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Thermal Fatigue Performance of Integrally Cast Automotive Turbine Wheels

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National Aeronautics and Space Administration
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U.S. DEPARTMENT OF ENERGY
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FOREWORD

This report, DOE/NASA/9696-1 (NASA CR-165227), "Thermal Fatigue Performance of Integrally Cast Automotive Turbine Wheels", summarizes the results of thermal fatigue testing of automotive turbine wheels. This work was sponsored by the U.S. Department of Energy and performed under NASA Lewis Research Center Contract NAS3-19696. Work described here was conducted during the period July 1975 to October 1979. All thermal fatigue testing was conducted using fluidized bed heating and cooling over the range 935°/50°C (1715°/122°F). Other thermal fatigue data generated in this facility have been reported in NASA CR-72738, CR-121211, CR-121212, CR-134775, CR-135272, CR-135299, CR-159798, and CR-159842.

Work on this program was performed with P. T. Bizon of the NASA-Lewis Research Center as the Project Monitor. IITRI personnel contributing to the program include V. L. Hill (succeeded by K. E. Hofer), Project Manager, and V. E. Humphreys, Project Engineer. Editorial and clerical support were provided by V. E. Johnson and M. Dineen, respectively. Other IITRI personnel who contributed to the program include B. A. Humphreys and M. Dimenn.

This report has been given the IITRI internal designation of M6003-54 (formerly B6135). Data in this report are recorded in IITRI logbooks No. C23547, C23860, C23867, C24095, C24428, and C24430.

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SUMMARY

This report, DOE/NASA/9696-1 (NASA CR-165227, describes the results of temperature calibration and thermal fatigue data for 16 integrally cast automotive turbine wheels. Fourteen of the turbine wheels were fabricated by investment casting IN-792 + 1% Hf; the other two wheels were gatorized AF2-1DA alloy. All testing was conducted employing fluidized bed heating and cooling of eight turbine wheels simultaneously, in two stacks of four test wheels. Other thermal fatigue data generated in this facility have been reported in NASA CR-72738, CR-121211, CR-121212, CR-134775, CR-135299, CR-159798, and CR-159842.

Thermal fatigue data were obtained for the 16 turbine wheels--6 pocketed and 10 unpocketed--for 1000 to 10,000 accummulated cycles. Crack propagation on both wheel and blade sections of the integrally cast wheels was measured. In addition, temperature transients during thermal cycling were measured in three calibration tests employing either 18 or 30 thermocouples per wheel. Calibration tests were conducted on investment cast wheels at 950°/50°C (480 sec total) cycles and 935°/50°C (600 sec total) cycles. Based on these calibrations, the 935°/50°C thermal cycles were selected for thermal fatigue evaluation. The final calibration test was conducted on a gatorized AF2-1DA alloy wheel at 935°/50°C using 18 thermocouples.

Thermal fatigue cracking of unpocketed wheels progressed more rapidly than that of pocketed wheels based on crack length, although pocketed wheels cracked earlier. Crack initiation for pocketed wheels occurred in 8-13 cycles as compared to 75-250 cycles for unpocketed wheels. None of the pocketed wheels exhibited cracks in excess of 19 mm after 5000-10,000 cycles. Two unpocketed wheels exhibited 45 mm cracks extending to the hub after 1000 and 2000 cycles. Addition of drilled crack arrest holes in the pockets of two pocketed wheels resulted in an overall increase in crack propagation.

Cracks at the trailing edge of blades were first detected in unpocketed wheels between 250 and 600 cycles. Trailing edge blade cracking of pocketed wheels was not detected prior to 2250-5250 accummulated cycles for individual wheels.

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THERMAL FATIGUE PERFORMANCE
OF INTEGRALLY CAST AUTOMOTIVE TURBINE WHEELS

1. INTRODUCTION

This report, DOE/NASA/9696-1 (NASA CR-165227), summarizes the results of thermal fatigue testing of 16 integrally cast automotive turbine wheels. This work was supported by the U.S. Department of Energy and performed under contract NAS3-19696 directed by the National Aeronautics and Space Administration Lewis Research Center. The test program evaluated 10 unpocketed wheels and 6 wheels with pockets at the base of the turbine blades. Unpocketed test wheels were fabricated by three manufacturers using three different manufacturing techniques: (1) Airefrac casting, (2) lost wax investment casting, and (3) gatorizing. The six pocketed wheels were fabricated by two manufacturers using the first two casting techniques. All wheels, except the gatorized wheels, were IN-792 + 1% Hf; gatorized wheels were fabricated from AF2-1DA alloy. All wheels were approximately 140 mm in diameter and contained 53 blades.

Integrally cast automotive turbine wheels were cycled for 1000-10,000 accumulated cycles at 935°/50°C (1715°/122°F). Heating and cooling were conducted in the fludized bed facility using a symmetrical thermal cycle consisting of 300 sec heating and 300 sec cooling (600 sec total cycle). The fluidized bed facility consists of a heating bed mounted between two cooling beds which permitted simultaneous testing of two stacks of four test wheels. Thermal fatigue crack initiation and propagation were measured as a function of accumulated cycles on both the wheel and blade sections of the burbine wheel. Crack measurements were made at periodic intervals over the nominal 5000 cycle exposure for each wheel. Testing was performed in two groups of four wheels in each stack for two 5000 cycle campaigns.

To select a cycle for thermal fatigue testing, two temperature calibrations were conducted using 30 thermocouples attached to both wheels and blades. Thermal transients were measured for two different thermal cycles, the first consisting of a symmetrical 480 sec total cycle and the second a 600 sec cycle. In addition, a third calibration (600 sec cycle) was conducted on a gatorized wheel employing 18 chromel-alumel thermocouples.

Thermal fatigue data obtained previously on Contract NAS3-19696 have been reported in NASA CR-159798(1). Other thermal fatigue data generated in the IITRI fluidized bed facility on Contracts NAS3-14311, NAS3-17787 and NAS3-18942 have been reported in NASA CR-27238(2), CR-121211(3), CR-121212(4), CR-134755(5), CR-135272 (6), CR-135299(7), and CR-159842(8). This effort comprises part of a general study of thermal fatigue being conducted by the NASA-Lewis Research Center. Further details of the study have been reported by Spera et al., (9,10), Bizon et al., (11-13), and Howes (14). Most of the previous work was conducted on thermal fatigue test specimens; this program was the initial major effort to evaluate actual equipment components.

Any material exposed to repeated temperature transients is subject to tensile failure by thermal fatigue, sometimes also defined as thermal shock. The thermal fatigue degradation mechanism involves accumulation of damage during multiple thermal cycles. Thermal shock, on the other hand, generally involves failure in relatively few cycles. The difference generally lies in the tensile ductility of the material within the temperature range of the imposed thermal cycle. Ductile materials tend to fail by thermal fatigue, whereas brittle materials fracture by thermal shock.

Material properties, other than ductility, important in thermal fatigue are hot tensile strength, elastic modulus, thermal conductivity, and thermal expansion. Oxidation resistance apparently also plays a role in thermal fatigue. The interrelationship of material properties, the imposed thermal cycle, and component geometry defines the ability of a structure to resist thermal fatigue. However, the synergistic effects of these variables are quite complex, and prediction of thermal fatigue behavior from basic properties is difficult. A major objective of a current NASA fatigue program is to develop and verify a viable statistical model for thermal fatigue by comparing experimental data with computer-derived predictions of thermal fatigue life (9).

Thermal fatigue data in this report were generated using a multiple retort fluidized bed test facility consisting of one heating bed and two cooling beds. Glenny and co-workers reported the first use of fluidized beds to study thermal fatigue.[15] Fluidized bed heating and cooling provides very rapid heat transfer for both portions of the thermal cycle. An additional advantage of the fluidized bed method is that it provides a ready means of exposing a number of samples under identical test conditions. In this program, up to 8 turbine wheels were exposed simultaneously.

The objective of the thermal fatigue test program was threefold:

1. Determine the number of imposed thermal cycles to initiation of the first wheel crack and obtain data on the rate of propagation of the wheel cracks.

2. Determine the number of imposed thermal cycles to initiation of blade cracking and measure the rate of propagation of the blade cracks.

3. Compare the effect of method of fabrication and wheel design on thermal fatigue behavior.

Wheels with pockets located beneath the blade root flange between each blade were intended to evaluate crack arrest. In addition, two of the pocketed wheels had small diameter holes drilled at the base of the pockets to investigate potential crack arrest by this method. All wheels were supplied by the NASA-Lewis Research Center ready for testing, except for final machining of the hub section. IITRI completed fabrication by drilling the center hole, which was necessary to support the wheel during thermal fatigue testing.

2. MATERIALS AND PROCEDURES

2.1 Experimental Procedure

Thermal cycling was conducted in the 50 kW IITRI fluidized bed thermal fatigue facility shown in Fig. 1. This facility, employing air as the fluidizing medium, was capable of cycling up to 8 test turbine wheels simultaneously over the range 935°/50°C. The equipment contains one hot bed and two cooling beds. Consequently, eight turbine wheels were tested simultaneously in two stacks of six wheels each; four test and two dummy wheels.

During thermal fatigue testing, the turbine wheels were removed from cycling for visual examination of cracking after accumulating 25, 50, 75, 100, 200, 300, 500, 700, 1000 cycles and thereafter at each subsequent 500 accumulated cycles to the maximum accumulated cycles. Visual examination was conducted using a 30X binocular microscope to determine the cycles to initiation of cracking and measurement of crack lengths. This technique permitted detection of cracks in excess of 0.25 mm (0.01 in.). Other detection techniques, such as dye penetrant inspection were not employed because of the roughened surface of the wheels and oxide layers on blades. Furthermore, it was intended to avoid contamination of the wheel surfaces by inspection fluids. Visual measurement of thermal fatigue cracking has been extensively employed at IITRI in previous thermal fatigue programs.

Each test stack consisted of four test turbine wheels and two dummy wheels. The dummy wheels (one at the top and bottom of each stack) were included to eliminate possible end effects. During testing, wheels were replaced randomly in the four central positions of the stack after each inspection period. However, the four test wheels were always maintained in their individual stack for the complete thermal fatigue campaign.

The spaces between the wheels, resulting from the hub projections, were packed with fiberfrax which was held in place by a 304 stainless steel retainer ring. The retainer rings were located immediately inside the blade root flange, and were replaced as needed during the test program. The intent of the insulation was to provide radial heat transfer from the blades to the wheel to simulate turbine operation. A 304 stainless steel air deflector cone was attached to the bottom of each test stack to direct the fluidizing air uniformly around the test stack based on the temperature calibration tests. A typical test stack and attachment fixture are shown in Fig. 2a.

2.2 Wheel Fabrication and Composition

Table 1 lists the identification, fabricator, and method of manufacturing of the 16 test wheels and 12 calibration wheels. Identification of the dummy wheels is not included in the table. Wheels fabricated by AiResearch Casting Company (Airefrac casting) and Howmet Corporation (lost wax investment casting) were of IN 792 + HF alloy. Wheels manufactured by Pratt and Whitney Division (gatorize casting) were AF2-lDA alloy. The composition of the remelt stock used by AiResearch (heat # V3622) was 0.13 C, 12.5 Cr, 1.92 Mo, 3.94 Ta, 9.1 Co, 3.97 W, 3.62 Al, 3.91 Ti, 0.88 Hf, 0.13 Zr, 0.18 B, and bal. Ni. The composition of the remelt stock used by Howmet (heat # 140B3429) was 0.17 C, 12.30 Cr, 1.94 Mo, 4.03 Ta, 9.03 Co, 3.96 W, 3.39 Al, 4.03 Ti, 1.00 Hf, 0.10 Zr, 0.012 B, and bal. Ni. The nominal composition of the AF2-lDA alloy was 0.35 C, 12 Cr, 10 Co, 3 Mo, 5W, 5 Ti, 4.6 Al, 1.5 Ta, 0.10 Zr, 0.015 B, and bal. Ni.

The IN 792 + Hf wheels were heat treated before thermal fatigue testing. They were solution heat treated for 2 hours at 1121°C followed by aging for 24 hours at 843°C. The cooling rate was about 140°C/min. for the blades and 80°C/min. for the hub.

Pocketed wheels P5 and P6 had 1.6 mm diameter holes drilled in the internal end of the pockets as additional crack arresting construction. These holes were drilled in all pockets within an area 180° of the wheel periphery; the remaining 180° of these wheels was retained in the as-fabricated condition.

2.3 Temperature Calibration

Prior to thermal fatigue testing, two temperature calibrations were conducted with 30 chromel-alumel thermocouples to measure temperature transients during thermal cycling. These calibrations were conducted on an unpocketed wheel using both a 480 and a 600 sec total symmetircal thermal cycle. Each wheel was instrumented with 14 thermocouples on the wheel section and 16 on the centerline of the airfoil turbine blades around the circumference of the disk. Blade thermocouple locations were: (1) at the root; (2) one-third the distance to the tip; (3) two-thirds the distance to the tip; and (4) at the tip. Wheel thermocouple locations were distributed geometrically on both the disk and the shaft sides (side containing hub) of the wheel. In each calibration test, three complete thermal cycles were completed prior to recording of the temperature transients.

The first calibration test involved a 480 sec total cycle (240 sec heating and 240 sec cooling) between bed temperatures of 950°/50°C. Results obtained in this test suggested that the thermal cycle and hot bed temperature should be modified to obtain the desired metal temperatures about 915°/65°C. Furthermore, an air deflection cone at the bottom of each stack-up was desirable to distribute heated air uniformly around the circumference of the wheels. The first calibration test did indicate that the insulation technique provided radiant heat transfer during cycling.

The second calibration test was conducted at 935°/50°C using a 600 sec total symmetrical cycle. In this test, an air deflection cone was added resulting in more uniform heating and cooling of the turbine blades. Results of the second calibration test indicated the 935°/50°C-600 sec cycle test provided the desired metal temperature thermal cycle of about 925°/50°C.

A third calibration test was conducted using a gatorized wheel after completion of thermal fatigue testing. In this calibration, 18 thermocouples were employed--14 on the wheel area and 4 on selected blades. Three of the blade thermocouples were located at the root and distributed 120° apart on the periphery. The last blade thermocouple was located at the tip of a blade that also contained a root thermocouple. Cycling conditions for the third calibration were 935°/50°C-600 sec total cycle; equivalent to that employed for the second calibration test.

Calibration tests were conducted with 0.5 mm diameter sheathed chromel-alumel thermocouples with 0.05 mm diameter elements. The hot junctions were attached to the turbine wheels with a high-temperature ceramic cement. Figure 2b shows the thermocouple installations for calibration tests. The locations of the thermocouples on the turbine wheels are shown in Figs. 3 and 4 for the disk and shaft sides of the wheel, respectively, for the first two calibration tests. Locations of the 18 thermocouples for the third calibration test of the gatorized wheel are shown in Figs. 5 and 6. Although not clearly shown in Figs. 3 to 6, thermocouples attached to the shaft and disk sides were located on corresponding radii but opposite sides of the wheel.

3. RESULTS

3.1 Temperature Calibration

Calibration tests were conducted with the six wheel stack-up as used later for the thermal cycling tests. The instrumented wheel was installed as one of the two center wheels, located in the stack so that the leading edge of the blades faced downward in the stack. This orientation was intended to provide fluidizing air flow through the blades simulating the gas path in turbine operation.

Results for the first calibration test at 950°/50°C-480 sec cycle are contained in Table 2. Identification of thermocouples in this table is shown in Figs. 3 and 4. Blade thermocouples, which were attached at the centerline of the airfoils, are identified as 1-16 and wheel thermocouples as either disk (D) or shaft (S) sides of the wheel; the shaft side contained the hub projections. Data in Table 2 indicate that out-of-phase heating and cooling were obtained in thermocouple positions near the hub. Thermocouples D11 and D13 recorded about a 30 sec delay on both heating and cooling; i.e., heating on the cooling cycle. Other thermocouples located closer to the hub, D4, D5, S9, and S10, exhibited delay in thermal transients of about 90 sec before reversal occurred. These results indicated that the insulation system was efficient in obtaining radial heat transfer from the turbine blades.

Examination of the data in Table 2 indicates that the 480 sec cycle resulted in variable temperature transients around the wheel periphery. This was considered due to non-uniform distribution of the fluidizing air by the flat bottom of the dummy wheel at the bottom of the stack. To eliminate this effect, an air deflection cone was added at the bottom of each test stack for the second calibration test. Furthermore, the hot bed temperature was reduced to 935°C and the symmetrical thermal cycle extended to 600 sec (300 sec heating and 300 sec cooling) to obtain desired metal temperatures of about 915°/65°C.

Thermal transients measured during the second calibration tests at 935°/50°C-600 sec cycle are summarized in Table 3. Thermocouple identification is equivalent to that shown in Table 2. As in the first calibration test, out-of-phase transients were measured for internal thermocouples near the hub. Temperature transients of blades around the wheel were considerably more uniform than in the first calibration test. Some variation in temperatures was observed at blade root positions; because of the radius at the root it was difficult to locate root thermocouples accurately. Accordingly, the variation in temperature at blade roots was likely due principally to thermocouple position rather than nonuniform fluidizing air passing through the blades. Based on the second calibration test, the conditions selected for thermal fatigue testing were 935°/50°C-600 sec total cycle to obtain the desired blade metal temperatures of about 915°/65°C.

The final calibration test was conducted on a gatorized AF2-1DA turbine wheel at 935°/50°C-600 sec cycle using 18 thermocouples. Gatorized wheels had a slightly different configuration than that of unpocketed investment cast wheels, as shown in Figs. 5 and 6. This consisted of a thinner hub section and smaller diameter shaft hub. Fourteen of the 18 thermocouples were located on the wheel section equivalent to that employed for the first two tests and four on the blades. Three blade thermocouples were located at the root and one at the tip of selected blades (Fig. 5).

Calibration data for the gatorized wheel are summarized in Table 4 (temperatures were recorded to the nearest 5°C). Because of the different wheel configuration, out-of-phase transients differed from that of the investment cast wheel. However, out-of-phase transients were still obtained for locations D4, D5, S9, and S10. The overall temperature variation of the wheel section was generally greater for gatorized wheels than for investment cast unpocketed wheels, as indicated by Tables 3 and 4. This was apparently due to the thinner hub cross section and lower overall weight of the wheel.

3.2 Thermal Fatigue

Thermal fatigue tests were conducted in four stacks of six wheels each: a dummy wheel at the top and bottom along with four test wheels.

Table 5 lists the wheels exposed in each test stack and the accumulated cycles for each test wheel during the thermal fatigue tests; each stack was subjected to 5000 cycles. Stacks W1 and W2 were tested initially, and stacks W3 and W4 in the second test. Unpocketed wheels U3 and U4 in stack W1 were replaced with wheels U5 and U6 after 1000 accumulated cycles, due to excessive cracking. Wheels P2 and P4 of stack W2 were reintroduced into stack W3 after 2000 cycles. Accordingly, these pocketed wheels received 8000 thermal cycles during the total exposure. Similarly, pocketed wheels P1 and P3 were included in both stacks W2 and W4, and received 10,000 thermal cycles. The additional 25 cycles recorded for wheels P2 and P3 were the result of using these wheels in the stack-up for calibration tests; 16 cycles in calibration test 1, and 9 in calibration test 2.

Testing of pocketed wheels P1, P2, P3, and P4 beyond 5000 cycles was initiated to study crack propagation inward from the base of the pockets. Testing of unpocketed wheels did not exceed 5000 cycles in any test. Only unpocketed wheels U1, U2, U11, and U12 received 5000 accumulated cycles; other pocketed wheels were cycled for 1000-4000 cycles.

