FUNDAMENTALS OF ROLL COOLING AND CONTROL OF FLATNESS AT PRIMARY COLD REDUCTION

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PREAMBLE

In the process of Rolling the most significant aspect is the generation of heat through friction and deformation in the roll bite and in a typical Cold Tandem Mill, work roll temperatures normally fall in the range of $55^{o}C – 70^{o}C$ with strip recoil temperatures and inter-stand strip temperature rarely exceeding $160^{o}C$ depending on product.

Roll Bite temperatures in slower heavily drafted stands can peak in the region of $300^{o}C$, diminishing with the reducing thickness and increasing speed in the downstream mill stands. In general the Temperature parameters are dependent on drafting, steel grade, gauge and width.

The most important aspects are maintaining uniform, stable roll temperatures, circumferentially around the roll and transversely across the roll with optimum thermal crowns and minimum differential in temperature in the upper and lower work rolls with effective heat extraction.

Because of the current demands on mills to process much lighter exit gauges from increased incoming hot strip thickness, much larger reductions are necessary on individual mill stands, such high reductions at a nominal width result in a larger area of contact with corresponding higher rolling force, friction and heat generation (see Fig 1 below "Area of Contact").

1.   HEAT GENERATION IN THE COLD ROLLING PROCESS

The Area of Contact (roll and Strip) between the hard work roll surface and the softer steel strip surface is where friction is created, deformation occurs and heat is generated.
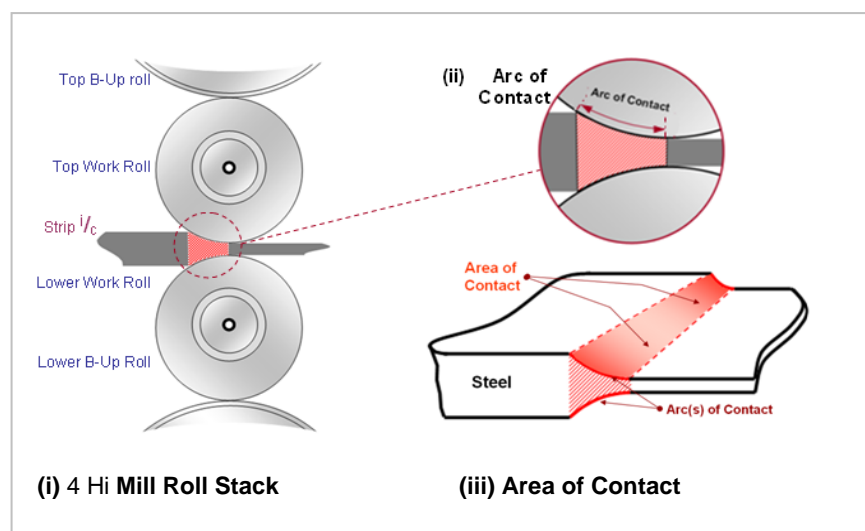
The "Area of contact" is defined by the strip width in the transverse plane and the circumferential "Arc of Contact" (AoC) between the roll and strip

The area of contact varies with the changing AoC and the strip width thus a small reduction gives a short arc of contact and combined with a narrow strip with gives a smaller area of contact and visa versa.

The heat generated at the frictional interface (Area of Contact) and through the energy used in deformation is transferred into both the strip and the roll in the roll bite.

Fig1, Area of Contact

2. DYNAMIC HEAT EXCHANGE IN THE MOVING STRIP AND ROTATING ROLL

In the rolling process where the area mass ratio is higher because the gauge is "thin" a large proportion of the "strip heat" is lost to air with further losses to such things as coolant wash-over, however, heat absorbed by the rotating roll is subject to a more complex thermal mechanism.

Heat will continuously migrate to cooler zones in and out of the roll body due to the localized elevated temperature in the area of contact (bite) and localized "chill zones" created in the impingement areas of coolant sprays on the surface.
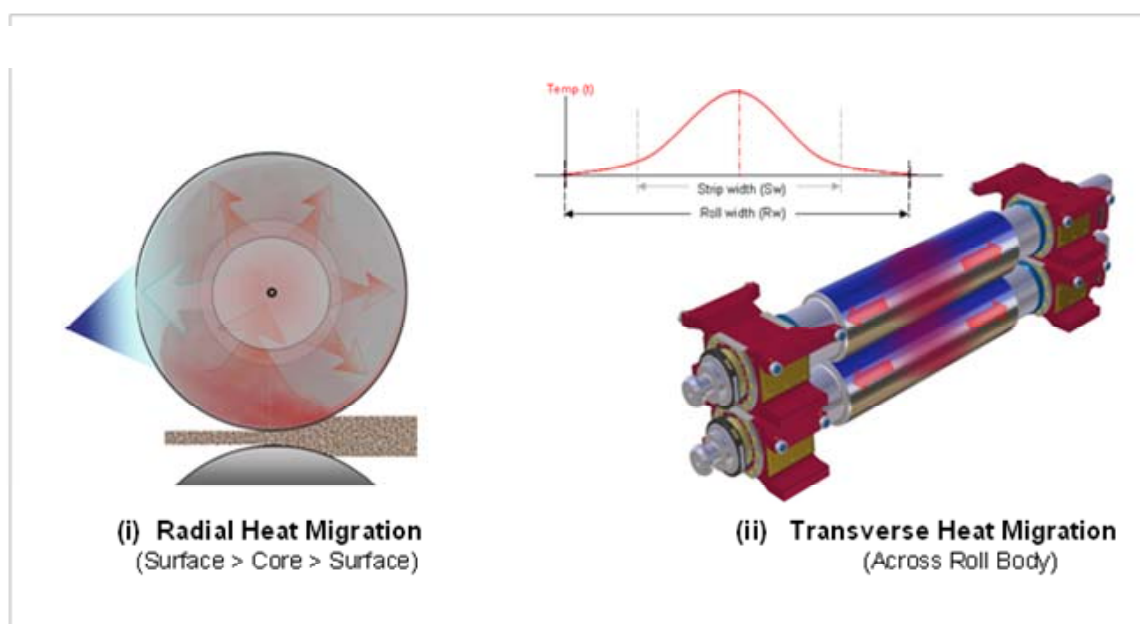

Fig 2, Heat Migration in Cold Mill Work rolls (Hotter regions shown in red)

This localized heat input / output process results in a non-uniform distribution of heat, circumferentially around the roll and transversely across the roll body.

