AUTOMATION SYSTEM UPGRADING OF CONVENTIONAL HOT STRIP MILLS, BETA STEEL CASE[1]

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Abstract
In January 2006, Beta Steel Corporation in Portage , Indiana - USA places an order to Danieli Wean United and Danieli Automation for the revamping of its Hot Strip Mill to meet the increasing market demands on product quality and coil tonnage. The upgrade of the HSM facilities (one two-high roughing and five four-high finishing stands) was aimed at improving final product quality by installing new descailing facilities and upgrading the Water Wall™ strip laminar cooling and at increasing mill production by installing new equipment, such as a rotary drum shear, WR changing system, downcoiler and walking beam coil conveyors and handling facilities. The equipment was supplied in less than 12 months; two-phase mill upgrade required just 40 days of mill shutdown. Danieli Automation had a important role in the success of the project, by providing a new process control automation system based on client-server architecture, allowing retrieval of rolling practices set-up, technological and production data, implementing new technological functions to improve the performances of the plant and the material quality. Beta Steel HSM modernization, a project that stands among others recent revamping references (Hadeed - Saudi Arabia, Cogne – Italy, Birmingham Steel – USA, …), to confirm Danieli Automation capability to supply state of the art upgrades of automation system for existing rolling mills.
Key words: Modernization; Process; Functions; Upgrade.

SISTEMA DE AUTOMAÇÃO PARA ATUALIZAÇÃO DE LAMINADORES DE TIRAS A QUENTE CONVENCIONAIS, CASO BETA STEEL

Resumo
Em janeiro de 2006, a Beta Steel Corporation em Portage, Indiana – EUA colocou uma ordem para a Danieli Wean United e Danieli Automation para a reforma de seu Laminador de Tiras a Quente, para atender o crescimento da procura de mercado para qualidade de produto e tonelagem de bobina. A atualização das instalações do LTQ (uma cadeira duo e cinco cadeiras quadro acabadoras) foram utilizados na melhoria da qualidade do produto acabado novas instalações de descarepação e atualização da tira laminar de resfriamento Water Wall™; e no aumento da produção do laminador novos equipamentos, como uma tesoura rotativa, sistema de troca de cilindros de trabalho, desbobinador, tranportador de bobinas tipo “walking beam” e instalações de manuseio. O equipamento foi fornecido em menos de 12 meses; duas fases para atualização do laminador requereram apenas quarenta dias de parada do laminador. A Danieli Automation teve um papel importante no sucesso deste projeto, por providenciar um novo processo de controle para o sistema de automação baseado na arquitetura cliente-servidor, permitindo a recuperação das configurações da pratica de laminação, dados de tecnologia e produção, implementando novas funções tecnológicas para melhorar a performance da planta e a qualidade do material. Modernização do LTQ da Beta Steel, um projeto entre outras referências de recentes reformas (Hadeed - Saudi Arabia, Cogne – Italy, Birmingham Steel – USA, …), confirmam a capacidade da Danieli Autmation em fornecer atualizações no estado da arte de sistemas de automação State of the art para laminadores existentes.
Palavras-chave: Modernização; Processos; Funções; Atualização.

1 *Technical contribution to 44th Rolling Seminar – Processes, Rolled and Coated Products, October 16 to 19, 2007, Campos do Jordão – SP, Brazil.*
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Plant Configuration and Basic Data

Rolled steel grades:		Low Carbon steel Medium Carbon steel API grade (up to X70) in future
Input slab size:		thickness 254 mm (max) width 800 to 1.550 mm length 7.000 to 12.000 mm
Input slab weight:		30 ton (max)
Coil Data (Before revamping):	Weight: Max. PIW:	18 ton 14,3 kg/mm
Coil Data (After revamping):	Thickness: Width: Weight: Max. PIW: Coil diameter:	from 1,5 to 19 mm from 800 to 1.550 mm 30 ton 20,0 kg/mm 1.980 mm

Slabs heated up in the re-heating furnace are processed by a reversible 2-HI stand with edger and subsequently by five 4-HI finishing stands.
Danieli intervened on the existing mill configuration to improve the quality of the final product and to increase the coil weight, by modifying the furnace exit area with a new dischraging machine, by installing a new crop shear for head/tail cut, a new laminar cooling system at the exit of the mill, a new downcoiler to increase the coiling capability and the quality of the wraps, a new coil handling system, a new quick roll changing system and other auxiliary components. Figure 1 below is a representation of the plant layout.

