CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Introduction

This chapter deals with the final conclusions regarding key aspects of this project. Recommendations for future research are also made. The following issues are considered:

- The use of FEM to help determine the feasibility of vibration based damage detection on an actual structure (the EFBDS in this case)
- The viability of using frequency changes for damage detection in blade structures where the location of damage is usually known
- The practical implementation of the developed techniques with specific emphasis on sensor and telemetry requirements

Recommendations are made regarding further development of the damage detection method, along with areas that needs further research.

6.2 Conclusions

6.2.1 Use of FEM for feasibility study

Rapid progress in computer technology and software has led to the situation where powerful packages such as MSC Marc can be used on desktop systems. This made it possible to study the effect of damage on the dynamics of a structure such as a blade prior to constructing an experimental test structure. From this analysis it could clearly be seen that certain mode shapes were more susceptible to damage than others. These findings correlated well with findings during a literature study. It was also found that the type of element used was extremely important. Higher order elements gave superior accuracy although they were computationally more expensive. First order solid elements are not a real proposition due to their poor performance in bending. Since most mode shapes have some element of bending, results provided by first order solid elements were found to be unacceptable even for simple structures.

After the results from the EFBDS were compared to the predictions made by making use of a FEM, certain modes were found to exhibit different behaviour to the predictions made by the FEM. After careful consideration it was postulated that this was most likely due to global dynamics of the structure not taken into account by the simplified FEM used initially. After an extended FEM model was constructed, all discrepancies between the initial model and the EFBDS could be explained (chapter 5 deals with these findings in detail).

Clearly, while FEA is certainly a powerful and valuable tool, very careful consideration regarding assumptions and boundary conditions have to be made. Provided this is done, FEA can be used with great success not only to study the feasibility of damage detection but also to determine optimal sensor location and number.

6.2.2 Frequency changes as damage indicator on fan blades

From the results obtained with the EFBDS, it is clear that damage can be accurately detected at levels as low as 10% using one sensor per blade only. During routine maintenance at the Majuba power plant, damage levels of up to 70% were found on some blades that were still operating. Sufficient warning for future maintenance would therefore be given if 10% damage can be detected accurately.

The frequency changes were more consistent damage indicators than time domain indicators such as variance, Crest factors, Kurtosis, *rms* levels, etc.

The ARMAX model used in conjunctions with peak picking provided accurate enough natural frequency values for damage identification. This algorithm needs little user input and experience once it has been set up for specific data sets and an automated on line damage detection method could therefore be developed.

The amount of data that needs to be processed did prove to be fairly high as did the CPU time. This is not an insurmountable problem as a set of measurements can be taken at specified intervals, leaving ample time for processing of the data.

6.2.3 Practical implementation of on-line technique

Any technique developed for damage detection will be of little use if it cannot be implemented on a structure, other than an experimental test structure. The practical implementation of the on-line, vibration based, damage detection method was therefore of paramount importance throughout the project. A considerable amount of time was spent in search of sensor and telemetry technology for this application. The most significant problem for this application is the transfer of data from sensors mounted on a rotating fan blade to a processing unit. Alternatively an integrated sensor will do the processing and send only a result to a monitoring station. Be that as it may, some form of wireless transfer will probably required. Slip rings are usually not easy to install on an existing structure and due the contact between a stationary brush and the rotating structure, a certain amount of wear is inevitable. Bluetooth technology should become readily available within the next two years. This is a standard for the wireless transfer of data between various portable devices and manufacturers of sensors are also looking into this technology.

Due the advent of MEMS, wireless sensors and smart sensors have already been developed and this trend seems set to continue. These smart sensors are already being used in applications such as air bag deployment in the automotive industry.

6.3 Recommendations

6.2.1 Further development of FEM

It was made clear from the outset that this is a long term project. The initial findings are very encouraging and on-line, vibration based damage detection on structures such as fan blades has proved to be a viable means of damage level indication. The next stage would probably be to develop a more detailed FEM of the fan on which the technique will first be tested in industry (probably the FD fan at Majuba). Because of global and local mode shapes, it may make sense to develop a simplified FEM of the complete system. Higher order elements should be used even though computational time is higher.

6.3.2 Sensors and telemetry

Some preliminary measurements will have to be taken on the FD fan. This will be necessary to verify the FEM results and confirm that frequencies can be measured accurately and repeatedly. Due to the installation it will be possible to use fairly conventional sensors for these measurements as the fan are switched on and off at fairly regular intervals for peak power demand although this may change in future. Data can be stored and downloaded when the fan is switched off without the need for (expensive) wireless equipment. Further studies regarding the implementation will be a high priority.

Since the EFBDS already exist, it will make sense to use it to fine-tune the technique. Possible improvements to the technique are described in the next section. The simple plate type blades can be substituted with curved blades easily due to the modular design of the EFBDS.

6.3.3. Further development of detection technique

As mentioned in Chapters 4 and 5, the damage level indicators developed during this project should make good features when used in a pattern recognition algorithm such as neural networks or self-organising maps. The complex interaction between the different blades may not show any clear pattern by just looking at it, but these algorithms may well make it possible to use these features as indicators of damage levels on other blades and make instrumentation of all the blades unnecessary.

6.4 Epilogue

A technique for the on-line detection of damage in fan blades was developed. As a first step in the development of an on-line monitoring system for use on industrial fans, it showed that vibration based damage detection can be developed as a reliable and relatively inexpensive method of damage level indication. The method was shown to give good results even when time signals were polluted by blade pass frequencies and harmonics, as well as high levels of electrical noise. The next step would be to develop this method to such an extent that it can be integrated into existing fans. The large amount of research being done in the field of on-line condition monitoring shows that these methods will eventually become standard on any new equipment