Chapter 7

Conclusion and recommendations

7.1 Conclusion

In this dissertation a hot rolling mill process was modelled in order to yield a nonlinear plant simulator that was used in the identification of a linear plant model. The linear plant model can be used for control system design purposes. The hot rolling mill investigated in this dissertation was based on an industrial Steckel Mill. Literature on Steckel Mills are scarce and this work partially fill this void. Possible reasons for this lack of literature are that Steckel Mills are installed mainly in developing countries or where a large product mix are produced. South Africa has at least 3 hot rolling Steckel mills making this work applicable to the South African rolling industry.

Process behaviour was modelled in order to reflect centerline gauge behaviour, thickness crown behaviour and tensions in the strip on either side of the roll gap. The mill simulator was constructed by modelling the 4-high mill stand as an equivalent 2-roll pack rolling mill. This approximation has been made in [59] and is suggested in [40]. The rollers were modelled as continuous masses yielding distributed parameter systems, while the rest of the mill stand elements were lumped together. From this modelling approach a partial differential equation model was derived describing the dynamic behaviour of the mill stand. The spatial and time dependencies found in the PDE model was solved using the Assumed Modes Method, normally used in the analysis of vibration problems [54]. This spatial dynamic model gives the simulator the capability to simulate the bending of the rolls and to account for the crown behaviour of the strip associated with roller bending.

The nonlinear behaviour of the hydraulic actuators was modelled from first principles and this model was combined with the mill stand model, resulting in an 18th order nonlinear state-space model. Eight states of the mill simulator are associated with the rolling mill stand. The other 10 states are attributed to the two similar hydraulic systems.

The material behaviour in the roll gap was accounted for by using Orowan's roll gap model. The calculation of the specific rolling force that the strip exerts on the working rollers was evaluated along the length of the rollers (perpendicular to the rolling direction), resulting in a distributed load that acts on the two roll packs. This distributed load serves as input to the 18th order state-space model used in the simulator.

The interaction between the roll gap model and the applied tensions to the strip, while rolling, was modelled and investigated. From this work it can be stated that the tension interactions do influence the centerline exit thickness, but the interaction is small, for the chosen operating point. A conjecture (based on the importance of tension control for cold rolling) can be made that the tension interactions will feature more during the later passes in the Steckel rolling mill schedule.

The mill simulator was used to identify a linear time invariant MIMO transfer function model, that can be used for control system design at the operating point at which the plant was linearized.

7.2 Contribution of this work

Current automation projects can be worth millions of dollars and there are many companies around the world that specialize in automation of rolling mill processes, for example Kvaerner, Cegelec, Siemens, Mannesman Demag, Tippins to name a few. These companies rely on the accuracy of their models and a lot of time and resources are invested in the development of proprietary models. With this dissertation a research program was launched that will ultimately help with the industrial research of rolling mills in South Africa.

This work has further contributed to the field of modelling of rolling mills by modelling a Steckel hot rolling mill process. Modelling work on rolling mills are normally documented for multistand hot rolling mills, and literature of investigations into the tension interactions on the thickness behaviour of the strip for a Steckel mill are scarce, if not non-existent.

One of the aims of this dissertation was to develop a nonlinear mill simulator that can be used in a continuing research program that will ultimately investigate the feasibility of applying Model Predictive Control to a Steckel Hot Rolling Mill process.

The main contributions of this work can be summarized as:

- A nonlinear plant simulator was developed, with which an investigation into the nonlinear behaviour and interactions between the;
  - hydraulic actuators,
  - mill dynamics,
  - and the material properties of the strip being rolled was completed successfully.

One of the leading rolling mill researchers, R-M Guo [8], stated that in order to evaluate a comprehensive total gauge control loop it might be necessary to model all of the above components as well as the dynamics of the drives and the motors. In [8] this involved modelling was not done, and only the hydraulic actuators were modelled in detail. The work in this dissertation addresses the modelling and the identification of the interactions between the key components itemized above. This investigation is considered a significant contribution to the field of dynamic hot rolling mill modelling.

