SwRI-7794-106

SOUTHWEST RESEARCH INSTITUTE

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INVESTIGATION OF TURBINE DISC KEYWAY CRACKING

North Anna Unit 2

SwRI Project No. 06-7794-106
FINAL REPORT

to

Virginia Electric and Power Company
P. O. Box 26666
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INTRODUCTION

Ultrasonic inspections of the North Anna, Unit 2, LP turbine rotors were performed during the April 1983 scheduled outage. These inspections identified cracks at the keyways in the No. 1 and No. 2 discs of both rotors. Keyway cracks were detected in the No. 1, governor-end disc and the No. 2, generator-end disc of the LP-1 rotor. In the LP-2 rotor, ultrasonic crack indications were obtained at keyways of both No. 1 discs and both No. 2 discs. The LP turbines at North Anna, Unit 2, are Westinghouse BB 281 machines and the rotors had accumulated approximately 14,500 hours of operation at the time of the outage. Both rotors were returned to the manufacturer and upgraded by the installation of new No. 1, No. 2 and No. 3 discs of the heavy-hub, keyplate design. After the original discs were unstacked, a hub sample containing a keyway crack was cut from the No. 1, governor-end disc of the LP-1 rotor and forwarded to Southwest Research Institute (SwRI) for metallurgical examination. A photograph of the sample, as received at SwRI, is shown in Figure 1. The objective of the investigation was to establish the nature and extent of the keyway cracking and compare the features of the crack(s) with those determined for other cases of LP turbine disc cracking.

12164

FIGURE 1. DISC SAMPLE. Spotted effect is rust which was present when shipping crate was opened.

VISUAL AND MAGNETIC PARTICLE INSPECTION

The surface rust was removed from the keyway region by light abrasion with 400 grit paper and the keyway was subjected to a magnetic particle (MP) inspection. A d-c magnetic yoke and a dry powder indicator were employed. This inspection revealed several distinct crack indications within the keyway, see Figure 2. These indications were oriented parallel to the long axis of the keyway and were distributed along its length to within approximately 1/2 in. of the open end. In the inner one-half of the keyway, the crack indication appeared as several nearly-connected segments located end-to-end near the centerline (Segment D, Figure 2). One separate, small crack indication was noted at the conical end of the keyway extending a short distance along the disc bore surface, (Segment E, Figure 2). The largest indication near the open end (Segment A) was displaced from the centerline of the keyway.

Some mild corrosive pitting was visually evident within the keyway. Small corrosion pits were randomly distributed over the keyway surface, but circumferential machining marks were still present. There was no evidence to indicate that the pitting was directly related to the cracking.

After the initial magnetic particle inspection, the keyway surface was coated with a silicone resin to seal the cracks. A 1-1/2-in. x 2-1/2-in. x 5-in. block specimen containing the complete keyway was then saw-cut from the hub sample to facilitate further metallographic and fractographic examinations.

