AUTOMATIC FLATNESS CONTROL FOR COLD ROLLING MILLS

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1. INTRODUCTION

Automatic Gauge Control has, during the past two decades, developed from an interesting new gadget on some experimental mills into a necessity on practically all new cold mills.

Automatic Flatness Control will most probably follow the same pattern. It is considered already today as a necessity on all new high speed aluminium mills. Also in the steel field Automatic Flatness Control is seriously considered for practically all new cold mills.(1)

There are of course a number of different reasons why Automatic Flatness Control is becoming more and more important. Two of the most important ones are:

- Requirements from customers are becoming more and more stringent.
- With full control of strip flatness it is possible to increase rolling speeds and thereby production.

Other important factors are:

- To achieve a more uniform product
- To reduce the amount of scrap
- To reduce "after treatment"
- To reduce rejects (internal and external)

2. SHAPE OF FLAT PRODUCTS

In most mills actual shape control is completely dependent on the skill of the operator. It is often very difficult for the roller to judge the interstand shape due to the interstand tension.

Shape indicates the observable flatness or its deviations seen along the length of the rolled strip.

- Profile is defined (2) as the distribution of thickness over the width of the strip. The profile is determined by the shape of the unloaded work roll, the applied rolling forces, rolling speeds, strip width and steel grade of strip and rolls.
- Crown of the strip (fig. 1) is the difference in thickness between the middle of the strip and a point near the edge.
  When the profile of the strip is convex, the crown is positive and when the profile is concave the crown is negative. In case of equally distributed thickness over the strip width, the crown is zero and the profile is called flat.

  When flat strip with convex profile is rolled into a less convex profile, the reduction for the strip middle is larger than for the edge of the strip. This results in a larger length of the strip middle producing center buckle (fig. 2).

- On the other hand, when the strip edges are reduced more, wavy edges will occur (fig. 2). Should the edges of an initially flat strip have the same percent age of reduction as the strip middle the strip will remain flat.

Factors determining the form of the rolling gap

Slow-changing factors; ground work roll shape, wear and thermal expansion of the work roll.
The remaining factors are linked with the distribution of forces throughout the entire mill during deformation and only exist when the strip is in the rolling gap.

Slowly varying factors

Shape of work roll due to grinding and wear (fig. 3).
Thermal expansion (fig. 4). Thermal crown depends on time of control between work roll and strip, the temperature of the roll, strip and cooling water, the idle time, the amount of reduction of the strip and diameter and material of the roll.

Quickly changing momentary factors.

Deflection of work roll and back up roll (fig. 5).
Flatning of back up roll and work roll (fig. 6).
Poisson deformation of work and back up rolls (fig. 7).

To make it possible to control the flatness of a cold rolled strip during rolling one needs a flatness sensor.

3.
FLATNESS MEASUREMENT - ASEA STRESSOMETER

3.1
General

ASEA commenced the development of a flatness sensor in collaboration with the Canadian firm Alcan, at the beginning of the Sixties. Today the flatness sensor is the heart of our STRESSOMETER Flatness Control System.

The present lecture describes the STRESSOMETER system and presents the state of the act of flatness measurement and control.

3.2
System units

As can be seen from fig. 8, the STRESSOMETER system consists essentially of a measuring roll, electronics, video display unit, operator panel and the necessary wiring.
The measuring roll replaces a normal deflector roll on the exit side of the mill. A constant wrap-angle is not needed and therefore there is no need for an extra roll under the strip.

The electronics receive signals from the measuring roll, operator panel and rolling mill and transmit control signals to the mill as well as signals to the video display unit and recorder. The operator selects the control mode from his panel and can read the strip flatness on the video display.

3.3
Principle of measurement

The strip tension between the last stand and the coiler of a cold mill is normally so high that the strip appears to be perfectly flat. However, if there does exist some varitations in the specific tension across the strip, it means that some parts of the strip are stretched more than others, in which case the strip will show bad flatness when the strip tension is reduced or released.

The measuring roll is divided into a number of zones[4]. Each measuring zone measures the radial force from the strip with the aid of four magneto-elastic force transducers of PRESSDUCTOR(R) type.