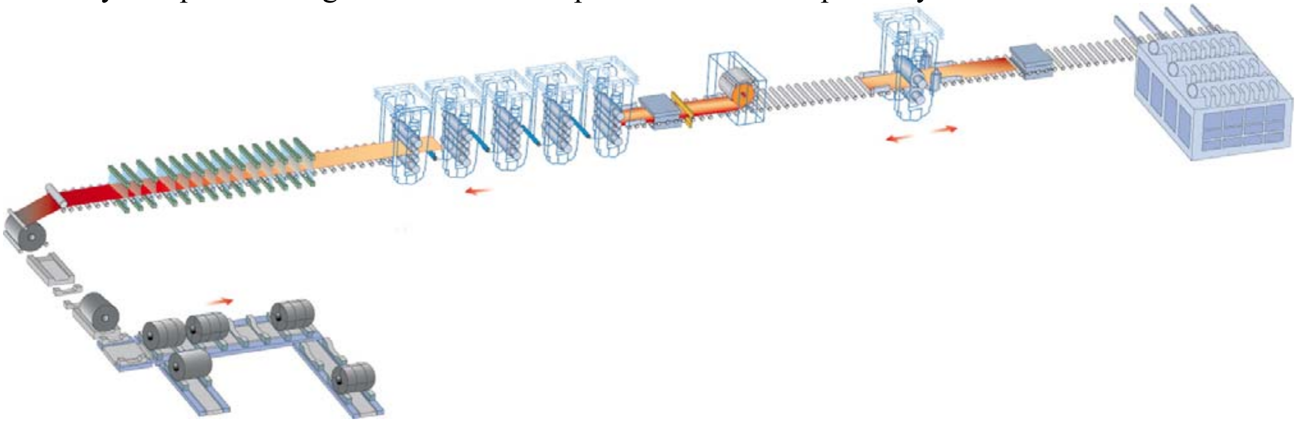


Figure 1 - Beta Steel plant layout

Project Execution

The planning of the project has been studied to have the minimum impact on the production of the plant and for this reason the installation of the equipment has been planned in two phases.
The installation of the new mechanical and electrical equipment was performed in two months off-line, that is without interrupting the production of the existing mill.
During the 40 days of shutdown the final installation was completed; in particular the new electrical and automation system was interfaced with the existing one. The new pre-arranged panels installed in place of the old ones and existing cable connections re-used as far as possible to avoid loosing time.
First coil was rolled in December and fine-tuning of the mill was performed in parallel to the production scheduled by the customer. The following figures 2 and 3 are pictures taken in the plant showing some of the new installed equipment.

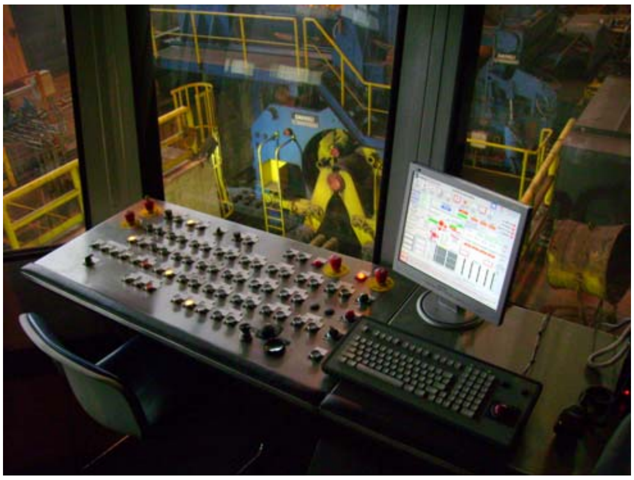


Figure 2 - View from the pulpit of downcoiler in operation

Figure 3 - View of the finishing area during the revamping

Automation System Architecture

The system is organized according to modern standards with indipendent units PLC-based and high-speed HiPAC controllers dedicated to specific process function (figure 4). The above mentioned units are linked through a local area network and, through it, interconnected with operator workstations embedding SCADA supervisory functions as well as level 2 operator interaction functions for models monitoring and maintanance.
The level 2 is based on a distributed architecture with Clients accessing a Server to save/retrieve technological and production data and to interact with the calculation models. The database hosts production and technological data to avoid data mismatch and minimise maintenance activities.
Control Desks installed in main operator room and supervision interfaces make wide use of windows-based, intuitive graphical screens to visualise the equipment and relevant process data.

The Maintanance Suite includes powerful diagnostic and maintenance equipment such as Fast Data Analyzer (FDA), Engineering Workstation (EWS), PLC programming tools.

Moreover the supply includes electrical system for motors control, both at fixed and variable speed interconnected through with speed profibus link.

The most significant process controls, described in the following pages, are:

- Cooling set-up model;
- Coil Temperature control;
- Crop optimization;
- Mill exit set-up;
- Down coiler wrapping, tension control.

