Ansaldo Sistemi Industriali

RESULTS TO THE POWER OF THREE

Automation Systems in Flat Products

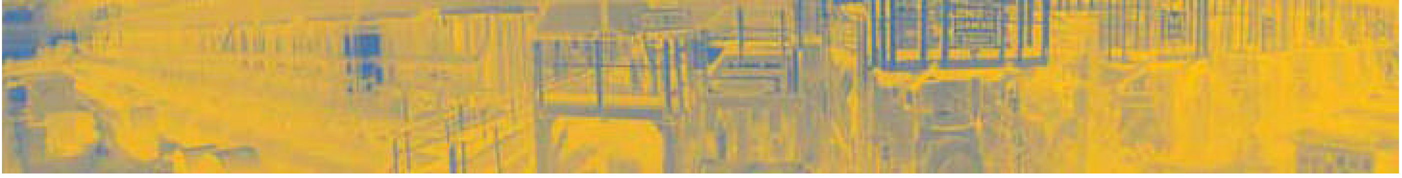
PREFACE

The transformation of a slab into a coil or into a plate is a complex process which must take into account a number of technological constraints in order to obtain a final product with the optimal metallurgical properties the market increasingly demands today.

Ansaldo Sistemi Industriali (ASI) provides state of the art, dependable, accurate automation systems: this white paper presents the functions and technologies at the root of its success, achieved after many years of experience meeting customer's needs.

Ansaldo Sistemi Industriali strives constantly to keep its automation functions up to date as a way of guaranteeing final product quality and customer satisfaction under all plant conditions in both cold rolling and hot rolling and therefore attempts have been done to keep the material in this document as up to date as possible.

Gratitude must be expressed to those personnel responsible for the operation of mill facilities who, with their feedback and constant support, have allowed us to successfully develop the automation controls that are described in this document. It is our hoped that this paper will be useful to them and to the design engineers associated with mill facilities.



Metal Industry: Automation Systems in Flat Products

SUMMARY

PROCESS CONTROL

Mill Setup

A reliable high-performance automation system is necessary to make the most of the mechanical and hydraulic equipment in a complex rolling process: ASI has already supplied and commissioned numerous hi-tech systems with an upper part, the mill setup, which calculates the schedule for rolling the high quality product required by its customers, taking into account mill constraints, energy consumption, equipment deterioration and plant productivity.
The autoadaptive mathematical models underlying ASI's setup calculation cover all the most common types of hot and cold rolling mills: hot strip mills, steckel and plate mills, continuous and coil-to-coil tandem mills and single stand mills for steel and aluminum; the models for accelerated cooling and hot and cold levelers typical of plate production processes are also worthy of note.
References to the level 1 automation system and to the actuators, i.e. the rolling schedule, are calculated by the mathematical models for each piece to be rolled in order to take into account the variance intrinsic to the mill: for instance, possible differences in temperature between two slabs entering a hot strip mill, and the impact this difference has on the rolling force required to obtain the same final thickness; or the wear a work roll is subject to, piece by piece, and its impact on the thickness of the piece.
The basic input data may be listed as follows:

- geometric and physical data on the entry product (dimensions and steel quality);
- target data on the final product (thickness, width, temperature, profile, … , depending on the process);
- plant data and mill limits.

ASI's automation system takes particular care to track the piece from entry into the mill to the time the coil or plate is produced and exits the plant; piece tracking recognizes all the pieces throughout the entire plant, enables measurement acquisition and manages the events in which setup and adaption must run (refer to the "Level 2 Basic Functions" section for details).
Three factors contribute to mill setup: rolling strategies, mathematical models and model adaption; they are discussed in the paragraphs below, grouped by mill type.

1.1 – Finishing stand in a plate mill (TISC – Tianjin, PRC)

Hot Rolling

Hot rolling mill setup is performed, with the differences and peculiarities identified below, for a number of different types of plant:

- hot strip mill;
- reversing and continuous roughing mill;
- single and double stand plate mill;
- steckel mill.

Rolling Strategies

By way of example, it is clear that a virtually infinite number of combinations of drafts can be applied to the n stands in a hot strip mill or to the finishing passes in a steckel or plate mill in order to obtain the required exit thickness, starting from the thickness of the entry product; the same is true of definition of width reductions at the edgers in a roughing mill, or in a plate or steckel mill.

In some plants interaction between thickness and width is equally delicate; in a 2-stand plate mill, it is necessary first of all to define how to divide the passes among sizing, broadside and finishing phases in order to obtain the desired width, in addition to the correct thickness, and in order to balance rolling times and therefore the plant's production.

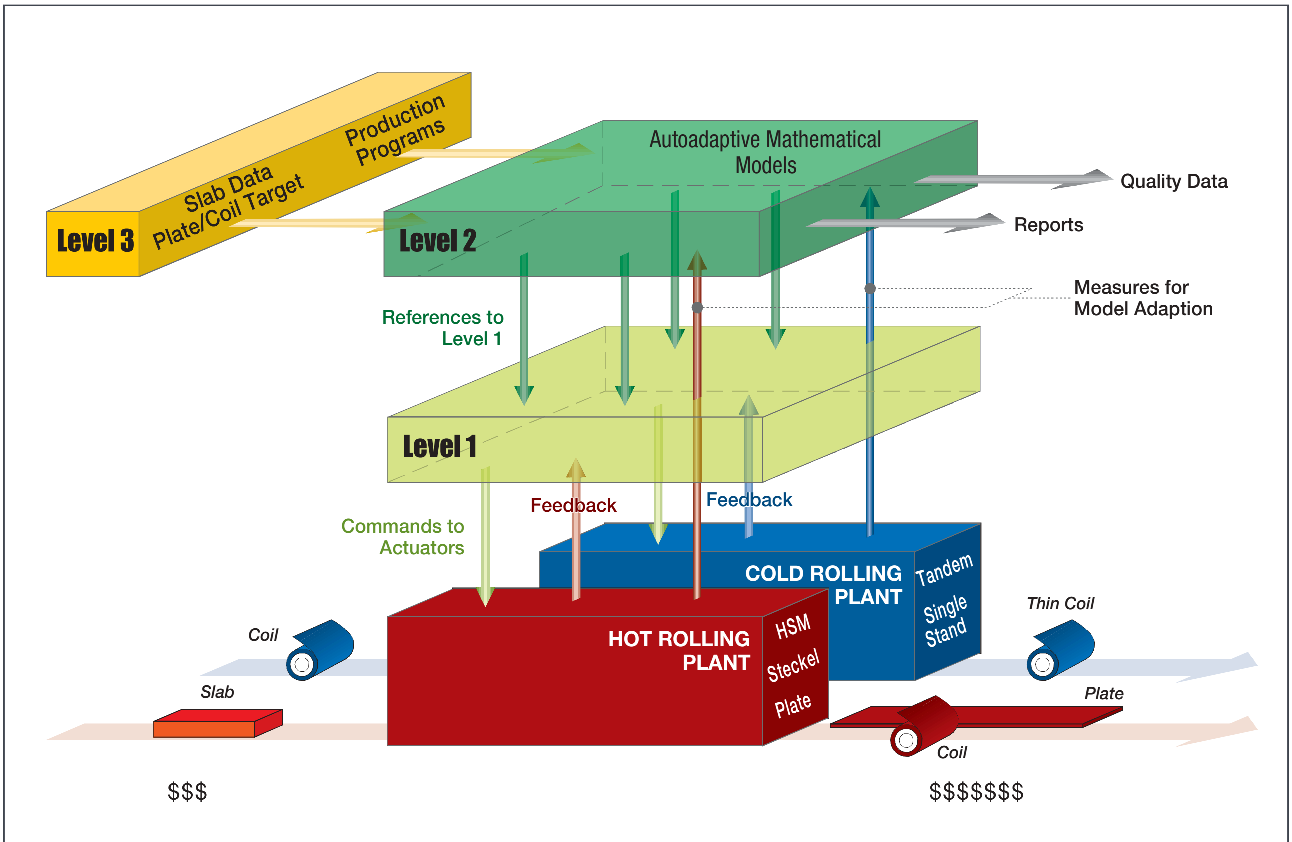
These choices are made on the basis of reliable strategies drawing on ASI's know-how and experience with rolling processes and plants, so that, for instance, the draft distribution to be applied to each stand in a hot strip mill is calculated or retrieved from dedicated model tables according to the product to be rolled (i.e., thickness, width, steel quality); ASI's algorithms assign great importance to every aspect of these different processes and aim to optimize both overall mill behavior and productivity.

1.3 – Main pulpit in a Steckel Mill (IPSCO - Mobile, Alabama, USA)

Mathematical Models

A number of modules implement rolling models and accurately calculate intermediate and final rolling parameters:

- **Piece width:** width behavior is evaluated by taking into account the different phenomena that affect piece width during rolling: the piece is affected by the spread



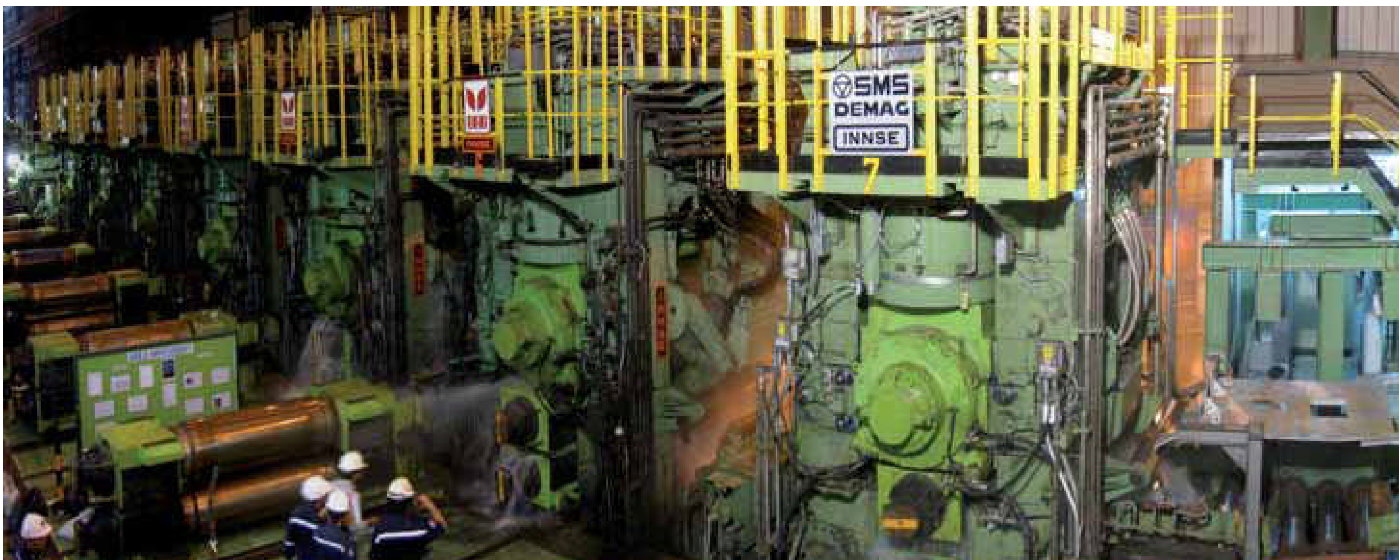
1.2 – ASI automation system at-a-glance

due to thickness reduction and by the so-called "dog-bone" effect created by the edging process (when the edger is present).

- **Speeds:** the kinematic diagrams that the piece has to follow are calculated, and later in the calculation they will be used with forward slip to determine speed references for the motors.
- **Piece temperatures, forces and torques:** the temperature evolution of the piece along its rolling process is calculated, as well as the force

and roll thermal expansion have a direct impact on the crown and the flatness of the rolled material; their accurate evaluation allows a tangible increment of strip shape with consequent improvements in final product quality (refer to the section on Shape Control).

- **Roll gap position:** the final gap reference is calculated on the basis of the piece thickness previously defined for each stand or pass, taking into account stand stretch, oil film compensation, roll deflection, roll wear and thermal expansion.



1.4 – 3.2 millions ton/year 7 stand hot strip mill, fully automated by ASI (SSI - Bang Saphan, Thailand)

necessary to roll it and the torque required of the motors, because they are intrinsically related to one other: the hotter the piece, the smaller the force (and the torque) required to obtain the same reduction; in addition, piece temperature during the rolling process plays an important role in obtaining the correct metallurgical properties for the desired steel grade. Classical formulae from rolling literature (Sims, Hitchcock, Stephen-Boltzmann, …) are applied, as well as model tables associated with each product to be rolled, to obtain the best match between theory and practical experience. Mill and equipment limits are checked and countermeasures are taken if limit is overcome, basically by adjusting thickness reductions and speeds.

- **Shape setup:** transversal deformation of the rolls (due to mechanical stress during rolling), roll wear

- **Thickness tapering:** improvements in plate rectangularity in a plate mill or in the final shape in a steckel mill can be achieved by varying the thickness of head and tail ends with respect to the body; calculation of a tapered profile to be followed by basic automation during rolling is so included in ASI's models.
- **Sensitivity coefficients:** the dynamic response of feedback regulators is based on the gains chosen for them, but gains are heavily dependent on the product's characteristics (e.g., width, thickness, hardness, reduction, …) and a mill normally produces a large number of different products: if a regulator with fixed gains were used, the variations in controller response would be absolutely unsatisfactory for the entire product range and would lead to poor control performance. For this reason, ASI's feedback

regulators allow for schedule dependent gain, which makes the controller's dynamic response insensitive to the different products to be rolled, improving performance and reducing tuning times. Feedforward regulators also benefit from correct schedule-dependent gain because steady-state error is directly dependent on the accuracy of feedforward gain. Extensive use of ASI's mathematical models permits insertion of perturbations in selected variables to derive the sensitivity of other variables and therefore calculate the necessary schedule-dependent gains.

1.5 – Single-stand steckel mill: mother plates on the cooling bed (IPSCO – Montpelier, Iowa - USA)

Model Adaption

Plant measurements automatically acquired during the rolling process are averaged to obtain a sort of snapshot of the plant; after this, the adaption process runs the mathematical models again, fed with the averaged data, to update the model parameters to values as close as possible to the current rolling conditions.

In a hot strip mill, the measurements are collected just after that the strip head has completely threaded the mill and the model adaption is run just after measurement averaging.

In piece-by-piece scheduling at reversing mills (steckel and plate mills), measurements are collected during each rolling pass and a pass-to-pass adaption is executed at the end of each pass to adjust the rolling schedule for the remaining passes; the usual piece-to-piece adaption is in any case executed after the last pass.

Cold Rolling

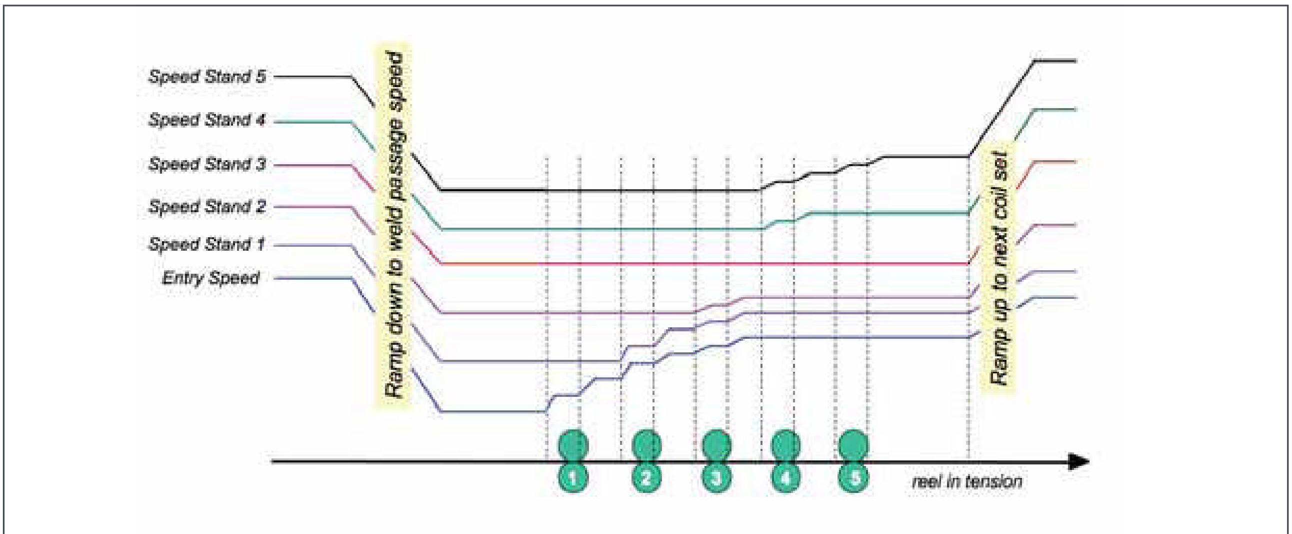
Cold rolling setup calculation is also carried out for many different plants:

- coil-to-coil tandem mill;
- continuous tandem mill;
- 2-stand reversing mill;
- reversing and not reversing single stand mill;
- cluster mill.

Rolling Strategies

The basic concepts illustrated in hot rolling also apply to cold rolling; a number of peculiarities are of course taken into account:

- tensions play a basic role in obtaining the desired exit thickness: here ASI applies reliable criteria for determining not only correct draft distribution, but also entry, interstand and exit tension distributions;



1.6 – In a continuous tandem mill, ASI's flying setup system calculates suitable speed cones as illustrated in this example, where the 3rd stand is the pivot stand; they will be applied when the weld between two strips passes the point marked by the vertical dotted lines.

- the strategies depend on the product to be rolled and also on the rolling characteristics, such as bright or shotblast rolling;
- the operator and the process engineer, on the basis of their own experience and particular plant conditions, have more opportunities to interact with and drive the calculations of the mill setup, by means of dedicated trims and directives, and can chose to optimize draft and tension distribution basing, for instance, on powers rather than on forces.

Mathematical Models

- **Speeds:** the kinematic diagrams that the piece has to follow are calculated, and later in the calculation they will be used with forward slip for determining the speed references for the motors.

1.7 – 5-stand tandem mill (Heng Tong Group-Tang Shan, PRC)

- **Piece forces and torques:** the force necessary to roll the coil and the torque required for the motors are calculated on the basis of classical formulae from rolling literature (Bland & Ford, Hitchcock...) and model tables associated with each product to be rolled are managed for the best match between theory and practical experience. Mill and equipment limits are checked and countermeasures are taken if a limit is overcome, basically by adjusting thickness reductions and speeds.
- **Shape setup:** deformation of the rolls due to thermal stress and wear is taken into account in defining a preset for bending and cooling spray values in coil-to-coil tandem mills or single stand mills; their accurate evaluation permits a tangible increase in the in-tolerance length of strip flatness, with consequent improvements in final product quality.
- **Roll gap position:** the final gap reference is calculated from the piece thickness defined previously, taking into account stand stretch, oil film compensation, roll wear and thermal expansion.
- **Threading and low speed setup:** different calculations with respect to the full speed setup must be made to improve safety operations and overall mill performance during the threading and tail out phases; at low speed, when higher friction coefficients and different yield stress characterize the strip, to

minimize the deviation of final thickness from the target, a new calculation is performed for adjusting interstand tensions, gaps and bending forces.