Additionally the roll is subjected to Thermal and Mechanical Fatigue during rolling:

- Thermal fatigue as the roll cycles through the elevated temperatures in the roll bite and the lower temperature zones cooled under the coolant spray footprints.

- Mechanical Fatigue by mechanical compression (flattening) and physical distortion (deflection) caused by the rolling force and the necessary torque applied by the motor.

High reduction schedules combined with the requirement to produce a widening range of material cross-sections and a more varied range of softer and harder materials, results in increasingly greater challenges in the control of roll temperature and the effective transfer / extraction of heat.

Given the more diverse range of thermal conditions it is important to install efficient and robust roll cooling systems that can establish both heat balance and controllable thermal conditions around the work roll as well as across its width by controlled selective cooling and efficient heat transfer.

3.   THE KEY PRINCIPLES OF CONTROLLING PROCESS HEAT

Heat Balance:

To establish heat balance it is imperative that heat transferred into the roll is transferred out, however as the heat input and output is not distributed uniformly the fundamental requirement to achieve effective heat extraction is to ensure:

- The roll surface temperature range around the circumference is minimized which reduces thermal fatigue and roll surface degradation as well as lowering the potential for surface defects, impaired lubricant performance and roll wear.

- The transverse temperature distribution is controlled to assure strip flatness is not affected by excessive thermal crowning or excessive localized expansion across the rolling width and in particular at the edges (edge waves).

The average roll temperature is difficult to establish during the rolling process but the difference in the temperature at the exit of the roll bite will represent the highest value in the range and the temperature after the final cooling zone, in the area ahead of the entry bite should represent the lowest in the range around the circumference: it is necessary to apply coolant and configure sprays such that the difference in those two values is minimized.

It is also imperative to establish the same "temperature profile" on both top and bottom rolls as a pair to avoid differential thermal crowns and transverse profiles

Effective roll cooling is dependent two major design objectives

- Effective Header Geometry: most efficient positioning of headers.

- Effective Footprint Geometry to achieve homogeneous cooling.

Ideal positioning of cooling headers for the most efficient cooling <u>is rarely achievable</u> due to several other considerations related to: Mill furniture layout, physical space Lubrication application etc; hence it is necessary to apply fundamental principles in the design which assure the most effective layout given the limitations of space.

Fig 3, Ideal Coolant spray positions
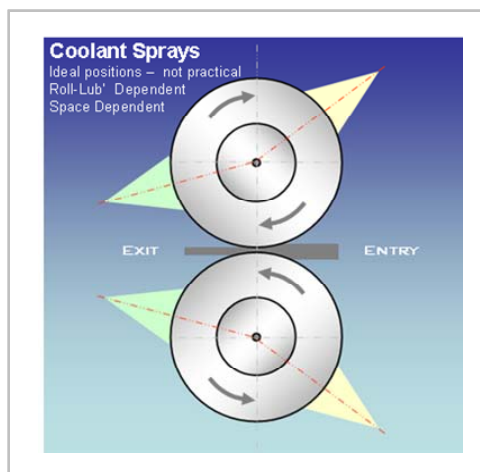
Entry Lubrication is either applied directly (DA) by a separate header and lub' system or indirectly (IDA) in the coolant

When direct application (DA) is deployed entry coolant headers must not impair the entry rolling lubrication

With indirect application (IDA), header flows can be balanced or with slightly reduced flows on the entry side.

Coolant Headers on the exit side should be as near to the exit bite as possible to efficiently control heat migration into the roll body

Previous studies indicate that exit side cooling spray impingement, being close to the point of heat generation (exit of the roll bite), is more effective in controlling heat migration into the roll core.

However coolant applied to the entry side effectively transfers away the heat migrating to the roll surface, after the exit side cooling zone. Therefore in practice the optimum balance of coolant distribution each side of the stand is best modeled to take account of the available space in the mill and best header positions around the roll (header / bar offset angles).

Footprint Geometry

Effective and precise Footprint Geometry is the fundamental requirement to establish a **Homogeneous Cooling** application and is achieved by the configuration of a uniform Cooling Area on the work roll, formed by the impingement of an array of adjacent sprays, equally spaced and positioned to assure consistent cooling intensity and impact pressure of the spray, transversely across the cooling area.
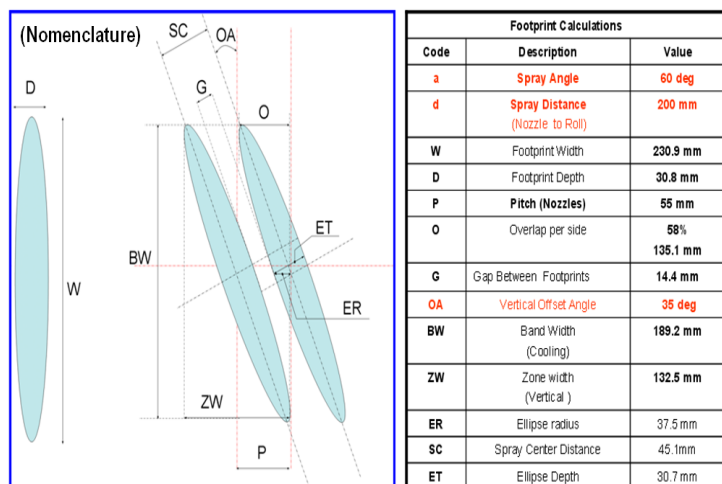

Footprint Calculations		
Code	Description	Value
a	**Spray Angle**	**60 deg**
d	**Spray Distance** (Nozzle to Roll)	**200 mm**
W	Footprint Width	230.9 mm
D	Footprint Depth	30.8 mm
P	**Pitch (Nozzles)**	**55 mm**
O	Overlap per side	58% 135.1 mm
G	Gap Between Footprints	14.4 mm
OA	Vertical Offset Angle	35 deg
BW	Band Width (Cooling)	189.2 mm
ZW	Zone width (Vertical)	132.5 mm
ER	Ellipse radius	37.5 mm
SC	Spray Center Distance	45.1mm
ET	Ellipse Depth	30.7 mm

Fig 4, Typical Flat Fan type footprint configuration

The configuration and layout of the individual coolant footprints should be designed such that they together form a single homogenous cooling band across the roll width resulting in consistent and uniform heat extraction across the spray cooling area on the roll.

