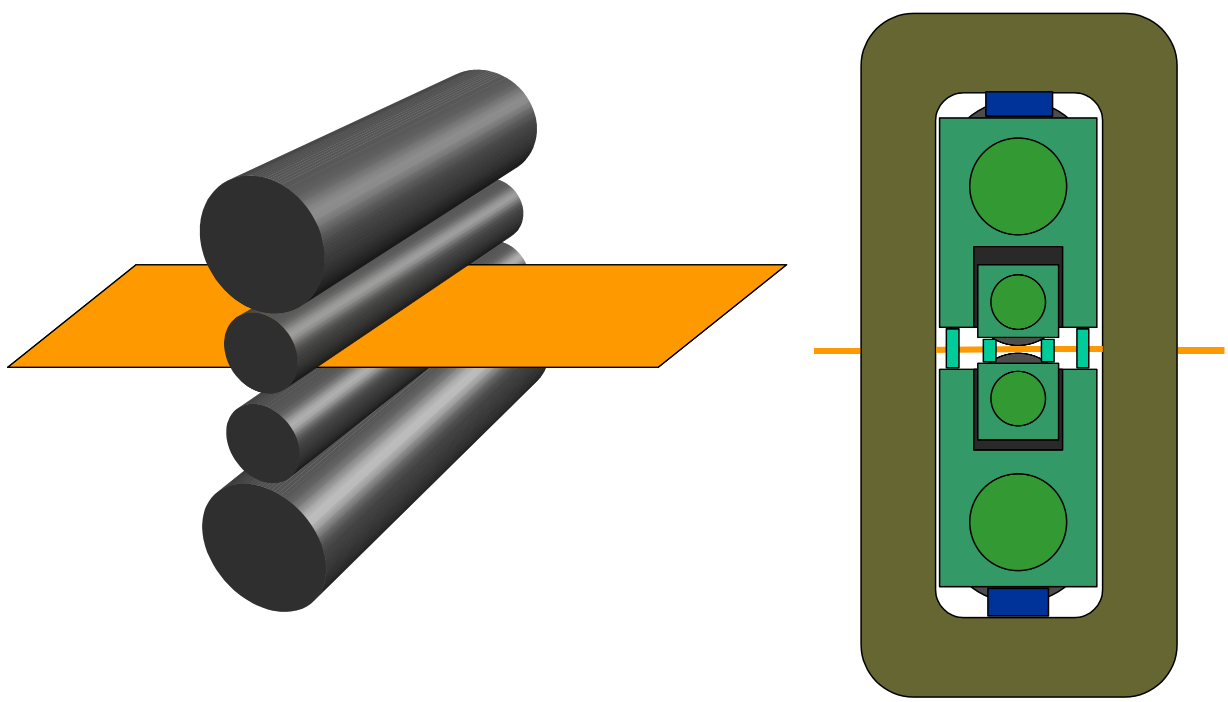
Finishing Mill Operator Training

for

AK Steel Butler Works



by

Luther Holton Associates Inc.

May 2000

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Luther Holton Associates Inc
Hamilton, Ontario, Canada
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Presented by Luther Holton
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Course Outline

The material has been organized into six sections:

1. Rolling Theory
2. Mill Sensors
3. FM Model Functionality
4. AGC, Loopers and Mill Speed Control
5. Operator Controls and MMI
6. Rolling Problems and Recommended Actions

The material for this course begins with a presentation of basic rolling theory. Factors affecting the roll force and main drive current are reviewed along with a reasonably detailed discussion of the mill stand and roll stack. Strip and stand thermal effects are mentioned. The effects of roll wear and roll stack thermal expansion on the shape of the roll gap presented to the strip are demonstrated. Finally, a brief discussion of strip shape including crown, flatness, camber and wedge is included.

Some of the more important mill sensors are presented along with their basic theory of operation and practical problems which may affect their readings.

The review of the functionality of the adaptive FM setup model includes a high level description of its calculations including limit checks and model table layouts. Inputs and outputs are listed along with the various modes of operation. Model adaption is described and a distinction is made between adaption and off-line tuning. The various analysis and reporting tools available are listed.

Level 1 control of the strip thickness, tension and mass flow balance is covered under the headings AGC, Loopers and Mill Speed Control. For each, the various control loops are described and interactions with the Setup Model and operators are discussed.

Selected operator controls and MMI functions specific to this mill are presented. Only those controls related to the FM Model and its setup or adaption functions are included.

This course concludes with the discussion of a series of practical problems. These are intended to test the course participants' understanding of the mill as an integrated control system.

Course Objectives

- Present rolling theory along with a description of the major automation functions so that operating and maintenance personnel can appreciate some of the more important control interactions.
- Provide an understanding of the FM Model setup and adaption functionality so that operators will know when intervention is appropriate as well as the effects of any intervention on subsequent calculations.

Preliminaries

Three Letter Acronyms (TLA)

For some reason, automation people have a habit of shortening the names for things to acronyms that usually have three letters. After a while, these are used like any other word and sometimes, we even forget what the acronyms stand for. Here is a list of some of the more common acronyms that appear in this training material.

AGC - Automatic Gauge Control
CLD – Center-line Deviation
DAS – Data Acquisition and Analysis System
FMA - Finishing Mill Adaption (Learning)
FMS - Finishing Mill Setup
FSR - Feed-forward Setup Revision
LHA – Luther Holton Associates Inc.
MMI - Man (Human) Machine Interface (sometimes HMI)
MPM - Model Performance Monitor
MSR - Master Speed Regulator
PDI - Primary Data Input
TPS - Thyristor Power Supply
VXL - MMI Screen Display System

Rolling Problems – For Discussion

A number of sample problems will be described so that the appropriate operator actions can be discussed. These will be introduced at the beginning of the training sessions and then reviewed in detail towards the end of the material presented.

- FM setup errors
- Tracking or measurement problems
- Mass flow errors, looper stability
- Head and tail end camber
- Body CLD errors and long edge
- Mid-bar scrapping
- Predictable errors
- When to call for help

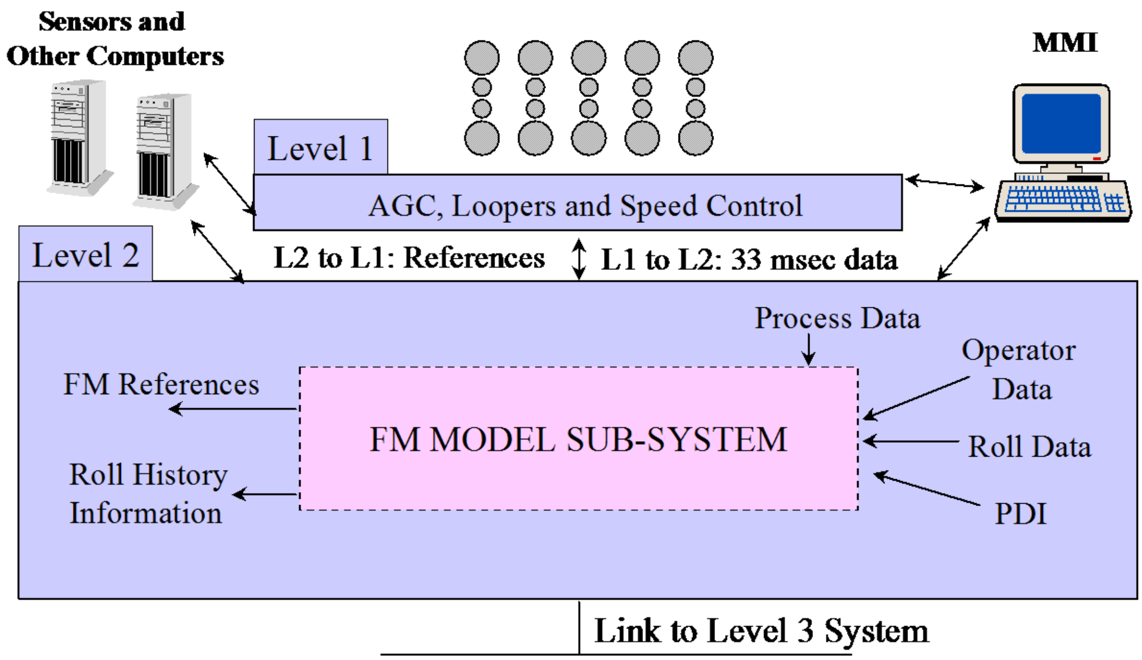
Control Hierarchy

- Level 0 Sensors, Drives, Actuators
  X-ray, Width Gauge, Load Cells, TPS, Screwdowns
- Level 1 Local Regulators (AGC, MSR)
  Feedback control loops
  Implemented in Programmable Logic Controllers
- Level 2 Unit Tracking, Setup and Adaption
  Product dependent actions
  Implemented using Fortran Programs on an Alpha Computer
- Level 3 Facility Coordination, Data Management
- Level 4 Order Entry, Business System

- MMI – Man Machine Interface or HMI – Human Machine Interface
  Usually refers to graphic or text screen computer interfaces but really includes all operator interfaces which can be seen, felt or heard:
    - Level 1 and Level 2 MMI station display and input screens
    - “Must Hits” Screen
    - Sensor interfaces (X-ray Profile Sensor)
    - Desk controls and indicators
    - Audible devices (Buzzers, horns and voice)
    - Flashing lights in the pulpit or out on the mill
    - View of the mill equipment including any mechanical devices or indicators
    - May even include variations in pulpit lighting

  MMI design determines how the operators interact with the mill.

Mill Levels of Control and MMI



Rolling Theory

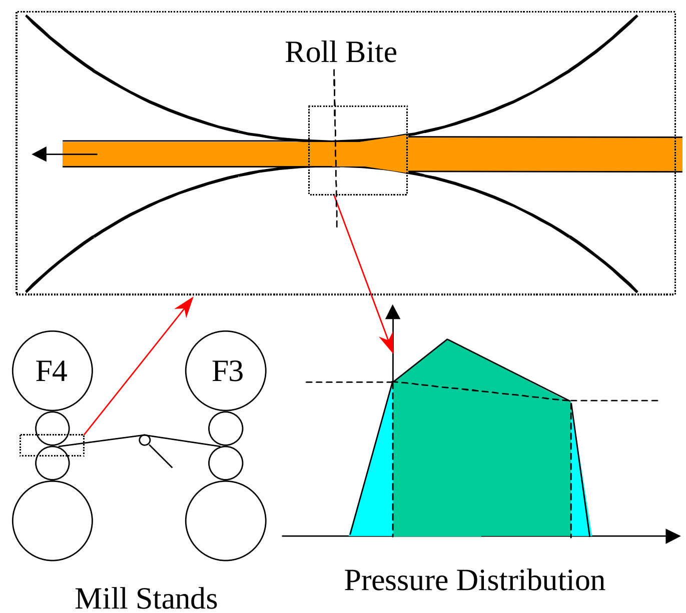
Topics to be studied include:

- Roll force and torque (power/current)
- Mass flow and strip tension
- Thermal considerations
- Mill stretch and the gaugemeter principle
- Profile, flatness, level and steering

In this section, rolling theory is presented in a fair amount of detail. The treatment is conceptual with the objective of helping to build an understanding of the factors influencing the behavior of the strip in the mill.

Factors Affecting Roll Force

- Hot steel is plastically reduced as it passes through the roll bite.
- At the entry and exit sides of the roll bite, there are small regions of elastic deformation which contribute to the total roll force.
- Inside the roll bite, the pressure required to deform the strip is determined by the yield stress of the steel and the coefficient of friction at the work roll to strip interface.
- The total area under the pressure distribution determines the roll force.

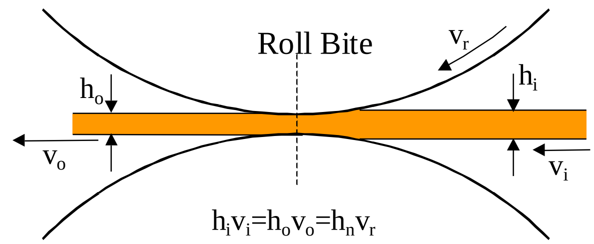


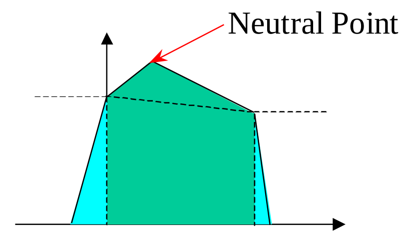
Between the rolls, the strip is deformed due to the pressure exerted by the roll stack. Through the arc of contact, the pressure depends on the yield strength of the material being rolled which varies with temperature and work hardening.

Within the roll bite, a friction hill in the pressure distribution is due to the constraining effect of the strip itself held between the two rolls (picture the steel being compressed between two plates). The steepness of this friction hill is a function of the coefficient of friction between the rolls and the strip. Rolling lubrication can reduce the roll force required to take a reduction by reducing the height of the friction hill. Typically, the yield stress of the strip is higher on the exit side of the roll bite due to temperature loss and work hardening.

Forward and Backward Slip

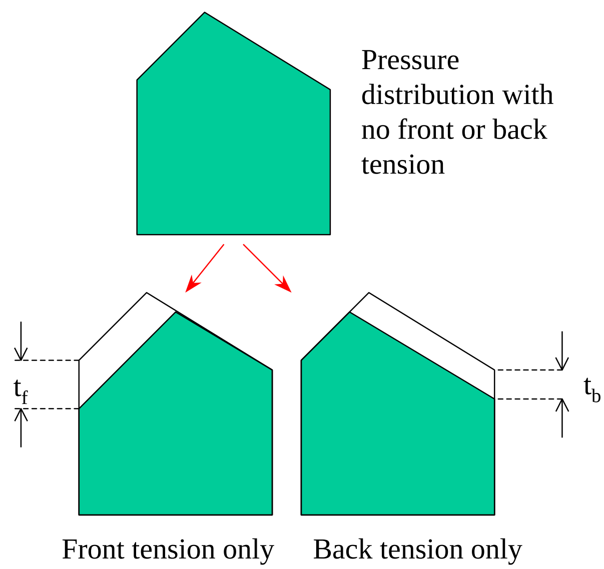
- As the steel is reduced in the roll bite, it must speed up to maintain balanced mass flow.
- At the neutral point in the roll bite, the surface speed of the work rolls and the average speed of the strip are equal. On the entry side of this point, the rolls are faster than the strip (backward slip) while on the exit side of the neutral point, the strip is faster than the surface of the work rolls (forward slip).





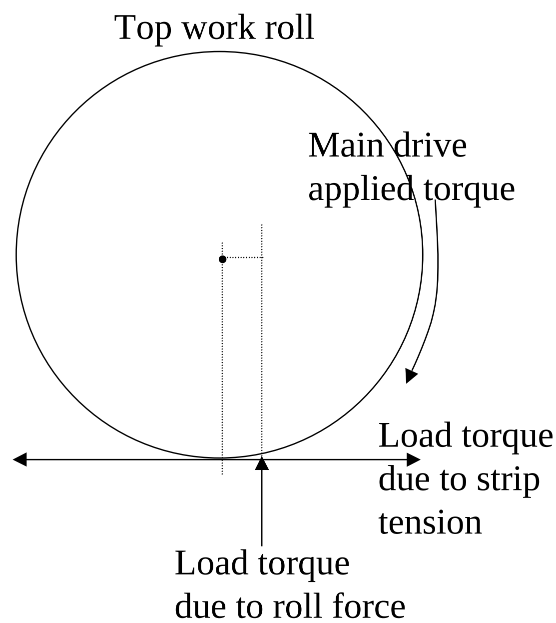
Influence of Strip Tension on Roll Force

- The pressure required to plastically deform the steel is reduced by the amount of tension stress.
- Increasing front (exit side) tension will lower the total roll force and move the neutral point towards the entry side of the roll bite (increasing forward slip and mass flow).
- Increasing back tension will also lower the total roll force but move the neutral point towards the exit side of the roll bite (increasing backward slip and decreasing mass flow).



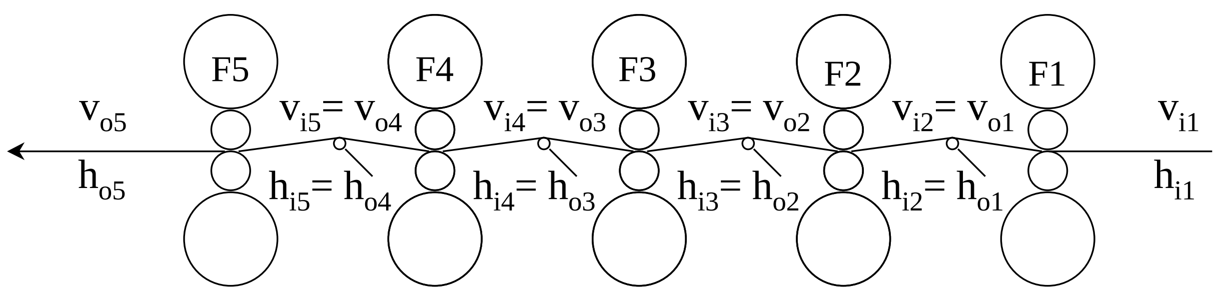
Factors Affecting Rolling Torque

- Roll torque is required to turn the work rolls against the strip force.
- Back tension increases the roll torque.
- Front tension reduces the roll torque.
- Main drive current is proportional to the product of main drive torque and roll speed.
- Main drive power is the product of main drive current and voltage.
- Main drive speed will drop when the rolling torque is greater than the main drive applied torque.



Mass Flow

- The mass flow at any point in the mill is the product of the strip thickness, width and speed.
- Mass flow is preserved through each roll bite. As the strip is reduced in thickness, it must speed up.
- If the mass flow leaving one stand does not equal the mass flow entering the next, then the loop length between the two stands will increase or decrease.
- If the downstream stand is too fast, the strip will be stretched. Mass flow will be preserved.

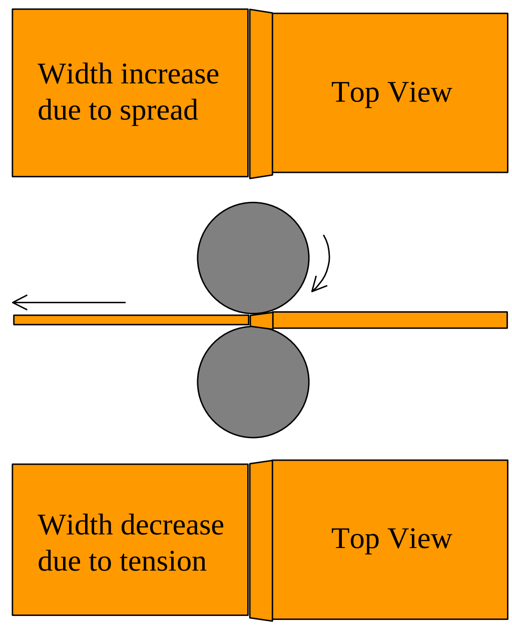


$$v_{05}h_{o5}w_{o5} = v_{o4}h_{o4}w_{o4} = v_{o3}h_{o3}w_{o3} = v_{o2}h_{o2}w_{o2} = v_{o1}h_{o1}w_{o1} = v_{i1}h_{i1}w_{i1}$$

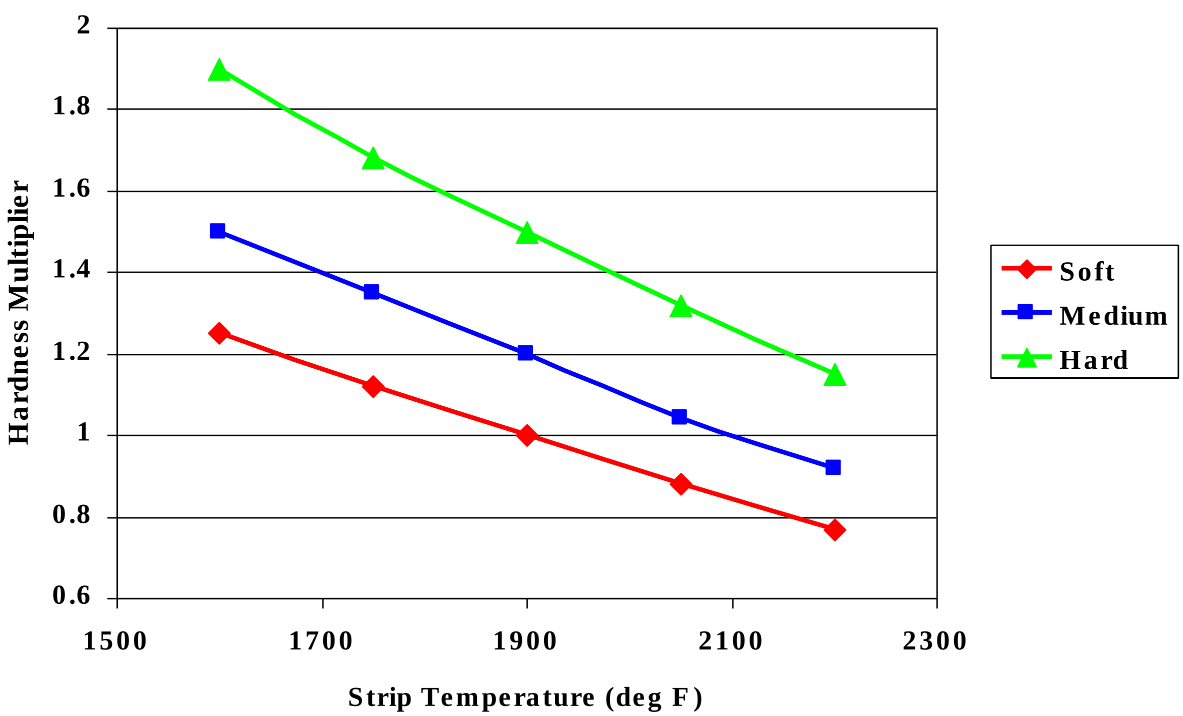
FM Width Variations

A combination of three factors determine FM width variations

1. Spread increase due to lateral flow in the roll bite as the strip is pressed.
2. Necking due to high tensions. This may occur in the roll bite or between stands.
3. The hot strip width contracts as the temperature drops at a rate of about 0.1% for every 100°F. Typical reductions through the FM will be from about 0.1 to 0.3"



Yield Stress as a Function of Temperature



Yield stress decreases with increasing temperature (generally by about 8% for every 50 F°). The rate of change of yield stress with temperature may vary quite a bit, especially around transformation temperatures.

Effect of Chemistry on Material Hardness

- The chemical composition of the steel affects the strength and hence the rolling pressure required to deform the steel.
- At a given temperature, some grades will be harder to roll than others.
- The mill setup model uses grade hardness multipliers to keep track of the relative hardness of each grade rolled. Model adaption measures and learns the actual relative hardness for each grade rolled.
- Variations from the nominal chemical composition for a grade may affect the strip hardness and hence the roll force and current required to roll it.

Heat Transfer

- **Losses due to Radiation**
  - Outside the roll bites – Very important at high temperatures.
- **Losses due to Conduction**
  - Roll contact (work rolls, looper rolls, table rolls)
- **Losses to Sprays**
  - Descale, laminar and roll cooling sprays – Surface chilled to water temperature.
- **Heating due to Deformation**
  - Work converted to heat – “Internal Friction”.
- **Friction Heating**
  - Due to slipping in the roll bite under high pressures.

Heat Transfer - Radiation

- Hot bodies radiate energy at a rate approximately proportional to the fourth power of their absolute surface temperature.
- The heat capacity of the bar or strip is directly proportional to its thickness.
- The rate of temperature loss for a 1" thick bar:

    at 165°F is 0.01 F° / sec
    at 1440°F is 1.75 F° / sec
    at 1800°F is 3.50 F° / sec
    at 2225°F is 7.00 F° / sec

"Absolute Temperature" = °R = °F+460

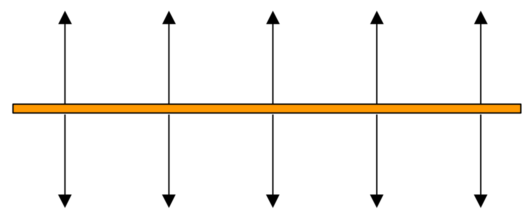
The ambient temperature term becomes important with table covers.

Ambient temperature
Surface temperature
Surface area
Radiation constant

$$\frac{dT}{dt} = -k\frac{A}{V}(T^4 - T_a^4) \approx -\frac{k}{H}T^4$$

Volume
Thickness

Temperature change per unit time

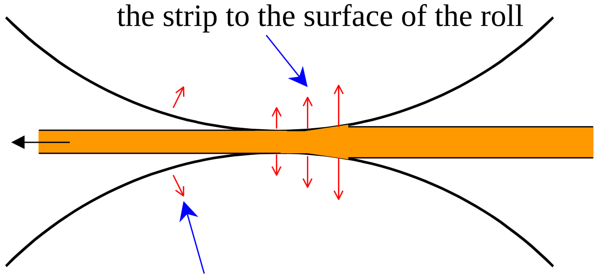


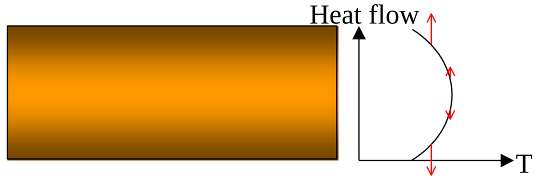
We are all familiar with the feeling of heat radiating from the hot strip or bar. It feels hot because the energy we receive on our skin is greater than the energy we radiate away (thanks to the large temperature difference between our skin and the surface of the hot steel). Passive table covers help retain heat in the transfer bar after they have had a chance to heat up. Once the inside surface of the table covers is hot, then it radiates energy back to the transfer bar at a rate approaching the rate at which the bar is radiating energy from its top surface. The net effect is that the bar looses heat more slowly. Table covers are designed so that the surface facing the transfer bar heats up easily. Insulation behind the surface minimizes the energy drawn away from the surface into the bulk of the table cover assembly.