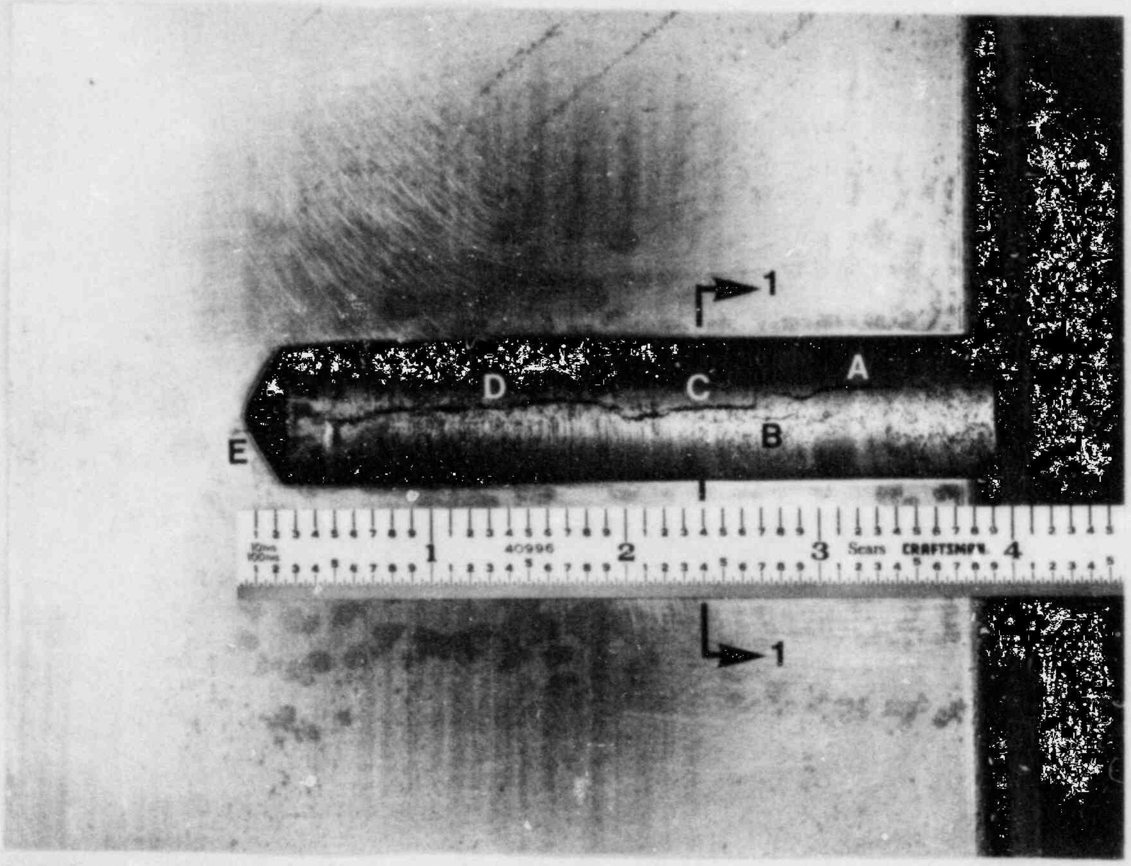

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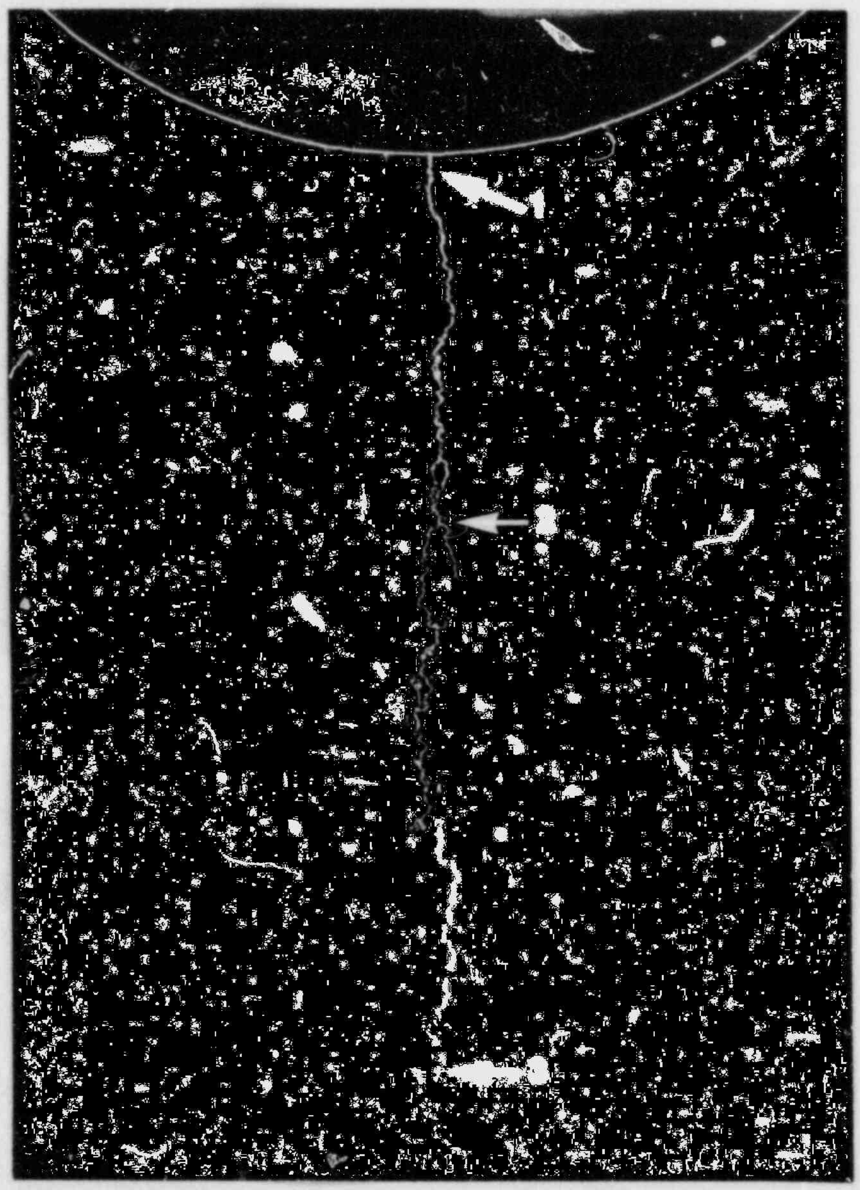
FIGURE 2. MAGNETIC PARTICLE CRACK INDICATIONS IN KEYWAY. Actual size.