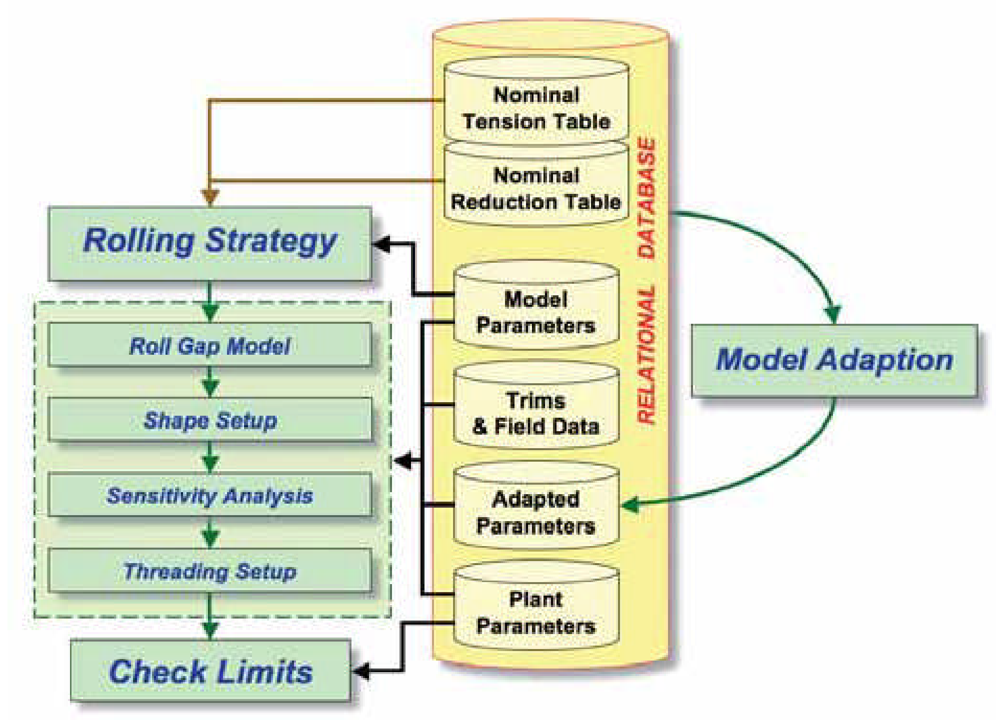
- **Flying setup change:** management of a continuous tandem mill involves several technical innovations in comparison with the batch process typical of a coil-to-coil mill, in order to produce different strip thicknesses by manipulating actuators without stopping rolling; this module calculates a set of references (basically, gaps and speed cones) with the aim of maintaining rolling stability (preventing accidents) and minimizing the length of off-specification rolled strip (see figure 1.6).
- **Sensitivity coefficients:** (see the relevant paragraph in hot rolling).

Plant type	Model adaption is performed…
Coil-to-coil tandem mill	– at the end of each rolled coil
Continuous tandem mill	– at the end of each rolled coil – during full speed phase (in steady-state conditions)
Reversing mill	– at the end of each pass: pass-to-pass adaption, for adjusting the rolling schedule for the remaining passes – at the end of the last pass: piece-to-piece adaption

Table 1.1 – Model adaption

Model Adaption

Analogously to hot rolling, plant measures are acquired at particular times during the process and averaged to adapt the mathematical models: in a tandem mill, collection is performed during the full speed phase, at intermediate values of speed and also in the low speed phase.
Once that the measured values have been opportunely averaged, the adaption process is started depending on the peculiarity of each cold rolling mill (see table 1.1)

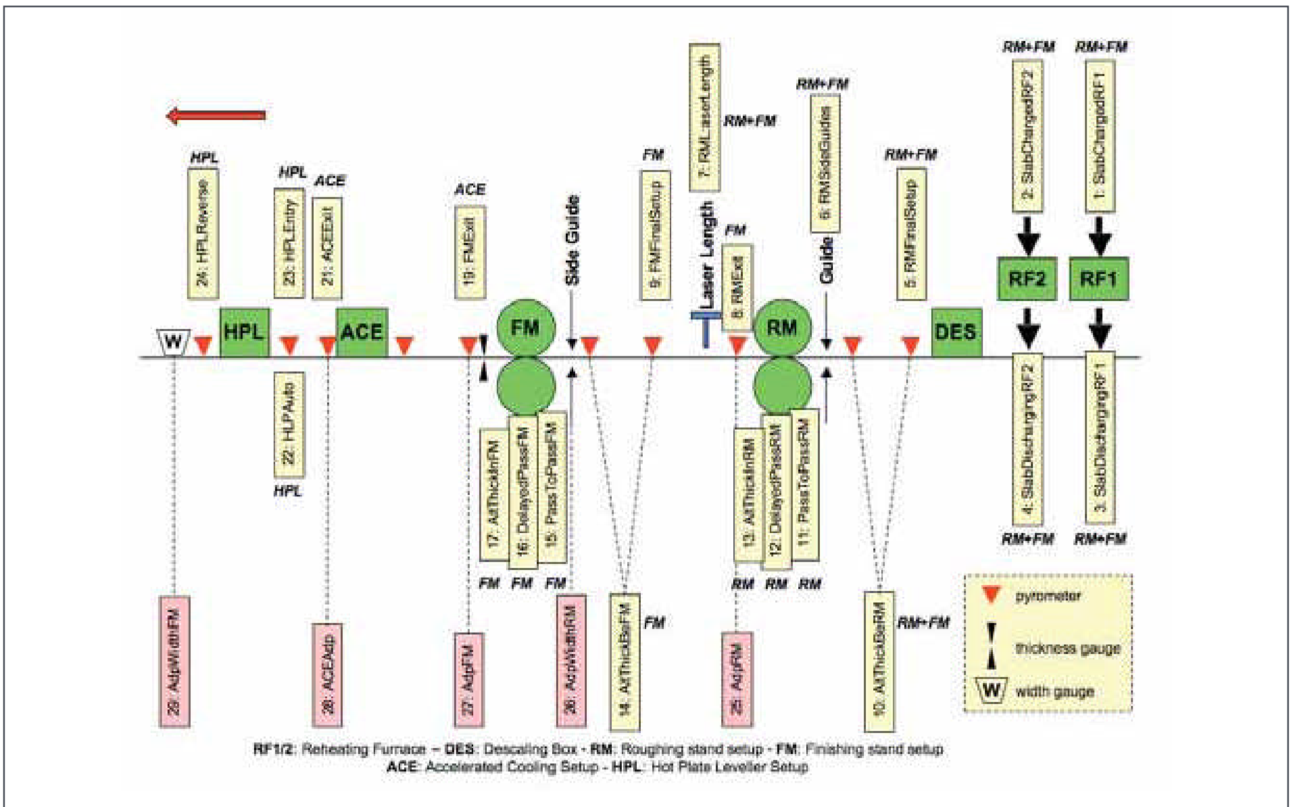


1.8 – Model Calculation Sketch for a Cold Tandem Mill

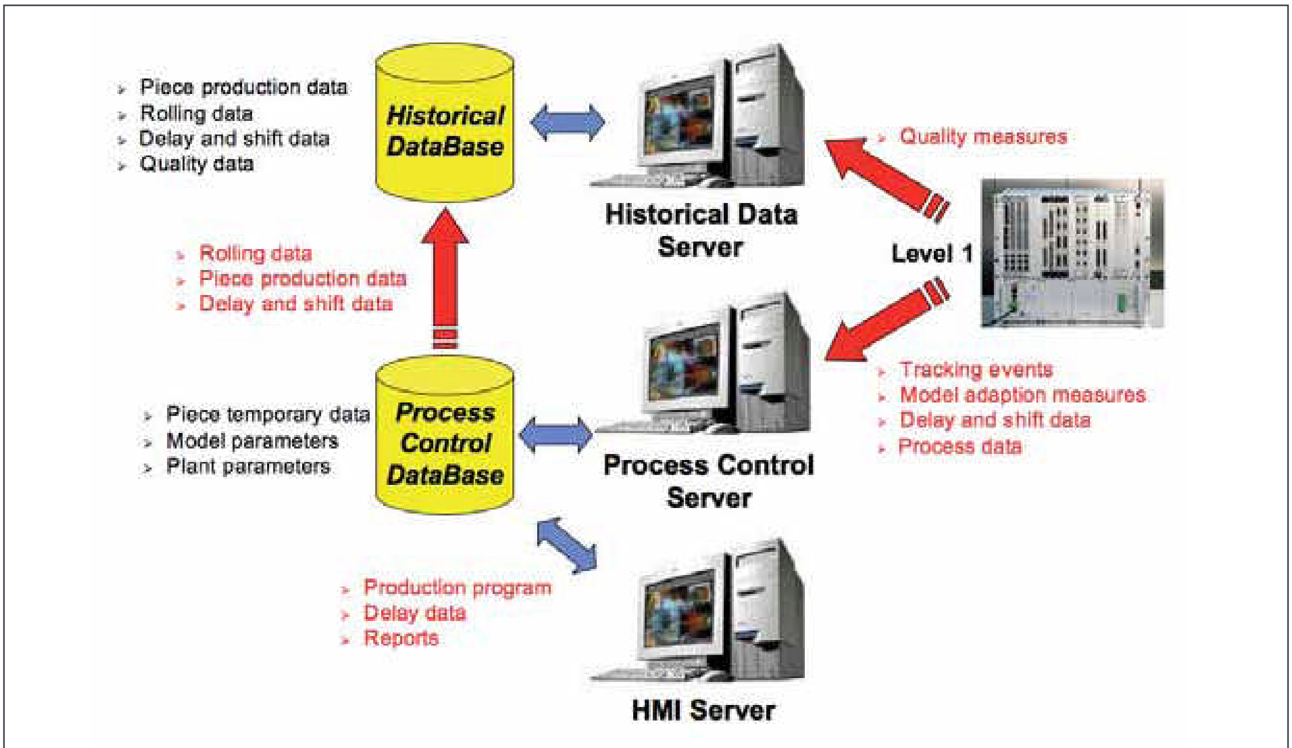
Level 2 Basic Functions

The completeness, flexibility and user-friendliness of ASI's automation system is based on a suite of basic functions described below, which are strictly integrated with level 2 mathematical models, level 1 controls and the HMI system.

- **Piece tracking:** maintains the identity and location of each piece, from the entry of material in the mill (slab or hot rolled coils) up to the final product (hot or cold rolled strip or plate); information on where each piece is must be kept very carefully because mathematical models are executed on particular tracking events and can act differently depending on where the piece is.
  Figure 1.9 refers to an example for a plate mill and shows the correspondences between tracking events and mathematical models to be activated.
  The current tracking status is displayed to the operator, who must act in the event of abnormal conditions (cobble, ...) for updating to the real situation (e.g., piece removal).
- **Piece management:** all the pieces to be processed in the plant, sometimes grouped into rolling programs, are managed starting from their primary data; this is the information required by the level 2 system for completely defining the dimensions and properties of the incoming piece and the resulting final product: e.g., in a hot strip mill, primary data includes entry slab dimensions and steel quality as well thickness and width target; primary data, coming from level 3 (or entered by operators in case level 3 is not available), is checked by piece management function against pre-determined upper and lower limits and then used by mathematical models in calculation of the rolling schedule.
- **Historical Data Management:** the more a plant produces, the greater the amount of data that must be collected and stored for a number of purposes; ASI's architecture includes a server and some dedicated level 1 tasks providing the best response to the need for reporting, piece documentation and the quality that the market requires of a rolling plant today.



1.9 – 2-Stand Plate Mill Tracking: the piece tracking function, in correspondence with each event usually associated with a plant sensor, launches mathematical model calculation: e.g., when the slab goes out from any furnace (events 3 or 4), both RM and FM setup calculations are executed, while when the bar passes under the intermediate pyrometer (event 9), the last setup calculation for FM only is executed (TISC – Tianjin, RPC)



1.10 – ASI includes a dedicated server with a relational database for Historical Data Collection

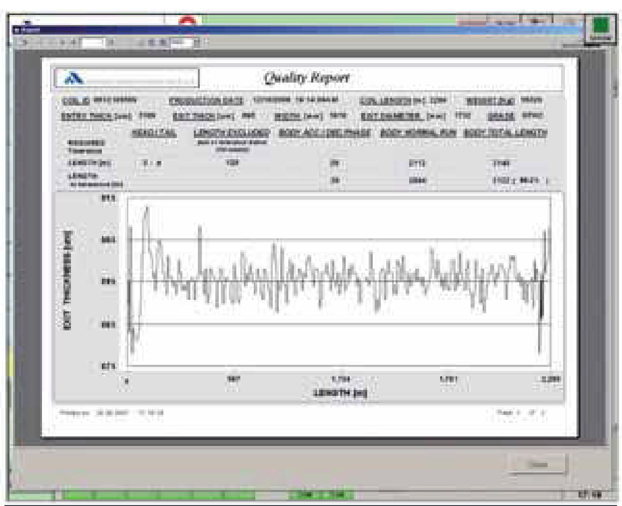
– **Data Collection:** a large amount of data identifies and characterizes each piece and its history throughout the rolling process, including data on its production, setup calculation and model parameters used for setup: this data is collected by the level 2 system during rolling and stored in a relational database on a dedicated historical data server (see figure 1.10); at the end of the rolling process, all the data referring to the piece is available for any operation that RDB can provide (displaying, reporting, printing, graphics, etc.).

– **Reporting system:** a number of reports are available to document activity in the plant (production report, shift report, delay report, …) and to perform accurate tuning of the mathematical models (engineering reports).

– **Quality management system:** product quality is such an important requirement that it deserves the greatest attention in ASI process automation; a data logger is present in the level 1 system for acquiring and sampling the measurements necessary to document its quality throughout the length of the piece (e.g., the thickness profile coming from the x-ray); this information is later stored in the historical database.

A performance monitoring system based on quality measurements groups products according to their range of thickness, width, etc. and calculates the performance the plant is achieving (see figure 1.11).

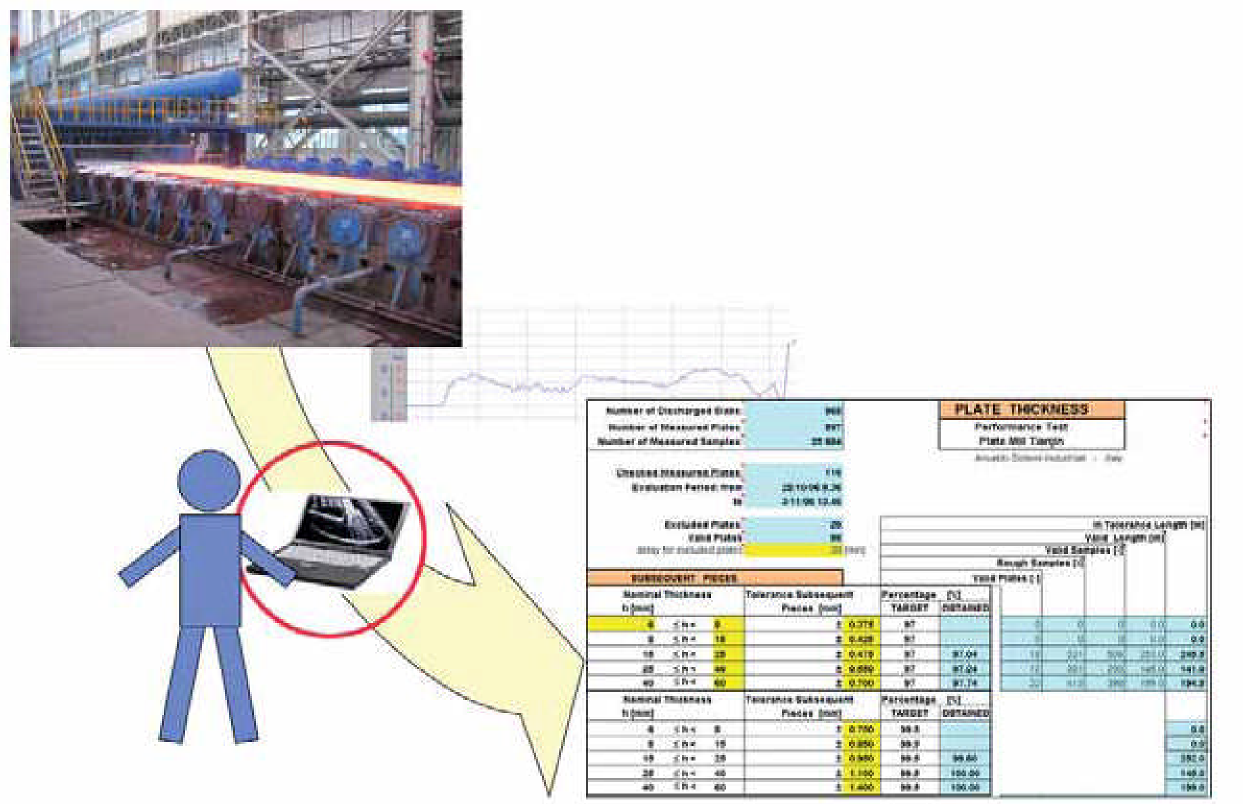
As performance calculation must not be dependent on the presence of level 2, ASI has developed a



1.11 – Thickness quality report in a continuous tandem mill (Heng Tong Group, pickling line & tandem mill n. 3 – Jing Tang Gang, PRC) standalone performance monitoring tool (see figure 1.12): a PC can be connected to the ASI data logger task on the level 1 system or, even more simply, it can obtain the specified data acquired from a customer's equipment, process it and calculate performance figures.

- **Level 2 system reliability care:** the importance of having the level 2 system continuously and fully operating is a strong point in ASI's automation system and its absence often cannot guarantee the levels of productivity and quality that the modern market requires: redundant field networks, backup servers and user-friendly procedures for maintaining large databases are only some of the most meaningful examples of ASI's reliability.

- **Communication with external and/or third-party systems and packages:** ASI takes care to interface its own system with external equipment: level 3, first of all, but also casting and reheating furnace computers in a hot rolling process or the hot strip mill computer in a cold process, as well as downstream equipment such as marking machines or storehouse computers.



1.12 - ASI quality management in a stand-alone tool: rough measurements coming from the plant are processed offline and a performance report is generated.

TECHNOLOGICAL CONTROLS IN HOT ROLLING MILLS

Thickness Control

The thickness of the final product, whether it be a coil or a plate, is usually the most important requirement for each steel user; ASI's experience matured in more than 40 years in rolling mill automation offers a stable, accurate and reliable system for customers' plants and guarantees high performance for all thickness ranges down to 1 mm thick hot rolled strip. The thickness of the product exiting a stand or, more in general, a mill, depends on so many factors that many regulators have to work in strict cooperation and with hydraulics for getting the expected results.

HGC: The fast and precise response of hydraulic gap control, of course coupled with performing mechanical and hydraulic equipment, directly affects, under both static and dynamic conditions:

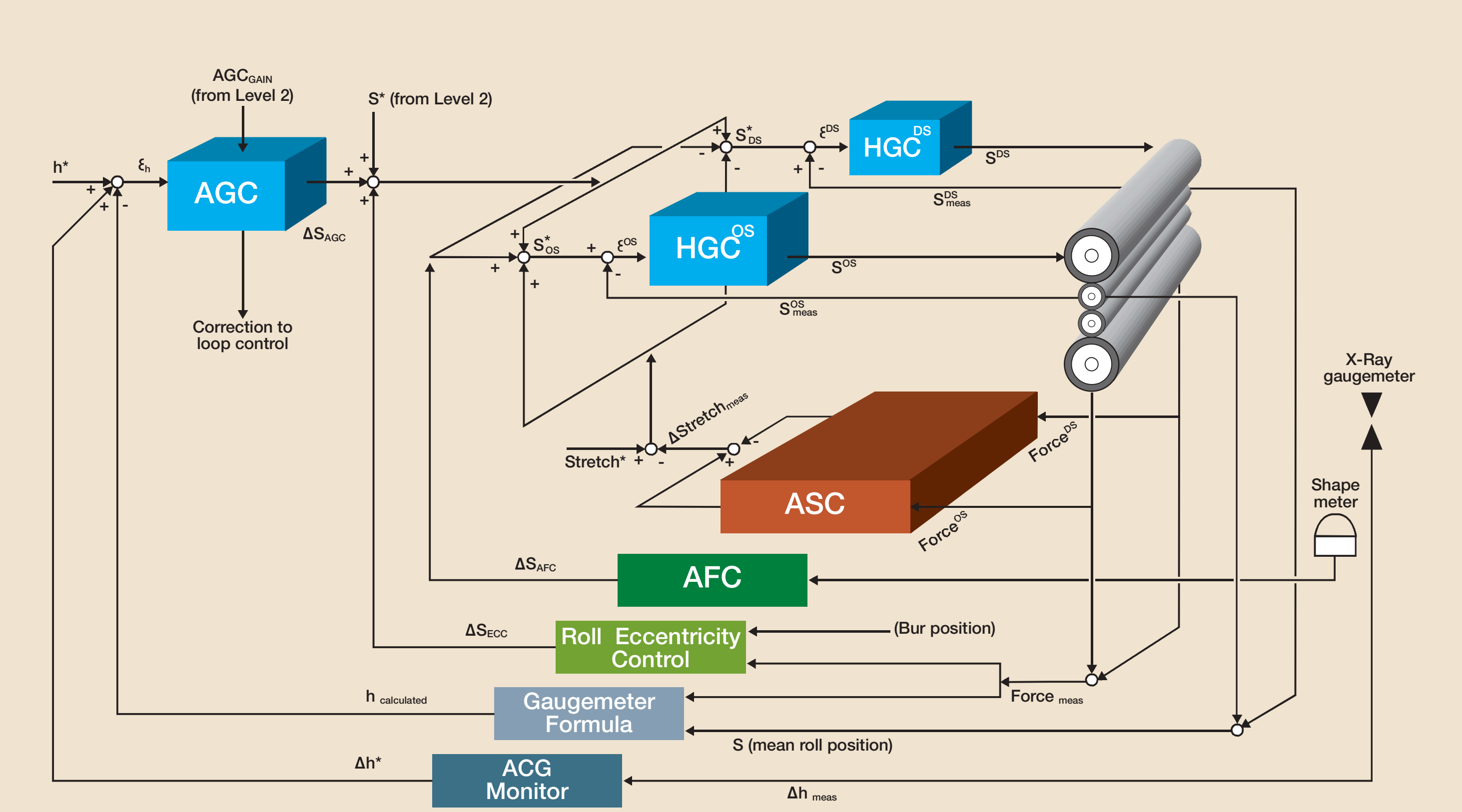
- mill threading;
- strip camber;
- strip tension along the mill;
- strip thickness, flatness, crown and wedge;
- strip breakages and cobbles.

