

A SECOND-GENERATION SYSTEM FOR DETECTION AND
CHARACTERIZATION OF STEAM-TURBINE ROTOR FLAWS

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INTRODUCTION

Detection and characterization of steam-turbine rotor flaws are of prime concern in decisions affecting life extension. Rotors represent large capital investments where life extension can provide significant returns, especially if a forced outage or catastrophic failure is avoided. Nondestructive evaluation (NDE) of flaws has proven to be a valuable tool in extending the life of rotors.

Flaws within the first 4 inches of a steam-turbine bore are the most critical for making life-extension decisions. In the past, conventional ultrasonic testing (UT) methods could not accurately detect and size flaws in this highly stressed area, so rotor residual-life estimates were conservative.

To resolve this problem of reliably and accurately inspecting the rotor's center-bore area, the automated Turbine Rotor Examination/Evaluation System (TREES) was developed [1,2,3] and has proven to be highly successful in actual field applications over the past 8 years. A second-generation TREES, providing greatly enhanced data collection and analysis capabilities, is now available. A diagram of this system is shown in Fig. 1.

TREES FEATURES

Some of TREES features are

- Aberration-corrected, focused ultrasonic search units that compensate for bore curvature to maintain the required sensitivity;
- Interactive window-based analyses;

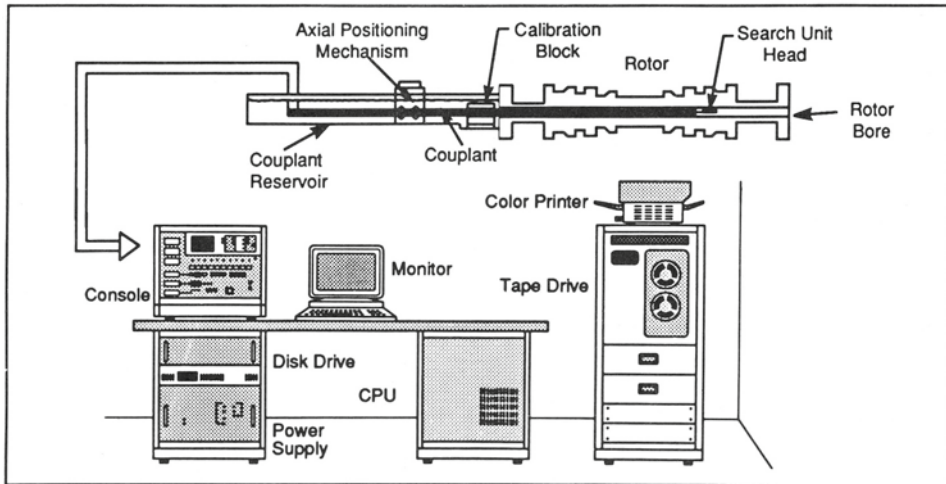


Fig. 1. Schematic Diagram of TREES

- "Point and click" user interface;
- Color display to show signal amplitude;
- B-scan, C-scan, cross-section, and diameter displays; and
- Integrated data preprocessing for direct data input into a fracture-mechanics based analysis program entitled Stress and Fracture Evaluation of Rotors (SAFER).

COMPUTER-DESIGNED SEARCH UNITS

The focused search units used in TREES are equipped with computer-designed lenses. These correct the astigmatism resulting from beam arrival-time variations encountered when performing refracted angle-beam examinations through curved surfaces, such as the rotor bore. The focusing and aberration correction act together to produce a nearly uniform, highly narrowed beam with an approximately circular cross section that focuses in a defined examination zone in the rotor. TREES has six examination zones corresponding to six radial zones of varying distances from the bore surface; these collectively provide complete volumetric inspection of the material surrounding the rotor bore.

