ANALYSIS OF STEAM TURBINE BORESONIC NDE DATA USING A FIELD PORTABLE COMPUTER

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ABSTRACT

Due to the high combined stress caused by thermal and rotational loading, the highest stress in the hollow rotor forging of typical nuclear power steam turbine and generator units is in the region at or near the bore. Material discontinuities aligned along the axis of the rotor centerline, with depth in the radial plane of the rotor, have the highest probability of becoming flaws of concern to the integrity of the rotor. Due to the nature of the casting/forging process a great number of material discontinuities can be found near the rotor bore. During the ultrasonic examination of rotors with a large number of discontinuities, the engineer must determine if these discontinuities are ultrasonic reflectors caused by fabrication anomalies, reflectors that are probably fabrication discontinuities but in such close proximity that they may link up and form a defect of concern to future operation, or reflectors that have significant size and are real growing flaws, but may appear as separated indications. Until recently, plotting of ultrasonic data to determine the significance of closely spaced indications was time consuming and required special 3-D analysis methods to determine if indications were isolated or linked to form larger discontinuities. To overcome this problem, a software program, compatible with portable personal computers, was written to define a parameter necessary for determining if a group of indications detected from nondestructive ultrasonic testing of turbine and generator rotors could combine to form larger ones. The approach involved using a computer algorithm to model each indication as a three dimensional sphere with a diameter equal to the ultrasonic signal amplitude from an equivalent flat bottom hole reflector and setting a minimum gap distance between spheres necessary for a link up. The program was implemented following a commonly used data format accepted by industry recognized computer codes. The gap distance and link up parameters were developed empirically. In addition, these parameters can be optimized further by taking into account other factors such as metal composition, stress level and location with respect to the bore surface. Once the discontinuity is defined in three dimensions it can be used with a number of commercially available computer codes (SAFER, etc.) to determine remaining life of the rotor and the number of safe stop/start cycles until the next required inspection.

INTRODUCTION AND SUMMARY

The hollow rotor forgings of typical steam turbine and generator units experience high stress during operation due to the combined effects of thermal and rotational loading. As shown in Figure 1, this stress is highest in the region at or near the bore. To detect material discontinuities in the rotor forging that have the potential for flaw initiation and growth, ultrasonic inspection is conducted from the surface of the rotor bore as shown in Figure 2. Due to the nature of the casting/forging process a great number of material discontinuities can be found near the rotor bore. These conditions are very pronounced in rotors fabricated prior to 1960.
Figure 2. Typical arrangement of ultrasonic transducers for boreside examination of rotor.

During the ultrasonic examination of rotors with a large number of discontinuities, the engineer must determine if these discontinuities are:

1. Ultrasonic reflectors caused by fabrication anomalies such as porosity, non-metallic inclusions, etc.

2. Reflectors such as those in #1 above, but in such close proximity that they may link up and form a discontinuity of concern to future operation.

3. Reflectors that have significant size and are real growing flaws, but may appear as separated indications due to the irregular shape of the flaw, dispersing or not reflecting ultrasonic energy back to the interrogating transducer.

The first step in analyzing ultrasonic data acquired during boreside ultrasonic examination is to plot the data and select areas of the rotor that will require further analysis. A software program called BOREPLOT was developed to plot the data acquired using 2-D displays such as angular location (θ) versus axial location (Z), or metal path (MP) versus axial location (Z) as well as polar plot. The ultrasonic data points are colored using ranges in 20% increments. The coloring is determined by using amplitude in % ESH (Full Screen Height) or EFBH (Equivalent Flat Bottom Hole) diameter or metal path.

To aid the NDE engineer in data analysis, a software program (titled LINK-UP) was developed. The program integrates the expert judgement of several level III NDE engineers, mechanical engineers, and metallurgists regarding the probable size, shape, location, and severity of detected ultrasonic reflectors. This analysis is critical to determining flaw sizes for use in fracture mechanics analysis of remaining rotor life.

The LINK-UP program is used to analyze the data acquired during ultrasonic nondestructive testing of turbine or generator rotors. The primary functions of this program are to determine which indications have a high probability of being linked and to graphically display the indications in three dimension. The secondary function is to determine the degree of potential link-up between the indications that are in close proximity.

In this program, the ultrasonic signal amplitude of the indications is used to model each indication as a three dimensional sphere with its diameter equal to the diameter of an equivalent flat bottom hole reflector. In order for two indications to be considered linked, the distance between indications must be less than a preset gap distance (any number of linkages are possible, including creep-fatigue flaw growth, fatigue flaw growth, etc). Once all of the link-ups are determined, the program determines the degree of link-up, by a numerical evaluation of the degree to which these points are linked based on the amplitude of the indications, as well as the distances between them.