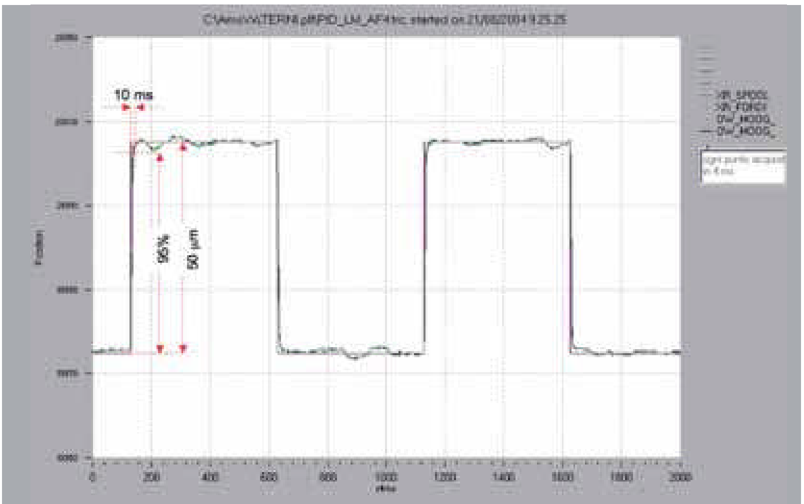
The control loop is closed by HGC by supplying references to the hydraulic capsules' servo-valves; each capsule has its independent position regulator so that the misalignment that occurs if the two sides have different dynamic behavior is avoided by the slanting control, which compares the two regulating loops and slows down the faster loop in the event of error.

The HGC package also includes:

- Servo-valve flow linearization, for maintaining a constant response time with any main pressure and direction of displacement.
- A leakage compensation function aimed at compensating spool wear or incorrect calibration of the servo-valve and oil leakage in the hydraulic circuit downstream of the servo-valve.
- Additional special countermeasures ensuring the same dynamics along the whole capsule stroke (very important in long stroke capsules).
- A Mill Modulus Acquisition procedure that automatically collects the data necessary to represent the behavior of the mill modulus under

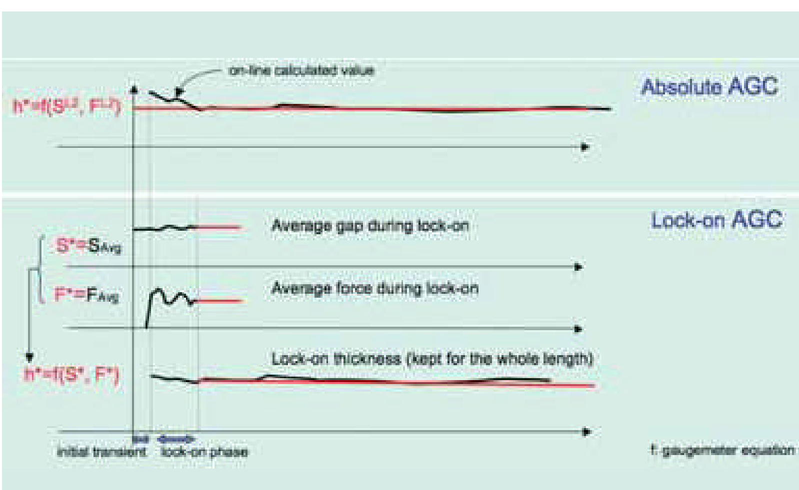
2.1 – Thickness Control in Hot Rolling at-a-glance





2.2 - HGC dynamic behaviour in a hot strip mill
with new hydraulic capsules in F4 stand (TKAST – TNA 66" Terni, Italy)

2.3 - Hot Strip Mill, after ASI revamping in 2005: minimum
exit thickness reached 1 mm (SSI – Bang Saphan, Thailand)



2.4 - AGC operating modes

different loads (vital for AGC based on gaugemeter formula).

- For stands with oil film-type backup roll bearings, an automatic procedure for acquiring oil film thickness vs speed curve
- The possibility of taking two curves into account in reversing mills (e.g plate or steckel mills), where stand behavior also depends on rolling direction: one for forward rotation and another for backward rotation.

The closed loop response of the equipment is very important, and figure 2.2 shows a typical response obtained with ASI automation.

The position offset for impact drop compensation is another important contribution: before the piece enters the stand, the work rolls are positioned at a gap closer than the setup value; the offset is calculated with the aim of avoiding the transient position, mainly induced by oil compressibility, which occurs upon impact with the piece and which, if not properly compensated, would result in a thickness disturbance at the piece's head end.

AGC: Automatic Gauge Control is the external loop that actually regulates the thickness of the material at the exit of each stand: because exit thickness cannot be measured directly and promptly, it is calculated, for each stand, by applying the gaugemeter formula fed with measurements of force and gap and by taking into account both the oil film phenomenon and the deflection, wear and thermal expansion of the rolls. A schedule-dependent gain from the level 2 mathematical model permits accurate conversion from a correction in thickness to the correction in gap required by HGC. In a hot strip mill, a speed correction is sent to the stands upstream to prevent disturbance of loop controls and consequently the strip stretching across the width.

Two operating modes are foreseen for AGC, with different strategies in terms of definition of the thickness reference (figure 2.4):

- **Absolute AGC -** the strip/plate thickness reference (h* in figure 2.1) is based on the level 2 setup and is calculated by applying the gaugemeter equation, starting from the gap preset and from the predicted force coming from Level 2.
- **Lock-on AGC -** the thickness reference is the thickness estimated on the head end, calculated by applying the gaugemeter equation, starting from the gap and from the rolling force measured at the beginning of the piece.

Depending on the type of mill, lock-on AGC may or may not be applied.

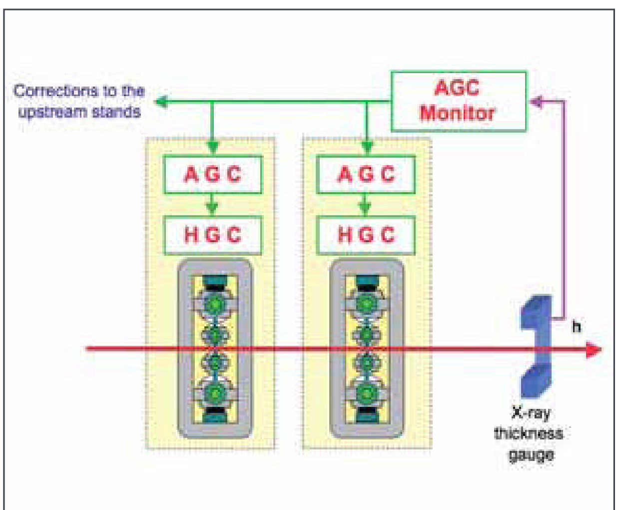
In steckel and plate mills, where the thickness tapering function is applied, absolute AGC is used because the thickness reference must follow a well-defined profile coming from level 2 and cannot depend on the head-end transient (see figure 2.5).
Tapering compensates for the increase in hardness occurring at the head and tail ends due to heat loss for passes in which the piece ends remain behind the stand and not within the furnace coiler.

For those passes, the mill setup calculates specific position and force references for head, body and tail (see figure 2.5). Corresponding specific thickness references for head, body and tail are used by AGC.

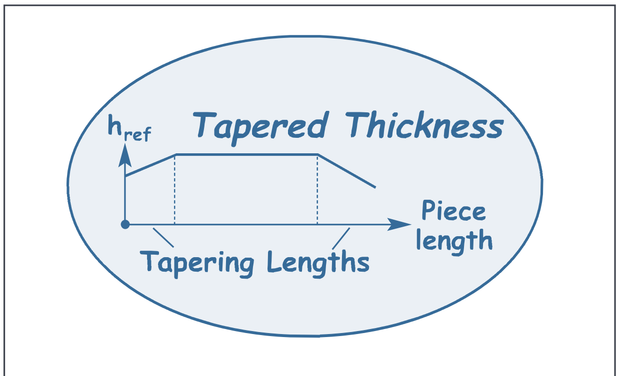
AGC monitor: aims to keep the piece thickness exiting the last stand as close as possible to the final target value: the measurement coming from the gauge located at the mill exit is used to close an external loop on the last stand (or the last stands, in cascade, in the case of a hot strip mill – see figure 2.6) and a correction is sent for the corresponding AGC thickness references.

AFC: Automatic Flatness Control is part of the shape control system (see details in the paragraph on this topic); it processes symmetric and asymmetric components of flatness error from the shapemeter located downstream of the last stand, and calculates both bending correction to compensate for symmetric defects in the final product and tilting correction to compensate for asymmetric defects (this action does not influence thickness at the centerline).

ECC: Roll Eccentricity Control estimates roll eccentricity by means of a Fourier analysis of the measured force and compensates for it by adjusting the references to HGC; proximity switches or an encoder on the back-up rolls are necessary (see details in the paragraph on this topic in the "Technological Controls in Cold Rolling Mills" chapter).



2.6 - AGC Monitor



2.5 - Thickness Tapering

ASC: the Automatic Steering Control function, intended for single stand mills (steckel and plate mills), aims to prevent camber at the stand exit, which may be caused by a number of reasons: temperature differences between the two sides of the bar, stretch differences between the two sides of the mill housing, bar incorrectly centered, cambered or wedged on entry; basically, continuous calculation of mill stretch per side is made and the difference is controlled by acting on the references of gap to HGC, without affecting exit thickness in any way.

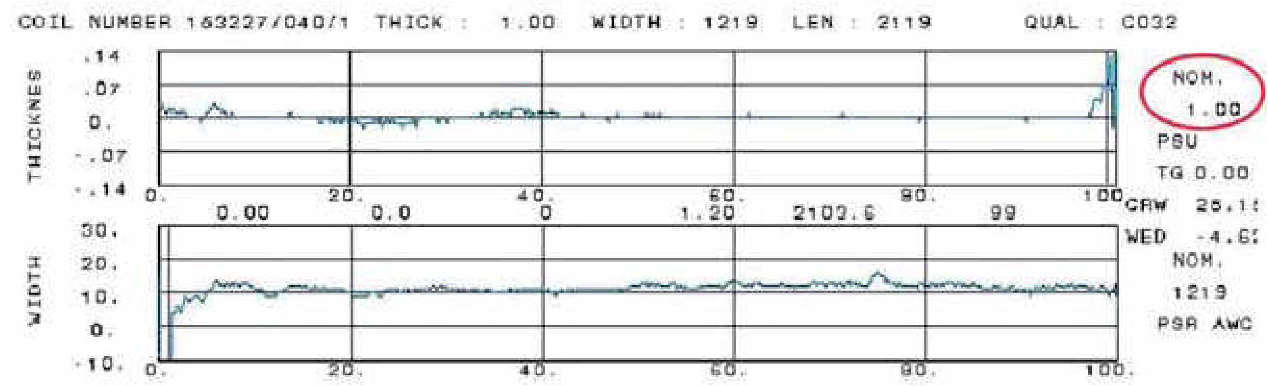
Thin Thickness Rolling

Thin thickness rolling in hot rolling strip mills can be achieved only with a highly accurate, reliable and high performance automation system.
The achievement of 1 mm rolling is the result of many concurrent factors, mainly:

- level 2 Process Control System;
- level 1 Technological Control system;
- practices for mill operations.

In particular, the proven key factors in achieving this goal are:

- proper selection of roughing mill thickness target (according to RM temperature and final target thickness)
- dedicated model tables for highly accurate setup calculation
- scheduling of 1 mm production at the end of the rolling program



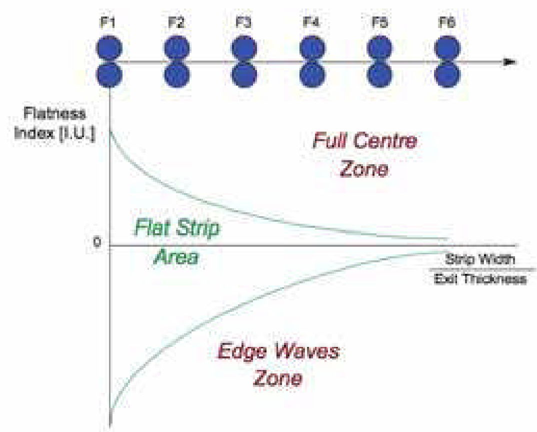
2.7 - Measures of thickness and width for the first 1.0 mm coil rolled in a 7-stand hot strip mill (SSI – Bang Saphan, Thailand)

Shape Control

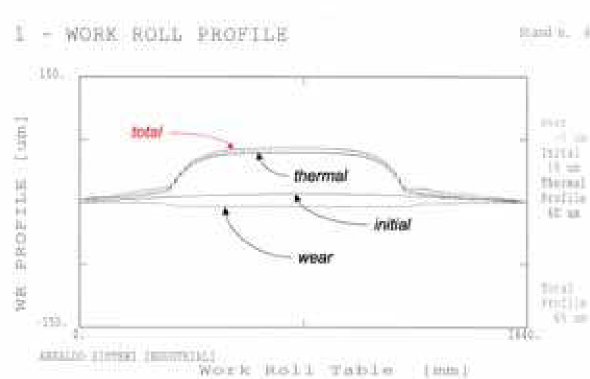
The shape of a rolled strip is characterized by its transverse section profile (crown) and by its flatness; shape control is becoming more and more important because of increasing demand for quality on the steel market.

A number of components are integrated in shape control in both level 1 and level 2 automation systems:

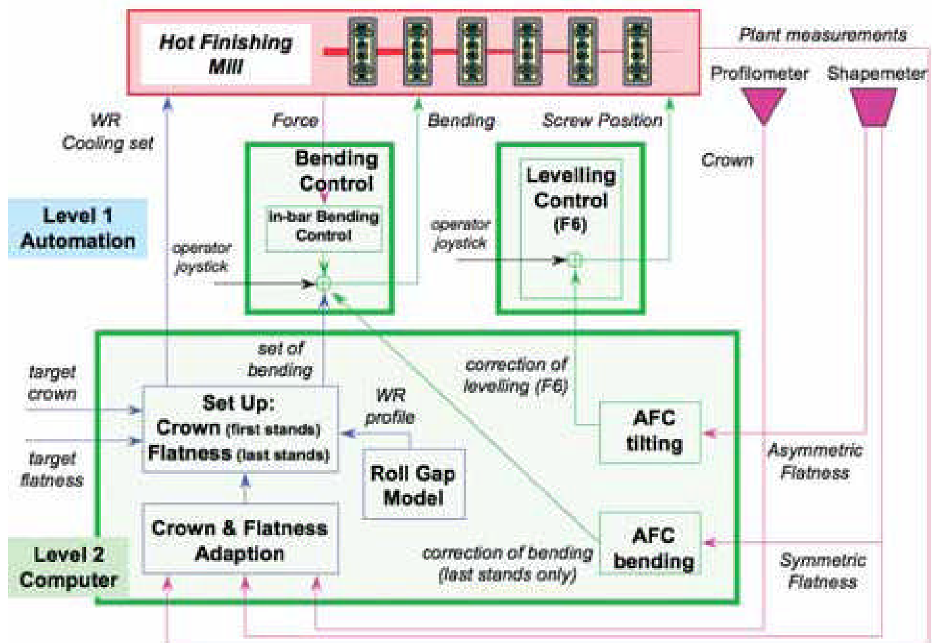
- **Shape Setup:** the basic strategy followed by the mathematical models is to calculate the actuator references so as to achieve the desired strip profile with strip flatness not exceeding predetermined tolerances. On the basis of load distribution coming from the finishing mill setup and on the evaluated roll profile, bending distribution is evaluated in order to achieve the target exit crown within proper flatness constraints. Flatness is not affected as long as the material is able to spread in the roll gap, i.e., when strip thickness is high enough. And so in early stands (in a finishing mill) or earlier passes (in a reversing stand), where the material is thicker, bending can act more efficiently to reach the target crown without causing flatness problems (the flat strip area is quite wide, such as, for example, in figure 2.8), while in the later stands, bending acts with the specific purpose of controlling flatness only. The adaption mechanism is as well implemented for crown and flatness.
- **Roll Profile Evaluation:** the strip shape is created by the work roll byte and is heavily dependent on the



2.8 - Strip flatness limits in finishing mills



2.9 - The different components of the work roll profile, evaluated by ASI Shape Control (SSI Hot Strip Mill – Bang Saphan, Thailand)



2.10 - General sketch of the ASI shape control system for a hot strip mill (SSI, before adding the 7th stand - Bang Saphan, Thailand)

initial work and backup roll profiles as well as their thermal behavior and wear. The roll profile (figure 2.9) is continuously evaluated by a dedicated process that calculates the thermal expansion and wear of each work roll, taking into account rolling time and gap time and work roll shifting; the task then adds the initial (mechanical) profiles and supplies the shape set up with total work roll profiles.

- **Automatic Flatness Control:** strip symmetric and asymmetric flatness are measured, during rolling, by a laser shapemeter located at the exit of the finishing mill; symmetric error is corrected by acting on the work roll bending of the last stands; asymmetric error is corrected by acting on the tilting (differential gap) of the last stands, or on the differential bending, if present.

- **in-bar Bending Control:** force can change during rolling, and this can affect the shape of the strip exiting the stand; for this reason, feedforward compensation is applied, on each single stand, in order to correct shape error in advance by acting on work roll bending (schedule-dependent gains come from shape setup).

Hydraulic Looper Control

Constant tension is strongly recommended in the interstand of a hot strip mill because too high a tension can cause strip necking or breakage, while reduction of tension can lead to the formation of folds: the looper is the mechanical device for dealing with these phenomena.
Two main types of loopers are usually adopted in hot strip mills:

- electrical loopers, driven by an electrical motor, have guaranteed good performance for many years;
- hydraulic loopers, driven by a hydraulic motor, with enhanced promptness and maintainability, are normally installed in the most modern plants.

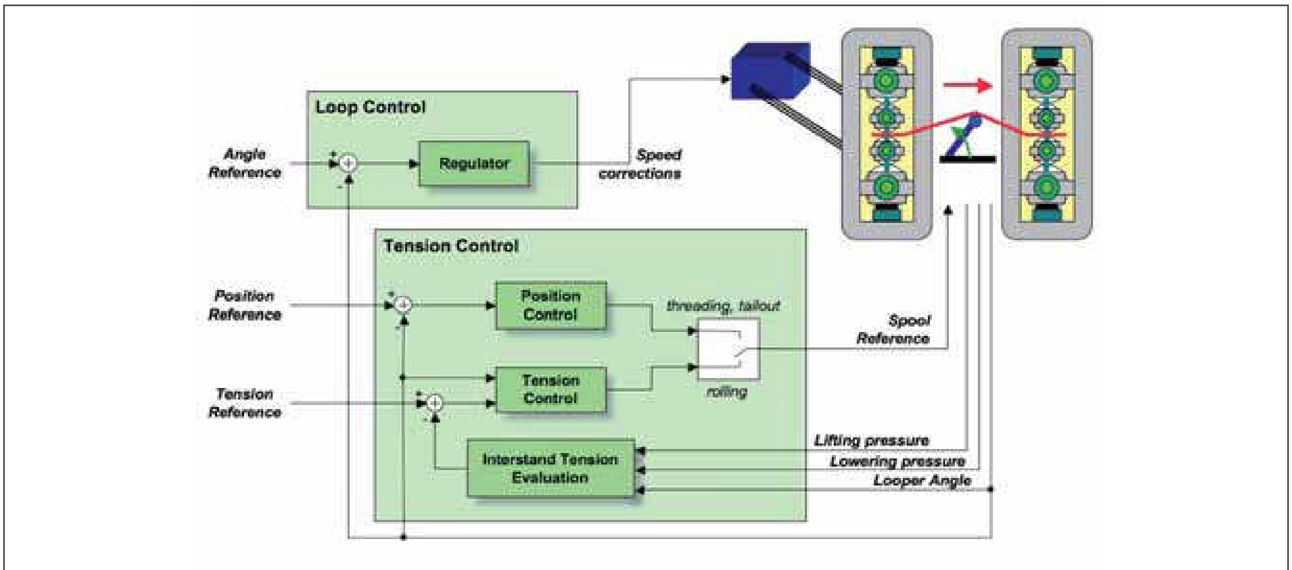
Loopers have to satisfy 2 different requirements:

- holding up the strip during rolling at the correct tension;
- supplying a measurement of the loop that the strip creates in the interstand.