CONTROL POSITIONING

Because the high-resolution search units used to examine a turbine rotor produce a tremendous amount of ultrasonic data, a computer is needed to schedule and control data collection. During rotor examination, the focused transducers must be pulsed and data collected so that a complete volumetric inspection of the material surrounding the rotor bore is obtained. To do this, the computer generates a pulsing sequence and initiates and controls the movement of the search-unit head assembly as it makes helical scans along the rotor bore. The computer interrogates the axial and circumferential position of the head assembly housing the 15 search units and controls the scan rate to assure that the transducer

pulsed sequence will cover the required volume. The operator also can stop and resume scanning if necessary.

DATA ACQUISITION

The UT data are transferred by the electronic subsystem to the computer via an IEEE-488 interface, and the data are qualified by the computer before storage on disk. The examination parameter data are stored in the same data file as the UT data to form a complete record of the rotor examination.

DATA PROCESSING

TREES data processing is also accomplished using the computer. The TREES processing program takes the raw UT data, calculates the volumetric location of the indicated flaw, and builds a data file representing a three-dimensional map composed of discrete cells from which the graphic and tabular displays are generated.

Each cell within the volumetric data file contains the flaw reflector amplitude to allow rapid redisplay of the data at different threshold levels without extensive reprocessing of the data.

VOLUMETRIC DATA

Because of the small beam-diameter sizes from 0.03 to 0.125 inch (detection at specific locations), and the amount of data from the pairs of search units for each zone and multiple zones, vast amounts of data are generated. These data must be organized to allow for rapid storage and retrieval and for meaningful data displays. The TREES computerized analysis method reduces and correlates the data into a data structure that can be readily manipulated by the computer.

The data structure is a mathematical model of the rotor volume segmented into contiguous cells (see Fig. 2). Cells are established by subdividing the length of the focal zone into units approximately equal to the beam diameter. Cells are then allocated from the bore surface outward in the radial-circumferential and radial-axial directions for all zones (Fig. 2). When a reflector is detected in an examination zone, a time is measured to the peak of the received signal amplitude. Using this time, which is equivalent to metal-path distance, and the search-unit position information, the computer determines the corresponding cell location in the model and flags that cell for a reflector indication.

DATA DISPLAYS

To assist in data analyses, TREES has four graphic displays. Three of the displays--the C-scan, B-scan, and cross-section--present the composite data of the focused shear transducers from different perspectives; and the fourth, the diameter display, presents the data produced by a diameter-measuring transducer. For each of these displays, the analyst can limit the dimension of the axis being compressed in the display.

All displays limit themselves to graphically portraying only the indications in their data which exceed the display threshold selected by the operator. This threshold-selection process is accomplished by means

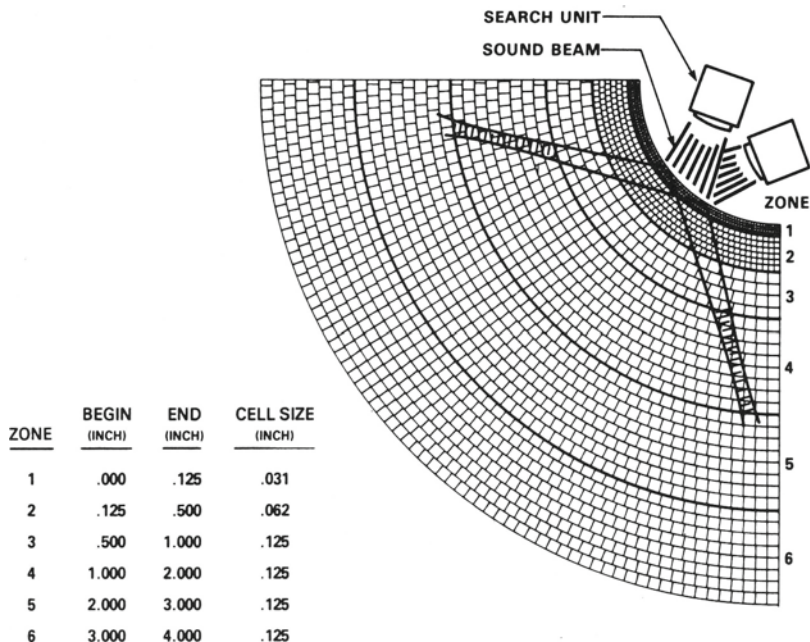


Fig. 2. Clockwise/Counterclockwise Examination of Each Zone

of a control depicted on the display, which is operated through simple manipulations of a cursor driven by a mouse-pointing device. When the operator sets the display threshold at its minimum value, all recorded indications are presented.