To measure crack propagation, each wheel was marked with a permanent reference position. Crack locations were then identified relative to the reference mark looking at the shaft/disk side proceeding clockwise around the wheel. It was found that cracks on the wheel section always originated between the

53 turbine blades. Accordingly, crack length data in this report are identified relative to two blades, for example 1-2. This represents a crack located between blades 1 and 2, measured clockwise on the shaft/disk side from the reference mark. Thus, each wheel had the potenital for generation of 53 cracks on the wheel section. In a few cases, two cracks were detected between the blades; the longest of the cracks was measured and marked.

Table 6 summarizes crack initiation and propagation for the 16 test wheels. Included in the data are total accumulated cycles and cycles to the first crack (0.25 mm) on the shaft and disk sides of the wheel, accumulated cycles to generate a 10 and 20 mm crack, maximum crack length, number of major cracks in excess of 10 and 20 mm, and total number of cracks for each wheel. Cycles to first crack for unpocketed wheels differed somewhat for the disk and shaft sides. Normally, the crack would initiate at the blade root flange on either the disk or shaft side, and progress across the wheel width before emerging on the other side of the wheel. Subsequently, crack lengths on the disk or shaft side did not differ significantly. For pocketed wheels, the cracks always had progressed completely across the wheel width when first detected.

In Table 6, cycles to first crack and accumulated cycles to 10 and 20 mm cracks were taken to be the mean of the test inspection period without a crack (or 10 mm long crack) and the next inspection period in which a crack was visible (or was 20 mm long). Accordingly, if a crack was not visible at 50 cycles, but was detected at 100 cycles, accumulated cycles to crack initiation was considered to be 75 cycles. The typical appearance of pocketed and unpocketed wheels prior to testing is shown in Fig. 7.

3.2.1 Unpocketed Wheels

3.2.1.1 Wheel Cracks

Accumulated 935°/50°C cycles to crack initiation for all unpocketed wheels varied from 75 to 250 cycles, as shown in Table 6. This was considerably later than that of pocketed wheels; however, unpocketed wheels generally exhibited longer cracks due to crack arrest at the bottom of the pockets for pocketed wheels. Maximum crack lengths for unpocketed wheels ranged from 23 mm (U5-1000 cycles) to 45.8 mm (U4-1000 cycles), the distance from the flange to the center support hole in the hub. Accumulated cycles to generate a 10 mm crack varied between 150-2250 cycles, and 250-2250 cycles for a 20 mm crack. All unpocketed wheels, except U4, developed at least two cracks of 10 mm length during their respective exposure. Wheels cycled 5000 cycles--U1, U2, U11, and U12--generated 3-6 cracks of 10 mm length. Typical crack initiation and propagation for unpocketed wheels is illustrated in Fig. 8.

Comparison of Tables 1 and 6 indicates no major significant effect of either manufacturer or fabrication technique on cracking behavior. Gatorized wheels tended to propagate cracks more rapidly than investment cast or Airefrac cast wheels. However, the gatorized wheels were AF2-1DA alloy, whereas all other wheels were IN-792 + Hf. Furthermore, the thinner web section of the gatorized wheels likely caused the more rapid crack propagation.

Crack initiation and propagation data for the wheel section of unpocketed wheels are detailed in Tables 7 to 16. The appearance of the disk side of the wheels after exposure is shown in Figs. 9 to 13. Generally, unpocketed wheels appeared to generate 3 to 4 major cracks located either 90° or 120° apart, with one of the cracks showing slower propagation. After the major cracks had propagated about 10 mm, secondary cracks began to propagate at a location approximately bisecting the angle of the major cracks. The exceptions were wheels U4 and U8, both of which developed one major crack extending to the hub.

3.2.1.2 Blade Cracks

In addition to cracks in the wheel section of the turbine wheels, inspection for crack initiation and propagation in the blades was also conducted. A summary of blade crack initiation and propagation is contained in Table 17. Cracks in blades invariably occurred near the root flange in the trailing edge. Included in Table 17 are total accumulated thermal cycles and cycles to the first crack, accumulated cycles to crack lengths of 0.5 and 1.0 mm, maximum crack length, and total number of cracked blades after completion of thermal cycling. Total cracked blades varied widely, ranging from 15 cracked blades for U8 (2000 cycles) to 53 blades for U2 (5000 cycles). Unpocketed wheels cycled 4000-5000 cycles--U1, U2, U6, U7, U11, and U12--exhibited cracks at the trailing edge radius on practically all of the 53 blades.

Data in Tables 6 and 17 indicate that blade cracks were initiated significantly later than wheel cracks. Accumulated cycles to the first cracked blade varied from 250-600 cycles, for unpocketed wheels. Apparently, blade cracks originated after progression of the wheel cracks sufficient to produce a separate thermal stress state in the segments between wheel cracks.

Tables 18 to 26 detail crack initiation and propagation data in the blades for unpocketed wheels in the U1-U12 series. Although numerous blade cracks were detected, propagation of these cracks was relatively slow. No blade crack in excess of 1.8 mm was measured on any wheel; crack length usually ranged from 0.5-1.0 mm.

3.2.2 Pocketed Wheels

3.2.2.1 Wheel Cracks

Six wheels, P1-P6, with 10 mm long pockets located just inside the blade root flange were evaluated in the test program. The intent of the pockets was to arrest cracks at the base of the pockets; wheels P5 and P6 also had 1.6 mm diameter holes drilled through the cross section at the base of the pockets as additional crack arrestors. These holes were drilled in all pockets over a 180° arc in the wheels to provide a direct comparison to pockets without holes.

Crack initiation and propagation data for pocketed wheels are summarized in Table 6. All pocketed wheels had thermal fatigue cracks at the first inspection cycle, 16 calibration cycles for wheels P2 and P3, and 25 cycles for wheels P1, P4, P5, and P6. Several cracks were detected in all pocketed wheels after the first inspection period. After only 16 cycles, wheels P2 and P3 exhibited 17 and 3 pocket cracks, respectively. Cracks in the pockets propagated rapidly to the base of the pocket approximately 10.4 mm from the blade root flange. Thus, Table 6 indicates 10 mm cracks were present in the wheels after 8-75 cycles. No apparent significance of manufacture or casting technique was detected, although wheels P3 and P4 tended to develop fewer, though longer, cracks early in the cycling program at 3-5 blade intervals. Wheels P1, P2, P5, and P6, however, tended to develop a more random cracking pattern.

Tables 27-32 contain crack initiation and propagation data for pocketed wheels P1 through P6. Pockets on the disk and shaft sides of the wheel were offset about 1/2 blade space in order to locate them between the blades at the leading and trailing edges. On the shaft side, the pockets were nearly a vertical projection, whereas on the disk side they had an angular projection to coincide with the bottom of the pocket formed by the shaft side projection. This configuration sometimes resulted in cracks originating at either the trailing or leading edge and progressing slowly across the wheel blade root flange. These conditions are identified in Tables 27 to 32.

Crack propagation data in Tables 31 and 32 indicate that the holes drilled in the pockets of wheels P5 and P6 (blade pockets located at 1-2 thru 26-27) did not effectively arrest thermal fatigue cracks. In fact, the longest cracks in these wheels were measured for the pockets with the holes. On examination of Tables 31 and 32, the distance from the blade root flange to the holes was about 8.4 mm, as compared to 10.4 mm to the base of the pockets. Cracks in pockets with holes were arrested temporarily at 8.1-8.4 mm, but eventually reinitiated on the other side of the hole. They then progressed out of the pocket, toward the hub, at generally a faster rate than for pockets without holes. Thus, overall, the presence of holes in the pockets increased crack propagation rates.

Figure 14 illustrates typical thermal fatigue crack initiation in pocketed wheels. Figures 14a and b, respectively, show a crack extending to the base of the pocket, and the typical crack pattern between blades.

Figures 15 to 19 compare the disk sides of pocketed wheels P1 through P6 after 5000, 8000, and/or 10,000 accumulated thermal cycles. The appearance of wheels P1 and P3 at 5000 and 10,000 cycles is shown in Figs. 15 and 17, respectively. Wheels P2 and P4 after 5000 and 8000 accumulated cycles are shown, respectively, in Figs. 16 and 18. The appearance of wheels P5 and P6 after 5000 thermal cycles is shown in Fig. 19. Comparison of these photographs with those of unpocketed wheels in Figs. 8 to 13 indicates considerably shorter wheel cracks in spite of greater total cycling for pocketed wheels. Spalling of oxidation products from pocketed wheel blades after 8000-10,000 cycles at 935°/50°C is apparent in Figs. 16 to 18.

3.2.2.2 Blade Cracks

A summary of blade crack initiation and propagation for pocketed wheels is presented in Table 17. Data for individual wheels P1-P6 are detailed in Tables 33 to 35. Blade cracking for pocketed wheels was delayed considerably, compared to unpocketed wheels, but when detected they also appeared at the trailing edge radius. Blade cracks for pocketed wheels were detected at 2250-5250 accumulated thermal cycles compared to 250-600 cycles for unpocketed wheels. Accordingly, the pockets apparently changed the stress state at the trailing edge of the blades to effectively retard blade cracking. This resulted in both fewer cracked blades, 6-12 per wheel, and shorter crack lengths of 0.3-1.0 mm for the total cycles accumulated. Since the pocketed wheels were cycled for greater accumulated cycles, the reduction in blade cracks for these wheels was significant.

4. SUMMARY OF RESULTS

Sixteen integrally cast automotive turbine wheels were thermally cycled at 935°/50°C in a fluidized bed facility for 1000 to 10,000 accumulated cycles. Six of the wheels contained cast pockets inside the blade root flange to act as thermal fatigue crack arrestors. Thermal fatigue crack initiation and propagation were measured for the 16 wheels in both the wheels and blades as a function of accumulated cycles. During thermal cycling, the spaces between the wheels was filled with insulating material to provide radial heat transfer from the blades.

Prior to conducting thermal fatigue tests, two calibration experiments were conducted using 30 chromel-alumel thermocouples to measure temperature transients. Sixteen of the thermocouples were installed on blades, and 14 on the wheel area of integral wheels. The thermal cycle for the first calibration was 950°/50°C (hot and cold bed temperatures)--480 sec symmetrical total cycle (240 sec heating and 240 sec cooling). The second test was conducted at 935°/50°C-600 sec total cycle. Based on these tests, the 935°/50°C-600 sec total cycle was selected to obtain the desired metal temperatures about 915°/65°C. Subsequently, a third calibration test was conducted on a gatorized wheel using 18 thermocouples. In all calibration tests, out-of-phase thermal transients were measured for internal areas of the wheels.

The results of thermal fatigue testing in this program indicate the following conclusions:

1. Wheel cracks were generated in unpocketed wheels after 75-250 cycles at 935°/50°C. Thermal fatigue cracking of the wheels tends to occur progressively, first by initiation and propagation of two to four large cracks, followed later by generation of cracks between each blade. No apparent effect of manufacturing technique was detectable for unpocketed IN-792 + 1% Hf turbine wheels based on thermal fatigue data. Gatorized wheels, fabricated from AF2-1DA alloy, generally exhibited more rapid crack propagation than IN-792 + 1% Hf, but these wheels also had a thinner hub section in the wheel design. In two unpocketed wheels, a single 45 mm long crack extending to the hub was obtained in 1000-2000 cycles.

2. Blade cracks were detected at the trailing edge in unpocketed wheels after 250-600 thermal cycles. Cracks in blades tended to be generated after initial cracks had propagated significantly toward the hub. This apparently modified the stress state at the trailing edge root, resulting in blade cracking. Propagation of blade cracks was relatively slow and did not exceed 1.8 mm for the total of 1000-5000 accumulated cycles.

3. Pocketed wheels developed cracks extending into the pockets in 8-13 cycles at 935°/50°C with almost simultaneous extension to the base of the 10.4 mm pockets. Major cracking of pocketed wheels occurred at 3-5 blade intervals in the initial stages and, subsequently, initiated at all 53 blade intervals. The base of the pockets provided crack arrest for 700-1500 cycles before cracks progressed into the hub area. Maximum crack lengths for unpocketed wheels were considerably shorter, 16-19 mm, after 5000-10,000 cycles at 935°/50°C. No apparent effect of manufacturing technique on thermal cracking behavior was apparent for pocketed wheels.

4. Incorporation of 1.6 mm diameter crack arrest holes at the base of the pockets of two pocketed wheels, P5 and P6, resulted in an overall increase in crack propagation. Crack arrest in the holes was only temporary, followed by more rapid propagation than in pockets without holes.

5. Blade cracking in pocketed wheels was delayed until 2250 to 5250 accumulated cycles. Furthermore, unpocketed wheels developed fewer blade cracks, even with greater accumulated cycles than for unpocketed wheels.

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Table 1

IDENTIFICATION OF TURBINE WHEELS
FOR THERMAL FATIGUE TESTS

Test Wheel Identification	Manufacturer	Manufacturer Identification	Method of Manufacture
		Unpocketed Wheels	
U1	AiResearch	1921-1	Airefrac casting
U2	AiResearch	1921-2	Airefrac casting
U3[a]	AiResearch	1921-3	Airefrac casting
U4	Howmet	PA01-10EVY	Investment casting
U5	Howmet	PA04-10EVY	Investment casting
U6	Howmet	PA12-10EVY	Investment casting
U7	Howmet	PA14-10EVY	Investment casting
U8	Pratt & Whitney	PW1	Gatorizing
U9	Pratt & Whitney	PW2	Gatorizing
U10[a]	Pratt & Whitney	PW3	Gatorizing
U11	AiResearch	AH	Airefrac casting
U12	AiResearch	AR	Airefrac casting
		Pocketed Wheels	
P1	AiResearch	D530-5A	Airefrac casting
P2	AiResearch	D530-9A	Airefrac casting
P3	Howmet	B40-10EVY	Investment casting
P4	Howmet	AA63-10EVY	Investment casting
P5[b]	Howmet	AB15-10EVY	Investment casting
P6[b]	AiResearch	#19	Airefrac casting

[a]Used for temperature calibration.

[b]Included 1.6 mm holes at the base of 27 pockets.

Table 2

TEMPERATURE CALIBRATION DATA FOR AUTOMOTIVE TURBINE WHEEL U3 AT 950°/50°C - 480 SEC CYCLE

Time, min-sec		Temperature at Thermocouple Position, °C															
		Tip				2/3				1/3				Root			
min	sec	3	7	11	15	2	6	10	14	1	5	9	13	4	8	12	16
		Heating Bed															
	0	145	137	149	164	153	158	173	188	165	196	201	199	208	238	215	251
	3	489	430	454	506	420	420	517	489	326	447	326	390	328	345	314	351
	6	608	632	576	542	544	571	580	540	544	492	473	460	468	428	393	419
	9	657	667	628	599	599	613	625	580	594	521	529	506	515	494	441	464
	12	692	701	665	624	638	632	657	608	629	543	569	540	546	520	477	493
	15	717	724	694	645	671	653	684	625	658	558	601	582	576	549	510	511
	30	800	799	786	714	771	723	746	706	757	642	695	662	680	628	601	593
	45	844	846	832	752	821	766	782	745	811	685	749	706	744	674	661	653
1	0	867	869	857	779	847	795	808	772	841	719	782	744	782	709	706	697
	15	883	886	874	799	866	815	828	795	860	747	806	762	812	737	742	728
	30	896	900	888	816	880	831	843	811	876	775	824	781	833	760	767	753
	45	906	909	898	832	891	847	855	825	886	799	837	798	849	786	788	775
2	0	914	918	906	843	899	857	866	837	896	821	848	811	862	799	806	792
	15	921	924	914	853	906	868	876	849	903	834	856	824	870	815	819	806
	30	926	929	919	863	912	877	883	857	909	849	863	835	878	826	830	816
	45	932	934	924	871	917	886	891	866	914	859	870	846	884	833	839	828
3	0	936	937	928	879	921	896	896	873	918	871	878	855	890	848	848	839
	15	938	941	931	886	924	904	902	881	922	882	883	863	895	857	856	848
	30	940	942	934	891	927	911	907	886	924	891	888	872	900	864	863	854
	45	942	943	936	896	929	918	911	892	926	899	892	880	904	873	870	862
4	0	943	944	938	902	932	924	915	898	927	905	896	885	907	880	879	871
		Cooling Bed															
	0	902	910	900	870	897	897	890	867	903	880	875	853	889	862	851	850
	3	743	743	743	714	743	724	735	728	796	776	783	764	834	811	809	798
	6	567	603	585	580	603	627	643	653	703	704	714	700	763	759	763	768
	9	491	528	514	514	533	542	543	587	623	635	637	640	692	728	720	734
	12	427	468	448	483	468	468	492	549	553	571	551	583	620	700	683	718
	15	376	417	396	460	417	401	448	520	497	510	497	544	551	676	640	691
	30	289	311	306	372	323	316	380	428	364	406	417	449	432	574	511	569
	45	256	267	270	324	283	273	333	377	318	357	374	400	383	508	414	483
1	0	233	242	245	290	257	243	299	340	282	330	341	357	345	451	363	431
	15	214	223	225	266	236	225	274	308	258	301	314	330	318	419	328	393
	30	201	209	210	244	218	214	254	285	239	283	292	308	296	388	300	363
	45	189	197	198	227	206	205	238	268	225	272	275	288	279	366	278	341
2	0	181	188	188	215	196	200	226	253	213	260	261	271	267	348	260	328
	15	173	179	180	205	187	194	216	241	204	252	248	259	255	328	247	316
	30	166	171	173	198	180	190	207	231	197	243	238	249	245	312	237	306
	45	159	163	166	192	173	185	200	222	189	236	229	239	236	299	231	296
3	0	155	157	162	186	168	180	193	214	183	230	222	231	228	287	227	287
	15	151	151	157	181	164	175	188	208	179	222	214	224	220	275	222	278
	30	147	147	153	176	159	171	183	202	175	214	208	217	214	264	218	267
	45	145	143	151	171	157	164	179	198	171	207	204	210	209	254	215	259
4	0	144	141	149	167	154	159	176	193	169	200	202	203	205	247	212	248

Table 2 (cont.)

