Evolution of Automatic Gauge Control philosophy for flat rolling
By Amitabh Kumar Sinha*

i) AGC through control of Back Tension

Before Hydraulic AGC Cylinders became a standard fixture in flat rolling mills, electrical motors were used to adjust top rolls for roll gap adjustment. Considering the slow response of such screw downs, alternative method was needed for gauge control rather than roll gap adjustment. The fastest means was to control the back tension. Back tension Fz changes the roll force needed for same reduction in following manner

$$Ra = Rf(1-k1*Fz) \ldots\ldots\ldots\ldots\ldots (1)$$

Where Ra is actual roll force, Rf is roll force for same reduction with back tension zero and k1 is a multiplication factor.

Now we know that
$$t2 = s + Ra/mm \quad (\text{ie loaded gap} = \text{no load gap} + \text{mill stretch})$$

Where t2= output thickness, s= unloaded gap in the mill and mm= mill modulus.

Thus replacing Ra from first equation we get:

$$t2 = s + (Rf*(1-k1*Fz))/mm \ldots\ldots\ldots(2)$$

Thus first fixing a calculated roll gap then manipulating back tension Fz as required up to a set limit, and then changing roll gap allowing some more correction in Fz fast gauge control was achieved.

Earlier tension control of Pay off reel or tension reel was controlled using field control of DC motor since SCR for armature control of such powerful motors were not available then. This type of tension control was known as "Tension Control" as opposed to torque control now applied. This control works with following principle:
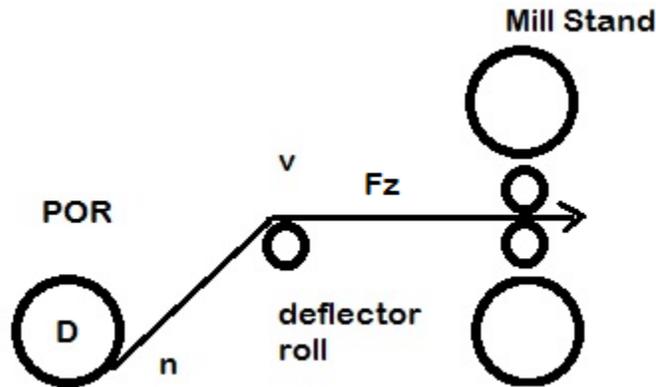
Fig-1

n = reel rpm in MPM (measured by motor tacho / GR)
v = material speed in meter /min (measured by deflector roll tacho)

$v = \pi * D * n$ ie $D = v//\pi/n$ ……………… (3)

Torque $T = Fz * D/2$ ie $Fz = T * 2/D$ ……….(4)

Since $T \propto Ia * \emptyset$, $T \propto Ia * If$ …………………..(5)

Where Ia = motor armature current and If = Motor field current. It follows

$Fz = 2 * k2 * Ia * If/D$ Where $k2$ is a constant. ……. (6)

For field control $n \propto 1/\emptyset$ and $\emptyset \propto If$ where $\emptyset$= Field Flux, ie $n = k3/If$ …. (7)

For a given fixed mill speed v, $D * n = D * k3/If$

Hence if If/D is kept constant $Fz \propto Ia$ ………………(8)

For keeping tension to a set value the motor has to run in constant power mode, where entire motor control is in field weakening range – keeping motor voltage constant. Base speed of motor is available at max OD of the coil and top speed at the ID of the coil. Motor current is adjusted as per tension required. We know motor power is proportional to tension x mill speed, Hence keeping motor power constant results in constant tension and if motor voltage is constant this means keeping motor current constant.

