Chapter 5 Updating of the Finite Element Model

5.1. FEM Updating

In the process of updating the FEM, a number of issues were addressed:

5.1.1. Structural Damping

It was decided to incorporate structural damping in the FEM in order to obtain more realistic FRFs from it. This is also suggested by Strydom [49]. The structural damping of all the materials in the FEM was assumed to be 1%, using Fredö et al. [18] as a guideline for weld seams and solid connections.

5.1.2. Frequency Tuning

The first torsional modal frequency of the FEM (NMS #5) was tuned to the first torsional EMS frequency (EMS #2). This was decided upon in the aim of correlating the frequencies of NMS #19 to EMS #4 (the second shaft-related torsional mode shapes) as these mode shapes prove to be very important in terms of damage detection as described by Maynard and Threthewey [35] and noted in Section 3.4.

In order to do this, it was decided to revisit the design of the FEM. The solid element modelled shaft was replaced with a beam element modelled shaft. The reason for this is that it is much easier to adjust the diameter of the modelled shaft when beam elements are used as opposed to solid elements. This also serves to simplify the model ([49]). The beam element modelled shaft was connected to the rest of the FEM by means of an RBE2-type MPC as shown in Figure 5-1. The same nodal constraints were applied here as on the shaft of the previous FEM.

By performing modal analyses on the FEM for arbitrarily chosen shaft radii, a graph was drawn up relating the frequencies of NMS #5 to the different shaft radii as shown in Figure 5-2. A shaft radius that will yield the desired frequency was calculated as 21.08 mm. By updating the FEM accordingly, NMS #5 was changed from 68.3 Hz in the initial FEM to 57.28 Hz, corresponding very well with the 57.24 Hz frequency of EMS #2.
The frequency of the NMS corresponding with EMS #4 shifted from 416.96 Hz to 393.97 Hz, moving closer to the frequency of EMS #4 which is 361.07 Hz. This improved the frequency error from 15.5% to 6.4%.