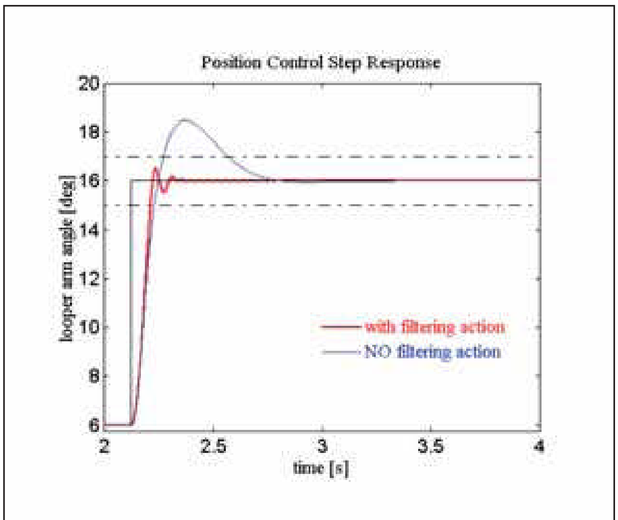
ASI has developed a suitable automated hydraulic looper control, divided into a number of modules (see figure 2.11):

- **Position Control:** the looper is position controlled during its rise at threading and its slope at tailout; a notch filter has been synthesized with simulations during design (see benefits in figure 2.12).

- **Interstand Tension Evaluation:** once the looper has met the strip, it is possible to evaluate the tension



2.11 - The hydraulic looper control: tension control and loop control

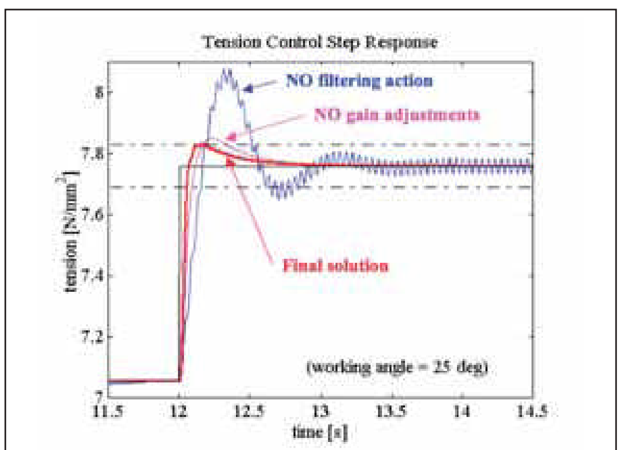


2.12 - Benefits of filtering action

that the strip is subject to: this is the feedback to the main module, tension control.

- **Tension control:** aims to maintain constant tension during rolling, equal to the preset value coming from the mathematical model at setup time; this is obtained by changing the looper torque as a function of the looper arm angle and by feeding the servo-valve of the hydraulic looper with the correct spool reference. Here too a notch filter has been inserted; further simulation activities revealed great sensitivity of the regulator gains to the different product to be rolled: for this reason, an automatic gain adjustment algorithm has been implemented for guaranteeing uniform performance under different conditions (see figure 2.14).
- **Loop control:** in this case, the looper supplies loop position as feedback.


2.13 - Looper at work, hot strip mill (SSI - Bang Saphan, Thailand)



2.14 - Improvements with filtering action and gain adjustment

Water Cooling

The metallurgical properties of a strip or plate are partly dependent on how it is cooled after having been rolled and reduced to the desired thickness and width. This is why controlling the temperature at the hot mill exit requires the same reliability and accuracy as in thickness, flatness or width controls.
ASI's systems cover both coiling temperature control for strips and accelerated cooling for plates, even though different approaches have been developed due to the intrinsic differences between the two processes.

Coiling Temperature of a Strip

The core of the system is an accurate thermal model able to evaluate the number of cooling units to be opened (and their flow as well, if the hydraulic system allows flow control) for obtaining the desired coiling temperature, taking into account:

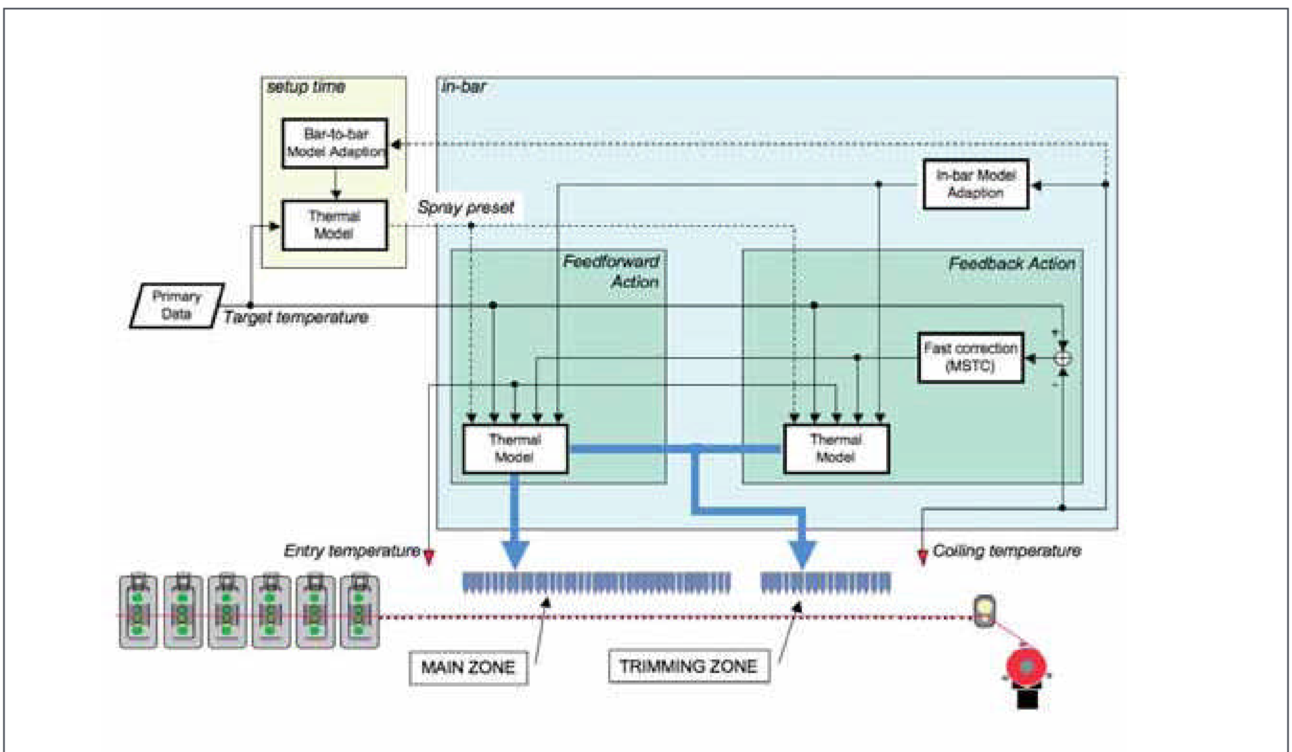
- the thermal phenomena which a strip is subject to when exiting a hot strip mill or a steckel mill;
- the temperature drop due to contact with air and water.

The strip is divided into a number of samples for correlating a measurement to a control action; the sample length depends on speed, and each sample is tracked throughout its passage under the cooling units.

2.15 - Strip Cooling System in a hot strip mill (Middle East)

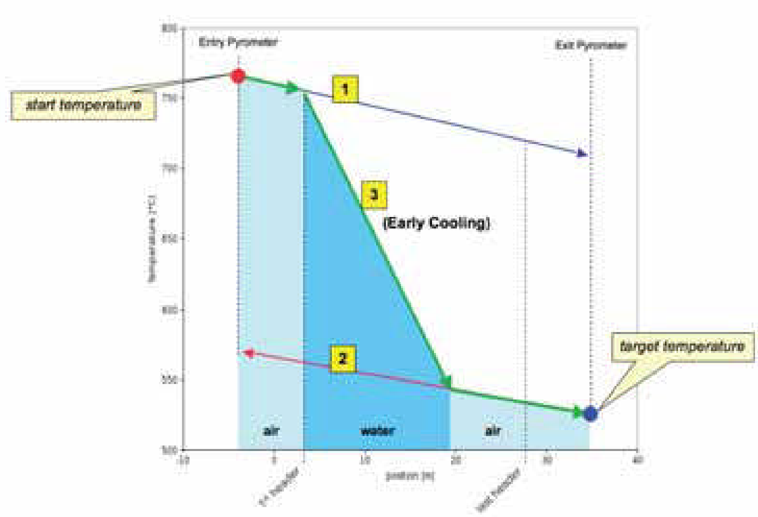
The thermal model (see figure 2.16) is widely used:

- **at setup time:** level 2 calculates a preset for level 1
- **in-bar:** a first dedicated module carries out a feedforward action for re-calculating the references, while the strip runs under cooling units: it uses the temperature measured by the 1st pyrometer;
- **in-bar:** a second module starts playing its role when



2.16 - The configuration of ASI coiling temperature control system in a hot strip mill the head end coil reaches the 2nd pyrometer and a feedback loop can be closed on the trimming section; a dedicated algorithm (Minimum Settling Time Control) deals with the delay between measurement and control action by calculating a rapid correction, used by both the modules.

2.17 - Plate is entering accelerated cooling: the 1st row of water sprays is visible, with the water falling down from the edge masking system, on the right (TISC Plate Mill – Tianjin, PRC)



2.18 - ASI model for plate cooling defines the target temperature, spray by spray

The model is adapted on two levels:

- in-bar adaption is performed, sample by sample, for further improvement of the correction mechanism;
- the classic bar-to-bar model adaption considers the piece in its wholeness and acts on the model parameters for the next piece to be cooled.

Different cooling methods are implemented, because the strip can have different targets along its length, due to metallurgical and process reasons:

- uniform cooling;
- hot head;
- hot tail;
- hot head and tail.

An additional function worth of note is edge masking: the lateral edges of the coil are masked from the falling water to keep them a little bit hotter and reduce the difference in stretching of the lateral fibers with respect to the central ones, which could cause flatness defects in the cooled coil.

Accelerated Cooling of a Plate

Cooling a plate is conceptually very close to cooling a strip, even though some peculiarities exist and require a number of differences in the automation system.
An accurate mathematical model is also used, but due to the shortness of a plate with respect to a coil, in-bar action is not applicable and the model is used at setup time only and with adaption; some peculiarities are listed below:

- greater attention is dedicated to thermal distribution inside the plate, which is much thicker than a strip;
- speed is calculated and maximized for productivity purposes, while in the hot strip mill it is an input imposed by the finishing mill.

Different operating modes in which the model can operate are:

- early cooling;
- delayed cooling;
- constant cooling (the model calculates a cooling rate equal for all the sprays).

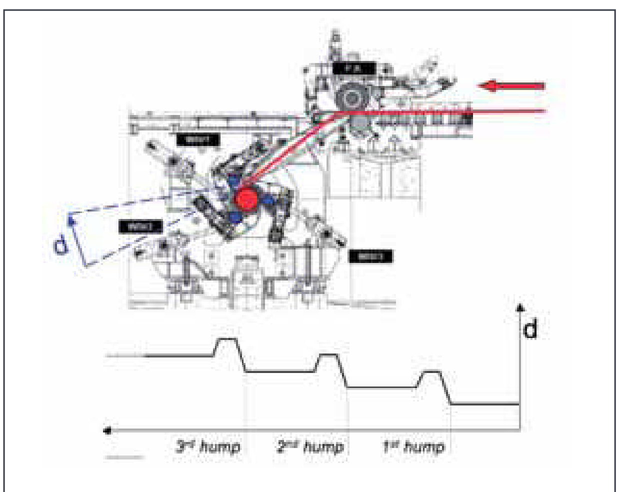
The plate is tracked under the cooling units by the level 1 system, also in order to avoid cooling the head and tail ends: this prevents the ski effect which could occur at the plate ends especially on thin plates, by avoiding accumulation of water along the body, resulting in lack of uniformity during cooling and therefore flatness defects.

Down Coiler Control

2.19 - A coil rolled at HSM (SSI - Bang Saphan, Thailand)

The down coiler is the last item of equipment acting on the steel before it finishes its transformation from slab to strip in a hot strip mill, and it must support and maintain the strip qualities achieved during rolling.
ASI's automation system is the product of extensive experience with down coilers and their devices and supplies all the technological functions necessary in modern plants.

- **Tension Control:** maintains strip tension at the target calculated at setup time by ASI's mathematical models as speed and coil diameter change during coiling; inertia compensation, bending torque and mechanical and electrical losses are also taken into account.

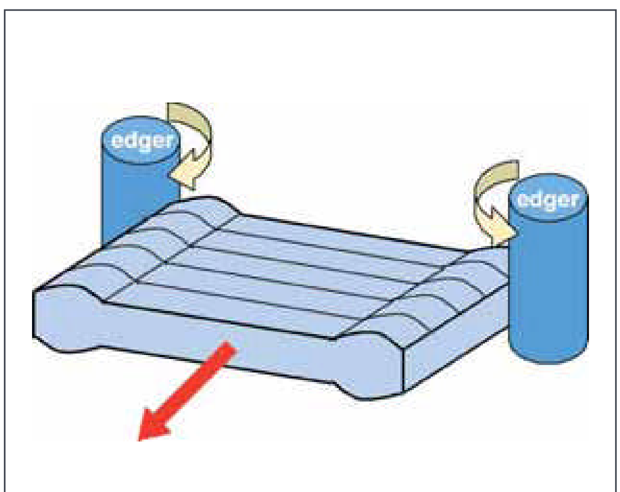


2.20 - Jumping control avoids damage from humps during the first revolutions at the down coiler (SSI - Bang Saphan, Thailand)

- **Pinch Roll Control:** from position control before the strip threads the coiler, it switches to force control when the strip is in; an overspeed is applied during threading to favor correct threading; later on, depending on the chosen working method, the pinch roll may continue to stay in contact with the strip for decoupling the tension between the coiler and the last stand (with an underspeed to aid decoupling), or it may rise to reduce wear and favor driving of the material. A load sharing control for balancing top and bottom drives is present.
- **Wrapper Roll Control – Jumping Control:** from position control while waiting for the strip, it moves to jumping control during threading, and passes to force control when the tail approaches. Jumping control is a very important and delicate function which must prevent dangerous bumps between wrapper rolls and the humps formed by the strip head end, for some wraps during coiler threading (see figure 2.20): the head end is tracked with precision and each wrapper roll opens its gap just prior to the arrival of the hump.

Width Control

The width of a strip arriving to the final customer has to be defined at the very beginning of the hot and cold rolling process: indeed, it can be achieved with the necessary accuracy during the roughing phase only.
In a cold mill the strip width is not modified by the rolling process, because of the low rolling temperature

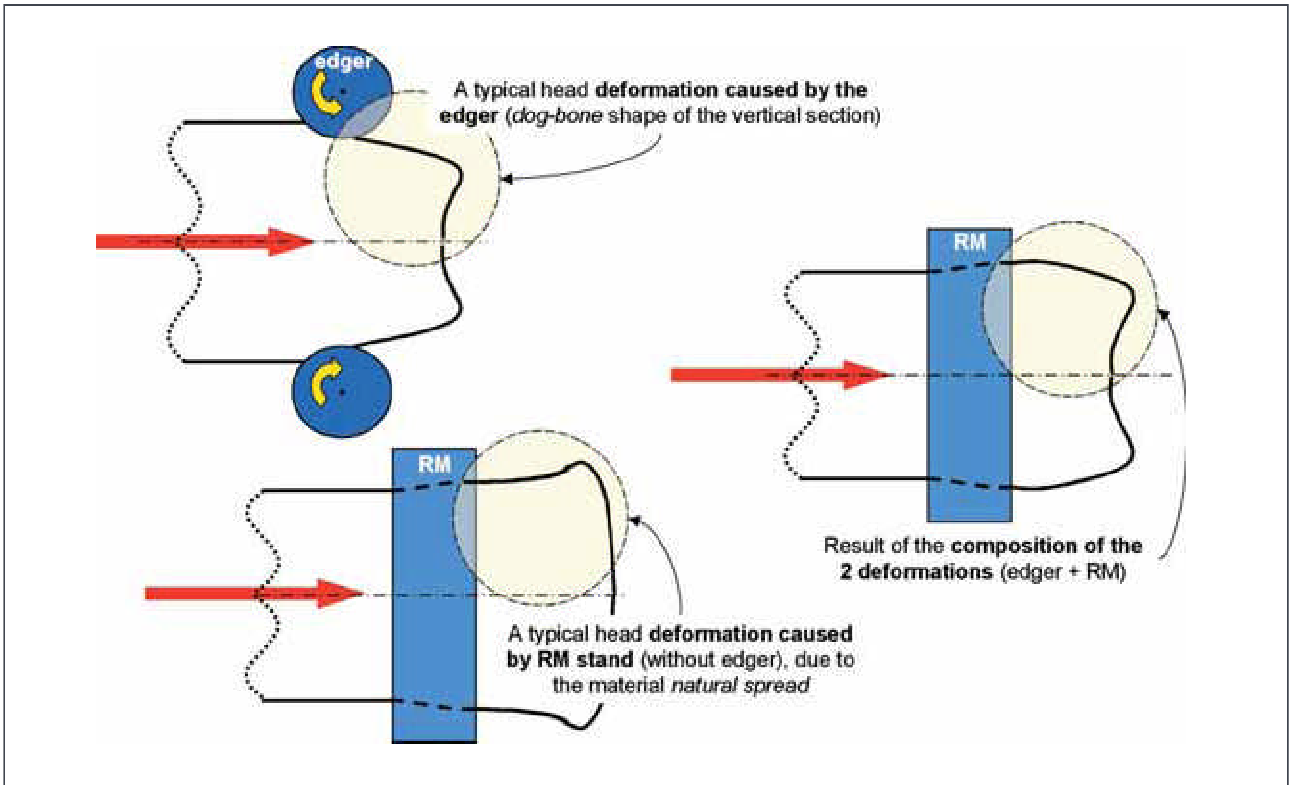


2.21 - Typical dog-bone shape in the vertical section after rolling at edgers and, especially, because the material is very thin with respect to its width. During rolling at the edger in a hot rolling mill, on the contrary, the piece is very thick and hot and can be reduced in width; nevertheless, after rolling at the edgers, at the rougher and, to a lesser extent, at the finisher, the piece exits with a width that is not uniform because of a number of physical and process phenomena:

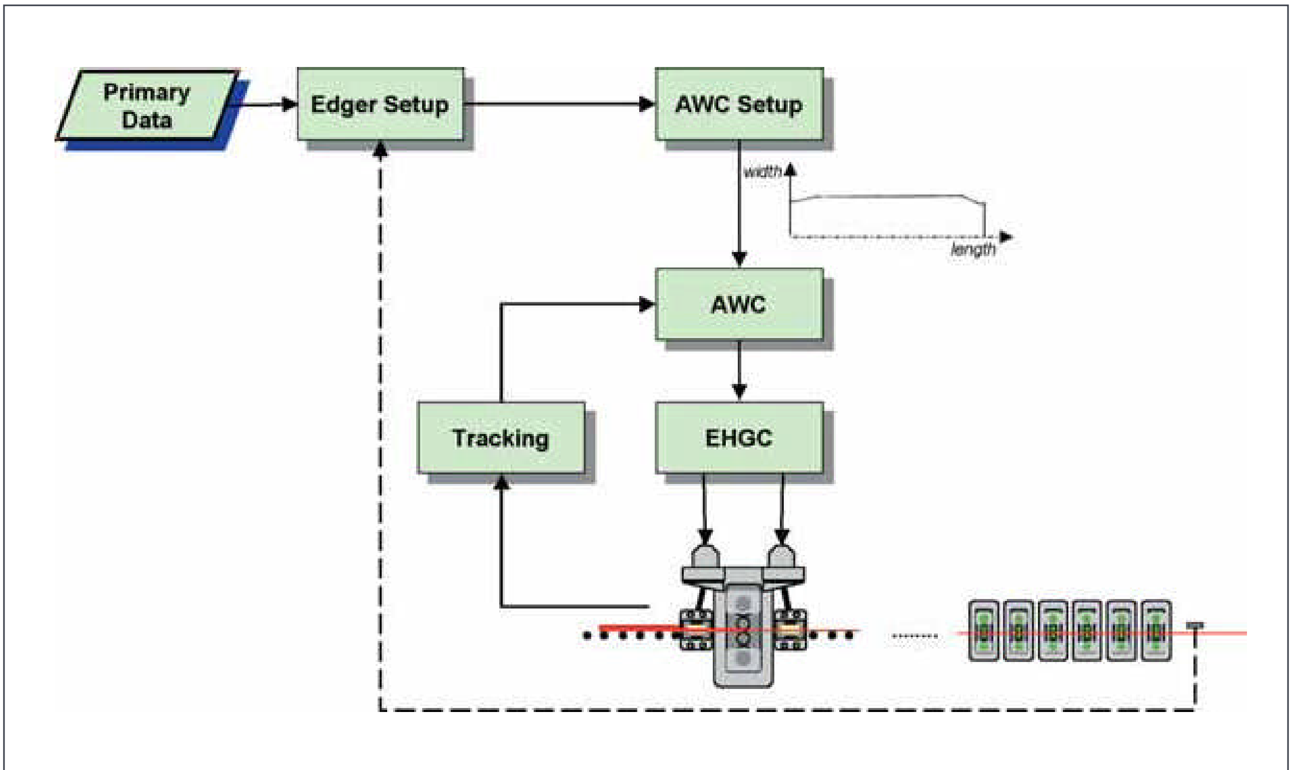
- **Dog-bone:** the vertical stands (edgers) press the bar to reduce its width to the desired target, but insert a vertical deformation so that the vertical section of the bar assumes a sort of dog-bone shape (see figure 2.21), while the head end width becomes narrower than the body (see figure 2.23); something similar occurs at the tail end.
- **Natural spread (out of piece rectangularity):** rolling at the roughing mill produces a transversal and, in a lower measure, longitudinal spread on the piece, so that head and tail ends have a width greater than the body (see figure 2.23). Note that natural spread also occurs in the finishing mill, enlarging the strip by an amount which is not negligible along its entire length.
- **Necking:** acceleration / deceleration transients and threading transients on the loopers in the finishing mill can cause stretching of the strip and a consequent reduction of width on thin strips.

2.22 - Reversing roughing mill (TKAST hot strip mill – Terni, Italy

The combined effects of dog bone and natural spread are illustrated in figure 2.23, showing a case in which the contribution of dog-bone is more important than that of natural spread.



2.23 - Representation of head width defects while rolling at edger and at roughing mill stand(behavior is similar at tail end)

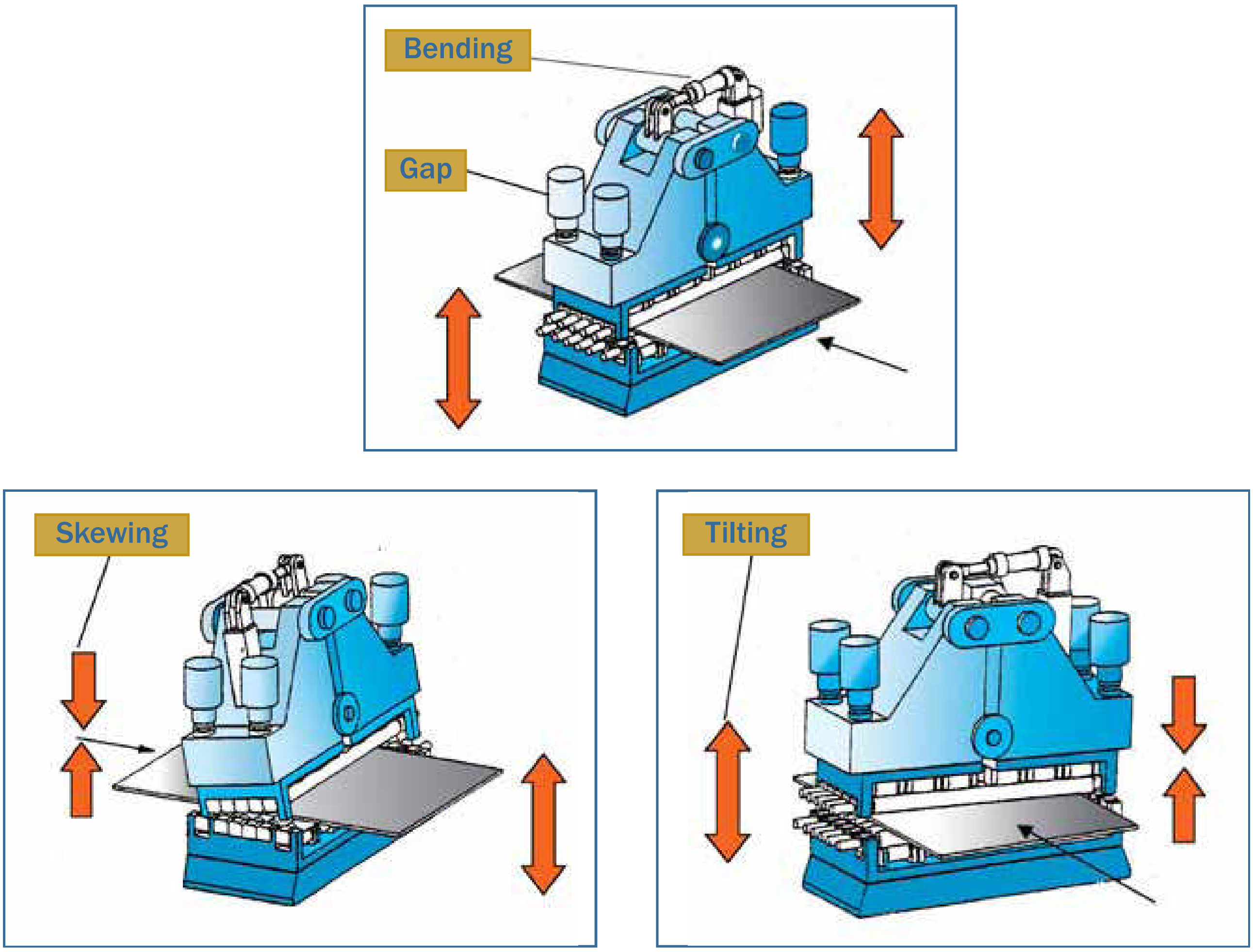


2.24 - Dataflow in the width control system; AWC

It is possible to compensate for this lack of uniformity in width in order to gain a significant amount of in-tolerance strip when edgers are driven by hydraulic capsules that can move during rolling; in this case, ASI's dedicated autoadaptive mathematical models evaluate the phenomena described above and calculate the movement profile that the edgers will have to follow to minimize defects (see figure 2.24: AWC Setup calculates the movement profile); necking defects at the finishing mill are compensated so that at the roughing mill exit the bar width is not constant along its length.
Automatic width control (AWC) is level 1 technological function which basically carries out accurate tracking of the head piece while rolling at the edgers so as to associate each point of the movement profile with a reference to be sent to the edger hydraulic gap control EHGC (see figure 2.24).

Plate Leveler Control

The final quality of a hot rolled plate depends largely on its flatness: in spite of all the countermeasures adopted during rolling and cooling, plate flatness may be further increased and, in all cases, uniformed by means of the leveling process which may be applied to hot plates, after accelerated cooling, or to cold plates, after final cooling in air, in the cooling beds.
The job of a hot or cold leveler is quite delicate, because it is the last treatment to which the plate is subjected; the automation system must therefore be performing: ASI has developed a complete package for the mathematical model and level 1 capable of getting the most from a leveler.
Basically, the leveler performs a sort of stretching of the material by driving it through a number of rolls, set at a calculated gap and able to impress a calculated tension on the material in different ways, as shown in figure 2.25.
On the basis of the steel quality, thickness and entry flatness evaluated by the operator, the ASI level 2 automation system runs a mathematical model concerning the material behavior in the plastic field which takes into account structure stretch and the



2.25 - The particular movements of a leveler are sketched here; skewing and tilting can be achieved with a series of accurate actions on the 4 hydraulic cylinders, calculated by ASI's models.

leveling strategy for calculating the references to the main drives and hydraulic actuators; the concepts on the basis of which these models work may be summarized as follows:

- Plate fibers that are shorter than the others are elongated by inflexion of the plate driven into the leveling rolls.
- The entry top rolls are closer than the exit rolls (skewing) so to ensure that plastic deformation decreases from entry to exit: this eliminates the internal tensions that cause flatness defects after plate cutting.
- The entry bottom roll position is adjusted below the pass line to make plate head threading easier, while the exit position is adjusted to avoid plate tail ski (exit roll).
- Bending correction aims to eliminate symmetrical defects in the plate and structural inflexion due to leveling force.
- Tilting correction acts on the plate's asymmetrical defects.
- Leveling speed is evaluated with the twin purposes of maximizing productivity and preventing the motor current limit.
- Threading speed makes it easier to thread the plate into the leveler.

The complement to accurate setup calculation is the suitable ASI level 1 regulation package, guaranteeing correct positioning of:

- the four main hydraulic cylinders for the gap
- the cylinder for bending
- the entry and exit bottom rolls

by taking into account oil leakage compensation and inserting gain adjustment on the proportional valves, based on the "flow rate vs. valve opening" curve.

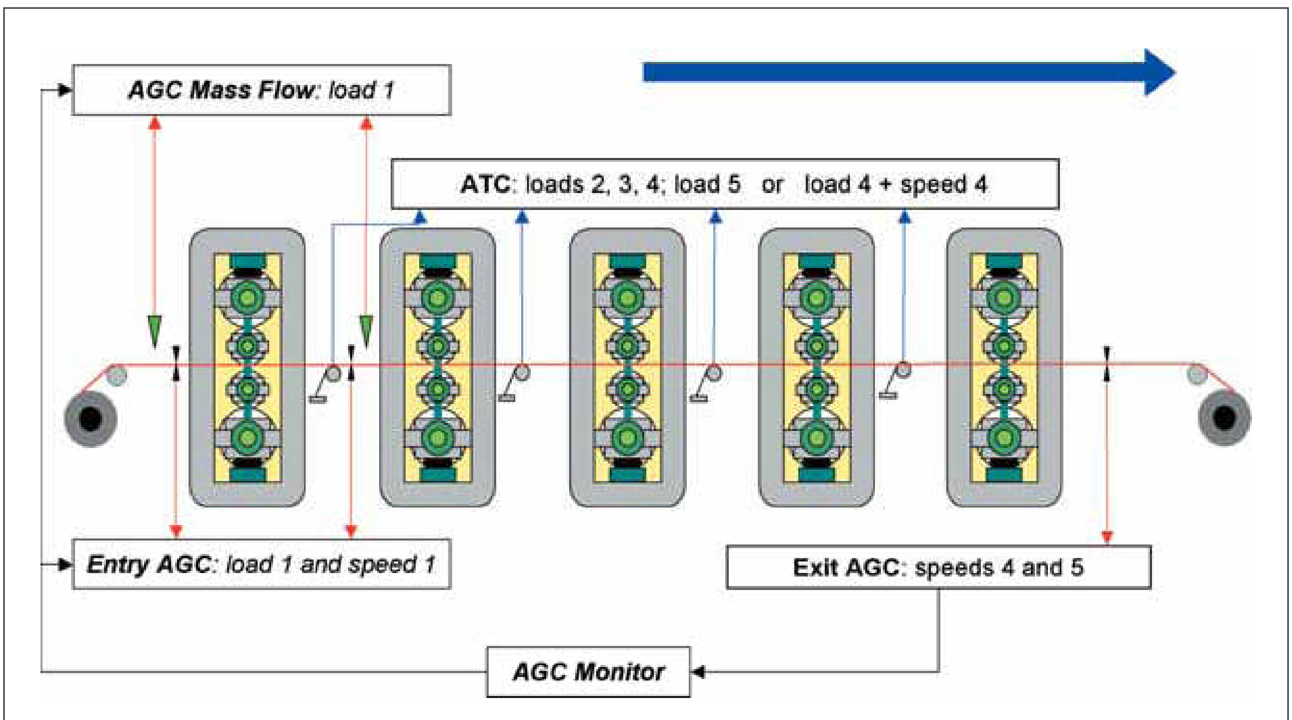
2.26 - Hot Plate Leveler (TISC Plate Mill – Tianjin, PRC)

TECHNOLOGICAL CONTROLS IN COLD ROLLING MILLS

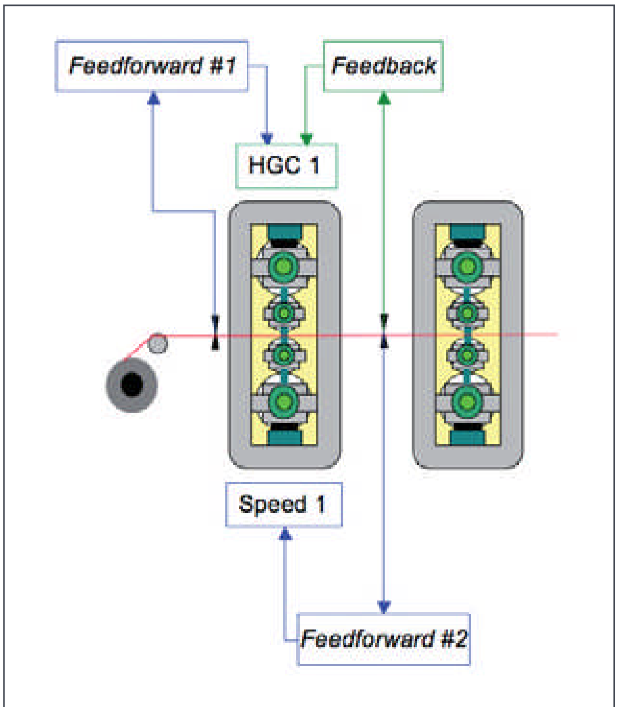
Thickness and Tension Control

Final coil characteristics such as thickness and flatness are the most important requirements of every steel user; many years of experience in cold rolling plants qualifies ASI to supply the reliable, highly accurate systems required by users and the steel market in general.
It is extremely difficult to separate the contributions of Automatic Gauge Control (AGC) and of Automatic Tension Control (ATC) in strip thickness in a cold rolling tandem mill: their actions are so strictly correlated as to require us to consider both AGC and ATC when dealing with thickness in tandem mills.

- **ATC:** Automatic Tension Control must ensure that tension is as constant as possible and equal to the preset from level 2, based on ASI's autoadaptive mathematical models; a regulator for each interstand gets the feedback from the tensiometer and corrects the load of the stand downstream (ATC by load).
  Particular attention must be paid to the last stand load, which could affect exit flatness: level 2 models therefore calculate tension and load distribution taking into account this phenomenon; in addition, correction on the last stand load may be substituted with a correction distributed on the load and speed of the penultimate stand (ATC by speed). Nevertheless, at low speed (during threading in a coil-to-coil mill or weld passing in a continuous mill), the friction coefficient between work rolls and strip increases so much that it requires excessive corrections of force that would affect strip flatness; in this situation, ATC automatically switches from load to speed to preserve flatness and prevent strip breakage.
  No speed adjustments are given to the pivot stand (usually the 3rd stand in a 5-stand tandem cold mill) while feedback action is applied to speeds 1 and 2 and feedforward action is applied to speeds 4 and 5.
- **Exit AGC:** the regulator closes the loop on the speeds of the last two stands, by performing the classical feedback mechanism; in this way, ATC only works on loads and does not receive interaction from AGC; note that the transport delay model is applied to thickness feedback (the strip is divided into samples, a correction is applied to a sample and the feedback is correlated to the sample on which the action had been applied).
- **Entry AGC:** the highest sensitivity of the load on the



3.1 - Thickness Control in Tandem Mill at a glance (note that Entry AGC and AGC mass flow are mutually exclusive)



3.2 – Entry AGC details

strip thickness is on the first stand, so that this is usually equipped with two thickness gauges, one upstream and one downstream: so both a feedback and a feedforward action are applied to the 1st stand load; in addition, a feedforward action on the 2nd stand is applied by acting on 1st stand speed.

- **Mass Flow AGC:** the most powerful and precise effect on strip thickness can be obtained by acting on mass flow at the stand 1 exit; reliable speed gauges (such as laser speedmeters) are necessary to apply fast, correct control action and nullify massflow error, which may be defined as follows:

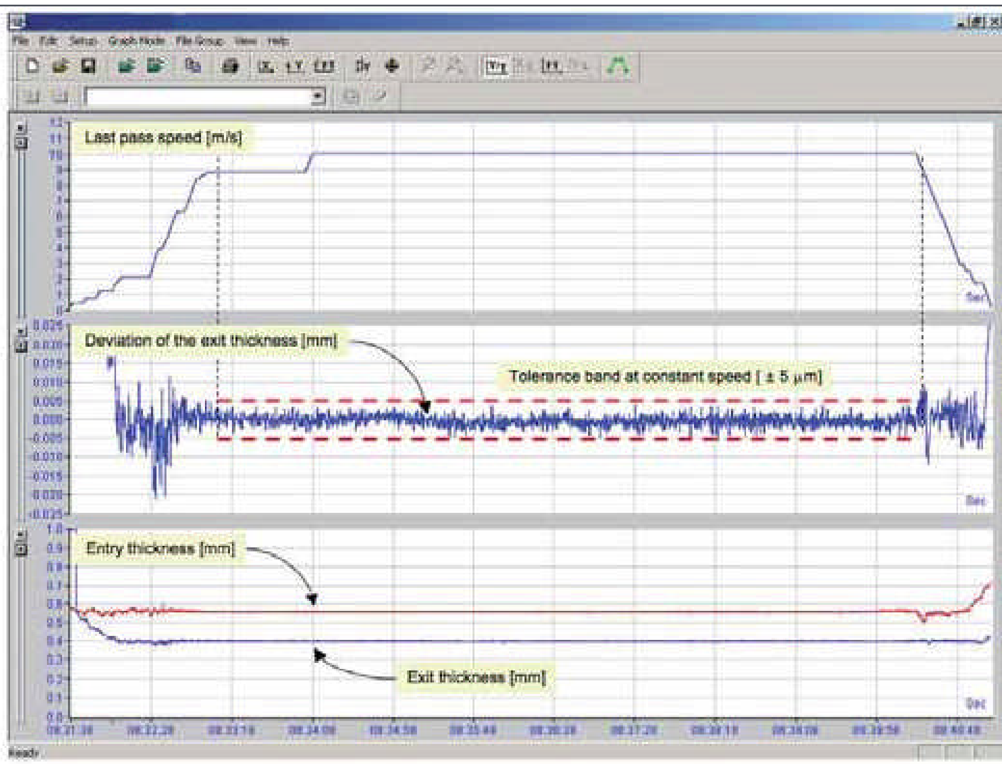
$$h_{IN} \cdot v_{IN} = h_{OUT} \cdot v_{OUT}$$

$$\Rightarrow \varepsilon_{massflow} = \frac{v_{IN}}{v_{OUT}} - \frac{h_{OUT}}{h_{IN}}$$