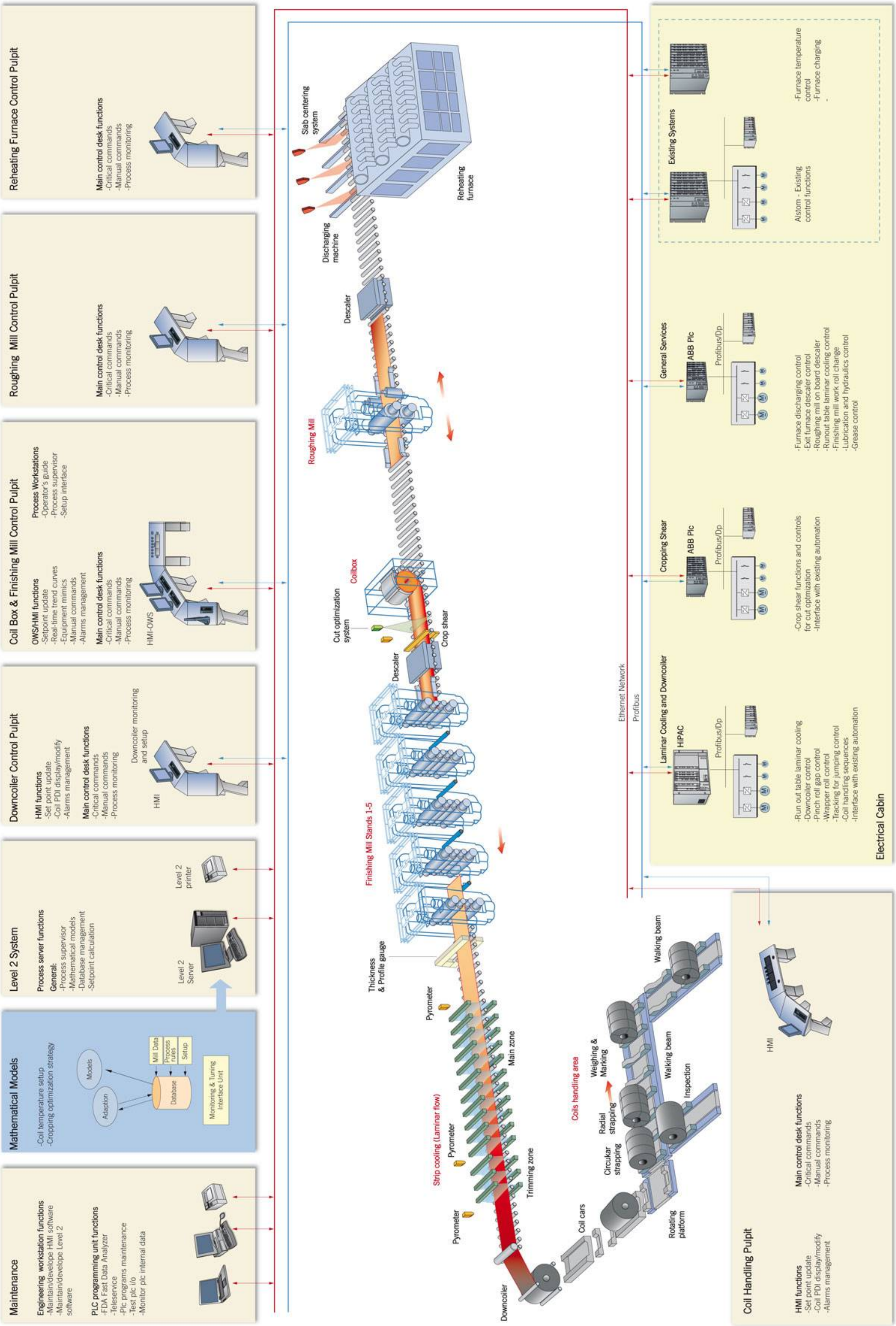


Figure 4 - Automation system configuration

HiPAC process control

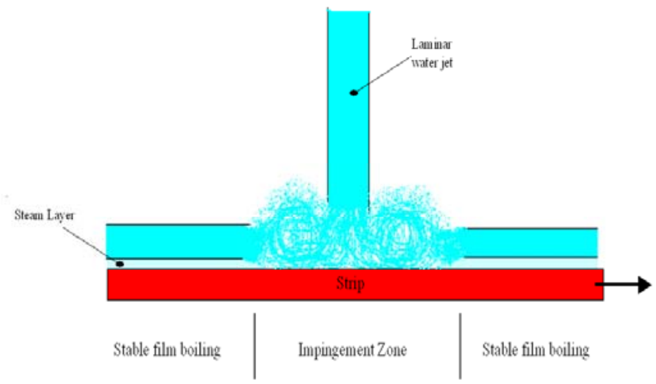
In order to optimize the rolling process and improve the material quality, the following functions have been implemented in the HiPAC process control system.