The above calculations and control block diagram are shown in the graph below (fig-2).
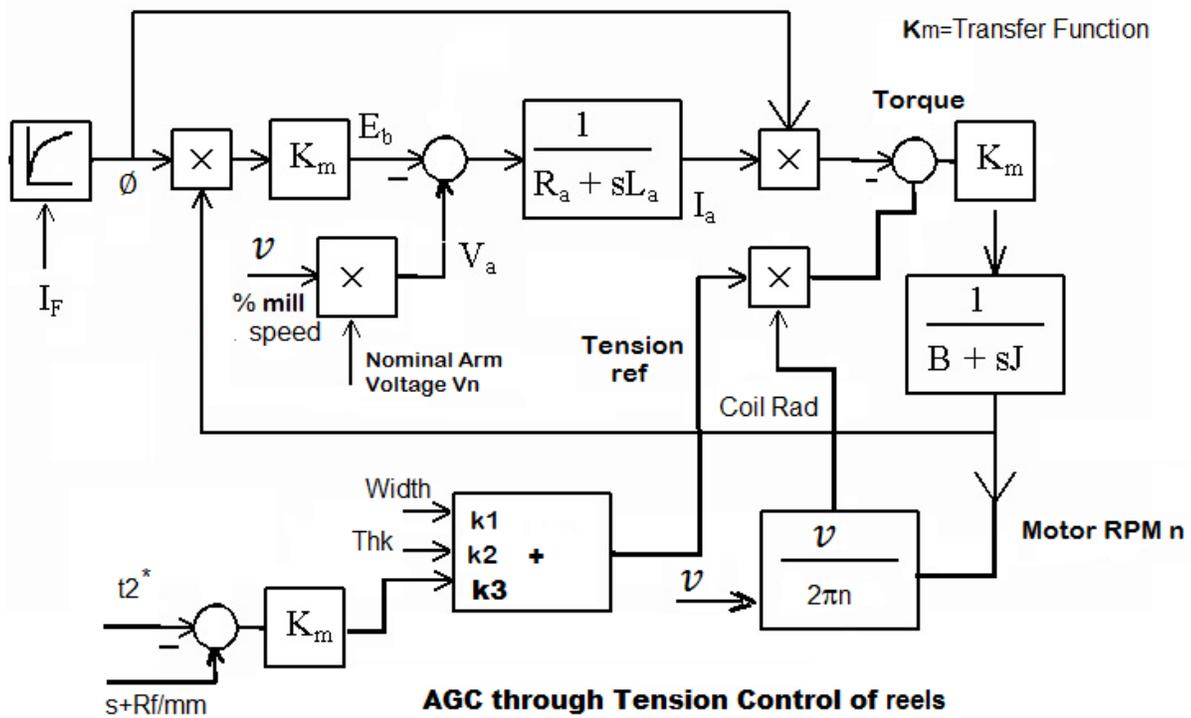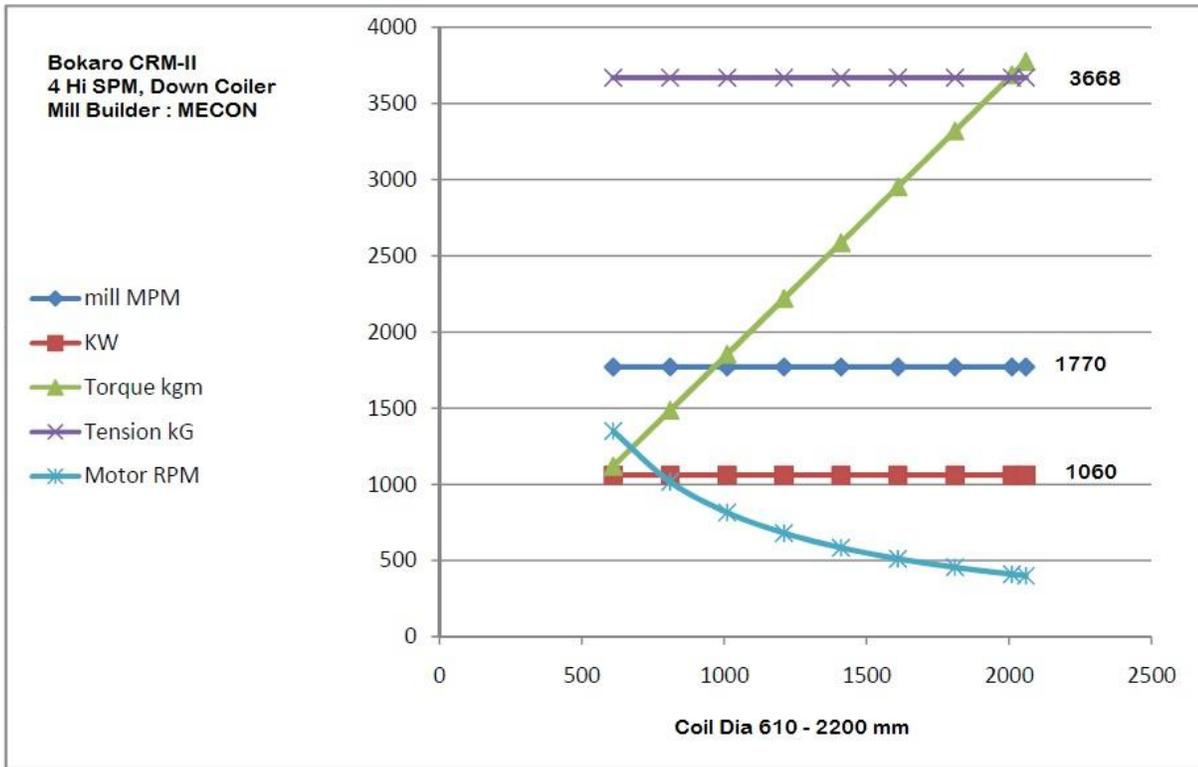
Bokaro CRM-II
4 Hi SPM, Down Coiler
Mill Builder : MECON