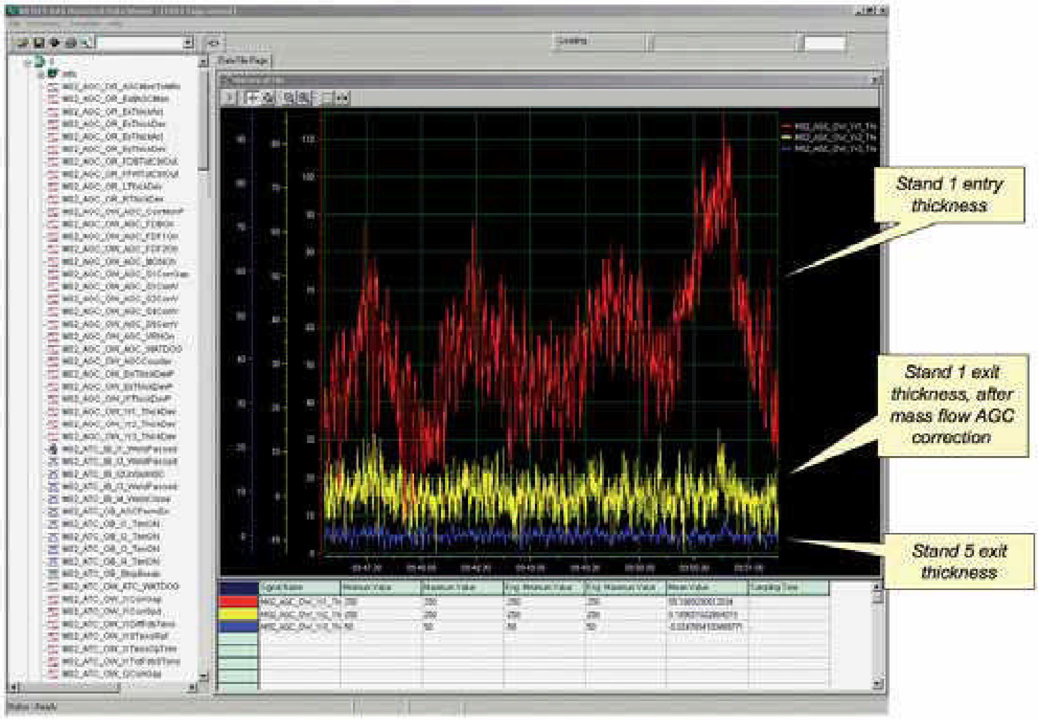
where h_{IN} / h_{OUT} : entry/exit thickness
v_{IN} / v_{OUT} : entry/exit speed

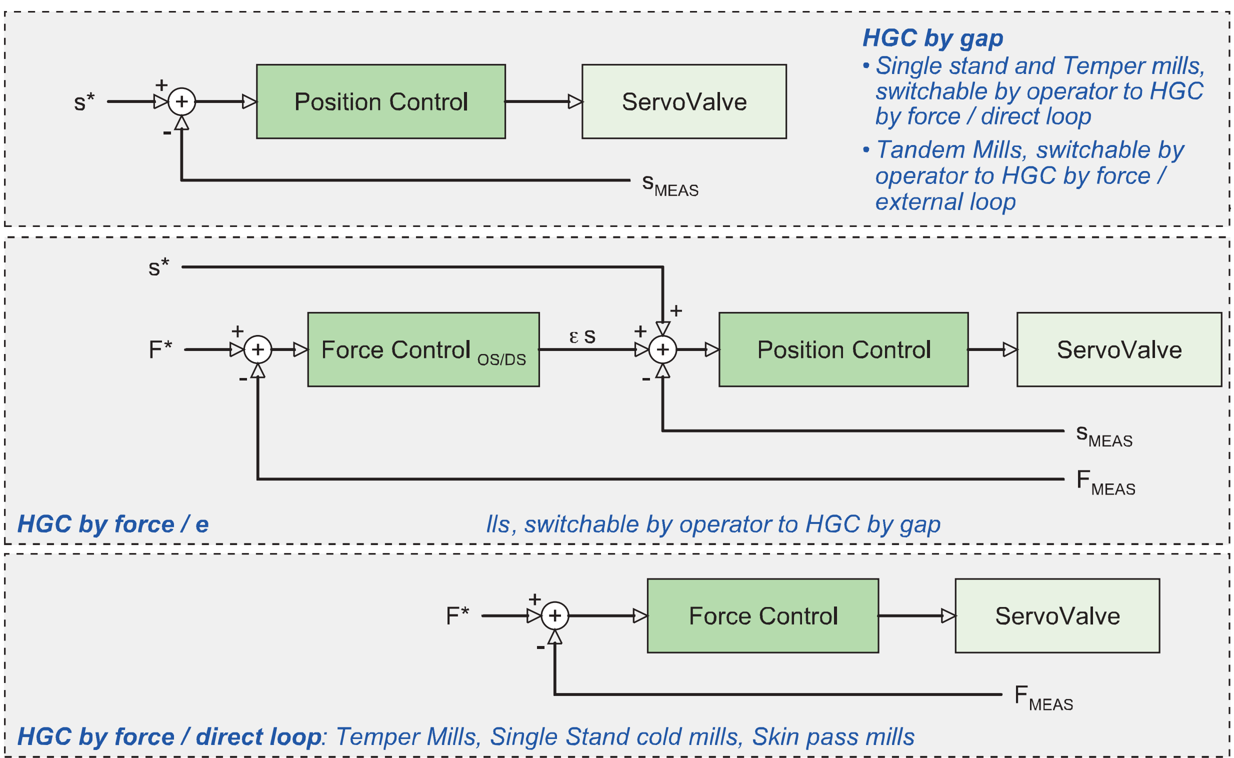
and, clearly, nullifying $\varepsilon_{massflow}$ means obtaining strip exiting the 1st stand at the thickness calculated by the mathematical model; because the majority of thickness error can be corrected by acting on the 1st stand only, the correct thickness at the 1st stand allows exit AGC to work at its best.
ASI has also a double massflow action in progress, on stand 1 and also on stand 2: three reliable speed measures, in a continuous mill, come from the bridle encoder upstream of stand 1 and from 2 laser speedometers located upstream and

3.3 - AGC behavior in a single stand reversing mill (FengMing - Tianjin, PRC)



3.4 – ASI mass flow AGC results (Heng Tong Group, Continuous tandem mill n. 1 – Jing Tang Gang, PRC)

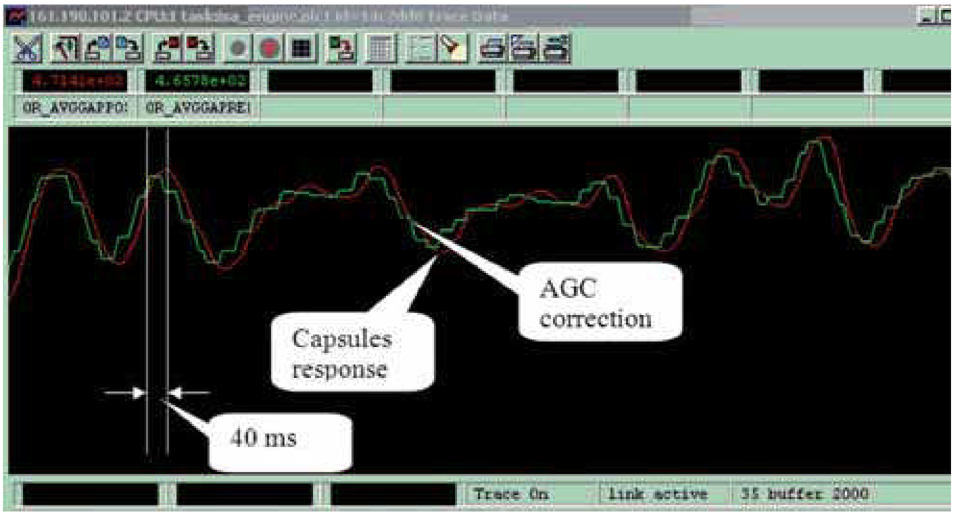




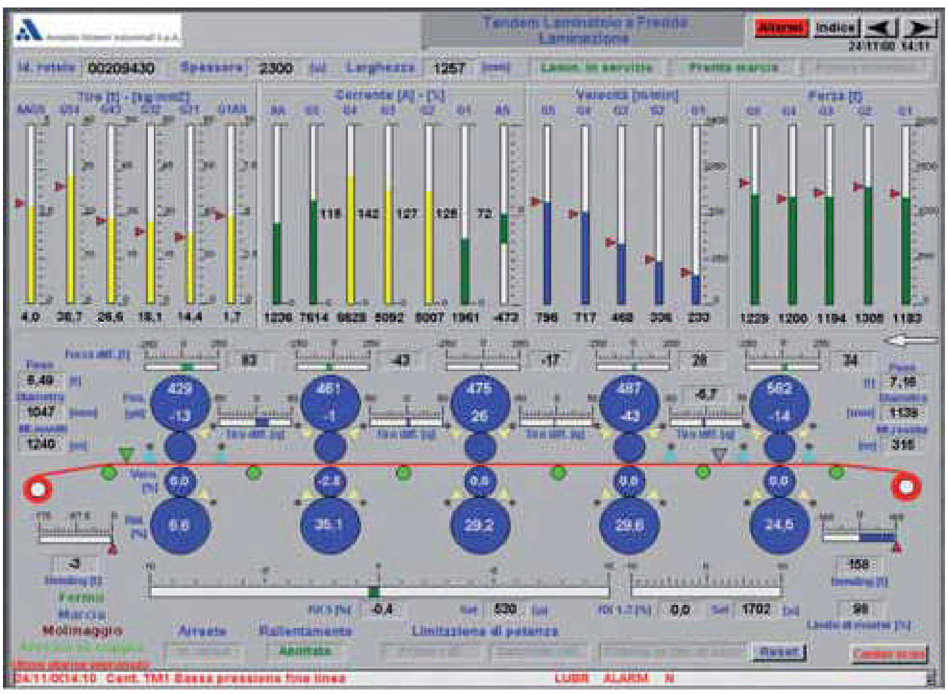
s, F** :presets of gap and force coming from level 2
s_{MEAS}, *F*
lid both for Operator Side and Drive Side

3.5 – Different schemes of HGC

3.6 - Gap feedback (red) and gap reference, including AGC correction (green) in a 6-high single stand reversible cold mill (Yingzhan – Ningbo, PRC)



3.7 – Mill Mimic (Ilva, Tandem Mill n. 1 – Genova Cornigliano, Italy)



downstream of stand 2: this improves overall system performance by supplying exit AGC with a thickness closer to the reference (see figure 3.4).

- **AGC monitor:** the regulation actions of entry AGC (whether it is feedback / feedforward or mass flow) are in all cases supported by a coordinated contribution from exit AGC. This external loop definitively makes the entire system more robust.

All the above refers to a tandem mill, whether continuous or coil-to-coil; when the reduction process is performed in a single stand reversing mill, only the considerations regarding feedback / feedforward AGC and mass flow AGC remain entirely meaningful and apply in full.

- **HGC:** While a number of HGC general properties do not depend on hot or cold rolling (see the "Technological Controls in Hot Rolling Mills" chapter in relation to slanting control, servo-valve flow linearization, valve dynamic countermeasures, mill modulus and oil film acquisition), some peculiarities of cold rolling are taken into account by ASI's automation system.
As shown in figure 3.5, HGC foresees not only position control with a direct loop, but also force control (in a direct loop or as an external loop to position control), typically in the following cases:
  - last stand of tandem mill with shotblast rolls or last pass of reversing mill: force control ensures

good strip shape by keeping rolling force at a constant value;
- temper and skin-pass mills: it aims to allow elongation control to work at its best;
- aluminum foil mill: in the case of such a thin material, only force mode can ensure correct leveling.

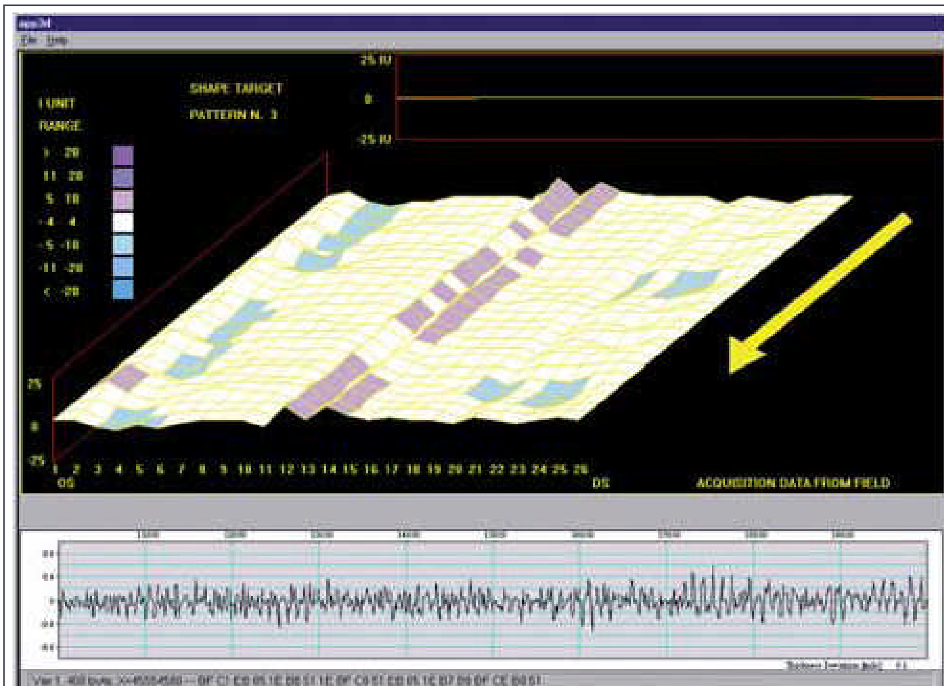
3.8 – 6-hi stand (Heng Tong Group, Continuous Tandem Mill n. 3 – Jing Tang Gang, PRC)

Automatic Flatness Control

Strip flatness is the most important final product characteristic, along with thickness, to which the steel market is extremely sensitive, and ASI automation has developed a high performance system to satisfy every Enduser of both steel and aluminum products.
A basic requirement is that the cold rolled strip must be flat and completely free of camber; flatness defects in the final product will occur if the residual stresses remaining after rolling exceed critical values. In this case, the strip will show flatness defects as wavy edges or centre buckles.
Basically, poor flatness is caused by elongation variations across the width of the strip, and these arise from an incorrect roll-gap profile; a number of factors can contribute to this:

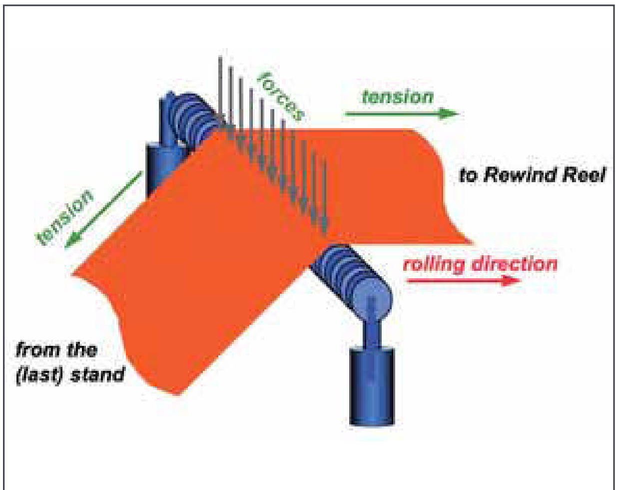
- bending and shear deformation of work rolls due to rolling force and bending force;
- flattening of the contact surface between work roll and strip;
- roll mechanical profile (once ground at roll shop);
- roll thermal profile.

Poor strip shape occurs if changes in the above factors upset the balance between roll-gap contour and strip profile: the most common causes include roll force fluctuations due to yield stress and friction coefficient changes, variable hot strip profile, thermal camber deviations and inappropriate mechanical roll



3.9 – On-line 3D representation of strip flatness and thickness (Barmet Aluminum Mill - Ulrichville, USA)

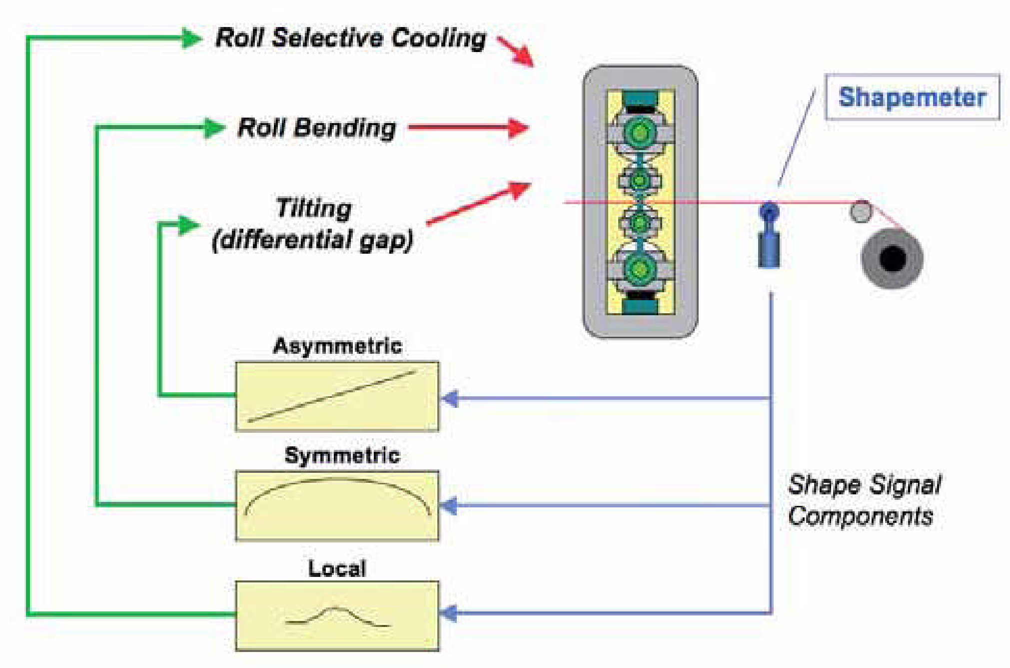
profiles; conversely, control of strip shape is achieved by adjusting one or more terms to restore the desired condition of equilibrium.
Strip flatness is measured with a shapemeter: a segmented roll located at the mill exit (single stand or tandem) which measures, rotor by rotor, the vertical forces to which the strip is subjected during rolling, across the width of the strip (see figure 3.10); it is then mathematically possible to obtain the longitudinal tensions from the forces and, from them, the flatness index of the strip.
ASI's flatness control processes rough measurements coming from the shapemeter in order to extract the three components of the error that the available actuators can most efficiently correct (see figure 3.11); bending quickly and accurately compensates symmetrical defects, while tilting acts on the asymmetrical defects in the strip.
Localized defects, usually a result of thermal phenomena, can be efficiently corrected by selective cooling sprays: they have a slow dynamic, but can act on a precise area of the strip.
A Feedforward Force Compensation function (FFC) calculates a further contribution of bending, taking into account that the force can change during rolling, e.g. due to corrections from AGC or from ATC (Automatic interstand Tension Control).
The performance of regulators may be further improved with use of schedule-dependent sensitivity coefficients, calculated by ASI's mathematical models for shape setup:



3.10 - Working scheme of the shapemeter:
the rotors measure the vertical forces

$G_{F_j-Flat_{s\_err}}$	symmetric error in flatness is converted into correction of work roll bending
$G_{S-Flat_{a\_err}}$	asymmetric error in flatness is converted into correction of tilting
G_{Thc-t}	a local error in tension stress is converted into flow rate correction of the corresponding spray
G_{F_j-F}	a variation in rolling force is converted into compensation of work roll bending (for FFC)

