Utility Power Corporation

Engineering Report ER-8401

ULTRASONIC DISK INSPECTION

August 1984

Ultrasonic Disk Inspection

Introduction

At the American Power Conference in April 1983 we introduced our nuclear LP turbine disk inspection device as well as first results of tests from one LP rotor applying the corner reflection method only. In the meantime, test experience has been gained and other ultrasonic test methods were used, permitting not only the indication of small cracks, but also the measurement of crack depth in hub bore and keyways.

Ultrasonic Inspection Methods

Three different test methods have been applied to identify and measure stress corrosion cracks in LP turbine disks:

- Corner Reflection Method

Our first inspection of disks with this technique confirmed the high sensitivity of the method in finding the smallest defects especially in the hub bore region. As shown in **Figure** 1, the ultrasonic signal is applied in an approximately 45° angle to the suspected crack at the hub bore. A double reflection at the hub surface and any axial/radial oriented stress corrosion crack provides an indication of the crack. This method was utilized at our first tests, as reported at the American Power Conference in April 1983.

- Grazing Incidence Method

Testing keyway regions with the corner reflection method is possible, but somewhat more difficult because the keyway bore and the corner formed by the hub bore and the keyway bore reflect similar signals that are approximately equal or equal to sonic distances of signals reflected by a crack starting from the keyway as shown in **Figure 2.** To indicate a crack at this location, the grazing incidence method has been proven to be more effective. The ultrasonic sensor is applied tangetially to the assumed corrosion crack and receives a direct reflection from a crack. The different sonic distances of the keyway bore and a crack are measured as shown in the lower sketch of **Figure 2** and so an axial/radial corrosion crack can be positively identified.

- Crack-Parallel Incidence Method

The test methods described before are utilized to indicate axial/radial corrosion cracks during our inspection which covers 100% volume of the hub bore and keyway vicinities. They do not necessarily provide sufficient information about the depth of a found crack. Therefore, the crack-parallel incidence method is additionally utilized to determine the crack depth of branched stress corrosion cracks, as shown in **Figure 3.** The different sonic distances of the branched crack and the hub bore or keyway bore surface are used as a measure of the crack depth. Extensive investigtions on disks of other manufacturers with actual corrosion cracks revealed a maximum deviation between the measured and the real crack depth of 2.5 mm or 0.1 in. A slightly smaller measured crack depth can be explained by the fact that the echo reflects from the last branch and not from the tip of the crack.

Test Results

Our presently achieved test capability is not only based on extensive R & D work, but also on test results from various applications of our ultrasonic inspection technique and devices. Testing of the following disks has been performed:

- Shrunk-on test disk #5 with about 60 axial/radial oriented simulated cracks of different sizes.
- 10 disks of an LP turbine rotor tested after 76,000 service hours.
- 10 disks of an LP turbine rotor tested after 83,000 service hours.
- 10 disks of an LP turbine rotor tested after 24,000 service hours.
- Disks of fossil AEG turbines with actual corrosion cracks.

- Shrunk-on Test Disk #5

About sixty axial/radial oriented artificial notches simulating corrosion cracks were eroded into a test disk at the hub bore and keyway bore. Three different crack sizes were simulated with the following dimensions in depth and length:

2.5 mm x 5 mm or 0.1 in. x 0.2 in.
5 mm x 10 mm or 0.2 in. x 0.4 in.
10 mm x 20 mm or 0.4 in. x 0.8 in.

Additionally, the angle of some notches was varied from the normal 90° radial direction.

The disk with the simulated cracks was shrunk onto a stub shaft to provide actual conditions for the calibration of the ultrasonic inspection device (see **Figure 4**). All artifical defects were indicated with both the corner reflection and grazing incidence method. This includes 2.5 mm or 0.1 inch deep defects at the keyways.

- LP Rotor after 76,000 Service Hours

100% volumetric testing of this fully assembled and bladed rotor was performed utilizing mainly the corner reflection method. One of the 10 disks showed several indications with amplitudes of 2 mm or 0.08 in. equivalent flat bottom hole (EFH), on the average, with a maximal length of 100 mm or 4 in. Not a single indication of a possible crack at the keyways was observed.