In designing effective footprint geometry the key parameters relate to precise foot print and spray interaction on the roll surface with consistent intensity,

It is vital that appropriate overlaps and gaps between the footprints are a maintained with no spray interference between the adjacent footprints.

The key footprint parameters which have to be maintained are:

- The Gap to ensure adjacent sprays will not collide and interfere with each other.
- The Overlap to compensate for the increasing gaps between adjacent oval-shaped foot prints and the lower spray intensity at the outer width of the footprint due to curvature of the roll surface;
- The Offset angle which dictates the circumferential coverage and the area of cooling.

To ensure the actual foot print impingement is correct it is essential that header positions are precisely maintained in relation to the roll centre datums and pass-line (X-Y coordinates) so that impingement angles and impact pressure of adjacent sprays are identical, assuring uniform spray intensity.

Similarly headers that are dislocated or installed "out of parallel" to the work roll datums need to be repositioned to match design coordinates to avoid degrading of the spray impingement or creating transverse temperature gradients.

4.   FUNDAMENTALS OF SYSTEM DESIGN

Modeling

As mentioned previously the Ideal system layout is rarely achieved as the design has to take account of the mill space and the layout of the mill furniture which rarely affords optimum positioning of the system hardware but various modeling concepts are deployed to achieve the optimum design taking all parameters into consideration

Additionally, the thermal characteristics of different Mill applications are such that each system configuration is specifically designed to meet the thermal and lubricating requirements regardless of whether it is a DA system or an IDA system thus the application of modeling is key to ensuring the system delivers optimum cooling and heat transfer as well as utilizing the minimum level of flows.

Subtle changes from "ideal" system design criteria to one or more of the numerous dimensional and application parameters will impair heat extraction; the most critical impediments relate to poor liquid distribution, reduced spray intensity and loss of homogenous cooling due to gaps or interference between spray footprints.

Spray Impingement Model	Is used to establish liquid application characteristics and efficiency of the spray parameters, coolant volumes, flows, distributions and interactions on the roll surface
Heat / Energy Balance Model	Derives predicted heat input / output in the material, rolls and process, taking account of deformation energy and power
Heat Transfer Model	Establishes the predicted heat extraction (Q-dot) for the specific coolant application

Fig 5, Design Software (Models)

It must also be considered that where there is a significant differential in the rate of heat transfer (in and out of rolls) between top and bottom work rolls in the same roll stack, then a complex set of adverse conditions develop as regards roll temperature, differential thermal crowns, thermal crown height, profile, shape, surface and in the worst case lubrication, which is where modeling becomes a very important part of the design procedure to ensure.

Other Design Software

Other dedicated Design software is used to create effective nozzle / footprint layout and geometry to assure a high degree of homogeneity in the cooling area on the roll. This is dependant on maintaining discrete cooling footprints that interact without interference or creating hot and cool bands in adjacent cooling zones whilst achieving uniform surface flow of coolant on the roll surface.

Computer Fluid Dynamics is utilized to simulate the velocity and flow characteristics of fluid (coolant) through the system, headers and valves to ensure that the configuration does not create impediments to flow and losses through turbulence and resistance in the delivery system.

The objective in modeling is to design a coolant system that delivers sufficient volume of coolant onto the roll surface in an optimally sized cooling area such that there are uniform impingement characteristics and spray intensity across the width with optimum coolant coverage around the roll circumference.

Such a design assures efficient control of thermal profile and temperature distribution in the work rolls resulting in two key rolling requirements being satisfied

- The fast response roll bending is optimized by being kept within working range for the maximum time as roll condition and friction changes

- The strip flatness is maintained within standard quality parameters until progressive roll surface wear dictates that a roll change is due.

Symmetry

Thermal symmetry between top and bottom rolls is heavily dependant on:

- The application of equal volumes and flows to the top and bottom rolls (Flow symmetry).

- The geometrical and dimensional symmetry of the top and bottom header layout

Differentials in spray intensity and volumes on the exit versus the entry side of a roll stack are "by design" but it must be underlined that any differences in the top and bottom cooling application create problems.

Significant differences in cooling and consequent heat extraction on the top and bottom work rolls will result in temperature variation and physical differences in the thermal profile of each work roll because of a different thermal growth and thermal crown.