This force represents the actual stress in the corresponding strip section. The stress distribution across the width of the strip varies depending on the relative elongation at different points and is thus a measure of the strip flatness. This is presented as a flatness profile on the video display unit.

3.4
Measuring roll

The measuring roll comprises a number of measuring zones, each with a width of 52 mm. Each of these measuring zones contains four magneto-elastic transducers mounted in axial grooves in an inner core[4]. These grooves are displayed 90° in relation to one another. A hardened steel ring is shrunk on over each measuring zone to protect the transducer, to give the roll a hard and robust surface and to transmit the force from the strip to the transducers.

The roll can, for instance, work continuously with a surface temperature of 175°C. It can also be subjected to a radial force of 170 kN (17 tons) continuously and almost 10 times this value momentarily.

The measuring roll replaces the conventional billy roll on the exit side of the mill, and no mechanical arrangements are necessary to limit the wrap angle or to protect the roll.

3.5
Electronics

The electronic part of the STRESSOMETER system is based on the ASEA DS-8 system, which is a programmable digital system using a microprocessor. As the system uses programmable electronics it is a very flexible system, and it is made to suit all types of cold rolling mills.

3.6
Display unit

The video display presents the deviations from the mean strip stress in a bar diagram. A thick horizontal line in the middle of the display represents the mean value. A network pattern with a vertical line for each 5 zones is presented to facilitate the reading. The total width of this network corresponds to the total number of measuring zones, i.e., to the mill width (see fig. 9).

Uncovered measuring zones are not displayed, and thus the picture corresponds to the actual strip width.

At the bottom of the screen there are two rows of dots. One of these rows indicates which cooling valves are switched on, and the other one indicates if a zone for some reason is switched off from the calculation and automatic control.

3.7
Recording of strip flatness

It is desirable to be able to record the measured strip flatness. This is also useful during commissioning.

Recording of strip flatness can be done at intervals of 100 or 200 meters or more frequently if desired during mill acceleration or retardation. Strip length is also recorded simultaneously.

A conventional two-channel Y/t recorder is used. A typical recording is shown in fig. 10.

As an alternative, the flatness over the entire strip length can be picked up by a video tape recorder and reviewed whenever desired.

3.8
Auxiliary functions

Advantages have been taken of the microprocessor to integrate a number of very useful auxiliary functions. These result in the system being self-checking and also facilitate servicing.

The system contains two independent programs for calibration. One is set during factory calibration and corrects for differences in sensitivity between the zones. The other program checks automatically during operation that the gain in each zone remains unchanged, i.e., that there is no drift, ageing or changes due to temperature variations.

The system also checks its own function and the incoming signals. Should something be wrong, e.g., one incoming signal is missing or an impossible combination of strip tension, width and thickness has been set, the display starts flashing.

Modern electronic systems have an inherently long MTBF (Mean Time Between Failure). However, it is important to ensure also that the MTTR (Mean Time to Repair) is kept short. Therefore extensive testing and checking facilities have been incorporated in the system.

A number of test programsare stored in the microprocessor memory and can be activated by knobs and selector switches on a mimic panel in the control cubicle (see fig. 11). Some of the checks that can be made are:

a Rapid test of the entire electronic system
b Checking of individual measuring zones
c Checking of measuring roll function and sensitivity
d Checking of video display and associated electronic modules.

4. MEASURING ACCURACY

4.1 Definition of accuracy

Factors influencing the measuring accuracy can be related to the measuring roll, the electronics, the display and, last but not least, the mill. Errors introduced by strip temperature gradients across the strip are quite appreciable. The following points are very important when defining measuring accuracy:

- Accuracy must be defined in terms of deviation of stress from the displayed stress profile, and not in percentage of the applied force, as this does not tell the user anything of interest nor can it be used when defining the accuracy of a flatness control system.

- The conditions under which the accuracy is given must be defined.

- The influence on accuracy of errors derived from the mill itself, e.g., due to uneven temperature distribution in strip or poor alignment.