Legend:
- mill MPM
- KW
- Torque kgm
- Tension kG
- Motor RPM

3668
1770
1060

Coil Dia 610 - 2200 mm

K_m = Transfer Function

Torque

ϕ

$\times$

K_m

E_b

$\dfrac{1}{R_a + sL_a}$ I_a

$\times$

$-$ K_m

$\dfrac{1}{B + sJ}$

I_F

v

$\times$

V_a

% mill
speed

Nominal Arm
Voltage Vn

$\times$

Tension
ref

Coil Rad

Width

Thk

k1
k2   +
k3

v

$\dfrac{v}{2\pi n}$

Motor RPM n

$t2^*$

K_m

v

$s+Rf/mm$

AGC through Tension Control of reels

Fig-2

ii)   **AGC through calculated Roll Gap:**

During late 70's after hydraulic AGC were introduced and became popular the faster controls of roll gap became possible and full dependence on tension control was not needed. However measuring out going thickness was not very fast and was not accurately possible when material was in bite. This led to using the calculated roll gap for control of thickness using roll position control, roll force control & mill modulus to generate the calculated loaded roll gap and hence output gauge. Finer roll gap correction was done using X-Ray or isotope type thickness. Gauge Difference from set value was corrected using faster AGC position control and more accurate gap measurement using LVDT, Sony-magascale, Kelk or other position sensors. This however called for a procedure named calibration of the mill and position controller.

Calibration:

In this write up I assume that mechanical screw down for moving the rolls to compensate for roll turn downs for keeping pass line, are mounted at the top of the mill where as hydraulic cylinders are mounted in the bottom. Process as per author's experience is given below:

i)   Top motorized screw down is moved down to bring the rolls to pass line keeping it parallel as far as possible.

ii)   Bottom rolls are lifted under roll force mode with kissing roll force reference differential roll force reference as zero.

iii)   Rolls will rise to touch to top rolls and touch either on drive or operator side as per skew due to error in parallel position of top rolls.

iv)   Roll force will develop and rise up to the set value. Differential roll force also will rise since the rolls touches only on one side.

v)   Differential roll force controller comes into action to achieve the set value of zero, thus ensuring the rolls touch both side with equal force.

vi)   The above roll position is registered as kissing position or unloaded zero gap position. Rolls are rotated at small speed.

vii)   Total roll force is then raised to another set value called the calibration roll force.

viii) Though the rolls are still touching but position sensors will read another position due to mill stretch and this is also registered. The difference in the two registered position divided by roll force gives mill stretch coefficient ie mill modulus "mm"