Strip Cooling Control - DL-FLOW mathematical model

Coil temperature setup model, to calculate spray pattern and flow rates for main and trimming cooling zones. Capacity of adaptation, as part of selflearning mechanism able to provide automatic updating of setup models parameters. Following tasks are supplied:

- Preliminary setup calculation (Feed-Forward strategy);
- Online samples saving function;
- Online simulation;
- Online control (Feed-Forward and Feedback strategies);
- Adaptation.

All the above features employ a numerical model of run out table cooling which gives a complete physical description of the cooling process. The model uses an implicit finite difference method to calculate the through-thickness temperature at the strip centerline from the finishing mill exit to the downcoiler. The control strategy is the combination of **feedforward** and **feedback** actions. Feedforward strategy takes action within the main spray section while the feedback strategy utilizes only the trim spray section.
The model uses the Crank-Nicholson implicit finite difference method to calculate the through-thickness temperature at the centerline of the strip. The number of nodes through the thickness of the strip has been optimized to ensure numerical accuracy without any superfluous calculation.



Three cooling processes are considered on the top of the strip surface:

- **Forced convective** heat transfer within the impingement zone of each header where water is in direct contact with strip;
- **Stable film boiling** with a steam layer between surface water and strip;
- **Radiation** heat transfer (when there is no water);

The average convective heat transfer coefficient (htc) at each top header is calculated using the following equation.

$$htc = \Pr^{0.33} \cdot \left(0.037 \cdot \mathrm{Re}^{0.8} - 850\right) \cdot \frac{k}{x}$$

htc = *convective heat transfer coefficient [W / (m2K)]*
Pr = *Prandtl number [-]*
Re = *Reynolds number [-]*
k = *Thermal conductivity of coolant [W / (m K)]*
x = *Impingement zone width [m]*

expressing the average value of the *htc* within the impingement zone in terms of the temperature dependent properties of the coolant at temperature *Tf*. Above a surface temperature value of approximately 350 to 400 °C, the *htc* for boiling film is not dependent on temperature, therefore *htc* for radiation to air is calculated using the Stephan-Boltzmann equation:

$$hr = \frac{\sigma \cdot \varepsilon \cdot \left(T_S^{\,4} - T_a^{\,4}\right)}{T_S - T_a}$$

hr = radiative heat transfer coefficient [W / (m2 K)]
Ta = ambient temperature [K]
ε = emissivity
σ = Stefan-Boltzmann constant

The model incorporates the temperature-dependent thermal properties appropriate for each quality group, including Specific heat, Density and Termal conductivity. The Specific Heat curve takes account of phase transformation phenomena, which may be interpreted as a sudden increase in specific heat values (Figure 5).
Model simulation was performed for each specific application (example shown in Figure 6 and 7).