4.2 Checking of STRESSOMETER measurements

The measuring accuracy of the STRESSOMETER shape-meter has been checked a number of times. Below are listed some of the methods used. Great care must be taken to choose the correct method as the accuracy to be verified is very high. In view of the large number of installations where the accuracy has already been verified, we consider it unnecessary to spend more time and money only to find that there is no method more accurate than the STRESSOMETER shape-meter itself.

(i) Non-destructive methods:

a Determining the "Flatness Index" - as Alcan does by measuring the amplitude and the number of waves on a given length of metal sheet; the metal sheet is placed on a surface table. This method provides only an indication of the mean flatness - the corresponding STRESSOMETER zones cannot be checked.

b With the aid of the "shadow method"; light falling at an angle projects the shadow of a wire stretched across the metal sheet; the length of the shadow provides an indication of the "unflatness" of areas corresponding to the STRESSOMETER zones.

(ii) Destructive methods:

a With the aid of the "Alcan method"[5]; strips are scribed on the sheet while it is stretched and without buckles, after which it is cut into strips; the lengths of the strips are then compared in the stress-free condition and the variation in the lengths represents the flatness.

b With the aid of strain gauges; the sheet is supported in a specially designed rig and the strain gauges glued to the areas corresponding to each zone; the sheet is stretched, the strain gauges read off and the flatness is calculated from the differences in tensile stress; this method has been used by Hoesch AG of West Germany, among others.

c With the aid of the "Pearson method" (6); this is a method which is simple to apply and is the one that has been most widely used up to now - the sheet is cut into strips (see fig. 12) and the curvature of each strip element after relief of buckling stresses when cut from a sheet, reflects the elongation in each section; this elongation can be transformed to tensile stress, in accordance with Hooke's law, and the profile developed from all tensile stresses together can be directly compared with the one indicated by the STRESSOMETER shape-meter.

5. AUTOMATIC CONTROL OF STRIP FLATNESS

5.1 General

In order to control flatness in 4-high mills, a number of control strategies have been integrated in the system, namely the thermal crown control system, the feedback to the roll bending system, a MONITOR and a feedback to the screwdown system.

5.2 Thermal crown control

One way of controlling strip flatness is to control the distribution of roll coolant along the work roll. For manual control this is a well-known method used over many years in aluminium mills (see fig. 13a).

The optimal distribution of cooling sprays should be one individually controlled cooling zone per STRESSOMETER measuring zone (i.e., 52 mm valve pitch).

This is already accepted as a standard in aluminium mills. However, a distance somewhat more than 52 mm between sprays can be accepted. The STRESSOMETER system then recalculates the output signals into one signal per cooling zone and the video display shows one bar or line for each colling zone.

With manual control over selective cooling it is normal practice to have valves with proportional control of the flow so that the operator can find a position giving exactly the correct amount of cooling for each zone.

Due to the relatively long thermal time constant of the work rolls, it is possible to achieve the same result using simple on-off valves operated with a controlled ratio between on-time and off-time. This method of operation would be impos sible to use manually, but presents no difficulty to an automatic system.

5.3 Control via work roll deflection

In this control system the STRESSOMETER signals are used for controlling the roll bending system. These signals are assessed as shown in fig. 13 b, i.e., the flatness of the middle edges of the strip is studied.

In the CPU the signals are weighed in a certain way and the sum of the contributions of the edges (A+B) and of the middle (C) are evaluated and the CPU gives an order to the roll bending system according to fig. 14 a, b, c or d.

5.4
Control via screw downs

This control is used in combination with the control via the roll bending system. Its purpose is to eliminate flatness defects varying linearly over the strip width.

The STRESSOMETER signals are assessed according to fig 13 c, i.e., flatness of the strip edges is studied. In the CPU the signals are weighed and the difference between the contributions of the edges (A+B) is evaluated according to fig. 14 e and f.

5.5
Control via roll deflection and roll cooling (MONITOR)

This control system combines two separate systems, which have been described already. Symmetrical flatness defects are eliminated via the roll bending system, while local flatness defects are eliminated via the roll cooling system. To be able to increase the total control range of the system, both systems are interconnected via a MONITOR (see fig. 13 d). This ensures that the roll bending system operates within its control range. The thermal crowning of the rolls can be changed through the monitor by changing the number of zones to be cooled under "Automatic Thermal

Crown Control" without the cooling profile being altered. The working range of the thermal crowning is generally several times greater than that of the mechanical crowning.