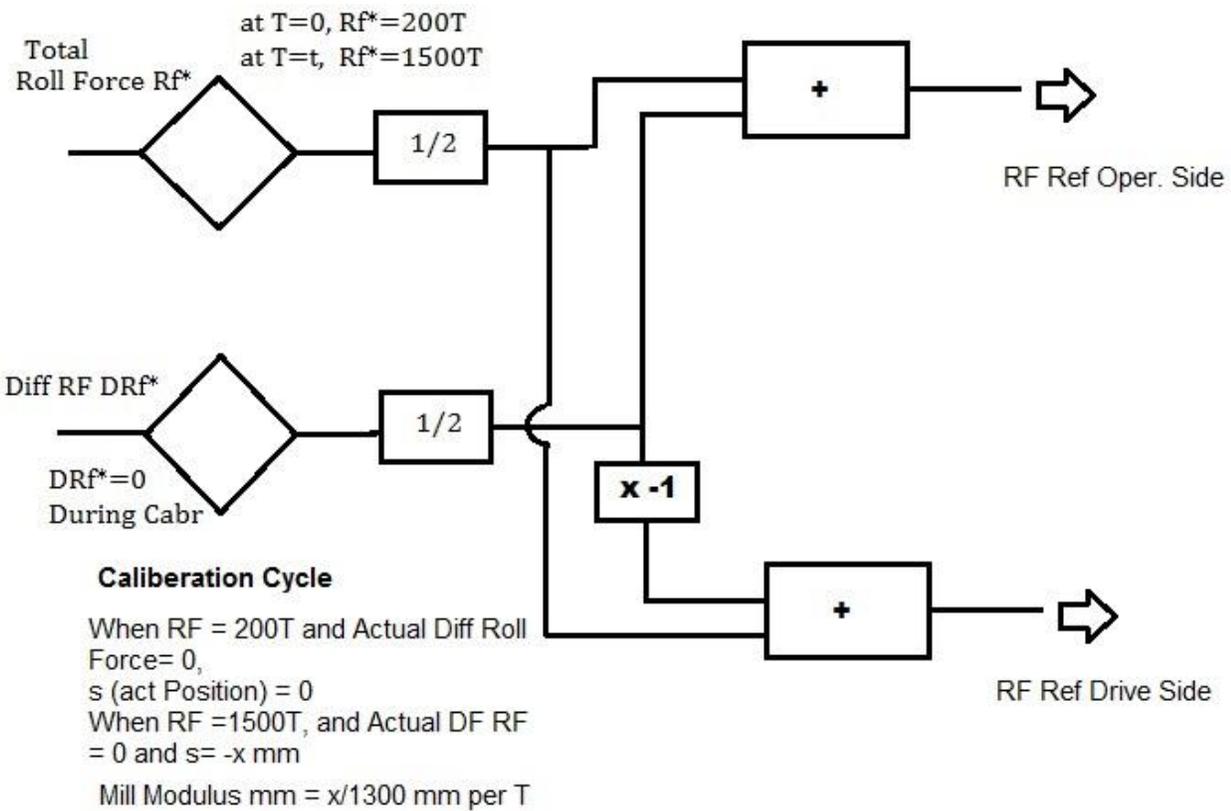ix)   Mill calibrated signal lights up.

Fig-3

Safety setting for servo valves: Servo valves usually will have some null leakage (leakage within servo valve with servo valve current = zero). For safe operation rolls must separate parallel when servo valve current is zero or else the rolls will come closer and closer with roll force rising to un safe value. To ensure this rolls gap is set to a given value in position mode and null setting screw on the servo valve is adjusted such that drive side and operator side servo valves need an equal positive current (which would have reduced roll gap if not in position mode). This means once servo valve current is zero, the rolls will move with almost equal speed and separate till max roll gap is attained.

iii) Mass Flow Principle

With the advent of faster non-contact thickness gauges, AGC suppliers introduced a another method of measuring loaded roll gap or output thickness by using a simple principle that mass remains constant. Thus if entry side thickness is h_{in} and entry material speed is $v1$, exit side thickness is h_{out} and exit side material speed is $v2$ then considering that there is no change in width of material,

$h_{in} * v1 = h_{out} * v2$, thus $h_{out} = h_{in} * v1/v2$ ………………………………… (9)