As part of this first complete LP rotor inspection program, the rotor was disassembled and underwent a complete magnetic particle inspection. No stress corrosion cracking or crack indication was found and the ultrasonic indication of the one disk were positively identified as score marks from the initial shrink-on process.

- LP Rotor after 83,000 Service Hours

The 10 disks of this rotor were also 100% volumetrically inspected by the corner reflection method with no crack indication. Additionally, the grazing incidence method was used to confirm the results for the keyway vicinities. This inspection did not reveal any reflection above the normal ultrasonic signal noise level, which clearly supports the corner reflection test result that the hub bores and keyways of these 10 disks are free of corrosion cracks.

- LP Rotor after 24,000 Service Hours

Both, the corner reflection and the grazing incidence methods were applied similar to the earlier described case. The inspection of all 10 disks of this rotor also confirmed that stress corrosion cracking did not occur.

- AEG Disk-type Rotors

KWU performs the service work for AEG turbines which includes non-reheat, fossil-fueled turbines in South Africa. These turbines of an old AEG design, have suffered from stress corrosion cracking. Extensive testing was performed to determine the accuracy of our ultrasonic inspection techniques and device for indicating and measuring real corrosion cracks. Ultrasonic measuring results from an actual 0.26 in. deep axial/radial corrosion crack at the disk side showed the following results:

Distance from the Disk Face	Real Crack Depth	Ultrasonically Measured Crack Depth
0 mm or 0 in.	6 mm or 0.24 in.	not measured
4 mm or 0.16 in.	6.4 mm or 0.26 in.	not measured
25 mm or 1 in.	5.5 mm or 0.22 in.	5.5 mm or 0.22 in.
45 mm or 1.8 in.	5.1 mm or 0.22 in.	5.0mm or 0.2in.
65 mm or 2.6 in.	4.7 mm or 0.19 in.	5.0mm or 0.2in.
95 mm or 3.8 in.	5.3 mm or 0.21 in.	not measured

The test results confirm that the accuracy of the crack depth measurement was far better than the earlier stated 2.5 mm or 0.1 inch. It was important also to get sufficient confidence in the differentiation of corrosion cracks from score marks or other surface defects. Therefore, an 0.5 mm (20 mil) deep and 180 mm (7 inch) long notch was eroded into the hub bore of a disk as a simulated defect to be tested after the disk was shrunk onto a shaft.

The overall results from the three applied methods conclude the following:

- Corner Reflection

  A positive differentiation of a defect such as a 0.5 mm (20 mil) deep notch from a 5 mm (0.2 in.) deep crack is not possible since the sonic distances are equal and the signal amplitudes are of about equal magnitude with similar deviations.

- Grazing Incidence Method

  This method distinguishes between cracks and score marks because the amplitudes of signals from cracks were ≥ 2 mm (≥ 80 mil) EFH and those of score marks always < 2 mm (< 80 mil).

  Figure 5 compares test results from a simulated score mark, an actual corrosion crack of an AEG turbine disk and results from the test disk #5 with artificial defects of different sizes. The corner reflection method clearly indicated the simulated score mark, artifical defects and the actual crack. However, only the grazing incidence method identified 0.5 mm or 20 mil deep score mark as an indication of smaller 2 mm (80 mil) EFH.

- Crack-Parallel Incidence Method

  Additional measurements and metallurgical investigations were performed to define the limit of our crack depth measurements. The results from various tests indicate that cracks with a minimum depth of about 2 mm (80 mil) can be measured with a maximum tolerance of plus 2.5 mm (0.1 in.)