At high temperatures, radiation losses are significant. In our everyday experience, radiation is less important since the difference in temperature between us and our surroundings is normally quite small.

Heat Transfer – Conduction

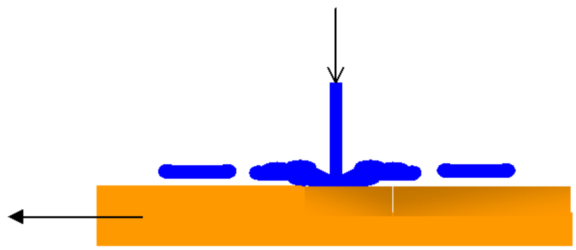
- Heat flows from the body of a bar or strip to the surface by conduction. It can also flow to a roll in contact with the bar or strip surface.
- The rate of heat flow by conduction depends on the temperature gradient and the coefficient of conductivity. Good insulators have very low thermal conductivity.
- Roll contact losses are proportional to the square root of the roll contact time.





Heat Transfer – Water Cooling

- Water chills the contact surface to the water temperature. Heat then flows from the body to the surface by conduction.
- Temperature losses are proportional to the square root of the speed of the strip through the spray.
- Water has a very high specific heat and a high heat of vaporization.
- Water sitting on the hot strip surface tends to float on a steam barrier.



We are familiar with the way beads of water slide on the surface of hot steel. They move so easily because they are not really in contact with the surface. They ride on a cushion of steam which tends to act as an insulator between the strip surface and the water.

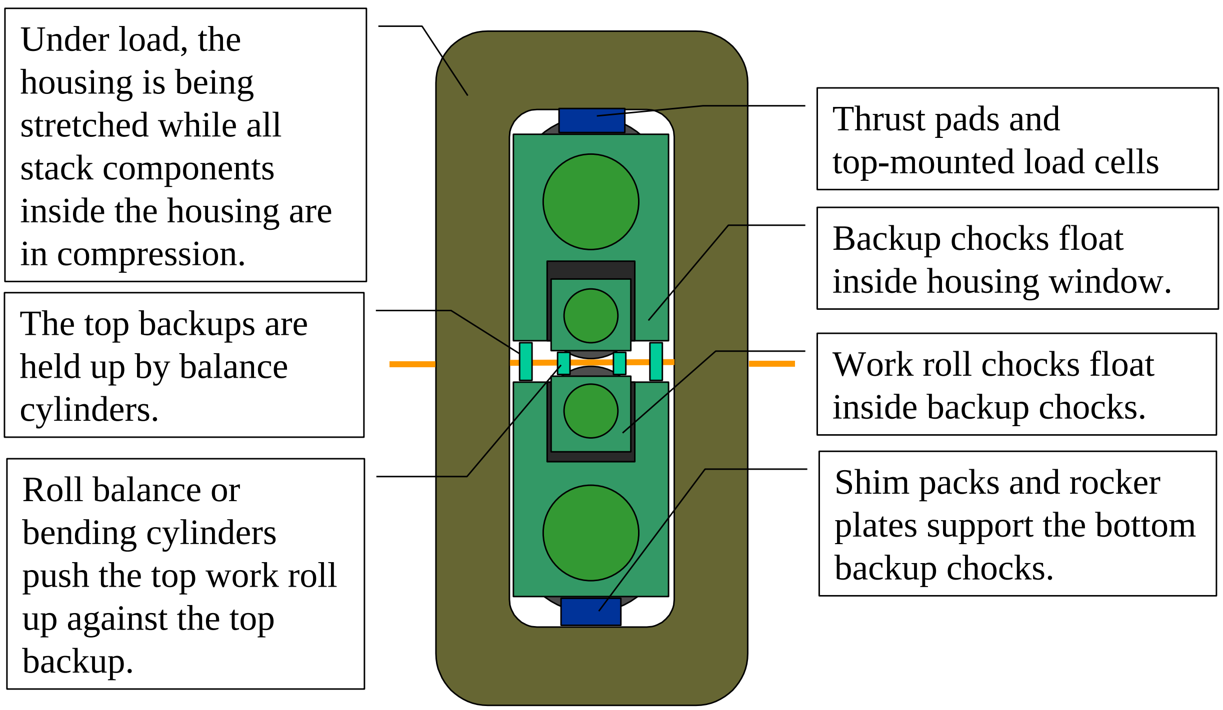
On the run out tables, strip cooling is more efficient if any water riding on the surface can be removed so that subsequent sprays directly cool the surface. Cooling sprays are designed to maximize surface contact for more efficient cooling.

Mill Stretch

- Housing stretches
- Roll stack components are compressed
- Calibration with typical rolling force
- Screw opening vs. loaded gap

The Mill Stand

Mill Housing and Roll Stack



"Crown-in" or "positive" roll bending has been installed on the last stand at AK Steel Butler Works HSM. The bending system pushes the work roll chocks apart with a controlled pressure. This effectively increases the stack crown and reduces the strip crown (or tends to correct edge wave).

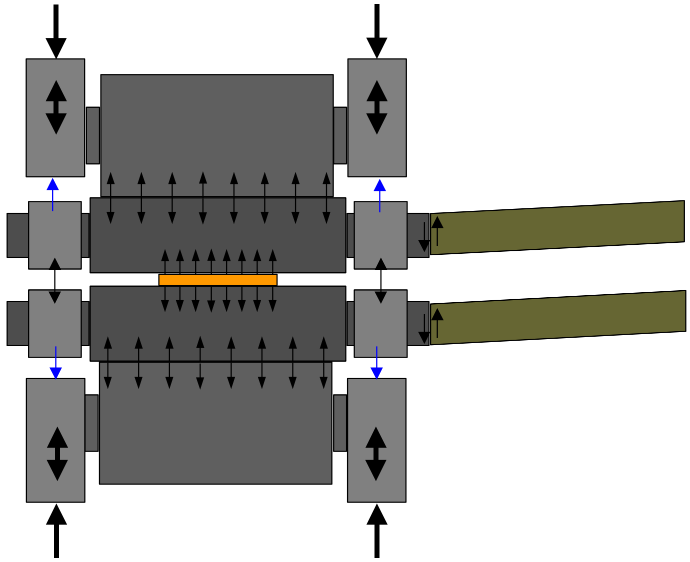
Note that the load cells will measure the sum of the strip force and the bending force. It is therefore important that both FM Setup and AGC take the roll bending force into consideration properly.

For this mill, the load cells are mounted in the top of the stack. Other mills have the load cells mounted under the stack. Top mounted load cells allow us to measure more of what is going on in the stack but tend to make gaugemeter AGC over-gained for small errors. This can be looked after by including a "deadband" in the control. AGC stability is easier to achieve with bottom mounted load cells but all force variations less than the friction force hysteresis deadband are hidden from us.

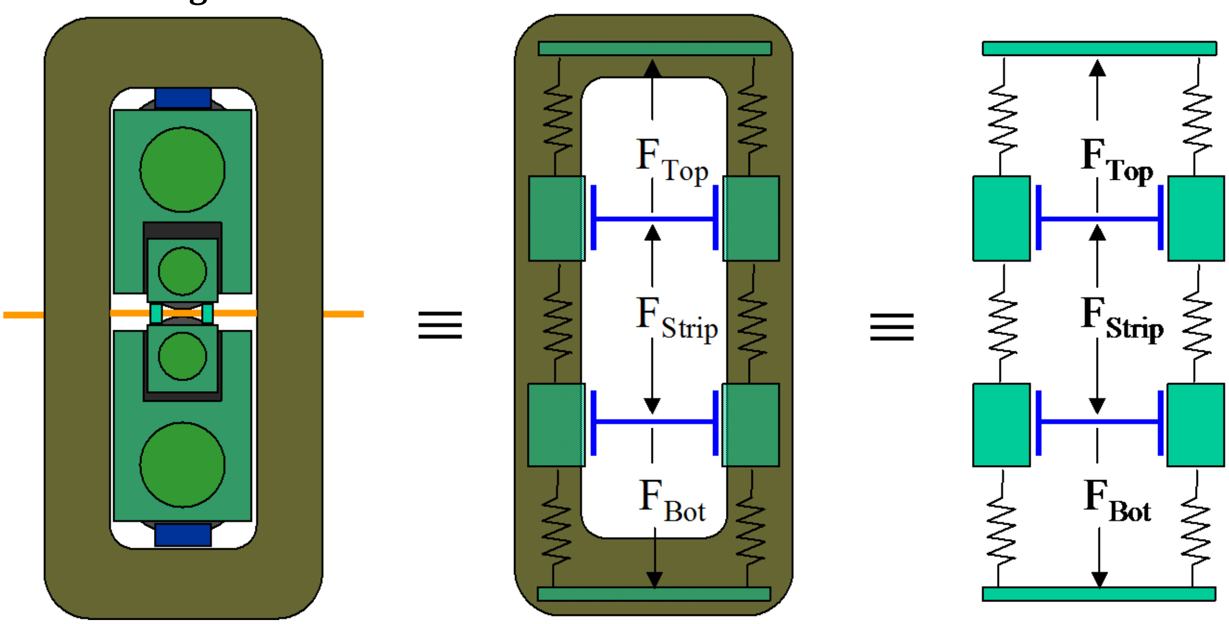
Roll Stack Force Paths (no friction)

With strip in the mill, the main force path is from the strip through the work roll barrels into the backups and then through the backup necks and bearings to the backup chocks and then into the housing in the top and bottom of the mill.

Roll balance supports the top of the stack when there is no strip in the mill.



Mill Housing Stretch Model

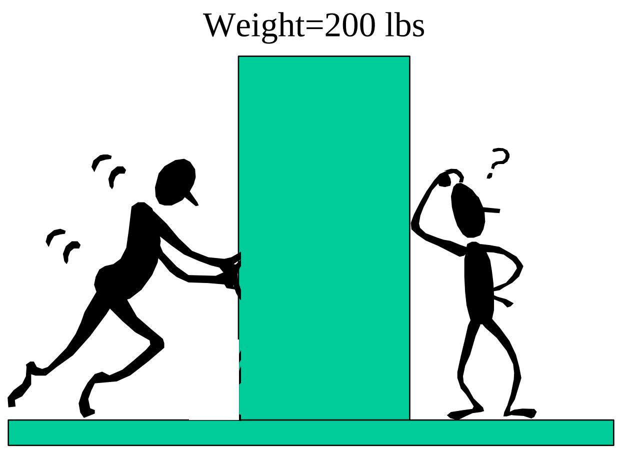


With force on the mill, roll stack components are compressed (including roll flattening) while the housing is stretched.

The roll stack and housing can be modeled as a system of springs with friction surfaces at the backup roll chock to housing liner interfaces. Force can be shunted at these surfaces so that the force seen at the load cell in the top of the stack is not the same as the force seen by the strip in the middle of the stack. If the roll gap is opening, then the strip force will be greater than the load cell force and if the roll gap is closing, then the strip force will be less than the load cell force. Top chock friction is more of a concern that bottom chock friction since the load cells and screwdowns are both on the top of the stack.

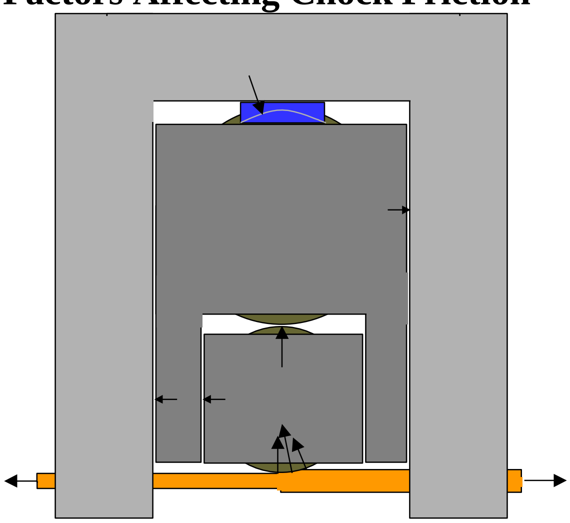
Hysteresis

- Hysteresis is an important consideration in rolling mills and control systems.
- Friction hysteresis results in us not being able to measure some small force changes.
- Consider two people pushing or pulling on a large box. The person on the right is trying to determine how hard the person on the left is pushing or pulling. In this example, the hysteresis is ±60 lbs of force.



Coefficient of Friction = 0.3
60 lbs force is required to move the box

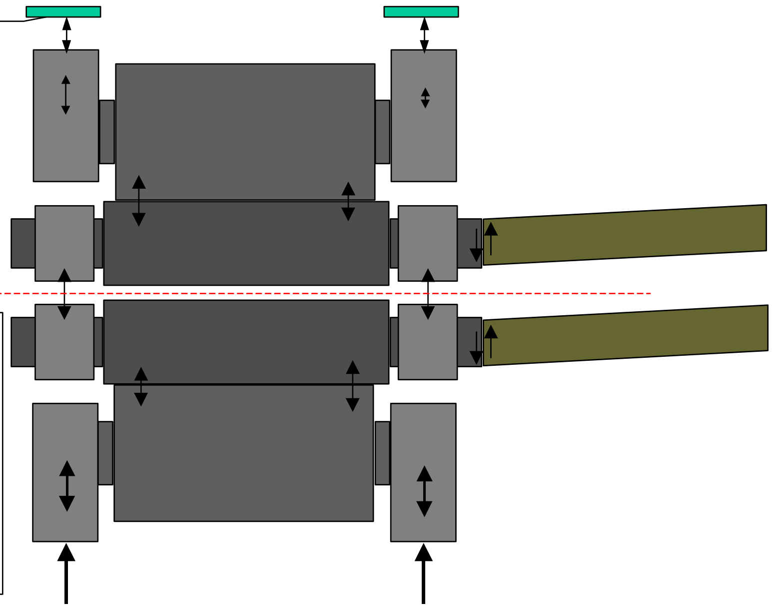
Factors Affecting Chock Friction



- Net horizontal or torsional force
  - Stack alignment
  - Breaker block alignment
  - Strip tension forces
  - Excessive clearances
- Inadequate clearances
  - Clearances decrease as force increases (hourglass effect)
  - Thermal effects
  - Excessive clamping
  - Work roll axial thrust
- Coefficient of friction
  - Chock/liner condition (scale and dirt, galling of liner surfaces, loose liners)
  - Lack of lubrication

Roll Stack with "Zero" Force (no strip)

The force at the top-mounted load cell is the sum of the work roll balance/bending and backup roll balance less the weights of the top roll assemblies and top spindle.

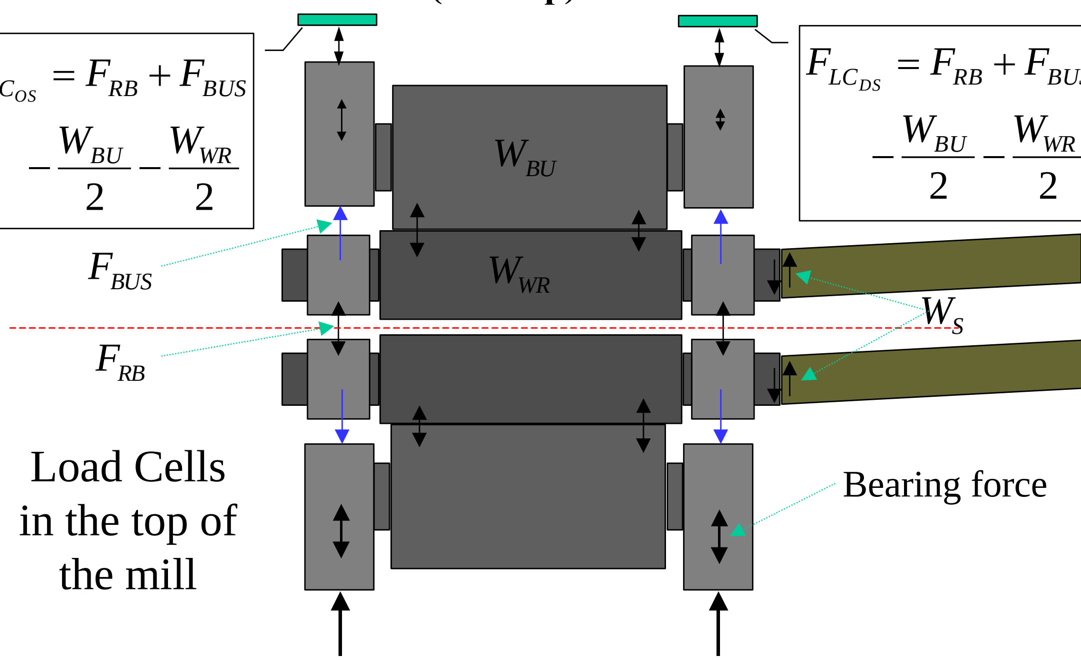


The load cell force should be zeroed out when the gap is open and the bending is off (at balance pressure). Top chock friction hysteresis will cause the zero force to drift depending on the direction of the last screw move.

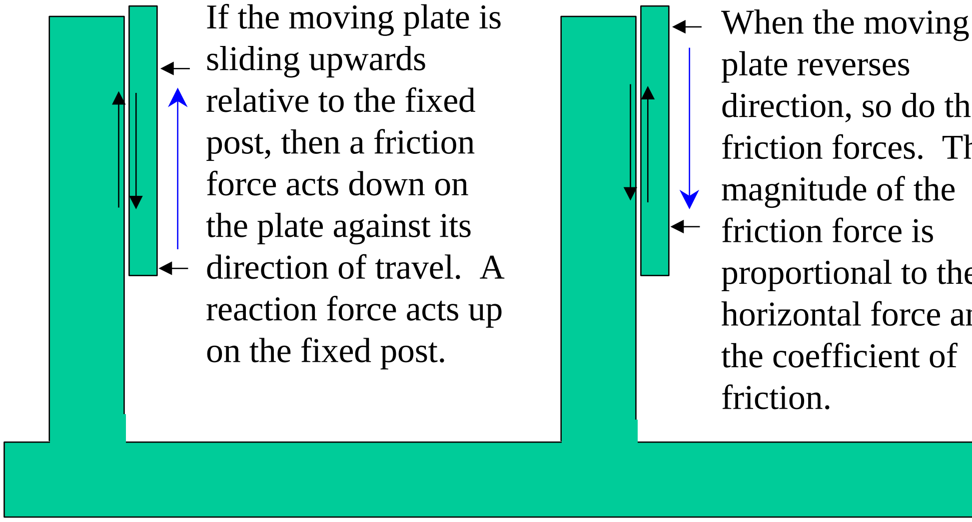
Roll Stack with "Zero" Force (no strip)

$$F_{LC_{OS}} = F_{RB} + F_{BUS} - \frac{W_{BU}}{2} - \frac{W_{WR}}{2}$$

$$F_{LC_{DS}} = F_{RB} + F_{BUS} - \frac{W_{BU}}{2} - \frac{W_{WR}}{2} - W_S$$



Effect of Friction on the Roll Stack

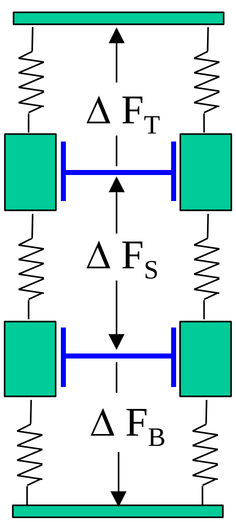


If the moving plate is sliding upwards relative to the fixed post, then a friction force acts down on the plate against its direction of travel. A reaction force acts up on the fixed post.

When the moving plate reverses direction, so do the friction forces. The magnitude of the friction force is proportional to the horizontal force and the coefficient of friction.

Mill Stretch Modeling

The change in mill stretch for a force change is given by:



$$\Delta S = \frac{\Delta F_T}{M_T} + \frac{\Delta F_S}{M_S} + \frac{\Delta F_B}{M_B}$$

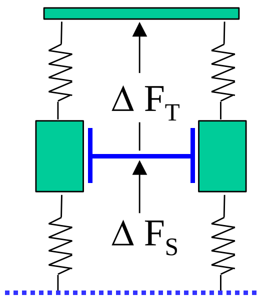
$$= \frac{\Delta F_S - \Delta F_{TC}}{M_T} + \frac{\Delta F_S}{M_S} + \frac{\Delta F_S - \Delta F_{BC}}{M_B}$$

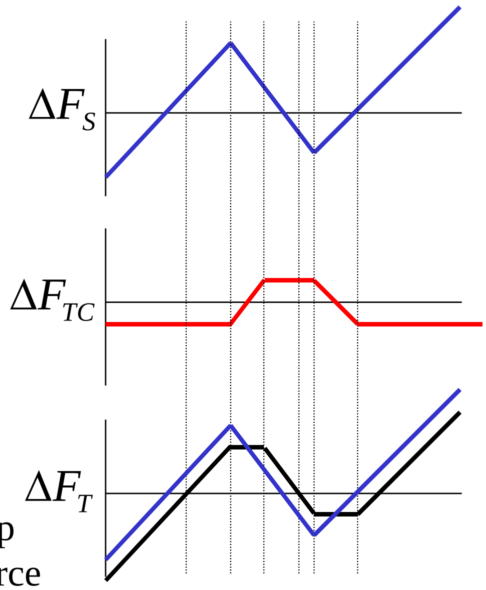
If there is no chock friction, then:

$$\Delta S = \Delta F_S \left(\frac{1}{M_T} + \frac{1}{M_S} + \frac{1}{M_B} \right)$$

$$= \frac{\Delta F_S}{M}$$ This is the gaugemeter assumption.

Effect of Backup Chock Friction



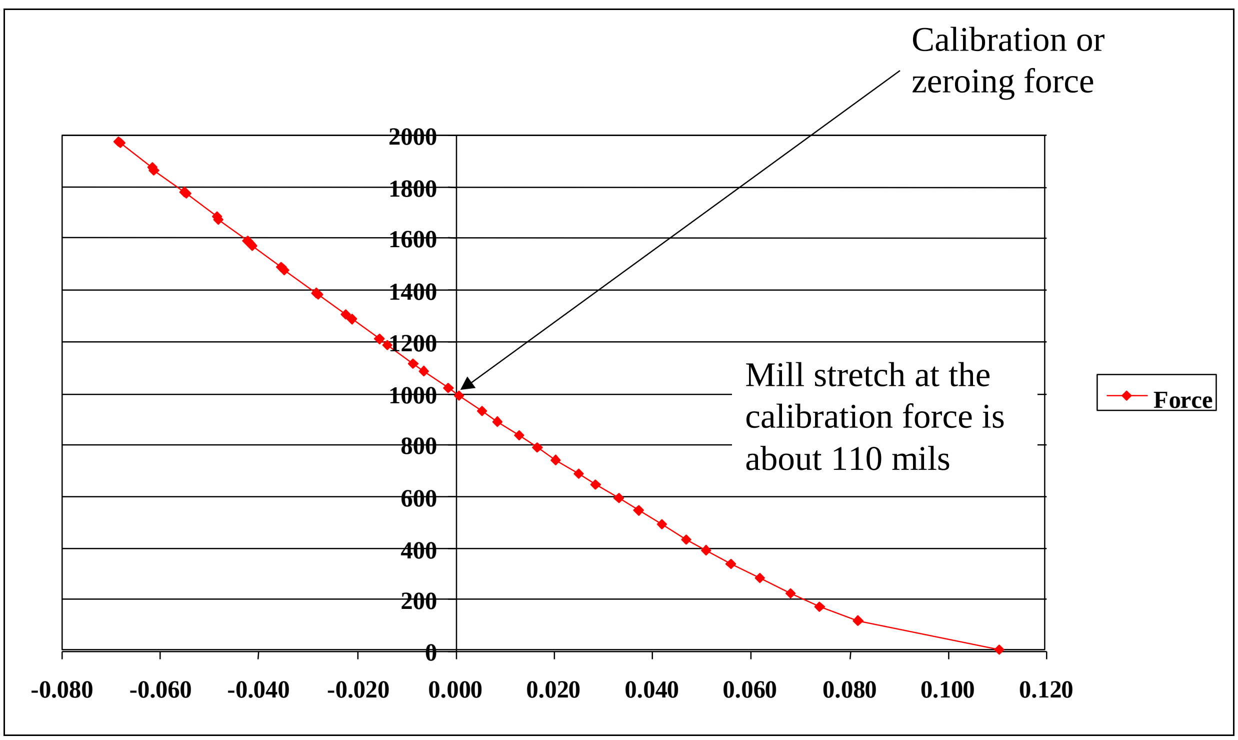


Note the offsets between the strip force and the force in the top of the stack.

