Chapter 1

Introduction

This dissertation deals with the modelling for control of a Steckel hot rolling mill process. Hot rolling is the process of shaping metal by passing it between rolls revolving at the same peripheral speed and in opposite directions, while the the strip metal is at temperatures of about $1000°C$. Conservation of mass (massflow) holds as the metal deforms predominantly plastically across the roll gap. The roll gap is set at a gap setting calculated in order to achieve a desired reduction in strip thickness. A reheated slab is transferred from a reheating furnace on a transfer table to a roughing mill, where the initial thickness reduction is done, and then to the hot rolling finishing mill that shapes the metal into a finished or semi-finished product.

Different kinds of flat rolling mills exists, e.g. Sendzimer, Cluster, Steckel, 4-high, 5-high, 6-high, Z-high and Planetary mills [1, 2, 3]. In this dissertation the modelling of the hot rolling mill process is based on a Steckel Hot Rolling Mill. In the Appendix a short definition of common rolling terms are given.

1.1 Background

Modern Steckel Mills (manufactured after 1980 [4]) can be divided into two main categories regarding production. The first type of the new generation of Steckel Mills has been installed in industrial countries producing mainly Stainless Steels. The production capacity of these mills lies between 150,000 and 450,000 t/yr [4]. For these steel grades the Steckel Mills are suitable due to their high flexibility and low investment costs. The second category of modern Steckel Mills is characterized by a very large product mix regarding materials and strip sizes that can be economically produced. Beside carbon, stainless and silicon steels, non-ferrous metals and alloys such as titanium, copper, brass are also rolled [4].

Most of the new Steckel mills are equipped with two stands, capable of producing 500,000 t/yr., but in some cases single stand Steckel mills, capable of 10,000-100,000 t/yr., are installed [4]. Single stand Steckel Mills are usually installed for low production capacities or for products without very high requirements regarding surface quality [4]. The capital expenditure associated with the installation of a Steckel mill is less in comparison to the capital investment associated with the installation of a multi-stand (5-7 stands) hot rolling mill.

Over capacity of steel production has introduced much more competition and the quality of the produced strip, i.e. dimensional accuracy, surface finish, flatness, and physical properties [4, 5, 3], is used to distinguish strip manufacturers from each other. Rolling mill companies are installing advanced control systems to improve the overall quality of their products.

The conventional hot rolling operation has developed significantly during the past thirty years [3]. The main driving forces behind this development are the need to increase the throughput and improve the strip's quality, with the emphasis on the dimensional accuracy, surface finish, flatness and the strip's physical properties. Automation projects of modern hot rolling mill focusses on [4]:

1. Material tracking;
2. Automatic slab and coil storage control;
3. Reheating furnace control;
4. Automatic control of the rolling process focussing on mill sequence control, mill-setup and correction, pass schedule calculation and optimization [6], automatic crop shear control, automatic gauge/thickness control (AGC) [7, 8], automatic crown and shape control [9, 10], finishing/coiling temperature control as well as control of the mechanical properties of the strip [5, 11];
5. Data logging.

The bulk of the current research projects concerned with hot rolling of metals addresses issues reported in point 4 as can be seen in [12, 13, 14]. In this dissertation the focus falls on some of these subjects (in particular thickness profile control and tension control).

The drive for automation of the rolling process is part of larger projects, valued at millions of dollars, the aim to automate the process of steel manufacturing. These automation specialists conduct research on these processes and develop propriety models, that ensure their survival in a competitive market.

The largest part of this dissertation deals with model derivation and integration in order to create a nonlinear plant simulator. Nonlinear modelling is necessary, due to the unavailability of suitable models, simulators and data. The lack of models and data is attributed to the competitive rolling mill environment. The development of nonlinear models can be time consuming and control system experts estimate that modelling can make up 90% of the time taken to establish an industrial control system [15].

1.2 Dissertation Motivation

The control of strip thickness has largely been solved and the application of advanced control methods are being investigated for application on industrial mills. Most of the literature concerned with thickness and tension control in the hot rolling mill environment are done for multiple stand rolling mills [13, 16] with loopers that control the interstand tension. The Steckel mill layout is similar to that of a single stand cold rolling mill and strip tension plays a larger role for a Steckel mill process than it would for a multiple stand mill. In [3] it is reported that a Steckel mill relies on a drawing process rather than a rolling process to achieve the desired reduction. Further it is suggested that the coiler motors supply the energy necessary to draw the strip through the roll gap. For a hot rolling Steckel mill, however the tension aids the rolling process and the bulk of the reduction is done with a rolling process, where the work rolls are driven. In the literature only a few articles dealing with Steckel Mills are found. This can be attributed to the scarcity of Steckel mills as was reported in [4].

In hot rolling emphasis is increasingly being placed on the control of strip crown and shape [17], and hence the this dissertation will investigate the strip crown behaviour. The simulation of the shape forming of the strip falls outside the scope of this dissertation.

Industrial Steckel automation projects[1] focuses on:

- Dual gaugemeter system, featuring mean and differential gaugemeter loops
- X-Ray thickness feedback and feedforward control
- Speed compensation
- Tail end compensation
- Roll thermal compensation
- Backup roll eccentricity control

In this dissertation selective items of the above items are modelled, and the distinction can be summarized as follows:

Dissertation emphasis

- The dual gaugemeter principle, arising from the difference of mill stiffness on either side of the mill.
- The difference in entrance speed and exit speed of the roll gap.

[1]Document compiled by Dr. Tony Bilkhu of Cegelec Projects Ltd. Rugby England, concerned with Cegelec Steckel Mill AGC.

