Roll Stack Deflection Model for Hot Rolling Mill

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Abstract—Roll stack deflection model for hot rolling mills with Ekelunds method for roll force approximation and macaulay's method for deflection calculations.

I. INTRODUCTION

This paper intend to study hot rolling roll stack deflection and assist in control of work piece flatness which is an important parameter of product quality. Finding of paper can be used as guidelines for pass schedule designing or efficient work roll bending system design. Ekelund's method is used for deformation resistance approximation and Macaulay's method is used for roll stack deflection calculation. Method involves repeat integration of moment equation, application of boundary conditions for approximation of integration constants.

II. MATHEMATICAL MODEL

Figure 1 Shows arrangement of four high reversing mill and strip force and supports provided by mill it can be seen that mill housing supports are provided via bearing at the bottom and at the top is the mill AGC/screw down supports through bearing. The model consists of roll force approximation and deflection calculation based on that.

A. Modeling of rolling force



Figure.1: Arrangement of four high reversing mill 1) General equation for roll separating force

The following equation is generally used for calculation of roll separating force (as the action of force tries to separate the work rolls) for flat products (1)

$$P = K_w * \tilde{F}_d = K_w * w * \mathbf{l}_d$$

Where = Projected area between work roll and work piece F_d l_d = Projected length of contact between work roll and work piece

= Mean work piece width w

Kw = Deformation resistance of work piece P = Rolling force or roll separating force

The projected area of contact of work piece and roll is given by

 $F_d = w * l_d$ (2) Since for hot rolling roll flattening is ignored, The projected length of contact is given by

 $l_d = \sqrt{R * \Delta - \frac{\Delta^2}{4}}$

Where

$$\Delta = Draft$$

Since Δ is very small value as compared to R the

term $\frac{\Delta^2}{4}$ is very small and can be ignored. So above equation reduces to

$$l_d = \sqrt{R * \Delta} \tag{3}$$

If the work rolls are of unequal diameter then equivalent radius is to be considered in above equation

$$R = \frac{2 * R_T * R_B}{R_T + R_B}$$

The rolling force most heavily depends on the deformation resistance of the work piece. The deformation resistance depends on following factors

- Material chemical composition
- _ Material metallurgical characteristics
- Material temperature
- Geometry of the deformation zone
- External friction in the deformation zone
- Material work hardening prior to the pass under consideration
- Strain rate of deformation

Whilst the size of the projected area is only imposed by the geometrical conditions of the rolling process, the actual resistance to deformation of the material is a function of the properties of the material and the rolling temperature, as well as of the existing deformation conditions. In this connection the influence of friction between rolls and material is particularly noticeable, because it increases the resistance the material has to overcome when it is being forced away from the roll gap and resistance to deformation is correspondingly increased. Furthermore, the resistance to deformation in hot rolling is primary function of temperature and rate of deformation.

Owing to the complexity of the problem it has been impossible so far to express by formula the different influences sufficiently simple for them to be readily applied in practice. When determining the resistance to deformation therefore it might be advisable to start from the available experimental results.

Compressive tests undertaken by different persons have thrown a good deal of light on resistance to deformation which occurs when hot rolling steel of different compositions on plain rolls. In these tests the influence of rolling temperature, % reduction and thickness ratio are

1

determined. The big rise in deformation resistance in line with the reduction of thickness ratio on one hand and temperature reduction on the other is well defined. The influence of reduction per pass is very slight. The increase in deformation resistance going along with height reduction of rolled stock is due to the fact that the flow resistance due to friction on the roll increases with height reduction of the rolls material.

2) Model for deformation resistance

For this research and calculation of deformation resistance we will use EKELUND's method[1] for which deformation resistance is given by following equation

$$K_{w} = \left(1 + \frac{0.8 * \mu * l_{d} - 0.8 * \Delta}{h_{a}}\right) \\ * \left(Y_{c} + \frac{\eta * V * \sqrt{\Delta/R}}{h_{a}}\right) (4)$$

Where,

V = Peripheral rolling speed, mm/sec

R = Roll radius, mm

= Co efficient of plasticity, Kg sec/mm² n

= Yield stress of the rolled material corresponding Yc to a given temperature and chemical composition, Kg/mm²

= Average strip thickness, mm ha

The co efficient of friction μ is calculated as function of rolling temperature, type of roll and their surface condition as given below

For cast iron and rough steel rolls

$$\mu = 1.05 - 0.0005 * t$$

For chilled and smooth rolls
 $\mu = 0.8 * (1.05 - 0.0005 * t)$ (5)
For ground steel rolls

 $\mu = 0.55 * (1.05 - 0.0005 * t)$

The yield stress is calculated as function of rolling temperature and chemical composition of a work piece. It is given by following equation

 $Y_{c} = (14 - 0.01 * t) * (1.4 + C + M_{n} + 0.3 * C_{r}) (6)$ Where

C, Mn & Cr = % of carbon, manganese and chromium respectively

t = Rolling temperature, °C

The co efficient of plasticity of the rolled stock is given by

(7)

 $\eta = 0.01 * (14 - 0.01 * t)$

B. Solution method for deflection

This method mainly consists in the special manner in which the bending moment At any section is expressed and integration is carried out. In this method deflection calculation is carried out by integration of the moment equation. For modeling we will consider the example of beam as shown in figure. The beam is divided into sections based on loading and flexural rigidity.



Fig. 2: beam considered for modeling

Since we cannot have a common equation for a beam loaded as above the loading can be re arranged in order to maintain continuity of equation and simplicity.