3.11 - The 3 components of shape error are corrected differently

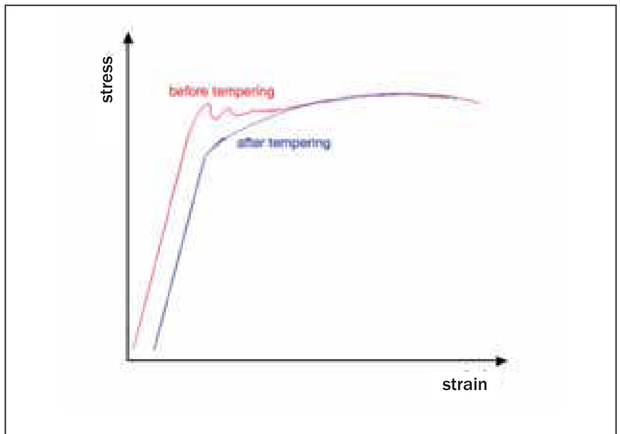


Temper and Skin Pass Mills

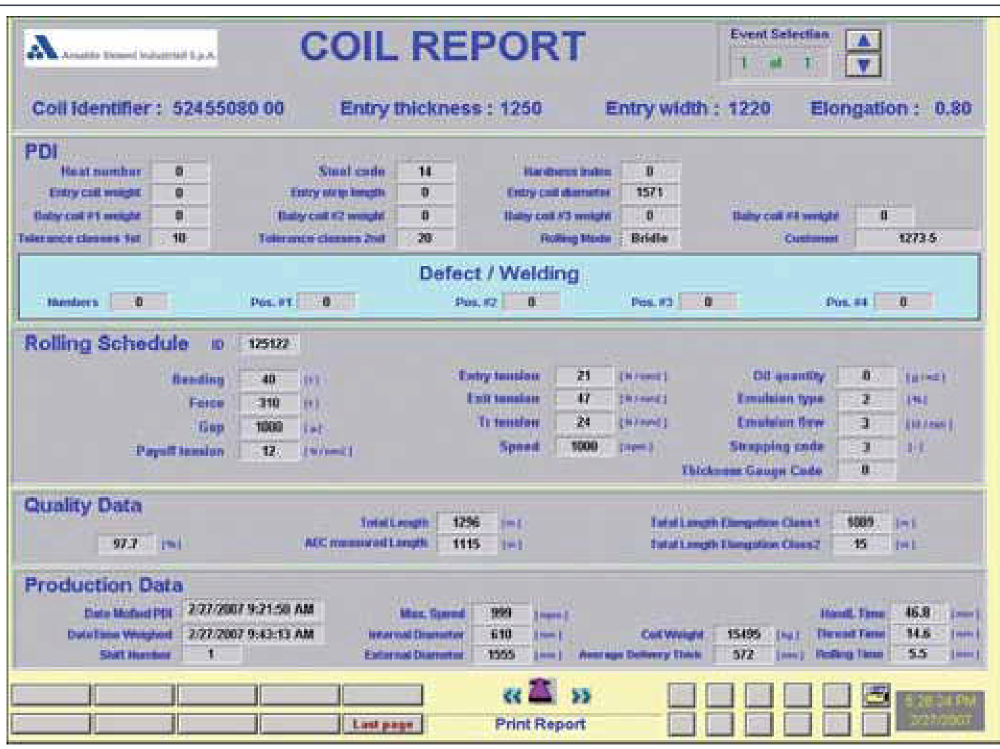
ASI's automation experience includes all aspects of rolling flat products, even those which often do not get the attention they deserve, such as tempering and skin-pass processes; indeed, these mills often act on a valuable part of the rolled product, at the very end of the rolling chain, just before delivery to the final user.
Basically, the tempering process adjusts the mechanical properties of the material to the ones required by particular final products; this is done by applying a slight reduction for smoothing the upper yield point of the stress-strain curve (see figure 3.12).
This category of mill includes the 2-stand temper mill, which is a very flexible plant capable of working in different operating modes:

- **Dry tempering:** results in very slight elongation, which changes metallurgical properties to prevent stretching strain and breaking of the surface as a result of subsequent drawing operations and only a slight reduction in strip thickness.
- **Wet tempering:** similar to dry mode, but with greater elongation.
- **Double reduction:** both reduction and tempering are done during the pass: a medium reduction is carried out on the 1st stand, while a hard temper is achieved at the 2nd stand.

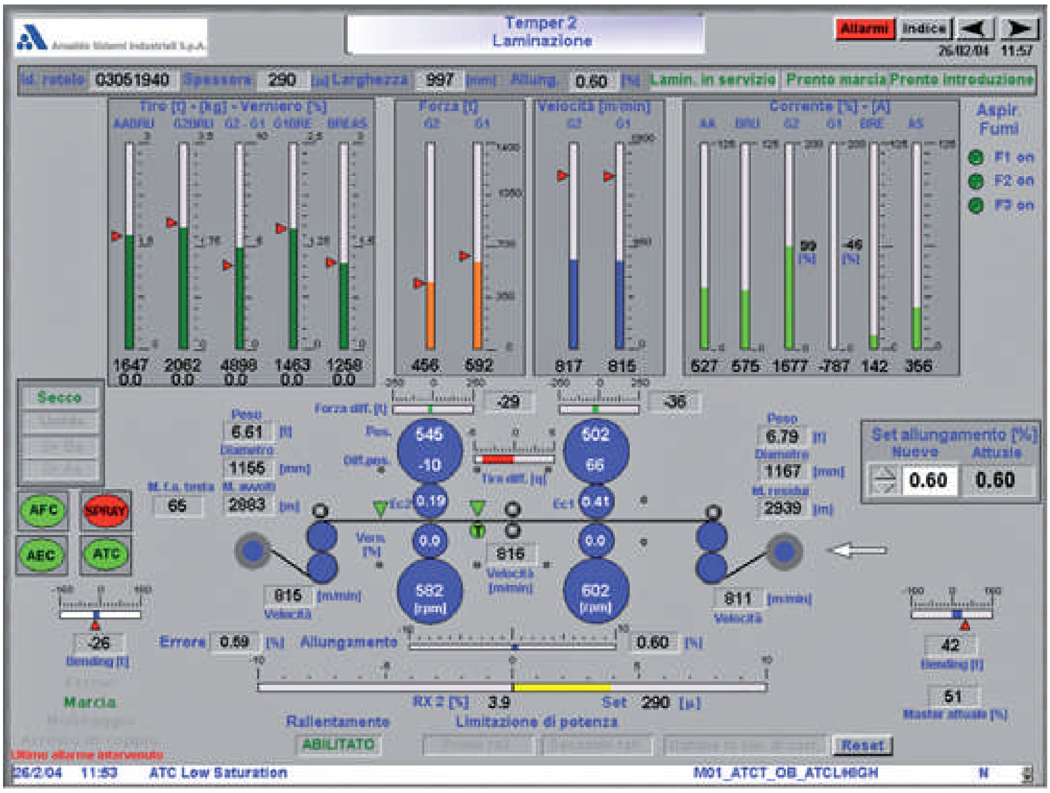
ASI uses dedicated mathematical models, which are different in the case of reduction or of tempering because, in the latter case, the slight reduction renders the approach used by classical reduction models ineffective. Due to the difficulty of controlling such small reductions, the best performance may be obtained by regulating strip elongation, calculated by encoders or, better yet, on the basis of laser speed upstream and downstream of the stand.
ASI's automatic elongation control (AEC) works on stand force in the case of a single stand skin-pass (acting on tensions in the case of force adjustment saturation) or on interstand tension in 2-stand temper mills (with action on the 1st stand load in the case of tension adjustment saturation).



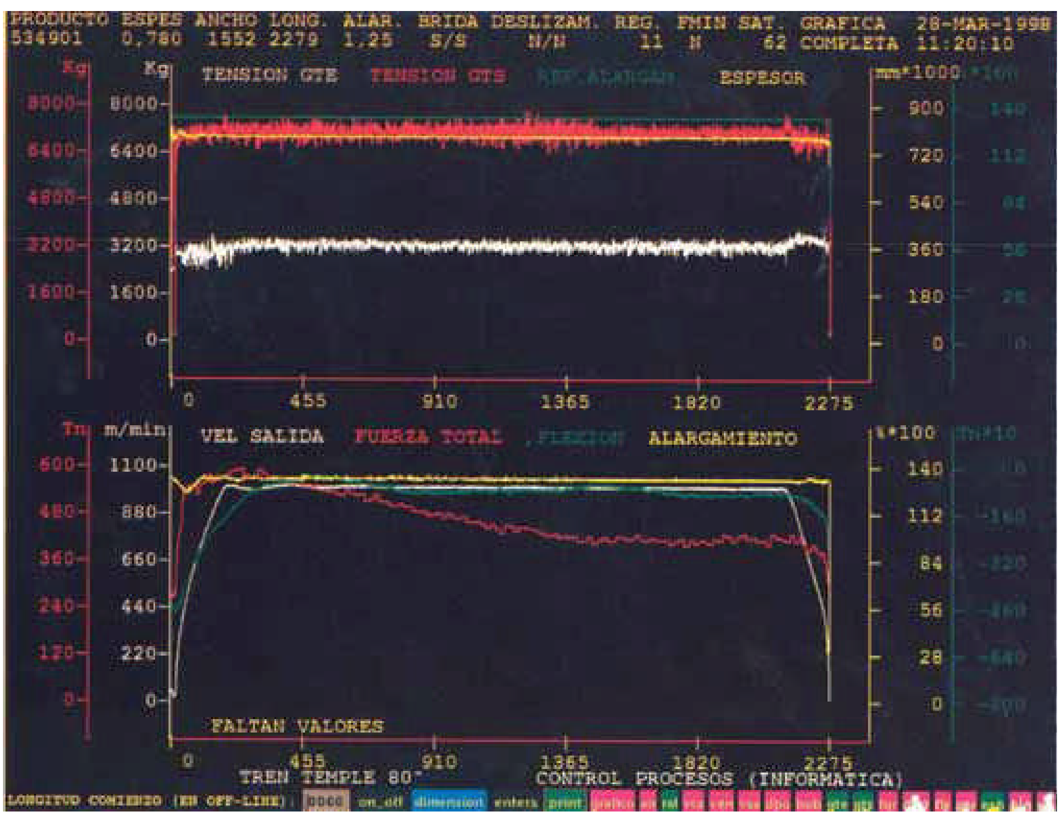
3.12 – Tempering process acts on the stress-strain curve of the strip



3.13 – Elongation report at skin pass mill (Middle East)



3.14 – Mill mimic of temper mill (temper mill n. 2, Ilva – Genova, Italy)

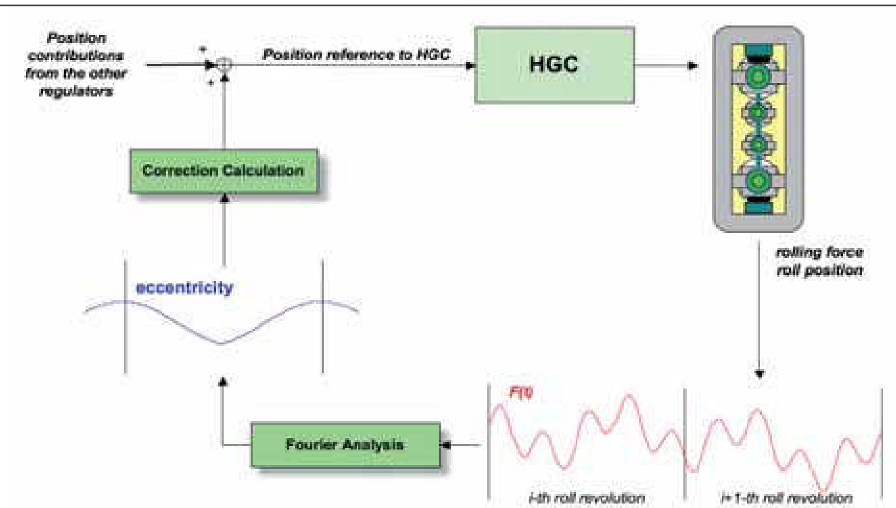


3.15 – ASI elongation control and setup (SidMed - Valencia, Spain)

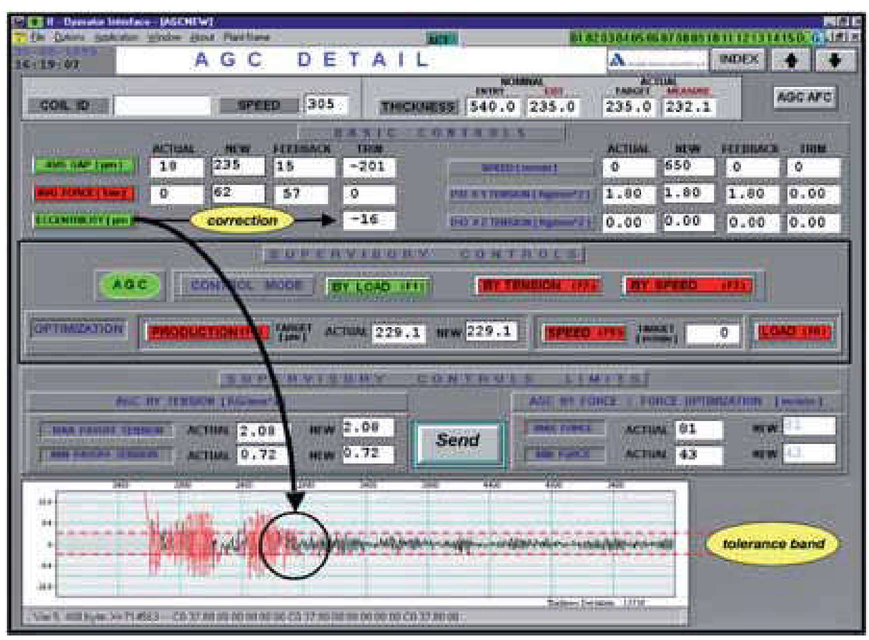
Eccentricity Control

The rolls of a stand, whether it is in a cold tandem mill or in a hot strip mill, may present some ovalization phenomena on work rolls and, especially, eccentricity phenomena on back-up rolls, due to a number or reasons: the most common are slight inaccuracies during roll grinding and asymmetric bearing wear in the chocks; this means that the rolls, during rotation, cause slightly different gaps affecting the final thickness of the rolled piece.
Eccentricity control involves detection of a roll eccentricity component and subsequent derivation of a correction signal which is applied to hydraulic gap control to compensate for roll eccentricity (see figure 3.16).
Rolling force is acquired continuously from the stand sensors and processed by a Fourier analysis module; this method, which may be classified as an "active roll eccentricity control method", compensates for the 1st harmonic component of roll eccentricity.
Eccentricity control can work in the absence of dedicated sensors, but a proximity switch signaling each roll revolution or, better yet, an encoder giving the roll's angular position makes an effective contribution: these basically shorten the amount of time required to recognize the amount of eccentricity and therefore eliminate the defect.
In recent years ASI has invested considerable time and resources in studying this problem, simulating the defect and implementing the solution described above; figure 3.17 shows the benefits of eccentricity control, demonstrated by a simulation.

3.16 - The eccentricity component of the rolls is evaluated on the basis of measurements of force and roll position and a suitable correction is added to the other contributions; ASI applies the eccentricity control algorithm to both hot and cold rolling plants.



3.17 - Benefits of the eccentricity control on the exit thickness of an aluminum mill



ASTRO! THE REAL TIME SIMULATOR

The level of complexity, interaction and improvement of final product quality is growing rapidly in industrial plants today. In the metals industry, the rolling mill is a very complex and time-varying system that includes a fast process with a lot of parameters dependant on the material to be rolled and on the rolling conditions themselves.
The automation system for such a plant normally includes both process control and basic automation. The former (level 2 automation) is able to manage all the data referring to each piece to be rolled and calculate the references to be sent to the regulators; the latter (level 1 automation) includes the regulation loops able to control the actuators directly, maintain the references and manage the logic.
Development of automation requires powerful hardware and versatile software in order to meet the market's demands for improved product quality. Also, the testing of such software must be as reliable and complete as possible before it is used in the plant. Training of the final customer's personnel has great importance as well, to decrease the amount of time necessary to familiarize them with the new system.
A seller of automation must absolutely be able to promote its systems and present its solutions and know-how at their best.

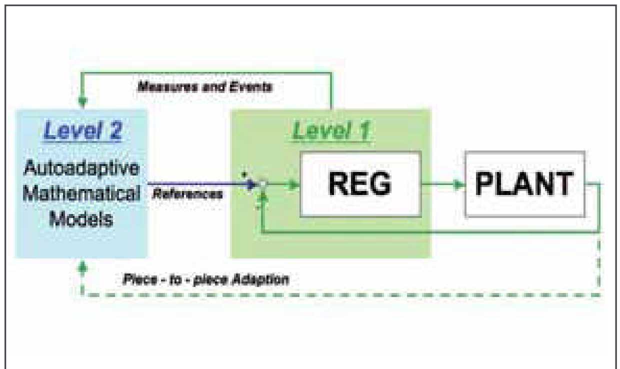
Components	hydraulic capsules
	electrical screwdowns
	work roll bending capsules
	intermediate roll shifting cylinders
	horizontal work roll shifting cylinders
	main motors
	bridle motors
Sensors	X-ray thickness gauge
	shapemeter
	tensiometer
	speed lasermeter
	load cell
	pressure transducer
	position transducer
	pulse generator
Logic	main logic
Operator Desks	roll zeroing
	strip movement commands (threading, run, stop…)
	operator verniers
	technological functions insertion (AGC, ATC, AFC)
Process	strip motion along the mill
Disturbances	strip thickness
	strip tension
	strip speed
	strip flatness
	back-up roll eccentricity
Simplified Controls	HGC
	Bending Control
	Speed Master, Reel Control, Coil Tracking
	Presets Management

Table 4.1 – automation functions simulated by ASTRO!

An essential factor providing essential benefits in relation to the above is simulation know-how. ASI has absorbed the culture of simulation and developed a number of instances dedicated to different plants from almost 15 years: it now counts the plant simulator among its standard automation functions, demonstrating the enhanced quality of the rolling automation and technology available in ASI's systems. The ability to close the loop before the commissioning of the plant is very important not only during final testing before shipping the system, but already during system development; ASTRO! makes it possible to substitute the block *plant* (see figure 4.1) with a real time simulator capable of exercising control functions, the supervision system, signal linking and so on in different plants.
ARTICS (described in the following chapter) is ASI's platform for the level 1 automation system, and its main hardware component is the AMS, usually based on the VMEbus standard, but also available on the industrial PC platform.

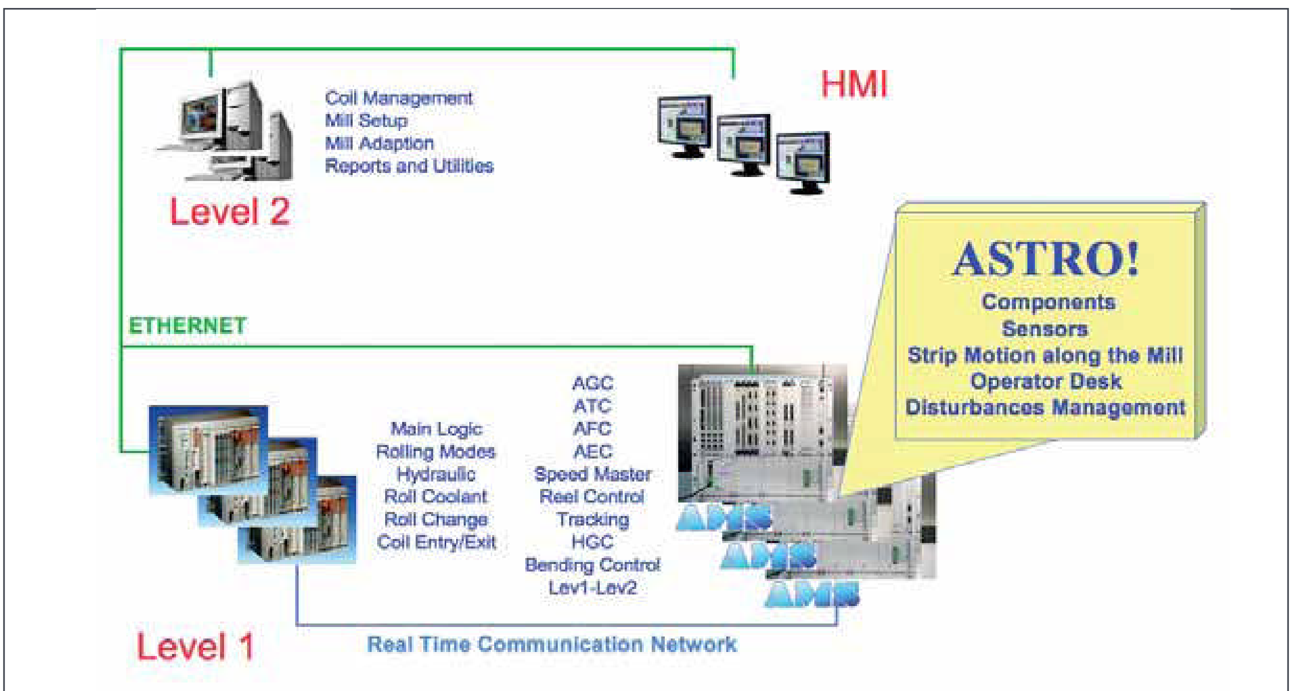
Cold Rolling Mill	Single Stand	One-way
		Reversing
	Tandem	2-stand, reversing
		5-stand, coil to coil
		5-stand, continuous

Table 4.2 – Plants simulated by ASTRO!



