The Sims Power and Labour PyRoll Plugin

Christoph Renzing

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This plugin provides the roll force and roll torque model developed by Sims [1]. The basic equations are derived from classic strip theory with suitable simplifications suitable for hot rolling. Weber [2, 3] described the method as suitable for calculation of roll force, as for roll torque calculations, the derived method doesn't yield acceptable results. For the presented plugin, the specific roll torque at the upper work roll is calculated using the original model from Sims as well as the adjusted method by Weber. Usage of the equations for groove rolling is only valid, when using a equivalent rectangle approach. Heights used for calculation and therefore equivalent values for a equivalent flat pass. The work by Sims, implements a flattened roll radius R_1 which is to be calculated from the nominal radius R_0 through suitable models (e.g. Hitchcock's model Hitchcook and Trinks [4]). Furthermore, the used variable h is the height of the equivalent flat workpiece and b_m it's mean width, $k_{f,m}$ represents the mean flow stress of the material and ϵ the reduction of the equivalent pass in height direction. The indices 0 and 1 denote the incoming and exiting profile and L_d is the contact length of the pass.

1 Model approach

To calculate the roll force in hot rolling, the following equation was developed:

$$F_{Roll} = k_{f,m}\sqrt{R_1 \Delta h}\, b_m Q_{Force}(\frac{R_1}{h_1}, \epsilon_h) \tag{1}$$

The function Q_{Force} is a which combines the influence of the reduction of the pass. This function depends on the height of the workpiece at the neutral line h_n. Calculation of the neutral line angle α_n numerically using (4c) by Sims [1]. A fallback implementation is (4d) from Sims. The height of the workpiece dependent on the roll angle α is express with equation 2b.

$$Q_{Force} = \frac{\pi}{2}\sqrt{\frac{1-\epsilon}{\epsilon}}\arctan\left(\sqrt{\frac{\epsilon}{1-\epsilon}}\right) - \frac{\pi}{4} - \sqrt{\frac{1-\epsilon}{\epsilon}}\sqrt{\frac{R_1}{h_1}}\log\left(\frac{h_n}{h_1}\right) + \tag{2a}$$
$$\frac{1}{2}\sqrt{\frac{1-\epsilon}{\epsilon}}\sqrt{\frac{R_1}{h_1}}\log\left(\frac{1}{1-\epsilon}\right)$$

$$h(\alpha) = h_1 + 2R(1 - \cos(\alpha)) \tag{2b}$$

$$k_{f,m} = \frac{k_{f,0} + 2k_{f,1}}{3} \tag{2c}$$

As for the roll torque M_{roll}, Sims developed a similar equation.

$$M_{roll} = 2R_1 * R_0 k_{f,m} Q_{Torque}(\frac{R_1}{h_1}, \epsilon) \tag{3}$$

The function Q_{Torque} depends on the entry angle of the equivalent flat pass α_0, which is calculated from equation 4b, using the minimal radius R_{min}.

$$Q_{Torque} = \frac{a_0}{2} - \alpha_n \tag{4a}$$

$$\alpha_0 = \arcsin\left(\frac{L_d}{R_{min}}\right) \tag{4b}$$

$$0 = \left(\sqrt{\frac{R_1}{h_1}}\arctan(\sqrt{\frac{R_1}{h_1}})\alpha_n - \sqrt{\frac{R_1}{h_1}}\arctan(\sqrt{\frac{R_1}{h_1}})\alpha_0\right) - \frac{\pi}{4}\log\left(\frac{h_1}{h_0}\right) \tag{4c}$$

$$\alpha_n = \sqrt{\frac{h_1}{R_1}}\tan\left(\frac{1}{2}\left[\arctan\sqrt{\frac{h_0}{h_1}-1} + \sqrt{\frac{h_1}{R_1}}\frac{\pi}{4}\log\frac{h_1}{h_0}\right]\right) \tag{4d}$$

As already mentioned the calculated roll torque derives from measured values by more than 20% stated by Weber [3]. Therefore the plugin also calculates the roll torque using the approach by Weber [2]. The general equation used to calculate the roll torque is (5a) utilising (5b) for calculation of the lever arm coefficient, published by Sims and Wright [5] which is valid till $\frac{R}{h_1} \leq 25$.

$$M_{roll} = F_{roll}L_d m \tag{5a}$$

$$m = 0.78 + 0.017\frac{R_1}{h_1} - 0.163\sqrt{\frac{R_1}{h_1}} \tag{5b}$$

2 Usage instructions

The plugin can be loaded under the name `pyroll_sims_power_and_labour`.

An implementation of the `roll_force` and `roll_torque` hook on `RollPass` and `RollPass.Roll` is provided, calculating the roll force and torque using (3) and (1). Several additional hooks on `RollPass` are defined, which are used in power and labour calculations, as listed

Table 1: Hooks specified by this plugin.

Hook name	Meaning
`equivalent_height_change`	Height change Δh
`equivalent_reduction`	Reduction ϵ
`equivalent_entry_angle`	Entry or bite angle α_0
`equivalent_neutral_line_angle`	Angle of neutral line α_n
`equivalent_height_at_neutral_line_angle`	Height at angle of neutral line h_n
`lever_arm_sims`	Lever arm m for roll pass
`roll_torque_general`	Roll torque M_{roll} from (5a)

in Table 1. Base implementations of them are provided, so it should work out of the box. For `sims_force_function` and `sims_torque_function` the equations 2a and 3 are implemented. Provide your own hook implementations or set attributes on the `RollPass` instances to alter the spreading behavior.

References

[1] R. B. Sims. "The Calculation of Roll Force and Torque in Hot Rolling Mills". en. In: *Proceedings of the Institution of Mechanical Engineers* 168.1 (June 1954), pp. 191–200. ISSN: 0020-3483, 2058-1203. DOI: 10.1243/PIME_PROC_1954_168_023_02. URL: http://journals.sagepub.com/doi/10.1243/PIME_PROC_1954_168_023_02 (visited on 05/09/2022).

[2] K. H. Weber. *Die Brauchbarkeit des Sims'schen Rechenverfahrens für das Warmwalzen und das Verhalten der Formänderungsfestigkeit und des Formänderungswiderstands beim Warmwalzen.* Vol. 48. Freiberger Forschungshefte. Berlin, 1960.

[3] K. H. Weber. *Grundlagen des Bandwalzens.* 1st ed. Leipzig: VEB Deutscher Verlag für Grundstoffindustrie, 1973.

[4] J. H. Hitchcook and W. Trinks. *Roll neck bearings.* en. New York, 1935, p. 51.

[5] R. B. Sims and H. Wright. "Roll force and torque in hot rolling - a comparison between measurment and calculation". In: *Iron and Steel* (1962), S.627–631.