Conclusion

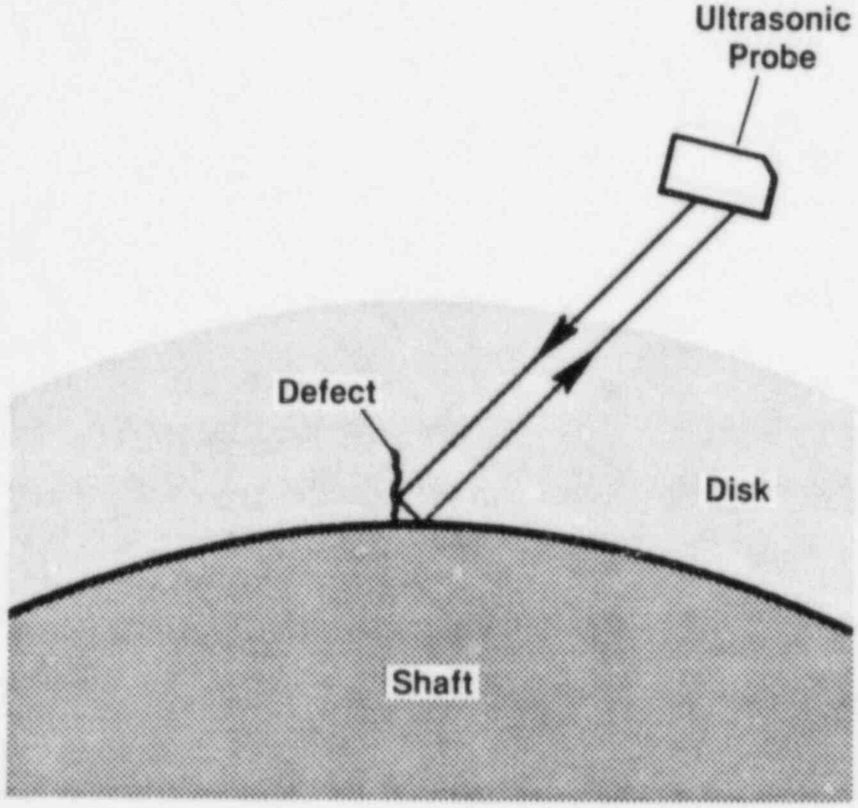
Even though stress corrosion cracking has not occurred with our PWR and BWR units, we have developed an ultrasonic test technology and device to thoroughly inspect disk-type rotors. Based on our present experience, we can find with the corner reflection method, defects with a depth of ≥0.5 mm (≥20 mil) at the hub bore. With the grazing incidence method, we are able to identify defects at the keyways with a minimum crack depth ≥ 2.5 mm (≥0.1 in). Both methods applied allows additionally to define the relevancy of small indications. Stress corrosion cracks which extend more than 2 mm or 80 mil into the disk hub bore or keyway area can be measured with the crack-parallel incidence method. With this method, we can measure crack depth with a tolerance of +2.5 mm (+0.1 in).

References:

"Design, Operating and Inspection Considerations to Control Stress Corrosion of LP Turbine Disks" American Power Conference, April 1983