Time, min-sec	Wheel Temperature at Thermocouple Position, °C													
	Disk Side							Shaft Side						
	D1	D2	D3	D4	D5	D11	D13	S6	S7	S8	S9	S10	S12	S14
	Heating Bed													
0	250	280	418	466	480	413	423	260	395	445	526	538	380	390
3	324	299	415	463	476	411	416	321	393	442	521	535	375	385
6	378	321	413	459	472	409	412	375	390	440	517	531	372	382
9	421	348	413	456	463	407	409	419	391	438	515	528	370	383
12	460	371	415	452	455	405	409	453	392	435	512	525	370	384
15	489	390	415	449	453	408	409	472	393	437	509	523	375	386
30	574	465	432	443	450	425	419	534	432	440	497	515	392	424
45	628	530	453	443	450	459	449	577	476	465	485	496	434	472
1 0	665	583	502	447	450	505	484	611	519	490	483	488	493	519
15	692	622	545	456	452	542	529	641	557	515	482	487	538	560
30	718	657	576	468	453	570	554	665	590	538	483	487	569	599
45	740	685	603	483	465	596	581	689	618	560	487	490	603	625
2 0	752	706	628	499	480	618	607	709	632	583	490	494	629	650
15	763	722	649	515	496	640	626	728	664	600	499	499	653	672
30	769	736	668	534	513	657	645	744	681	616	509	509	673	690
45	784	746	680	549	531	672	662	763	699	631	525	518	690	697
3 0	795	758	697	564	549	686	678	776	712	645	532	529	707	716
15	803	765	709	580	565	702	692	786	725	658	545	542	721	726
30	811	774	719	594	580	716	702	796	741	671	558	556	734	736
45	818	781	730	609	595	727	713	805	748	683	571	567	748	747
4 0	823	787	741	625	609	739	725	813	763	693	586	578	761	758
	Cooling Bed													
0	819	789	743	629	613	741	727	815	763	695	592	584	761	759
3	818	788	748	633	616	744	732	813	763	696	599	592	763	764
6	811	784	751	636	619	744	735	810	760	696	602	596	763	767
9	789	775	751	639	623	741	736	788	758	696	607	601	762	766
12	759	765	749	640	625	738	736	755	755	695	611	605	761	762
15	731	758	744	641	628	735	735	725	746	693	617	607	758	753
30	648	674	718	651	630	702	716	632	706	680	628	618	731	719
45	574	613	690	651	633	670	697	563	667	668	638	628	687	683
1 0	508	555	652	641	635	639	662	505	630	647	641	636	648	643
15	457	521	621	629	633	605	634	456	595	629	645	642	608	608
30	419	478	591	617	625	575	604	417	563	610	645	645	576	578
45	388	450	565	601	614	545	579	388	538	592	637	640	550	551
2 0	366	422	542	589	601	523	557	360	516	574	632	635	524	527
15	348	399	523	575	588	505	538	342	499	552	621	625	503	508
30	328	377	504	560	575	484	521	327	483	535	612	618	483	488
45	312	359	488	544	560	470	504	315	466	519	601	608	466	472
3 0	299	346	473	529	545	455	491	305	451	504	589	599	450	455
15	287	326	457	513	528	444	474	295	438	489	577	585	436	438
30	274	311	444	498	515	434	458	286	424	474	564	573	421	423
45	264	297	432	484	502	426	442	275	412	460	553	560	407	408
4 0	254	284	421	479	487	415	427	266	401	447	541	549	393	394

Table 3

TEMPERATURE CALIBRATION DATA FOR AUTOMOTIVE TURBINE WHEEL U3 AT 935°/50°C - 600 SEC CYCLE

Time, min-sec		Blade Temperature at Thermocouple Position, °C: Tip				2/3				1/3				Root			
		3	7	11	15	2	6	10	14	1	5	9	13	4	8	12	16
									Heating Bed								
	0	70	72	84	80	95	90	98	98	129	121	123	117	141	176	184	180
	3	480	398	460	390	500	495	500	495	325	355	314	320	322	270	253	329
	6	622	639	589	610	595	607	577	577	495	495	485	450	455	389	360	409
	9	732	732	698	680	650	655	620	624	562	578	565	522	510	452	413	450
	12	784	776	740	729	685	694	669	666	603	618	606	575	547	487	448	485
	15	805	795	783	782	710	717	695	692	626	648	628	618	580	518	481	516
	30	858	848	836	839	790	798	788	775	720	731	706	718	678	626	589	602
	45	887	877	871	868	831	837	831	818	762	770	745	764	728	685	657	661
1	0	898	894	886	880	855	858	855	839	795	802	777	800	770	722	702	696
	15	904	900	894	889	867	873	867	855	814	824	799	822	796	751	730	726
	30	904	900	900	892	878	880	878	866	827	841	815	836	808	771	759	749
	45	905	901	904	896	884	888	884	876	843	853	827	849	820	790	777	771
2	0	906	901	906	898	888	892	888	881	854	859	836	859	829	802	790	788
	15	906	902	906	899	889	894	890	882	863	864	845	865	839	810	800	796
	30	907	902	907	900	890	894	890	883	872	869	849	870	845	820	808	805
	45	907	903	907	901	891	895	891	884	876	874	855	874	850	829	814	814
3	0	908	903	908	902	892	896	892	885	882	876	859	876	854	834	820	822
	15	909	904	909	904	894	897	894	886	886	877	863	877	857	839	829	828
	30	910	904	910	906	896	898	896	886	888	878	867	878	860	843	833	835
	45	911	905	911	907	897	899	897	887	890	879	870	879	863	847	840	841
4	0	912	906	912	908	898	900	898	887	892	880	872	880	867	850	841	843
	15	913	907	913	909	899	901	900	888	894	882	874	882	870	854	845	845
	30	914	908	914	910	900	902	901	890	896	884	876	884	873	858	849	847
	45	915	909	915	911	902	903	902	892	898	885	878	885	876	861	853	849
5	0	915	910	915	912	904	904	904	894	900	886	880	886	880	863	855	851
									Cooling Bed								
	0	876	874	876	874	896	890	896	890	882	884	879	880	869	853	845	843
	3	603	608	620	616	718	730	718	730	741	720	741	767	761	786	786	786
	6	427	430	430	450	427	450	425	450	559	522	554	556	604	673	651	665
	9	325	345	358	360	343	352	358	355	489	452	448	460	522	624	597	624
	12	277	305	310	312	309	313	305	304	440	415	406	403	479	579	567	593
	15	242	270	282	286	276	284	267	263	403	393	374	362	446	546	542	563
	30	149	162	180	194	189	200	181	178	317	313	279	272	364	444	456	450
	45	105	114	127	142	146	160	144	151	270	270	243	229	297	385	397	395
1	0	84	93	110	117	132	141	130	137	248	243	215	205	270	346	356	358
	15	82	87	100	107	126	127	126	127	227	221	198	188	249	313	325	321
	30	80	83	97	100	116	115	118	113	213	203	186	174	235	288	305	299
	45	78	79	95	98	110	108	112	108	198	191	174	166	221	270	288	276
2	0	77	76	94	96	108	104	110	103	188	179	168	158	207	253	272	258
	15	75	73	93	94	106	100	108	98	178	168	162	147	194	238	258	243
	30	73	70	92	93	104	95	105	93	170	159	156	143	182	227	246	231
	45	72	69	90	92	102	92	102	91	164	152	150	137	174	216	235	221
3	0	71	68	88	91	100	90	100	90	158	147	145	132	168	208	224	213
	15	70	67	86	90	99	89	99	89	153	142	141	127	163	200	215	205
	30	69	66	84	88	98	88	98	88	148	137	137	123	159	192	207	197
	45	68	65	82	86	96	86	96	87	143	133	133	120	154	186	201	190
4	0	67	64	80	84	95	84	95	86	138	129	128	117	149	180	195	183
	15	66	64	78	82	94	83	94	84	134	125	123	114	144	180	190	178
	30	65	63	76	81	93	82	93	82	130	121	121	112	139	174	186	176
	45	64	63	75	80	91	81	91	80	128	119	119	110	137	168	182	174
5	0	63	63	74	78	90	80	90	80	126	119	117	108	135	165	178	172

Table 3 (cont.)

Time, min-sec		Wheel Temperature at Thermocouple Position, °C													
		Disk Side							Shaft Side						
		D1	D2	D3	D4	D5	D11	D13	S6	S7	S8	S9	S10	S12	S14
		Heating Bed													
	0	215	233	375	443	457	372	372	215	329	400	493	500	346	344
	3	252	241	373	441	454	368	372	237	327	397	490	496	340	338
	6	290	254	371	439	451	364	371	264	327	395	487	493	334	333
	9	325	269	370	437	448	360	370	307	327	393	483	490	331	329
	12	358	289	368	435	444	356	372	346	329	391	480	487	329	329
	15	391	312	368	433	440	353	372	388	331	390	477	483	327	331
	30	485	393	376	425	434	364	376	489	364	389	464	473	347	354
	45	567	479	401	421	428	389	401	569	409	399	456	463	384	399
1	0	618	542	432	425	424	424	428	608	454	415	447	453	427	444
	15	655	589	464	436	432	462	458	657	499	444	444	443	467	485
	30	685	630	495	450	440	495	491	687	540	468	444	440	504	518
	45	710	657	526	469	452	526	518	714	570	493	450	448	538	554
2	0	730	685	546	490	471	554	546	732	589	516	458	456	568	577
	15	747	707	573	508	489	579	569	751	608	540	470	468	589	602
	30	759	722	593	526	505	599	589	763	628	559	483	481	609	622
	45	769	733	614	540	522	620	608	773	646	579	497	495	631	642
3	0	780	744	630	553	538	638	624	782	661	597	511	509	652	659
	15	790	753	646	571	556	653	640	792	677	614	527	523	668	675
	30	800	763	660	587	573	668	655	802	692	629	543	538	680	687
	45	804	770	673	601	589	682	667	807	702	642	558	553	693	699
4	0	810	775	685	615	603	695	679	812	712	657	575	568	704	710
	15	816	779	696	631	616	708	689	816	722	667	591	583	716	721
	30	820	783	705	644	628	720	700	822	732	677	607	598	728	733
	45	824	787	714	656	640	731	708	827	739	688	621	612	740	745
5	0	827	790	720	667	651	743	716	830	747	698	636	626	750	756
		Cooling Bed													
	0	828	791	723	672	653	745	718	833	749	700	638	628	755	759
	3	790	765	726	676	655	748	718	802	750	704	641	631	760	763
	6	749	741	728	679	659	750	720	768	751	706	644	633	763	767
	9	712	716	730	682	663	751	722	731	751	708	647	636	765	769
	12	679	701	732	685	665	751	722	696	747	710	649	640	767	767
	15	651	686	730	687	667	749	722	662	740	712	651	642	765	763
	30	552	606	712	698	675	734	704	550	700	706	662	655	740	734
	45	483	526	685	698	679	704	679	481	660	692	673	667	690	685
1	0	423	476	657	692	682	671	646	426	618	674	675	677	648	649
	15	389	443	626	675	672	640	622	385	585	649	673	677	612	614
	30	362	413	598	658	660	616	595	362	552	626	671	675	580	581
	45	340	389	573	640	646	591	571	338	524	604	665	670	552	554
2	0	321	370	550	623	632	567	546	313	499	583	655	660	526	529
	15	305	350	531	607	617	544	525	297	477	565	644	648	503	507
	30	290	333	513	590	602	526	507	282	460	546	632	636	481	485
	45	278	320	495	574	590	507	493	270	442	527	618	623	464	469
3	0	269	307	477	560	576	488	477	260	427	509	604	610	448	453
	15	260	295	460	545	561	471	460	251	412	493	591	598	433	438
	30	251	283	446	528	546	454	448	243	398	479	577	585	418	423
	45	242	272	432	513	532	440	434	235	386	464	562	571	406	409
4	0	235	263	419	499	518	426	419	229	374	452	548	557	394	395
	15	227	256	407	485	504	413	406	225	362	440	534	543	382	383
	30	223	250	395	472	490	401	395	219	352	428	521	529	370	370
	45	218	244	385	458	476	388	385	215	342	415	508	516	359	358
5	0	213	239	378	446	462	376	374	211	331	403	496	503	349	348

Table 4

TEMPERATURE CALIBRATION DATA FOR GATORIZED TURBINE WHEEL U10 AT 935°/50°C - 600 SEC CYCLE

Time, min-sec	Wheel Temperature at Thermocouple Position, °C														Blade Temp. at Thermocouple Position, °C			
	Disk Side							Shaft Side							Root			Tip
	D1	D2	D3	D4	D5	D11	D13	S6	S7	S8	S9	S10	S12	S14	R1	R2	R3	T1
								Heating Bed										
0	185	260	355	390	450	345	360	175	325	395	455	465	305	320	175	175	115	230
3	190	265	355	390	445	345	360	295	320	390	455	465	305	320	380	610	430	590
6	210	265	360	385	445	340	360	370	320	385	450	465	310	315	450	670	545	720
9	245	270	360	385	440	335	360	420	320	385	450	460	310	315	505	705	610	780
12	280	280	360	385	440	335	360	455	320	385	445	460	315	315	550	725	655	815
15	335	300	365	380	435	335	360	490	325	380	440	460	320	320	600	755	695	840
30	510	410	385	380	425	350	360	620	365	375	425	445	365	360	730	815	805	890
45	615	505	415	395	420	390	390	690	425	390	420	430	435	420	780	845	835	905
1 0	675	560	450	410	420	435	430	730	480	415	420	425	490	475	815	865	860	905
15	725	610	495	430	435	475	470	770	530	450	420	425	550	525	835	880	875	910
30	755	650	530	460	450	515	510	785	565	480	430	435	590	560	850	885	880	915
45	780	680	560	490	475	550	540	800	600	510	440	445	620	595	860	890	885	920
2 0	795	700	590	515	490	580	570	815	625	540	460	460	645	625	870	895	890	920
15	810	715	615	540	515	605	595	825	650	560	480	475	665	645	875	895	895	920
30	820	735	635	565	530	630	615	830	670	585	500	495	685	670	880	895	900	920
45	830	750	655	585	555	645	635	835	690	610	520	515	700	685	880	900	900	920
3 0	840	760	670	605	575	665	655	840	705	635	535	535	720	705	885	905	905	920
15	850	775	690	625	590	685	675	845	720	650	555	555	730	720	890	905	905	920
30	855	780	705	640	610	695	690	850	735	665	575	570	745	730	890	905	905	925
45	860	795	715	655	625	710	700	855	745	680	595	590	755	745	895	905	905	925
4 0	860	800	730	670	640	725	715	860	755	690	615	605	765	755	895	905	905	925
15	865	805	740	685	655	735	725	865	765	705	630	620	775	765	900	905	910	925
30	870	815	750	695	670	745	740	870	775	715	645	635	785	775	900	910	910	925
45	875	820	760	705	680	755	745	875	785	730	660	650	790	780	905	910	910	925
5 0	875	820	765	715	690	765	755	875	795	740	670	665	795	790	905	910	910	925
								Cooling Bed										
0	875	825	765	715	695	765	760	870	795	740	680	670	800	790	875	890	900	905
3	875	825	765	715	695	765	760	830	800	745	685	675	800	795	760	570	705	680
6	875	825	765	715	695	765	760	765	800	750	685	675	800	800	680	480	580	545
9	875	825	765	715	700	765	760	730	800	750	690	680	795	800	610	420	495	425
12	820	825	765	720	700	770	765	695	800	750	690	685	790	795	560	385	440	355
15	795	815	765	720	705	770	765	660	795	750	695	690	780	785	525	350	395	300
30	665	735	750	720	710	760	750	510	750	745	700	695	725	750	400	280	280	180
45	565	665	700	715	710	735	730	430	700	730	700	705	670	700	320	245	230	150
1 0	490	600	665	705	710	695	695	370	650	710	705	710	620	645	280	220	200	125
15	435	555	635	685	700	660	660	330	615	685	700	710	580	605	255	200	185	110
30	395	515	610	660	685	630	630	300	580	655	690	700	550	570	230	180	165	105
45	365	480	585	640	670	600	600	285	555	635	680	690	520	540	215	165	155	100
2 0	340	455	560	620	655	570	575	265	520	605	665	670	490	520	200	155	145	95
15	315	425	540	595	635	545	555	250	500	585	645	655	465	500	190	145	135	90
30	295	405	515	575	620	525	530	240	480	560	630	635	440	480	180	135	130	90
45	275	390	495	555	600	500	510	225	460	540	615	615	425	460	170	130	120	85
3 0	260	370	480	535	585	470	490	220	435	515	600	595	405	440	160	125	120	85
15	245	355	455	515	565	460	470	210	415	495	575	580	385	420	155	120	110	85
30	235	340	440	500	550	445	455	200	405	475	555	555	370	405	145	115	110	80
45	225	325	425	480	535	425	435	190	385	460	540	540	360	390	140	110	105	80
4 0	215	310	405	465	520	410	420	185	370	445	525	530	345	375	140	110	105	75
15	210	300	390	450	500	395	405	180	360	430	510	510	335	365	135	110	100	75
30	205	290	385	440	485	385	395	175	345	415	490	500	320	350	130	105	100	75
45	195	280	370	420	470	365	380	170	335	405	480	490	315	340	130	105	100	75
5 0	190	270	360	405	455	355	370	165	325	395	470	475	305	330	125	105	100	75

Table 5

SUMMARY OF ACCUMULATED THERMAL CYCLES FOR TURBINE WHEELS CYCLED AT 935°/50°C

Wheel Number	Wheel Type	Accumulated Thermal Cycles[a]
	Stack W1	
U1	Unpocketed	5000
U2	Unpocketed	5000
U4[b]	Unpocketed	1000
U5[b]	Unpocketed	1000
U6[b]	Unpocketed	4000
U7	Unpocketed	4000
	Stack W2	
P1	Pocketed	5000
P2	Pocketed	5025[c]
P3	Pocketed	5025[c]
P4	Pocketed	5000
	Stack W3	
U8	Unpocketed	2000
U9	Unpocketed	2000
U11	Unpocketed	5000
U12	Unpocketed	5000
P2[d]	Pocketed	3000[e]
P4[d]	Pocketed	3000[e]
	Stack W4	
P1	Pocketed	5000[f]
P3	Pocketed	5000[f]
P5	Pocketed	5000
P6	Pocketed	5000

[a]Accumulated thermal cycles in each stack.

[b]Replaced U4 and U5 with U6 and U7 at 1000 cycles.

[c]Includes 25 cycles during calibration tests.

[d]Replaced U8 and U9 with P2 and P4 at 2000 cycles.

[e]Total accumulated cycles 8025 for P2 and 8000 for P5.

[f]Total accumulated cycles 10,000 for P1 and 10,025 for P3.

Table 6

SUMMARY OF CRACK INITIATION AND PROPAGATION FOR WHEEL SECTION OF TURBINE WHEELS CYCLED AT 935°/50°C

Wheel No.	Accumulated Thermal Cycles	Accumulated Cycles to First Crack[a]		Accumulated Cycles to Given Crack Length[a]		Maximum Crack Length, mm	No. of Major Cracks		Total No. of Cracks
		Shaft	Disk	10 mm	20 mm		10 mm	20 mm	
				Unpocketed Wheels					
U1	5000	75	150	850	850	30.0	6	2	53
U2	5000	150	250	600	600	31.5	3	2	53
U4	1000	150	150	600	600	45.8	1	1	45
U5	1000	75	150	850	850	23.1	2	2	48
U6	4000	150	150	2250	2250	26.4	2	2	53
U7	4000	150	250	1750	1750	24.9	2	2	53
U8	2000	250	75	400	400	45.2	4	3	53
U9	2000	250	150	400	600	35.1	4	4	51
U11	5000	250	250	1250	1250	27.2	5	3	53
U12	5000	150	150	150	250	26.7	6	4	50
				Pocketed Wheels					
P1	10,000	-	13	75	>10,000	18.8	19	0	53
P2	8,025	-	8	38	>8,025	18.0	18	0	53
P3	10,025	-	8	8	>10,025	19.6	19	0	53
P4	8,000	-	13	13	>8,000	16.0	20	0	53
P5[b]	5,000	-	13	75	>5,000	18.4	15	0	53
P6[b]	5,000	-	13	38	>5,000	18.1	17	0	44

[a]Average of last inspection cycle without (or with less than 10 or 20 mm) crack and subsequent inspection with a 0.25 mm (or greater than 10 or 20 mm) crack.

[b]Included 1.6 mm holes at base of 27 pockets.

