Cyclic Symmetry Analysis of a Turbomachinery Blade

by

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ABSTRACT

Turbomachines such as those in the jet engine and power industries are becoming larger in capacity and higher in performance. Those complex machines require more accurate structural analysis to predict peak stress levels and vibratory characteristics of their life limited parts such as turbine blades and disks. Finite element modeling of an entire turbine stage including all blades and a disk is complicated and time consuming. The model would have so many degrees of freedom and will require large amounts of computational time. To treat this problem cyclic symmetry analysis is introduced. Cyclic symmetry only models one blade and a disk sector instead of the entire wheel, hence it uses the inherent symmetry of a turbine stage wheel structure. This only requires a fraction of the degrees of freedom and saves greatly on computational time. In my engineering seminar project I am planning to investigate the process and capabilities of modal vibratory and static cyclic symmetry analysis using ANSYS finite element code and will compare the results to a full bladed disk model of an entire turbine wheel. Preliminary results showed that both frequencies and modeshapes for modal runs were almost identical between the employed methods. However, cyclic symmetry was found to be more powerful since it accomplished the task at a fraction of time and computer resources.
Introduction and Modeling Methodology:

By definition cyclic symmetry is defined as a component or assembly that has a correspondence in form or arrangement of parts that are in a repetitive pattern centered on an axis. Spur gear or fan and turbine wheels are typical examples of cyclically symmetric structures.

ANSYS was used to analyze our models. The procedure for creating cyclic symmetry models is as follows. First we need to define the basic sector, to do so we obtain a bladed-disk sector geometry and mesh it; the model used solid45 elements for simplicity. The mesh on the cyclic faces of the disk section should match, that can be accomplished by using the sweep mesh function, if that’s not possible the MSHCOPY can be used to copy the mesh from one sector side to the other.

Using the automated procedure, the code will determine the number of sectors, the sector angle and the cyclic coordinate system. To confirm that cyclic symmetry boundary conditions were created successfully ANSYS provides a status windows and shows that the sectors have matched as shown in figure 1. At the inner disk diameter an ALL DOF constraint BC was applied to both models as shown in figures 2. The full model was basically a sector model physically duplicated 24 times to create a full wheel.
Figure 1: Cyclic Symmetry and Full model

Figure 2: ALL DOF boundary conditions applied to the inner disk diameter
**Results:**

Looking at the results it was important to note their sequence between the two models. As shown in Figure 3, the cyclic symmetry model shows all the modes corresponding to a specific ND or harmonic index while the full model solution shows its predicated frequencies in sequence and those frequencies vary by nodal diameter and modeshapes.

Figures 4, 5 and 6 compare the frequency and modeshape (EWB – Easy Wise Bending) between the two models for ND1, ND2 and ND3, respectively. Cyclic symmetry model modeshapes were expanded using /CYCEXPAND which basically allow the sector to expand into its full wheel structure form. All the cyclic symmetry plots show the harmonic index (Nodal Diameter) value.

![Cyclic Symmetry vs Full model comparison](image)

Figure 3: Results Summary Sequence

Overall, both models’ frequencies and modeshapes were very similar. Table 1 compares a sample of the obtained results. The highest difference was about 1.94% at ND0 while beyond ND4 the difference was a minimum (~0%).
<table>
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<tr>
<th></th>
<th>Full</th>
<th>Cyclic</th>
<th>%e</th>
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<tbody>
<tr>
<td>ND0</td>
<td>1973.1</td>
<td>1934.8</td>
<td>1.94%</td>
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<tr>
<td>ND1</td>
<td>2081.7</td>
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<td>4327.3</td>
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<tr>
<td>ND6</td>
<td>4382.6</td>
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</tr>
</tbody>
</table>

Table1: Mode1 (EWB) frequency comparison

**Figure 4: Mode1 ND1 EWB**

Cyclic Symmetry sol shows the ND or Harmonic Index while the Full model solution does not since its inherent in the structure.
Figure 5: Mode 1 ND2 EWB

Figure 6: Mode 1 ND3 EWB
The project as of 3/3/2008 is on schedule according to the defined tasks above. As discussed earlier the model for the cyclic symmetry sector and the 24 bladed full wheel systems were meshed. Modal analysis ran on both models. The remaining weeks before the final deadline will be tweaking the analysis and post-processing the results. It will also involve finalizing the final report draft with all of its sections.