REVISION

a		
b		
c		
d		
e		



INSPECTION OF DISK
HUB BORE WITH
CORNER REFLECTION METHOD

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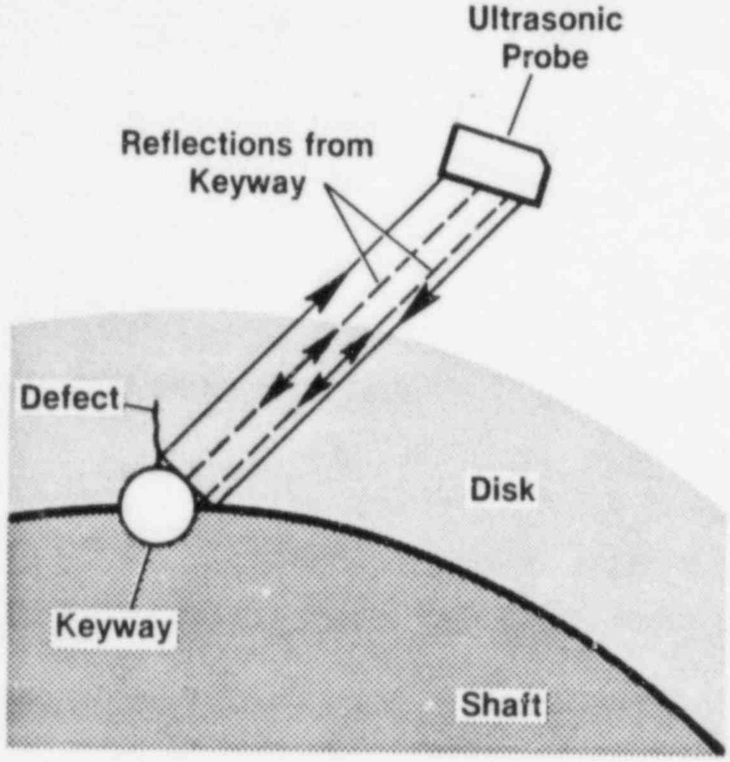
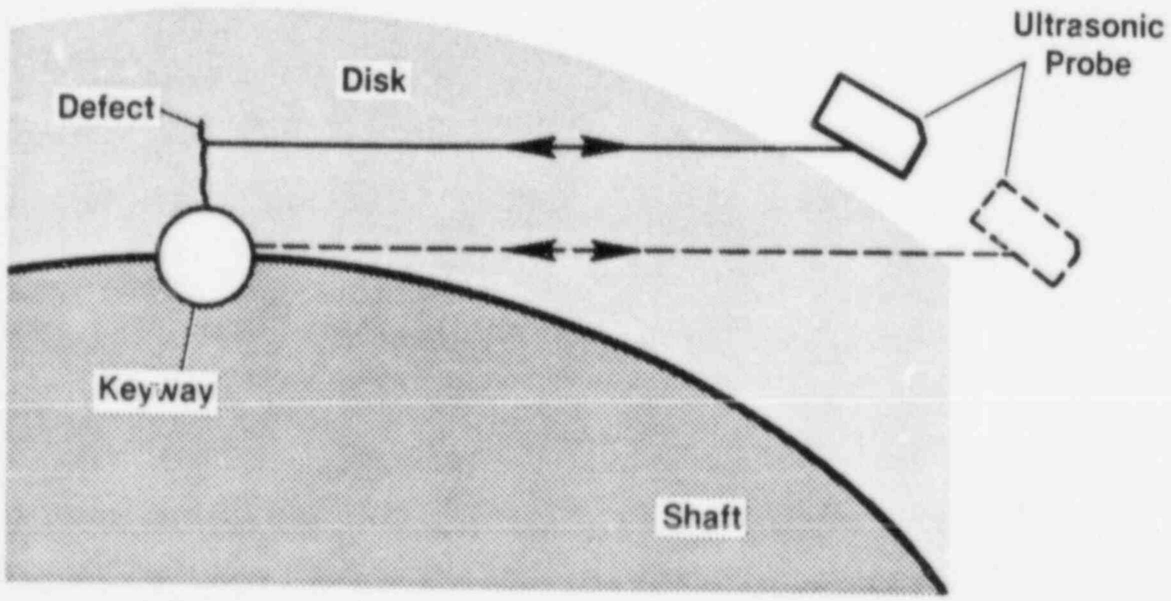
FIGURE 1/1E84.066