- The nonlinear plant simulator uses practical plant data as inputs and is also tuned in order to reflect adequate practical process behaviour;
- The nonlinear simulator is able to simulate the thickness profile (and in particular the centerline exit thickness) and tension behaviour of a hot rolled strip while rolling.
- The modularity of the simulator is such that the simulator can be extended to investigate the shape forming process of the strip and this extension is one of the recommendations for further projects;
- The simulator can be used to derive linear models on any part of the process speed curve, e.g. on the speed up, speed down ramp or at threading speed, by specifying different input files.
- Similarly linear models can be identified for any rolling pass of the rolling schedule, by specifying the appropriate input files.

The creation of a simulator of a Steckel hot rolling mill, modelled according to an existing practical mill that agrees acceptably with the literature and practical data, is seen as a major contribution in the absence of extensive literature on Steckel hot rolling mills.

The work in this dissertation should be seen as the foundation of a new research program aimed at investigating model based control techniques applied to the Steckel hot rolling mill process.

7.3 Recommendations

The recommendations for future research projects are concerned with process modelling and control projects. Both sections of the recommendations are divided into graduate and undergraduate research projects.

7.3.1 Modelling and identification projects

Graduate projects

- The investigation into the mill stand behaviour for the four roller model can be conducted. In the work for this dissertation this model was only partially solved. It should be noted that the time variant and invariant case of the four roller model (discussed in section A.2) increase the complexity of the simulator and the simulation time increases substantially.

- The shape forming of the strip should be incorporated into the current mill simulator. In chapter 3 a possible modelling approach is discussed.

- An investigation and model extension should be conducted to identify the influence that thermal crown build-up on the rollers has on the strip thickness crown.

- The effect of roller wear over time on the strip crown might be an interesting avenue to pursue, but might only be of importance if an adaptive mill simulator needs to be created, due to the slow varying structural changes.

- Torsional vibration modelling of the connecting drive spindles between the mill motor and the work rolls, should be incorporated in the current simulator as is proposed by Dobrucki et al. [40] and investigated in [110]. The modelling of the drive and motor dynamics might form an integral part of this study, just as the dynamics of the hydraulic actuators formed an integral part of the modelling in this dissertation .

Undergraduate projects

- The nonlinear plant simulator can be used to identify different linear plant models at different points of the process speed curve as well as for different passes.

- The current capability of the simulator is not yet fully exploited, and an undergraduate project can focus on the identification of transfer functions between the thickness crown outputs and the hydraulic stroke inputs on either side of the mill centerline. The application of the hydraulic strokes need not be seen as one manipulated variable and transfer functions can also be identified for differential gauge operation.

7.3.2 Control projects

Graduate projects

- The application of MPC on a supervisory level to the Steckel rolling mill process should be conducted according to the initial control problem formulation of chapter 6. The results obtained should be compared to the current control schemes used on the investigated Steckel mill.

- The possible economic benefit of the proposed control method on the speed up ramp of the mill speed needs to finally be assessed, in order to verify intuition.

- An interesting project might be an investigation into the optimal mill setup.

Undergraduate projects

- An study could be conducted in order to identify traditional industrial and advanced (academia orientated) control methods used for Steckel hot rolling mills. Simulations of these methods can proof valuable to the first listed graduate control project.
- And lastly the optimal setup problem might also be addressed by an undergraduate student.

Final Word

The modelling and control of a rolling mill is a challenging but applicable field of research in the context of the large steel and aluminium industries found in South Africa. Competitive rolling mill companies rely on state of the art automation and instrumentation of their plants. This state of the art knowledge is confined to leading European countries, America and Australia. The result being that the South African rolling companies pay top dollar for this knowledge.

The South African rolling mill companies can benefit from local research conducted on modelling and control of rolling mills, generating in-house knowledge obtained from the local research projects. This dissertation lays the ground for a successful continuing research programme on modelling and control of hot rolling mills.