Table 7

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U1

Crack Location[a]	Crack Length at Given Cycle, mm														
	50	100	200	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1-2		-	-	1.0	3.1	3.1	4.3	4.6	4.8	4.8	4.8	4.8	4.8	4.8	4.8
2-3		-	-	-	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.0
3-4		-	-	-	-	-	-	.51	1.5	4.3	4.3	4.6	4.6	4.6	4.6
4-5		-	2.5	3.1	3.8	5.8	24.6	26.9	29.0	29.0	30.0	30.0	30.0	30.0	30.0
5-6	N	-	-	.76	.76	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
6-7		-	-	-	.76	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
7-8	o	-	-	-	-	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
8-9		-	-	.25	.25	.76	1.5	1.8	2.0	2.3	2.3	2.3	2.3	2.3	2.3
9-10	C	-	-	-	.51	.76	1.3	1.8	1.8	1.8	2.3	2.3	2.3	2.5	2.5
10-11		-	-	-	.51	.76	.76	1.3	1.8	2.0	2.0	2.0	3.3	4.3	4.3
11-12	r	-	-	-	-	.51	1.3	1.3	1.8	2.3	3.6	3.8	3.8	3.8	3.8
12-13	a	-	-	.25	.51	1.5	1.8	2.0	2.5	2.5	3.3	3.3	3.3	3.3	3.3
13-14		-	-	-	-	.76	2.3	2.5	2.5	3.0	3.6	3.8	3.8	4.1	4.1
14-15	c	-	-	-	-	1.0	1.0	1.0	2.0	2.0	3.3	3.3	3.3	3.3	3.3
15-16		-	-	-	-	1.0	1.0	1.3	1.5	2.8	3.3	3.3	3.3	3.3	5.3
16-17	k	-	-	-	.51	1.5	3.1	5.1	6.1	6.4	7.4	8.1	8.9	9.7	10.4
17-18	s	-	-	-	-	.25	.76	.76	.76	.76	.76	1.3	1.3	2.0	2.0
18-19		-	-	-	-	1.3	2.0	2.5	2.8	2.8	2.8	2.8	3.3	3.3	3.3
19-20		-	.51	.76	.76	.76	2.0	2.3	2.3	2.3	2.3	2.5	3.6	3.6	3.6
20-21		-	-	-	.51	.76	1.0	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.3
21-22		-	-	.76	1.0	1.0	1.3	3.8	6.6	6.9	6.9	6.9	7.1	7.1	7.1
22-23		-	-	-	-	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
23-24		-	-	-	.76	.76	.76	2.0	2.0	2.5	2.5	2.5	2.5	2.5	2.5
24-25		-	-	-	-	-	.76	1.8	1.8	2.3	3.6	3.6	3.6	3.6	4.1
25-26		-	-	2.5	4.1	5.6	6.6	7.1	17.3	17.5	22.1	23.1	24.4	24.4	24.9
26-27		-	-	-	.51	1.3	1.3	1.8	2.0	2.0	2.0	2.3	2.3	3.8	4.1
27-28		-	-	-	-	1.3	1.3	2.0	2.3	2.5	2.5	2.5	2.5	3.6	3.8
28-29		-	-	-	.76	1.3	2.0	3.1	3.3	3.6	4.1	4.1	4.1	4.1	4.1
29-30		-	-	-	-	1.0	1.3	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
30-31		-	-	-	-	.51	1.3	2.0	3.3	5.3	5.3	5.3	5.3	5.3	5.3
31-32	N	-	-	-	1.0	1.3	2.0	2.0	2.5	2.8	3.3	3.3	3.3	3.3	3.3
32-33		-	-	-	-	.76	1.3	1.5	5.1	6.4	6.6	8.9	10.2	12.4	13.5
33-34	o	-	-	.51	.51	.76	2.3	3.8	4.8	5.1	5.1	5.3	5.3	5.3	5.3
34-35		-	-	-	.76	.76	2.3	2.3	3.6	4.8	4.8	4.8	4.8	4.8	4.8
35-36		-	-	-	-	.51	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.3
36-37		-	-	-	1.3	1.8	2.5	2.8	2.8	3.1	3.1	3.1	3.1	3.1	3.1
37-38		-	-	-	-	-	-	-	.76	1.3	1.5	1.5	1.8	1.8	3.1
38-39		.76	.76	1.0	1.0	1.3	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.3
39-40	C	-	-	.76	1.0	2.8	4.1	6.4	8.9	10.4	12.2	13.0	15.2	16.5	16.5
40-41		-	-	-	-	-	-	1.5	1.8	1.8	1.8	1.8	1.8	1.8	1.8
41-42	r	-	-	-	-	.76	1.5	2.0	2.0	2.5	3.1	3.1	3.1	3.1	3.1
42-43	a	-	-	-	.51	.76	1.3	1.3	1.8	1.8	2.3	2.3	3.1	3.6	3.6
43-44		-	-	-	-	.76	.76	.76	2.0	2.0	2.5	2.5	2.5	2.5	4.1
44-45	c	-	-	-	-	.76	1.5	1.8	1.8	2.0	3.1	3.3	3.3	3.3	3.3
45-46		-	-	-	.51	.51	1.3	1.3	1.5	1.5	1.5	1.8	2.0	2.0	2.3
46-47	k	-	-	-	-	-	.76	.76	1.5	1.5	3.1	3.1	3.1	3.1	3.3
47-48	s	-	-	.51	.51	.51	.51	1.3	1.3	1.5	1.5	1.5	1.5	1.8	2.8
48-49		-	2.5	2.5	3.1	3.6	4.6	6.1	6.1	7.6	12.2	13.7	14.0	14.2	15.0
49-50		-	-	-	-	.76	1.0	1.0	1.3	1.5	1.5	1.5	1.8	1.8	1.8
50-51		-	-	.51	.51	.76	.76	.76	1.3	1.3	1.3	1.3	1.3	1.3	1.3
51-52		-	-	-	.76	1.3	1.3	1.3	1.3	1.3	1.3	1.8	1.8	2.0	2 0
52-53		-	-	1.3	1.3	3.1	3.3	3.3	3.8	3.8	3.8	4.1	4.1	4.1	4.1
53-1		-	-	-	-	.51	.51	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[a]Location with reference to blades numbered clockwise from the reference mark.

Table 8

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U2

Crack Location[a]	Crack Length at Given Cycle, mm 100	200	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1-2		.76	1.0	1.0	1.8	2.5	3.1	3.3	3.6	3.6	3.6	3.8	3.8	3.8
2-3		-	-	-	-	1.0	1.5	1.5	1.5	1.5	1.8	3.3	3.3	3.3
3-4	N	-	.76	.76	.76	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.8	3.1
4-5		-	-	-	-	2.0	3.1	3.3	4.3	5.1	5.3	5.3	5.3	5.6
5-6	o	-	-	-	-	.76	1.3	1.3	1.3	1.3	1.3	1.5	1.5	1.5
6-7		-	-	.51	.76	1.3	1.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8
7-8	C	-	-	-	1.0	2.3	2.8	3.3	3.8	4.3	4.3	4.8	4.8	4.8
8-9		-	-	-	.76	1.3	1.3	1.3	1.5	1.5	2.5	2.5	2.5	2.5
9-10	r	-	-	-	-	2.5	2.8	2.8	2.8	2.8	2.8	2.8	3.8	5.1
10-11		-	-	-	.76	1.0	1.0	1.0	1.0	1.3	1.3	1.5	1.8	2.3
11-12	a	-	.76	1.0	1.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
12-13	c	-	.51	.51	1.0	2.3	3.1	3.1	3.1	3.1	3.6	4.1	4.3	4.3
13-14		-	.25	.51	.76	1.3	1.3	1.3	1.5	1.5	1.8	1.8	1.8	1.8
14-15	k	.51	.76	1.5	2.5	4.1	9.4	20.6	22.6	24.4	24.4	24.4	25.6	25.6
15-16		-	-	-	-	.76	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
16-17	s	-	.51	.76	1.0	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
17-18		-	-	-	1.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
18-19		-	.25	.51	1.3	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
19-20		-	-	-	.51	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20-21		-	-	-	.76	2.3	2.8	3.3	3.3	3.3	4.1	4.1	4.1	4.1
21-22		-	-	-	-	.76	2.3	3.3	3.3	3.3	4.1	4.1	4.1	4.1
22-23		-	.76	.76	.76	1.8	2.8	2.8	2.8	2.8	3.3	4.3	5.3	8.4
23-24		-	-	.25	1.0	1.5	2.3	2.3	2.3	2.3	2.5	2.5	4.1	4.1
24-25		.51	.51	.51	.76	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.3
25-26		.25	.51	.51	.76	1.0	1.5	1.8	2.3	2.3	2.3	2.3	2.3	2.3
26-27		-	-	-	.51	1.3	1.3	1.5	1.5	1.5	1.8	1.8	1.8	1.8
27-28		-	-	-	-	-	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5
28-29		-	-	-	-	1.8	2.5	2.5	3.1	4.3	4.3	4.3	4.3	4.3
29-30		.25	.76	.76	1.0	1.0	1.3	1.5	2.0	2.0	2.0	2.0	2.0	2.0
30-31		-	-	-	-	-	2.0	2.0	3.1	3.1	4.3	4.6	5.1	5.6
31-32		-	.25	.25	1.3	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0
32-33		-	-	-	-	-	.76	1.0	1.0	1.0	1.3	1.5	1.8	1.8
33-34	N	-	-	.25	.51	.76	.76	1.3	1.3	1.3	1.8	2.0	2.5	2.5
34-35		-	-	-	-	1.3	2.0	2.3	2.3	2.3	2.3	2.3	2.5	2.5
35-36	o	-	-	-	-	-	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
36-37		-	-	-	-	.25	1.3	1.3	1.3	1.3	1.8	2.0	2.0	2.0
37-38		-	-	-	-	-	-	.25	.25	.25	1.0	1.3	1.3	1.3
38-39		-	-	3.8	20.8	29.5	30.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5
39-40	C	-	-	-	-	.76	.76	.76	1.0	1.0	1.0	1.5	1.5	1.5
40-41	r	-	-	.25	.25	.25	.25	.25	.25	.25	1.3	1.3	1.3	1.3
41-42		-	-	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
42-43	a	-	-	-	-	-	2.0	2.0	2.0	2.0	2.0	2.0	2.3	2.3
43-44		-	-	-	-	.51	.76	1.0	1.0	1.0	1.0	1.0	1.0	1.5
44-45	c	-	-	-	-	.76	.76	.76	1.3	1.3	1.3	1.3	1.3	1.3
45-46		-	-	-	-	-	1.3	1.3	1.3	1.3	2.3	2.3	2.3	2.8
46-47	k	-	-	-	.76	1.3	1.5	1.8	1.8	1.8	2.0	2.0	2.0	2.0
47-48		-	-	.25	.76	1.3	2.0	2.3	2.8	2.8	3.8	4.6	4.8	5.1
48-49	s	-	-	-	-	1.0	1.3	1.3	1.3	1.3	1.5	3.1	3.1	3.3
49-50		-	-	-	-	.51	1.0	1.0	1.3	1.3	1.3	1.8	1.8	3.3
50-51		-	-	-	1.0	1.3	1.8	1.8	1.8	1.8	2.0	2.0	2.0	2.0
51-52		-	-	.76	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
52-53		-	-	1.0	1.5	2.3	5.3	6.4	8.4	8.4	12.7	12.7	14.5	15.8
53-1		-	-	.25	1.5	1.5	1.5	1.5	1.8	1.8	1.8	1.8	1.8	1.8

[a]Location with reference to blades numbered clockwise from the reference mark.

Table 9

CRACK INITIATION AND PROPAGATION
FOR UNPOCKETED WHEEL U4

Crack Location[a]	Crack Length at Given Cycle, mm					
	100	200	300	500	700	1000
1-2		.51	1.0	2.3	24.4	36.3
2-3		-	-	.25	.51	.76
3-4		-	-	.51	1.0	1.0
4-5	No Cracks	.25	.25	.51	1.0	1.0
5-6		.25	.25	.76	1.3	1.3
7-8		1.0	1.0	1.5	1.5	1.8
8-9		-	-	1.3	1.3	1.5
9-10		-	-	-	.76	.76
10-11		2.5	2.5	3.1	3.3	3.6
11-12		.51	.76	1.0	1.3	1.5
12-13		-	-	-	.25	1.3
13-14		-	-	-	1.8	2.8
14-15		.25	.76	1.0	1.5	2.5
17-18		-	.25	.51	1.0	1.5
18-19		-	-	-	.76	.76
19-20		-	-	-	.51	1.3
20-21		-	-	-	-	1.0
21-22		-	-	.25	1.0	1.8
22-23		.51	.51	1.0	1.8	3.1
23-24		.25	.25	.76	1.5	1.5
25-26		.25	.51	1.0	2.0	3.3
26-27		-	-	-	-	.51
27-28		-	-	.51	.51	2.0
28-29		.51	.51	1.0	2.0	3.8
30-31		-	-	2.5	3.6	8.1
31-32		-	-	.51	1.3	2.5
32-33	No Cracks	-	-	.51	.51	2.5
33-34		-	.51	1.0	1.5	1.8
34-35		-	-	-	1.8	2.5
35-36		-	-	2.5	3.1	4.3
36-37		-	-	.51	1.0	1.0
37-38		-	-	-	.51	.51
38-39		-	-	1.0	1.8	4.6
39-40		-	-	-	.76	1.3
40-41		-	.25	.76	2.3	2.5
41-42		-	.25	.76	2.5	3.3
42-43		-	-	.25	.76	1.0
44-45		-	-	.51	1.0	1.8
46-47		-	-	.76	.76	3.1
47-48		-	.25	.51	.76	1.0
48-49		-	-	.25	.25	.51
49-50		-	-	-	.25	.25
50-51		-	.25	.76	.76	.51
51-52		.51	.51	.76	1.5	1.8
53-1		-	-	.51	.76	.25

[a]Location with reference to blades numbered clockwise from the reference mark.

Table 10

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U5

Crack Location[a]	Crack Length at Given Cycle, mm						
	50	100	200	300	500	700	1000
1-2	N	-	-	.25	.51	1.8	2.3
2-3		-	-	-	.51	1.0	1.0
3-4		-	-	.51	.76	1.0	2.3
4-5		-	-	-	.51	.76	2.0
5-6	o.	-	-	-	2.3	3.1	3.3
6-7		-	-	-	.51	1.5	1.5
8-9		.76	.76	.76	1.5	2.3	3.3
9-10		-	-	-	.51	.76	1.5
10-11		-	-	-	.76	1.5	2.0
11-12	C	-	-	-	1.5	2.8	3.1
12-13		-	-	-	1.3	2.0	2.3
13-14		-	-	-	.76	1.0	1.3
14-15	r	-	-	-	1.0	4.3	5.1
15-16		-	-	-	-	.25	.51
16-17		-	.51	.51	3.0	4.3	23.1
19-20	a	-	-	-	-	1.3	1.3
20-21		-	-	-	-	.76	1.0
21-22		-	-	-	-	1.3	2.5
22-23		-	-	-	-	1.0	1.0
23-24	c	-	-	-	-	.25	6.4
24-25		-	-	.25	.76	1.8	2.8
25-26		-	-	-	1.0	1.5	1.5
26-27	k	-	-	-	.25	.76	1.5
27-28		-	-	.25	1.0	1.8	3.1
28-29		-	-	-	1.0	1.3	1.8
29-30		-	-	.76	1.8	3.1	4.3
	s						
31-32		-	-	-	.76	1.8	2.8
32-33		-	-	-	-	.51	.76
33-34		-	-	-	1.0	1.0	1.5
34-35		-	-	1.0	1.5	3.8	4.1
36-37		-	-	-	-	.76	1.8
37-38		-	-	-	.51	1.5	3.1
39-40		-	-	-	.51	1.8	2.5
40-41		-	-	-	.25	1.0	1.0
41-42		-	-	-	.25	1.3	1.3
42-43		-	-	-	.51	1.8	2.3
43-44		-	-	-	.25	.76	1.3
44-45		-	-	-	.25	.76	1.0
45-46		-	.51	.76	.76	1.3	1.5
46-47		-	-	-	.76	1.8	2.0
47-48		-	-	-	.51	.51	1.3
48-49		-	-	-	.51	1.0	1.8
50-51		-	-	-	.51	.76	.76
51-52		-	.25	1.0	1.8	3.8	22.9
52-53		-	.25	.51	1.8	2.0	2.3
53-1		-	-	-	-	1.3	1.8

[a]Location with reference to blades numbered clockwise from the reference mark.

Table 11

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U6

Crack Location[a]	Crack Length at Given Cycle, mm											
	100	200	300	500	700	1000	1500	2000	2500	3000	3500	4000
1-2		-	.25	.76	1.0	1.3	1.8	2.0	2.5	4.1	4.3	5.3
2-3		-	-	-	.76	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3-4		-	-	-	.76	.76	1.0	1.0	1.0	1.0	1.0	1.0
4-5		-	-	-	.25	.51	1.8	2.5	3.8	3.8	3.8	5.1
5-6	No Cracks	-	-	-	-	1.3	1.3	1.3	1.3	2.3	3.1	3.8
6-7		-	-	-	1.0	1.0	1.8	1.8	1.8	2.3	2.3	2.8
7-8		-	-	-	.25	.25	.51	.76	1.3	1.3	1.3	1.3
8-9		-	-	-	-	-	.51	.51	1.0	1.0	1.0	3.1
9-10		-	-	-	.25	.25	1.0	1.3	1.3	1.3	1.3	1.3
10-11		-	-	-	.25	.76	1.3	1.8	2.0	2.3	2.5	3.3
11-12		-	.76	.76	.76	1.0	2.3	3.3	4.8	5.6	6.1	7.1
12-13		-	-	-	.51	.76	.76	.76	.76	.76	.76	.76
13-14		-	-	-	.76	1.0	2.5	2.8	3.1	3.3	3.3	3.3
14-15		-	-	-	.76	1.3	2.3	3.3	4.6	4.8	5.3	5.6
15-16		-	-	-	.51	.76	1.0	1.3	1.3	1.3	1.3	1.3
16-17		-	-	-	.25	.76	1.5	2.0	3.6	3.8	3.8	4.1
17-18		-	-	-	-	.25	.25	.25	.76	.76	.76	2.3
18-19		-	-	.51	.76	1.0	1.5	3.1	4.3	5.6	5.6	5.8
19-20		-	-	-	.51	.51	.76	1.0	2.0	2.3	2.3	2.3
20-21		-	-	-	-	-	-	1.0	1.3	1.3	1.3	1.3
21-22		-	-	-	-	.51	1.5	2.5	4.1	5.1	5.1	5.1
22-23		-	-	-	.51	.51	.76	1.3	1.3	1.3	18.0	20.4
23-24		-	-	-	.25	.76	1.0	1.5	1.5	2.0	2.0	2.0
24-25		-	.51	.51	.76	2.0	3.1	3.3	3.6	4.1	4.1	4.1
25-26		-	-	-	2.3	3.1	3.6	4.3	4.6	5.1	5.3	5.3
26-27		-	-	-	-	-	.51	.51	.51	.51	.51	.51
27-28		.51	.51	.51	1.0	1.8	1.8	2.3	2.3	2.8	2.8	2.8
28-29		-	.25	.25	.76	.76	.76	.76	.76	.76	.76	.76
29-30		1.0	1.0	1.0	1.3	2.3	4.6	6.4	6.6	7.6	7.6	8.4
30-31		-	.25	.51	.51	.51	.51	.76	.76	.76	.76	.76
31-32		-	.51	.76	.76	.76	2.0	2.0	3.1	4.1	4.3	4.3
32-33		-	-	-	-	1.0	1.5	1.8	2.0	2.5	2.5	2.5
33-34	No Cracks	-	-	-	-	.25	.25	.76	1.3	1.3	1.3	2.3
34-35		-	.25	.25	.51	.76	.76	1.3	1.3	1.3	1.5	1.5
35-36		-	.25	.25	.76	1.0	1.8	2.5	2.5	2.5	2.5	2.5
36-37		-	.76	.76	.76	1.0	1.8	2.5	2.8	2.8	2.8	3.1
37-38		-	-	-	1.0	1.0	2.3	2.8	2.8	2.8	2.8	2.8
38-39		-	-	-	-	-	-	-	-	.76	.76	.76
39-40		-	-	-	-	1.0	1.8	2.3	2.3	2.3	2.5	2.5
40-41		-	-	-	-	-	.25	.25	.25	.51	.51	.76
41-42		-	-	-	-	-	1.0	1.0	1.0	1.0	1.0	1.0
42-43		-	-	-	.76	1.0	1.0	1.0	26.4	26.4	26.4	26.4
43-44		-	-	-	-	.51	1.3	1.3	1.3	1.3	1.3	1.5
44-45		-	-	-	-	.51	1.0	1.0	1.0	1.0	1.0	1.0
45-46		-	-	-	.76	2.3	2.3	2.3	2.5	2.5	2.5	2.5
46-47		-	-	-	.25	.76	1.0	1.5	1.5	1.5	1.5	1.5
47-48		-	-	-	-	-	-	1.3	1.3	1.8	2.0	2.0
48-49		-	-	-	-	-	-	-	1.0	1.0	1.0	1.3
49-50		-	-	-	-	1.5	2.5	4.6	4.8	5.3	5.3	5.3
50-51		-	-	-	-	-	.76	.76	.76	.76	.76	.76
51-52		-	-	-	-	-	1.0	1.3	1.3	1.8	2.5	2.5
52-53		-	-	-	-	-	1.8	1.8	1.8	1.8	2.5	3.6
53-1		-	-	-	-	-	-	-	1.3	1.8	2.0	2.8