4.1 - Classical representation of an automation system

Including a plant simulator in one of ASI's automation systems for test purposes simply means integrating a new automation function: ASTRO! is developed using exactly the same hardware, basic software structures and application libraries as ASI's systems use.
During tests of a new automation system, ASTRO! is usually loaded on the CPUs that host the control tasks, but a dedicated CPU can be easily added in the presence of particularly pressing execution times (see figure 4.2).
As an operator training simulator, ASTRO! can be the same as or quite similar to a test simulator when dealing with an ASI system; but ASI can also supply training simulators for existent or third party automation systems if the customer wants a stand-alone simulator



4.2 – ASTRO! test configuration (Continuous Tandem Mill - Middle East)

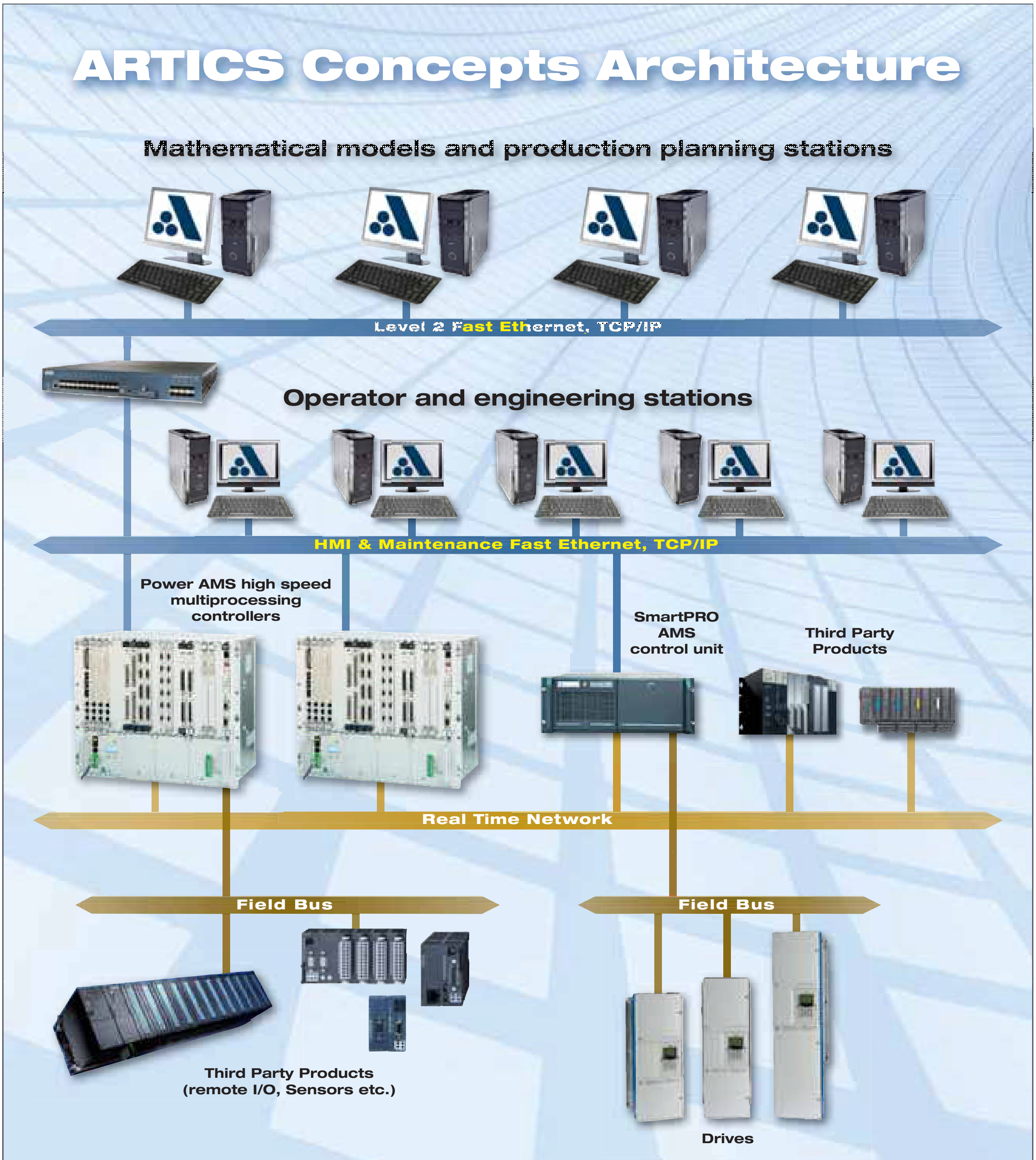
for its operators to use during training sessions.
Another possibility is the all-in-one configuration, in which a general simulation of plant behavior is carried out and ASTRO! also includes the most important automation functions, in a single object supplying trainees with an introductory but meaningful and realistic overview of the most important operations in the mill.
An all-in-one low-cost solution, particularly suitable for training and demo purposes, uses smartAMS, the hardware of which is based on an industrial PC, but in which applications are exactly the same as the standard AMS (figure 4.3).
Finally, a demo simulator may perfectly well be included in the previous cases or supplied alone, especially for academic purposes (see figure 4.4) or where a simplified but appealing simulation and a very user-friendly object are required to permit use by non-technicians.

4.3 - ASTRO! all-in-one solution: a low cost hardware based on smartPRO AMS

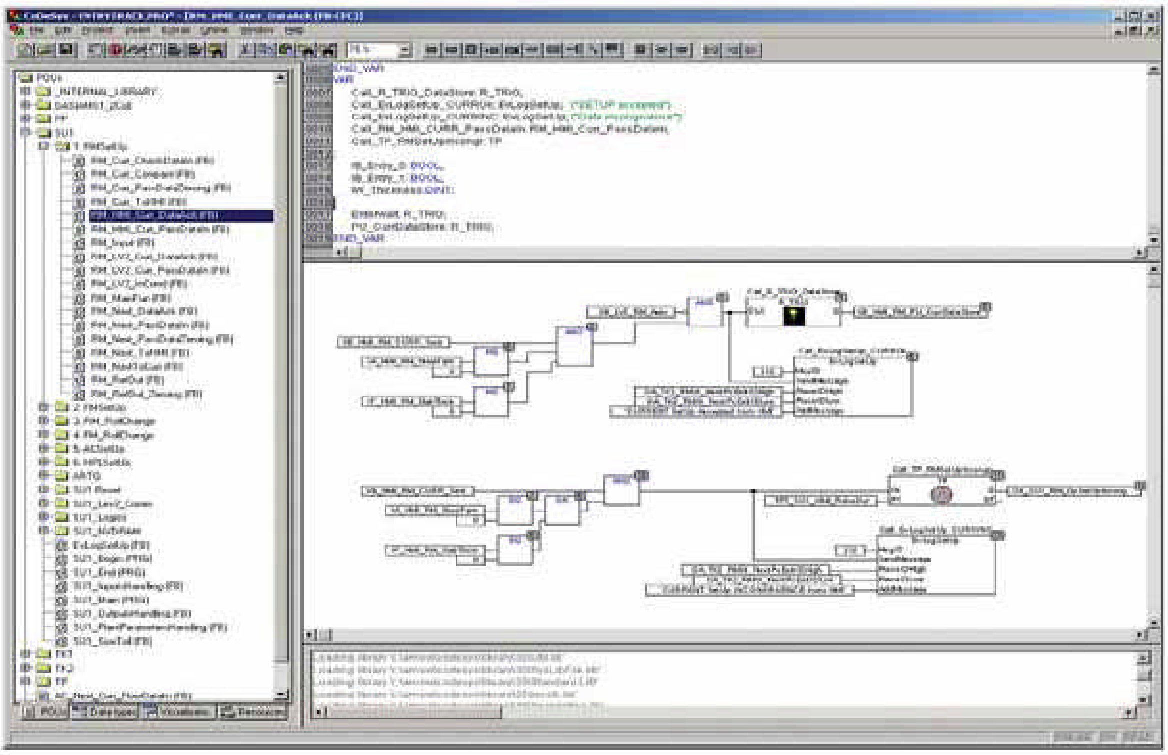

4.4 - ASTRO! as a teaching tool for engineering students of Genova University

ARTICS - ASI REAL TIME INTEGRATED CONTROL SYSTEM

ASI Real Time Integrated Control System (ARTICS) is an automation system solution for process control and gathering real-time data from remote locations to help control mechanical and electrical equipment and processes in the plant.
In short, ARTICS integrates and simplifies several



5.1 – ARTICS framework



5.2 – a CoDeSys application in ARTICS environment: an example (TISC Plate Mill – Tianjin, PRC)

steps in the automation control process. The system's input/output devices interface directly with drives, basic automation processes, data acquisition functions, process control functions and the engineer. ASI automation applications in flat rolling process often require highly demanding calculation power in extremely reduced cycle times: just think of hydraulic gap control, which must be able to run at least every 2 ms, or the large amount of calculation required for eccentricity control or automatic flatness control at each cycle time!

Since the early 1990s ASI has developed a platform perfectly capable of meeting these demanding requirements, efficiently supported and continuously updated by a dedicated team of engineers: ARTICS has been designed to exceed even the most stringent real-time requirements and demonstrates its reliability and versatility every day in hundreds of installations in metals industries and paper mills worldwide.

ARTICS is based on AMS (ASI Micro System), a family of multifunctional units oriented toward real time control of fast processes, with cycle times in the milliseconds; flexible, powerful and based on state-of-the-art hardware and software, AMS is the simplest multiprocessing micro system available for industrial applications: development and running of applications in a multitasking environment is made possible by using the best programming language for each specific control function (C, ISaGRAF, CoDeSys, ...) (see figure 5.2).

5.3 – a typical AMS rack: 4 CPUs, DI, DO, AO, AI, SSI, Counter, Profibus, TPL boards are installed

	VME solution – power AMS	PCI solution: smartPRO AMS
Real time processor		**32/64 bits 32 bits**
Multi-processing	Up to 9 CUP boards	–
Slots	21 / 8 / 7 / 5	10
network	2 ethernet 10/100 Mbit for each CPU, TCP/IP full support	2 ethernet 10/100 Mbit, TCP/IP full support
Real time network	Redundant ARCNET (RS485 or Ethernet), Shared Memory Network, other available (e.g., RTNET, CSF)	
Field bus	EtherCat	Profibus
	Profibus	…
	AB control Net	
	GE Genius	
	Ge series six	
	…	
Real time operating system	VxWorks	
Development and HMI platform	**Windows / Personal computer**	
Programming environments	ISaGRAF 3.46 – CoDeSys 2.3 – C	
User languages	Function Block Diagram, Ladder, Sequential, ST, IL, C	
HMI drivers	DDE, OPC	
HMI tools	All compliant with DDE and OPC	
SW services		
Integrated development tool	AMS development tool	
Event log	1 ms timing	
Task synchronous tracing	8 channels each program	
Data acquisition	Multi-target, up to 1024 signals	
Integrated profibus configurator	Slave parameters included	
Project signals data base manager	Client/server architecture, .NET architecture	
Drives data and parameters manager	Available	
System integrator connection	ActiveX, DLL components	

Table 5.1 – ARTICS hardware and software basic features

It is an open standard platform based on commercial hardware:

- VME industrial bus for hi-performance systems (PowerAMS) (figure 5.3);
- PCI bus for small and economic systems (SmartPRO AMS) and software (see table 5.1); it allows integration with the most popular PLCs while providing efficient maintenance and is compatible with off-the-shelf supervision systems (Intouch, Cimplicity, RsView, ...) and data acquisition software programs.

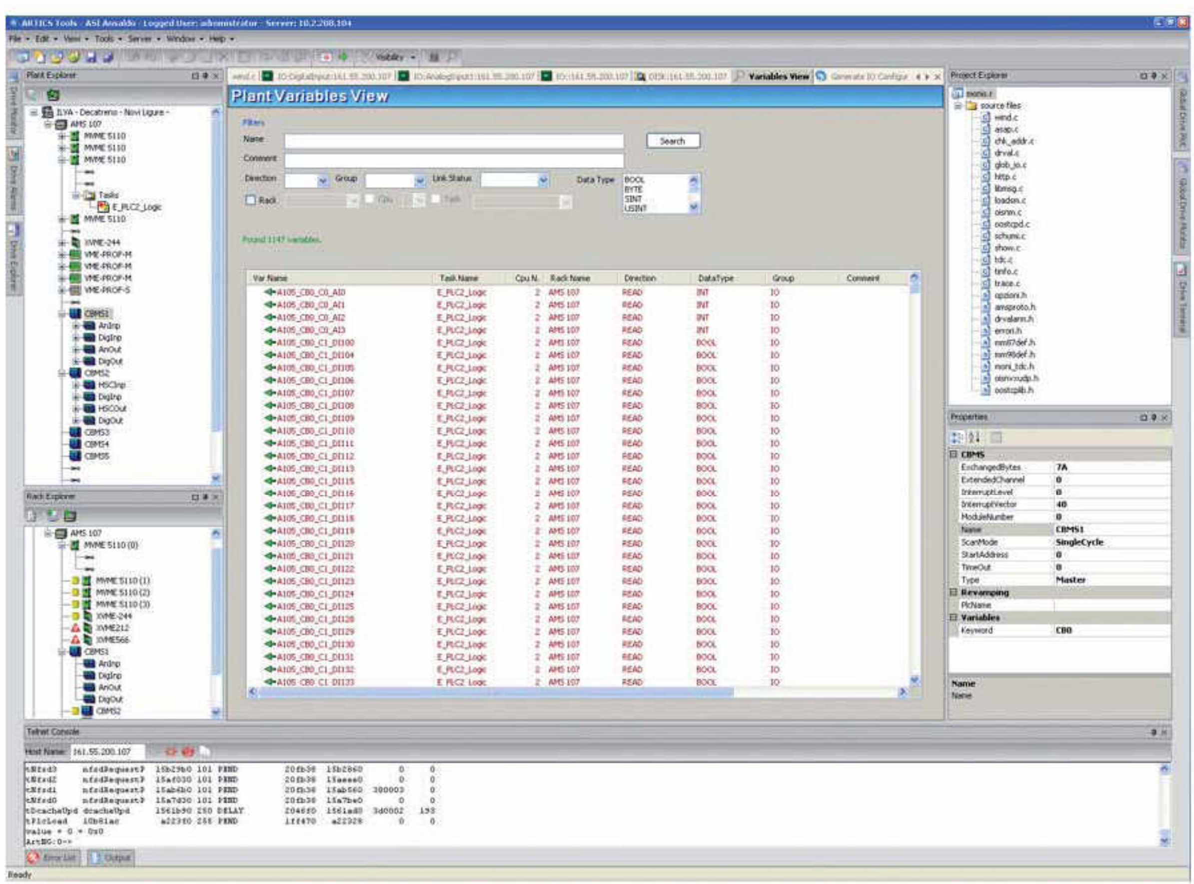
The ARTICS team supports a powerful suite of development, diagnostic and HMI tools for ASI applications based on the Windows platform for personal computers; user-friendly operations are thus guaranteed by an easy PLC-like graphic interface for looking inside the applications, getting detailed diagnostics on drives, checking and tracing signals and events, and so on.

ARTICS Tools is a configuration and management software for plants developed on the basis of the ARTICS automation system (figure 5.4); based on the Microsoft .NET environment, it is a modern, user-friendly tool that allows multi-user to:

- create, modify and view complete hardware and software plant configurations based on AMS systems;
- import signals from application tasks;
- create I/O links;
- generate configuration files (including profibus configuration) and download them into AMS racks.

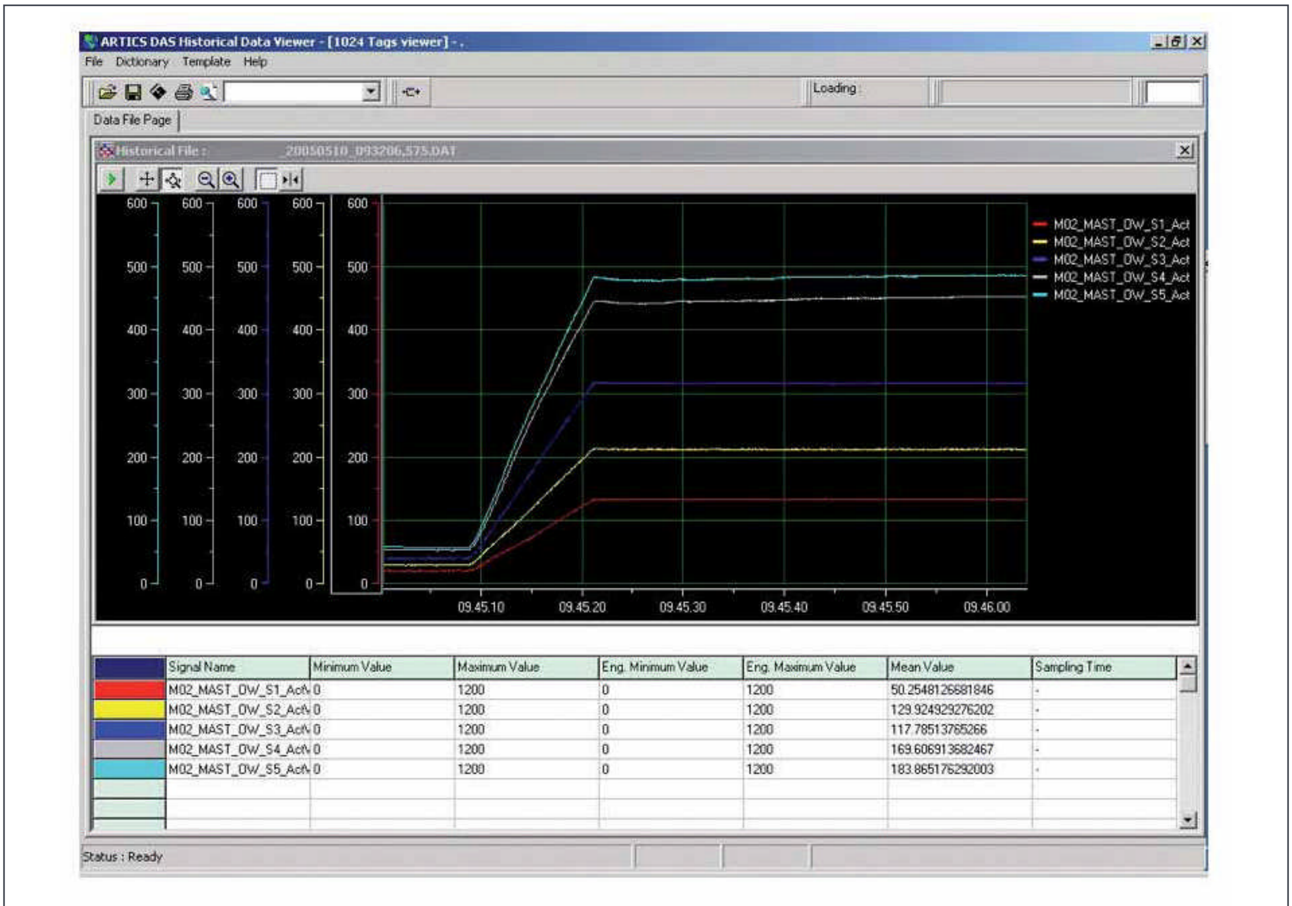
The aim is to decrease configuration/development time by automating operations such as auto-linking of task communication signals.

DAS (Data Acquisition System) is a multi-channel data logger for recording and displaying high-speed event values; it is used for plant analysis, for reducing



5.4 – Signal management and linking via ARTICS Tools (ILVA Tandem Mill coupled with Pickling Line - Novi Ligure, Italy) maintenance waiting time and for identifying high-speed events:

- client/server concept : server is on dedicated tasks on AMS while clients are installed on personal computers;
- up to 1024 different values can be acquired, with up to 4 different sampling times;
- data acquisition sampling time configurable down to 1 ms;
- data analysis;
- historical data production integrated with the historical data management system in process control basic functions;
- change of display settings while viewing real-time or historical trends;
- familiar strip-chart recorder appearance.



5.5 – Speed-up ramps in a tandem mill acquired by means of DAS

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