

Appendix A

Appendix A

A.1 Rolling Mill Definitions

As with any industrial process a lot of process terminology is used that are not common industrial terms. In this section a brief description of the most common terms used in the process description and problem formulation of this dissertation is given.

- **Reversing mill:** A reversing mill is a single stand mill that uses multiple passes to achieve the desired reduction. The rolling mill drive can rotate both ways and the strip can be rolled against the direction of the general process flow.
- **x -High Rolling Stand:** The rolling stand has x number of rolls.
- **Steckel Rolling Mill:** A Steckel rolling mill is a four high reversing single or tandem stand mill [4]. In this work only a single stand mill will be investigated.
- **Finishing Mill:** The term finishing mill is a global name and can consist of 5 to 7 non reversing tandem mill stands or a single/double tandem reversing mill stand/s as is the case with a Steckel rolling mill. The main differences between the different types of finishing mills are the annual throughput of the mills. The tandem non reversing mills are capable of higher processing speed and has higher throughputs.
- **Work- and Backup Rolls:** A typical four high mill has two work rolls and two backup rolls. The work rolls are in contact with the strip being rolled and the backup rolls are fitted to support the thinner work rolls [57]. The work rolls are driven by the main mill drive motor [111].
- **Roll gap:** The roll gap is defined as the contact zone between the strip being rolled and the working rolls of the mill stand [2, 24, 28].
- **Pass:** A pass is defined as the action of passing the whole length of strip through the roll gap of the mill. The terminology of a pass is only used for a reversing type mill.

- **Threading:** The rolling of strip is normally a batch process, although there are examples of continuous processing lines. For a Steckel rolling mill the rolling of strip proceeds as a batch process and the mill speed is ramped up to a constant speed, called the threading speed, and decelerated before the strip is delivered after the completion of the pass.
- **Gauge:** The gauge of the strip is defined as the centerline thickness of the strip.
- **Profile (Σ):** Profile is defined as the distribution of thickness over the width of the strip [61]. The profile is determined by the shape of the unloaded work rolls, the required reduction and thus the rolling forces, rolling speeds, strip width, material properties of the strip and the rolls.
- **Crown (C_r):** Crown of the strip is defined as the thickness difference in the width of the sheet between the middle of the strip and a point near the edge. If the profile of the strip is convex then it is said that the strip has positive crown and similarly a concave profile is labelled negative crown [61]. Crown and profile are expressed as,

$$C_r = h_m - h_r, \quad \Sigma = \frac{C_r}{h_m}, \quad (\text{A.1})$$

where h_m is the centerline thickness of the sheet and h_r is the thickness of the strip near the edge. The terminology **Camber** and **Crown** are used interchangeably by the rolling mill community.

- **Shape:** Is defined as a transverse distribution in strain across the width of the strip. When the percentage reduction in the strip thickness reduction varies across the width a transverse variation in elongation will result. The application of tension to the strip whilst rolling will convert some or all of the variation in elongation into a transverse stress distribution across the strip width. The strip shape is latent if the mean applied tension is great enough to pull the strip flat. If all the length change is not converted into a stress distribution the strip will exhibit flatness defects, such as buckles, and the shape is said to be “manifest”. If the percentage reduction in the strip is constant across the strip width there will be no transverse variation in stress and the strip will have zero or perfect shape.
- **Flatness:** Flatness refers to the ability of the strip to lie flat when placed on a flat surface with no applied tension to the strip. Flatness is a function of how the the thickness crown evolves during the rolling process. Flatness is related to shape in that a transverse variation in stress may result in a buckled strip when the applied tension is removed. When the reduction in the thickness profile is not uniform pass to pass, poor flatness arises due to uneven longitudinal extensions across the strip width. This uneven longitudinal extensions are seen as buckling or warping effects [112]. The shape can be defined as,

$$S = \frac{L - \lambda}{\lambda} = \left(\frac{A\pi}{2\lambda} \right)^2 = \frac{\Delta L}{L}, \quad (\text{A.2})$$