5.6 Automatic roll deflection control

Another system for Automatic Flatness Control that should be mentioned here is the Automatic Roll Deflection Control, ARDC.
This system senses changes in the rolling load and compensates automatically for the changes in work roll deflection that otherwise would occur due to changes in the rolling load (see fig. 15).

This is a very quick-acting system as there is no transport delay at all, but the system needs a manual presetting of the roll bending. The system can be connected to the STRESSOMETER equipment for closed loop control as described above.

5.7 Flatness reference setting

It is sometimes of interest to produce strip with a specified flatness which is not dead flat. One example is when rolling strip with edge cracks. It is then desirable to roll with a loose edge but with the rest of the strip flat.

This flatness profile, or any other desired profile, can be entered into the STRESSOMETER system and used as a reference value for the Automatic Flatness Control.

6. COMPENSATIONS

6.1 Partly covered edge zones

It is sometimes of great importance to receive correct information from the edge zones. A separate program calculates the degree of coverage and corrects the output signal from the edge zone in relation to the degree of coverage (see fig. 16).

This program covers two types of correction:

a The strip is assumed to lie symmetrically over the measuring roll, and therefore both edge zones are corrected in the same way.

b The strip is assumed to lie asymmetrically over the measuring roll and therefore each edge zone is corrected separately. For this correction the position of the strip edge must be measured with a position transducer.

6.2 Uneven strip temperature distribution

Strip temperature gradients across the strip introduce differential thermal strains which are sensed by the STRESSOMETER system during rolling. As these temperature gradients disappear on the final product,the resultant flatness will no longer be the same as during rolling. The magnitude of thermal strains is 1.7 $N/mm^2/^oC$ in aluminium and 2.5 $N/mm^2/^oC$ in steel. As typical strip temperature differences in aluminium mills are in the range of 2-5^oC, the effect of the gradients is of some importance. As the operator, or a control system, controls on zero flatness deviation, this will consequently result in an unflat final product if no correction for strip temperature gradients is made.

The microprocessor contains a program enabling a certain profile compensation to correct the measured flatness profile.
The magnitude of the profile compensation can be selected on the control panel. As a further development, signals from a continuous strip temperature profile measuring device can be used for on-line correction.

6.3 Deflection of the measuring roll

The measuring roll, which is homogeneous and rigid, is never theless subjected to a certain degree of deflection when strip tension is applied. In extreme cases where the strip tension is very high while at the same time the angle of wrap is large, the roll deflection may affect the system measuring accuracy. The normal measuring program is supplemented in such cases by a correction factor which compensates for the roll deflection, taking into account its weight and width as well as the strip tension and width.

6.4 Uneven coil build-up (Coil crown)

One of the problems experienced when trying to produce absolutely flat strip is the coiling process itself. If the cross-sectional strip thickness profile is not rectangular but the strip is, for instance, thicker in the middle (strip crown) this can be reflected on the coil build-up.

The diameter of the coil and thereby its circumference will then be greater at the centre of the strip than at the edges. This will become more and more evident as the coil builds up.

When the strip is wrapped around this coil it has to be stretched more in the middle where the coil circumference is greater. In some cases the yield point can be reached and the elongation becomes permanent.

Thus, a strip may be rolled with Automatic Flatness Control and leave the roll gap absolutely flat, but after coiling (especially on a large coil) it is possible that it is no longer flat. This occurs when rolling soft aluminium alloys.

The methods available for solving this problem are the following:

- try to minimize strip crown
- if possible, use less front tension in order not to reach the yield point.
- use a compensation in the STRESSOMETER system (Flatness Reference System). With this, the strip can deliberately be rolled short in the middle to an extent proportional to the coil diameter.

It should be noted here that this problem is in no way created by the Automatic Flatness Control. It is a general coiling problem that will occur any time strip is coiled with an unfavourable combination of strip tension, coil crown and yield point. On the contrary, the Automatic Flatness Control can be used in such a way that this problem is reduced.

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