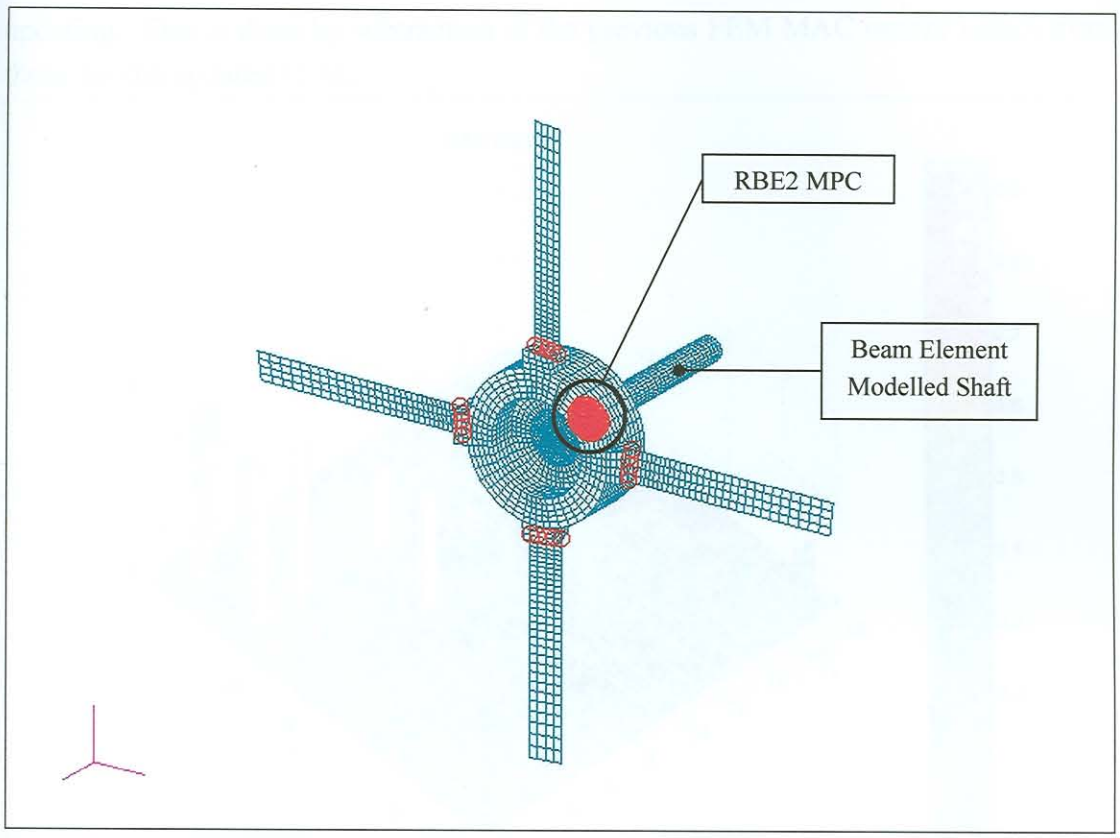


Figure 5-1: Updated Finite Element Model

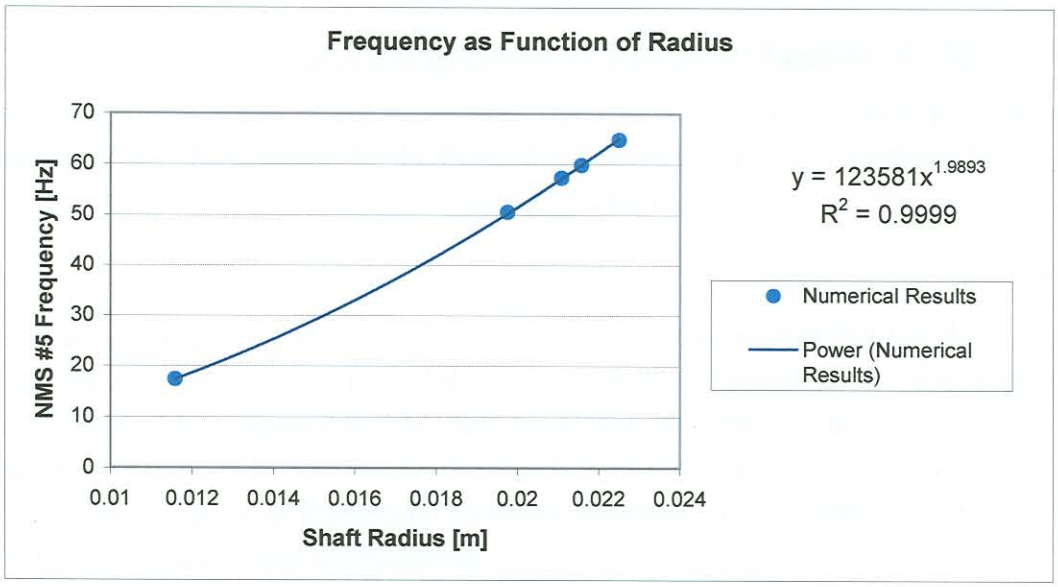


Figure 5-2: Shaft Radius Effect on First Shaft Torsional Frequency

5.2. MAC Matrix Calculations for Updated FEM

Again, a MAC matrix was calculated for the updated FEM as shown in Figure 5-3. Compared to Figure 4-16, the MAC matrix for the updated FEM is less "noisy" and also has a bit better defined diagonal. Also, the MAC matrix values for the updated and previous FEMs are compared in Figure 5-4, showing the effects of the model

updating. This is done by subtraction of the previous FEM MAC matrix values from those for the updated FEM.

