Chapter 6

Conclusions and recommendations for future work

6.1 Conclusions

The monitoring of incipient failure in gears and gearbox systems is of outmost importance to engineers since failures in large gearboxes without any backup systems could easily lead to production losses that can quickly amount to millions of Rands. Most of the vibration analysis techniques for gearboxes require time domain or synchronous averaging. Although direct time domain averaging has been around for decades, it still remains a challenge to develop an efficient time domain averaging filter (synchronous filter) that is suitable for implementation on an online gear condition monitoring system. This is particularly so because direct time domain averaging requires a large amount of data to be collected and stored in the data acquisition system before the TDA is calculated.

In this work the use of ANNs and SVMs in the development of a synchronous filter for time domain averaging of gear vibration data is investigated. Two models that utilise ANNs and SVMs for time domain averaging are developed. The first model (Model 1) utilises a feedforward network structure to map the input space (rotation synchronised gear vibration signals) to the target (TDA of the rotation synchronised gear vibration signals) in a single step. The second model (Model 2) estimates the TDA of the input space in small sequential steps, analogous to taking a running average of the input space. Model 2 consists of a number of small feedforward networks but instead of the networks being used to predict the TDA of the whole input space in one step, are used to first sequentially predict the average of subsections of the input space (instantaneous averages). The output of the first set of feedforward networks are used as inputs into a second feedforward network that predicts the TDA of the whole input space.

The developed models considerably reduce the amount of gear vibration data that needs to be stored in the data acquisition system to execute synchronous averaging. This characteristic of the developed synchronous filtering models brings us yet another step

closer to the development of an online vibration based gearbox condition monitoring system that makes use of TDA to enhance its diagnostic capabilities.

Chapter 1 of this work presents a literature study of different vibration based gear condition monitoring techniques, filtering and the application ANNs and SVMs in pattern recognition. ANNs and SVMs are attractive in study because of the following properties:

- They can form arbitrary decisions so that any complex mapping from a set of noise-contaminated signals to a noise-free signal can be realized.
- They can easily be implemented as software or in specialized hardware
- They are quite resilient against distortions in the input data and have a capability to learn and generalize well when they are properly trained.

In Chapter 2 the theory and mathematics of existing time domain averaging models are presented. The characteristics of some of the existing time domain averaging models are investigated using numerical examples and experimental vibration data from the accelerated gear life test rig. From this analysis it is concluded that calculating the TDA by direct averaging is most suitable for filtering out the vibration content that is not synchronous with the rotation of the gear of interest.

In Chapter 3 the theories of the MLP neural network, the RBF neural network and SVMs are presented. Preliminary simulations using data from the accelerated gear life test rig to investigate the suitability of these formulations for use in the synchronous filter are conducted. It is concluded from the simulation results that MLP, RBF and SVMs are all suitable for use in the synchronous filtering model.

Chapter 4 presents the actual development process for the synchronous filter for time domain averaging of gear vibration data. Two different filter models are developed. Using Model 1, which utilises ANN or SVMs to map input space (rotations synchronised gear vibration signals) to the target (TDA calculated with 160 rotation synchronised gear vibration signals by direct averaging) in one step an input vibration data reduction of 75 % was achieved. At first glance SVMs seem to be a more attractive option because of the slightly better TDA prediction they produce. Their attractiveness

is reduced by the fact that they are more computationally expensive than MLP and RBF, therefore the analyst needs to be cautious when SVMs are implemented in an online system that requires retraining regularly. On the other hand the MLP and RBF networks are much quicker and easier to train, therefore can be suitable for online systems even when required to retrain online. Model 2 operates in two stages. In the first stage it uses 10 inputs (10 rotations synchronised gear vibration signals) to predict the instantaneous TDA of the gear vibration. The input data to the first stage can immediately be deleted from the memory of the data acquisition system after use. The outputs of the first stage are saved and used as inputs to a second feedforward network to predict the TDA of the entire gear vibration signal. In this work this results in an effective data reduction of 83.75 % in the amount of data that needs to be stored in the data acquisition system in order to calculate the TDA.

In Chapter 5 the developed synchronous filters for time domain averaging of gear vibration data are tested on a new data set from the accelerated gear life test rig to assess their diagnostic capabilities and suitability for use over the entire gear life. The performances of the different formulations on the developed models are found to be equal for data measured under constant load conditions for both Model 1 and Model 2. For data measured under varying load conditions Model 2 performs much better than Model 1 over the entire gear life for all three formulations. This is because Model 2 uses the whole data set for training and simulation therefore it exposes the used formulation to all the transient effects within the data set. The performance of Model 1 depends on the generalisation capabilities of the formulation that is used.

6.2 Recommendations for future work

As future work on the development of a synchronous filter for time domain averaging of gear vibration data the following issues still need to be addressed:

- The two models that were proposed in this work should be made more robust by implementing proper optimisation schemes for the network architecture for a specific data set.
- The developed models should be implemented in a DSP board for use in actual online gear condition monitoring system.

- The test data that was used to test the developed models was from a controlled experimental set-up. The developed models should be tested on data from an industrial application.
- An investigation of the suitability of the developed models for use in condition monitoring of other rotating machinery that require time domain averaging should be conducted.