As mentioned above, it is well established that it is more effective to increase flows on the exit side in comparison to entry on a mill stand, on all but a final stands where it is normal to have no exit side coolant to avoid carry-over of coolant / lubrication so the layout on the exit side can / does differ from the entry side, but in considering top and bottom application: there should be no measurable difference in coolant application.
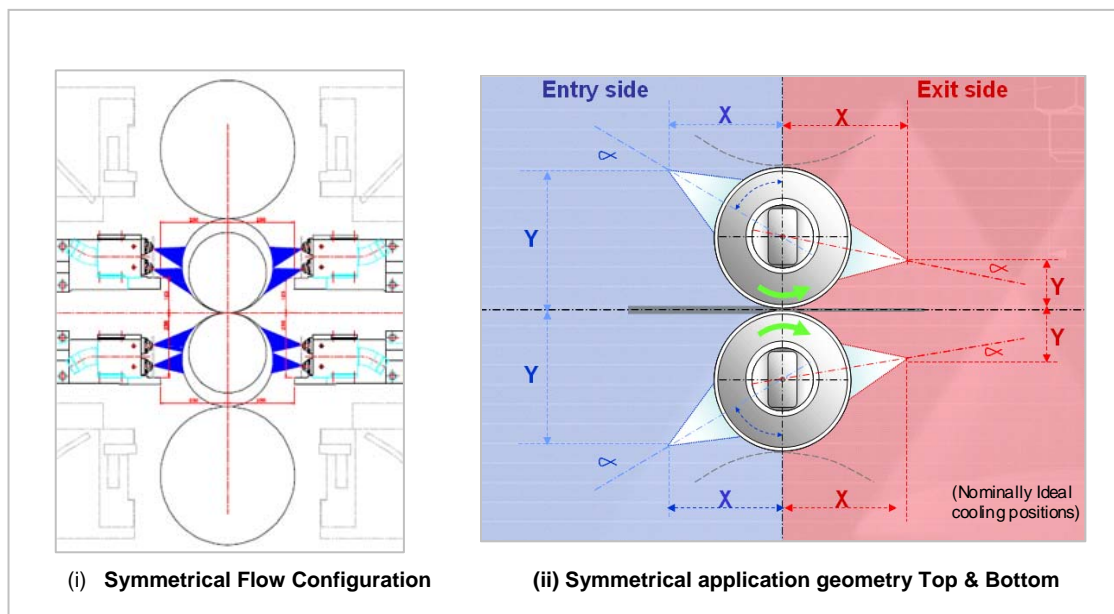

| (i) **Symmetrical Flow Configuration** | (ii) **Symmetrical application geometry Top & Bottom** |

Fig 6, Application Symmetry

Fundamental to achieving equal cooling top and bottom is the need to ensure geometrical and dimensional symmetry of the top and bottom header layout. Effective arrangement design is based on ensuring that header positions and impingement angles are symmetrical in relation to the mill pass-line and vertical centerline (x-y coordinates) through the roll stack and ideally perpendicular to the roll surface as shown in Fig 6.

Disparity in top and bottom cooling will invariably lead to differential thermal crowns, but differing arcs of contact (length), differences in friction, cooling and lubrication characteristics between the top and bottom roll, results inconsistent cold working on the upper and lower surfaces of the strip and ultimately uneven rates of roll surface wear in the top and bottom roll.

Considering the above points and the thermal conditions the main issues are:

- Differential Heat generated at the contact area of the individual work rolls ,
- Consequentially differential Heat transferred into each work roll in the pair.
- Differential in the levels of Heat transferred out of each work roll in the pair.

All mills have different components above and below the pass-line which result in the system layout and symmetry between top and coolant application being different.

- The layout of mill furniture, without exception, will rarely if ever afford optimum positioning of cooling headers; some headers can be positioned in ideal position but never all.
- Generally Mill equipment installed above the pass-line is different than in the lower position below the pass-line, consequently available space for headers, top vs bottom is different.

It is important therefore for system designers to take account of such limitations and minimize their effect by intelligently developing solutions to offset or compensate such anomalies in other aspects of the design and hardware specifications

Summary of the key Principles of System Design

1. **Optimum cooling application on top and bottom work rolls depends on:**
   - Symmetrical Header Geometry
   - Header Position in relation to Window and pass-line datums
   - Spray Angles and distances

2. **Effective control of circumferential heat migration**
   - Cooling zones established as near to the roll bite as space permits
   - Maximum Degree of Circumferential Coverage
   - Optimum balance of Volumes, entry vs Exit

3. **Effective control of Transverse Temperature distribution**
   - Effective Selective cooling in final stands
   - Control of center and edge coolant in back mills

4. **Uniform Coolant application**
   - Equal Volumes (top vs bottom)
   - Uniform Impact and intensity top vs bottom

5. **Homogenous Spray impingement**
   - Optimum Header configuration
   - Precise alignment of header to roll datums in all planes
   - Uniform Footprint Geometry, (Offsets, Gaps and overlaps etc)
   - Spray distance (nozzle front to roll surface) should be between 150 and 250mm

5.   FLATNESS AND SELECTIVE ROLL COOLING (SELECTOSPRAY)

Overview

Irregular and asymmetrical rolling loads across the work roll cause a non uniform transverse temperature distribution. Hot zones on the roll lead to an increase in the roll diameter in those particular areas, changing the transverse profile and crowning of the roll barrel. When the heat affected roll profile (thermal profile) is transferred to the material the profile and flatness in the strip is immediately degraded.

Consider if the center of the roll was allowed to continue thermally expanding with insufficient or no coolant being applied; as shown in **Fig 7.**

The strip would be rolled with an increasing center buckle corresponding to the hot region (centre) of the work roll and the bending system would eventually be unable to apply sufficient negative bending to maintain the strip shape.

Thus the roll would need to be cooled reducing thermal expansion (excessive thermal crown) in the center, eliminating the centre buckle (full shape) in the strip.
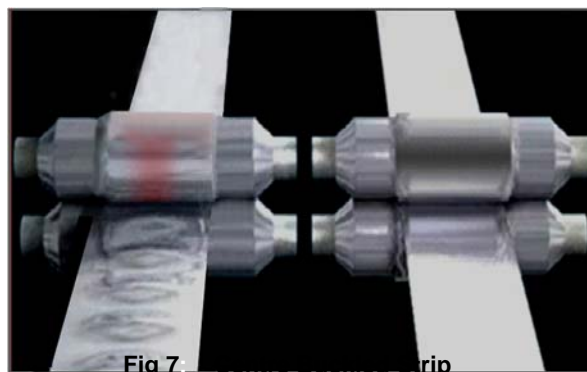

Fig 7   Centre Buckled Strip

It is imperative that the thermal profile and crown is controlled by selective cooling such that the roll bending remains "in range" and is not saturated.