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 12

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U7

Crack Location[a]	Crack Length at Given Cycle, mm											
	100	200	300	500	700	1000	1500	2000	2500	3000	3500	4000
1-2		-	-	-	-	.25	1.5	1.8	1.8	1.8	2.3	2.8
2-3		-	.51	.51	.51	.76	1.5	1.5	2.8	2.8	2.8	2.8
3-4		-	-	.51	.76	1.0	2.8	6.1	22.4	22.6	24.9	24.9
4-5		-	-	-	-	.76	.76	1.3	1.3	1.5	1.5	1.8
5-6	N	-	-	.76	1.3	1.3	2.3	2.8	2.8	3.1	3.1	3.1
6-7		-	-	-	1.8	1.8	2.3	3.1	3.1	3.1	3.1	3.3
7-8	o	-	-	-	-	.51	.76	1.0	1.3	1.3	1.5	1.8
8-9		-	-	.51	.76	1.5	2.0	3.1	3.6	3.6	3.8	4.1
9-10		-	-	-	-	-	-	-	1.0	1.0	1.5	1.5
10-11		-	-	-	-	-	-	-	-	-	.76	1.0
11-12	C	-	-	-	-	-	-	.25	2.5	2.5	2.5	2.5
12-13		-	-	-	.25	1.3	2.3	2.8	3.8	4.6	4.6	5.3
13-14		-	.25	.25	.25	.25	.25	.25	1.3	1.3	1.8	2.8
14-15		-	-	-	1.8	1.8	2.3	2.3	2.5	2.5	3.1	3.1
15-16	r	-	-	-	-	-	.25	1.3	1.3	1.3	1.3	1.5
16-17		-	-	-	-	-	.25	.25	.76	.76	.76	1.0
17-18	a	-	-	-	-	-	-	-	.25	.25	.51	.51
18-19		-	-	-	-	.51	1.0	1.3	1.5	1.8	2.3	2.5
19-20		-	-	-	.51	.51	.76	.76	1.0	1.0	1.3	1.3
20-21	c	-	-	-	.25	.25	1.3	1.8	2.5	2.5	3.6	4.3
21-22		-	-	-	-	-	-	-	-	-	-	.25
22-23	k	-	1.5	1.8	1.8	1.8	3.1	3.6	4.1	4.8	5.6	6.4
23-24		-	-	-	-	-	-	-	-	-	1.5	1.5
24-25		-	-	-	.25	.25	.25	.51	.51	.51	.51	.51
25-26	s	-	-	-	.25	.51	1.8	3.1	3.6	4.8	4.8	4.8
26-27		2.0	2.0	2.3	2.5	2.5	2.8	3.6	3.6	3.6	3.6	3.6
27-28		-	-	-	-	-	.51	.51	.51	.51	.76	2.8
28-29		-	-	-	-	-	.76	1.5	1.5	1.5	1.5	1.5
29-30		-	-	-	1.0	1.5	3.1	3.1	3.1	3.1	3.1	3.3
30-31		-	-	-	.76	1.0	2.3	3.8	3.8	3.8	3.8	3.8
31-32		-	-	-	-	-	-	-	-	.25	.25	.25
32-33	N	-	-	-	-	-	-	-	-	.51	.51	.51
33-34		-	-	-	.76	1.3	3.3	24.6	25.4	25.4	25.4	25.4
34-35		-	-	-	.51	.76	1.5	1.5	1.5	1.8	1.8	1.8
35-36	o	-	-	-	.25	.25	.51	.76	.76	1.0	1.0	1.0
36-37		-	-	-	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0
37-38		-	-	.76	1.5	2.3	6.1	7.1	7.1	7.4	7.4	7.4
38-39		-	-	-	-	-	-	-	-	.25	.51	.51
39-40	C	-	-	-	1.0	1.0	1.3	2.3	2.3	3.6	3.6	3.6
40-41		-	-	-	-	-	.51	.51	.51	1.0	1.3	1.3
41-42	r	.51	.51	.76	1.0	1.5	3.8	4.3	4.8	4.8	4.8	5.1
42-43		-	-	-	.76	.76	1.0	1.0	1.3	1.3	1.3	1.3
43-44		.51	.51	.51	1.0	1.0	1.0	1.3	1.3	1.8	4.8	4.8
44-45	a	-	-	-	-	-	.51	.51	.76	.76	.76	.76
45-46		-	-	-	1.8	2.3	3.8	4.1	4.3	5.1	5.1	5.1
46-47		-	-	-	.76	.76	1.0	1.3	1.5	1.5	1.5	2.0
47-48	c	.25	.25	.51	1.3	1.8	3.6	4.6	5.1	5.3	6.1	6.9
48-49		-	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.5
49-50	k	-	-	-	.76	.76	1.8	1.8	1.8	2.0	2.0	2.3
50-51		-	-	-	.51	.51	1.3	1.3	1.3	1.3	3.1	3.1
51-52		-	-	-	-	-	-	-	.25	.25	.51	2.5
52-53	s	-	-	-	-	-	.51	.76	1.0	1.0	1.3	2.5
53-1		-	-	-	-	-	.76	1.8	1.8	1.8	1.8	1.8

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 13

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U8

Crack Location[a]	Crack Length at Given Cycles, mm								
	50	100	200	300	500	700	1000	1500	2000
1-2		-	-	.25	.25	.51	.51	.51	.76
2-3		-	-	.25	1.0	1.5	2.0	2.3	2.5
3-4		-	-	.25	.25	.25	.51	.51	.51
4-5	N	-	-	.25	.51	1.5	1.5	19.1	21.1
5-6		-	-	.25	.76	1.5	2.0	2.5	2.5
6-7	o	-	-	.51	.51	.76	1.0	1.0	1.0
7-8		-	.51	.51	1.3	1.3	1.3	1.8	1.8
8-9		-	-	-	.51	.76	.76	.76	.76
9-10	C	.25	.51	.76	1.0	1.0	2.0	2.8	3.1
10-11		-	-	.25	.25	.25	1.0	1.0	1.0
11-12	r	-	-	-	.25	.76	1.0	1.3	1.5
12-13		-	-	.25	.76	.76	1.0	1.3	1.3
13-14	a	-	.25	.51	1.3	1.3	1.8	2.3	3.3
14-15		-	-	.25	.51	.51	.51	.76	.76
15-16	c	.25	.25	.51	.51	.51	.51	.76	2.3
16-17	k	.25	.25	.25	.76	.76	1.0	1.0	1.0
17-18		.51	.51	.51	1.0	1.0	1.3	1.3	1.3
18-19	s	-	-	.25	.25	.25	.51	.51	.51
19-20		.25	.25	.25	.76	.76	.76	.76	.76
20-21		-	-	-	-	-	1.0	1.0	1.0
21-22		-	.25	.25	.76	.76	.76	.76	.76
22-23		-	-	.25	21.8	37.3	45.2	45.2	45.2
23-24		-	-	-	-	1.3	1.3	1.3	1.3
24-25		-	-	-	-	.76	.76	.76	.76
25-26		-	-	-	.51	.51	.51	.76	.76
26-27		-	-	-	.76	.76	.76	.76	.76
27-28		-	-	-	.25	.25	.51	.51	.51
28-29		-	-	-	.76	1.0	1.0	1.0	1.0
29-30		-	-	-	.51	.51	.76	.76	1.0
30-31		-	-	.51	.76	.76	1.3	1.3	1.5
31-32		-	.25	.25	.51	.51	.76	1.0	1.0
32-33		-	-	-	.51	.51	.51	.76	.76
33-34		-	-	.25	1.0	1.3	1.8	3.8	13.7
34-35		-	.25	.25	.51	.76	.76	.76	.76
35-36		-	-	.25	.51	.76	1.3	1.3	1.3
36-37	N	-	-	.25	.25	.51	.51	.51	.51
37-38		-	-	-	.25	.51	.76	1.3	1.5
38-39	o	-	-	.25	1.0	1.5	2.0	3.8	4.1
39-40		-	-	.25	.51	.76	1.0	1.3	1.3
40-41		-	-	.25	.76	1.0	1.8	3.3	3.8
41-42	C	-	-	.25	.76	1.0	1.3	1.5	1.8
42-43		-	-	-	.51	.51	.76	.76	.76
43-44	r	-	.25	.25	1.0	1.0	1.0	1.5	1.5
44-45		-	-	.25	1.0	1.5	2.3	4.1	4.3
45-46	a	.25	.51	.51	.76	.76	.76	16.7	20.8
46-47		-	.25	.25	.51	.51	.51	.51	.51
47-48	c	-	.25	.25	.76	.76	.76	.76	.76
48-49		-	.25	.25	.51	1.0	1.8	1.8	2.3
49-50	k	-	.25	.51	.76	.76	.76	1.5	1.5
50-51		-	.25	.51	.76	1.0	1.5	1.5	1.5
51-52	s	-	-	-	.51	.51	.51	.51	.51
52-53		-	.51	.76	1.5	2.3	3.8	7.3	8.9
53-1		-	-	-	.51	.51	.51	.51	.51

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 14

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U9

Crack Location[a]	Crack Length at Given Cycle, mm 100	200	300	500	700	1000	1500	2000
1-2	No Cracks	-	-	-	1.0	18.0	21.3	22.9
2-3		.25	.25	.25	1.8	2.8	2.8	3.3
3-4		.25	.25	.25	.25	.25	.25	.25
4-5		.25	.25	1.0	1.3	1.5	1.8	2.0
5-6		.25	.25	1.3	1.5	2.0	2.3	2.8
6-7		-	.25	.76	.76	1.0	1.0	1.3
7-8		.25	.51	1.0	1.3	1.5	1.5	1.8
8-9		-	.51	1.5	2.0	2.5	3.6	3.6
9-10		-	-	.76	1.0	1.3	1.5	1.5
10-11		-	.25	.76	.76	.76	.76	1.0
11-12		-	.51	1.8	1.8	1.8	2.0	2.3
12-13		-	-	-	-	-	-	-
13-14		.25	.25	1.0	1.0	1.0	1.0	1.0
14-15		-	.25	.25	.25	.25	.25	.25
15-16		-	.25	.51	.51	.51	.76	.76
16-17		-	1.0	17.3	33.8	33.8	35.1	35.1
17-18		.25	.25	.25	.51	.76	.76	.76
18-19		-	-	-	-	-	-	-
19-20		-	-	-	-	-	-	-
20-21		-	-	1.3	1.8	2.0	2.0	2.3
21-22		-	-	1.0	1.0	1.3	1.3	1.5
22-23		-	-	1.3	1.3	1.8	2.3	2.5
23-24		.25	.25	1.0	1.0	1.0	1.3	1.5
24-25		.25	.25	.76	1.0	1.0	1.5	2.0
25-26		-	-	-	.76	1.0	1.0	1.5
26-27		.25	.51	.51	1.8	1.8	2.3	3.8
27-28		-	-	.25	.25	.51	.76	1.3
28-29		-	.51	1.0	1.5	1.8	2.0	2.8
29-30		.25	.51	.51	.76	.76	.76	.76
30-31		.25	.51	1.0	1.3	1.5	1.5	1.8
31-32		-	-	.76	1.0	1.0	1.0	1.0
32-33		-	.25	.51	.51	.76	.76	1.0
33-34		.25	.25	.51	.51	.51	.51	.51
34-35		.51	.76	3.6	22.9	24.1	24.1	24.1
35-36		.25	.25	.51	.51	.51	.51	.76
36-37	No Cracks	.25	.25	.25	.25	.76	.76	.76
37-38		.25	.25	.51	.51	.76	.76	.76
38-39		.25	.25	1.3	1.8	1.8	2.0	2.0
39-40		.25	.76	1.0	1.3	1.3	1.5	1.5
40-41		.25	.51	.76	.76	1.0	1.0	1.0
41-42		.51	1.0	1.5	2.0	2.3	2.3	2.3
42-43		-	.51	1.0	1.3	14.0	20.8	23.1
43-44		.25	.25	.25	.25	.51	.51	.51
44-45		-	.51	1.0	1.5	2.0	2.0	2.0
45-46		.25	.76	1.3	1.5	2.0	2.0	2.0
46-47		.51	.51	.76	1.3	1.3	1.3	1.3
47-48		.25	.51	.51	1.5	2.0	2.5	3.6
48-49		.25	.51	.51	1.5	2.0	2.3	2.5
49-50		-	.25	.25	1.0	1.3	1.3	1.5
50-51		.25	.51	.51	.76	1.0	1.0	1.0
51-52		-	-	-	.76	1.3	1.3	1.3
52-53		-	-	.51	.76	.76	.76	.76
53-1		-	-	.51	.76	.76	1.3	1.3

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 15

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U11

Crack Location[a]	Crack Length at Given Cycle, mm												
	200	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1-2		-	-	.25	.25	.25	1.0	1.3	1.3	1.3	1.3	1.5	1.5
2-3		-	-	-	-	.25	.25	.25	.25	.25	.51	1.0	1.0
3-4	N	-	-	-	-	.51	1.8	1.8	1.8	2.0	2.0	2.0	2.0
4-5		-	-	-	-	.25	.51	1.8	1.8	2.0	2.0	2.0	2.0
5-6		-	-	.76	1.0	1.0	1.0	1.0	1.3	1.3	1.3	1.3	1.3
6-7	o	-	-	-	-	20.3	24.1	24.1	24.1	25.4	26.4	26.4	26.4
7-8		-	-	-	-	.25	.25	.25	.25	.76	.76	.76	.76
8-9		-	-	.51	1.3	1.3	1.3	1.3	1.5	1.8	1.8	1.8	2.0
9-10		-	-	.76	1.3	2.8	2.8	3.1	3.1	3.1	3.1	3.1	3.1
10-11	C	-	-	-	-	-	-	-	.51	.76	.76	.76	.76
11-12		-	-	-	1.3	1.5	1.5	1.8	2.0	2.0	2.0	2.0	2.0
12-13	r	-	-	.51	.51	.51	1.0	1.0	1.0	1.0	1.0	1.5	2.0
13-14		-	-	-	-	-	.25	.25	.51	1.3	1.3	1.3	1.3
14-15		-	-	1.3	2.0	2.8	3.6	3.6	3.8	3.8	4.1	4.8	5.6
15-16	a	-	-	-	.25	.25	.25	1.5	1.5	1.5	1.5	1.8	1.8
16-17		.51	1.3	1.5	2.3	3.3	3.8	4.3	4.3	5.1	5.1	5.3	5.8
17-18		-	-	-	-	-	-	.76	.76	.76	.76	.76	.76
18-19	c	-	-	.51	.51	.51	.51	2.5	2.5	2.5	2.5	2.5	2.5
19-20		.25	.51	1.8	2.8	2.8	3.6	3.6	3.6	3.8	3.8	3.8	3.8
20-21		-	-	-	-	.76	.76	.76	1.3	1.3	1.3	1.3	1.8
21-22	k	-	-	-	-	.25	.25	.76	1.0	1.0	1.3	1.3	1.5
22-23		-	-	.51	.51	.51	1.0	16.8	17.8	20.8	21.6	23.1	23.9
23-24	s	-	-	1.5	1.5	2.0	2.8	2.8	2.8	2.8	2.8	3.1	3.1
24-25		-	-	.51	.76	1.0	1.5	1.8	2.0	2.0	2.0	2.0	2.0
25-26		-	.25	.25	.76	.76	2.5	2.8	2.8	3.1	3.1	3.3	3.3
26-27		-	-	-	-	-	-	.76	.76	.76	.76	2.0	2.0
27-28		-	.76	1.3	1.3	1.5	1.8	1.8	2.0	2.3	2.3	2.3	2.3
28-29		-	-	-	-	.51	.76	.76	.76	.76	.76	.76	.76
29-30		-	.51	1.0	2.0	2.3	2.8	3.1	3.1	3.1	3.1	3.1	3.3
30-31		-	-	-	.51	.51	.51	.51	.51	.51	.51	.51	1.0
31-32		-	-	-	2.8	3.8	4.6	5.8	6.9	7.4	8.4	10.2	13.0
32-33		-	-	-	-	-	-	-	.76	.76	.76	.76	.76
33-34		-	-	-	-	-	-	.51	.51	2.8	2.8	3.6	3.6
34-35		-	-	.76	2.3	2.3	2.8	2.8	2.8	2.8	2.8	3.1	3.1
35-36	N	-	-	.25	.25	.25	.25	.51	.51	.51	.51	.51	.51
36-37		-	-	-	.76	.76	.76	.76	.76	1.0	1.0	1.3	1.5
37-38	o	-	-	-	-	.25	.25	.76	.76	.76	1.0	1.0	1.0
38-39		-	-	-	.76	.76	.76	1.0	1.8	1.8	1.8	1.8	1.8
39-40		-	-	-	-	.25	.25	.25	.25	.25	.25	.25	.51
40-41	C	-	.76	1.5	1.8	23.1	24.1	25.9	25.9	26.4	26.7	26.7	27.2
41-42		-	-	-	1.0	1.0	1.0	1.0	1.3	1.3	1.3	1.3	1.3
42-43	r	.25	.51	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.8	1.8
43-44		-	-	-	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.3
44-45	a	-	.25	.76	1.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.3
45-46		-	-	-	-	.51	.51	.51	.76	.76	.76	1.8	1.8
46-47	c	-	.25	.25	.25	.25	.51	.76	.76	.76	.76	.76	.76
47-48		-	-	.25	.25	.51	1.3	1.5	1.5	2.0	2.3	2.5	2.5
48-49	k	-	-	.25	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.8	2.3
49-50		-	-	-	.51	.51	1.0	1.5	1.8	2.5	3.6	4.1	4.3
50-51	s	-	-	-	.25	1.5	1.5	1.8	1.8	1.8	1.8	1.8	11.4
51-52		-	-	-	.25	.25	.51	.51	.51	.51	.76	.76	1.8
52-53		-	-	-	-	1.0	1.0	1.5	2.3	2.3	2.3	2.3	2.3
53-1		-	-	.25	.76	2.0	2.5	3.1	3.3	3.3	4.1	4.1	4.1