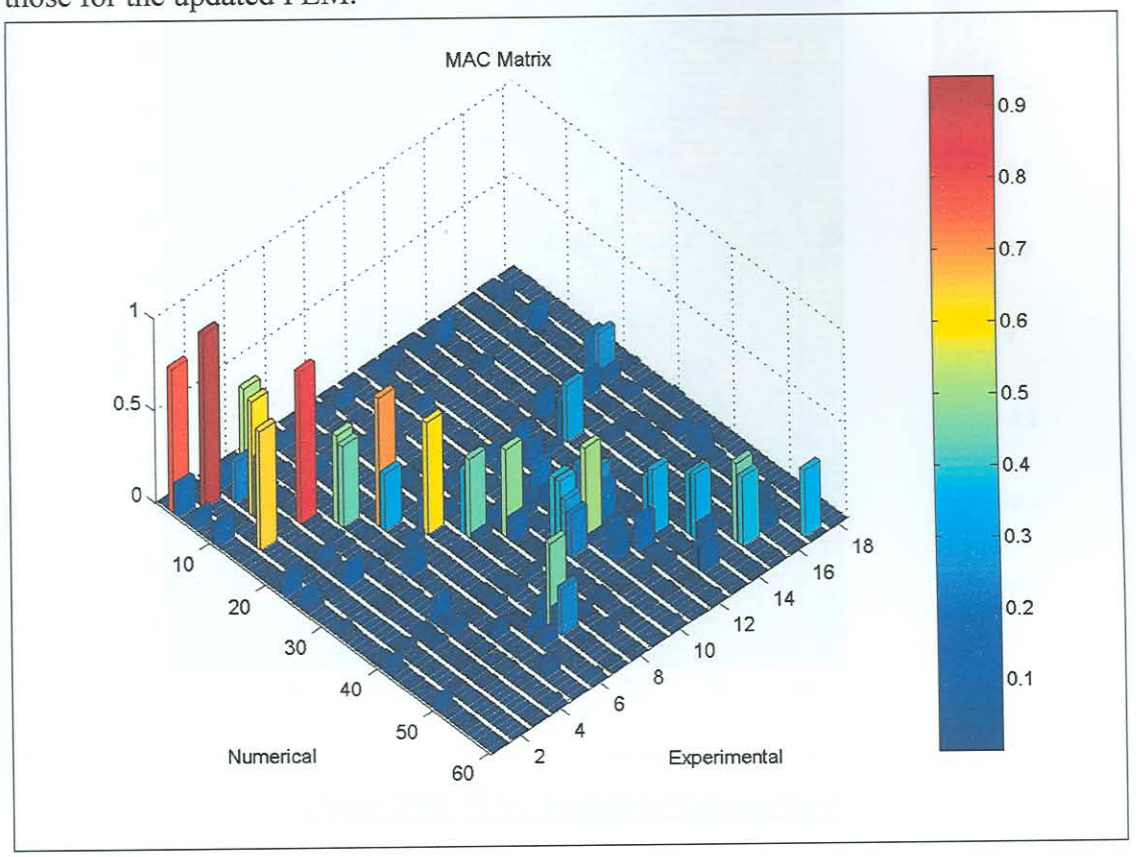


Figure 5-3: Three-Dimensional MAC Matrix for Updated Model

As in Section 4.6.2, a linear curve was fitted to a frequency scatter plot for the updated FEM. The equation for the linear fitted curve is given by Equation (5-1):

$$f_{exp} = 1.0859 f_{num} - 54.1252 \qquad (5\text{-}1)$$

Comparing Equation (5-1) with Equation (4-2), it can be seen that the slope of the graph for the updated FEM is slightly closer to unity. However, when the frequency scatter plots are compared for the first six EMSs, the improvements are clear. As shown in Figure 5-5, the modal discrepancy problem that was a cause of great concern as discussed in Section 4.7 has been resolved. The improvement of the first shaft torsional frequency is also shown.

An additional mode shape was identified at about 1800 Hz and was previously not used. This mode shape will be referred to as EMS #X. From MAC calculations it corresponds well to NMS #41 (MAC=0.5011) and NMS #42 (MAC=0.375). EMS #X and NMS #41 are graphically depicted in Figure 5-6.