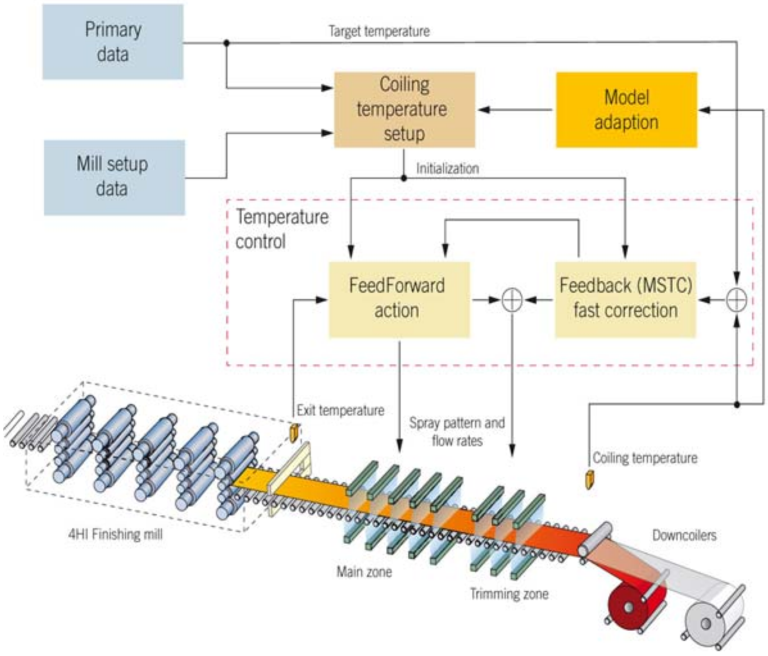


Figure 5 - Diagram of coiling temperature control

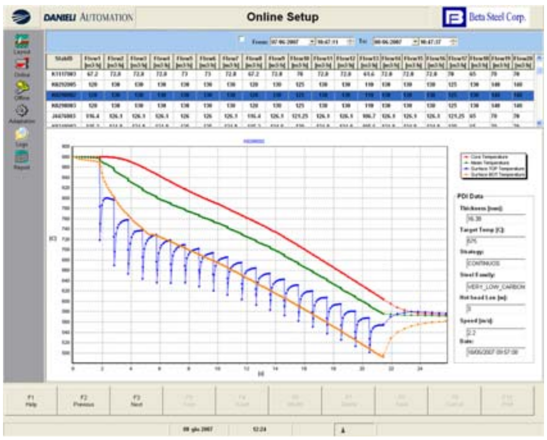


Figure 6 - Model for spray control, coil thermal simulation

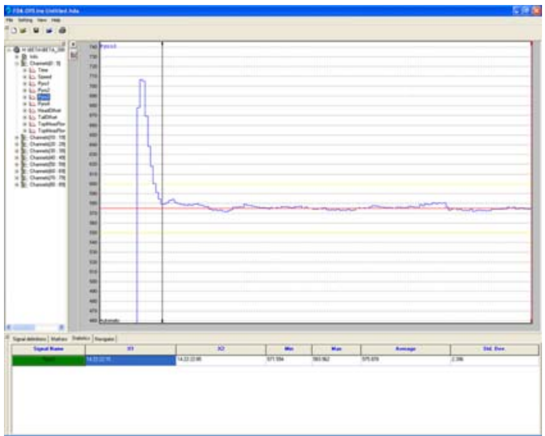


Figure 7 - Coiling temperature, FDA screenshot

Stirp Cut - D-COPT Crop Optimization system

The Crop optimization system integrates the signals of a width gauge and of a speed meter installed down stream the Rougher stands (figure 8).

The aim of this function is to minimize the Head and Tail crop of the strip that must be cut due to their bed shape.
The operator has the possibility to set the length of strip that must be cut according to the image of the Head and Tail of the strip that will be show on the Operator Workstation.

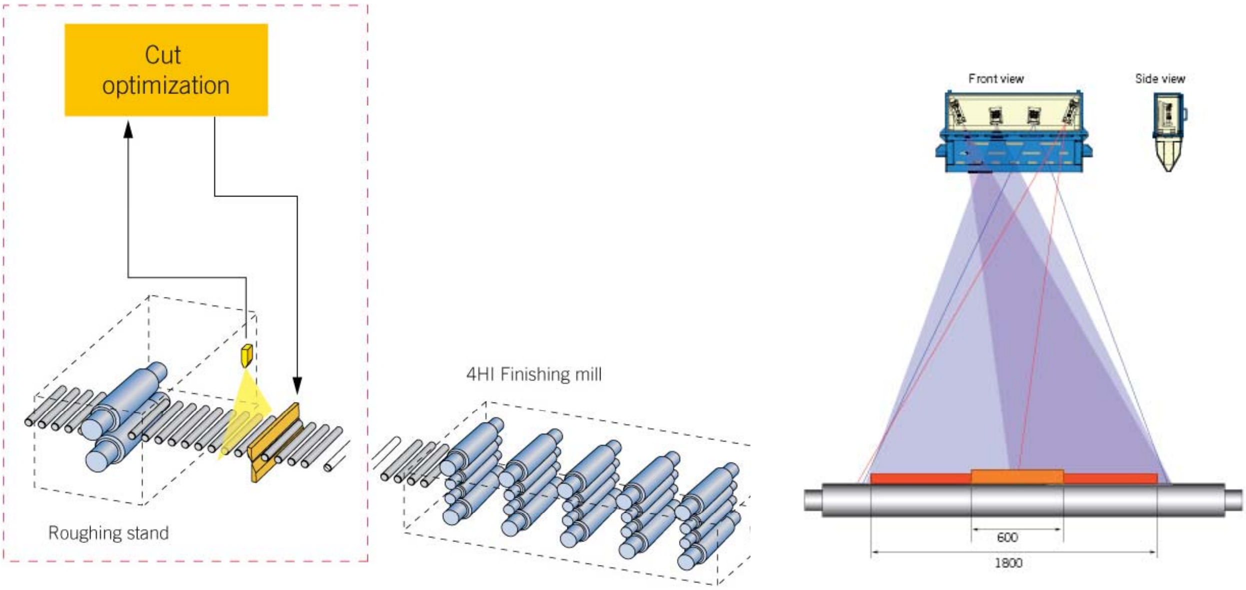


Figure 8 - Crop optimization system

The gauge system computer define the strip shape and sends it to the shear controller which calculates the optimal shear set-point optimizing Head and Tail scrap starting from the shapes measured by the HiWIDTH gauge.
A graphical interface system is used to display Head and Tail shapes and the cut set-points computed by the gauge.
HiWIDTH Stereoscopic Width Gauge employs an advanced digital edge detection process that captures the digitized camera data.
Software routines running on the high speed processor perform edge determination in two dimensional space.
The camera data are digitally filtered and the true width of the material is calculated using geometric triangulation. These trigonometric functions allow very accurate width measurement in spite of the influences of material pass line variations, thickness variations and flutter.
The system, not yet installed in Beta Steel, is ready for operation.

