Improving Product Quality with Advanced Hot Width Measurement and Automatic Width Control in Hot Strip Mill of Bokaro Steel Plant

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ABSTRACT

The Hot Strip Mill at Bokaro Steel Plant is a continuous 2,000 mm 4.0 MT wide strip mill. The mill is highly automated and Level -3 controls are executed for high level of HR coil production with stringent quality parameter controls. The Roughing mill is recently modernized providing the mill with the cutting edge technology of controlling bar thickness and width to match nominal gauge requirements.

02 nos. of accurate width measurement gauges with Laser Sectioning principle were installed after RR2 (reversible roughing stand 2) and R5 (roughing stand 5). The technology is such that the measurement is not influenced by strip wandering, bouncing or tilting. The width control is done by AWC (Automatic Width Control) .The aim of this control is to produce a bar having proper width profile in order to get a constant width along the piece at the rolling end. The presence of hydraulic capsules on the edger stand gives the possibilities of correcting the dis-uniformities coming from both roughing mill processing. The rolling schedule calculations are an iterative process based on various controls such as impact drop compensation, short stroke control, HAGC control and position loop control.

Today’s cut throat competition over providing better quality as per norms in the finished product specification has called for up-gradation of the finishing mill exit width measurement gauge which was taken up by instrumentation department. The recently commissioned width Gauge has been specially designed for the non-contact measurement of width of hot strips during the production process in hot rolling mills.
with high accuracy and reliability. A complete system consists of 04 line scan CCD cameras which gives actual width, width deviation, centre line deviation and camber and are located in a gauge house above the mill centerline. Edge detection with highly sophisticated grey level image processing technique is used to detect the true edges of the hot strip with high accuracy (+/- 0.5 mm) and reliability under not ideal environmental condition.

It is now possible control under width and over width of HR coils and width rejection rates are consistently going down.

Key words: width, gauge, mill, camera, AWC, hot strip, HSM,

INTRODUCTION

Nowadays, the increasing needs of the customer for secondary process streamlining, automation, yield improvement, cost reduction and higher quality materials; steelmakers are strongly requested to supply flat rolled products satisfying these requirements. Under these circumstances, quality requirements from Bokaro, HSM are also getting more stringent than before, covering various sector use, Hi Carbon steel uses, etc. Apart from uniform mechanical and metallurgical property, the requirements include higher accuracy of product size and shape in thickness, width, profile and flatness. To meet the requirement, major modernization project was taken up in Bokaro Roughing mill along with finishing width measurement system up gradation. All these lead to many benefits due to first ever measurement and control of bar width in 02 strands of roughing mill in Bokaro and precise measurement of coil width in finishing mill. Now there is continual improvement in width control in HSM products.

DESCRIPTION OF HSM

The Hot Strip Mill at Bokaro Steel Plant is a continuous 2,000 mm 4.0 MT wide strip mill (fig 1). The mill is highly automated and Level -3 controls are executed for high level of HR coil production with stringent quality parameter controls. In the Reheating furnace area, 04 walking beam furnaces of 300 T/Hr capacity uniformly heat concast slabs to a temperature of approx. 1200 deg C. the Roughing area consist of 04 stands including 01 reversible stand (02 high) and 03 normal stands (04 high). This stage reduces the slab
thickness from 225 mm to 32-36 mm for final processing in finishing mill. The Finishing mill consists of 4 high 7 stands with AGC control. The finishing mill reduces the incoming Bar of approx. 35 mm to the final ordered thickness from 1.8 mm to 18.0 mm. and finally 04 automating coiler takes care of the coiling of the finished product.

**ROUGHING MILL**

The Roughing mill is recently modernized providing the mill with the cutting edge technology of controlling bar thickness and width to match nominal gauge requirements. 02 nos. of accurate width measurement gauges with Laser Sectioning principle were installed after RR2 (reversible roughing stand 2) and R5 (roughing stand 5). The technology is such that the measurement is not influenced by strip wandering, bouncing or tilting.

**MODERN WIDTH GAUGES FOR BAR WIDTH MEASUREMENT IN ROUGHING MILL**

The recently commissioned gauges are designed to measure the width of flat hot Bar/Plate. The key features of the *Widthgauge* system are:

1) In-line non-contact measurement and without moving parts with high precision.
2) Real-time measurement of Hot Bar width brought back to room temperature.
3) Real-time measurement of Hot Bar position as to the roller table center-line.
4) The measurement accuracy (+/- 1.2 mm, 2 sigma) is not affected by vibrations and by the center-line deviation between the rolling axis and that of the Hot Bar itself.
5) The active illumination on the Hot Bar occurs from above by LASER. Each Laser unit (Fig. 2) illuminates one half of the Bar. But each camera reads both edges of the Bar.