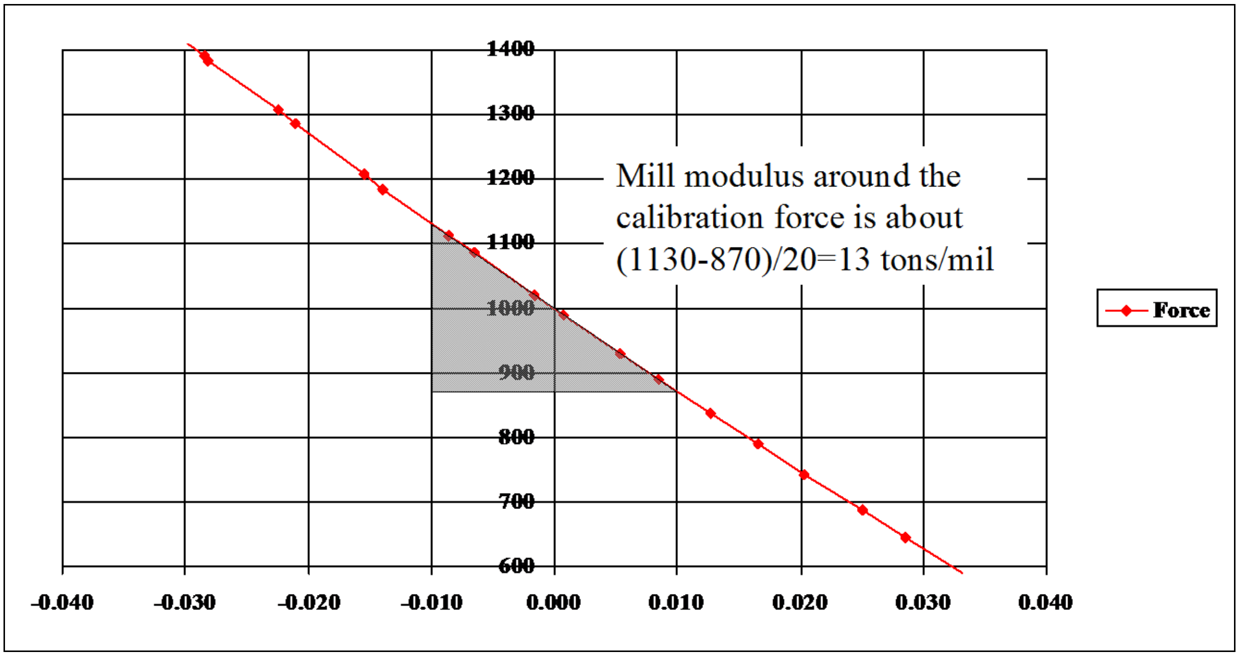
$$\Delta F_S = \Delta F_T - \Delta F_{TC}$$

- Suppose that the strip force is varying as shown here.
- As the strip force increases, the chock force will be negative.
- When the strip force starts to decrease, the chock friction must be overcome first before any change is detected at the load cell.
- This effectively “hides” a portion of any strip force change from the load cells when the change in strip force changes directions.

Mill Stretch

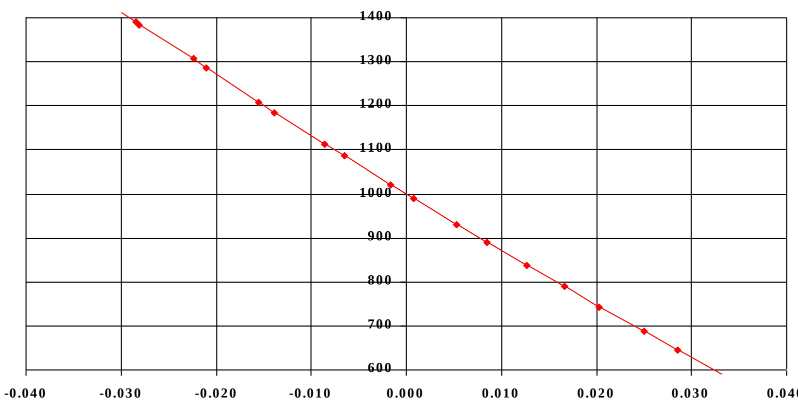


Mill Modulus Around the Calibration Force



Mill Modulus - Gaugemeter Calculation

Suppose the mill is rolling 0.100" material at a force of 1000 tons. If the force then increases to 1026 tons with no gap adjustment, what is the strip thickness?



Mill modulus=13 tons/mil

$$\Delta H = \Delta S + \frac{\Delta F}{M}$$

$$= 0 + \frac{26}{13}$$

$$= 2$$

The strip thickness will increase to 0.102"

$\Delta H =$ Thickness change

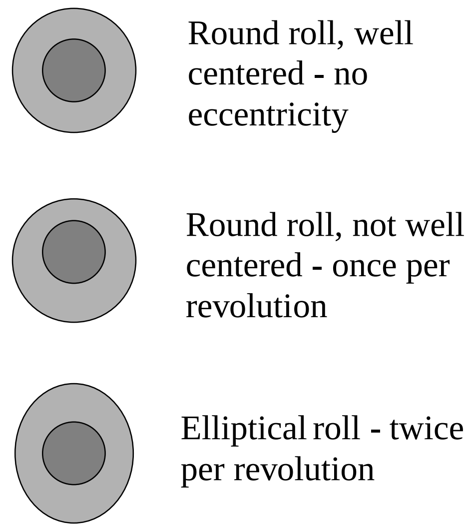
$\Delta S =$ Screw change

$\Delta F =$ Force change

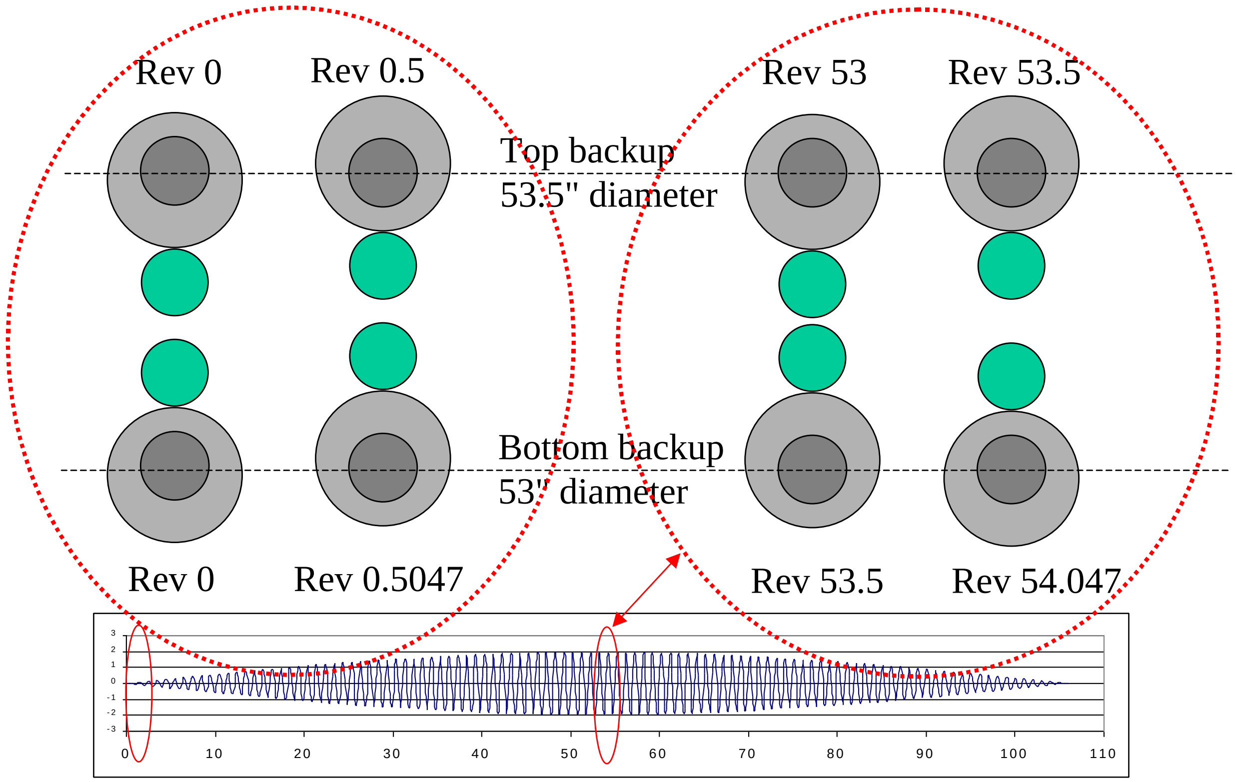
$M =$ Mill modulus

Roll Eccentricity

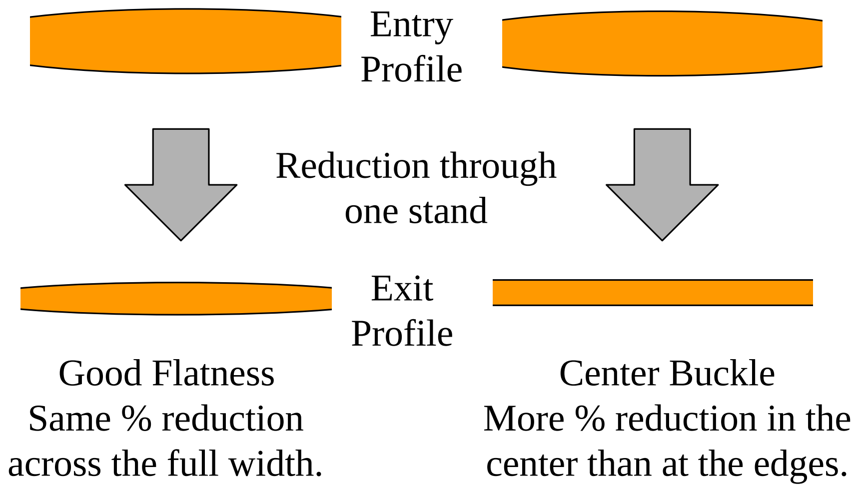
- Roll eccentricity is present when a roll is not perfectly round, or if the axis of rotation is not in the center of the roll.
- When this roll is used in the mill, the eccentricity will cause the gap to open and close. Variations in roll force and strip thickness will result.
- The rotational speed of the roll and the nature of the eccentricity will determine the frequency of the force disturbance.

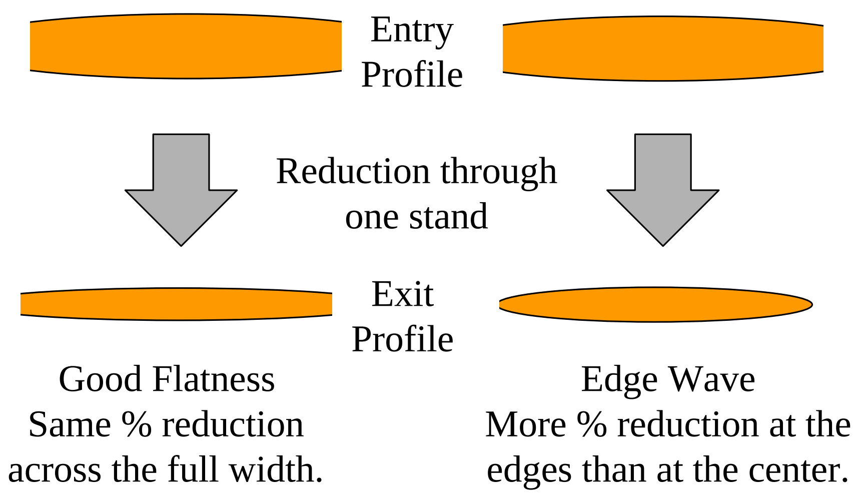


Roll Eccentricity Beat Frequency

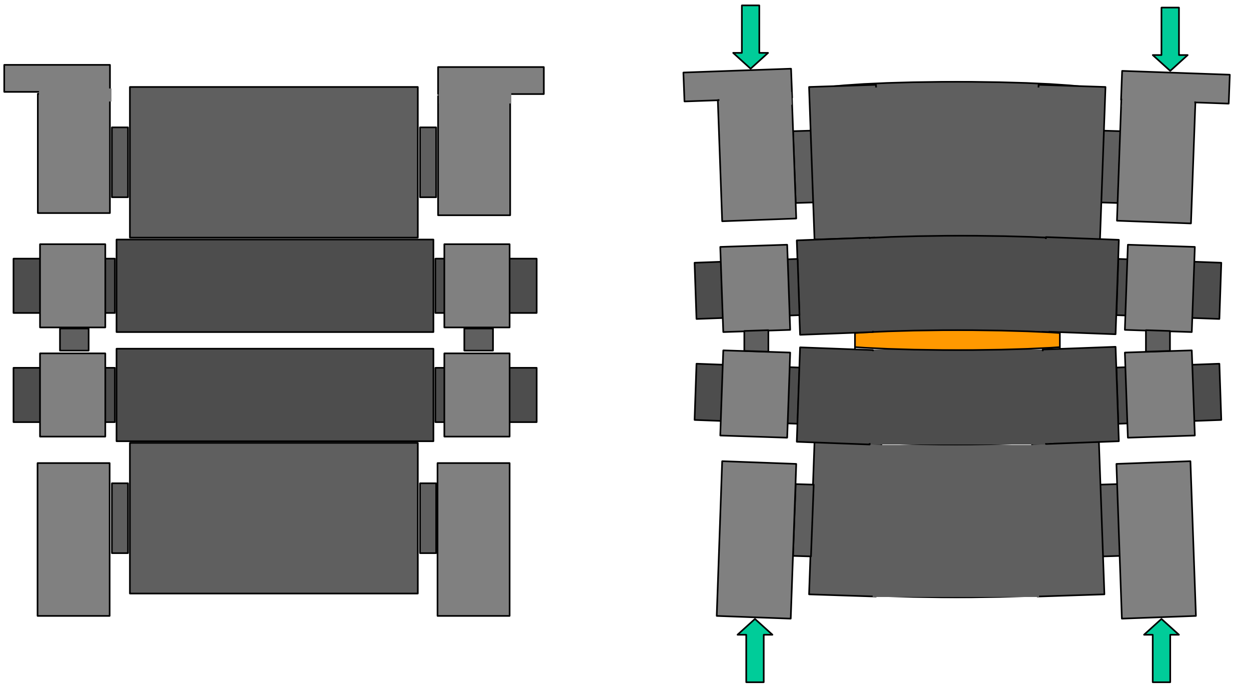


Profile and Flatness



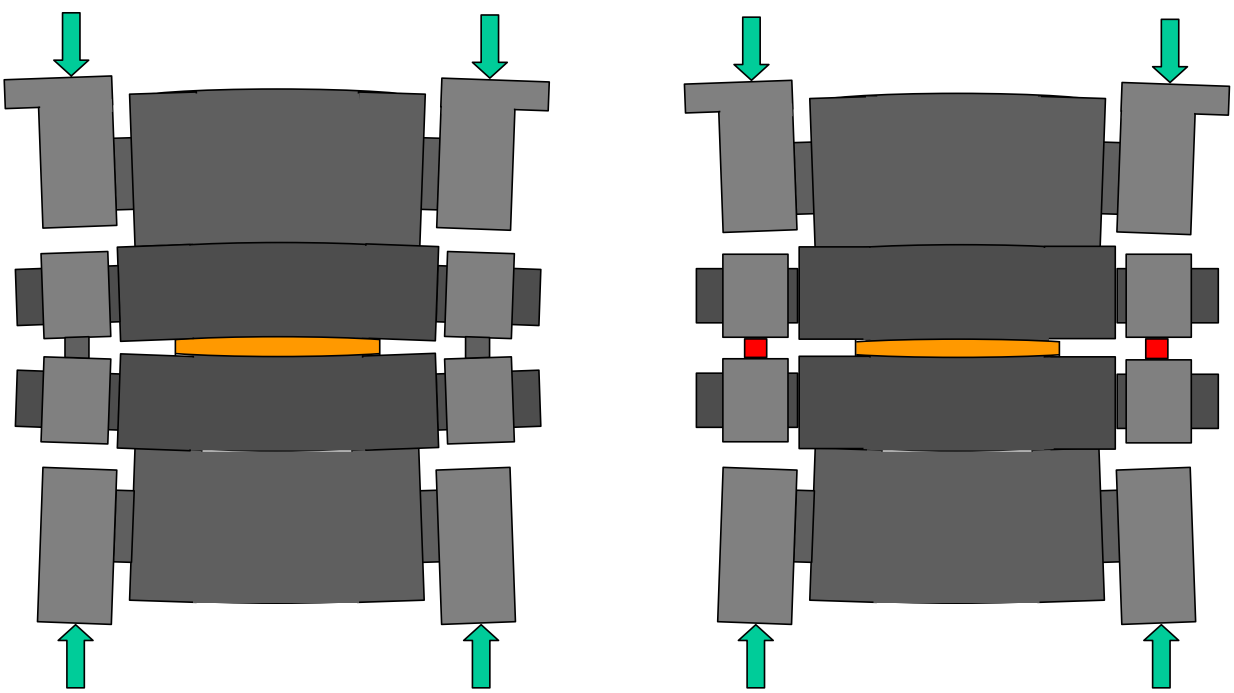


Effect of Rolling Load on the Stack Profile



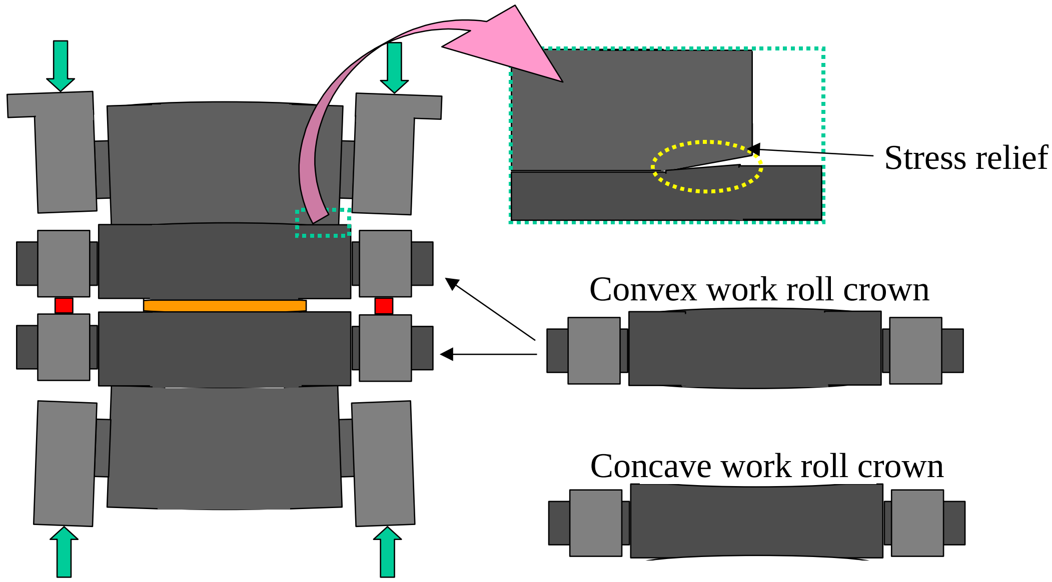
Strip force causes the roll stack to bend around the strip.
Increases in strip force result in increases in strip crown.

Positive or "Crown-in" Bending



Bending cylinders between the work roll chocks push the ends
of the work rolls apart and reducing strip crown.

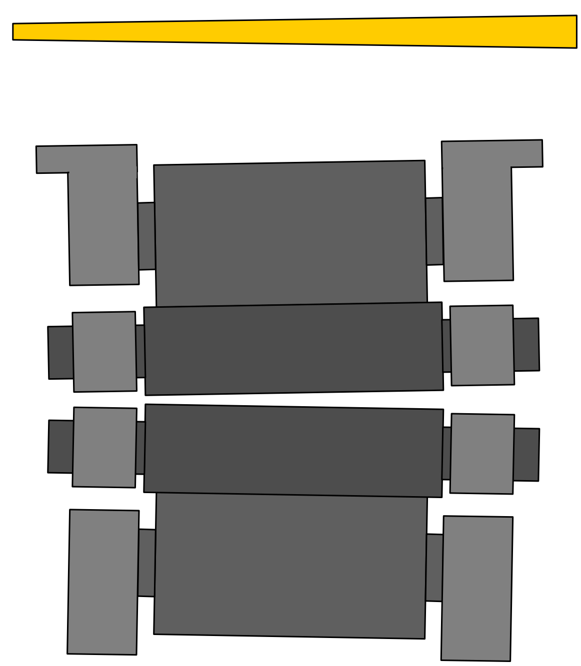
Roll Grind Profiles



Work roll crowns are ground to produce the desired strip crown under load. Backup roll chamfers relieve pressure at the roll shoulder.

Wedge and Camber

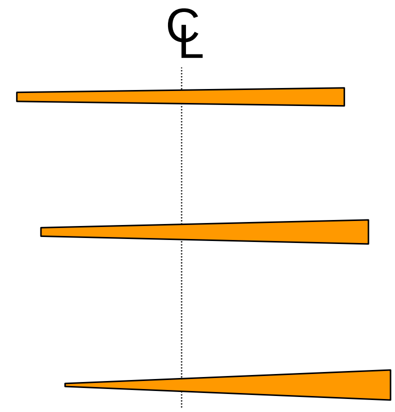
- A strip is wedged when one side of the strip is heavier than the other.
- A roll bite is wedged when the gap opening is larger on one side than the other.
- Strip camber is the term used to refer to head or tail end hook resulting from one side of the strip being longer than the other.



Wedged Roll Gap Profile

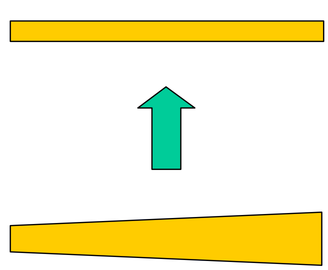
- If the roll gap profile is wedged, then the strip will tend to be pushed to the open side of the wedge.
- As the strip moves, the roll gap is pushed open further on the drive side. The wedge gets worse and the strip is pushed harder to the open side.
- This tendency is worse with low or negative strip crowns.
- Running the sideguides close to the strip helps control the shifting.

Strip shifting to the right:

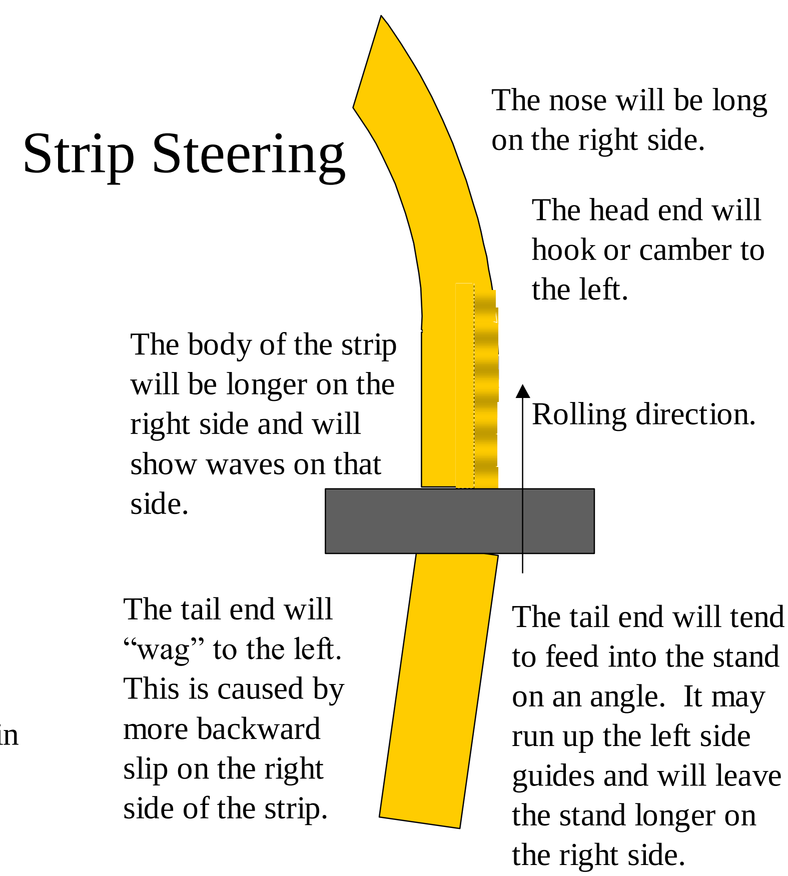


If the guides can stop the strip shifting before the sideways force is high enough to cause the strip to turn over on the guides, then the strip will not scrap.

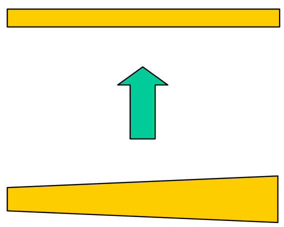
Strip Steering



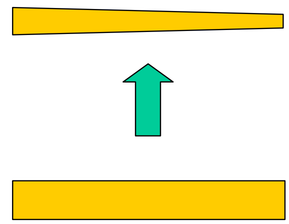
With more reduction on the right side of the strip, the strip will behave as shown in the view to the right.