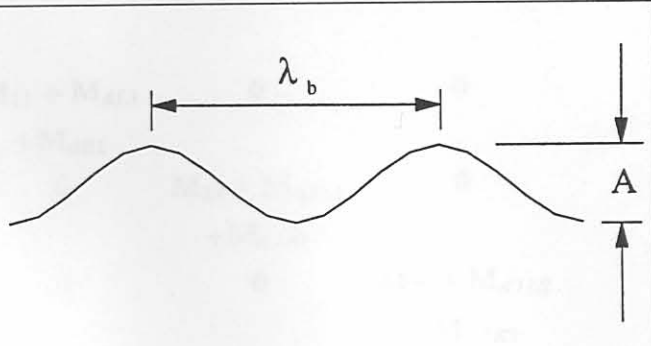


Figure A.1: Shape Definition

where L is the length of the strip, λ is the wavelength of the shape defect (center buckle or edge buckle assuming a sinusoidal waveform) and ΔL is the non uniform elongation of the strip over the width. In Fig. A.1 the variables featured in Eq. A.2 are shown.

- **Units of shape:** There are a few units used to express strip shape namely,

$$i. Mon = \frac{\Delta L}{L} 10^4, \quad (A.3)$$

$$ii. Mon.cm^{-1} = \frac{\Delta L}{L} \frac{10^4}{w}, \quad (A.4)$$

$$iii. I unit = \frac{\Delta L}{L} 10^5, \quad (A.5)$$

where w is the strip width.

Although many other terminologies are used they are however self explanatory and will not hamper the understanding of this dissertation.

A.2 Four Roller Model

The solution methodology is similar to the two roller model. The mass and stiffness matrices differ and are given as,

$$\widehat{\mathbf{M}} = \begin{bmatrix} \mathbf{M}_{11} + \mathbf{M}_{dL1} & 0 & 0 & 0 \\ +\mathbf{M}_{dR1} & & & \\ 0 & \mathbf{M}_{22} + \mathbf{M}_{dJL1} & 0 & 0 \\ +\mathbf{M}_{dJR1} & & & \\ 0 & 0 & \mathbf{M}_{33} + \mathbf{M}_{dJL2} & 0 \\ +\mathbf{M}_{dJR2} & & & \\ 0 & 0 & 0 & \mathbf{M}_{44} + \mathbf{M}_{dL2} \\ +\mathbf{M}_{dR2} & & & \end{bmatrix} \quad (\text{A.6})$$

$$\widehat{\mathbf{K}}(t) = \begin{bmatrix} \mathbf{K}_{11} + \mathbf{K}_{c11}(t) & -\mathbf{K}_{c12}(t) & 0 & 0 \\ & \mathbf{K}_{22} + \mathbf{K}_{c22}(t) & -\mathbf{K}_{strip23} - \mathbf{K}_{Jd23L} & \\ -\mathbf{K}_{c21}(t) & +\mathbf{K}_{strip22} + \mathbf{K}_{Jd22L} & -\mathbf{K}_{Jd23R} & 0 \\ & +\mathbf{K}_{Jd22R} & & \\ & -\mathbf{K}_{strip32} - \mathbf{K}_{Jd32L} & \mathbf{K}_{33} + \mathbf{K}_{c33}(t) & \\ 0 & -\mathbf{K}_{Jd32R} & +\mathbf{K}_{strip33} + \mathbf{K}_{Jd33L} & -\mathbf{K}_{c34} \\ & & +\mathbf{K}_{Jd33R} & \\ & & & \mathbf{K}_{44} + \mathbf{K}_{c44}(t) \\ 0 & 0 & -\mathbf{K}_{c43}(t) & +\mathbf{K}_{strip44} + \mathbf{K}_{Jd44L} \\ & & & +\mathbf{K}_{Jd44R} \end{bmatrix} \quad (\text{A.7})$$

The solution of the time variant four roller model requires that at each time step the assumed stiffness matrix be recalculated. After this recalculation an eigenvalue problem is solved and the modal matrix is obtained. The vertical displacements at the same time step are recalculated and from this the nonlinear spring for the interface loading can be recalculated. This iterative process is terminated as soon as the draft of the strip stabilizes. Once this is achieved the simulator advances to the next time step. The four roller model falls outside the scope of this dissertation.