In all TREES displays, each individual indication is represented as an appropriately colored and proportioned cell. Bluish colors represent values slightly above the display threshold, and reddish colors represent values maximally above the display threshold. In all cases where cells overlap on the display, the indication of the highest magnitude is presented.

In addition to the color, further information about the indications may be obtained from the cursor. As the cursor moves through the display, its position in bore coordinates is updated. Whenever the cursor resides on an indication, the indication's magnitude is displayed. For the focused shear displays, the mean position of the indication on the hidden axis may also be acquired in this way.

The volume of data being displayed is set by a graphic control drawn on the screen. Each display contains at least two of these graphic controls that manipulate the two visible axes; the focused shear displays have one additional graphic control to manipulate the hidden third axis. These controls allow the operator to select one specific slice of the appropriate axis by simple mouse actions. The operator can zoom in on a desired indication as the slices for each axis are narrowed using the controls. An additional feature of the focused shear displays allows the axis representing the radial dimension to be operated in discrete zones rather than in the usual analog fashion.

C-Scan Display

The TREES C-scan display, shown in Fig. 3, is usually the first tool used by the operator to review the focused shear data. The display is essentially a projection of the focused shear data unrolled onto the plane formed by the θ and the z axes. This implies that the r axis is hidden in the projection.

The primary function of the TREES C-scan display is to present the operator with an overview of the condition of the rotor. The operator can then isolate areas of the focused shear data that contain patterns, or clusters, of indications. If a cluster is determined to be a flaw, the C-scan display is useful in establishing the extent of the flaw along the z axis. To a lesser degree, the display helps define the angular extent of flaws.

B-Scan Display

The TREES B-scan display, Fig. 4, is created by unrolling the focused shear data about the θ axis and projecting it onto the plane formed by the z and the r axes. Consequently, the θ axis is hidden in the projection. The B-scan display assists in determining the radial extent of flaws. It may also be used to determine the extent of the flaw along the z -axis, but the C-scan display is the more obvious choice for such investigation.

Cross-Section Display

The TREES cross section, Fig. 5, is generated by projecting the focused shear data onto the polar plane of the r and θ axes. In this display, the z -axis is hidden.