Strip Steering – Changes in Wedge



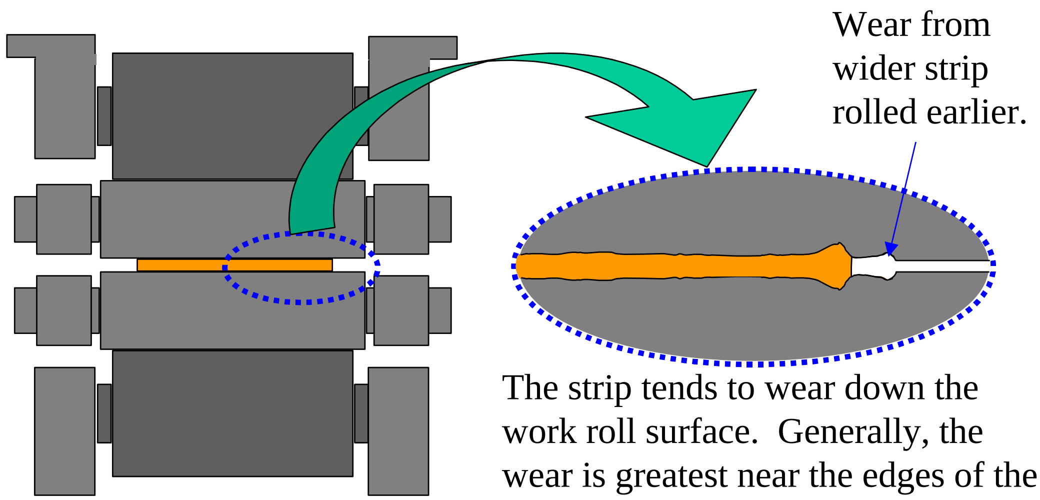
As far as strip steering is concerned, the profile change on the left will behave like the profile change on the right. Both will camber to the left with a long edge on the right side.



Mill Leveling - What Actually Happens

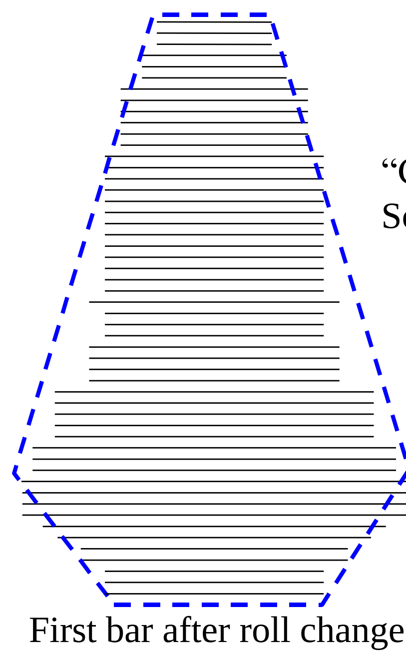
- Screwdown control is moved off-center.
- Initially, this causes the clutch to open between the two sides of the mill.
- Once the clutch is open, the screws start to run in opposite directions if the screwdown control is held off-center.
- If the mill is loaded, the screws will build up current and then “break away”. It is difficult to make a small change.
- There is some delay between the screw moving and the differential gap feedback being seen on the MMI.
- This interface makes it rather difficult to make fine adjustments to the mill level.
- You have to get a feel for how long to hold the control to open the clutch. Too short a time, and nothing happens. Too long and the correction is more than desired.

Roll Stack Wear



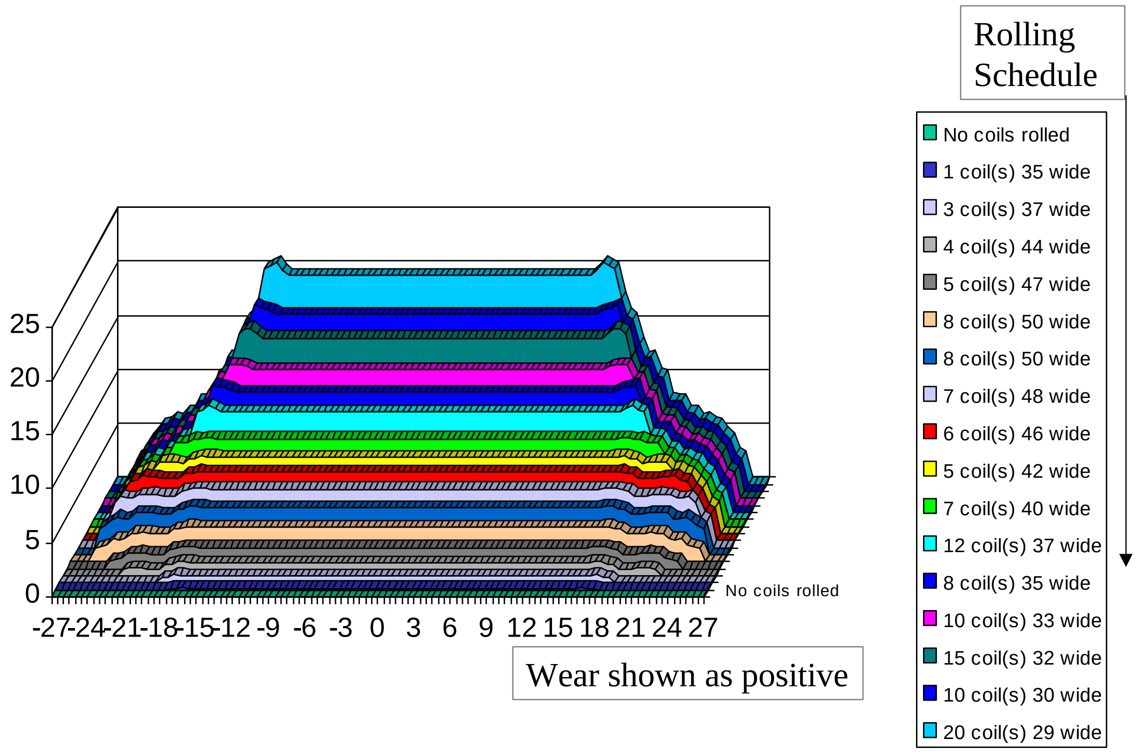
The strip tends to wear down the work roll surface. Generally, the wear is greatest near the edges of the strip. The work roll wear also affects the distribution of roll force across the work roll to backup roll interface.

- A “Coffin” schedule is used so that the worn work roll surface presented to the strip does not have too much wear profile.
- After a roll change, a few medium width coils are rolled so that the mill level can be adjusted.
- The width is then increased in a few more coils out to the maximum for the schedule.
- For the balance of the schedule the width is gradually reduced.



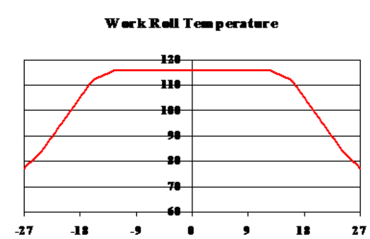
“Guttering” occurs at the strip edges when the strip shifts sideways onto a section of the work rolls with less wear.

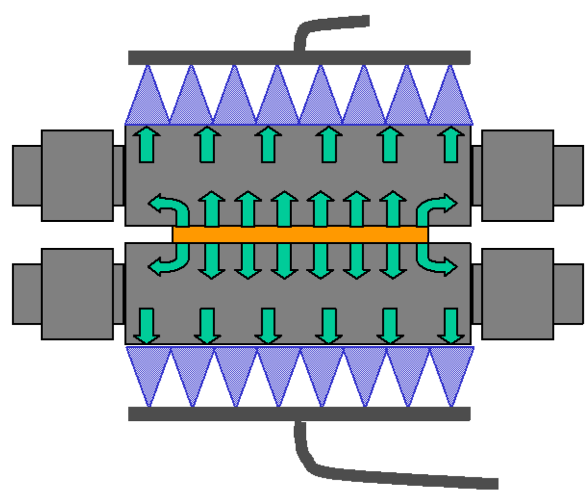
Roll Stack Wear (3D Plot)



Roll Stack Thermal Expansion

- Normally, heat flows into the work rolls from the hot strip.
- In the body of the roll, it flows towards the roll necks.
- Roll cooling removes heat from across the full face of the rolls.
- The heat causes the rolls to expand, increasing their effective crown.
- Roll expansion is approximately 0.001" for every 8°F





Roll Wear and Thermal Expansion

- Roll wear and thermal expansion work against each other. Wear makes the rolls smaller, thermal expansion makes the rolls larger.
- To look at the combined effects, we will think of the roll wear as being negative.

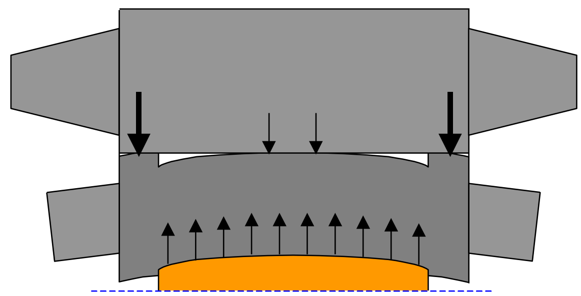
Gap = Gap setting
+ Stretch
- 2 x Work Roll Effects
- Backup Roll Effects

where

Roll effects = Thermal Expansion
- Wear

Effect of Work Roll to Backup Roll Interface

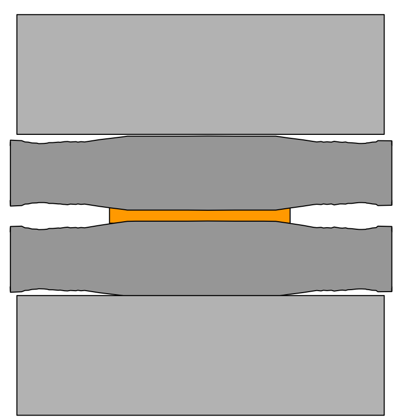
- As the work roll crown changes due to wear and thermal expansion, the force distribution at the work roll to backup roll interface changes.
- This causes the work roll to bend against the backup and results in a change to the roll crown presented to the strip.
- The schematic to the right shows the effect of worn work rolls, the true effect is much more subtle.



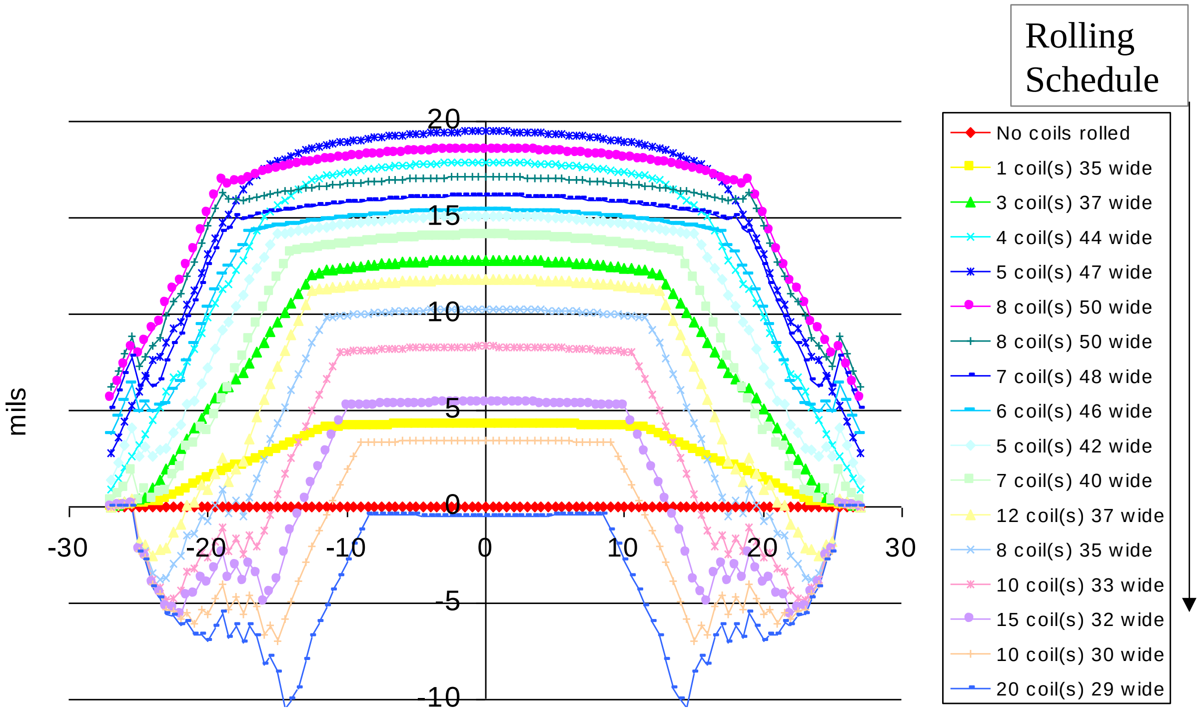
The downward force at the edges of the work roll combined with the upward force across the center of the work roll cause the work roll to bend into the backup.

Putting it all Together

- If we combine the simulated wear, thermal expansion and backup effects, we get a composite picture of the roll profile presented to the strip.
- Remember that the original roll grind profile and the bending of the roll stack under load will also influence the final profile presented to the strip.
- Also remember that the strip is not affected by the roll stack profile outside its edges.



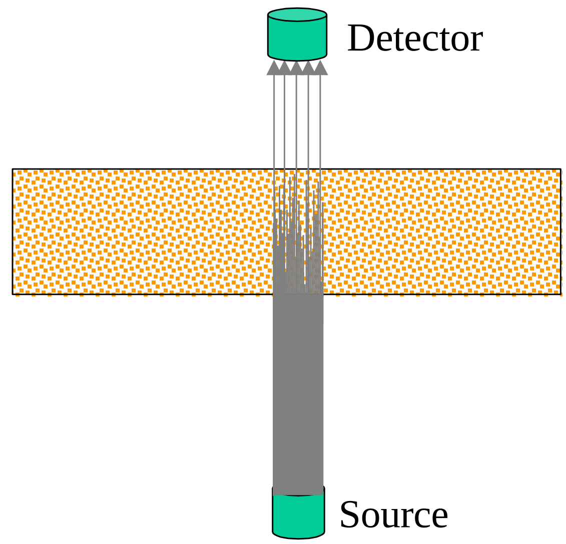
Roll Stack Thermal & Wear – History View

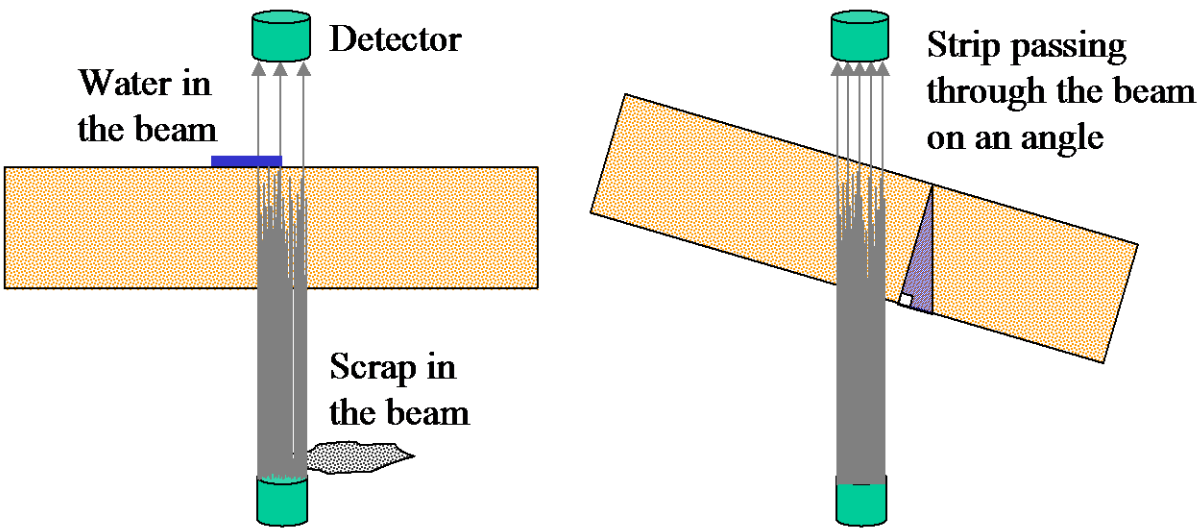


Mill Sensors

X-ray Thickness Measurement

- An X-ray detector measures the X-ray energy which is not absorbed by the strip.
- The transmitted energy will be affected by the thickness of the strip as well as its composition and temperature.
- A thickness target, alloy compensation and temperature compensation are all required to set up the X-ray.
- A magazine of standards is used to calibrate the X-ray between coils.

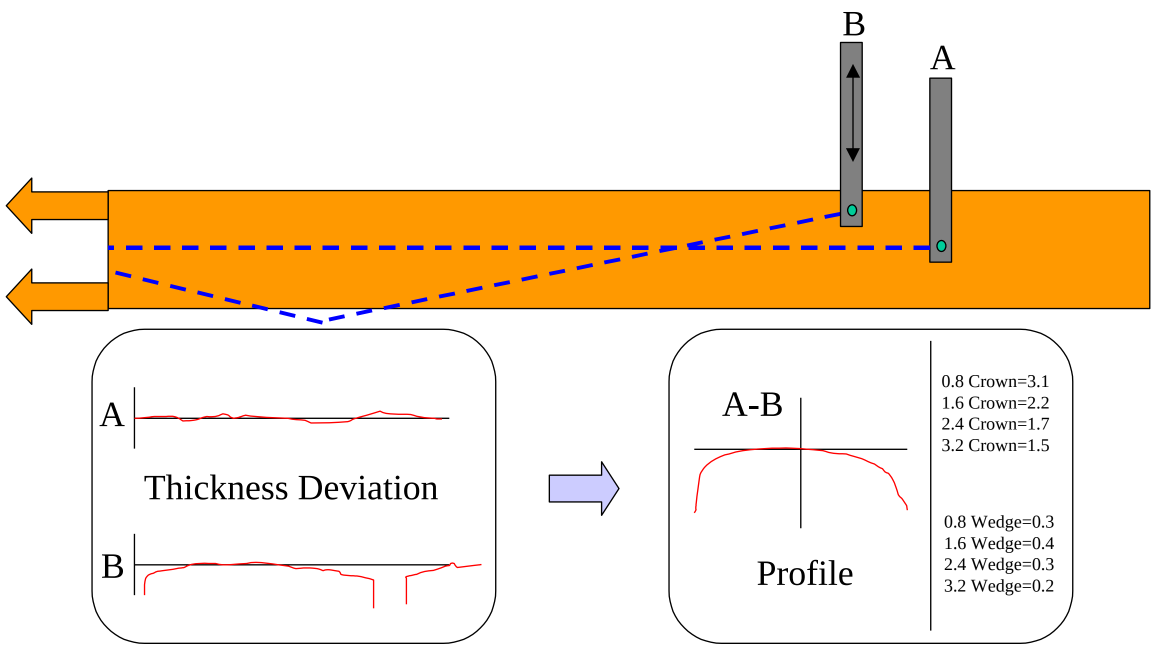




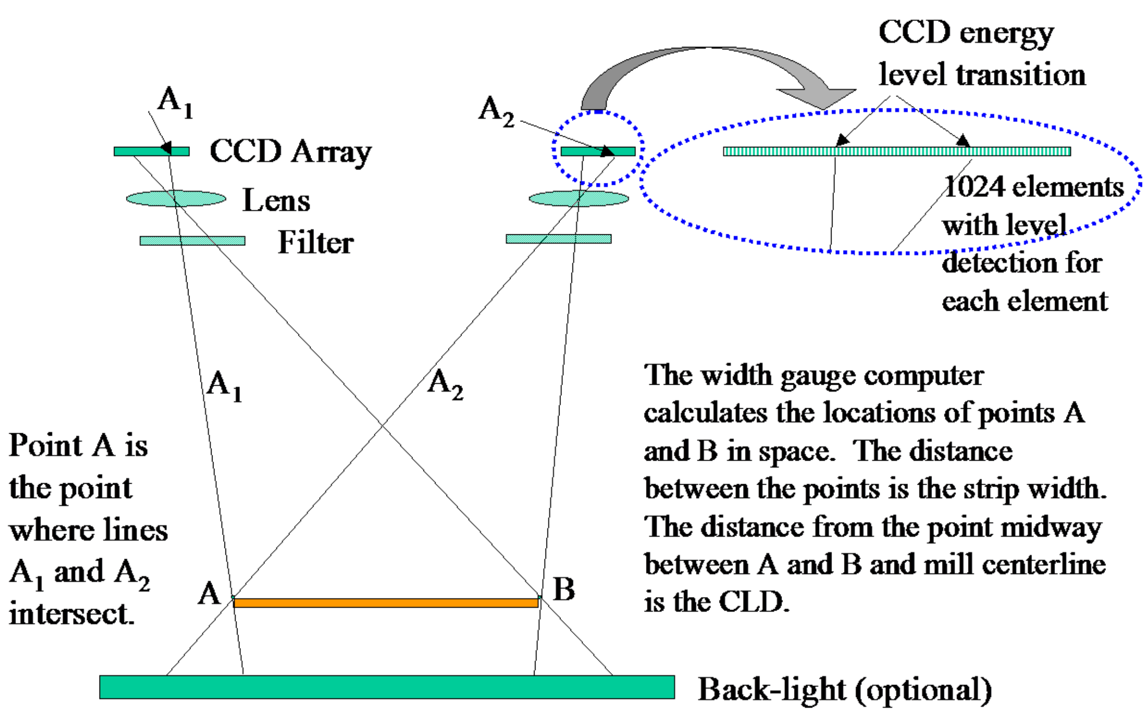
All make the strip appear to be thicker.

X-ray Profile Measurement

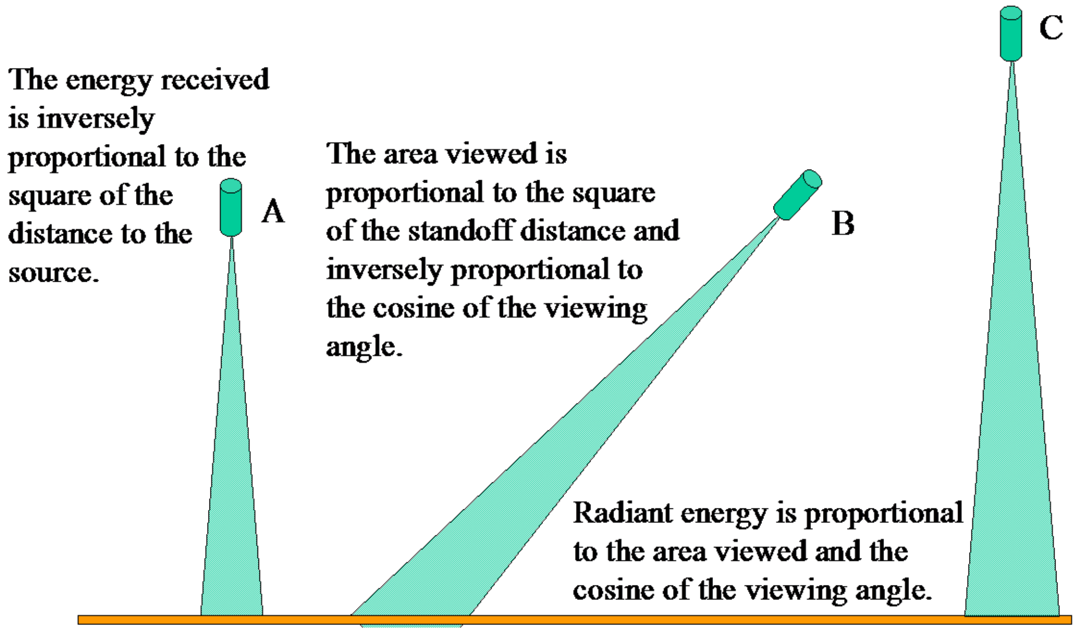
The profile computer uses the difference between the fixed and profiling gauges to construct the strip profile. It also calculates the crown and wedge at selected distances from the strip edge.