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 16

CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U12

Crack Location[a]	Crack Length at Given Cycle, mm: 100	200	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1-2		-	-	-	-	-	-	-	-	-	.25	.25	.25	.25
2-3	N	19.1	24.1	25.9	25.9	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
6-7		-	-	-	-	-	-	-	-	-	-	-	-	.25
8-9	o	-	-	-	-	-	-	-	-	-	-	.25	.25	.25
9-10		-	-	-	-	-	3.3	14.0	15.2	17.3	17.8	17.8	20.6	21.1
10-11		-	-	-	-	-	-	-	-	-	-	-	1.0	1.0
11-12		-	-	-	-	-	-	-	-	-	-	.76	1.3	1.3
12-13	C	-	-	-	-	-	-	-	-	-	-	.51	.51	.76
13-14		-	-	-	-	-	-	-	-	-	.76	1.3	1.3	1.3
14-15	r	-	-	-	-	.51	.51	1.3	1.3	1.3	1.8	2.5	2.5	2.5
15-16		-	-	-	-	-	-	.25	.25	.25	.25	.76	.76	1.3
16-17	a	-	-	-	-	.51	.76	1.0	1.3	1.3	1.8	4.8	4.8	4.8
17-18		-	-	-	-	-	-	-	-	-	-	.76	11.7	14.2
18-19	c	-	-	-	-	-	-	.76	1.0	1.3	1.5	2.0	2.0	2.0
19-20		-	-	-	-	-	.25	.51	1.5	1.8	2.0	2.3	2.3	2.3
20-21	k	-	-	-	-	1.0	1.5	1.5	2.0	2.3	2.3	2.3	2.5	2.5
21-22	s	-	.25	.51	.51	.51	.51	1.0	1.0	1.0	1.0	1.3	1.3	2.3
22-23		-	.51	.51	.51	.51	1.0	1.5	2.3	2.3	2.3	2.5	2.5	2.5
23-24		-	-	-	-	-	-	.51	.51	.51	.76	1.0	1.0	1.0
24-25		-	-	-	.25	.76	.76	1.0	1.8	1.8	1.8	1.8	1.8	1.8
25-26		-	-	-	-	-	.25	1.0	12.7	17.5	20.3	21.6	22.4	24.4
26-27		-	-	-	-	.51	.51	1.0	1.3	2.0	2.0	2.0	2.0	2.0
27-28		-	-	-	-	-	-	.25	.25	.25	1.0	1.0	1.0	1.0
28-29		-	-	-	-	-	-	-	1.0	1.0	1.8	1.8	1.8	1.8
29-30		-	-	-	-	-	-	.25	.76	1.3	1.8	3.3	3.8	3.8
30-31	N	-	-	-	-	-	-	.25	.76	1.0	1.0	1.0	8.9	11.2
31-32		-	-	-	-	-	-	.51	1.0	1.5	1.8	2.0	2.0	2.0
32-33	o	-	-	-	-	-	-	-	.25	.51	.51	1.0	1.0	1.0
33-34		-	-	-	-	-	-	-	.51	.51	.51	.76	.76	1.3
34-35		-	-	-	-	.51	.51	.51	.76	.76	.76	1.3	1.5	1.8
35-36	C	-	-	-	-	.25	.51	.51	.51	.51	.76	.76	.76	2.3
36-37		-	-	-	-	-	-	-	.51	.51	.51	.51	.51	.76
37-38	r	-	-	-	-	-	-	-	.25	.25	.25	.51	.51	.51
38-39	a	-	-	-	-	-	-	-	-	-	-	.76	.76	.76
40-41	c	-	-	-	12.4	17.8	20.3	25.4	25.4	25.4	25.4	25.4	25.4	25.9
42-43	k	-	-	-	-	-	-	-	-	-	-	-	.76	.76
44-45	s	-	-	-	-	-	-	-	-	-	-	-	-	1.3
45-46		-	-	-	-	-	-	-	.51	1.0	1.0	1.3	1.5	1.5
46-47		-	-	-	-	-	-	-	-	-	.25	.76	.76	1.3
47-48		-	-	-	-	-	-	-	.51	.51	.51	.51	.51	.76
48-49		-	-	-	-	-	-	-	-	-	-	-	-	.25
49-50		-	-	-	-	-	-	-	-	-	-	-	.51	1.0
50-51		-	-	-	-	-	-	-	-	-	-	.25	.25	.25
51-52		-	-	-	-	-	-	-	-	-	-	-	.25	.25

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 17

SUMMARY OF BLADE CRACK INITIATION AND PROPAGATION

Wheel Identification	Total Accumulated Cycles	Accumulated Cycles to Crack Initiation[a]	Accumulated Cycles to Given Crack Length,[a] mm		Maximum Crack Length,[b] mm	Total No. of Cracked Blades
			0.5	1.0		
			Unpocketed Wheels			
U1	5000	400	400	2250	1.5	52
U2	5000	400	400	2750	1.8	53
U4	1000	400	400	850	1.0	24
U5	1000	400	400	600	1.0	17
U6	4000	600	600	1250	1.3	51
U7	4000	600	600	3250	1.3	50
U8	2000	250	250	400	1.3	15
U9	2000	250	250	850	1.0	20
U11	5000	400	850	2250	1.3	52
U12	5000	400	400	4750	1.0	49
			Pocketed Wheels			
P1	10,000	5250	9250	>10,000	0.5	6
P2	8,025	5250	8025	> 8.025	0.3	4
P3	10,025	4275	7275	>10,025	0.5	7
P4	8,000	5250	6750	6,750	1.0	7
P5	5,000	2250	3750	> 5,000	0.5	12
P6	5,000	2250	4250	> 5,000	0.8	11

[a]Average of last inspection cycle without (or with less than 0.5 or 1.0) crack and subsequent inspection with a 0.25 mm (or greater than 0.5 or 1.0) crack.

[b]Largest crack measured on any blade in the wheel.

Table 18

BLADE CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U1

Crack Location[a]	Crack Length at Given Cycle, mm											
	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1		.25	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51
2		-	.51	.76	.76	.76	.76	1.0	1.0	1.0	1.0	1.0
3		-	-	.76	.76	.76	.76	.76	.76	.76	.76	.76
4	N	-	-	-	.51	.51	.51	.76	.76	.76	.76	.76
5		-	-	-	-	.25	.25	.25	.25	.25	.25	.25
6		.25	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51
7	o	.25	.25	.25	.76	.76	.76	.76	.76	.76	.76	.76
8		.51	.51	.51	.51	.76	.76	.76	.76	.76	.76	.76
9		-	-	-	-	.25	.25	.25	.25	.25	.25	.25
10		.25	.25	.51	.51	.51	.51	.51	.51	.51	.51	.51
11	C	-	-	.25	.25	.25	.51	.51	.51	.51	.51	.51
12		-	-	-	-	-	.25	.25	.25	.25	.25	.25
13		.51	.51	.76	.76	.76	.76	.76	.76	.76	.76	.76
14	r	-	-	-	-	-	.25	.25	.25	.51	.51	.51
15		.25	.25	.25	.25	.25	.25	.51	.51	.51	.51	.51
16		-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
17	a	-	-	-	-	.25	.25	.25	.25	.25	.25	.25
18		-	-	-	.51	.51	.51	.76	.76	1.0	1.0	1.0
19		.51	.51	.51	.76	.76	.76	.76	.76	.76	.76	.76
20	c	-	-	-	.25	.51	.51	.51	.51	.51	.51	.51
21		.51	.51	.51	.51	.51	.51	.76	.76	.76	.76	.76
22	k	-	-	-	-	-	.25	.25	.25	.25	.25	.51
23		-	.51	.51	.51	.51	.76	1.0	1.0	1.0	1.0	1.0
24		.51	.51	.76	.76	.76	.76	.76	.76	.76	.76	.76
25	s	-	.25	.76	.76	.76	.76	.76	.76	.76	.76	1.0
26		.51	.51	.76	.76	.76	.76	.76	.76	.76	.76	.76
27		.51	.51	.76	.76	.76	.76	.76	.76	.76	.76	.76
28		-	-	-	-	.25	.25	.51	.51	.51	.51	.76
29		-	-	.25	.25	.25	.51	.51	.51	.51	.51	.51
30		-	-	.25	.25	.51	.51	.51	.51	.51	.51	.51
31		-	-	-	-	-	-	.51	.51	.51	1.5	1.5
32		-	-	-	-	.25	.51	.51	.51	.51	.51	.76
33		-	-	-	-	.25	.25	.25	.25	.25	.25	.51
34	N	-	-	.25	.25	.25	.51	.51	1.0	1.0	1.0	1.0
35		.25	.25	.51	.51	.51	.51	.51	.51	.51	.51	.51
36	o	.25	.51	.51	.51	.51	.51	.51	.51	.76	.76	.76
37		-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
38		-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
39		-	-	.51	.51	.51	.51	.51	.51	.51	.51	.76
40	C	-	-	-	-	-	-	-	-	-	-	-
41		-	-	-	-	.25	.51	.51	.51	.51	.51	.76
42	r	.51	.51	.51	.76	.76	.76	.76	.76	.76	.76	1.0
43		-	-	-	-	.51	.51	.51	.51	.51	.51	.51
44		.51	.51	.76	.76	.76	1.0	1.0	1.0	1.0	1.0	1.0
45	a	.25	.25	.51	.51	.51	.51	.51	.51	.51	.51	.51
46		.51	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51
47		-	-	-	-	-	-	-	.25	.25	.51	.51
48	c	-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
49		-	.25	.51	.51	.51	.51	.51	.51	.51	.51	.51
50		-	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
51	k	.51	.51	.51	.51	.51	.51	.76	.76	.76	.76	.76
52		-	-	.25	.25	.25	.51	.51	.51	.51	.51	.51
53	s	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51

[a]Location with reference to blades numbered clockwise from the reference mark. All blade cracks developed at the blade root on the trailing edge.

Table 19

BLADE CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U2

Crack Location[a]	Crack Length at Given Cycle, mm											
	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1	No Cracks	.25	.25	.25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3
2		-	-	-	-	.25	.51	.51	.51	.51	.51	.51
3		-	-	-	-	-	-	.51	.51	.51	.51	.51
4		-	-	-	-	-	.25	.25	.25	.25	.25	.25
5		.25	.25	.25	.25	.51	.51	.51	.51	.25	.51	1.0
6		-	.51	.51	.51	.76	.76	.76	.76	.76	.76	.76
7		-	-	.51	.51	.51	.51	.51	.51	.51	.51	.76
8		-	-	-	-	.51	.51	.51	.51	1.0	1.0	1.0
9		.51	.51	.76	.76	.76	.76	1.0	1.0	1.0	1.5	1.5
10		-	-	.76	.76	.76	.76	.76	.76	.76	.76	.76
11		-	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51
12		-	-	-	-	-	-	-	-	-	.76	.76
13		.51	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51
14		-	-	-	-	.25	.25	.51	.51	.51	.51	.51
15		-	-	-	.25	.51	.51	.51	.51	.51	.51	.51
16		.51	.51	.51	.51	.51	.51	.51	.51	.51	.51	.51
17		-	.76	.76	.76	.76	.76	.76	.76	.76	1.0	1.0
18		-	-	-	-	.25	.25	.76	.76	.76	.76	.76
19		.51	.51	.51	.51	.51	.51	.51	.51	.51	.51	.76
20		-	-	-	.51	.51	.76	.76	.76	1.0	1.0	1.0
21		-	-	-	.25	.25	.25	.51	.51	.51	.51	.76
22		-	-	-	-	.51	.51	.51	.51	.51	.51	.51
23		-	-	-	-	-	-	.51	.51	.51	.51	.51
24		-	-	.51	.76	.76	.76	1.0	1.0	1.0	1.0	1.0
25		-	-	-	-	.51	.51	.51	.51	.51	.51	.51
26		-	-	-	-	.76	.76	.76	.76	.76	.76	.76
27		-	-	.51	.51	.51	.51	.51	.51	.51	.51	.51
28		.76	.76	.76	.76	.76	.76	.76	.76	.76	.76	.76
29		-	-	-	-	-	-	.25	.25	.25	.51	.51
30		-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
31	No Cracks	-	-	-	.51	.51	.51	.76	.76	.76	.76	.76
32		-	-	-	.51	.51	.51	.51	.76	1.0	1.0	1.0
33		-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
34		-	-	-	-	-	-	-	.25	.25	.25	.25
35		-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
36		-	-	-	-	.25	.25	.25	.25	.25	.25	.25
37		-	-	-	-	.51	.51	.51	.51	.51	.51	.51
38		-	-	-	-	-	.25	.25	.25	.51	.51	.51
39		-	-	-	-	-	-	-	.25	.25	.25	.25
40		-	-	-	-	.25	.25	.25	.25	.25	.25	.25
41		-	-	-	-	-	.25	.25	.25	.25	.51	.51
42		-	.51	.51	.51	.51	.76	.76	.76	.76	.76	.76
43		-	-	-	-	-	-	-	-	.51	.51	.51
44		-	-	-	-	-	.25	.25	.25	.25	.51	.51
45		-	-	-	-	.25	.25	.25	.25	.51	.51	.51
46		-	-	.25	.25	.51	.51	.51	.51	.51	.51	.51
47		-	-	-	.25	.25	.25	.76	.76	.76	.76	.76
48		-	-	.51	.51	.51	.51	.76	.76	.76	.76	.76
49		-	-	.25	.25	.25	.25	.51	.51	.76	.76	.76
50		-	.25	.76	.76	.76	.76	.76	.76	.76	1.0	1.0
51		.76	.76	.76	.76	.76	.76	.76	.76	.76	.76	1.0
52		-	-	.76	.76	.76	.76	1.0	1.0	1.0	1.0	1.0
53		.25	.51	.51	.51	.51	.51	1.8	1.8	1.8	1.8	1.8

[a]Location with reference to blades numbered clockwise from the reference mark. All blade cracks developed at the blade root on the trailing edge.

Table 20

BLADE CRACK INITIATION AND PROPAGATION
FOR UNPOCKETED WHEELS U4 AND U5

Crack Location[a]	Crack Length at Given Cycle, mm			
	300	500	700	1000
		U4		
3	No Cracks	.51	.51	.51
6		.25	.25	.25
7		-	-	.51
10		-	-	1.0
11		-	-	.76
18		-	-	.51
21		.51	.51	.51
22		-	-	.51
23		-	-	.51
25		-	.51	.76
26		-	-	.51
30		-	.25	.25
35		-	-	.76
37		-	-	.76
40		-	-	.51
41		-	.25	.51
43		-	-	.25
46		-	.51	.76
47		-	-	.76
48		.25	.51	.76
49		-	-	.51
50		.51	.51	.76
51		.51	.51	.51
53		.25	.25	.25
		U5		
3		-	.25	.25
7		.51	.76	.76
9		.25	.25	.51
11		.25	.25	.51
14		.51	.51	.51
15		-	-	.25
16		.25	.25	.25
17		-	-	.51
18		-	.25	.25
22		-	-	.25
25		-	.25	.51
26		.51	.51	.51
28		.25	.25	.51
37		.76	.76	.76
38		.76	1.0	1.0
39		-	.76	.76
47		.76	.76	.76

[a]Location with reference to blades numbered clockwise from the reference mark. All blade cracks developed at the blade root on the trailing edge.

Table 21

BLADE CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U6

Crack Location[a]	Crack Length at Given Cycle, mm								
	500	700	1000	1500	2000	2500	3000	3500	4000
1		.25	.51	.51	.51	.51	.76	.76	.76
2		-	-	.25	.25	.25	.25	.51	.76
3	No Cracks	-	-	.51	.51	.76	.76	.76	.76
4		-	-	-	-	-	.25	.51	.51
5		-	-	-	-	.25	.25	.25	1.0
6		-	-	.25	.51	.51	.51	.51	.76
7		-	-	-	.25	.51	.51	.51	.51
8		-	-	.25	.51	.51	.51	.51	.51
9		.25	.51	.51	.51	.76	1.0	1.0	1.0
10		.25	.25	.51	.76	.76	.76	.76	.76
11		-	-	-	.25	.25	.25	.25	.25
12		-	-	-	.25	.51	.51	.51	.51
13		-	-	.25	.51	.51	.51	.51	.51
14		-	-	-	-	-	.25	.25	.25
15		-	-	-	.25	.25	.25	.25	.25
16		-	.25	.25	.25	.51	.51	.51	.76
17		-	-	-	-	-	-	.25	.25
18		-	-	-	-	-	.25	.51	.51
19		-	-	-	.25	.25	.25	.25	.25
20		.25	.25	.25	.51	1.0	1.0	1.0	1.0
21		.25	.25	.25	.51	.76	.76	1.0	1.0
22		-	-	-	.25	.25	.25	.25	.25
23		-	-	-	1.0	1.0	1.0	1.0	1.0
24		-	-	.25	.25	.51	.51	.51	.51
25		.25	.25	.25	.25	.51	.51	.51	.51
26		.25	.25	.25	.25	.25	.51	.76	1.0
27		-	.25	.25	.25	.25	.25	.51	.51
28	No Cracks	-	.51	.51	.51	.76	.76	.76	.76
29		-	-	.25	.25	.25	.51	1.0	1.0
30		-	-	-	-	-	.25	.25	.25
31		-	.25	.51	.51	.51	.51	.51	.51
32		-	-	-	.51	.76	.76	.76	.76
33		-	-	.25	.25	.76	.76	.76	.76
34		.25	.51	.76	1.0	1.0	1.0	1.0	1.0
35		-	.25	.25	.25	.51	.51	.51	.51
36		-	-	-	-	.51	.51	.76	.76
37		-	-	-	-	.25	.51	.51	.51
38		-	-	-	-	.25	.76	.76	.76
39		-	-	-	.51	.76	.76	.76	.76
40		-	-	-	-	-	-	.25	.25
41		-	-	.25	.25	.25	.25	.25	.51
42		-	-	-	-	-	-	-	-
43		-	-	-	-	-	-	.25	.25
44		.25	.25	.25	.76	.76	.76	.76	.76
45		-	-	-	-	-	-	-	-
46		.25	.76	1.0	1.0	1.0	1.0	1.0	1.0
47		.25	.51	.51	.51	.51	.51	.51	.51
48		.76	.76	.76	1.0	1.0	1.0	1.0	1.3
49		-	-	-	.25	.25	.51	.51	.51
50		-	-	-	.25	.25	.25	.25	.51
51		.25	.25	.51	.51	.51	.51	.51	.51
52		.51	.51	.51	.76	.76	.76	.76	.76
53		-	-	-	.51	.51	.51	.51	.51

[a]Location with reference to blades numbered clockwise from the reference mark. All blade cracks developed at the blade root on the trailing edge.