Figure 3 illustrates the results of a link-up analysis performed on a file of 50 indications. The indications are shown as small circles, color
coded according to equivalent flat bottom hole diameter as indicated in the color key in the upper right hand corner. The lines drawn from the indications to the bore surface represent the depth of the indication. The depth lines are also color coded. Red lines are drawn between the indications that are linked. This is shown more clearly in Figure 4 which is from the same data file but shows a narrower axial (Z) range (16.00 to 19.50 inches instead of 6.11 to 282.15 inches as shown in Figure 3).

From this program the following input/output criteria is used:

INPUT: 1) File name containing the NDI Data (Metal path from bore, distance down the bore, distance around rotor, and amplitude of ultrasonics sizing).

2) Bore Diameter

OUTPUT Three dimensional display of linked indications and a computation of link-up parameters.

Parameters used in the program are defined below:

Indication: Data point found during ultrasonic examination

Link-up Parameter: Probable degree of link-up for a particular group of indications;

<table>
<thead>
<tr>
<th>DEPTH(x)</th>
<th>EFH(in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80-100</td>
<td>1/64</td>
</tr>
<tr>
<td>60-79</td>
<td>2/64</td>
</tr>
<tr>
<td>40-59</td>
<td>4/64</td>
</tr>
<tr>
<td>28-39</td>
<td>6/64</td>
</tr>
<tr>
<td>01-19</td>
<td>8/64</td>
</tr>
</tbody>
</table>

Figure 3. This is a diagram of the rotor showing the section from a Min z of 6.11 inches to a Max z of 282.15 inches. Where z is the axial distance down the bore. Extending from the yellow original rotor bore are lines connecting the indications to the bore, color coded by depth according to a color key. The indications are shown as small circles color coded by EFH. Link-ups between indications are shown as red lines drawn between indications. The rotor dimensions are OR (outer radius), RB (radius of bore), Depth (total metal thickness). The menu (grey box) shows the options that are available during program executions.
determined from engineering evaluation.

**Metal Path:** How far an indication is from the inner bore surface.

**Bore Distance:** How far down the bore the indication is in the axial direction.

**Theta:** The angular position of the indication in the circumferential direction.

**Amplitude:** The size of the indication in equivalent flat bottom hole diameter.

**OR:** The outer radius shown in the graphic display of the rotor (RB + DEPTH).

**RB:** The radius of the rotor bore.

**Depth:** Metal path distance from the inner bore surface.

Max \( z \): The maximum bore distance shown in the graphic display of the rotor.

Min \( z \): The minimum bore distance shown in the graphic display of the rotor.

The LINK-UP software is a valuable tool for analyzing the severity of indications detected by ultrasonic examination and has been used on site immediately following an inspection. The program can also be used on-line when the data acquisition system processes data in a computer compatible format. The program can also be used to analyze boreside ultrasonic data collected by others as long as the data is presented in a compatible format; EFH, Theta, Depth, and \( z \) dimension.

**REFERENCES**


**ROTOR DIMENSIONS**

<table>
<thead>
<tr>
<th>OR (in)</th>
<th>RB (in)</th>
<th>DEPTH (in)</th>
<th>MAX ( z ) (in)</th>
<th>MIN ( z ) (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.41</td>
<td>2.08</td>
<td>2.41</td>
<td>19.50</td>
<td>16.00</td>
</tr>
</tbody>
</table>

**MENU**

1. **ROTA T E (S TART /S TOP)**
2. **CH A NGE V IEW S E GMENT**
3. **CH A NGE D IRECTION**
4. **DO L INK-UP A NALYSIS**
5. **V IEW RO W D ATA**
6. **V IEW L INK-UP D ATA**

ENTER \( 1,2,3,4,5,6 \)

**COLOR CODE**

**CORRESPONDING TO SIGNAL AMPLITUDE AND DEPTH FROM ROTOR BORE SURFACE**

**DEPTH (\( \ell \))**  
- 00-100 1/64
- 00-79 2/64
- 40-59 4/64
- 20-39 6/64
- 01-19 8/64

**EFBH (in)**

**Figure 4.** This is an expanded view for indications located from a Min \( z \) of 16.00 inches to a Max \( z \) of 19.50 inches. The linked indications would be shown as a red line.