REVISION		
a		
b		
c		
d		
e		

Corner Reflection Method



Grazing Incidence Method



INSPECTION OF KEYWAY WITH GRAZING INCIDENCE METHOD

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FIGURE 2/1E84.067

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a		
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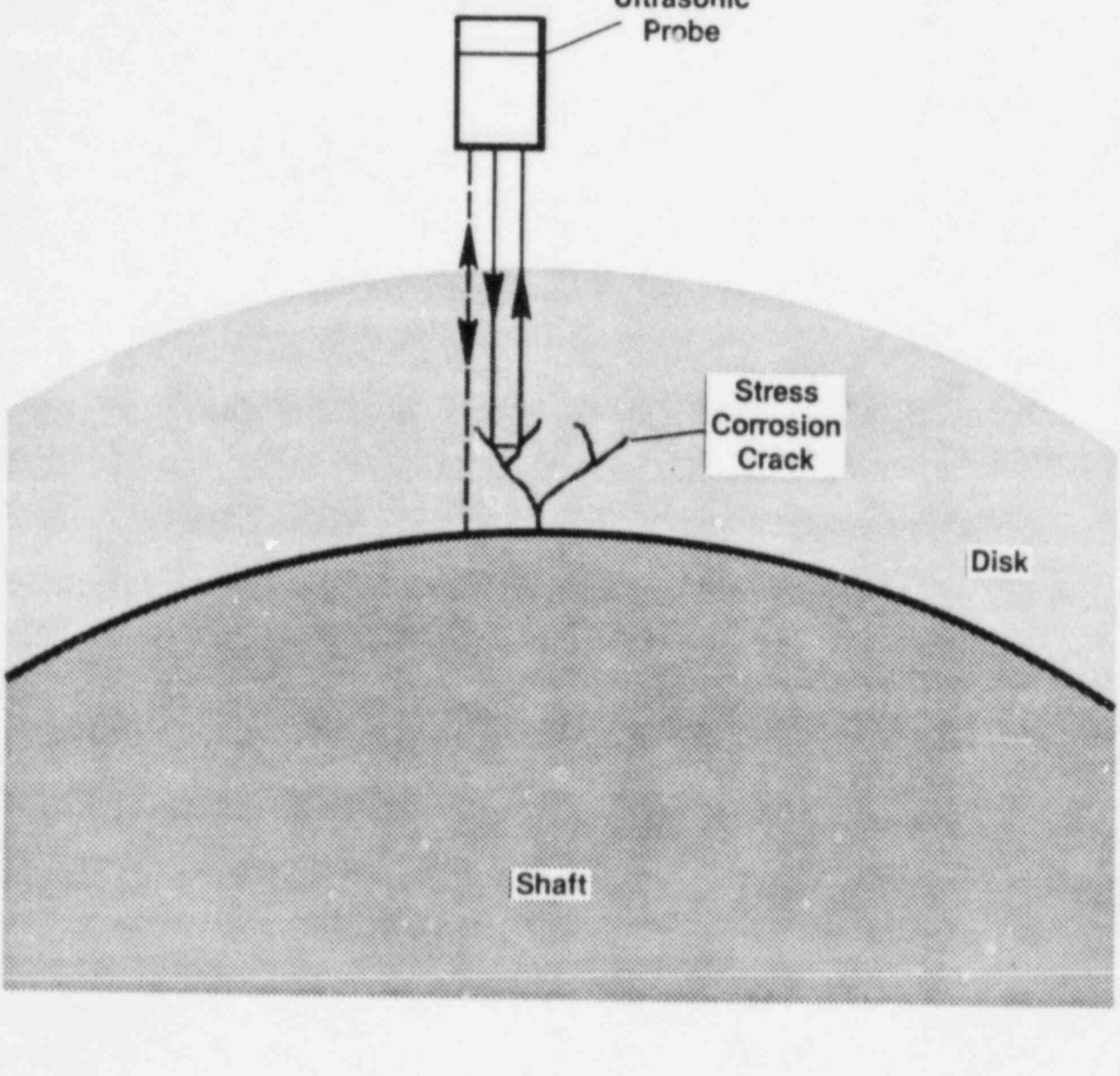