METALLOGRAPHIC EXAMINATIONS

A transverse metallographic section was taken through the keyway at a location approximately 1-1/2 inches from the open end. The location is marked as Section 1-1 in Figure 2. A photomacrograph of the crack as observed in that section is shown in Figure 3. At this point, the crack extended to a depth of 0.58 inch. Limited branching had occurred at two locations along the crack path.

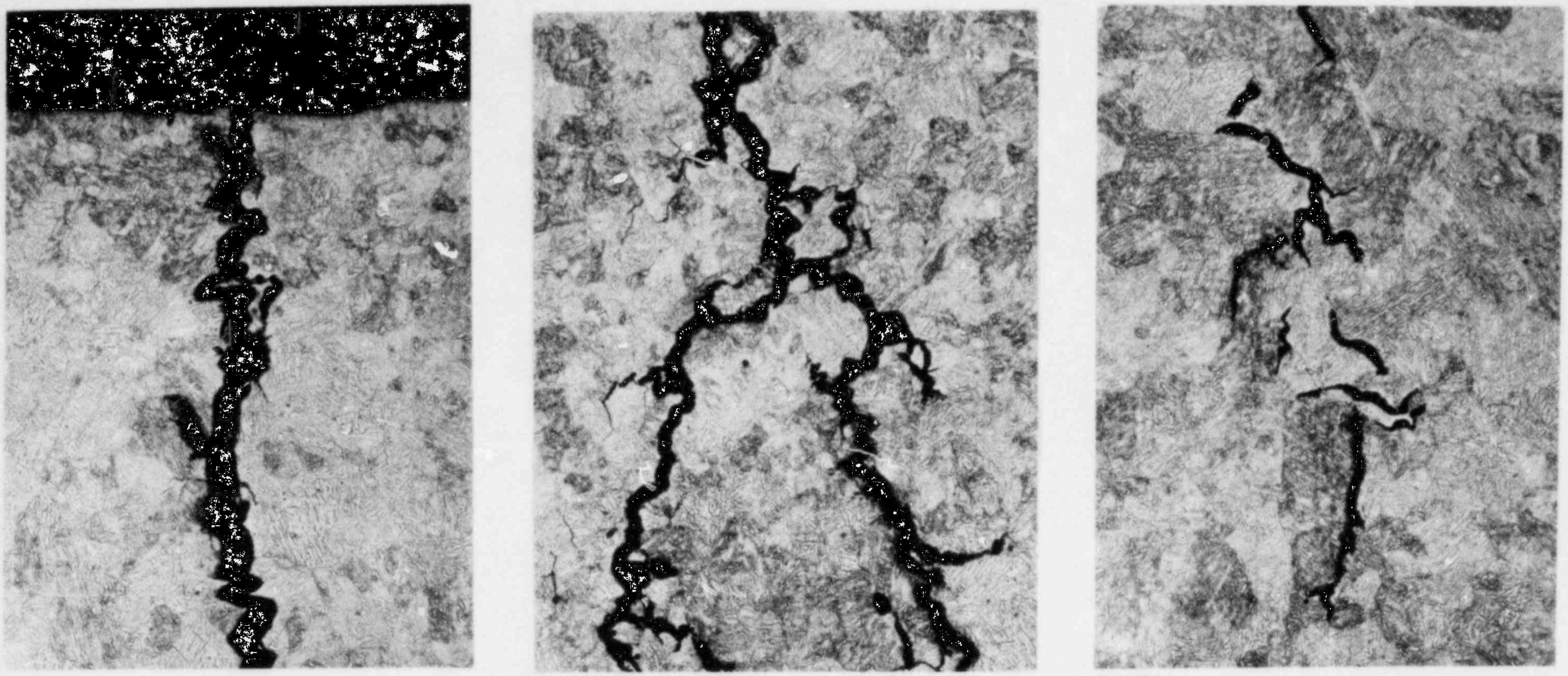
Photomicrographs illustrating the microstructural features of the cracking are shown in Figure 4. The crack path is predominantly intergranular over its entire length and localized branching, extending two or three grain diameters from the main crack, was present along the crack path. Most of these short branches were filled with an oxide and several were disconnected from the main crack in the plane of this section [Figure 4(b)]. In this section, the crack tip consisted of several disconnected intergranular segments [Figure 4(c)].

The keyway specimen was characterized by a bainitic microstructure typical of quenched and tempered 3.5 NiCrMoV alloy steels commonly employed for LP turbine discs (i.e., ASTM A471). No inherent material defects or abnormalities were observed.



12230 ≈8X

FIGURE 3. TRANSVERSE SECTION THROUGH KEYWAY.
Dark field illumination.



12270 (a) At keyway surface. Location 1, Figure 3.

12272 (b) Central portion of crack. Location 2, Figure 3.

12274 (c) Crack tip. Location 3, Figure 3.