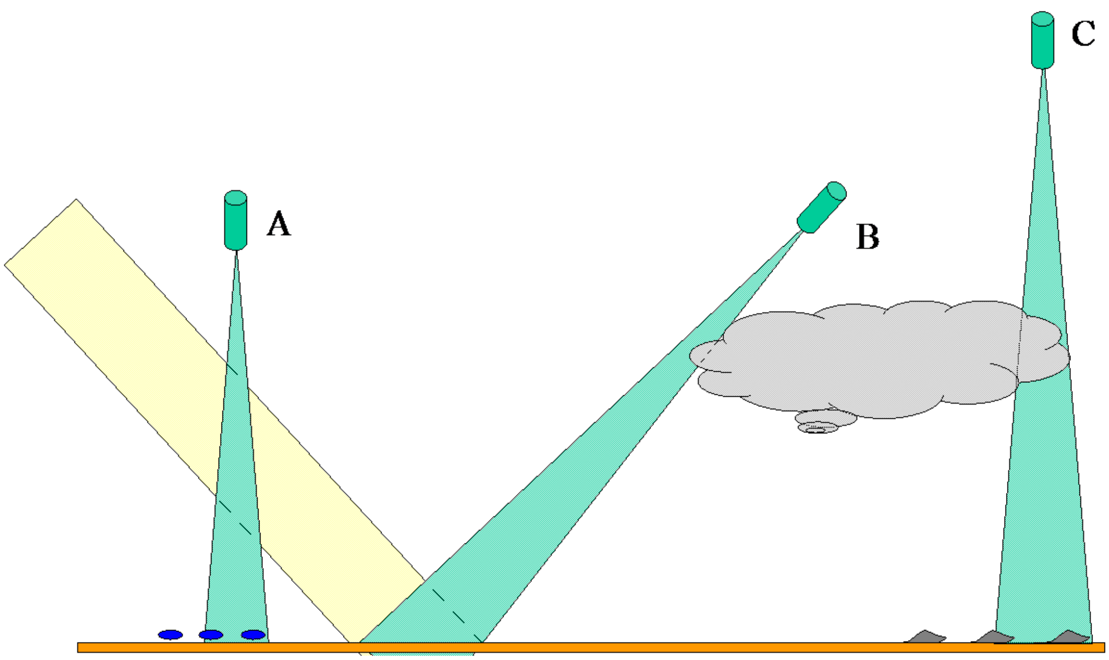
Width and CLD Measurement



Infrared Pyrometers



All three pyrometers receive the same amount of radiant energy even though the areas viewed are different (assuming that the strip temperature is uniform).



Water on the strip, steam or dust, reflected light, loose scale or other debris or obstructions all affect the amount of radiant energy seen by the pyrometer.

Hot Metal Detectors

Hot metal detectors work on the same principles as pyrometers. They are designed to sense the radiant energy emitted from the hot steel and turn on when that energy exceeds a threshold.

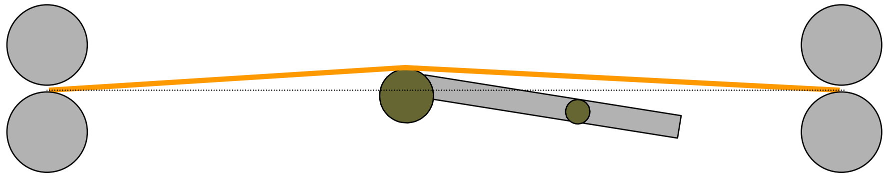
Load Cells

Load cells are designed to produce an electrical signal proportional to the applied force. They must be tough to withstand the very high applied forces without damage. Good load cell designs will result in force readings which do not vary much as the force distribution on the load cell shifts. Load cells are usually installed either in the top or the bottom of the roll stack. When they are placed next to the screwdown, we can get more useful information from the load cells (more interesting mill modulus test results). If they are mounted in the bottom of the roll stack, it is easier to avoid AGC stability problems.

Loopers

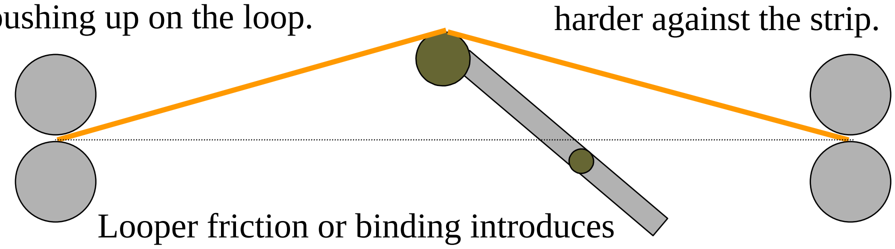
- Loopers are actuators used to support the strip between stands and regulate strip tension through applied torque.
- They are also sensors used to measure mass flow errors and strip tension.
- The vertical force applied by the looper to the strip is generated by electric torque motors designed to run continuously in a stalled condition. On other mills, the applied torque may be supplied by hydraulic or pneumatic systems.
- A good looper design has low inertia so that it can track strip movement well without producing large strip tension transients. It should also have low friction to minimize the hysteresis in the tension measurement and regulation control loop.

Looper Geometry



A looper supports the strip, its own unbalance weight and then makes strip tension by pushing up on the loop.

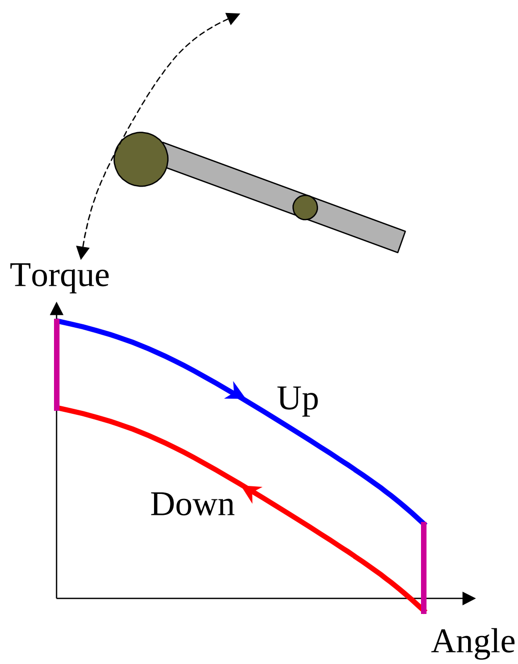
To maintain a given strip tension level with a high loop, the looper must push harder against the strip.



Looper friction or binding introduces hysteresis in the tension control. The effect is greater at low angles.

Looper Friction - The Unbalance Test

- The looper unbalance test provides a measure of the looper motor current (torque) as a function of looper angle as the looper is slowly raised and lowered.
- The average of the up and down torques at each angle is the torque required to support the looper arm.
- The difference between the up and down torques is a direct measure of twice the looper friction.

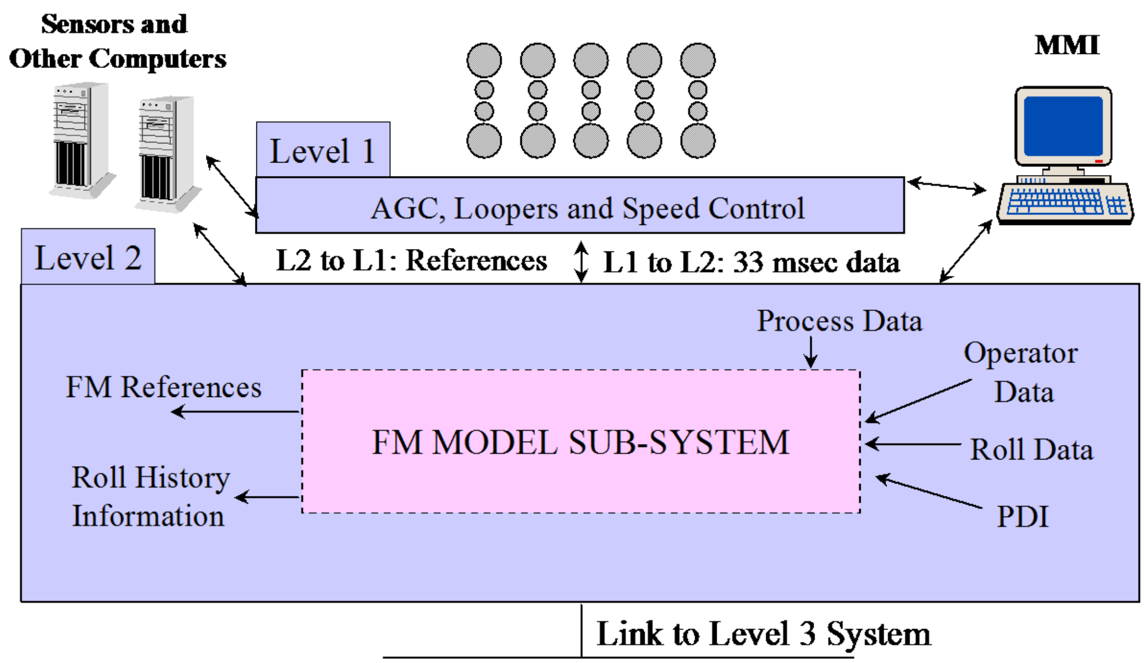


FM Model Functionality

Topics to be covered:

- Setup model objectives including what the model does not do.
- Understanding the setup calculations
- Mill limits and alternate thickness
- Feedforward Setup Revision
- FM Model Adaption
- Analysis and model tuning

FM Model System View



Fishing for an Example of an Adaptive Setup Model

As an example of a setup model with adaption, consider casting a fishing lure on a windy day. You decide where you would like the lure to go (your target). Then taking into consideration all of:

- the characteristics of your rod, reel and line
- the weight and size of the lure
- current wind direction and velocity

you cast the lure. How you do this is the result of an estimate based on your internal model (experience) and current conditions. You have made a setup prediction and then used your body to make the cast.

After the cast, you measure your error and update or adapt your setup model. You may adjust your casting model for the effect of the wind or the length of the cast. You are gaining experience or learning. As a novice you will tend to have large misses and will be making fairly large corrections as you learn. However, once your model is well tuned, the corrections required will tend to be small.

FM Model Objectives

- Achieve the FM exit head-end target thickness.
- Achieve the FM exit head-end target temperature (if selected).
- Distribute draft in the FM in a sensible way avoiding mill limits.
- Set up for balanced massflow during threading.
- Provide Level 1 control with parameters so that the setup targets can be maintained through-out the coil length.

What the Model Does Not Do

- Profile or flatness control
- Strip steering
- Any in-bar control

FM Model Inputs and Outputs

INPUTS

- PDI
- Roll stack information
- Operator inputs
- Measured mill data (force, temperature, speed, etc.)

OUTPUTS

- FM gap and speed references
- Looper angle and strip tension references
- Sideguide references
- FM sensor references
- Product dependent gains and mode selections for Level 1 control

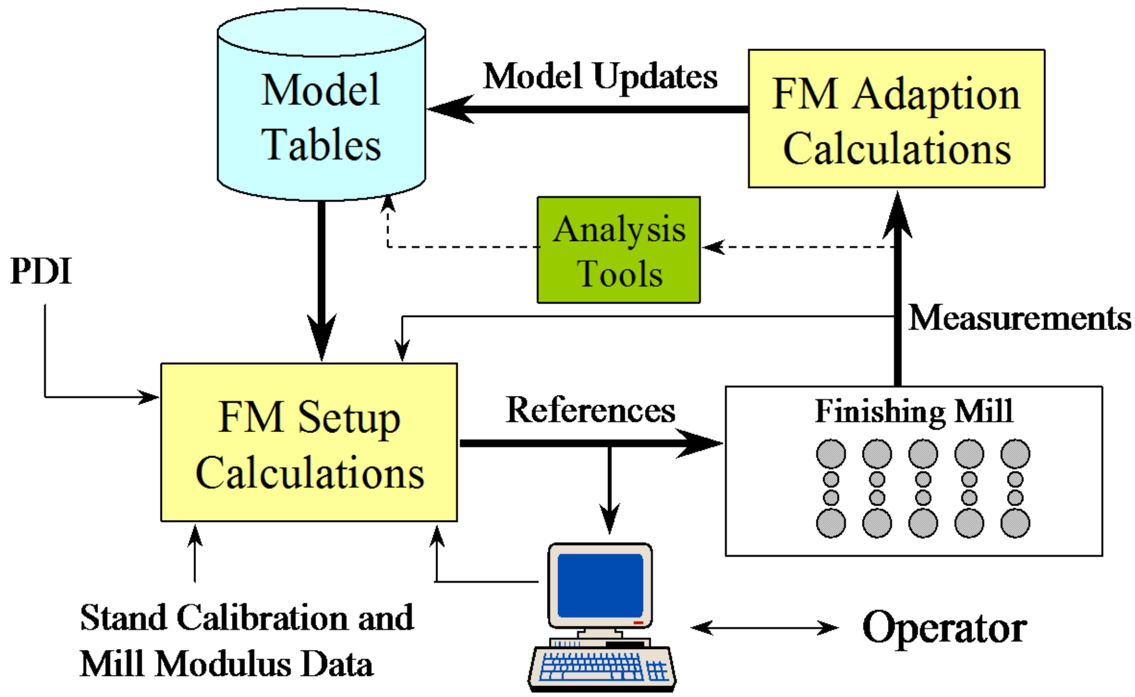
FM Model Outputs – More Detail

FM gap and speed references	⇒	These are setpoints for the screwdown position regulators and main drive speed regulators. Lead speeds also sent.
Looper angle and strip tension references	⇒	These are setpoints for the loop height control and the looper torque control. The tension calculation needs strip weight
Sideguide references	⇒	These are setpoints excluding short stroke.
FM sensor references	⇒	Xray thickness and grade, width gauge target width.
Product dependent gains and mode selections for Level 1 control	⇒	Certain AGC gains, mode selections and offsets (e.g., absolute/relative mode, nose offsets).

Rolling Theory Implementation

- Develop an equation (Model) that describes the process (efficient, yet reasonably accurate)
- Include model parameters which can be adjusted to make the equation agree with the measured data
- Store some of the parameters in product dependent Model Tables to remember product dependent model errors
- To adapt the model, calculate the model parameter from measured mill data by inverting the equation
- Use a simple gain to update the model parameter for the next setup calculation

The Setup and Adaption Cycle



Model Tables

Product Based Model Tables

- tables for each melt grade containing the grade constants and the grade hardness
- tables for each melt grade family and thickness range containing product related adaptors such as the stand yield stress multipliers
- tables for each standard practice group and thickness range containing setup information (load distribution, sideguide setup parameters, etc) and learned practice data (transfer bar thickness)

Mill Based Model Tables

- global adaptor table containing stand gaugemeter offsets and thread speed adaptors
- roll adaptor table containing roll wear and thermal expansion

Model Tables Breakout for AK Steel – Butler Works HSM

Melt Grade Families

- Low Carbon
- CRNO
- RGO
- TCH
- Ferritics
- High Temp Chrome
- Martensitic
- Alloy
- PH
- HiTmp 180
- HiTmp Ferritic

Standard Practice Groups

- Low Carbon
- CRNO
- RGO
- TCH
- Ferritics
- High Temp Chrome
- Martensitic
- Alloy
- High Temp CrNi
- PH-2150
- PH-2250 (A)
- PH-2250 (B)
- HiTmp 180
- ThinBar Ferritics
- ThinBar Martensitic
- HiTmp Ferritic

Thickness Ranges

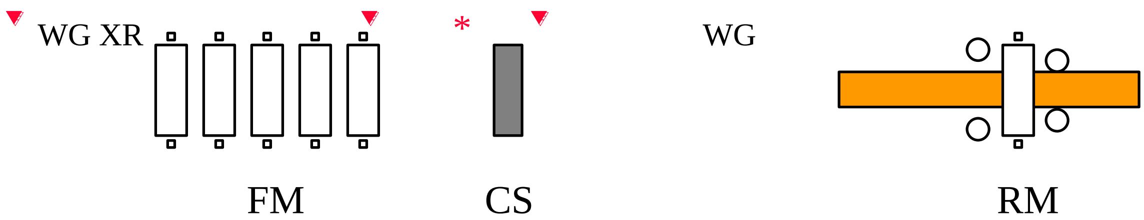
Twelve thickness ranges based on the PDI target thickness excluding any offsets:

- Range 1: up to 054 gauge
- Range 2: 055 to 064 gauge
- Range 3: 065 to 074 gauge
- Range 4: 075 to 084 gauge
- Range 5: 085 to 094 gauge
- Range 6: 095 to 109 gauge
- Range 7: 110 to 129 gauge
- Range 8: 130 to 154 gauge
- Range 9: 155 to 184 gauge
- Range 10: 184 to 224 gauge
- Range 11: 225 to 274 gauge
- Range 12: 275 to 400 gauge

New Piece from Slab Tracking

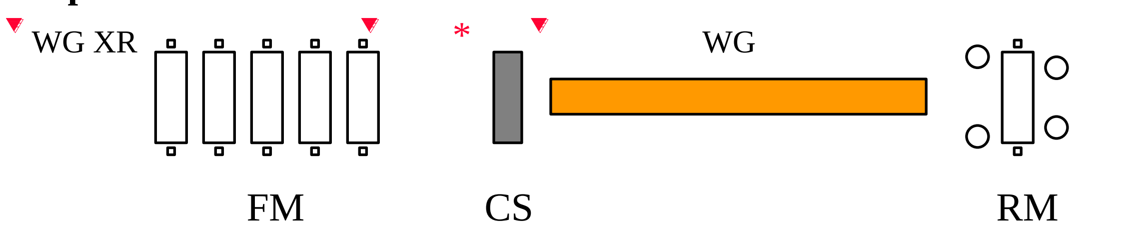
- Piece tracking is performed by the Slab Tracking computer.
- The next 5 pieces to be rolled and their locations are sent to the Level 2 computer.
- When Level 2 detects a new piece, the PDI is loaded into a coil data structure and a setup calculation is requested.
- Learned standard practice values are used for the transfer bar dimensions and temperature.
- The setup calculation is updated when the operator makes a change or when FM adaption completes.

Roughing Mill Exit



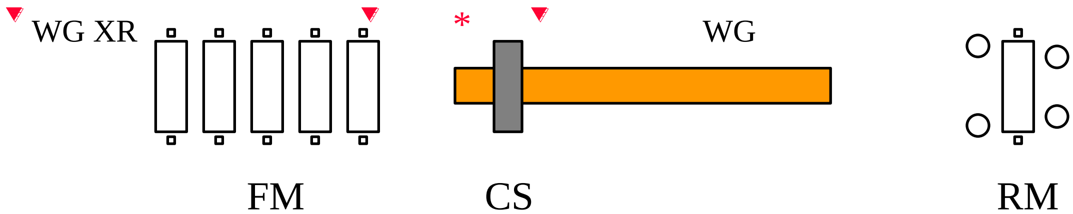
- The transfer bar thickness is calculated based on the measured last pass force and gap (using gaugemeter model).
- The transfer bar width is calculated based on the measured edger gap and the standard practice spread and recovery.
- The FM entry temperature is estimated based on the measured RM exit temperature and typical delivery time.
- For Ferritic grades, the grade hardness is updated based on the measured last pass RM force and draft.

Crop Shear Arrival



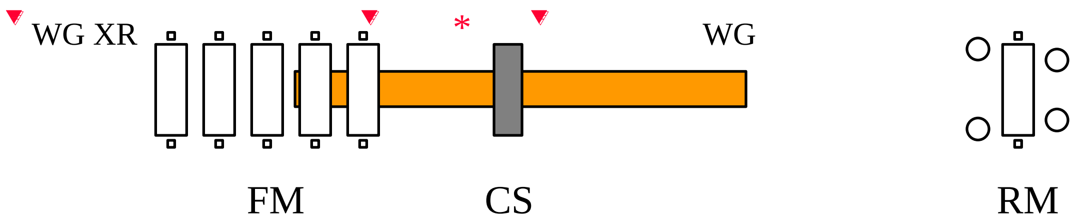
- The FM entry bar temperature is chosen from either the measured crop shear temperature or the radiated RM exit temperature (usually the crop shear temperature).
- If the measured RM exit width is close to the edger calculated width or PDI width, it is used as the transfer bar width.

Finishing Mill Entry



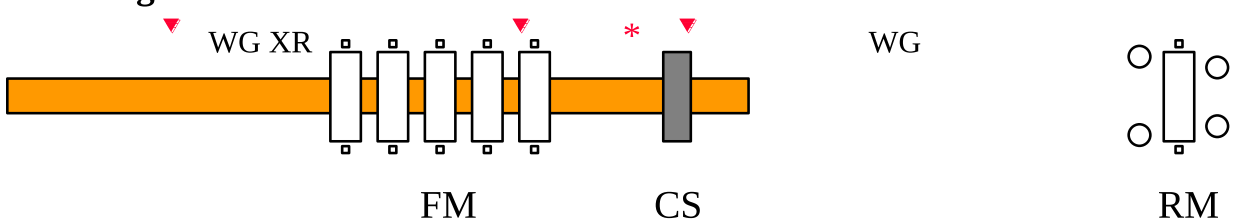
- If the piece is delayed entering the mill, setup calculations will be repeated every few seconds accounting for the fact that the transfer bar is cooling.
- The final setup calculation is performed when HMD27 picks up just before F1.

Finishing Mill Thread



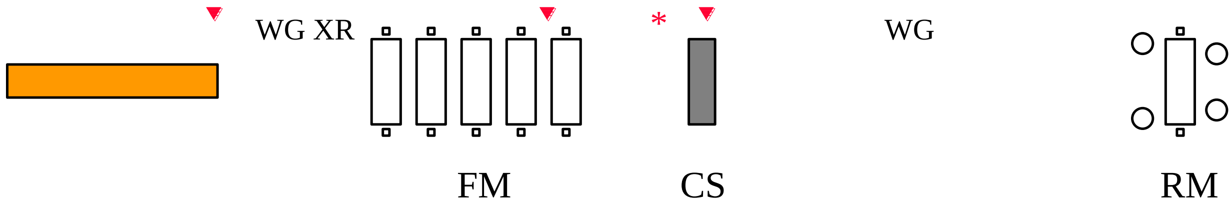
- After the bar threads F2, measured F1 and F2 values are used to calculate the actual strip hardness.
- If the strip is significantly harder or softer than expected, and if Feedforward Setup Revision (FSR) is enabled, the references for F4 and F5 are updated.
- FSR is <u>not</u> enabled for Carbon, RGO, TCH, CrNi or PH grades.

Finishing Mill In-Bar



- Model adaption scans are performed over several intervals, and the model adaptors are updated.
- Setup calculations are performed for all the pieces in tracking upstream from the FM (to use the updated adaptor values)

Finishing Mill Tail-Out



- Model tail-end and full-length scans are completed.
- Model performance is evaluated, checking for faults and updating statistics (serious faults are alarmed to the operator).
- Piece information is archived on the Level 2 system and a model log is created.

Other Events

Roll Change

- When new roll numbers are accepted, the calculated roll wear and thermal expansion are reset.

Stand Calibration

- The gaugemeter gap offset and stand thread speed trims are preset to initial values.

Mill Modulus

- When a mill modulus test is performed, the data is stored in a data file on Level 2.
- The mill modulus curves may be put on-line using the MMI interface.

Operator Trims

- When the operator makes an adjustment that changes the FM setup model inputs, (Level 1 MMI or Level 2 MMI), the setup is recalculated for all pieces in tracking upstream of the FM.

Long Delays

- The setup is recalculated for all the pieces in tracking upstream of the FM (every 2.5 minutes).

FM Setup Calculation Steps

- Calculate the FM entry dimensions and temperature.
- Iterate to distribute the FM draft and select the thread speed.
- Check tail-end force and current limits. If a limit is exceeded adjust the load distribution and repeat draft distribution calculations.
- Calculate the mill references based on the draft distribution selected.

Draft Distribution

There are two draft distribution modes:

Distribution by Force

- The draft is distributed to achieve the desired relative stand force ratio.
- This method is used for all products except RGO and TCH.

Distribution by Draft

- The draft is distributed to achieve the desired thickness reduction ratio.
- This method guarantees a given distribution of reduction for consistent magnetic properties.
- Used for RGO and TCH.

Draft Distribution by Force

- The relative stand loads are specified in the Standard Practice Table.
- Example of a load distribution pattern

F1	F2	F3	F4	F5
1.00	0.87	0.79	0.56	0.41

- With this pattern, F1 will have the highest strip force. The F2 strip force will be 87% of F1's strip force. Similarly, the F3 strip force will be 79% of F1's strip force.

Draft Distribution by Draft

- The desired stand draft is stored as percentage of the total FM draft.
- Example of a draft distribution pattern

F1	F2	F3	F4	F5
65.0	21.0	8.0	4.0	2.0

- If the total mill draft was 1.36" (1.450 - 0.090), the F1 draft would be 65% of 1.36 or 0.884".

Draft Distribution Operator Adjustments

- Operator adjustments are in percentage for both distribution by draft and by force.
- When draft is increased or decreased on a stand, the draft on the other stands is automatically adjusted so that the total amount of draft required is still taken.

Example:	F1	F2	F3	F4	F5	
(force factor)	1.00	0.87	0.79	0.56	0.41	(original distribution)
(Operator % bias change)					+20%	(desired change)
(new force factor)	1.00	0.87	0.79	0.56	0.49	(modified distribution)
(force change)	-2.2%	-2.2%	-2.2%	-2.2%	+17.3%	(actual changes)

Mill Limits

- FM setup will automatically shift load if any of the following limits are reached:
  - maximum per-unit draft
  - maximum force (head or tail)
  - maximum current (head or tail)
  - maximum head-end force per-unit width
  - minimum head-end force
  - maximum load shift increase (due to other stands in limit)
- The draft distribution mode will automatically switch to distribution by force when a mill limit is reached (just so that the redistribution of draft is handled properly).