Table 22

BLADE CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U7

Crack Location[a]	Crack Length at Given Cycle, mm								
	500	700	1000	1500	2000	2500	3000	3500	4000
1		-	-	.25	.25	.25	.25	.25	.25
2	No Cracks	-	-	.25	.25	.25	.25	.25	.25
3		-	-	-	.25	.51	.51	.51	.51
4		-	-	-	-	-	-	-	-
5		-	-	.25	.25	.25	.25	.25	.25
6		-	-	.51	.51	.51	.76	.76	.76
7		-	-	-	-	-	-	.51	.51
8		-	-	-	-	.25	.25	.51	.51
9		-	-	.25	.25	.25	.51	.76	1.0
10		-	-	.25	.25	.25	.25	.25	.25
11		-	-	-	-	-	-	.25	.25
12		-	-	-	.25	.25	.25	.25	.76
13		-	-	-	-	-	-	-	.25
14		-	-	.25	.25	.25	.25	.25	.25
15		-	-	-	-	-	-	-	-
16		-	-	-	.25	.51	.51	.51	.51
17		-	-	.25	.25	.25	.25	.76	.76
18		.25	.25	.25	.51	.51	.51	.51	.51
19		.25	.25	.25	.25	.51	.51	.51	.76
20		.25	.25	.25	.25	.51	.51	1.3	1.3
21		.25	.25	.25	.25	.51	.51	.76	.76
22		-	-	.25	.25	.25	.51	.51	.51
23		.51	.51	.51	.51	.51	.51	.51	.76
24		-	.51	.51	.51	.51	.51	1.0	1.0
25	No Cracks	-	.25	.25	.25	.25	.25	.51	.51
26		-	-	.51	.51	.51	.51	.76	.76
27		-	-	-	-	-	-	-	.25
28		-	-	.25	.51	.51	.51	1.0	1.0
29		-	-	-	-	-	.25	.25	.25
30		-	.25	.51	.51	.51	.51	.76	.76
31		-	.25	.25	.25	.25	.25	.25	.51
32		-	-	.25	.25	.25	.25	.51	.76
33		-	-	-	-	.25	.25	.51	.51
34		-	-	-	-	-	.25	.25	.25
35		-	-	-	-	-	.25	.25	.25
36		.25	.25	.25	.25	.25	.25	.25	.51
37		-	.25	.25	.25	.25	.51	.51	.51
38		-	-	.25	.25	.51	.51	.51	.51
39		-	-	.25	.25	.25	.25	.25	.25
40		.25	.51	.51	.51	.51	.51	.51	1.0
41		-	-	-	-	-	-	-	-
42		-	-	-	-	-	.25	.25	.25
43		-	-	.25	.25	.25	.25	.25	.25
44		.25	.25	.25	.25	.25	.25	.25	.76
45		-	-	.25	.25	.25	.51	.51	.76
46		-	-	.51	.51	.51	.51	.51	.76
47		-	-	-	.25	.51	.51	.51	.76
48		-	.25	.51	.51	.51	.51	.51	.76
49		-	.51	.51	.51	.51	.51	.51	.76
50		.25	.25	.25	.25	.25	.25	.25	.25
51		.25	.25	.25	.51	.51	.51	.51	.76
52		-	-	.25	.25	.25	.25	.25	.25
53		-	-	.25	.51	.76	.76	.76	1.0

[a]Location with reference to blades numbered clockwise from the reference mark. All blade cracks developed at the blade root on the trailing edge.

Table 23

BLADE CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U8

Crack Location[a]	Crack Length at Given Cycle, mm						
	200	300	500	700	1000	1500	2000
1	No Cracks	.76	1.0	1.3	1.3	1.3	1.3
4		-	-	-	-	.25	.25
6		-	-	-	-	-	.25
7		.25	.25	.25	.25	.25	.51
10		-	-	-	.25	.25	.25
13		-	-	-	.25	.25	.25
17		-	-	-	.25	.25	.25
21		-	-	-	-	.76	.76
31		-	-	-	.25	.51	.76
35		-	-	-	.51	.51	.51
37		.25	.25	.25	.51	.51	.51
38		-	-	-	.25	.25	.51
41		-	-	-	-	-	.25
43		-	-	-	-	-	.51
44		-	-	-	-	-	.25

[a]Location with reference to blades numbered clockwise from reference mark; all blade cracks developed at the blade root on the trailing edge.

Table 24

BLADE CRACK INITIATION AND PROPAGATION
FOR UNPOCKETED WHEEL U9

Crack Location[a]	Crack Length at Given Cycle, mm						
	200	300	500	700	1000	1500	2000
6		.25	.51	.51	.51	.51	.76
9	N	-	.25	.25	.25	.25	.25
10	o	-	.25	.25	.25	.25	.25
11		-	.25	.25	.51	.51	.51
13	C	.25	.51	.76	.76	.76	.76
14	r	-	-	.25	.25	.25	.25
18	a	-	-	-	.25	.25	.25
19	c	.25	.25	.25	.51	.51	.51
20	k	-	.25	.25	.51	.51	.51
23	s	-	-	.25	.25	.25	.25
24		-	-	-	-	-	.25
30		.25	.76	.76	.76	.76	.76
31		-	-	-	.25	.51	.51
36		-	-	.25	.51	.51	.51
37		-	-	-	-	.25	.25
39		-	-	-	-	.25	.25
42		-	.25	.25	.51	.51	.51
44		-	-	.25	.51	.51	.51
50		.51	.51	.51	1.0	1.0	1.0
52		-	.25	.25	.25	.51	.51

[a]Location with reference to blades numbered clockwise from reference mark; all blade cracks developed at the blade root on the trailing edge.

Table 25

BLADE CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U11

Crack Location[a]	Crack Length at Given Cycle, mm											
	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1		.25	.25	.25	.25	.25	.25	.25	.25	.76	.76	1.0
2		-	-	-	.25	.25	.25	.25	.25	.51	.51	1.0
3	N	-	-	.51	.51	.51	.51	.51	.76	.76	.76	.76
4		-	-	-	.25	.25	.25	.25	.25	.25	.76	.76
5	o	-	.25	.51	.51	.51	.76	1.0	1.0	1.0	1.0	1.0
6		-	-	.25	.51	.51	.76	.76	.76	.76	.76	1.0
7		-	-	-	-	-	.25	.25	.25	.25	.25	.25
8		-	-	.25	.25	.25	.51	.51	.51	.51	.51	.51
9	C	-	-	.25	.25	.25	.25	.51	.51	.51	.51	.76
10	r	-	-	-	-	-	-	.25	.25	.25	.25	.51
11		-	-	-	.25	.25	.25	.51	.51	.76	1.0	1.0
12	a	-	-	-	-	-	-	.25	.25	.25	.25	.51
13		-	-	-	-	-	.25	.25	.25	.25	.25	.51
14	c	-	-	.25	.25	.51	.51	.51	.51	.51	.76	.76
15		-	.25	.25	.25	.25	.25	.25	.25	.25	.51	.76
16	k	.25	.25	.25	.25	.51	.51	.51	.76	.76	1.0	1.0
17		-	.25	.51	.51	.76	.76	.76	.76	.76	1.0	1.0
18	s	-	.25	.25	.25	.76	.76	.76	.76	.76	.76	.76
19		-	-	-	-	.25	.25	.51	.76	.76	.76	.76
20		-	-	-	-	-	-	.25	.25	.25	.25	.25
21		-	-	.25	.25	.25	.51	.51	.76	.76	.76	.76
22		-	-	-	-	-	.25	.25	.25	.25	.25	.25
23		.25	.25	.25	.25	.25	.25	.51	.51	.51	.51	.51
24		-	-	-	-	.25	.25	.25	.51	.76	.76	.76
25		-	-	.25	.25	.51	.51	.51	.76	.76	.76	.76
26		-	-	-	.25	.25	.25	.51	.51	.51	.76	.76
27		-	-	.25	.25	.76	.76	.76	.76	.76	1.0	1.0
28		.25	.25	.25	.25	.25	.25	.25	.25	.51	.51	.51
29		-	-	.51	.76	.76	.76	.76	.76	.76	1.0	1.0
30		-	-	-	-	-	.25	.25	.25	.51	.51	.51
31		-	-	-	.25	.25	.25	.25	.25	.25	.25	.25
32		-	-	-	-	-	.25	.25	.25	.25	.25	.25
33	N	-	-	-	.25	.25	.25	.25	.25	.51	.51	.76
34		-	-	-	-	.25	.51	.51	.51	.51	.51	.51
35		-	-	-	-	-	.25	.25	.25	.25	.25	.25
36	o	-	-	.25	.76	.76	1.0	1.0	1.0	1.0	1.0	1.0
37		-	-	.25	.25	.76	.76	.76	.76	.76	.76	.76
38		-	-	.25	.51	.51	.76	.76	.76	.76	.76	1.0
39		.25	.25	.25	.25	.51	.51	.51	.51	.51	.76	.76
40	C	-	-	-	-	.51	.51	.51	.51	.51	.51	.51
41		-	-	-	-	-	-	-	-	-	-	-
42	r	-	-	-	-	-	-	-	.51	.76	.76	.76
43		-	.25	.25	.25	.25	.25	.25	.76	1.0	1.0	1.0
44		-	-	-	-	.25	.25	.25	.25	.51	.51	1.0
45	a	-	-	-	-	-	-	-	.25	.25	.25	1.0
46		-	-	-	.25	.51	.51	.51	.51	.51	.76	.76
47		-	-	-	-	-	-	-	-	.25	.25	.25
48	c	-	-	-	.25	.51	.76	.76	.76	.76	.76	.76
49		-	-	-	.25	.51	.51	.51	.51	.51	.76	.76
50	k	-	-	.25	.25	.51	.51	1.0	1.0	1.0	1.0	1.3
51		-	-	-	-	.25	.25	.25	.25	.25	.51	.51
52		-	-	-	-	-	.51	.76	.76	.76	.76	.76
53	s	-	-	.25	.25	.25	.25	.25	.25	.51	.51	.51

[a]Location with reference to blades numbered clockwise from reference mark; all blade cracks developed at the blade root on the trailing edge.

Table 26

BLADE CRACK INITIATION AND PROPAGATION FOR UNPOCKETED WHEEL U12

Crack Location[a]	Crack Length at Given Cycle, mm											
	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1		-	-	-	-	-	-	.25	.25	.51	.76	.76
3	N	-	-	-	.25	.25	.25	.25	.25	.25	.51	.76
4		-	-	.25	.25	.25	.25	.25	.25	.51	.76	.76
5		-	-	.25	.25	.25	.25	.25	.25	.25	.51	.51
6	o	-	.25	.25	.25	.25	.25	.25	.25	.25	.51	.76
7		-	.25	.25	.51	.51	.51	.51	.51	.51	.76	.76
8		-	-	-	-	-	.25	.25	.25	.51	.76	1.0
10	C	-	.25	.51	.51	.51	.51	.51	.76	.76	.76	1.0
11		-	.25	.25	.25	.25	.25	.25	.25	.51	.76	.76
12	r	-	-	-	-	-	.25	.25	.51	.51	.51	.51
13		-	-	.25	.51	.51	.51	.51	.51	.51	.76	.76
14		.25	.25	.25	.25	.25	.25	.51	.51	.51	.76	1.0
15	a	-	-	-	-	-	-	-	-	-	-	.25
16		-	-	-	-	-	-	.25	.25	.51	.76	.76
17		-	-	-	.25	.25	.25	.25	.25	.25	.51	.76
18	c	-	-	-	.51	.51	.51	.51	.51	.51	.51	.51
19		-	.25	.25	.25	.25	.25	.25	.25	.25	.51	.51
20	k	.25	.25	.25	.51	.51	.51	.51	.51	.51	.51	.76
21		-	-	-	-	.25	.25	.25	.25	.51	.51	.51
22		-	-	-	.25	.51	.51	.51	.51	.51	.76	.76
23	s	-	-	-	.25	.25	.25	.25	.25	.25	.51	.51
24		-	-	-	.25	.25	.25	.25	.25	.25	.51	.51
26		-	-	-	-	.25	.25	.25	.25	.25	.51	.51
27		.25	.25	.51	.51	.51	.51	.51	.51	.51	.51	.51
28		.25	.25	.25	.25	.25	.25	.25	.25	.25	.51	.51
29		.25	.25	.25	.25	.25	.51	.51	.51	.76	.76	.76
30		-	.25	.25	.25	.25	.25	.25	.25	.51	.51	.51
31		-	-	-	-	-	.25	.25	.25	.25	.51	.51
32		-	-	-	-	-	-	.25	.25	.51	.51	.76
33	N	-	-	-	-	.25	.51	.51	.51	.51	.51	.51
34		-	.25	.25	.25	.25	.25	.25	.25	.25	.51	.76
35	o	-	-	.25	.25	.25	.25	.25	.25	.25	.25	.25
36		-	-	-	-	-	-	.51	.51	.51	.51	.51
37		-	.25	.25	.25	.25	.25	.25	.25	.25	.25	.51
38	C	-	-	.25	.25	.25	.25	.25	.25	.25	.25	.76
39		-	-	-	-	.25	.25	.25	.25	.25	.25	.51
40	r	-	-	-	-	-	-	-	.25	.25	.25	.25
42	a	-	.25	.25	.25	.25	.25	.51	.51	.51	.51	.51
43		-	-	-	-	-	.25	.51	.51	.51	.51	.51
44	c	-	-	.25	.25	.25	.25	.25	.25	.51	.76	.76
45		-	-	-	-	-	-	.25	.25	.25	.25	.25
46	k	-	-	-	-	-	.25	.25	.25	.25	.25	.51
47	s	-	-	.25	.25	.25	.51	.51	.51	.51	.51	.51
48		-	-	-	.25	.25	.25	.51	.51	.51	.51	.51
49		-	-	-	.25	.25	.25	.25	.25	.25	.51	.51
50		.51	.51	.51	.51	.51	.51	.51	.51	.51	.51	.76
51		-	-	-	.25	.25	.25	.51	.51	.51	.76	.76
52		-	-	-	-	-	-	.25	.25	.25	.25	.25
53		-	-	-	-	-	-	.25	.25	.25	.25	.25

[a]Location with reference to blades numbered clockwise from reference mark; all blade cracks developed at the blade root on the trailing edge.

Table 27

CRACK INITIATION AND PROPAGATION FOR POCKETED WHEEL P1

Crack Location[a]	Crack Length at Given Cycle, mm[b]												
	25	50	100	200	300	500	700	1000	1500	2000	2500	3000	3500
1-2	-	-	-	-	-	-	-	-	-	-	-	-	-
2-3	-	-	-	-	-	-	-	-	-	-	-	-	-
3-4	8.4	9.1	9.7	9.9	10.2	10.2	11.2	11.2	11.4	11.7	12.2	12.4	13.0
4-5	-	-	-	-	-	-	-	-	-	-	-	-	-
5-6	-	-	-	-	-	-	-	-	-	-	-	-	-
6-7	8.4	9.1	9.1	9.9	9.9	9.9	9.9	9.9	9.9	11.2	11.2	11.4	12.7
7-8	-	-	-	-	-	-	-	-	-	-	-	-	-
8-9	-	-	-	-	-	-	-	-	-	-	-	-	-
9-10	8.6	9.4	9.7	10.2	10.2	10.2	10.9	11.2	11.2	11.7	11.7	12.4	12.7
12-13	8.6	9.1	9.1	10.2	10.2	10.2	10.2	10.2	10.2	10.2	11.2	12.2	12.4
14-15	.25[d]	1.8[d]	1.8[d]	3.8[d]	3.8[d]	4.6[d]	5.3[d]	5.6[d]	5.6[d]	5.6[d]	5.6[d]	6.6[d]	6.6[d]
15-16	3.8[e]	5.3[f]	5.8[f]	9.7	9.9	9.9	10.9	10.9	10.9	11.2	11.2	11.2	11.4
16-17	-	-	-	-	-	-	-	-	-	-	-	-	-
17-18	7.6	9.4	9.4	9.9	9.9	9.9	11.4	11.7	11.7	11.9	11.9	11.9	11.9
20-21	8.1	9.4	9.4	10.2	10.2	10.2	10.9	10.9	11.2	11.7	11.7	11.7	12.2
21-22	-	-	-	-	-	-	-	-	-	-	-	-	-
22-23	-	-	-	-	-	-	-	-	-	-	-	-	-
23-24	8.9	9.1	9.9	10.2	10.2	10.4	11.2	11.7	11.9	11.9	11.9	12.2	12.2
24-25	-	-	-	-	-	-	-	-	-	-	-	-	-
26-27	8.6	9.4	10.2	10.2	10.2	10.2	11.4	11.4	11.4	11.9	11.9	11.9	11.9
29-30	8.1	9.4	9.9	9.9	10.2	10.2	10.9	10.9	11.2	11.4	11.7	11.9	13.2
30-31	-	-	-	-	-	-	-	-	-	-	-	-	-
31-32	-	-	-	-	-	-	-	-	-	-	-	-	-
32-33	8.1	9.7	9.9	9.9	9.9	10.2	11.4	11.7	11.9	11.9	11.9	11.9	12.4
33-34	-	-	-	-	-	-	-	-	-	-	-	-	-
34-35	-	-	-	-	-	-	-	-	-	-	-	-	-
35-36	8.6	9.4	9.9	9.9	10.2	10.2	10.9	11.7	11.9	12.2	12.2	12.4	13.0
37-38	-	-	-	-	-	-	-	-	-	-	-	-	-
38-39	8.1	8.4	8.9	9.4	9.4	9.4	9.4	9.7	9.7	11.4	11.4	11.4	11.7
39-40	-	-	-	-	-	-	-	-	-	-	-	-	-
40-41	-	-	-	-	-	-	-	-	-	-	-	-	-
41-42	7.6	9.1	9.9	9.9	10.2	10.2	11.4	11.4	11.9	11.9	11.9	11.9	11.9
42-43	-	-	-	-	-	-	-	-	-	-	-	-	-
43-44	-	-	-	-	-	-	-	-	-	-	-	-	-
44-45	8.9	9.7	9.9	9.9	9.9	9.9	11.2	11.4	11.7	11.9	11.9	12.7	12.7
45-46	-	-	-	-	-	-	-	-	-	-	-	-	-
46-47	-	-	-	-	-	-	-	-	-	-	-	-	-
47-48	7.9	8.9	9.7	9.9	9.9	9.9	10.9	11.2	11.4	11.7	11.7	12.2	12.4
48-49	-	-	-	-	-	-	-	-	-	-	-	-	-
50-51	8.6	8.9	9.4	10.2	10.2	10.2	11.2	11.7	11.7	11.9	12.2	12.4	13.0
51-52	-	-	-	-	-	-	-	-	-	-	-	-	-
52-53	-	-	-	-	-	-	-	-	-	-	-	-	-
53-1	8.4	9.9	10.2	10.2	10.2	10.2	10.9	11.2	11.4	11.4	11.4	12.2	12.7

Table 27 (cont.)