FIGURE 4. PHOTOMICROGRAPHS FROM SECTION THROUGH KEYWAY.
Etchant: Nital 100X

FRACTOGRAPHIC EXAMINATIONS

The keyway specimen was cut into three approximately equal segments. Each segment was cooled in liquid nitrogen and then broken open to expose the crack surfaces. A photograph of the keyway after the segments were opened is shown in Figure 5. The segments broke open along the three major MP indications marked A, C and D in Figure 2. The short crack at indication B did not open.

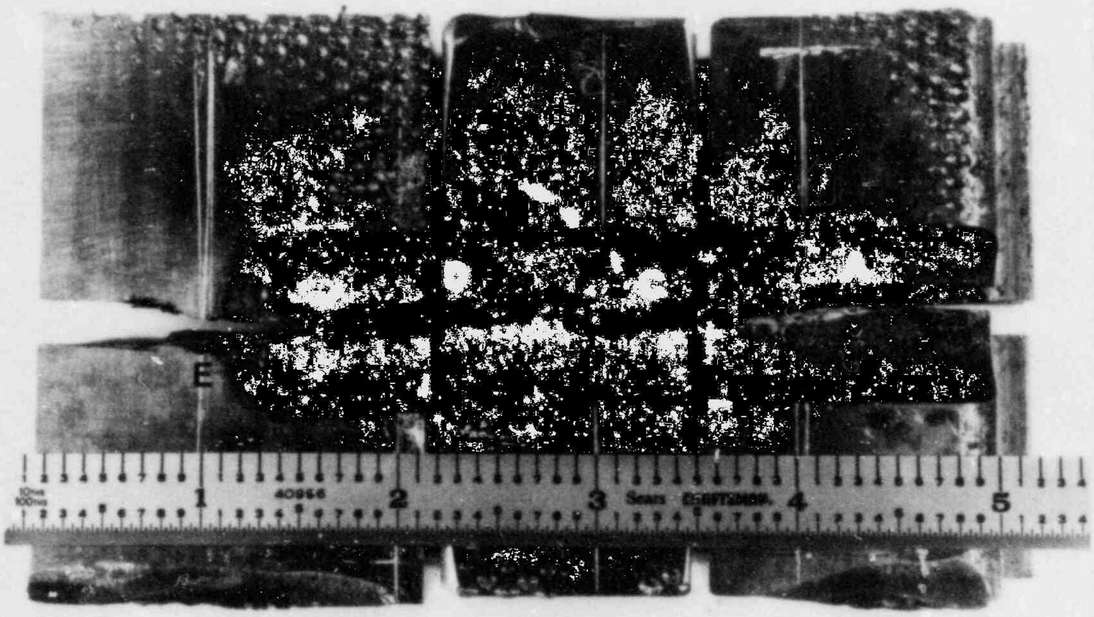
The crack surfaces presented a dark, blue-black appearance so that the extent of cracking was clearly delineated. Photomacrographs of the exposed crack surfaces are shown in Figure 6 and a scale diagram of the crack profile is shown in Figure 7. The segments corresponding to the individual MP crack indications are marked in each figure. Segments A and C clearly represent separate independent cracks. Segment D was continuous but was marked with several distinct steps indicating that this segment represented at least three initially independent cracks which joined together in the later stages of growth. These features are consistent with the segmented appearance of the MP indication (Segment D in Figure 2). The crack Segment E at the blind end of the keyway also proved to be a separate, independent crack. Opening of the outer segment of the keyway revealed two small cracks which were not detected in the MP inspection. These are marked as Segments F and G in Figure 7.

The three major segments of the keyway cracking (A, C and D in Figure 7) extended over nearly the full length of the keyway and measured 0.68 inch, 0.88 inch and 1.86 inches long, respectively. Segment C extended to a depth of 0.64 inch while Segments A and D were 0.30 inch and 0.52 inch deep, respectively.

One segment of the exposed crack surfaces was electrolytically cleaned (specimen cathodic) and examined in the scanning electron microscope (SEM) to identify the fine-scale topographic features. Representative SEM fractographs are shown in Figures 8 and 9. The SEM examination established that the crack surface was predominantly intergranular. Only a very few, isolated, transgranular facets were observed. There was some evidence of limited

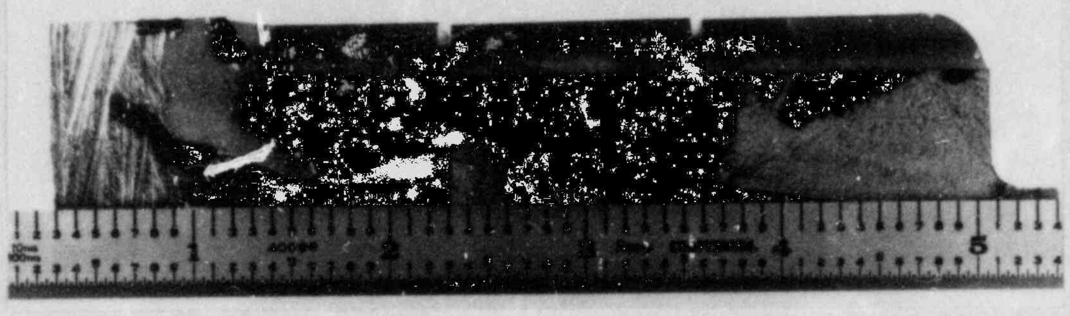
corrosive attack of the crack surfaces, but there was no significant difference in the extent of such attack over the several locations examined.