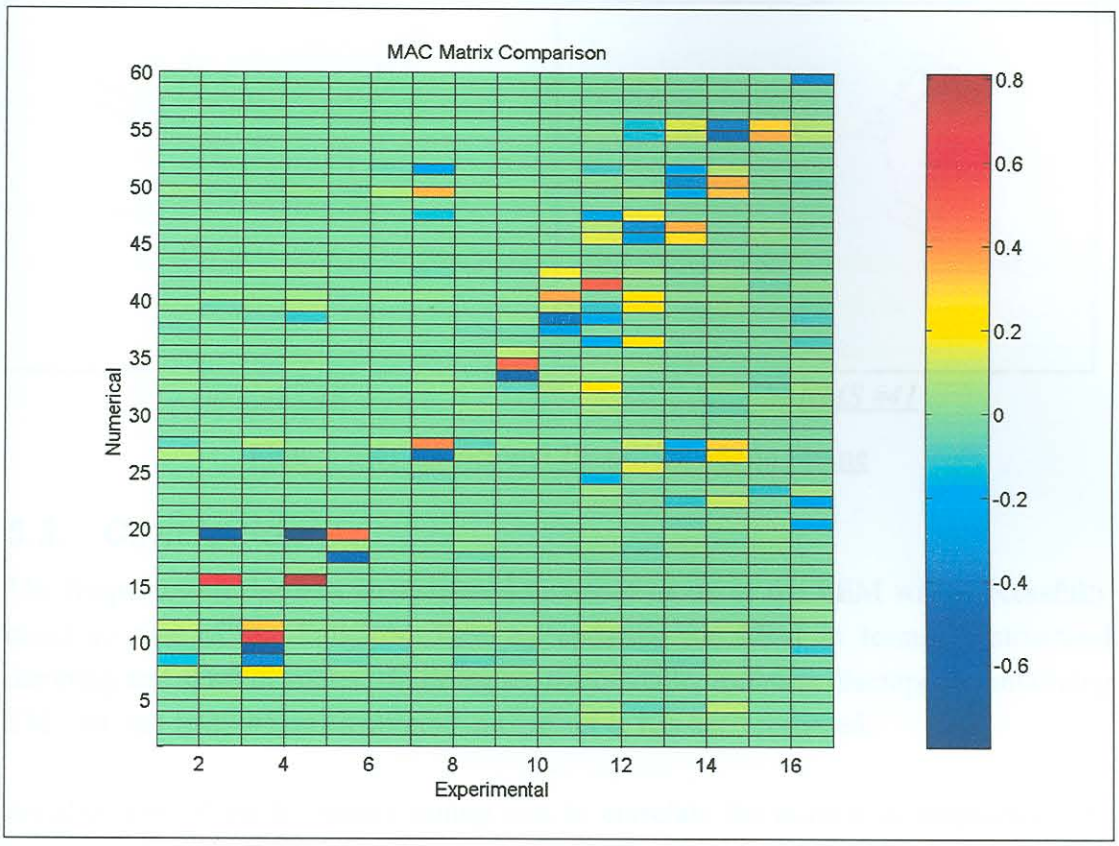


Figure 5-4: MAC Matrices Comparison

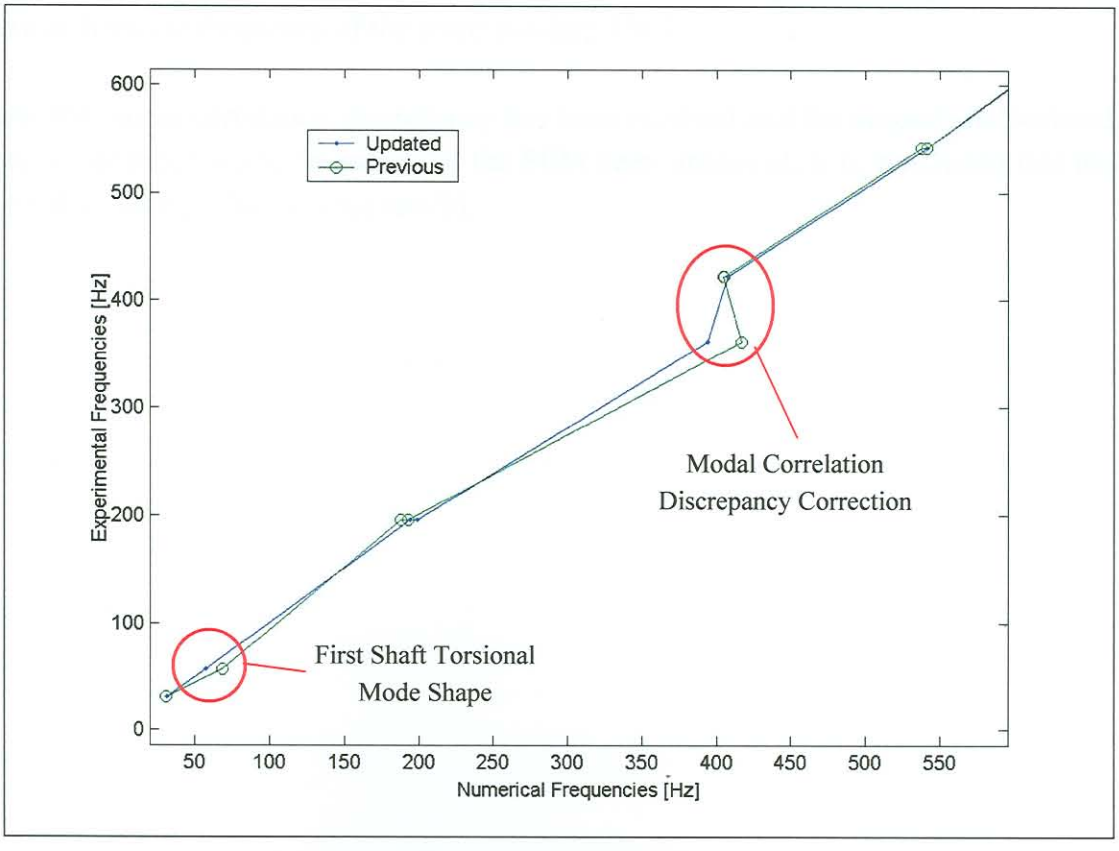
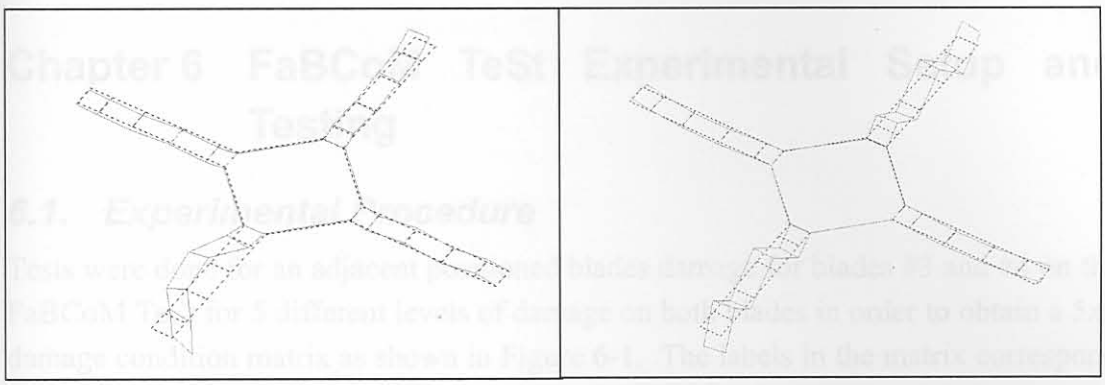


Figure 5-5: Frequency Scatter Comparison



a) EMS #X *b) NMS #41*

Figure 5-6: Additional Identified Mode Shape

5.3. Conclusion

The frequency of the first shaft-related torsional mode of the FEM was successfully tuned to that of the FaBCoM TeSt by updating the FEM in terms of structural damping and shaft diameter. In doing so, the modal correlation discrepancy involving EMS #4 and EMS #5 as mentioned in Chapter 4, has been resolved.

Another aim of the frequency tuning was to correlate the numerical frequency with the experimental frequency of the second shaft-related torsional mode shape. The frequency error of the NMS was more than halved, although still being about 33 Hz away from the frequency of the corresponding EMS.

As the modal correlation discrepancy has been resolved and the second shaft-related torsional mode shape frequency of the FEM been improved, it is concluded that the FEM updating effort was successful.