The Nature of "shape"

Nb. Flatness of rolled strip is referred to as "Shape"

A primary cold reduced strip exhibits two flatness states:

- Flat - Exhibits no waves, buckles or pockets, line bow or cross bow

- Non-Flat - Exhibits waves, buckles or pockets, line bow or cross bow

The term "shape" describes a deviation in flatness which can be as a result of non-standard, uncontrolled rolling conditions or by design to suit a downstream process.

Over-rolling the centre of the strip will result in centre buckle and conversely over rolling the edges will result in waves at the edge of the strip.

A localized thickness reduction on the strip produces a corresponding   and proportional extension in strip length.
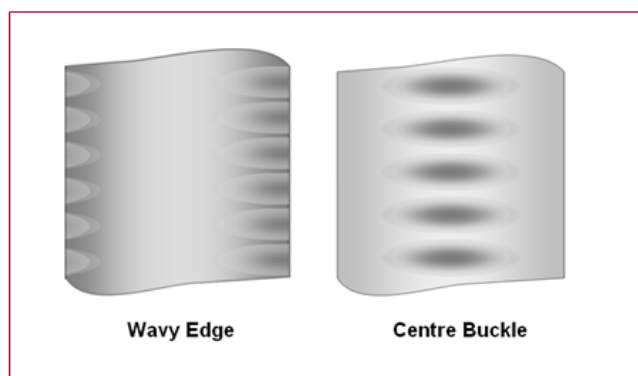
Physically a wave or buckle running through a length of Rolled strip results because the "unflat" section has been reduced more (thinner) and is therefore "elongated more" <u>and is constrained by</u> the adjacent shorter sections

Fig 8, Common Flatness Defects

If tension is applied to the strip then the tension or stress is most exerted on the shorter longitudinal sections not the longer buckled or wavy sections, hence, under tension in the mill, the over-rolled (unflat) sections exhibit a lower stress, thus the shape-roll measurement principle actually records the comparative longitudinal stress value as a distribution across the strip width and displays it as a deviation from the average stress.

Note: Because strip when cold rolled is under elastic tension (stretch) the shape in the form of buckles or waves cannot be seen unless the flatness / shape defect is gross.

Transient temperature changes in the Roll

Fig 9 illustrates how "localised" transient changes in temperature across the roll body create "localised" expansion of the roll when a spray is turned down/off.

The initial change is quite narrow and relatively fast on the roll but overtime it will grow in magnitude and area until a wave or buckle appears on the strip

With such a condition evident, the relevant Shape-roll sensor would register a lower stress value in the strip corresponding to the affected (hotter) zone on the roll and initiate the coolant spray.

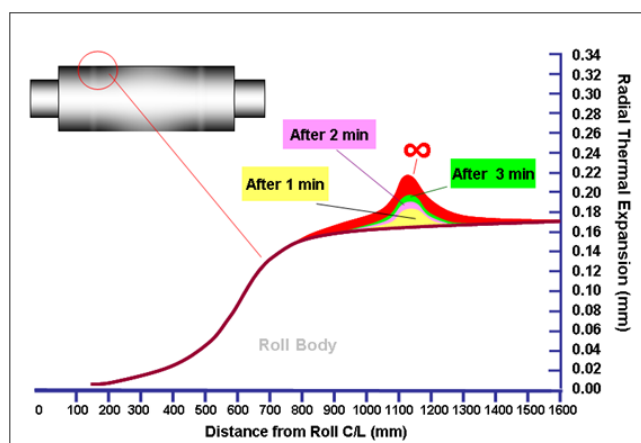The Selective cooling / shape control systems automatically measures and correct these effects

Fig 9, Transient temperature changes

6.   SELECTIVE ROLL COOLING AS PART OF A SHAPE CONTROL SYSTEM

The Selective cooling header is used in conjunction with a shape sensing device such as a Shape-roll, the Selective Roll Cooling configuration being dimensioned to exactly match the pitch of the shape metering roll segments (sensors)

To achieve controlled selective cooling, the work roll barrel is cooled by dedicated banks of spray nozzles equi spaced across its width precisely aligned to stress-measuring sensors (segments or rotors) on the shape roll, each nozzle/valve assembly being controlled by a solenoid valve receiving the electrical signal through an I/O unit from the shape meter control computer.

As a zone on the work roll expands through heat the c

corresponding section of the strip is reduced in thickness (over-rolled) and elongated proportionally throughout its length. However as that section is constrained by shorter zones a buckle (wave or pocket) is generated as shown in fig 7 and 8.

The buckled zones exhibits a lower stress than the shorter zones which is measured by the sensors in that zone on the shape roll

