pinching is chosen, time calculation is started when the tail of rod leaves HMD at the entry of the finishing mill,

$$t_{tail\_open} = \frac{L_2}{v_{tail} - (t_h + t_r)}$$

The pinch roll will be forced to open 0.5s after tail of rod leaves the HMD in front of it or when the head of the next rod has arrived the HMD in front of No.3 pinch roll.

6. Laying head control

6.1 Front-end positioning of the laying pipe

The laying head consists of a spinning structure containing a spiral shaped pipe for discharging the rod onto the cooling conveyor. The cooling conveyor consists of many rolls evenly spaced out with a gap between adjacent rolls and if the head of the first coil falling on the conveyor enters a inter-roll gap the risk of head cobbles is high. Positioning of the laying head is adjusted so that head end of the rod meets with the correct position of the exit point of laying head conveying pipe, thereby ensuring the correct position of the head of the first coil on the conveying rolls, thereby reducing the risk of cobbles.

To implement this positioning, an AC80 controller is used to directly control the drive. An encoder is installed at the non-drive end of the laying head motor with its pulse signals connected to the interface board for the drive for speed feedback, and also connected to the NPCT-01C interface board of AC80 for position detection along with a proximity switch used for the synchronization of the counter.

The trace of the pipe of a rotating laying head is shown in Figure 2. The positive rotation direction is clockwise, and its actual angle is calculated according to the following formula.

$$\alpha = \left(\frac{P_{act} + P_{corr} \cdot L_{head}}{P_{ppr} \cdot Z}\right) \times 360$$

where
- $P_{act}$, total pulse number from pulse counter board
- $P_{corr}$, measurement correction value
- $P_{ppr}$, pulse number for one revolution of the pipe
- $Z$, gear ratio

The range of $\alpha$ is $0^\circ$ to $360^\circ$

Positioning is done between MD1, the HMD at the entry of the finishing mill and MD2, the HMD in front of the pinch roll. When the rod head arrives MD1, the rod head position on the pipe trace is calculated in accordance with the actual position of the pipe and the distance between MD1 and the exit point of the pipe, by comparing it with the position reference value, a difference is generated and converted to speed correction value for the DC drive regulate the speed of the motor, in this way can the front end exit from the predefined position of the pipe.
6.2 Vibration detection of the laying head
Vibration detection is used for protection of the person and device safety. An ENTEK IRD544M vibration sensor and a ROCKWELL XM120 dynamic measurement module is used the output signal is connected to the LED on the local pulpit for operator’s monitoring while the settings of the alarm and shutdown level is done via specific configuration software. A typical setting is shown in Figure 3. If the shutdown signal is activated, the laying head will be shutdown after 5 second delay.

7. Summary
As finishing mill is the core device for rod production as the end product. It’s the control technology and influences the final product quality and hence the design of the finishing mill’s automation system is of great importance.
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