Chapter 6

Conclusions

6.1 Summary

The objective of the study is to find optimal driving methodologies for an implementation of the desired speed profile with energy consumption and in-train forces considered.

Firstly, three control strategies are proposed in this study for train handling.Keeping in mind the characteristics of traditional pneumatic braking systems and ECP braking systems, a simulation study of optimal open loop controllers is undertaken. The result shows that ECP braking systems demonstrate superb performance compared with pneumatic braking systems, especially together with iDP control.

Then, the study mainly deals with the control of a heavy haul train equipped with an ECP braking system. It is shown that there are redundancies in designing an open loop controller. An optimization procedure is applied to schedule cruise control by taking in-train forces and energy consumption into initial design consideration. Optimal open loop scheduling presents a better starting point for a closed-loop controller design. A type of LQR controller with state feedback is simulated to verify the above result.

However, the closed-loop control law is designed based on the full state feedback, which is not practical, since not all the states can be measured.

An observer could be designed to supplement the LQR controller if partial states are measured. This is, however, not the approach taken in this study. Instead, the application of output regulation of nonlinear systems with measured output feedback to the control of heavy haul trains is considered. Optimal scheduling of the open loop controller is still based on “trading off” the equilibria. Thus the balance between energy consumption and in-train forces is still maintained. For closed-loop control, speed regulation is imposed. This approach to design is practically feasible and manageable, and by its nature, is also easily integrable with human drivers. Instead of a linear system theory, a nonlinear system theory is adopted so that without a linear approximation philosophy, control is closer to reality. Another advantage of the approach is the assumption that only the locomotives' speeds are available for measurement.

In this study, the existing result of output regulation of nonlinear systems is also extended. The output regulation problem of nonlinear systems with measured output feedback is formulated in this study and solved for the local version and global version. For its application to train control, some application issues of the output regulation of nonlinear systems with measured output feedback to train handling are discussed. Based on the proposed theory, a speed regulator for train control is designed. Simulation result shows its applicability.

Lastly, this study concentrates on the fault-tolerant capacity of the speed regulator. Two kinds of fault modes are considered. Fault detection and identification for sensor faults and braking system faults are examined. Controller redesign is also given. Simulation results show that the FTC speed regulator proposed in this thesis has a fault-tolerant capacity to corresponding faults.

6.2 Assessment

It is should be pointed out that a speed profile is assumed first in the study. This assumption is a prerequisite for the study. The optimization between energy consumption and in-train force are only done at a point of the track on the assumption that the train is running at the reference speed. Firstly, this optimization is only local and is not global (considering the dynamics of the train). Secondly, this optimization does not consider the optimization of the speed profile, which is rather a problem of a "golden run" in terms of travelling speed.

The cruise phase of train handling is studied, as well as the speed acceleration/deceleration phases. The start phase and stop phase of train handling are not studied because the models of the train within those phases are different from those in this thesis and more aspects related to safe handling need to be considered. However, considering a train is running at cruise phase or acceleration/deceleration phases most of the travel period, the study of this thesis is significant.

The fault-tolerant control in chapter 5 is currently proposed for sensor gain fault, locomotive actuator fault and braking system fault, respectively. The FDI of locomotive faults is not discussed, which is also a study subject in the literature. The FDIs of sensor faults and wagon faults are discussed separately. As pointed out at the end of chapter 5, it is possible to study them or combine the two approaches to them. However, this combination is not finished because of difficulties in tuning the thresholds related to them. Nevertheless, this study is a good start to such an FTC problem.

The simulation in this study is undertaken on a short track (12 km long). It is enough for the test of a driving profile, which can be seen from the good speed tracking performance on such a track. However when the objective is to test the optimization combination of a driving profile and a reference speed profile, a longer track might be necessary. On the other hand, the track is largely downhill, which is the case with the COALink of Spoornet when the train is loaded. When the unloaded train travels back inland, because of the larger ratio of traction effort to mass, it is relatively easy to drive, which is not simulated in this thesis. Even on such a largely downhill track, the loaded train runs well when it passes over some hills on the track with a carefully designed speed profile.

6.3 Future work

To extend the research in this thesis further, the following directions are noted:

1) The optimization problem of the speed profile. Various papers [6, 7, 8, 9] have studied such a problem, with energy consumption considered. The problem considering the optimization of energy consumption and in-train forces is still open in an extremely long train.

2) The optimal scheduling problem with the dynamics of the train. Optimal scheduling in this thesis is done in ignorance of the dynamics of the train. Methods considering the dynamics of the system, such as model predictive control (MPC), might be able to improve the performance of optimal scheduling.

3) A uniform FDI design problem for the faults of sensors and actuators. The tuning criterion of the parameters of the FDIs for sensor faults and braking system faults needs to be studied further, as well as the FDI of the locomotive faults.

4) The optimization problem of the train composition structure. On the basis of this study, the researcher is of the opinion that the train structure (composition and sequence of locomotives and wagons) has a significant impact on the performance, besides the controller. The optimization of the train composition structure needs to be considered in future studies. However, the logistics of restructuring the train impose a much bigger constraint than any other technical ones.