Outside the scope of this dissertation

- The modelling of the eccentricity of the backup rolls.
- The modelling of roll thermal expansion and roller wear.
- In depth temperature modelling of the rolling process is not the emphasis of this work. Many compensation techniques exists for head and tail end compensation consists, of which compensation for the increase in the rolling force, attributed to the thermal rundown of the strip temperature is one.

One of the aims of this dissertation is to initiate an investigation into the potential benefits that can be gained if a modern advanced control method such as MPC is applied in the rolling mill environment on a supervisory level. The application of advanced MIMO control to rolling mills is increasingly being investigated [13].

The regulation of the mill outputs at threading speed have exhaustively been investigated [18] and the current trend is to improve the control on the head and tail end of the strip, in order to reduce the amount of off-specification product [19]. The Steckel hot rolling mill process investigated in this dissertation can be seen as a batch process with process start ups and process shut downs. The process start ups and stops are reflected through the speed up and down of the mill drive speed respectively. In this dissertation an investigation is initiated into the feasibility of thickness and tension control on such a process start up.

In the literature there is at least one reference of the application of Generalized Predictive Control (GPC) to a multiple stand rolling mill [18], showing that the investigation undertaken in this dissertation is not an isolated case. This application of GPC is on a supervisory level, which utilizes cascaded control schemes for its local control of the mill drive speed, hydraulic actuator strokes etc. The traditional Smith predictor feedback control scheme for the thickness control loop can be replaced by a model based predictive control method [20]. The controlled variables in this dissertation, namely:

- centerline exit gauge,
- thickness crown,
- strip tension,

are similar as is discussed in [18].

1.3 Aims and Contributions

One of the aims of this dissertation is to develop the basis for a continuing research program that will ultimately investigate the feasibility of applying MPC or other advanced control methods to a Steckel

Hot Rolling Mill process. The main contributions of this work towards this aim can be broken down into the following tasks and intermediate aims:

- A nonlinear plant simulator is developed, with which investigations into the nonlinear behaviour and interactions between the;
  - hydraulic actuators,
  - mill dynamics,
  - and the material properties of the strip being rolled can be conducted.

  One of the leading rolling mill researchers, R-M Guo [8], states 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. In this dissertation the modelling and the identification of the interactions between the key components itemized above is done. Such an investigation, concerned with dynamic hot rolling mill modelling, incorporates the following:

- The nonlinear plant simulator should reflect adequate practical process behaviour;
- The nonlinear simulator should be able to simulate the thickness profile (and in particular the centerline exit thickness) and tension behaviour of a hot rolled strip while rolling;
- The simulator should be constructed in a modular fashion such that it can be extended easily;
- The simulator should be made operable at any part of the process speed curve, in order to derive different linear models at any chosen operating point;
- An initial linear model should be identified on the process start up, in order to test certain control ideas;
- An initial control problem should be formulated, so that the performance of a proposed control method can be evaluated, by utilising the simulator as the process that has to be controlled.

With this dissertation a research program is launched that will ultimately help with the industrial research of rolling mills in South Africa.

1.4 Organization

This dissertation is organized as shown in table 1.1. In chapter 2 a general steel manufacturing process description is given, and it is accentuated where the hot rolling mill fits into the larger manufacturing process. The layout and practical operation of the hot rolling mill are then given. Finally the mechanics of the Steckel hot rolling mill process are described.

In chapter 3 models are identified that will be connected to each other in order to create the mill simulator. These model derivations are shown and their incorporation into the mill simulator is discussed. In chapter 4 the solution methodology for each model is discussed and the necessary physical constants are calculated or identified from the literature.

In chapter 5 simulation results are shown for the separate models. These results are discussed and their accuracy assessed compared to results stated in the literature. The design of steps that are applied to the manipulated variables of the mill simulator during the identification of the linear model are discussed, and some time simulation results from these tests are shown. The derivation of the linear model by using system identification is shown in this chapter. It is shown that the linear model can be used for controller design, although this dissertation does not focus on the design of controllers.

In chapter 6 general control problems in the rolling mill environment are discussed and an initial control problem formulation is stated. The proposed control method, Model Predictive Control (MPC), is discussed and controller specifications for this method are identified.

In chapter 7 conclusions are drawn and contributions discussed. Some recommendations for future research projects regarding rolling mill modelling and rolling mill control are identified and briefly discussed.

Table 1.1: Organization of this dissertation.

Chapter	Description
1	**Introduction:** A general introduction of the rolling mill environment is given. A motivation for this dissertation and the control problem formulation is given.
2	**Process description:** A general description of the practical operation of a Steckel rolling mill is given. The hot rolling process is described, focussing on: material behaviour in the roll gap; tension in the sheet whilst rolling; the mill stand's elastic stretching; the elastic bending of the rollers.
3	**Model derivation:** The models identified to simulate the thickness profile behaviour and the strip tension behaviour while rolling are discussed and derived. The roll gap model, stand model, hydraulic actuator model and tension models are derived and discussed in more detail.
4	**Nonlinear plant simulator:** The solution methodologies and steps followed to solve the models identified in chapter 3 and to incorporate them into the simulator are discussed. The practical input data for the simulator are identified and analyzed. Model coefficients are calculated and motivated.
5	**Simulation results:** Simulation results of model components are given. The strategy followed to identify the linear plant model is described, and the resulting LTI MIMO transfer function model is derived.
6	**Control problem formulation:** An initial control problem formulation is given. Constraints are defined on the manipulated variables and the output variables. These constraints result in a constrained optimization problem of a performance index associated with Model Predictive Control.
7	**Conclusions and recommendations:** A summary of the work and its contributions are given. Suggestions for future research projects are also given.