MEASUREMENT OF
CORROSION CRACK DEPTH
WITH CRACK-PARALLEL
INCIDENCE METHOD

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FIGURE 3/1E84.068

REVISION		
a		
b		
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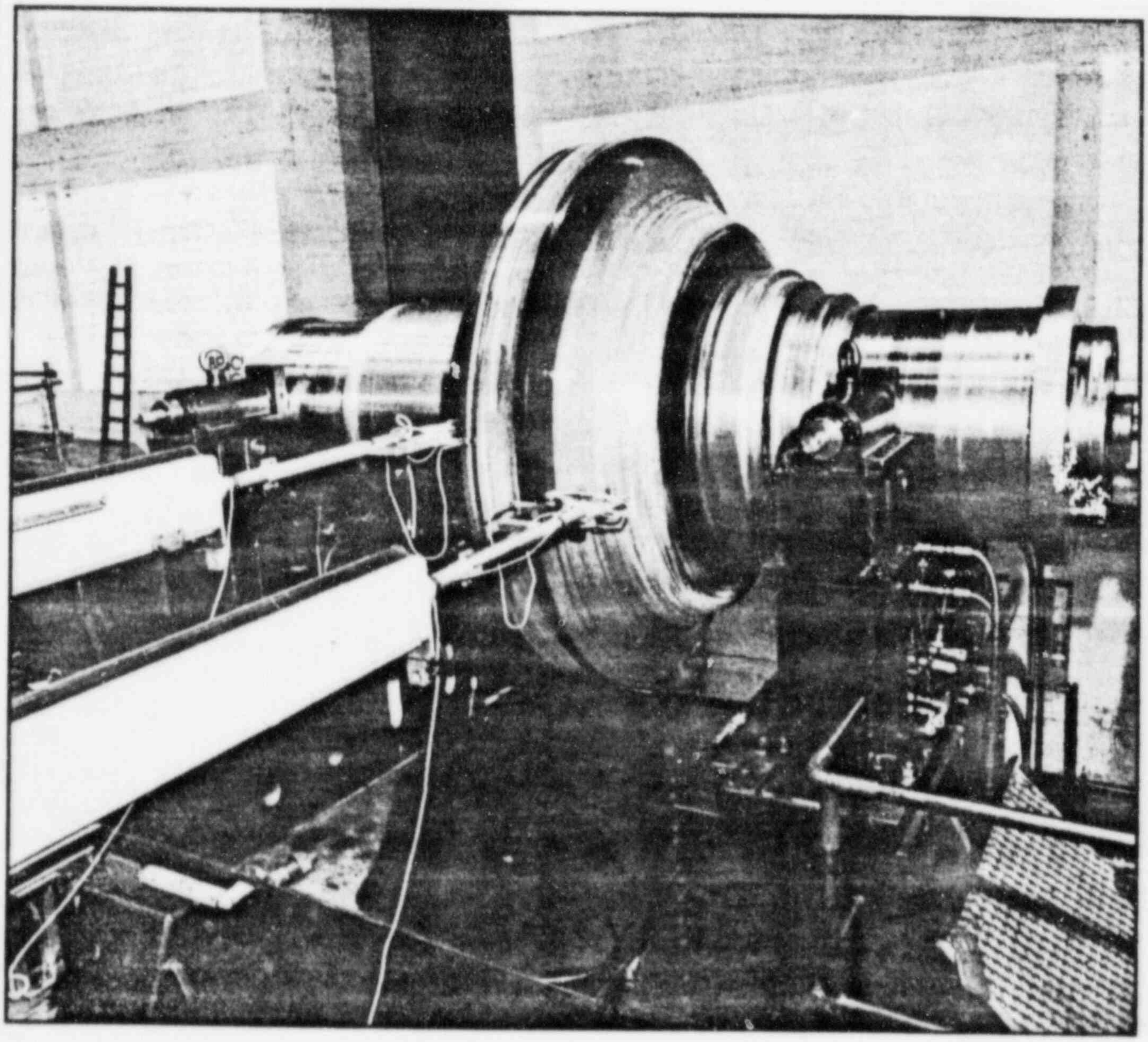