Down Coiler Control - D-COILING setup
Down coiler setup calculation based on tension strategy defined for each yield stress, material family and strip geometry (block diagram shown in figure 9).

Wrapper Control
When the strip head approaches a wrapper roll the wrapper is retracted by the strip thickness so as to avoid any impact forces being applied. Each wrapper jumps ahead of the coil 'bulge' in turn until the coil is formed and a tension between the mandrel and the pinch roll is detected.
Measured force is also a parameter used in the calculation of the retracting cycle.

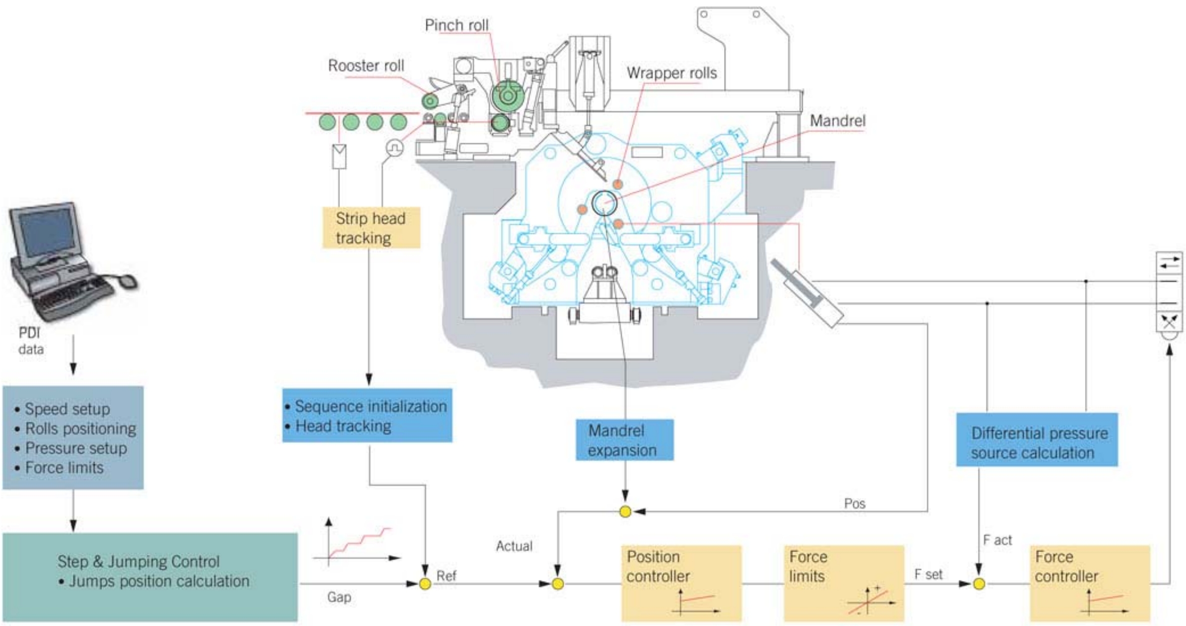


Figure 9 - Block diagram of the D-COILING system

<u>Tension & Speed Control</u>

The tension is normally established between the Pinch Roll Unit and the Mandrel. However, in the case of the upper pinch roll being raised during rolling, the tension is established between the Finishing Mill last active stand and the mandrel.

The mandrel is driven, via a gearbox, by a variable speed motor.

Downcoiler mandrel speed and tension control is performed by the following functions:

- Diameter Calculation
- Tension Reference Control
- Angular Speed Reference Control
- Torque Reference Control

During coiling the motor is to be controlled to maintain a constant strip tension. The mandrel remains in tension control until the tail leaves the pinch rolls.

The product speed at this instance is equal to or less than the Pinch Rolls tail out speed. At this point the mandrel drive control is smoothly transferred from tension to speed control but with an outer strip positioning control for tail spotting.

A mathematical model calculates the strip tension reference based on the product properties (yield stress) and dimensions (thickness and width). However, the operator is also given the facility to set a desired tension or to modify the derived tension.

The motor is able to provide tension up to 1.9 times of the motor nominal torque available at the speed of operation.