Fig. 3: Re arranged beam for calculations Resolving the forces vertically we get

 $R_A = R_B = 0.75 * w = P/2$ Where

= Reaction at A R_A = Reaction at B

R_B So the moment of the beam in first segment (0 - 0.5) is given by

$$E * I * \frac{d^2 y}{dx^2} = \frac{P}{2} * x$$

Ι

у

х

Where E = Modulus of elasticity

= Moment of inertia

= Deflection (Y axis)

Similarly for the second segment (0.5 - 2.0) is given by

$$E * I * \frac{d^2 y}{dx^2} = \left(\frac{P}{2} * x \right| - \frac{P * (x - 0.5)^2}{1.5 * 2}\right)$$

The mark of separation in this equation indicates that the term after the mark is applicable only if the distance x corresponds to the condition specified in bracket above and not otherwise. For example, for distance less than 0.5 only the term before separation mark shall be considered this is to be kept note of while making the calculations. The third section (2.0 - 2.5)

$$E * I * \frac{d^2 y}{dx^2} = \left(\left| \frac{P}{2} * x \right| - \frac{P * (x - 0.5)^2}{1.5 * 2} \right| + \frac{P * (x - 2)^2}{1.5 * 2} \right)$$
(8)

Since the beam is symmetrically loaded deflections at other are same at this end.

Integrating we get

$$E * I * \frac{dy}{dx} = \left(\left| \frac{P}{2} * \frac{x^2}{2} + C_1 \right| - \frac{P * (x - 0.5)^3}{1.5 * 2 * 3} \right| + \frac{P * (x - 2)^3}{1.5 * 2 * 3} \right)$$

Further integrating we get

$$E * I * y$$

$$= \left(\left| \frac{P}{2} * \frac{x^3}{6} + C_1 * x + C_2 \right| - \frac{P * (x - 0.5)^4}{1.5 * 2 * 3 * 4} \right| + \frac{P * (x - 2)^4}{1.5 * 2 * 3 * 4} \right)$$

The value of constant can be found by applying the boundary conditions

That is at x = 0 y = 0Which gives $C_2 = 0$ And at x = 2.5 $\mathbf{y} = \mathbf{0}$ Which gives $C_1 = -12.375 * P / 36$ The equation becomes $0 = \left(\left| \frac{P}{2} * \frac{x^2}{2} - \frac{12.375 * P}{36} \right| - \frac{P * (x - 0.5)^3}{1.5 * 2 * 3} \right| \quad \end{pmatrix} \right)$

$$0 = \left(\left| \frac{1}{2} * \frac{x^2}{2} - \frac{12.375}{36} \right| - \frac{(x - 0.5)^3}{9} \right| \right)$$

$$0 = 9 * x^2 - 12.375 - (x - 0.5)^3$$

u

0.

4

Ni

0.

4

V

0.0

8

Mb

0.1

5

can be taken as validation of above equation.								
Diameter Of Work Roll Barrel,	0.8	М						
Diameter Of Work Roll Neck,	0.56	М						
Work Roll Neck Length,	0.6	М						
Diameter Of Backup Roll Barrel,	1.6	М						
Diameter Of Backup Roll Neck	1.12	М						
Back Up Roll Neck Length	0.6	М						
Back Up Roll Bearing Cetre To Centre Diatance	2.5	М						
Modulus Of Elasticity For Work Roll Material E ₁	180	Gpa						
Modulus Of Elasticity Back Up Roll Material E ₂	140	Gpa						
Work Piece Width	1.5	М						

Solving we get x = 1.25 which is at the centre and can be taken as validation of above equation.

Table 1: Work Roll And Back Up Roll Dimensions For Calculations [2]

PASS NO	1	2	3	4	5	6	7	8	9	10	11	12
ENTRY THK	160	147	128	109	90	73	57	43	30	21	15	10
EXIT THK	147	128	109	90	73	57	43	30	21	15	10	8
TEMPERATURE	1107	1104	1103	1100	1100	1097	1093	1086	1086	1080	1080	1075
WORK ROLL DIAMETER				400 mm								
WORK ROLL SPEED				40 rpm								
Table 2 Dass schedule and transfer has temperature												

С

0.1

7

Μ

n 0.7 Р

0.03

5

(ASTM A 106) [3]

S

5

0.03

Si

0.

1

Table 2 Chemical composition of work piece material

Cr C

0.

4

 Table 3 Pass schedule and transfer bar temperature

III. RESULTS AND DISCUSSIONS

The figure shows roll force results as can be seen that values of 6 to 14 MN are observed depending on relative reduction final work piece thickness and work piece temperature. The values of roll force are well within the mill configuration specifications of 25 MN.



Fig. 4: Roll force

The deflection result shows maximum deflection of 0.07 (at the roll stack centre) in 8^{th} pass corresponding to the highest roll force as well as relative reduction. While the values are found to be of the order of 0.04 mm for 1^{st} and 12^{th} pass corresponding to lower roll force and relative reduction. In initial passes the draft is governed by bite angle limits and condition of biting and hence roll force and deflection are low. In final passes higher emphasis is given to the work piece flatness and hence lower values of deflections are required that is achieved by low draft.



Fig. 5: Deflection IV. VALIDATION

Results obtained are well within rolling mill standards of product quality and mill configuration and specifications validating results. Further the data of [4] was used to apply to this model and results were compared which shows satisfactory similarity with [4] can be taken as validation as well.



Fig. 6: Deflection (validation)

V. CONCLUSION

Roll stack deflection in hot rolling mill has greatest emphasis on final product flatness. Outcome of research shows direct impact of roll force on roll stack deflection. Further it depends on relative reduction in that pass and on final material thickness. Pass schedule included in this research is efficiently designed so that final roll stack deflection is well within flatness tolerances of the material. Further it is also influenced by material width and back up roll bearing centre.

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