Prior to cleaning, the deposit present on the crack surface was qualitatively analyzed by energy dispersive X-ray spectroscopy (EDS). An X-ray energy spectrum from the as-opened crack surface at a point near the keyway surface is shown in Figure 10. The principal elements detected were iron, chromium, and nickel; all constituents of the base metal. A small amount of chlorine was detected at this particular point. Except for extremely small peaks for chlorine and sulfur, no other extraneous surface elements were detected. These observations establish that the crack surface deposits are simply oxides of the base metal and that no unusual surface contaminants were present.



12325 Actual Size

FIGURE 5. KEYWAY SPECIMENS. Refitted after breaking open.



12324 Actual Size

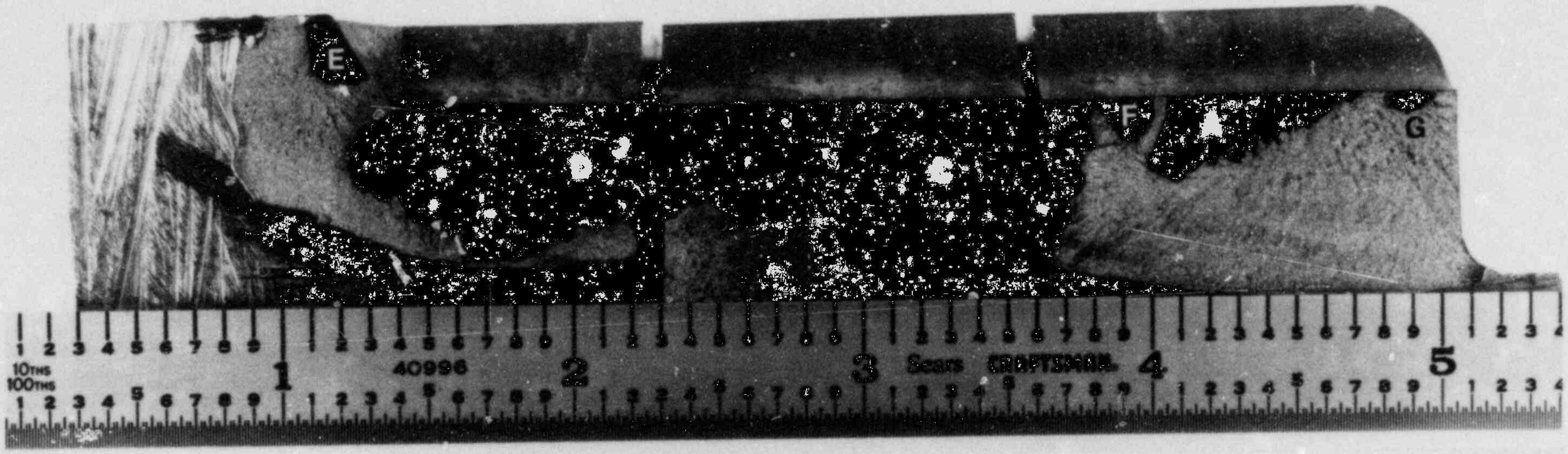


FIGURE 6. EXPOSED CRACK SURFACES.