TEST DISK #5 AND ULTRASONIC TEST DEVICE FOR PULSE/ECHO AND TANDEM TEST PROCEDURE

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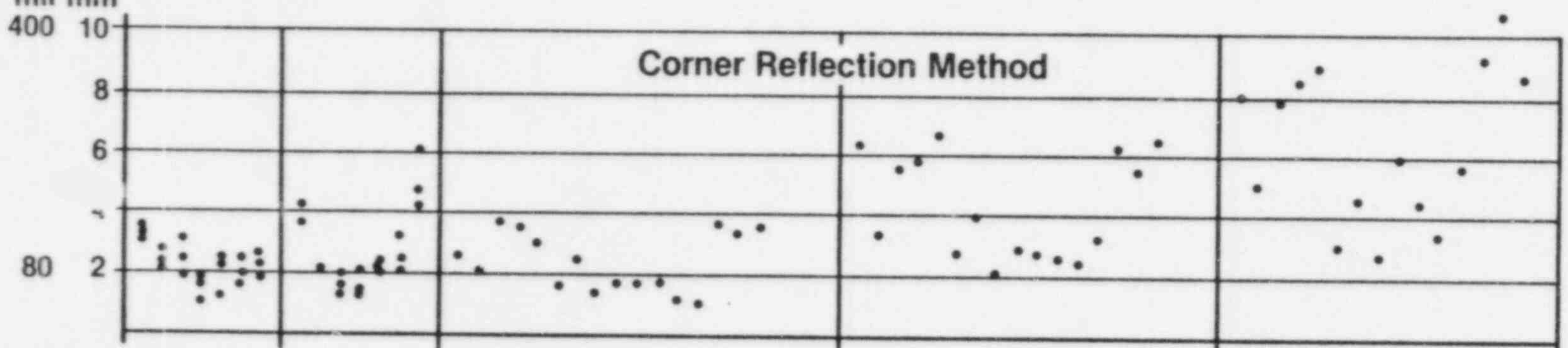
FIGURE 4/1E84.069

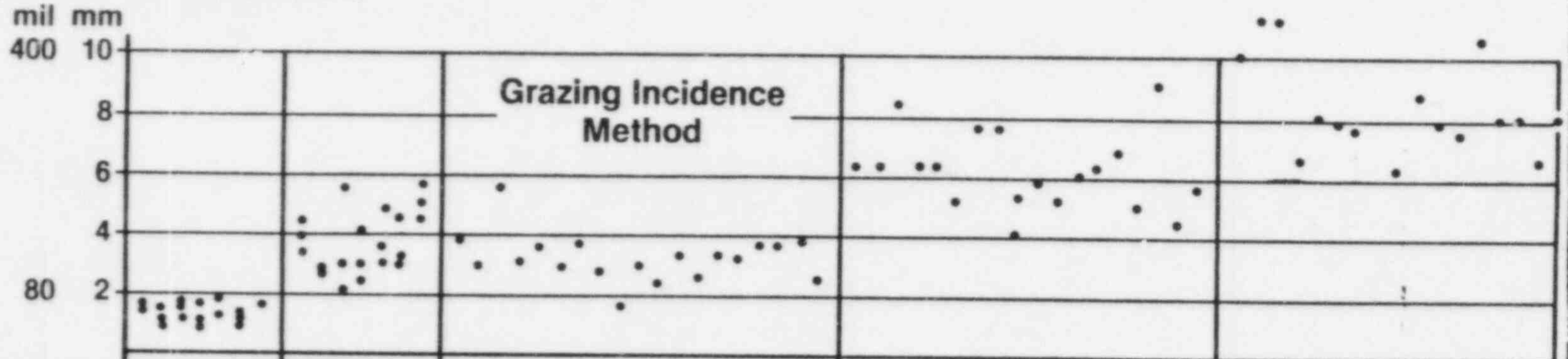
REVISION	a	b	c	d	e

Defect	Simulated Score Mark	Corrosion Crack	Artificial Notch	Artificial Notch	Artificial Notch
Depth	0.5 mm 20 mil	≈ 5 mm ≈ 0.2 in.	2.5 mm 0.1 inch	5 mm 0.2 inch	10 mm 0.4 inch
Length	180 mm 7.2 inch	180 mm 7.2 inch	5 mm 0.2 inch	10 mm 0.4 inch	20 mm 0.8 inch

Ultrasonic Indication
(Equivalent Flat Bottom Hole)



Ultrasonic Indication
(Equivalent Flat Bottom Hole)



ULTRASONIC TEST RESULTS USING CORNER REFLECTION AND GRAZING INCIDENCE METHODS

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FIGURE 5/1E84.070