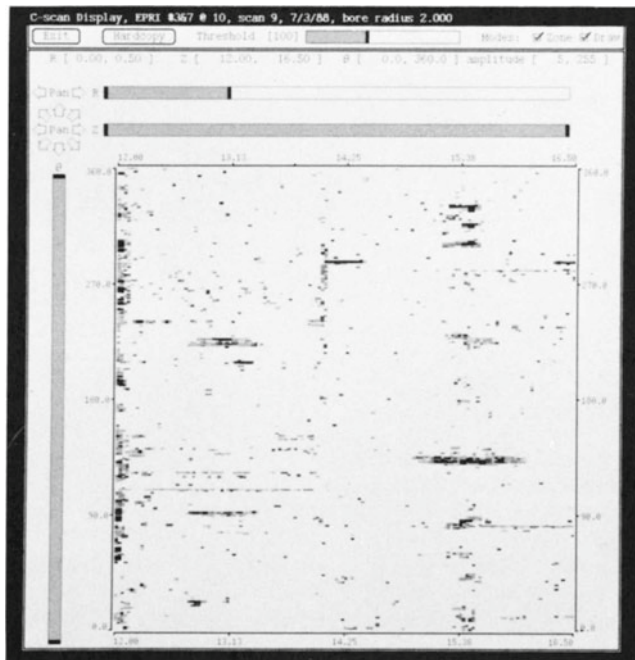


Fig. 3. TREES C-Scan Display Window

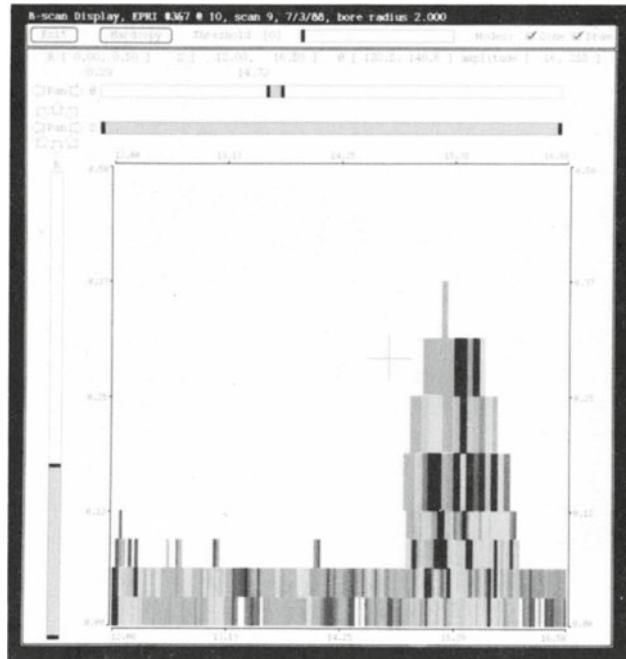


Fig. 4. TREES B-Scan Display Window

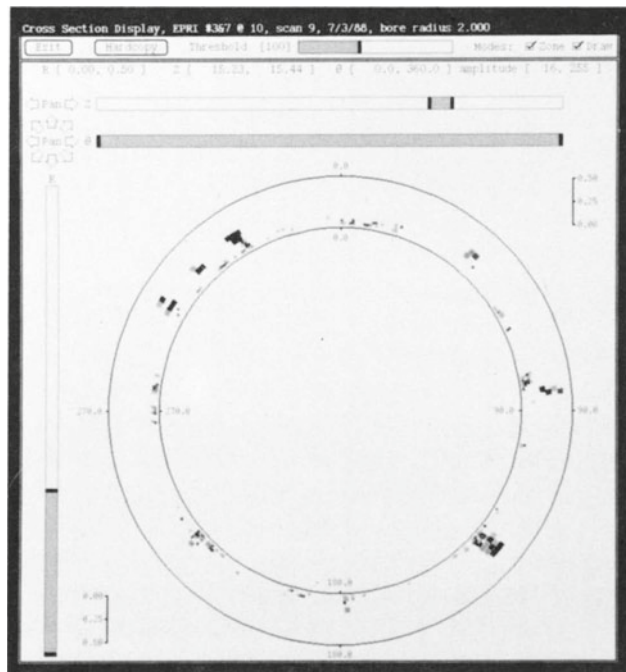


Fig. 5. TREES Cross-Section Display Window

The chief purpose of the TREES cross-section display is to complete the flaw identification process for the operator. This display does not convey any information that is not available from the C- and B-scan displays, but its unique perspective aids the operator in visualizing flaws. Similar to the B- and C-scan displays, the cross-section display can be used to size the radial and angular extent of flaws. In addition, the display is often used to perceive other indication clusters at a particular axial location.

Diameter Display

Much like the C-scan display, the TREES diameter display is created by unrolling the diameter data about the r axis and projecting it upon the plane formed by the θ and the z axes. No control for manipulating the hidden r axis is provided for this display, since the diameter transducer only collects surface data.

Detecting bore-surface anomalies due to previous repair operations is the principal function of the TREES diameter display. Anomalies can provide qualifying information about nearby indication clusters in the focused shear data. The display may also be useful in the visualization of out-of-round conditions in the bore due to abnormal stresses.

CONCLUSION

The second-generation TREES system described builds on a base of field-proven ultrasonic technology. Combined with recent advances in computer and user interface methodology, a synergistic effect is achieved, resulting in improved productivity, ease of data analysis, and user satisfaction. The TREES data also can be used in the SAFER program for rotor lifetime analysis, which is an important consideration for owners of steam generator turbines.

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