Alternate Thickness Selection

- Alternate thickness is selected when all stands are in limit (i.e., it is impossible to roll to the original target).
- The alternate thickness mode can be absolute (set to stockband gauges) or incremental (relative thickness steps until a valid setup is achieved).
- For all gauges less than 0.225", the alternate thickness mode is set to incremental mode with 0.010" increments.
- Alternate thickness is not enabled for gauges greater than or equal to 0.225"

Thread Speed Selection Modes

- The thread speed (F5 roll speed) selection is based on one of the following modes:
  - Manual (Operator specifics value directly)
  - Automatic (Model determines value based on the product dependent thread speed mode)
    - Standard massflow per-unit width
    - Calculated to achieve the FM exit temperature target
- The model calculates the individual stand speeds for balanced massflow during threading

Thread Speed Limits

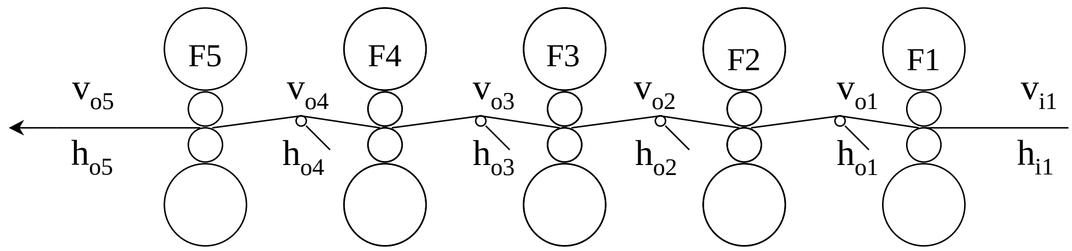
- The following limits are checked:
  - Operator entered limit (not checked in manual mode).
  - Standard practice thread speed limit (used for light gauge stability on the run out tables).
  - Maximum stand speed (with some allowance for looper height control).

FM Setup References

- Stand Speeds
- Mill Acceleration (Zoom)
- Looper Heights and Strip Tensions
- AGC References (gaps, forces, control modes, gains, offsets)
- FM Sideguide References (gaps)
- Sensor Setup Parameters
- MMI Display Values (all references as well as other values of interest. E.g. Tail end predictions)

Stand Speed Calculation

- Interstand strip speeds are calculated for balanced massflow through the FM. The product of the strip thickness, width and speed is the same before and after every stand. Since the width shouldn't change much, the speed of the strip leaving each stand is determined mainly by the strip thickness.



$$v_{o5}h_{o5}w_{o5} = v_{o4}h_{o4}w_{o4} = v_{o3}h_{o3}w_{o3} = v_{o2}h_{o2}w_{o2} = v_{o1}h_{o1}w_{o1} = v_{i1}h_{i1}w_{i1}$$

- The stand roll speeds are calculated from the stand exit strip speed and the predicted forward slip. The forward slip is the difference between the roll speed and the strip speed leaving the stand.

$$V_x = \frac{V_{ox}}{(1 + FwdSlip_x)}, \textit{where } x = 1 \ldots 5$$

Stand Speed Trims

- To calculate the individual stand speed references several trims are applied to the calculated stand speeds:
  - Stand Thread Speed Adaption trims (based on scanned looper heights during thread).
  - Safety bias speed trims (see next slide)
  - Operator speed verniers (applied at Level 1)
- All of the speed trims are cascaded.
- A lead speed trim is also applied prior to each stand's pickup to compensate for speed droop. The lead speed is calculated by Level 1 based on a predicted rolling torque from the model.

Safety Biasing

- Safety biasing is used to tighten the thread when there is less certainty in the model's predictions.
- Factors that will increase the safety biasing are:
  - long time since the product was last rolled (1 hour to 1 day)
  - product with few model updates (20 to 3)
  - new heat of an off-standard melt grade (on or off)
  - long time since last bar rolled (7 to 16 minutes)
  - large FM entry temperature change (from last bar) (40 to 100)
  - large FM exit % gauge change (from last bar) (10 to -20 or +30)
- These are all "product change" factors.
- Contributions from each of these factors is added up and then limited to a maximum.
- The amount of tightening per looper depends on the product being rolled. This is set up in the model standard practice tables.

Safety Biasing and Stand Thread Speed Trims

- Product change safety biasing should only be required for potentially difficult bars. It needs to be removed for normal rolling.
- Safety biasing will usually make a thread tighter than normally desired when it is active. Stand thread speed adaption would then try to loosen the thread for the next bar. If the safety biasing was also removed, then the next bar would likely be too loose.
- The adaption of the stand thread speed trims is carefully coordinated with the removal of the safety biases. For the product change trims, portions are moved into the stand thread speed trims before those trims are updated.
- Product change safety biases are only applied when they are greater than the safety biases left over after adaption of the previous bar.

First Bar after Roll Change/Mill Calibration

- In addition to the normal product change safety biasing, the initial stand thread speed trims and gaugemeter gap offsets are set so that the first bar will tend to have a tight thread and approximately the desired head end thickness.
- Theoretically, the gaugemeter gap offsets should be zeroed when a mill stand is calibrated. In practice, we try to minimize the first bar after roll change setup errors by presetting the gaugemeter gap offsets.
- With the stand thread speed trims, roll change on any stand causes the trims both for that stand and the preceding stand to be preset to values which will tend to produce a tight thread.
- If you feel that the initial setups after mill calibrations include consistent errors, these can be addressed through changes to the standard initial gap and speed trims.

Mill Acceleration References

- Acceleration (or Zoom) is used to control the FM exit temperature and/or to control the FM rolling time.
- Two acceleration rates (in F5 roll speed fpm/s) are used:
  - Pre-Coiler Load
  - Post Coiler Load
- The acceleration rate selection modes are:
  - Manual (Operator specifics the values directly)
  - Automatic (Uses standard practice acceleration rates)
- Mill Zoom must be selected on the operator's desk.

Mill Acceleration Control

- Mill acceleration is controlled by Level 1 based on the acceleration rates provided by the model.
- The acceleration rate for each stand is calculated based on the relative stand speeds (same percentage).
- Acceleration is stopped if any stand reaches a maximum speed or current limit.

Looper Height and Strip Tension

Looper Height

- Model references are stored as height above passline by product group and thickness range.
- The passline is adjusted for bottom work roll diameter variations.
- No operator adjustment is allowed.
- Height may be lower to achieve the strip tension reference if the looper motor is in a torque limit (rarely the case).

Strip Tension

- Strip tensions values are stored by product group and thickness range.
- The operator tension offset is applied at Level 1 so that the strip tension can be changed mid-bar.

AGC References

Mill Setup References:

- screwdown references

AGC Parameters:

- predicted roll force (for absolute gaugemeter)
- predicted inter-stand thicknesses
- gaugemeter mode (absolute or relative)
- mill modulus curve (±400 tons, plus two slopes)
- strip stiffness factor
- nose screw offsets

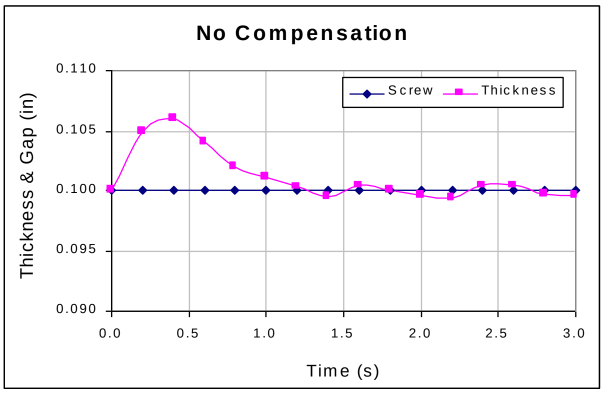
Screw Reference Calculation

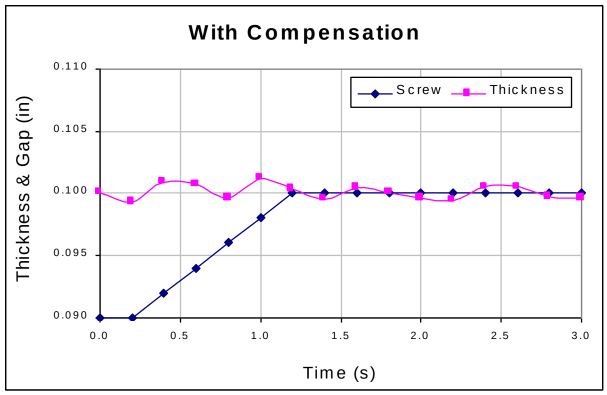
The stand screw references are based on the gaugemeter calculation:

Screw	=	Stand Exit Thickness
	–	Mill Stretch (at the predicted head-end force)
	–	Roll Stack Wear
	+	Roll Stack Thermal Expansion
	–	Gaugemeter Adaptor

AGC Screw Offsets

- Nose screw offsets are used to compensate for thickness variations that are too fast for AGC feedback control.
- Individual stand screw offsets are calculated based on the operator entered nose thickness offsets.
- Hold and ramp times are stored in the Standard Practice Tables.





Sideguide References

- The model provides the head-end sideguide references for the crop shear and FM sideguides.
- If short-stroke is selected on the Level 1 MMI, the sideguides are short-stroked in when each stand picks up.
- If the RM exit width gauge is enabled on the Level 2 MMI, the sideguide references are based on the calculated FM entry width. Otherwise the sideguide reference calculation is based on the PDI Width Off target.
- Operator biases are added for each sideguide.
- Sideguide references are rounded up to the next 0.1".

Sensor References

X-Rays
- Thickness target (may be alternate thickness)
- Alloy code (for absorption compensation)

Width Gauges
- PDI Width Off (hot)

Pyrometers
- Nothing required

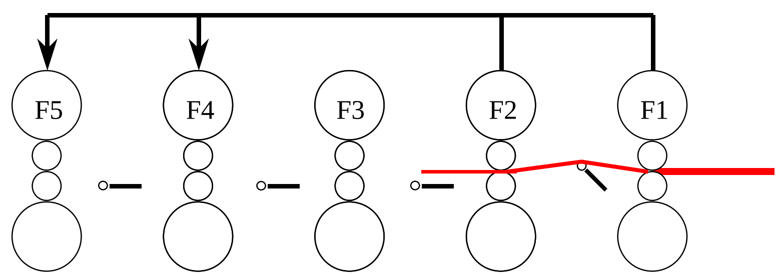
Automatic Crop Shear
- FM entry draft compensation

MMI References

- All mill references are available for display.
- FM setup modes (sideguide setup, thread speed).
- Predicted tail-end parameters (force, current).
- Model alarms.

Feed-Forward Setup Revision

- If the measured hardness error at F2 is large and if FSR is enabled the references for F4 and F5 are updated.
- The references for F3 are not updated because there is not enough time to set the screws.
- FSR is available for CRNO, ferritics, and high chrome grades.



FM Model Adaption

Model Adaption
- Automatic
- Uses the measured FM data from the last piece rolled.
- Performed every piece
- Designed so that setup predictions will match actual values.

Model Tuning
- Manual
- Uses the archived coil information (Analysis based on many pieces).
- Performed occasionally.
- Objective is to minimize adaptor movement.

Model Updates

Model Adaption

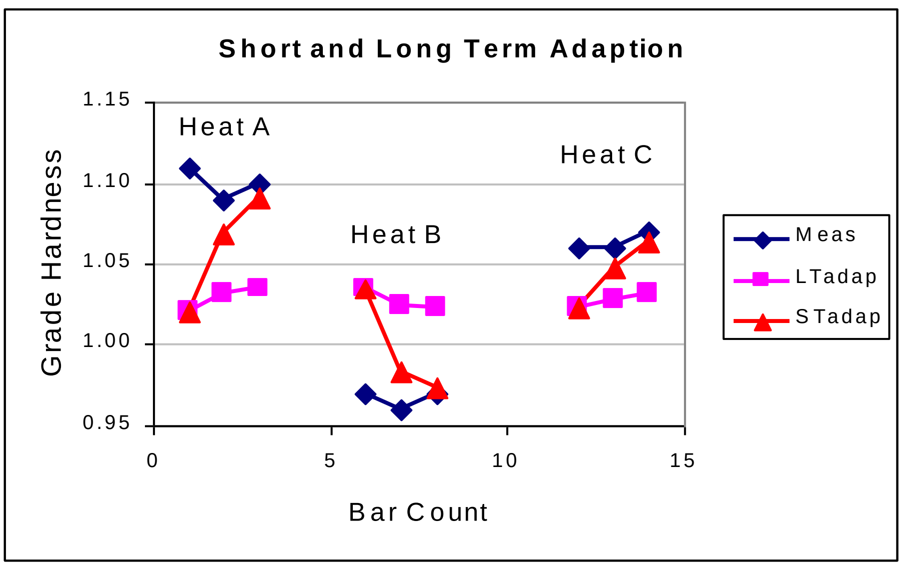
- gaugemeter model
- material/stand hardness
- stand torque (power)
- FM exit temperature
- stand thread speed trims
- learned standard practice values

Manual Tuning

- roll heating and wear models
- yield stress vs. temperature curve
- strip temperature models
- forward slip model
- scan timing
- model equations

Short and Long Term Adaption

- Short-term adaption quickly learns the current operating conditions.
- Long-term adaption maintains the long-term process average.
- On product changes, the short term adaptor is set to the long term adaptor.
- The short term adaptor learns the entire model error.
- The long term adaptor only learns the error left over after the short term adaptor.
- Product changes are determined by thickness range, grade and heat number.
- Global adaptors have only “short term” adaption.



FM Adaption Scans

Head-End Scan

- Scan location depends on product thickness.

Thickness	Delay	Scan
≤ 0.100"	50.0'	50.0' at FM Exit
≤ 0.200"	40.0'	40.0' at FM Exit
> 0.200"	30.0'	30.0' at FM Exit

- Scan the same length on the piece for each stand.
- Used for force and torque model updates.

Massflow Scan

- Scan all stand values at the same time.
- Try to scan when the mill is stable.
- Used for gaugemeter model updates.

Mid-Bar Scan

- Scans the middle of the piece after coiler pickup.
- Scans not performed for heavy gauges (strip too short).
- Used for mill acceleration calculations.

Threading Scans

- Scans looper heights during threading
- Used for stand thread speed adaption.

Other Scans

- Scan nose, tail and full-length.
- Used for model analysis.

Scan Information

Stand Data

- Load Cell Force
- Voltage and Current
- Screw Position
- Stand Speed

Looper Data

- Angle
- Motor Current

Sensor Data

- Strip Thickness
- Width
- Temperature

Massflow Calculation

- Using the massflow scan and assuming balanced massflow through the FM, calculate the interstand thicknesses.
- Knowing the thickness and the speed at the X-ray as well as the speed leaving each stand, we can calculate the thickness leaving each stand.
- This calculation assumes that we know the forward slip at each stand. The measurements taken for this calculation are averaged over a fairly long interval after the head end to minimize the effects of any transient behavior.
- X-ray measurement errors, forward slip modeling errors and stand linear speed measurement or calculation errors will all contribute to errors in the calculated massflow thicknesses.

Gaugemeter Model Update

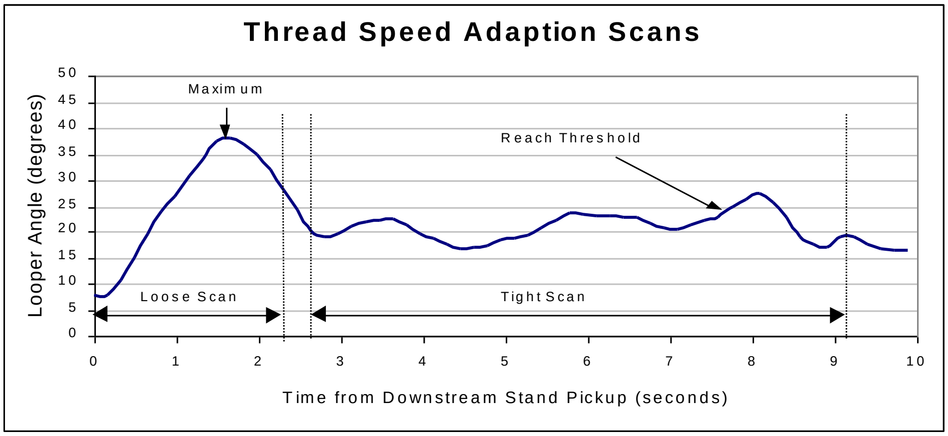
- For the measured stand forces and gaps averaged over the massflow scan interval, calculate the stand interstand thicknesses using the gaugemeter model.
- Update the gaugemeter model offsets based on the difference between the gaugemeter calculated thickness and the massflow calculated thickness (from the previous slide).
- Sudden changes to the measured gaugemeter model error point out errors in either the massflow calculation or the gaugemeter modeling. Off-line analysis of many coils is used to determine which.

Model Parameter Updates

- Using the calculated gaugemeter model offsets, calculate the interstand thicknesses for the head-end and mid-bar locations.
- For these thicknesses, calculate the model adaptors which result in the repredicted model calculations (forces, torques and temperatures) matching the measured data. These are the “measured” model adaptors.
- Update the model short and long term adaptors using simple gains and limits.

Stand Thread Speed Trim Adaption

- Two looper scans are performed during threading:
  - Loose Scan (captures the maximum looper height)
  - Tight Scan (determines when the looper angle gets close to its reference angle after threading)
- Scans also record the operator speed vernier bias and the looper speed correction.



FM Adaption Philosophy

- There are very few conditions that will inhibit adaption.
- This allows adaption to almost always learn the current rolling conditions and correct setup errors.
- However if there is a problem such as a bad load cell or an invalid roll diameter, the bad data will "corrupt" the model table adaptor values.
- The model tables can be recovered using a model utility.
- If the models are not recovered, the model will have to unlearn the bad data the next time the product is rolled.

Model Analysis Data

Alarms

- Single line messages from various processes (In this context, “process” is just another word for a dedicated computer program).
- Last 200,000 alarms are stored (about 3 days of normal rolling).
- Many of these alarms are “informational”. Nothing is really wrong, but we are keeping a record of things that went right. For example, certain scans were completed and the models were updated by adaption.
- Utilities are available for displaying and sorting by process, alarm severity, time interval or coil number.

Trend Data

- 6Hz (6 measurements per second) data stored from Crop Shear pyrometer pickup to FM exit pyrometer dropout
- Data stored on Level 3 for many days
- Graphical displays using Hot Mill viewer, MMI (Man-Machine Interface) or LHA DAS (Luther Holton Associates Data Acquisition and Analysis System). LHA DAS data will be at 30 Hz (0.033 seconds between samples).
- VXL short and long term trends (continuous)

Mill Modulus Data

- Last 24 mill modulus tests stored for each stand

Coil Data

- Stores PDI, operator and model data for each coil rolled (approximately 12,000 pieces of data per coil)
- Last 15,000 coils stored on disk (8-10 weeks)
- Used for model tune-up (Excel is used for data analysis)
- Possible to re-run model functions (FMS – FM Setup, FSR – Feedforward Setup Revision, FMA – FM Adaption, MPM – Model Performance Monitor)

Performance Data

- Daily model performance summary data is stored for the last 1000 days

Model Reports

Model Log

- 4 page report displaying data that is generally of interest when analyzing a model problem
- maintained on disk for 7 days
- can be generated from the 15,000 coil database

Model Table Reports

- reports displaying model table values

Model Performance Reports

- daily, weekly and monthly summary reports listing model faults and performance statistics

AGC, Loopers and Mill Speed Control

Level 1 Controls

Automatic Gauge Control (AGC)

- Gaugemeter
- Feed-Forward
- Tension AGC
- X-Ray Monitor

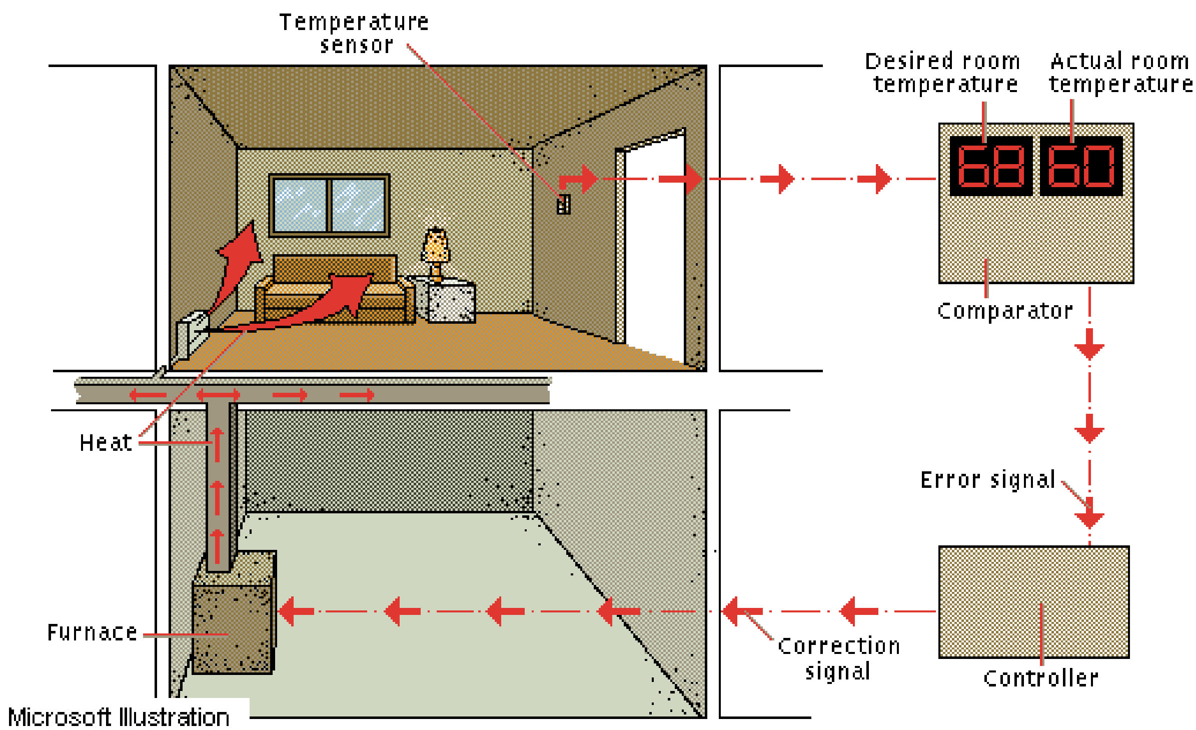
Looper Control

- Loop Height Control
- Strip Tension Control

Mill Speed Control

- Lead Speed
- Cascade
- Mill Zoom

Automation/Control Example



Example of a Feedback Control System - Illustration from Microsoft Encarta 98

In this example, the comparator (thermostat) sends an error signal to the controller. As long as the actual room temperature is less than the desired room temperature, the controller will run the furnace burner and fan so that heat is sent to the room. The control could be a simple on/off control, or the furnace temperature and fan speed might be a function of the size of the temperature error. Also, in systems of this type, some hysteresis is usually built in – the furnace will turn on at one temperature (perhaps one degree below the set-point) and turn off at a higher temperature (maybe one degree above the set-point). This hysteresis prevents the furnace from cycling too often.

Automation/Control - Other Examples

- Toilet tank (float valve - on/off control)
- Old fashioned electric blanket (occasional adjustments, continuously variable control)
- New “smart” electric blankets (continuous sensing and control in zones)
- Riding a bicycle (continuous sensing and control of direction, balance and speed).

Types of Feedback Control

- Most regulation systems use “negative” feedback control. The control action opposes or corrects the error.
- Positive feedback systems are inherently unstable (e.g., when a microphone is too close to its speaker).
- Proportional control: The correction is proportional to the size of the error. Errors are reduced, but not eliminated.
- Integral control: The correction continues to move in a direction to correct the error at a rate proportional to the size of the error. Eventually, the error should be eliminated.

Speed of Response and Stability Issues

- To speed the rate of response or reduce the magnitude of errors, we can increase the feedback gain.
- Most control systems include a time constant or lag. This is the sum of the time for the regulator to make its adjustment and the time required to measure the result of the control action.
- Systems with long time constants or lags need low feedback control gains. If the gain is too high, then the error will be over-corrected resulting in overshoot or unstable behavior.

Controller Gains – Simulation

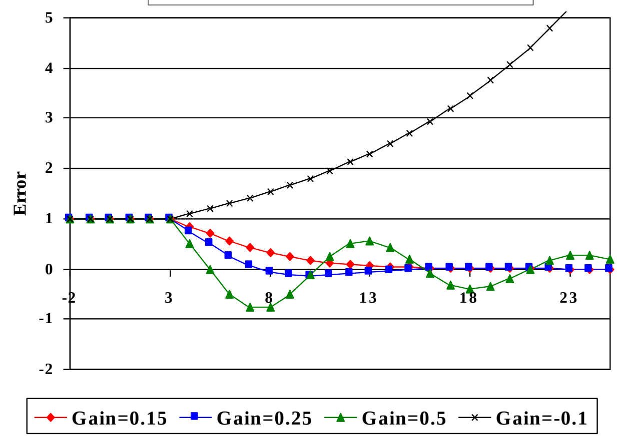
Consider integral control with gain of 0.5 per controller cycle and a transport lag of 3 controller cycles.