The following parameters are taken into consideration in the calculation of the torque reference:

- Base torque to generate strip tension: the control equipment increases torque directly with the coil built up to keep at constant value the strip tension.

$$M = T \times \frac{D}{2} = W \times H \times \sigma_{spec} \times \frac{D}{2x10}$$

M = mandrel torque (kg-m)
T = strip tension (kg)
W = strip width (mm)
H = strip thickness (mm)
D = coil diameter (m)
σ_{spec} = parameter depending from:

- yield stress f(steel grade, T)
- strip thickness

➢ Bending torque: The control equipment maintains constant bending torque during coil build up:

$$M_{B[KGM]} = \frac{\sigma_{YS} \times h^2 \times W}{4 \times 10^4}$$

W= strip width
h = strip thickness
σ_{ys} = parameter depending from yield stress f(steel grade, T)

➢ Inertia compensation torque
➢ Loss compensation torque

Prior to strip arrival the mandrel is set to run at strip delivery speed plus an over-speed factor. The motor speed reference is modified by the gearing and the mandrel first stage diameter such that at zero over-speed the tangential speed of the mandrel to be equal to strip delivery speed.
The lead speed value (always positive) is calculated for the Downcoiler mandrel taking into account a fixed value added to a component proportional to the linear speed (set by line master).
After second stage expansion the wraps on the mandrel tighten, slip reduces, the mandrel speed is reduced to strip delivery speed and tension is established. To prevent excessive tension transients during 'tension on' the mandrel over-speed is to be kept to a minimum.
Figure 10 below shows a HMI Page of the wrapper rolls and figure 11 is an averall view of the new downcoiler.

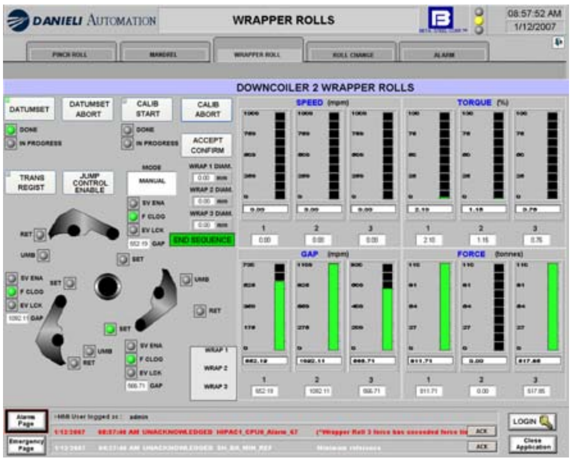


Figure 10 - Wrapper rolls setup on the HMI

Figure 11 - The new downcoiler during the installation

System Maintenance - Fast Data Analyzer

FDA Danieli Automation Fast Data Analyzer is included in the supply to give the maintenance team and the process engineer a powerful tool, multi-purpose monitoring system, designed to carry out detailed analyses of process variables and events.

FDA acquires information on process at high speed directly from local network in clientserver mode. While performing real-time data handling, the FDA can still support off-line data display, data analysis, data export to market-leading databases for long-term storage and access of third-party programs.
In particular the FDA is provided to support the process engineers and the maintenance staff in order to:

- Obtain a better understanding of the production process
- Trap critical situations and understand the dynamics of problems related to equipment control, material handling and quality
- Increase process data acquisition and storage capability.

Typical aims of monitoring are:

- Quality-related variables: speeds, temperatures, flow rates, pressures, etc.
- Regulation loops variables: set-points, actual values, regulation parameters, actuators feedback signals
- Equipment control and material handling signals: HMD, pyrometers, solenoid valves excitation, limit switches, encoders and other sensors/actuators.

Example screens of FDA analysis is shown in figure 12 and 13.

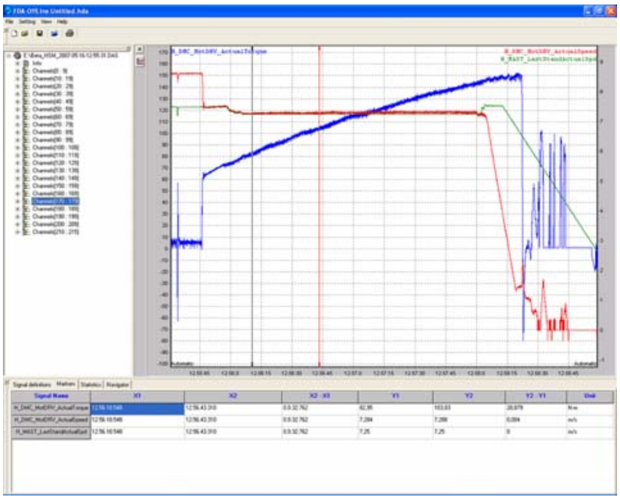


Figure 12 - FDA screen, real-time recording during the rolling process: Mandrel torque (blue) and speed (red) vs finishing stand speed (green)