Fig 2.0: WIDTH GAUGE

In this system, the measurement of a Hot Bar width is carried out by monitoring the shadow produced by the bar edges from above, when this is illuminated by a laser pair. The shadow is monitored by two stereoscopic CCD cameras, and the information obtained is processed by means of dedicated electronic circuits within the device. All the system components are found inside a single cabinet (Fig. 3), which, seen as a whole, can be considered as an optical sensor that provides measures and processes data related to the Hot Bar.

Fig 3.0: WIDTH GAUGE ENCLOSURE
Each camera is made up of a lens for larger formats, a linear CCD (3648 pixels), appropriate optical filters, adequate lens and monitors the whole Bar width. The CCD sensors generate an analog signal that is digitalized by means of special circuit boards; the “Diameter Terminal Equipment” subsequently processes the signals acquired by means of recognition techniques and software algorithms, to obtain the desired dimensional data.

The main processor board operation is based on the FPGA (Field Programmable Gate Array) and CPLD (Complex Programmable Logic Device) devices. The WIDTH system uses two processor boards, whose main functions are to digitalize the video signal generated by the camera unit, and to pre-process data. In addition to acquiring data coming from the camera unit, the boards manage the interface with the two Laser sources (660 nm), receive and generate various I/O signals and communicate with the network by means of a special data bus.

All equipment and devices are fitted inside an IP67 sturdy cabinet, whose walls are made of metal with the addition of thermal insulation to limit the effect of radiation coming from the material measured.

**AWC: Automatic Width Control setup**

The width control is done by AWC (Automatic Width Control). The aim of this control is to produce a bar having proper width profile in order to get a constant width along the piece at the rolling end. The presence of hydraulic capsules on the edger stand gives the possibilities of correcting the dis-uniformities coming from both roughing mill processing. AWC profile calculation bases on:

i) Primary data Input (Target width)

ii) Width Draft (from edger setup)

iii) Material data (from steel quality, yield stress)
HAGC FOR WIDTH CONTROL IN EDGER

It computes the movements for edger hydraulic capsules, during width reduction passes, in order to compensate bar head/ tail defects introduced by edger draft and subsequent thickness draft. The behavior of the spread on the Head and Tail ends is different from the bar body because of the material flow in the lateral direction, so increasing the enlargement.

The edger position reference is calculated from entry width pass and width draft by taking into account the edger roll shape.

HAGC system consists of 02 Edger drives (OS & DS) and 02 Edger force cylinder chokes. Each choke is comprised of two force cylinders (top and bottom) & one Pullback cylinder.
Top and bottom long stroke force cylinders regulate the position of relevant rolls (each side) by moving the common chock carrier simultaneously. Pullback cylinder for each side keeps the long stroke cylinders in contact with the chock carrier.

**HAGC SYSTEM FOR AUTO WIDTH CONTROL**

Edger Gap determines the width of the Bar. Edger gap (or width) is equal to the sum of drive side position plus operator side position both measured from the centerline. (Fig : 4) Position set point for the given width is converted under consideration of the chosen centerline into appropriate position set points for the hydraulic cylinders. The Control system calculates the new set points and adjusts the gap accordingly. During rolling of the Hot Bar, the cylinder position is continuously disturbed by changes in the edger roll bite. These disturbances are corrected by the position control loop without necessarily requiring a change to the set-point reference.

**THE CONTROL SYSTEM**

The HAGC position control method to be applied is the Average plus Differential position control where top and bottom cylinders (Fig: 3) are controlled by two interconnected loops, one for the average position and one for the differential position. In this manner both the cylinders, top and bottom, are automatically synchronized during movements. By using this dual control method, the differential movements of the cylinders, top to bottom, are Continuously monitored and controlled (Fig: 5).

![Fig 5.0: Average plus Differential Control](image-url)
The average set-point reference is compared to the average position feedback to produce the average error. The differential set-point reference is compared to the differential position feedback to produce the differential error. This average error and the differential error are passed through PID controllers (Item 2) and the outputs are linearised (Item 4) to compensate for the servo valve gain variation. A second function is to compensate for the oil compression (Item 5), varying with the stroke of the pistons of the hydraulic adjustment cylinders.