T= -2	C= 0.0	E= 1.0
T= -1	C= 0.0	E= 1.0
T= 0	C= 0.0	E= 1.0
T= 1	C= -0.5	E= 1.0
T= 2	C= -1.0	E= 1.0
T= 3	C= -1.5	E= 1.0
T= 4	C= -1.75	E= 0.5
T= 5	C= -1.75	E= 0.0
T= 6	C= -1.50	E= -0.5
T= 7	C= -1.125	E= -0.75
T= 8	C= -0.75	E= -0.75
T= 9	C= -0.50	E= -0.50

Control Start Time T = 0

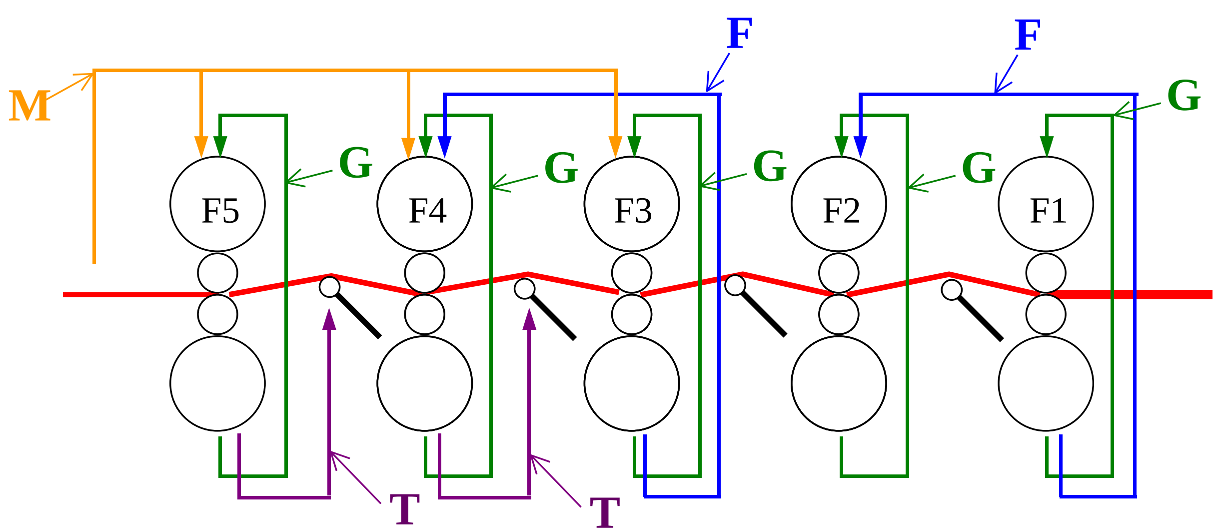
Error $E=1.0-C_{T-3}$

Control $C=C_{T-1}+0.5E$



AGC Control Loops

- Gaugemeter (inner loop) - **G**
- Feed-Forward (open loop) - **F**
- Tension AGC (fast fine control) - **T**
- X-Ray Monitor (outer loop) - **M**



Gaugemeter AGC

- This is the primary AGC control loop
- Normally active on all the stands
- Gaugemeter continuously calculates the roll gap separation accounting for mill stretch. It adjusts the gap so that the desired loaded gap is maintained in the face of roll force variations. It effectively makes the mill stands very stiff.
- **Absolute Gaugemeter** controls to the setup predicted gauges.
- **Relative Gaugemeter** controls to the calculated thickness measured during threading. (This is the mode currently in use at Butler).
- Compensates for strip hardness variations (mainly due to temperature) or incoming thickness variations. Both are detected through roll force measurements.
- Gaugemeter control is subject to the following errors:
  - work roll heating (from head to tail)
  - backup roll bearing oil film thickness (varies with speed and force)
  - roll eccentricity
  - screwdown backlash
  - mill housing friction (roll force hysteresis)

Gaugemeter Thickness Control

$\Delta H = \Delta S + \frac{\Delta F}{M} \quad or \quad \Delta S = \Delta H - \frac{\Delta F}{M}$ Gaugemeter Equations

For thickness control, we want $\Delta H = 0 \qquad \therefore \Delta S = -\frac{\Delta F}{M}$

So, if the force moves in a positive direction, the gap should be moved in a negative direction.
However, this will cause the force to increase more so the gap will have to be moved further then originally calculated.

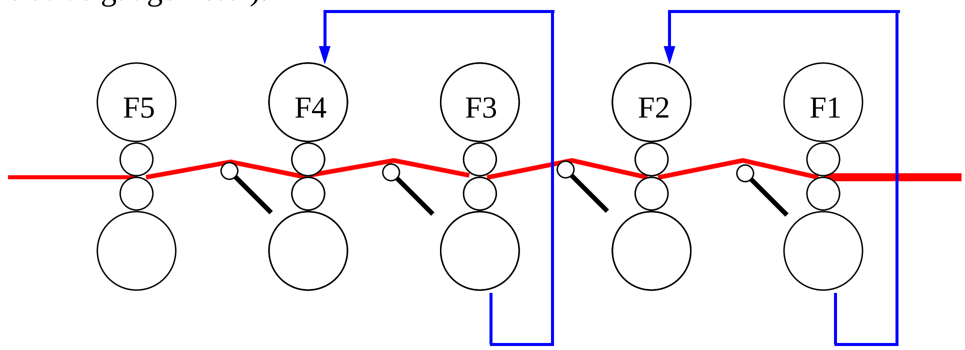
$\Delta H =$	Thickness change
$\Delta S =$	Screw change
$\Delta F =$	Force change
$M =$	Mill modulus (13 tons per mil)

Gaugemeter AGC

- To correct the thickness error effectively, the strip hardness needs to be considered.
- For a downward screw correction, the force will increase faster for hard light-gauge product.
- The screw correction multipliers for Gaugemeter AGC are supplied by the model and range from slightly greater than 1 to around 4.

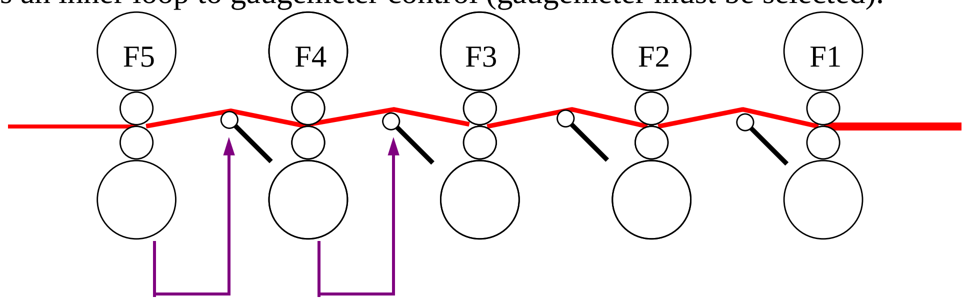
Feed-Forward AGC

- Thickness errors tracked from F1 to F2 and from F3 to F4
- Predictive control, screw movements lead the disturbance, thus eliminating the inherent lag with slow screwdowns.
- Used to help control large slow disturbances.
- Control starts shortly after stand pickup and regulates to a measured head-end thickness (like Relative gaugemeter).



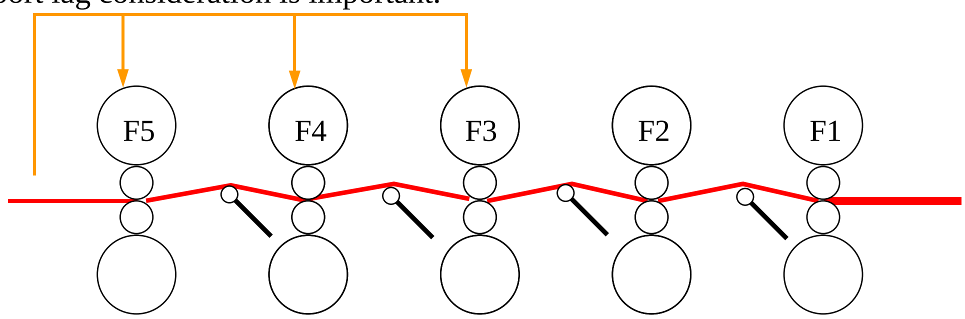
Tension AGC (Not Used at AK Steel - Butler Works)

- Small stand thickness errors (1-3 mils) are controlled by adjusting the strip tension reference (used on F4 and F5).
- Up to 10 times faster than control using screw position.
- Helps reduce roll force variation (gaugemeter control increases the force variation).
- Acts as an inner loop to gaugemeter control (gaugemeter must be selected).



X-Ray Monitor Control

- Regulates the measured X-ray thickness to the target thickness
- Controls mainly into the delivery stand (F5) with spill-back control into F3-F4 to reduce the massflow and shape disturbances.
- Transport lag consideration is important.



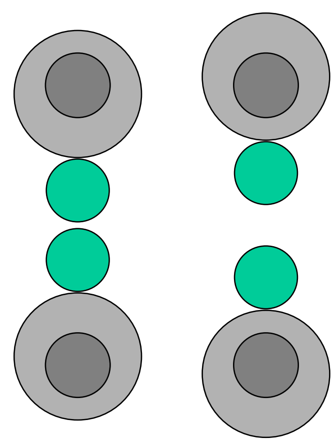
AGC Massflow Control

- AGC calculates stand speed trims required to help reduce the massflow disturbances caused by thickness variations.
- The massflow into and out of each stand is calculated based on the Gaugemeter entry and exit stand thicknesses.
- Speed trims are generated so that the strip linear speed out of a stand matches the strip linear speed into the next stand.

AGC Mass Flow Control and Eccentricity

- An increase in strip hardness causes the roll force and hence the mill stretch to increase. Mass flow control recognizes this and tries to correct for the increase in mass flow detected.
- The effect of roll eccentricity is to produce a roll force increase when the strip thickness has been reduced. Both gaugemeter and mass flow control will tend to act in the wrong direction.

$$\Delta H = \Delta S + \frac{\Delta F}{M}$$



AGC Limits

- Maximum Force (stop downward screw moves)
- Minimum Force (stop upward screw moves)
- Maximum Current(stop downwards screw moves)

- Screw Position Change Limits

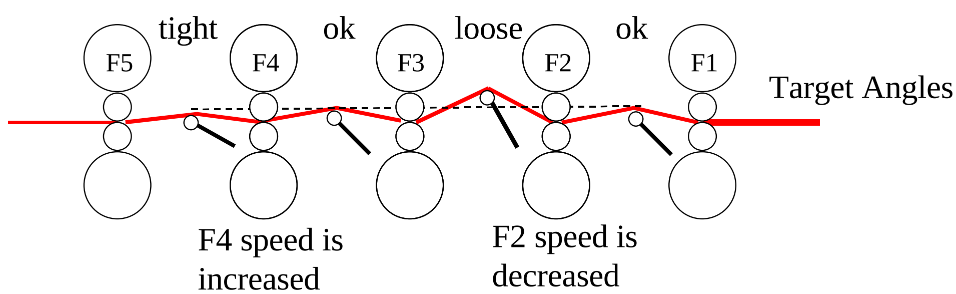
Looper Control

Loop Height Control
- controlled by adjusting the upstream stand speed
- feedback is based on the looper angle
- the objective is to maintain a massflow balance between the stands

Strip Tension Control
- controlled by adjusting the looper motor current (torque)
- no direct tension measurement (open loop control)
- the objective is to maintain constant strip tension at the setup reference

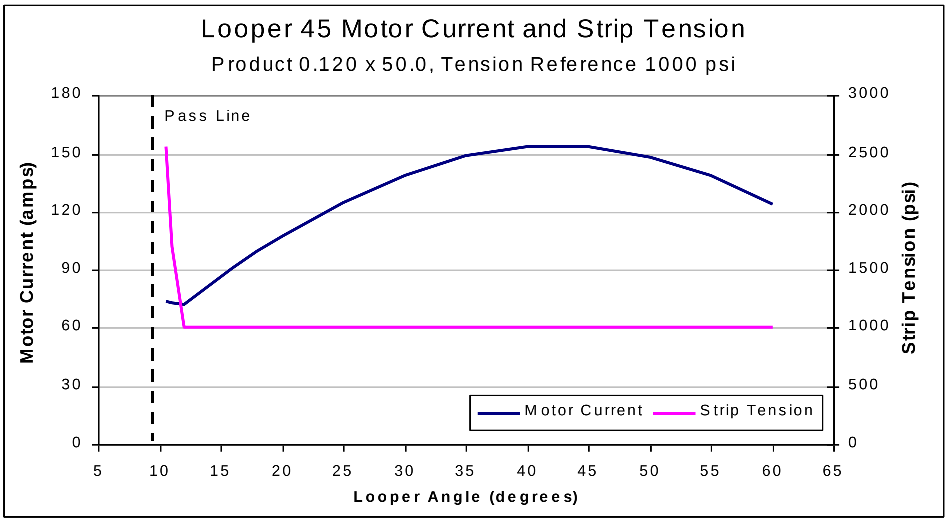
Loop Height Control

- The mill setup references include a target angle for each looper.
- If the looper angle is below that reference then the upstream stand speed is increased using proportional and integral control.
- If the looper angle is above the reference, the upstream stand speed is decreased so that the loop length is reduced.



Strip Tension Control

- Looper torque is required to:
  - support the looper weight (higher for lower angles)
  - support the strip weight (higher for lower angles)
  - bend the strip over the looper (more for heavier gauges)
  - supply the strip tension (less torque for low angles)
  - accelerate the looper
- The looper motor current is regulated to maintain the target strip tension as the looper angle varies.
- With constant tension control, the required motor current decreases with lower angle. To ensure the looper has enough upward force to follow strip, the control switches to constant torque control below a minimum angle.



Looper Sequencing

Head Ends

- We want to establish tension quickly without damaging the strip.
- Upon downstream stand pickup, the looper is position regulated up towards a high angle.
- After about 1/3 of a second, the looper should be in contact with the strip and the height control is enabled.

Tail Ends

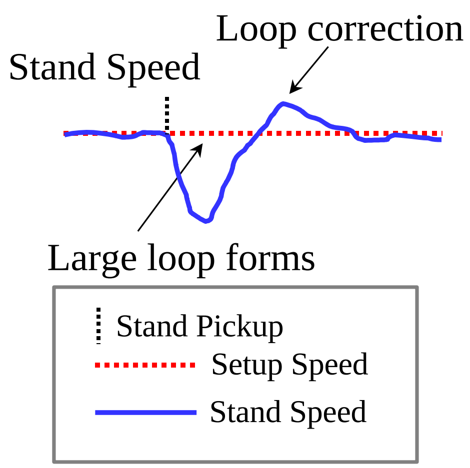
- We want to maintain tension for as long as possible but need the looper down when back tension is lost so that the tail ends are not “flipped”.
- The tail end is tracked and the loopers are lowered just before the upstream stand drops out.

Lead Speed/Impact Droop Compensation - Theory

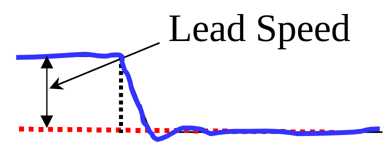
- Impact droop is the drop in stand speed when a load torque is applied (stand pickup).
- The stand speed will drop until the main drive current increases to the point where the applied torque is equal to the load torque.
- While the stand speed is less than the speed required to balance mass flow, the upstream loop grows.
- Without lead speed, the stand speeds must be set to avoid excessive loops. The result is necking after the head end.
- Lead speed is a positive bias applied to the speed reference until the stand picks up.
- Once the stand picks up, the lead speed bias is removed.
- With the right amount of lead speed, the stand speed droops to the speed required to match the upstream stand mass flow.

Lead Speed/Impact Droop Compensation – Speed Response

Without Lead Speed

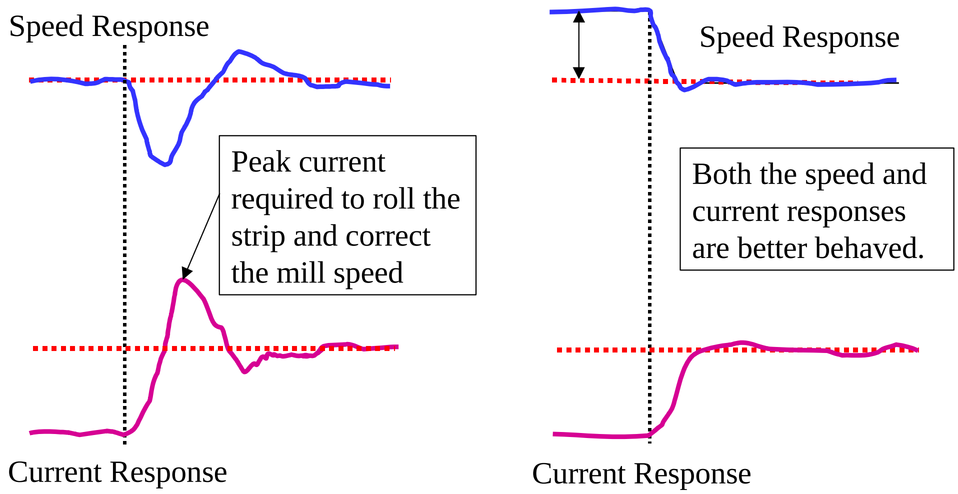


With Lead Speed



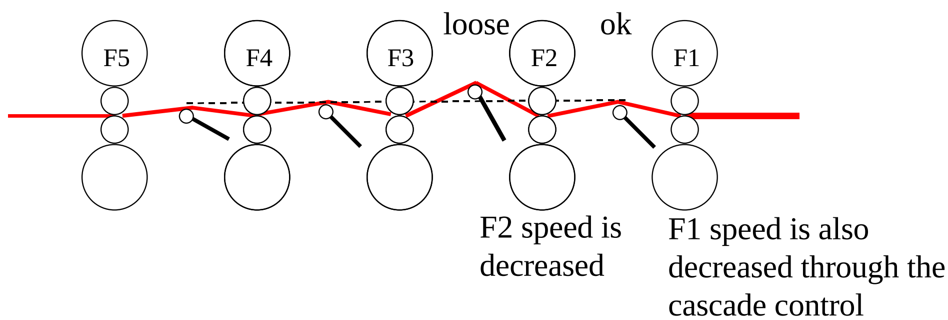
Lead speed compensates for impact speed droop so that the speed ends up in the right place without throwing a large loop.

Lead Speed/Impact Droop Compensation - Benefits



Speed Cascade Control

- Speed trims applied to a stand are "cascaded" to all earlier stands on a percentage basis. Without this, an adjustment at F4 would result in a ripple of corrections to F3 then F2 and finally F1.
- Looper height control trims, operator vernier trims and mass flow corrections are all cascaded.
- The only trim to F5 is the operator trim. It is not cascaded.



Mill Zoom Control

- Mill zoom control is normally used to compensate for tail end temperature run down. The zoom rate is expressed in fpm/sec.
- All the stand speeds are increased through a shared multiplier acting on the setup speed and applied trims. The effect is the same as if the F5 speed was ramped up with a cascaded correction to the upstream stands.
- Mill zoom is "held" if any stand approaches its upper speed or current limit.

Operator Controls and MMI

Selected Operator Controls and MMI

Desks Devices

- Speed vernier controls

Level 1 MMI (Human Machine Interface)

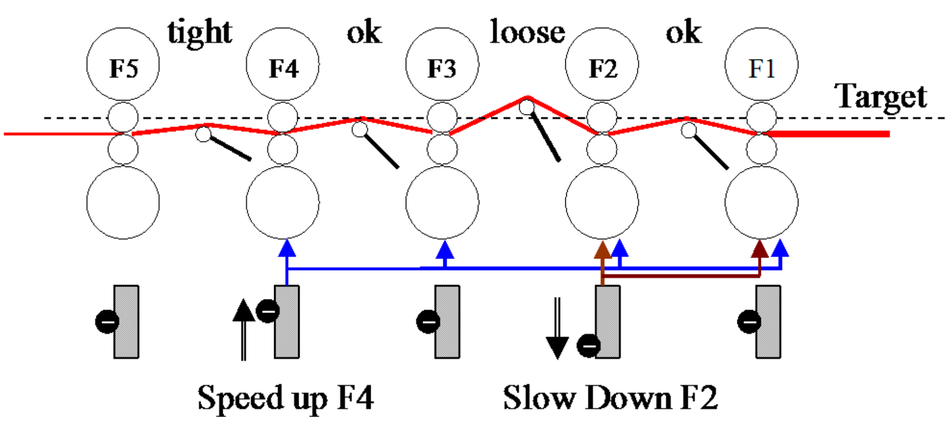
- Tensions biases
- Sideguide short-stroke offsets
- F5 work roll bending references

Level 2 MMI

- Setup entry screens
- FM Model alarms
- Mill modulus

Speed Vernier Controls

- These operator stand speed biases are used to adjust the stand speeds during threading and throughout the length of the bar.
- F4 through F2 are cascaded to upstream stands to maintain massflow balance.
- The setup model speed adaption tries to cooperate with the operator.



Speed Vernier Interaction with Thread Speed Adaption

- Stand Thread Speed Adaption adapts a setup speed trim so that the looper angles recorded during threading will tend towards a product dependent target.
- If the operator needs a tighter or looser thread, we need to stop this adaption from fighting with the operator.
- Stand thread speed adaption records the measured operator speed trim during threading. If the operator has tightened the thread, then the target angle used for adaption is reduced. If the operator has loosened the thread, the target angle is increased.
- The target angle adjustments are proportional to the amount of operator speed vernier correction recorded during threading.
- If large speed vernier trims are required for an extended period, an automation person should be notified.

Looper Transients during Threading

- Sometimes the loopers may not be very stable during threading (loose then tight).
- Thread speed adaption will try to compromise between the loose and tight portions.
- If the thread is unsatisfactory, the operator speed vernier may be used to tighten or loosen the thread.
- The operator verniers can also be dynamically adjusted during thread to compensate for the speed variations (tighten then loosen). However this would have to be repeated for each piece.
- Ideally the loopers should rise quickly to the operating angle and then regulate with small variations around that angle. In practice, this is very difficult to achieve.
- Regular erratic looper behavior should really be explained and, if practical, corrected.

Using the F5 Speed Vernier

- The F5 speed vernier should be treated differently from the speed verniers on the other stands since it affects the mass flow of the entire mill and since it is not cascaded.
- In practice, a loose strip between F4 and F5 can be corrected either by speeding up F5 or by slowing down F4 (which will slowdown F3, F2 and F1 because of the cascade).
- Generally the F5 speed vernier should not be used. It should only be used after the F4 speed vernier range has been used up.
- Remember that if a stand is in current limit, it will not speed up. Slowing F4 should therefore be more effective than speeding up F5.

Strip Tension Offsets

- The strip tension references are stored in the model standard practice tables by melt grade family and thickness range.
- Operator tension adjustments (in psi) can be made at any time from the ***Speed Live Data*** MMI screen.
- Higher strip tensions help rolling stability (by keeping the looper in tighter contact with the strip). For soft products, higher strip tensions may cause some width necking.
- Harder grades can tolerate higher strip tensions.
- The standard practice tensions were recently adjusted so that strip tension offsets should normally not be required.
- Strip tension offsets do not affect the stand speeds in any way.

Strip Tension Offset Adjustments

- If the strip is seen to sag over the looper before the looper rises to restore the proper strip tension, then the looper height control will tend to be unstable. The strip tension should be increased as long as this does not cause strip necking.
- If there is width necking with the looper near its normal operating angle, then the strip tension should be reduced.
- For soft products such as RGO, the loopers on this mill are just barely capable. The right tensions are a delicate balance between acceptable looper stability and minimizing width necking.
- Tension changes generally need to be fairly large:
  - Use tension increase steps of 30 to 70% (e.g., 300 to 700 psi for a 1000 psi reference). Tension decrease steps of 20 to 30% are reasonable.

Sideguide Short-Stroke Offsets

- Sideguide short-stroke is a Level 1 function (no model references).
- Short-short selection and magnitude control are entered via pop-up windows on the ***Speed Live Data*** MMI screen.
- The short stroke amount is the distance that the sideguide will move in once a stand picks up. Increasing the short stroke will therefore make the guides tighter unless an opposite adjustment is made to the sideguide setup bias.
- Therefore, if the sideguide position after short stroke is to be adjusted but we don't want to affect the sideguide width before short stroke, then the short stroke and bias amounts must both be changed.

Work Roll Bending Pressure

- Work roll crown-in (positive) bending has been installed on F5 and some work roll chocks for that stand have been fitted with the bending cylinders.
- The work roll bending selection and bending pressure can be entered any time before HMD27 pickup or after threading by the roller via a pop-up window on the ***AGC Live Data*** MMI screen.
- The model will adjust the predicted force and screw position based on the entered work roll bending pressure.
- If edge wave is observed out of F5 the roll bending pressure should be increased.
- If center-buckle is observed out of F5 the roll bending pressure should be decreased.

Level 2 MMI Screens

Display Screens
- Tracking Screen
- Model Alarms
- Model Setup Screen
- Model Detail Screen
- PDI Screen
- Roll Information Screen
- Mill Modulus Screen
- Archive Play-Back

Input Screens
- PDI Bypass
- Setup Entry Window
- Sideguide Entry Window
- Work Roll Entry Window
- Backup Roll Entry Window

PDI Bypass

With the PDI Bypass screen, the following PDI items can be selectively overridden by operator specified values:
- Aim Gauge
- Aim Width
- Melt Grade Code

The PDI Bypass applies to all the pieces in tracking and rolled after it has been enabled.
You must remember to turn it off when it is no longer needed!
PDI Bypass can sometimes be used to override tracking and save a bar.