Each of the zoned spray banks can be operated independently to cool the "hot zone" on the roll body that has expanded in diameter, effectively reducing its actual diameter and eliminating the "over-rolling that has resulted in that corresponding zone on the strip.
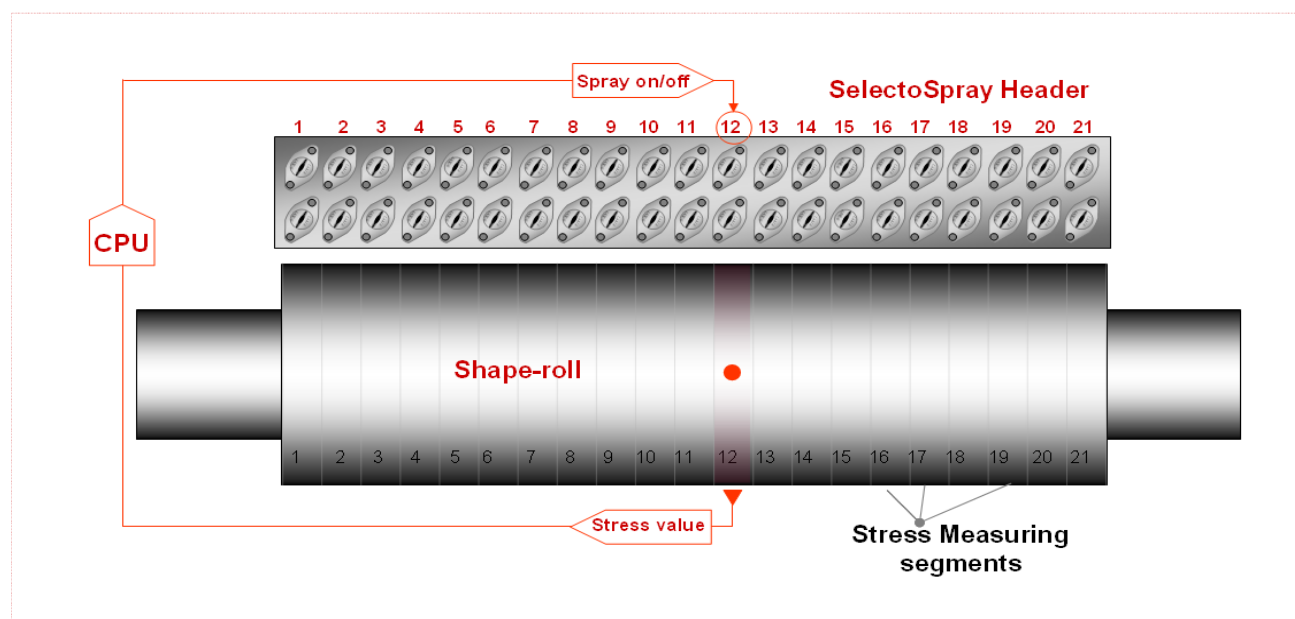

Fig 10, Shape control system concept

The Shape-roll roll comprises of an array of circular segments or rotors each housing several radially mounted stress measuring sensors ; typically a 26mm or 52mm pitch measuring the stress across the strip width as the strip (under tension) passes over the Shape-roll.

Each coolant valve / nozzle (spray) is controlled by feed back from a corresponding stress sensor on the shape roll or any other shape control system.

The selective cooling (SelectoSpray System) can also be controlled manually by the operators, semi automatically by a PLC, or automatically (closed loop) in conjunction with a shape control.

7.   PRACTICAL CONSIDERATIONS FOR GOOD FLATNESS AND EFFICIENT SELECTIIVE ROLL COOLING

Optimizing the Cooling System

A highly significant controllable parameter affecting the process for any given Tandem mill is the condition and effectiveness of coolant and lubrication systems throughout the mill.

Disciplined maintenance assures that the efficiency and condition of the system is optimum ensuring the ultimate degree of flatness and thermal control is achieved

There are two distinct subsystems for roll cooling in a tandem Mill

- The back mill system; simple single chamber or three or even five chamber headers in early stands

- The selective closed loop system; on the entry side of the final Stand comprising of a stress measurement device and selective cooling system.

For the Shape Control System to produce the best shape back mill header performance is as important, as the final stands as it is imperative that the strip profile entering the first stand is maintained through the preceding stands ahead of the shape system; Changing the incoming profile within the Cold Mill, in early stands generates a shape defect which the flatness system on the final stand will have to combat; thus it is correcting a defect introduced within the Cold Mill itself, as the Hot Rolled coil shape is degraded in the back mills due to uncontrolled process deviation.
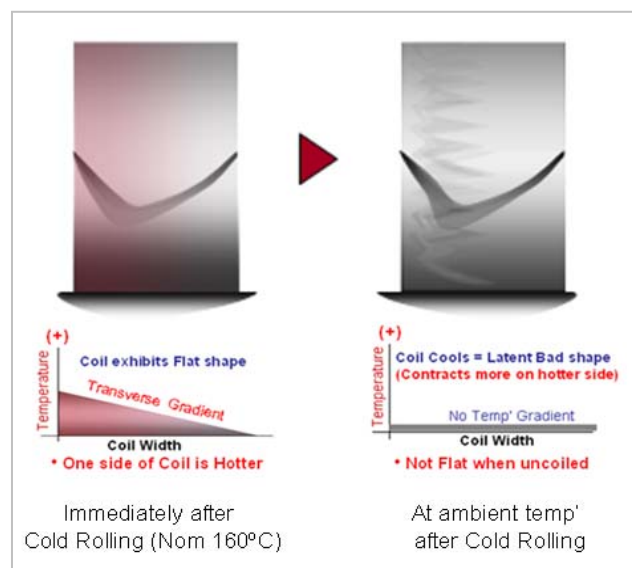
Strip and Roll temperature gradients

Fig 11, Transverse temperature gradients

Any gradient in transverse temperature across the strip will change/degrade the shape as a finished coil cools after recoiling.

Without complex monitoring of the transverse temperature profiles of work roll and the transverse temperature distribution of the strip the adverse cooling condition and consequent temperature gradients in the roll and strip will be undetected during rolling

If asymmetrical shape is being produced, the system selectively applies coolant to the roll body aligned to the zone exhibiting the bad shape on the strip (zone exhibiting lower stress)

If cooling is impaired **on one side** of the roll barrel then the roll will expand and the material will not only exhibit a corresponding shape defect on that side but will also develop a gradient in temperature.

When the shape roll detects the low stress zone in the strip the SelectoSpray will apply coolant to the heat affected (low stress) zones and if this does not eliminate the shape defect the mill would be tilted to reduce the rolling force and increase the gap on the side where the shape defect is evident.

As a result of such temperature gradients in the strip there will be asymmetrical contraction and resultant asymmetrical hoop stresses created as the finished coil cools to ambient temperature after final recoil.

Apart from the most modern and demanding installations, transverse strip or roll temperature distributions are not universally monitored (as a norm) through the mill so whilst a shape defect is physically corrected at the mill and the Shape-roll registers a symmetrical stress distribution and acceptably flat product for re-coiling: **an undetected temperature gradient will cause the flatness to deteriorate as the coil cools.**

This very common process deviation can create serious disruption on downstream units, particularly those with high speed/capacity entry tower loopers, such as CAPL lines and Galv' lines, as the shape defect and corresponding asymmetrical distribution in process tension will lead to tracking and strip breaks, particularly difficult if such a strip break occurs in a furnace section.