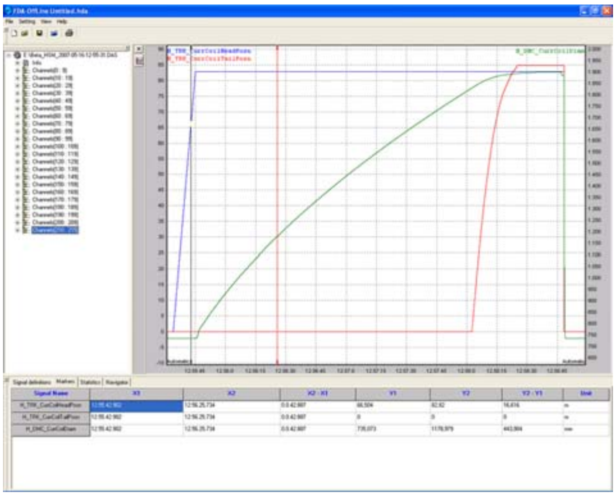


Figure 13 - FDA screen: Coil head (red curve) coil tail (blue curve), calculated diameter of the coil (green curve).

System Maintenance – Teleservice

A Teleservice unit allows Danieli Automation to remotely monitor the system for support purposes (block diagram shown below in Figure 14).

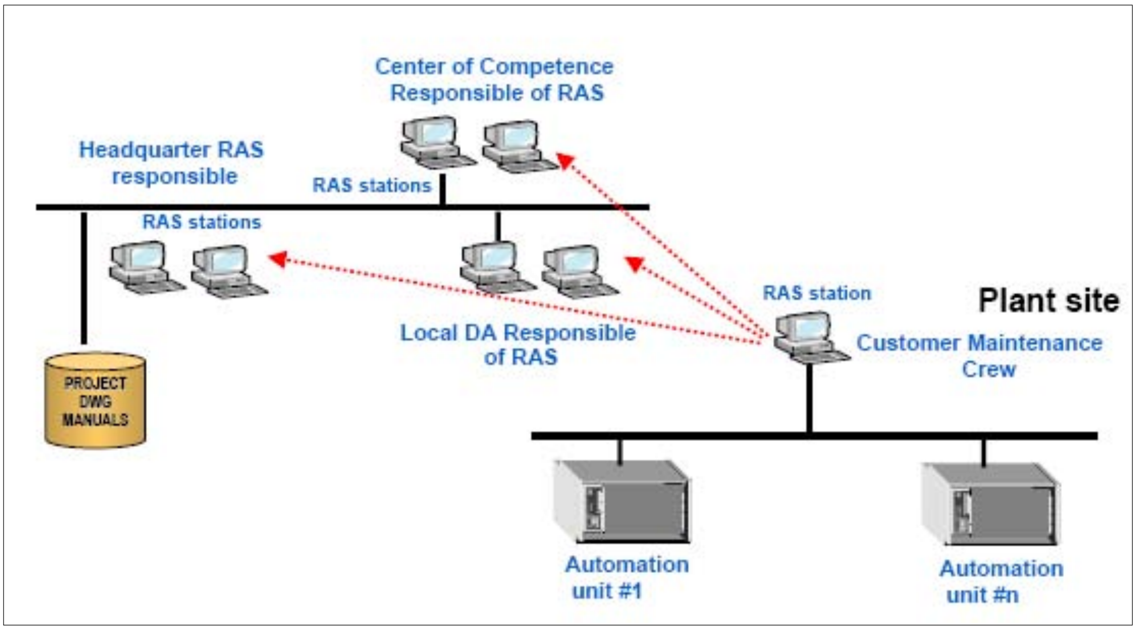


Figure 14: Teleservice Architecture

The Teleservice assures a remote non-stop service and a reliable support for a quick solution of unexpected malfunctions, giving the customer the benefit of immediate intervention of a specialist at any time and limiting or avoiding the specialist's travelling time and costs.

CONCLUSION

The new automation system, was fully integrated with the existing equipment, resulting in a short learning curve for the operators, distributing real-time information to the personnel, allowing production supervision and improving consistency of rolling practices thanks to an easy and flexible plant setup for different range of products and thanks to automatic adaptation to the actual rolling conditions.
Achivements:
- high availability of automation system;
- high accuracy of control system;
- increased coils weight;
- improved material quality;
- very short total mill shutdown.

The Final Acceptance Certificate (FAC) was signed on the 29 May 2007, with mutual satisfaction of Beta Steel and Danieli.