The average and differential PID outputs are drives the specific top and bottom servo valve (Item 6) drives. A velocity feed-forward reference (Item 1) based on the anticipated cylinder stroke rate during long-stroke movement are added to both top and bottom servo valve drives. As oil flows into or out of the cylinders the actual positions moves towards the average and differential reference values and the position errors reduce to zero.

This control is extremely effective while reducing width as per Level-2 setpoint in Reversible Roughing Strand where the slab width is reduced as per Level-2 setpoints in each pass.

A Model for correcting the Bar width by Edger gap correction in case of deviation from set width at R5 (roughing exit) measurement is also functional. The model is self-learning and takes feedback from slab grade, temperature, furnace number & last measured width e.tc.

**FINAL WIDTH MEASUREMENT OF THE HOT STRIP AT FINISHING END WITH AN UPGRADED &HIGHLY ACCURATE WIDTH GAUGE SYSTEM**

Today’s cut throat competition over providing better quality as per norms in the finished product specification has called for up-gradation of the finishing mill exit width measurement gauge which was taken up by Instrumentation Department. This recently commissioned Width Gauge has been specially designed for the non-contact measurement of width of hot strips during the production process in hot rolling mills with high accuracy and reliability. A complete system consists of 04 line scan CCD cameras which gives actual width, width deviation, centre line deviation and camber and are located in a gauge house above the mill centerline. Edge detection with highly sophisticated grey level image processing technique is used to detect the true edges of the hot strip with High Accuracy (+/- 0.5 mm) and reliability under not ideal environmental condition.
The cameras (Fig: 6) are mounted on two motorized positioning units, which allow the optical axis of each camera to be positioned according to the nominal strip width, received from the set-up data.

![Measuring bar with moving cameras](image)

**Fig 6.0: Measuring bar with moving cameras**

One camera is mounted on one positioning unit so for all widths, the measurement takes place at 90 Deg from top. This eliminates the error of false edge detection. The system is working with a backlight. Two infrared line scan cameras are installed for camber measurement. Measurement output data are: Actual width, Width deviation from a preset nominal value, Centre-line deviation & Camber.

**Width Measurement with Backlight**

This Width Gauge uses backlight (Fig: 7). The strip is scanned with two line-scan cameras (2048 photosensitive Pixels). The edges generate white / black transitions and are imaged onto the linear light sensitive CCD - Arrays, which are electronically scanned and provide an analogue output which is digitized in the camera and transmitted by Ethernet UDP to the gauge PC. This technique requires that the optical system has only one specific transition in the field of view of the camera (black / white), showing clearly the strip’s edge. Edge detecting depends on light intensity at the strip's edge. The cameras are equipped with optical band pass filters which are aligned to the wavelength of the backlight. The infra-red radiation of the hot strip is suppressed, only the backlight can be seen by the cameras. The transitions are not constant in amplitude and shape due to external influences such as water and steam in the optical path. This problem is solved with digital signal filtering.
Edge detection is done with Digital Signal Processors (DSP) in real-time. High sophisticated grey level image processing technique is used to detect the edges with high accuracy and reliability under not ideal environmental conditions. An ultra fast FPGA is integrated in the camera for pre-processing of the video data. An embedded power PC in the camera with a LINUX operating system does further arithmetical processing to detect the edges and transfers the data by UDP protocol to the gauge PC.

The cameras are mounted on two linear tables for positioning of the optical axis of each camera to the nominal strip width (Fig: 5). By positioning the optical axis perpendicular to the strip edges, round edges do not lead to an error as the gauge measures in the same way as a sliding rule. The cameras' positioning is controlled by the PC. Each camera is directed to one strip edge, and is positioned so that the optical axis runs through the nominal edge position. The camera position is fixed for strips with the same nominal bandwidth. Small and fast deviations of the edge position are within the field of view of each camera.

**Fig 7.0:** Width Gauge installation in Mill
CONCLUSION

1) Prior to modernization, there was no measurement and automatic control of Roughing Bar width. Now the Bar width can be accurately measured and controlled so now any particular Concast slab can be converted to a different width (More or less within limits) as per nominal order requirement. This resulted in huge flexibility in production planning.

2) The recent modernization in case of Accurate Width measurement in finishing mill has resulted in reduction in over-width and under-width variations which helped reduced diversions, increase production yield & generate customer confidence in our product.