Retrospective checking of shape logs on the mill will show good shape based on the transverse stress distribution (I units) but the fact that the coil shape has deteriorated after recoiling and cooling indicates that an adverse temperature profile/gradient was present at recoil

To avoid creating temperature gradients it is necessary to assure that coolant is applied symmetrically and rolls are cooled symmetrically.

The major operational impediments to the system

- Uncontrolled dislocations of headers throughout the mill, particularly the heavily drafted stands (back mills) which are normally given little attention

  - Through mill events (such as wrecks, strip breaks etc)

  - Uncontrolled positional changes (Hardware modifications)

- Deterioration of System Hardware (nozzles, header condition, pumps, filters)

- Poor Coolant condition and consequential system Contamination

Deteriorating system hard wear starts at the Pump and ends at the Nozzle with all components in between, contributing to the overall deterioration of the system.

Fig 12, Spray foot-print checks

- **Nozzles wear** at a rate that is dependant on coolant cleanliness and system pressure and must be changed regularly based on footprint checks as shown in Fig 12)

- **Headers become constricted** with detritus and cholesterol overtime and suffer nozzle blockages, internal build up of soaps, detritus and sludge, reducing the system flow and spray nozzle exit pressure

- **Pumps progressively wear** dependent on the nature and cleanliness of the fluid being pumped but must be monitored for wear, Vibration Temperature and pressure.

- **Filters degrade** becoming partially or entirely blocked ("Blinded") with semi solid particulates detritus and soaps and can be "holed " ;

  - Reducing the entire coolant system pressure.

  - Disrupting front end feeding, (Bad front end shape)

  - Causing surface striping defects (differential oil plate out and cooling)

  - Causing excessive roll changes (surface marks) and in the worst case roll losses.

Poor Coolant condition and consequent system Contamination

Even when hardware is maintained properly and in good operating state the progressive deterioration of coolant condition will still reduce cooling efficiency.

The cleanliness of coolant must be controlled within strict parameters in order to minimize detritus, suspended solids and tramp oils.

- **Detritus and suspended solids**

    Coolant with high levels of detritus and suspended solids will increasingly create problems in pipe-work and headers as solid contaminants carried into the cooling system and over time will create flow restrictions; cholesterol in the pipe work and build up gradually reduces the system volume and are eventually transported to the nozzle tip.

    At points of turbulence and null pressure points, solids will build up by precipitating out of the coolant; on a mill stop will become viscous, ultimately dehydrated and solid.

    On mill start up the "build up" is re-hydrated by coolant and large particles will detach in the build up zones to be transported through the system, causing more localized build up at the headers with subsequent restrictions and nozzle blockages.

- **Nozzle wear**

    Coolant condition, in particular the level of suspended solids will affect the rate of wear in Nozzles; coolant highly contaminated with scale, oxide and other metallics will create premature wear in the nozzle orifice which in turn will erode the footprint geometry such that gaps will close and interference of adjacent footprints will eventually occur causing a loss of cooling efficiency and uniform homogeneous cooling across the roll body.

A non-uniform delivery of coolant across a header due to such things as a localized build up of detritus in one side of header chamber with reduced pressure / flow of coolant in that section will cause a variation in flow and impingement of coolant across the roll width which will cause such gradients.

It is imperative that coolant recovery processes are operated efficiently with critical components and processes such as skimmer systems, magnetic filters, pressure filters etc being maintained correctly and operated efficiently; In the case of selective cooling headers, solids should be maintained at < 150ppm with tramp oils being targeted at less than 0.25%

Chemical contamination of Coolant (Tramp oils)

Water is an excellent coolant but a poor lubricant and rolling solutions are more than 94% water with sheet operations being closer to 97% water.

Oil is a good lubricant but a poor coolant and contamination from process oils such as morgoil systems, hydraulic systems and mechanical lubricating processes in the mill can seriously affect the conductivity of coolant, as well as introducing erratic lubricating conditions, all of which result in uncontrolled changes in cooling and coolant, reducing pressure flow and spray intensity.

Tramp oil contamination promotes the build up of soaps in the system adding to the problem of "solid" building up in the delivery pipe work particularly cholesterol in the piping.

In the case of selective cooling systems contamination "sludges-up" components impairing operation of the closed loop Selective Cooling System (SelectoSpray).

- Tramp oils must be maintained at negligible levels **(<0.25%)**

Fig 13, contaminated valve components

Dislocations of headers and uncontrolled repositioning of headers

The principle cause of headers being dislocated are catastrophic events such as wrecks heavy where a header arrangement can be significantly impacted by the strip, being moved out of level and out of parallel with the roll center line.

Back mill wrecks create more severe impacts, where the strip is heavier in gauge, and is the most common problem as regards dislocations

Disrupted front end threading, particularly on slower heavily drafted stands will always result over time when the header positions are not maintained or restored.
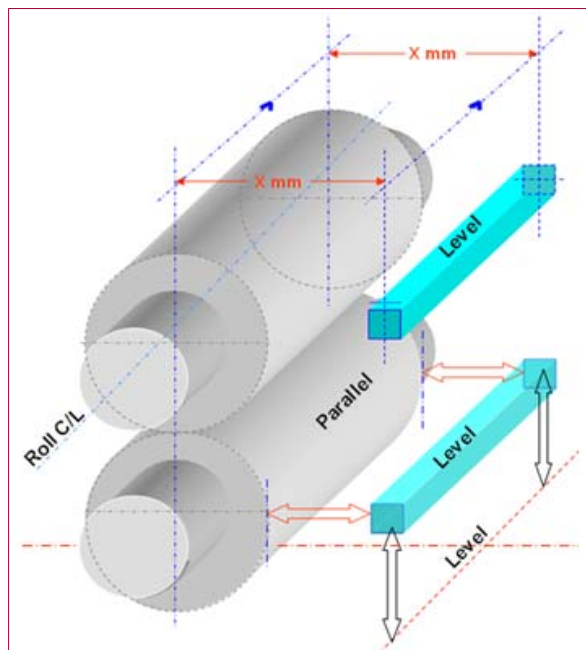

Fig 14 Headers must be parallel to the Roll Centerline and Level in all planes

Badly positioned headers result in temperature gradients and asymmetrical thermal expansion of the work rolls which in turn lead to bad shape through the mills which is masked by tension at mill operating speed.

