Chapter 1: Introduction

Due to an increasingly competitive market, good control and optimisation of processes are becoming increasingly important. In the mining industry new methods are also being investigated to improve performance. Milling circuits are widely used in the mining industry and since they are difficult to control (Craig & MacLeod, 1996), they offer exciting opportunities for applying innovative control techniques with substantial potential for improvement. The fact that milling cost forms a significant component of the total production cost in most mining and mineral-processing industries (Hulbert *et al.*, 1990) is another reason for applying techniques to improve milling performance.

There are a number of factors contributing to the difficulty of controlling milling circuits. The first difficulty is associated with the fact that the ore fed to the mill contains rocks that act as the main grinding medium (Craig & MacLeod, 1996) and that the feed rate of the rocks and the feed rate of the ore cannot be measured separately. A further problem is that the composition, size and hardness of the grinding medium fed to the mill will influence the process. All these variables cannot be measured and controlled separately and will therefore act as disturbances to the system. This will result in uncertain plant dynamics.

Other difficulties in controlling a milling circuit are the multivariable, interactive nature of the process, the long dead times and the large variety of possible disturbances. The process characteristics will furthermore also undergo substantial changes as the equipment ages due to the high level of mechanical wear. This will cause the performance of the controller to deteriorate with time. Another difficulty associated with milling circuits is controlling the throughput. The throughput of a milling circuit is usually a parabolic function of the load in the mill (Craig *et al.*, 1992). Since a maximum throughput is required, an optimisation controller needs to be used to effectively control the throughput.

A number of multivariable control techniques have been tried on milling circuits (Craig & MacLeod, 1996, Hulbert & Lyon, 1986). One of the techniques that were successfully implemented in this environment is the *Inverse Nyquist Array* (INA) technique (Hulbert *et al.*, 1990). The problem with this technique is that it requires considerable skill, intuition,

time and effort from an experienced control engineer to implement the control scheme. A controller that can be implemented with less effort and that requires a shorter implementation time is therefore required. Model predictive control (MPC) can be implemented quickly and easily and since it is known to handle most of the difficulties mentioned earlier extremely well, it was decided that the MPC technique should be tried for a milling circuit. The goal of this project is therefore to develop a model predictive controller for a milling circuit and to test it. In order to achieve this, a milling circuit is required on which to develop and test the controller. Since no actual milling circuit was available for testing, a simulator for a milling circuit was written that could be used to develop and test the controller. After the simulator was verified to be a reasonable representation of a milling circuit, the MPC controller was developed based on data obtained from the simulator. Microsoft Visual C++ was used for the development of both the simulator and the controller (Prata, 1998).

The controller was first tested using a very simple model of the milling circuit. The complexity of the simulator model was then increased step by step by adding real-life factors affecting effective control of the milling circuit. The problems that appeared as the complexity of the model increased were addressed accordingly and the MPC controller was improved to accommodate these difficulties. The main components that were therefore developed in designing the MPC controller are:

- An advanced simulator that includes hard and soft limits on inputs and outputs, noise, disturbances, dead time, drift rates, valve characteristics and nonlinearities to represent the dynamic behaviour of any milling circuit as closely as possible.
- A model predictive controller with the following features
  - Different MPC parameters for each input-output pair.
  - Feedforward control on disturbance variables.
  - A region of uncertainty around the setpoint within which the controlled variable is allowed to deviate. This is used to handle noise and to increase the robustness of the controller.
  - A choice between using the least squares or a quadratic programming method to solve the objective function.
  - Special features to handle integrators and integrating errors.
  - A manual adaptive scheme to retune the model when required.

- An optimiser that automatically tunes the many MPC parameters using a performance index. The optimiser was developed with the option to minimise the controller parameters like the horizons (and therefore minimising the computational effort) with a minimum deterioration in performance.
- An optimising controller to maximise the throughput of the milling circuit (amount of product produced).

The layout of this dissertation will be as follows: In the second chapter a discussion will be given of a general milling circuit. This will be followed by a detailed explanation of the theory of model predictive control. After the theory, it will be shown that the simulator that had been developed is a good representation of a real milling circuit. The next chapter will then be dedicated to the steps that were followed in designing the MPC controller and the results that were obtained. Finally the discussion will be rounded off by a number of conclusions and recommendations. The detailed graphs of all the results and other detail such as the simulator algorithm and a description of the software are given in the Appendices at the end of the dissertation.