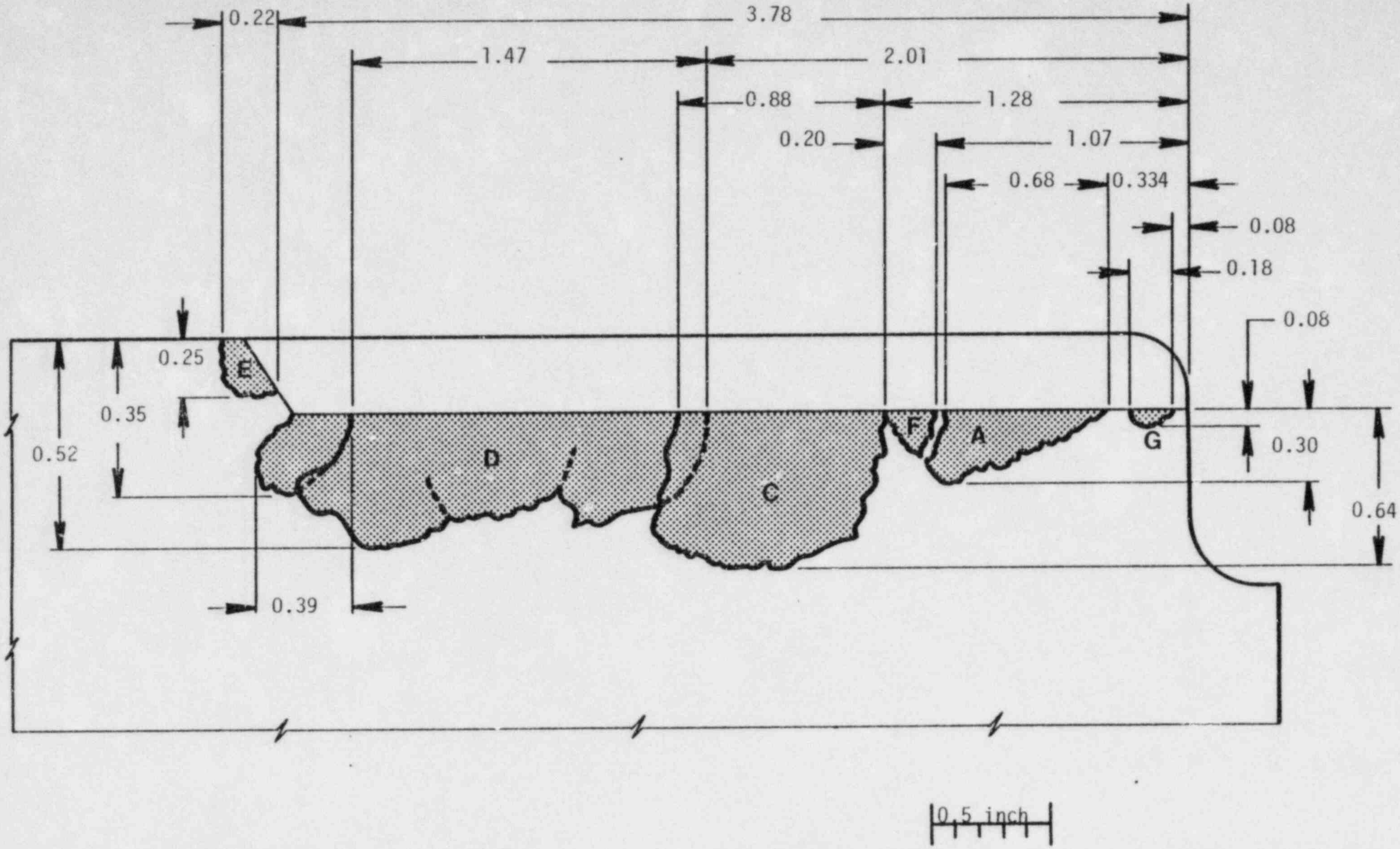
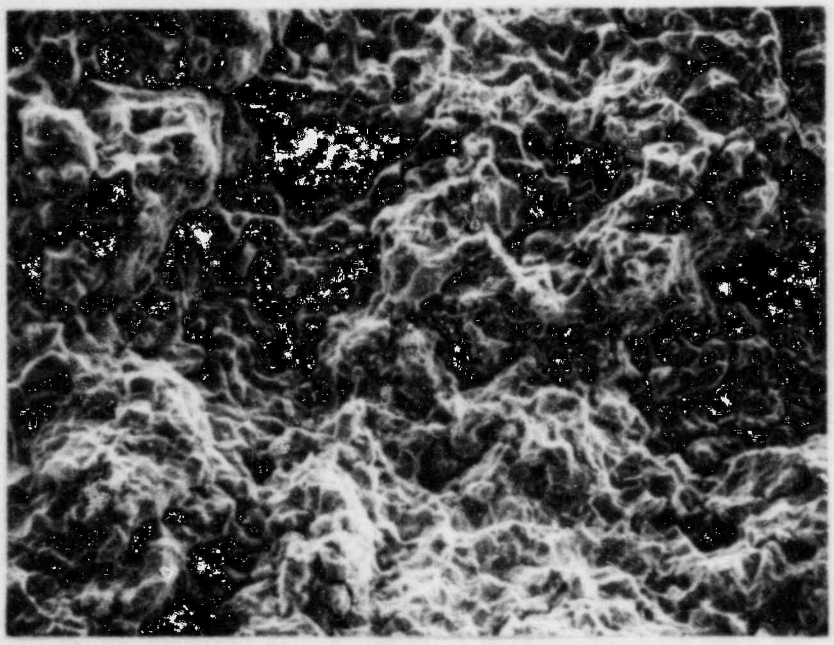
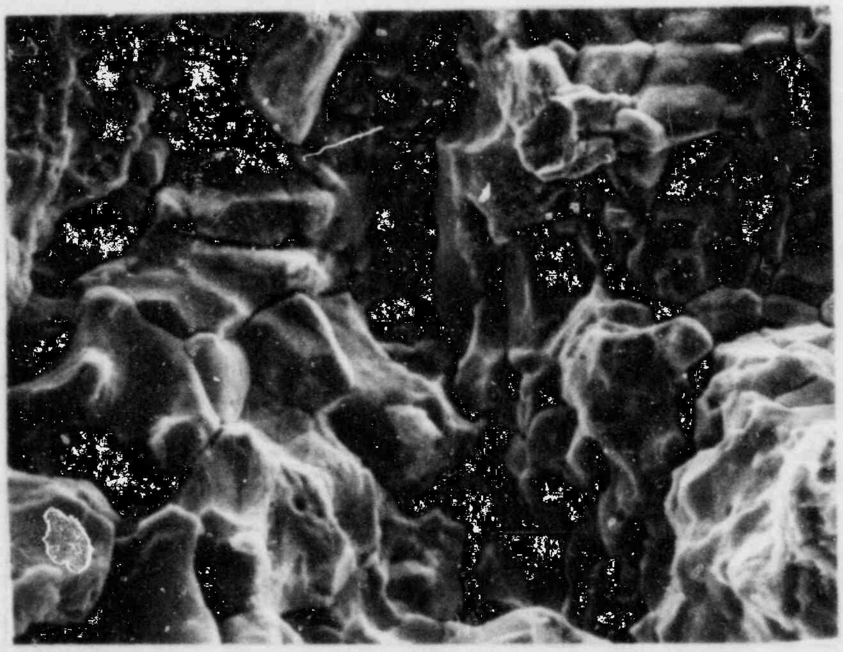