Setup Entry Screen

Thread Speed Selection
- Thread Speed Mode
- Thread Speed
- Maximum Thread Speed

Acceleration Selection
- Acceleration Mode
- Pre and Post Coiler Load Acceleration Rates

Model Modes
- Model (On/Off)
- Feed-Forward Setup (On/Off)

Load Distribution Biases

Head-End Offsets
- Head-End Thickness Offset
- In mils of thickness, not gap
- Head-End Temperature Offset

Thickness Transient Offsets
- Nose Thickness Offset
- Tail Thickness Offset

Setup Entry Screen - Thread Speed Selection

Thread Speed Mode

- Manual (specified by the operator)
- Automatic (determined by the model)
  - constant massflow per-unit width
  - calculated to achieve FM exit temperature target (available for RGO and TCH but not used)

Thread Speed

- F5 stand speed (fpm)
- only used in manual mode

Maximum Thread Speed

- maximum allowable F5 speed (fpm)
- only used in automatic mode

Setup Entry Screen - Acceleration Selection

Acceleration Mode

- Manual (rates specified by the operator)
- Automatic (rates determined by the model)
  - standard practice rates

Acceleration Rates

- pre and post coiler load rates
- F5 acceleration rate (fpm/s)
- only used in manual mode

Setup Entry Screen - Model Modes

Model

- ON - model calculated references used for mill setup.
- Should always be ON while rolling.

Feed-Forward Setup

- ON - FSR will be used if it is allowed for that product and the F2 measured force error is large.
- Should always be ON while rolling.

Setup Entry Screen - Load Distribution Biases

- Stand load adjustments in percent (percent draft for RGO and TCH, percent force for all other products).
- Load is shifted to/from the other stands based on the original load distribution.
- Load can be shifted for mill limits or shape considerations.
- Edge wave out of a stand can be reduced by off-loading the stand (using a negative bias).
- Center-buckle out of a stand can be reduced by increasing the stand load (using a positive bias).

Setup Entry Screen - Head-End Offsets

Head-End Thickness Target Offset

- Thickness target offset for setup only (mils).
- Opposite sense to the error (light gauge → positive offset).
- May be used to help Setup get on gauge after a large miss (should then be removed after a few bars as the model adapts).
- Only affects the first few seconds of a coil. After that, thickness is controlled by AGC.

Head-End Temperature Target Offset (°F)

- Only active when thread speed is being calculated to achieve a temperature target (currently not used).

Setup Entry Screen Thickness Transient Offsets

- Used to control the thickness transients on the head and tail ends (duration less than 1-2 seconds).
- Opposite sense to the thickness error (for example, for heavy gauge errors enter a negative offset) (mils).
- The offsets should be left in as long as they help. There is no adaption to correct the gauge errors these offsets address.
- The tail end offset does <u>not</u> work.

Sideguide Setup Screen

- RM Width Gauge Sideguide Setup Enable selection.
- Sideguide reference offsets are entered here.
- The sideguide offsets are added to the calculated sideguide setup widths.
- The offsets affect the width before short stroke.
- Since short stroke is in from the biased setup width, these biases affect the width before and after short stroke.

Model Alarms

- The alarm status for each piece is displayed on the bottom of the Level 2 screens:
  - Green — No alarm condition
  - Yellow — Warning (e.g., alternate thickness)
  - Red — Critical Alarm (e.g., invalid setup)
  - Blinking — Not acknowledged warning or fault
- The alarm screen displays up to 13 alarms.
- Critical alarms are displayed at the top of the screen.

Setup Calculation Alarms

FMS Fatal Alarms

- FMS/FSR Program Failure
- Unknown melt grade
- Entry temperature too cold
- All stands in limit
- Invalid thickness/width target
- Forces too low - hold bar

FMS Warnings

- Invalid slab dimensions or furnace number
- Alternate thickness selected
- Setup adjusted due to some limit
- Piece rolled narrow/wide from RM

FSR Fatal Alarms

- Last setup invalid
- Sequence number mismatch
- Calcs completed too late
- FM zone empty
- Different piece in FM zone
- Force error too large

FSR Warnings

- none

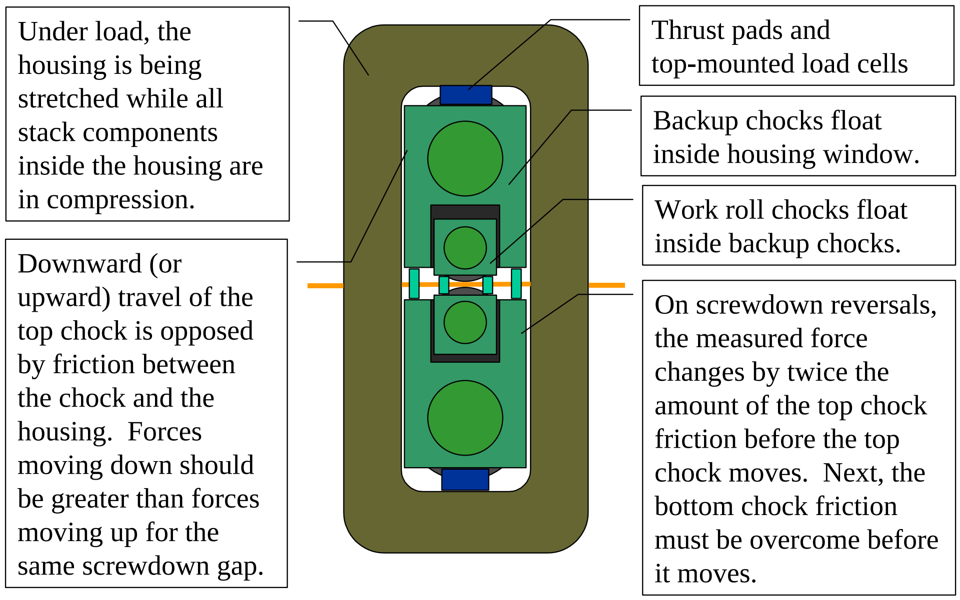
Performance Monitor Alarms

- Bar not tracked into FM (Ghost bar).
- Stand not calibrated after a roll change.
- Possible invalid roll diameter (based on stand measured yield stress).
- Possible wrong grade (based on overall measured hardness).
- HMD27 failed to pickup.
- Bar not backed past HMD27 after getting caught in the F1 sideguides
- Xray picked up before FM exit pyrometer.
- Loopers too low for at least two of the last four bars rolled.
- RM Exit width not used for four out of the last five coils.
- Adaptor in absolute limit for last three coils
  - stand gaugemeter, stand yield stress, stand torque, FM spread, stand thread speed trim, crop shear temperature, FM exit temperature
  - adaption may not null out corresponding errors.

Mill Modulus Display

- Displays the mill modulus curve(s) for selected stand(s).
- The last 24 mill modulus curves are stored for each stand.
- Plots show the measured force and screw positions taken in both the down and up directions with the current on-line mill modulus curve and the fitted curve.
- The operator and drive side forces and the differential forces are shown in the detailed view.
- The refresh button can be used to clean-up the display.

Mill Housing and Roll Stack



Using the Mill Modulus Display

- Problems with mill modulus data collection
  - Large shifts in the measured data. Think about what is being measured. Try repeating the test.
- Changes in mill modulus slope
  - The mill modulus curve is fitted to the down curve.
  - We want the on-line mill modulus curve to reflect current mill conditions since it is used by Setup and AGC.
- Indication of mechanical problems
  - Large differences between the down and up curves.
  - Maybe worse on one side of the mill. If so, expect steering problems.

Rolling Problems and Recommended Operator Actions

Rolling Problems

- FM setup errors
- Tracking or measurement problems
- Mass flow errors, looper stability
- Head and tail end camber
- Wedged profile and long edge
- Mid-bar scrapping
- Predictable errors
- When to call for help

FM Setup Errors

- Head end thickness errors could be due to one or more of the following factors:
  - Gaugemeter modeling including roll stack heating and wear.
  - Roll force errors due to material properties, strip temperature modeling or roll surface conditions (friction).
  - X-ray measurement problems:
    - Scrap or water interference
    - Bad alloy or temperature compensation
  - Mass flow problems - usually strip stretch caused by a poor thread.
- Stand thread speed adaption, gaugemeter adaption and yield stress adaption all work independently to try and correct any measured errors.
- Typically, between 1/3 and 2/3 of any error should be corrected from bar to bar through model learning.
- Try to guess the cause of any significant errors so that you can decide whether an offset or some other action is a good idea for the next bar.
- Under certain circumstances, it may be best to recalibrate the mill after the source of the problem has been found and corrected. Even then, some adaption will need to be undone. In extreme cases, archived adaptors can be restored to instantly “unlearn” any bad adaption.

Example#1: After a roll change, the first thread is very tight between F3 and F4 and very loose between F4 and F5.

- What is the likely cause for this problem?
- How will the looper speed trims react?
- How will the stand thread speed trim adaption react?
- Will the problem fix itself?
- What should you do?
  - The roll diameters entered for the F4 work rolls may be too small - The rolls are spinning faster than they should be.
  - For the first few bars, the looper speed trims will show a lot of slowdown for the F4 rolls. After that, the stand thread speed adaption will “hide” the error.
  - Internally, the model will think that the strip leaving F4 is thicker than it really is. The roll force multiplier for F4 will increase and the one for F5 will decrease for each product rolled.
  - If the error is not corrected, then the next schedule will also have problems.

Example #2: Scrap in the X-ray causes the strip to be measured heavy on the head end.

- How will AGC react? (Consider both gaugemeter and monitor loops.)
- How will the setup model gaugemeter gap offset adaption react?
- Will the problem fix itself?
- What should you do?

  - AGC will correct the gauge "error" - actually making the body of the strip too light.
  - Gaugemeter adaption will cause the gaps to be set lower for the next coil. After a few bars, there will be no apparent head end error. However, all coils rolled will be light until the scrap is removed.
  - Once the scrap is removed, the next coil's head end will be light. AGC will correct the gauge error.
  - It is most important to catch this early. You need to think about why that first coil might have been off gauge.

Example #3: A bar held in front of the mill until it was quite cold rolled heavy on the head end. The next coil is expected to roll at a normal temperature.

- The model is supposed to compensate for changes in temperature. Suggest possible causes for the setup error.
- What head end setup error might you expect for the second of these coils? Why?
- What should you do?

  - Unless the temperature was cold enough for adaption to be inhibited, the model will assume that it is underestimating the strip hardness. It will adapt the hardness multipliers for that product upwards and will likely be light on the head end of the next strip.
  - The roller may choose to second guess the model and add a small positive head end thickness bias.
  - Gaugemeter models should not be adversely affected by this type of problem.

Example #4: Due to a problem in the roll stack, the mill stretch curve on a stand is actually much flatter than the on-line curve (more stretch change for a given force change).

- On a product change resulting in higher roll forces, what would you expect to see? (Consider the problem for both the last stand and an intermediate stand.)
- How will model adaption react?
- Will AGC performance be affected? How?

  - Whenever the roll force increases from bar to bar, that stand gap will not be lowered enough. The strip will be tight on the entry side and loose on the delivery side.
  - Whenever the roll force decreases from bar to bar, that stand gap will be set too low. The strip will be loose entering the stand and tight leaving.
  - AGC will tend to be undergained. However, this is hard to tell just by observing the mill.

Tracking or Measurement Problems

- The system has been designed so that the FM is always setup to roll the next piece. If that piece fails to track to the FM, it can still be rolled as long as it shows as the next piece in tracking. However, it must then be removed from tracking or moved to the coiler to avoid "rolling it again".
- If the wrong piece is tracked to the FM or is the next to roll in tracking, the mill will be setup for that piece. If it is rolled, it will be rolled to the wrong PDI. Also, that PDI will be "used up" so that it will not be available when the piece matching that PDI is to be rolled. The tracked piece should be moved back. PDI bypass may be used to force the correct PDI when tracking is mixed up.
- Measurement problems will obviously confuse the system. The setup model will usually adapt to any bad measurements and must later "unlearn" through adaption.
- Our design philosophy was to allow adaption to proceed with some protection since the resulting system requires less maintenance than one with tight data validity checks.
- In cases of serious measurement errors which may have affected a large number of products, it may be best to replace the adapted model tables with a saved set. Model tables are saved daily at midnight and kept on-line for two weeks.

Head End Mass Flow Errors

- Head end mass flow errors result in the strip being too tight or too loose during threading.
- These can be caused by one or more of the following:
  - Poor speed setup
  - Stand roll gap or roll force prediction errors
  - Poor lead speed compensation
  - Poor speed regulation
  - Incorrect roll diameters
  - Incorrect operator speed biases
  - Head end hesitation (allows a loop to form)
- As with any observed problem, the first step is to try and understand the cause.
- If the error was fairly large, it is usually a good idea to use the speed verniers to bias the setup speeds so that the thread for the next bar is better.
- Normally, you should be able to slowly re-center the speed verniers as the model continues to learn. However, it is more important that the threads be good, so don't worry too much about off-center verniers.

Looper Stability Problems

Example #5: The looper angle varies wildly in bar and the strip is seen to "sag" over the looper just before the looper rises.

- The looper height control adjusts stand speeds in response to looper angle changes. Explain why the strip sagging on the looper confuses this control loop.
- What can you do to try and improve looper stability?

  - The looper is not tracking the strip properly. The control interprets a low looper as strip tightness and speeds up the upstream stand. By the time that the looper does rise to meet the strip, there is too much loop and then the control over-corrects tight again.
  - Try increasing the strip tension bias for that looper. With a higher tension reference the looper will tend to track the strip better.
  - A more labor intensive solution would be to try to interrupt the cycle by slowing the upstream stand a little just as the looper starts to rise so that the excessive looseness is corrected. However, in practice, if a looper wants to oscillate, it will start again on its own.

Example #6: A looper angle is seen to "step" up and down through the length of each coil rolled.

- Suggest a possible cause for this problem.
- What will be the effect of the problem on strip tension regulation?
- How will the looper height regulation be affected?
- What should you do?

  - If the looper is binding because of some mechanical problem, then the strip tension will have to change a lot before the looper will move.
  - This will tend to make the looper less stable than normal. Also, the strip tension regulation will be poor.
  - Have the looper checked by running the unbalance test to measure the magnitude of the problem.

Head and Tail End Camber

Example #7: The head end is hooked to the operate side leaving F5. In the body of the bar, the CLD is biased to the drive side.

- How could the mill level be adjusted to correct the camber? Suggest two approaches which will work.
- One of these approaches will also tend to center the body of the coil; the other will tend to make it worse. Explain.
- If the CLD was red flagged, what should you do?
- If the CLD was still green, what should you do?

  - The hook can be corrected by going up on the back of F5 or by going down on the back of F4 (and all earlier stands).
  - Since the body of the coil is running to the drive side, we should try to go down on the back of the earlier stands so that we can also go down on the back of F5 and push the strip back towards the center of the mill.
  - Since it is much easier to correct the camber with an adjustment to F5, it may be practical to combine an up move on the back of F5 with a down move on the earlier stands. The down moves on the earlier stands should be continued until you can make down moves on F5 and center the strip.

Example #8: The tail end of the strip is reasonably square but runs into the drive side of F4.

- Suggest two leveling options to correct this. Explain why each would work.
- How should you choose between the two?
- If you have just noticed the problem, when should you make your level adjustment.

  - The tail end is "wagging" to the drive side since there is more back slip on the operate side of F4. We need to let more material through the F4 roll bite on the operate side or send less material to the operate side of F4.
  - Watch the next thread carefully to decide whether to go down on the back of F4 or up on the back of the preceding stands. One or the other should be done before the tail end is rolled.
  - Occasionally, it may seem impossible to level the mill so that both the head and tail ends are straight. Try to determine why this is so and have the cause corrected.

Example #9: The tail end of the strip is long on the drive side entering F4 and runs into the drive side of F4.

- Is the problem due to F4 level or the strip entering F4? Think about what is happening to the F4 stack as the long tail passes through it.
- How will you correct this problem?

  - The long drive side tail is pushing the drive side of F4 apart. The wedged roll bite then causes the long tail to wag to the drive side.
  - Although it may be possible to steer the tail with F4, it is not the right thing to do. The problem needs to be corrected upstream so that the tail end is reasonably square.
  - Carefully observe the shape of the tail end to see where the long drive side tail begins to form. Go up on the drive side of that stand to correct it.
  - Note that once a long tail develops on one side, it is very difficult to correct in downstream stands (and not recommended).

Body CLD Errors and Long Edge

Example #10: The body CLD is biased to the drive side. Head and tail end CLD are acceptable throughout the mill.

- How should the FM level be adjusted to correct this?
- How can you tell whether the RM level should also be adjusted?

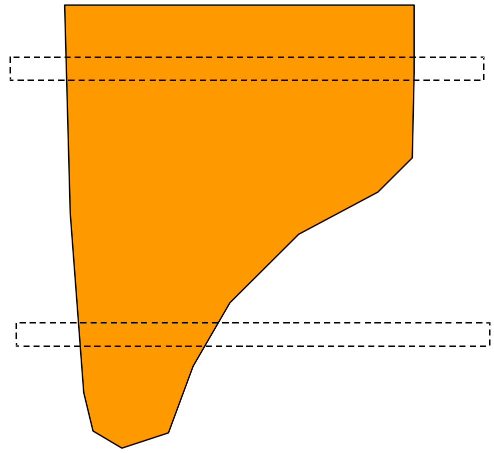
  - We would like to center the CLD for the body of the coil. Obviously, we want to do this without causing other problems.
  - Go down on the back of all FM stands. The corrections should be roughly proportional to the strip thickness at each stand. Make the corrections in reasonably small steps so that adjustments can be made for any steering problems that develop before they are large enough to be a problem.
  - If drive side waves or a long drive side tail develop at F1, see if the RM can go down on the drive side to help.

How to decide whether the RM needs to make adjustments to help with FM leveling:

  - Since the head and tail of the transfer bar are cropped square, watch for long heads and tails in the early FM stands.
  - If they exist, you can choose between FM adjustments to match the incoming transfer bar profile, or adjust the transfer bar profile to match the FM level.
  - If FM adjustments would tend to push the strip off mill center-line, then make RM adjustments first. If you are not sure, try leveling the FM first since the RM is already leveling to make a straight bar.

Interpretation of long edges:

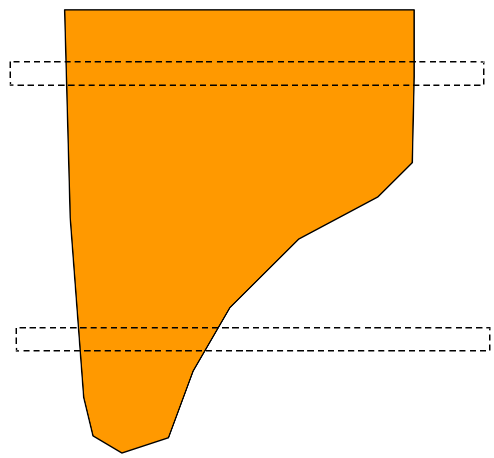
- As a long edged head or tail passes through a mill stand, the effective strip width and hence the force are lower than for the body of the strip. With less force, there is less mill stretch. The roll gap will therefore be thinner and the thickness of the long head or tail will be less than for the body of the strip. As a result, the long edge will tend to grow quite quickly.



The mill stretch near the tail could be 50 mils less than in the body. The strip will be that much thinner.

Correction of long edges:

- Once a long head or tail has started to form, it will tend to grow quickly in downstream stands.
- Do not be fooled into trying to level those downstream stands!
- The long edge needs to be corrected at the stand where it starts to form.



This tail will tend to run to the left as the mill stands are pushed open on that side.

Mid-bar Scrapping

Mid-bar scrapping may occur when:

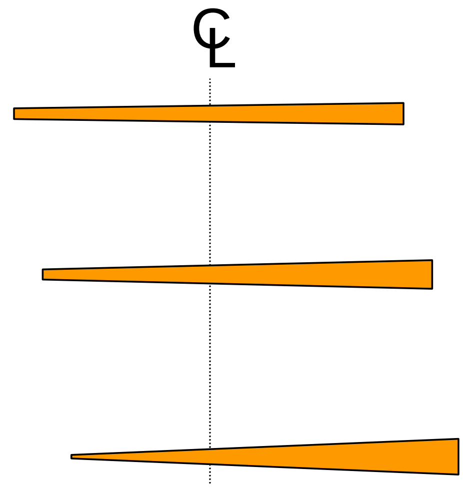
- The strip shifts hard to one side of the mill and folds over on the sideguides. See following slides.
- The strip shape is bad enough that the strip is chewed up as it passes through a mill stand. See following slides.
- A strip defect causes the strip to come apart. If the strip breaks, the mill will usually cobble.
- The strip goes loose enough to triple over through a mill stand. Usually, the result is a cobble.
- A roll spalls. The problem gets worse very quickly.

Mid-Bar Scrapping – Strip Shifting

- mill and folds over on the sideguides.
  - If the roll gap profile is wedged, then the strip will tend to be pushed to the open side of the wedge.
  - As the strip moves, the wedge gets worse and the strip is pushed harder.
  - This tendency is worse with low or negative strip crowns.
  - Running the sideguides close to the strip helps control the shifting.

If the guides stop the strip shifting before the sideways force is high enough to cause the strip to turn over on the guides, then the strip will not scrap

Strip shifting to the right:



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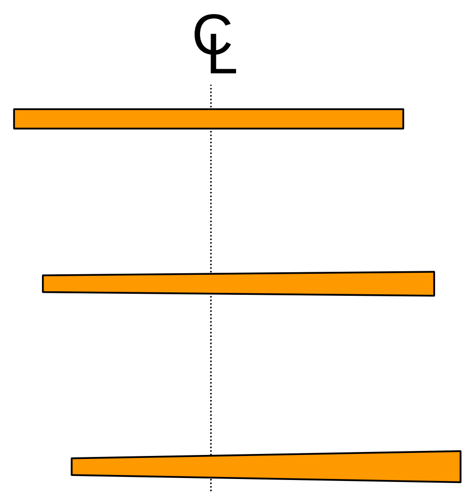
- Even if the roll gap profile is not wedged when the strip is in the center of the mill, if the strip shifts slightly, the roll gap will be forced into a wedge shape and the strip will tend to keep moving in that direction.
- The best you can do is to keep the mill level and the sideguides close to the strip.

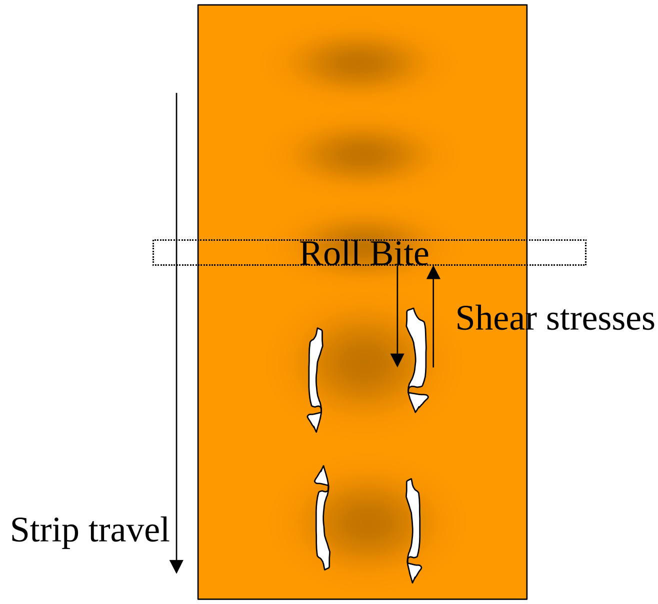
Sideguides will be more effective in controlling strip shifting when the strip is thick.

Strip shifting to the right:



Mid-Bar Scrapping - Bad Shape

- If the strip has very bad center-buckle or edge wave, then the shear stresses in the roll bite may cause the strip to tear up.
- The shape problems must be addressed through load distribution changes, roll bending or a roll change.



Concept of Predictable Errors

- Our modeling philosophy for this system is that if any error is predictable, then the model should be fixed so that it predicts and corrects for that error.
  - If during your hours, and days, and weeks, and months in the mill, you notice that some errors can be reliably predicted, get someone to do enough analysis of rolling data to confirm that the behavior is consistent and to quantify the sensitivities involved. For example, if coils from a cold furnace tend to roll lighter than coils from the other furnaces for certain grades, then we may need to adjust the yield stress versus temperature curve for those grades.
  - If you have found a predictable setup error, then the model can be modified to avoid it. Similarly, it should be possible to avoid predictable control errors.

When to Call for Help

Call when:

- you are having recurring tracking problems or if you think that one or more sensors are supplying invalid measurements
- the mill setup does not update when there is a bar in tracking
- you are getting serious alarms
- mill setups seem to be getting worse or are bad for all products