Thus if we are able to measure entry and output material linear speed and entry side thickness we have quite accurate and fast value for exit thickness, thus accurate AGC was possible with this calculated output thickness with over all vernier correction from exit thickness gauge. See figure-4.
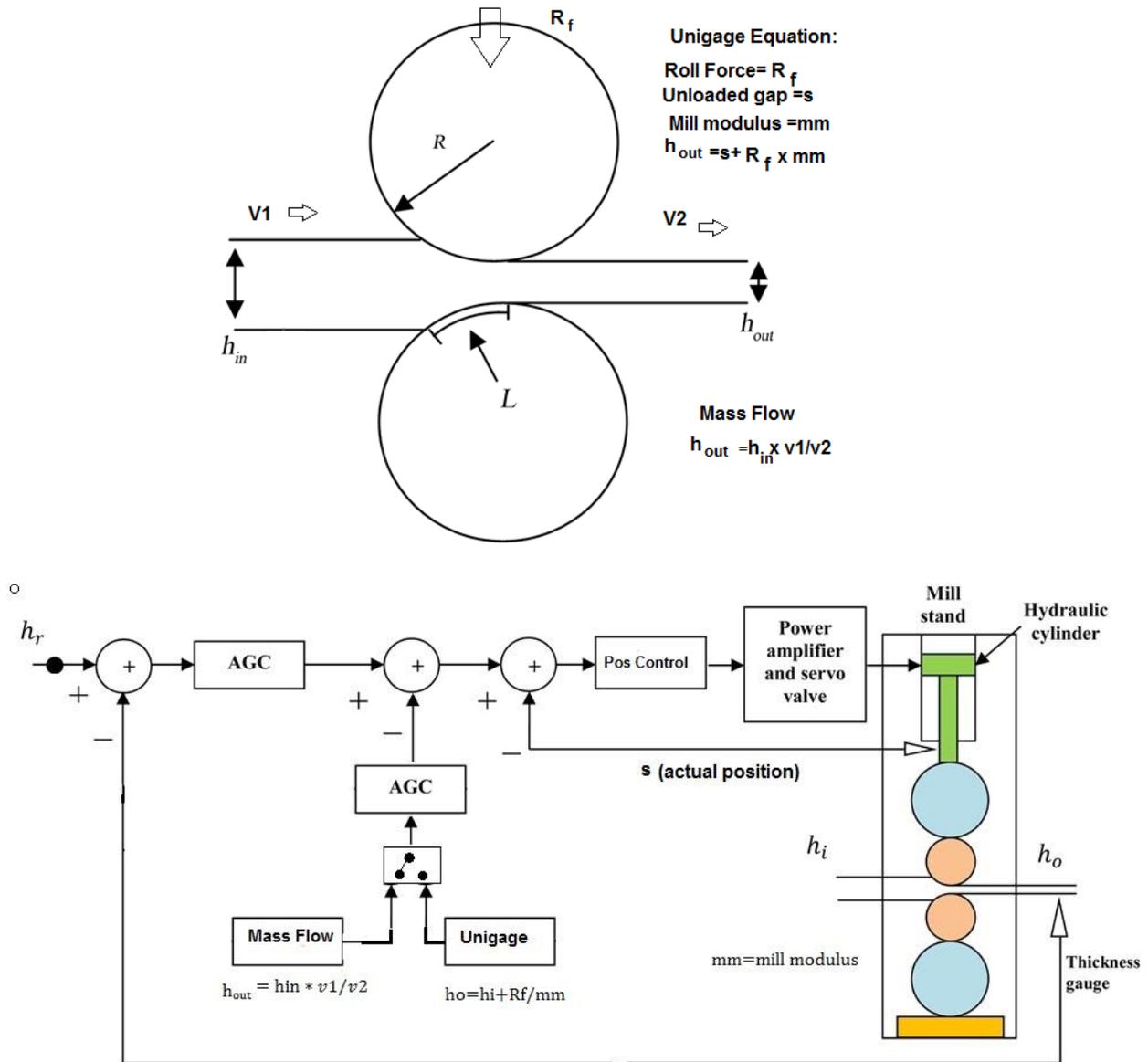
R_f

Unigage Equation:

Roll Force= R_f
Unloaded gap =s
Mill modulus =mm
h_{out} =s+ R_f x mm

V1 ⇨   V2 ⇨

h_{in} h_{out}

R

L

Mass Flow

h_{out} = h_{in} x v1/v2

h_r

AGC → + → + → Pos Control → Power amplifier and servo valve

Mill stand   Hydraulic cylinder

s (actual position)

AGC

Mass Flow   Unigage

h_{out} = hin * v1/v2   ho=hi+Rf/mm

h_i h_o

mm=mill modulus   Thickness gauge

Fig-4

Conclusion:

With the use of Hydraulic AGC cylinders and fast and accurate position sensors and thickness Automatic Gauge Control for flat mills have undergone sea change from controls through back tension to actual position. Temper passing in Cold Mill with constant roll force has also become feasible. In India Hydraulic AGC were introduced in late seventies and now is a standard fixture in flat rolling mills.

*About the author

Sri Amitabh Kumar Sinha is Fellow corporate Member of Institution of Engineers, and Life Member of ISLE (Indian Society of Lighting Engineers – apart from being Electrical Engineering Graduate of 1970 passing out batch. Sri Sinha has extensive 46 years Design Engineering and Commissioning experience in Steel Industry mainly in Metal Rolling. Sri Sinha has several papers to his credit. He is a well travelled person.