The importance of maintaining headers in the design position is paramount as the header location is based on complex modeling criteria to ensure optimum performance.

Uncontrolled changes to system layout create an identical problem but are very gradual and remain undetected and ignored unless they become gross.

This however is a widespread and a universal problem particularly on older mills where apart from the effects of mill events, over the medium to longer term headers and hardware components are invariably subjected to "minor uncontrolled repositioning" and Mill arrangement drawings rarely match the surveyed positions of headers precisely, indicating both uncontrolled and unrecorded changes have taken place.

Over time progressive ad hoc adjustments of header positions to accommodate minor modifications to mill hardware are commonly a source of these changes but can prove disastrous when interference or bad spray impingement results.

Apart from the contribution to strip and roll temperature gradients through non-uniform spray cooling across the roll associated with detritus build up in a header the most common fault is related to, bad header position.

Headers that are not parallel to the roll or are out of level through dislocation or bad alignment create transverse temperature gradients.

In batch mill operations where C.R coils stand after rolling, if an undetected temperature gradient exists at recoiling, on cooling there will be uneven contraction of the coil which will result in a shape defect.
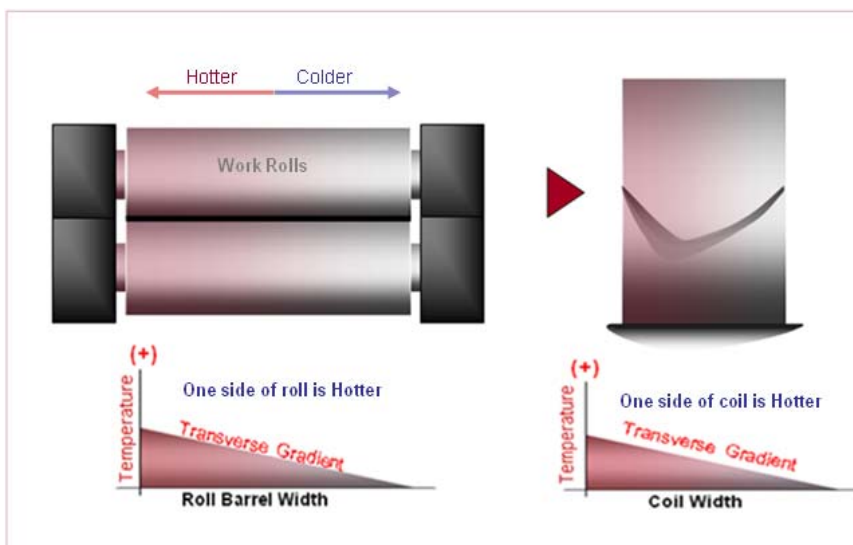

Fig 15, Temperature gradients (Rolls and Coiled strip)

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Experience shows that Temperature gradients are always evident in a mill stand but it is the magnitude of that gradient that is important as such it is therefore a practical necessity to minimize or eliminate all other contributory factors thereby ensuring that the gradient is minimized to a negligible level; hence the practical need to ensure that headers are set up parallel to the rolls whilst also delivering uniform flow and spray impingement over the roll barrel.

SUMMARY

Roll cooling systems are designed to extract heat from the rolling process in a controlled and efficient way that assures optimum control of Roll Temperature, transverse thermal profile of the rolls, strip shape whilst minimizing roll wear and degradation without unnecessary volumes of coolant.

Regardless of whether the header is a simple single chamber or a three chamber manual header installed in a slower "back mill" or a more sophisticated closed loop selective cooling header, the hardware design and function is robust enough to tolerate deviations in coolant condition, operating parameters and positional errors.

With a closed loop selective header, the dynamic control of the roll thermal profile and cooling, even with non ideal operating conditions, will produce shape of a different order to that which is achieved by manual control, however, adhering to the specified coolant parameters and system design standards ensures the full optimization of auto shape control in conjunction with a shape roll, achieving the highest standards of flatness on the finished product.

Establishing a uniform homogenous cooling zone across the rolling width with a uniform and acceptable thermal distribution (no gradients) is the ultimate goal as regards cooling and assures that the universal problem of post cooled shape after recoil is minimized.

Any dimensional change or deviation from the original design will adversely alter the very precise footprint configuration on the roll surface and Homogenous Cooling will be impaired and thermal differentials will be introduced between the in the top and bottom work rolls.

A well designed, cooling system in good operating condition will achieve several important objectives

- Maximum heat extraction for Minimum coolant volume applied
- Symmetrical thermal profiles on the work rolls (minimum gradient in temperature)
- Controlled thermal Crowns
- "Normal" Steady state roll temperatures
- No differentials in the thermal conditions between the top and bottom work roll
- Ensure that the roll bending system is kept within range by maintaining the appropriate thermal crown height and symmetry

In practice the three main priorities to maintain effective system performance are clear

- Maintain system geometry and dimensions throughout the mill cooling system
- Maintain coolant parameters
- Ensure hardware, <u>in particular Nozzles,</u> Pipes, pumps etc are condition monitored and replaced or rectified as necessary.

Like all mill systems and components the coolant application and hardware needs to be condition monitored and maintained and standard operating practices must be followed in all stands, not just on those fitted with a sophisticated selective cooling application but also in the slower "back-mill stands" where good incoming hot rolled shape can be degraded and go undetected, not being visible under tension.

This is not untypical and simply results in major corrections to shape being necessary in the final stand instead of fine tuning the final flatness.