FIGURE 7. DIAGRAM OF CRACK SURFACES.
Dimensions in inches.

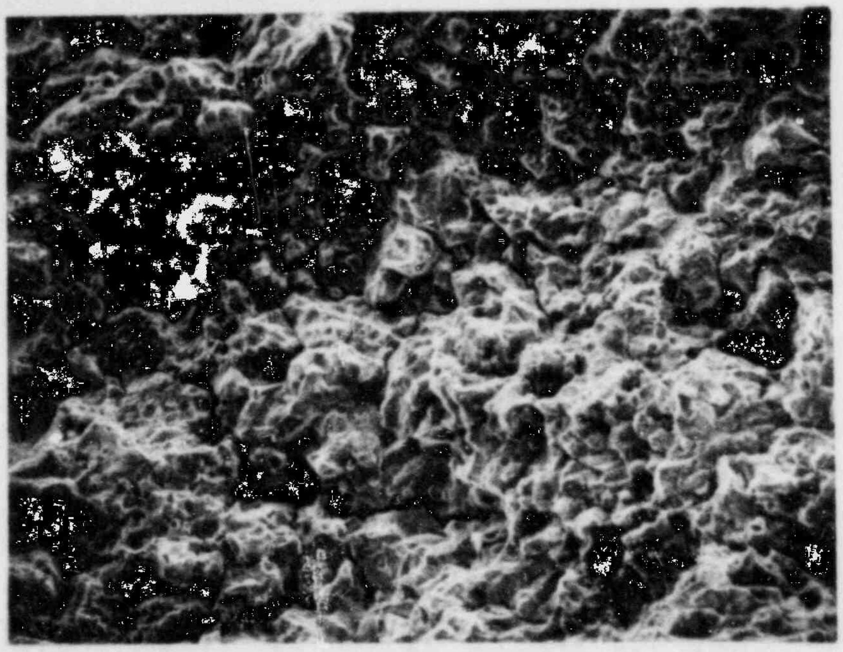


12396 100X



12397 500X

FIGURE 8. SEM FRACTOGRAPHS FROM EXPOSED CRACK SURFACE. Segment D, Figure 7, near keyway surface.



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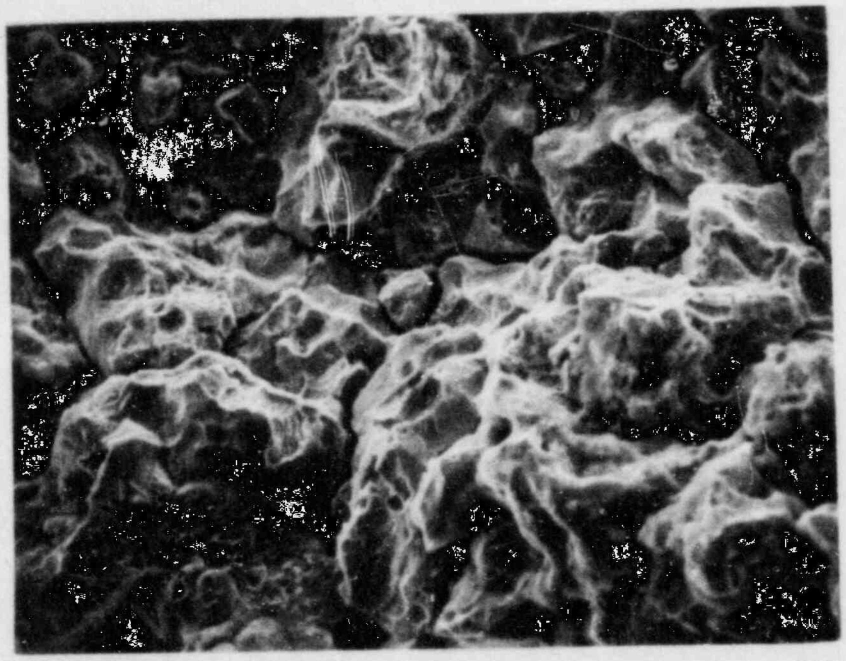
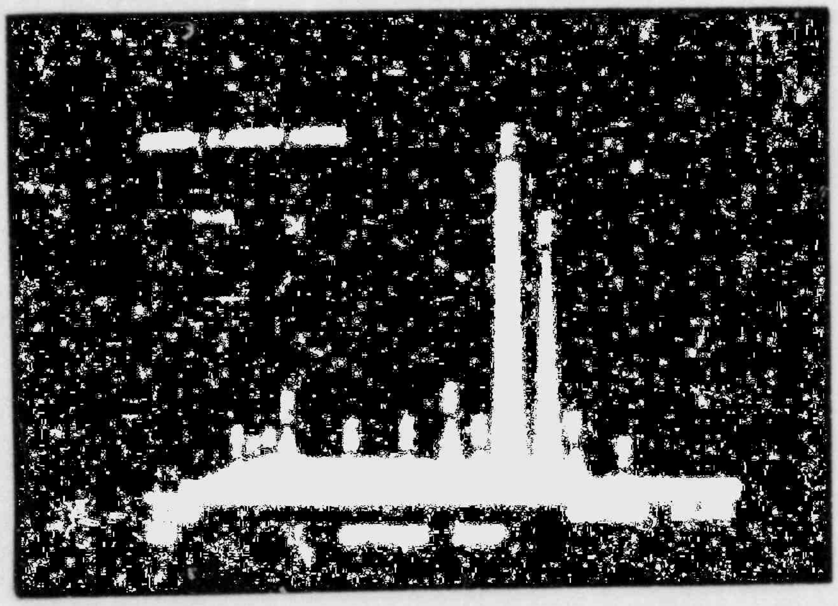


12395 500X

FIGURE 9. SEM FRACTOGRAPHS FROM EXPOSED CRACK SURFACE. Segment D, Figure 7, near crack front.



12326

FIGURE 10. X-RAY ENERGY SPECTRA FROM EXPOSED CRACK SURFACE.

SUMMARY AND DISCUSSION

The principal features of the keyway cracking in the No. 1, governor-end disc from the LP-1 turbine at North Anna, Unit 2, are summarized as follows:

1) The cracking developed by initiation and growth of at least seven independent cracks along the full length of the keyway. All of the cracks were parallel to the long axis of the keyway.

2) The keyway surface exhibited only mild corrosive attack in the form of shallow pitting.

3) The three largest cracks were 0.68 inch, 0.88 inch and 1.86 inches in length and the maximum crack depth was 0.64 inch.

4) For all practical purposes the cracking was completely intergranular. Only limited corrosive attack of the crack surfaces had occurred.

5) The crack surfaces were completely covered with a thin, adherent oxide film. No unusual contaminant species were present on the crack surface.

The macroscopic and microscopic features observed for this case of keyway cracking were essentially identical to those observed for the cracking which developed in the Surry Unit 1 discs.[1] In this instance, the cracking is somewhat more extensive in that it occurred over the full length of the keyway and was deeper. Both cases have all of the characteristics of two other LP disc keyway cracking incidents which were the subject of an earlier investigation.[2] In all four cases the cracking involved multiple initiation and developed in a predominantly intergranular mode. None of the four incidents involved any materials defect or any unusual contaminant species. These factors, together with the data from investigations of other types of LP disc cracking,[3,4] establish that the keyway cracks developed by intergranular stress corrosion cracking (IGSCC). The indications are that the root cause of the cracking was the inherent cracking susceptibility of

the turbine disc alloy in environments commonly encountered in large LP steam turbines in nuclear electric generating stations. Recent laboratory test programs have demonstrated that 3.5 NiCrMoV alloy steel is susceptible to IGSCC in areated and deareated pure water as well as in dilute caustic solutions.[5]

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