Crack Location[a]	Crack Length at Given Cycle, mm[b]												
	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10,000
1-2	-	-	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.8[c]	4.1[c]	4.1[c]	4.1[c]	5.6[c]	5.6[c]	5.8[c]
2-3	-	-	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	4.3[c]	4.3[c]	4.8[c]
3-4	13.0	13.5	13.5	13.5	13.5	13.5	13.5	13.5	14.0	14.5	15.0	15.0	15.2
4-5	-	-	2.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]
5-6	-	-	1.3[c]	1.3[c]	1.5[c]	1.5[c]	1.5[c]	1.5[c]	1.5[c]	1.5[c]	1.5[c]	2.0[c]	2.0[c]
6-7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
7-8	-	-	1.3[c]	1.3[c]	1.8[c]	1.8[c]	1.8[c]	2.0[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]
8-9	-	-	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.3[c]	2.3[g]
9-10	12.7	13.2	13.2	13.5	13.5	13.5	13.5	13.5	14.2	14.2	14.2	14.2	14.2
10-11	-	-	-	-	-	.51[c]	.51[c]	.51[c]	.76[c]	.76[c]	.76[c]	2.0[c]	2.5[c]
11-12	-	-	-	-	-	-	-	-	-	-	.51[c]	1.3[c]	1.3[c]
12-13	13.0	13.2	13.2	13.2	13.2	13.2	13.2	14.0	15.0	15.0	15.0	15.5	15.5
13-14	-	-	-	-	-	-	-	.51[c]	.51[c]	.51[c]	.51[c]	.51[c]	.51[c]
14-15	6.9[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]	10.2[d]	10.2[d]	10.2[d]	10.2[d]
15-16	11.4	11.4	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
16-17	-	-	.76[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]
17-18	11.9	12.4	12.4	12.4	12.4	12.4	12.4	12.7	13.2	13.2	13.7	13.7	14.0
18-19	-	-	-	-	-	-	-	.51[c]	.51[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]
19-20	-	-	-	-	-	-	-	-	-	-	-	1.0[c]	1.0[c]
20-21	12.2	12.4	12.4	12.4	12.4	12.4	12.4	12.4	13.2	13.2	13.5	13.5	14.0
21-22	-	-	-	-	1.3[c]	2.3[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]
22-23	-	-	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	3.1[c]	3.1[c]
23-24	12.4	13.0	13.0	13.0	13.0	13.5	13.5	13.5	13.7	13.7	13.7	13.7	14.2
24-25	-	-	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]
25-26	-	-	-	-	-	-	-	-	-	-	-	-	.51[c]
26-27	11.9	12.2	12.4	12.4	12.4	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
27-28	-	-	-	-	-	-	-	.51[c]	.51[c]	1.5[c]	1.5[c]	1.5[c]	1.5[c]
28-29	-	-	-	-	-	-	-	.51[c]	.51[c]	.51[c]	.51[c]	.51[c]	.51[c]
29-30	13.2	13.5	13.7	13.7	13.7	13.7	14.5	14.5	14.5	14.5	14.5	14.5	18.8
30-31	-	-	2.8[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]
31-32	-	-	-	1.5[c]	1.5[c]	1.5[c]	1.5[c]	1.5[c]	2.0[c]	2.0[c]	3.6[c]	3.6[c]	3.6[c]
32-33	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
33-34	-	-	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.8[c]	1.8[c]	1.8[c]	1.8[c]
34-35	-	-	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	2.0[c]	2.0[c]	2.0[c]
35-36	13.0	13.2	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.7	14.5	14.5	16.0
36-37	-	-	-	-	-	-	-	2.5[c]	2.5[c]	2.5[c]	3.8[c]	3.8[c]	3.8[c]
37-38	-	-	-	1.3[c]	1.3[c]	1.3[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]
38-39	11.7	11.7	11.7	11.7	11.7	11.9	11.9	11.9	11.9	11.9	13.0	13.0	13.0
39-40	-	-	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]
40-41	-	-	2.0[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	3.1[c]
41-42	12.2	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	13.5	13.5	15.0
42-43	-	-	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.8[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]
43-44	-	-	3.8[c]	3.8[c]	3.8[c]	3.8[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]	5.6[c]	5.6[c]	5.6[c]
44-45	12.7	12.7	13.0	13.0	13.0	13.7	13.7	13.7	13.7	13.7	14.0	14.2	15.5
45-46	-	-	-	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	3.1[c]
46-47	-	-	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]
47-48	12.4	12.4	12.4	12.7	13.0	13.0	13.0	13.0	13.0	13.0	13.2	13.2	13.5
48-49	-	-	2.0[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	3.1[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]
49-50	-	-	-	-	-	-	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.3[c]	1.5[c]
50-51	13.0	13.5	13.5	13.5	13.5	13.5	14.2	14.2	14.2	14.2	14.2	14.2	15.5
51-52	-	-	2.0[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.8[c]	2.8[c]	3.1[c]	3.3[c]	3.3[c]
52-53	-	-	-	1.3[c]	1.3[c]	1.3[c]	1.3[c]	2.0[c]	2.0[c]	2.0[c]	6.4[c]	6.4[c]	6.4[g]
53-1	12.7	12.7	12.7	13.2	13.7	13.7	14.0	14.0	14.0	14.2	14.2	14.5	14.7

[a]Location with reference to blades numbered clockwise from the reference mark.

[b]All cracks extend across the disk at the blade root except where noted.

[c]Root crack not present.

[d]Root crack 1/2 disk thickness from shaft side to disk side.

[e]Root crack 1/2 disk thickness from disk side to shaft side.

[f]Root crack 3/4 disk thickness from disk side to shaft side.

[g]Root crack 1/4 disk thickness from shaft side to disk side.

Table 28

CRACK INITIATION AND PROPAGATION FOR POCKETED WHEEL P2

Crack Location[a]	Crack Length at Given Cycle, mm[b]											
	15	25	50	75	125	225	325	525	725	1025	1525	2025
1-2	-	-	-	-	-	-	-	-	-	-	-	-
2-3	5.6	7.8	9.9	9.9	10.2	10.2	10.2	10.2	10.2	11.4	11.4	11.4
3-4	-	-	-	-	-	-	-	-	-	-	-	-
5-6	5.6	7.5	9.4	9.9	9.9	10.2	10.2	10.2	10.9	11.7	11.7	11.7
6-7	-	-	-	-	-	-	-	-	-	-	-	-
7-8	-	-	-	-	-	-	-	-	-	-	-	-
8-9	5.6	7.5	9.4	9.7	9.9	9.9	10.2	10.2	10.9	10.9	10.9	11.2
9-10	-	-	-	-	-	-	-	-	-	-	-	-
10-11	-	-	-	-	-	-	-	-	-	-	-	-
11-12	5.6	7.7	9.7	9.9	10.2	10.2	10.2	10.2	11.2	11.7	11.7	11.7
12-13	-	-	-	-	-	-	-	-	-	-	-	-
13-14	-	-	-	-	-	-	-	-	-	-	-	-
14-15	-	-	8.6	9.4	9.7	10.2	10.2	10.2	11.2	11.9	11.9	11.9
15-16	-	-	-	-	-	-	-	-	-	-	-	-
16-17	-	-	-	-	-	-	-	-	-	-	-	-
17-18	5.6	7.7	9.7	9.7	9.7	9.9	9.9	10.2	10.9	11.7	11.9	11.9
18-19	-	-	-	-	-	-	-	-	-	-	-	-
19-20	.75[d]	.75[d]	.75[d]	2.0[d]	2.0[d]	3.1[d]	3.1[d]	3.6[d]	4.8[d]	4.8[d]	4.8[d]	4.8[d]
20-21	.75	4.1	6.9[e]	7.9[e]	9.4[e]	9.7	9.9	10.2	10.2	10.9	10.9	10.9
21-22	-	-	-	-	-	-	-	-	-	-	-	-
22-23	5.6	7.4	9.1	9.1	10.2	10.2	10.2	10.2	10.9	11.2	11.7	11.7
23-24	-	-	-	-	-	-	-	-	-	-	-	-
24-25	-	-	-	-	-	-	-	-	-	-	-	-
25-26	5.6	7.5	9.4	9.9	9.9	10.2	10.2	10.2	10.9	11.4	11.7	11.7
28-29	5.6	7.8	9.9	9.9	10.2	10.2	10.2	10.2	10.9	11.4	11.7	12.2
29-30	-	-	-	-	-	-	-	-	-	-	-	-
30-31	-	-	-	-	-	-	-	-	-	-	-	-
31-32	5.6	7.7	9.7	9.7	10.2	10.2	10.2	10.2	10.9	11.7	11.7	11.7
32-33	-	-	-	-	-	-	-	-	-	-	-	-
34-35	5.6	7.9	8.2	9.4	9.7	10.2	10.2	10.2	10.9	11.2	11.4	11.4
36-37	-	-	-	-	-	-	-	-	-	-	-	-
37-38	5.6	7.9	9.9	10.2	10.2	10.4	10.4	10.4	10.4	11.4	11.7	11.7
38-39	-	-	-	-	-	-	-	-	-	-	-	-
39-40	-	-	-	-	-	-	-	-	-	-	-	-
40-41	5.6	7.7	9.7	9.7	9.7	9.7	10.4	10.4	10.4	10.4	10.4	11.2
41-42	-	-	-	-	-	-	-	-	-	-	-	-
42-43	-	-	-	-	-	-	-	-	-	-	-	-
43-44	5.6	7.9	10.2	10.2	10.4	10.4	10.4	10.4	11.4	12.2	12.2	12.2
44-45	-	-	-	-	-	-	-	-	-	-	-	-
45-46	-	-	-	-	-	-	-	-	-	-	-	-
46-47	-	-	2.8	3.6	6.4	9.7	10.4	10.4	10.4	10.4	10.4	10.4
47-48	-	-	-	-	-	-	-	-	-	-	-	-
48-49	-	-	-	-	-	-	-	-	-	-	-	-
49-50	5.6	7.9	10.2	10.2	10.2	10.2	10.2	10.2	10.9	11.4	12.2	12.2
50-51	-	-	-	-	-	-	-	-	-	-	-	-
51-52	-	-	-	-	-	-	-	-	-	-	-	-
52-53	5.6	7.5	9.4	9.7	9.9	10.4	10.4	10.4	10.4	11.2	11.2	11.4
53-1	-	-	-	-	-	-	-	-	-	-	-	-

Table 28 (cont.)

Crack Location[a]	Crack Length at Given Cycle, mm[b]											
	2525	3025	3525	4025	4525	5025	5525	6025	6525	7025	7525	8025
1-2	-	-	-	-	-	3.8[c]	3.8[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]	5.6[c]
2-3	11.4	11.7	12.4	12.4	12.4	12.4	12.4	12.4	13.0	13.0	13.2	14.0
3-4	-	-	-	-	-	5.3[c]	5.8[c]	5.8[c]	5.8[c]	6.4[c]	6.4[c]	6.4[c]
4-5	-	-	-	-	-	-	1.8[c]	2.5[c]	2.5[c]	3.8[c]	3.8[c]	5.3[c]
5-6	11.7	12.2	12.7	12.7	12.7	13.0	13.0	13.0	13.2	13.7	13.7	14.0
6-7	-	-	-	-	-	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]
7-8	-	-	-	-	-	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
8-9	11.7	11.9	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.4	12.4	13.2
9-10	-	-	-	-	-	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
10-11	-	-	-	-	-	3.8[c]	3.8[c]	5.1[c]	5.1[c]	5.8[c]	5.8[c]	5.8[c]
11-12	11.9	12.2	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	13.2
12-13	-	-	-	-	-	3.8[c]	5.1[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
13-14	-	-	-	-	-	4.1[c]	4.1[c]	4.1[c]	4.6[c]	4.6[c]	4.6[c]	4.6[f]
14-15	11.9	11.9	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.7	12.7	13.2
15-16	-	-	-	-	-	2.0[c]	2.3[c]	2.3[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]
16-17	-	-	-	-	-	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.4[c]
17-18	11.9	11.9	12.7	12.7	12.7	12.7	14.0	14.0	15.0	15.0	15.0	18.0
18-19	-	-	-	-	-	2.3[c]	2.5[c]	3.8[c]	4.1[c]	4.3[c]	4.3[c]	4.3[c]
19-20	4.8[d]	4.8[d]	4.8[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	6.4[d]	6.4[d]	6.4[d]
20-21	10.9	10.9	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.4	11.4	11.4
21-22	-	-	-	-	-	1.5[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]
22-23	11.7	11.9	12.4	12.4	12.4	12.4	12.7	13.0	13.0	13.5	13.5	14.5
23-24	-	-	-	-	-	3.8[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]	5.1[c]
24-25	-	-	-	-	-	2.8[c]	2.8[c]	3.3[c]	3.3[c]	3.8[c]	3.8[c]	3.8[c]
25-26	11.9	11.9	12.2	12.2	12.2	12.4	12.4	12.4	12.4	12.4	12.7	13.2
26-27	-	-	-	-	-	-	.51[c]	1.0[c]	1.0[c]	1.3[c]	1.3[c]	2.5[c]
27-28	-	-	-	-	-	-	-	.51[c]	.51[c]	.51[c]	.51[c]	1.3[c]
28-29	12.2	12.2	12.2	12.2	12.2	12.2	13.2	13.2	13.7[c]	13.7[c]	13.7[c]	14.7[c]
29-30	-	-	-	-	-	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]	2.5[c]
30-31	-	-	-	-	-	2.5[c]	2.5[c]	2.5[c]	2.5[c]	3.1[c]	3.1[c]	3.1[c]
31-32	12.2	12.2	12.2	12.4	12.4	12.4	12.4	12.4	12.4	12.7	12.7	12.7
32-33	-	-	-	-	-	3.6[c]	3.8[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]
33-34	-	-	-	-	-	-	-	.51[c]	.51[c]	1.3[c]	1.3[c]	2.0[c]
34-35	11.7	11.8	11.9	12.2	12.2	12.2	12.4	13.2	13.2	13.2	13.2	14.5
35-36	-	-	-	-	-	-	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]
36-37	-	-	-	-	-	1.3[c]	1.3[c]	2.5[c]	2.5[c]	3.1[c]	3.1[c]	4.1[c]
37-38	11.9	11.9	12.2	12.2	12.2	12.2	12.4	12.4	12.7	13.7	13.7	14.0
38-39	-	-	-	-	-	3.3[c]	3.3[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
39-40	-	-	-	-	-	5.1[c]	5.1[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]
40-41	11.9	11.9	11.9	11.9	11.9	11.9	11.9	12.2	12.2	12.7	12.7	13.0
41-42	-	-	-	-	-	5.6[c]	5.6[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
42-43	-	-	-	-	-	5.3[c]	5.3[c]	5.3[c]	5.3[c]	6.4[c]	6.4[c]	6.4[c]
43-44	12.4	12.7	12.7	12.7	12.7	13.0	13.0	13.0	14.7	14.7	14.7	16.0
44-45	-	-	-	-	-	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]	4.6[c]
45-46	-	-	-	-	-	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
46-47	10.4	10.4	10.4	10.9	11.2	11.4	11.4	11.4	11.4	11.4	11.4	11.9
47-48	-	-	-	-	-	5.6[c]	5.6[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
48-49	-	-	-	-	-	6.9[c]	6.9[c]	6.9[c]	6.9[c]	6.9[c]	6.9[c]	6.9[c]
49-50	12.4	12.4	13.0	13.0	13.0	13.0	13.0	14.2	15.5	15.5	16.0	17.3
50-51	-	-	-	-	-	5.3[c]	5.3[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
51-52	-	-	-	-	-	5.3[c]	5.3[c]	5.3[c]	5.3[c]	5.3[c]	5.3[c]	5.3[c]
52-53	11.7	11.7	12.2	12.2	12.2	12.2	12.2	12.2	12.7	12.7	13.2	13.2
53-1	-	-	-	-	-	.25[c]	2.0[c]	3.8[c]	3.8[c]	5.6[c]	5.6[c]	5.6[c]

[a]Location with reference to blades numbered clockwise from the reference mark.

[b]All cracks extended across the disk at the blade root except where noted.

[c]Root crack not present.

[d]Root crack 1/2 disk thickness from shaft side to disk side.

[e]Root crack 3/4 disk thickness from disk side to shaft side.

[f]Root crack 1/4 disk thickness from shaft side to disk side.

Table 29

CRACK INITIATION AND PROPAGATION FOR POCKETED WHEEL P3

Crack Location[a]	Crack Length at Given Cycle, mm[b]														
	15	25	50	75	125	225	325	525	725	1025	1525	2025	2525	3025	3525
1-2	-	-	-	-	-	-	-	-	-	-	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]
2-3	-	-	-	8.9[d]	9.4	10.2	10.4	10.9	10.9	10.9	11.4	11.4	11.7	11.7	11.7
3-4	-	-	-	-	-	-	-	-	-	-	-	6.4[e]	6.4[e]	6.4[e]	6.4[c]
4-5	-	-	-	-	-	-	-	-	-	-	-	3.1[c]	3.8[c]	4.1[c]	4.8[c]
5-6	-	-	-	-	9.1[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]
6-7	10.2	10.2	10.2	10.2	10.4	10.4	10.4	10.4	11.9	11.9	12.2	13.0	13.0	13.0	13.0
7-8	-	-	-	-	-	-	-	-	-	-	4.8[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]
8-9	-	-	-	-	-	-	-	-	-	-	3.8[f]	4.1[d]	4.3[d]	5.1[d]	5.3[d]
9-10	-	-	-	-	-	-	.25[g]	.25[g]	.25[g]	6.9[g]	10.2	10.2	10.2	10.2	10.2
10-11	-	-	-	-	.25[f]	.25[d]	.25[d]	.25[d]	.25[d]	8.4[d]	8.6[d]	9.4[d]	9.4[d]	10.2[d]	10.2[h]
11-12	-	-	-	-	-	-	-	-	-	-	4.6[e]	4.6[e]	4.6[e]	4.6[e]	4.6[e]
12-13	-	-	-	-	-	-	-	-	-	-	4.1[c]	4.1[c]	4.1[c]	4.1[c]	4.1[c]
13-14	-	5.6[d]	9.7	9.7	10.2	10.2	10.2	10.4	10.4	10.4	10.4	10.4	10.9	11.2	11.2
14-15	-	-	-	-	-	-	-	-	-	-	-	-	1.3[c]	1.3[c]	2.0[c]
15-16	-	-	-	-	-	-	-	-	-	-	-	2.0[c]	2.0[c]	2.0[c]	3.8[c]
16-17	-	-	-	-	.25[f]	.25[d]	.25	.25	10.2	10.2	10.2	10.2	10.2	10.2	10.2
17-18	-	-	-	-	-	-	-	-	-	-	-	-	2.8[c]	3.6[c]	3.6[c]
18-19	-	-	-	-	-	-	-	-	-	-	-	1.5[c]	4.1[c]	4.6[c]	5.1[c]
19-20	-	-	-	-	-	-	-	-	-	5.3	5.3[c]	5.3[c]	5.8[c]	5.8[c]	5.8[c]
20-21	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	11.9	12.2	12.4	13.2	13.5	14.0	14.2
21-22	-	-	-	-	-	-	-	-	-	-	-	1.3[c]	1.3[c]	1.3[c]	2.0[c]
22-23	-	-	-	-	-	-	-	-	-	-	4.1[e]	7.1[d]	7.1[d]	7.4[d]	7.6[d]
23-24	-	-	-	-	-	-	-	-	-	-	5.3[c]	6.4[d]	6.4[d]	6.4[c]	9.1[c]
24-25	-	-	-	-	-	-	-	-	-	-	5.8[c]	5.3[c]	6.6[c]	6.6[c]	6.6[c]
25-26	-	-	-	-	.25[d]	10.2	10.2	10.2	11.7	11.7	11.9	11.9	12.2	12.2	12.4
26-27	-	-	-	-	-	-	4.6[c]	4.6[c]	5.1[c]	5.3[c]	6.9[c]	7.9[c]	7.9[c]	7.9[c]	7.9[c]
27-28	-	-	-	-	-	.25[i]	.25[i]	.25[j]	.25[i]	.25[j]	.25[i]	3.8[i]	7.1[i]	7.1[i]	7.1[i]
28-29	-	-	-	-	-	-	-	-	-	-	5.1[c]	5.3[c]	6.[illegible][c]	6.6[c]	6.6[c]
29-30	-	-	-	-	9.9	9.9	10.2	10.2	10.4	10.9	10.9	11.2	11.2	11.2	11.2
30-31	-	-	-	-	-	-	-	-	-	-	-	3.8[c]	4.1[c]	4.6[c]	4.6[c]
31-32	-	-	-	-	-	-	-	-	-	-	-	1.3[c]	1.8[c]	1.8[c]	4.1[c]
32-33	-	10.4	10.4	10.4	10.4	10.4	10.4	10.4	11.4	11.7	11.7	11.7	11.7	11.9	11.9
33-34	-	-	-	-	-	-	-	5.1[c]	6.1[c]	6.1[c]	6.6[c]	6.9[c]	9.1[c]	9.1[c]	9.1[c]
34-35	-	-	-	-	-	-	-	-	-	-	.25[i]	3.6[i]	3.6[g]	3.6[g]	3.6[g]
35-36	-	-	-	-	-	-	.25[e]	.25[f]	.25[f]	3.3[d]	9.7	9.7	10.2	10.2	10.2
36-37	-	-	-	-	-	-	-	-	-	4.3[c]	4.3[c]	4.3[c]	4.3[c]	4.3[c]	6.1[c]
37-38	-	-	-	-	-	-	3.6[c]	3.6[c]	3.6[c]	3.6[c]	3.6[c]	3.6[c]	4.1[c]	4.1[c]	4.6[c]
38-39	-	5.8[d]	8.9	9.4	10.2	10.2	10.2	10.2	10.2	11.7	11.9	12.4	12.7	12.7	12.7
39-40	-	-	-	-	-	-	-	-	-	-	-	1.3[c]	2.0[c]	2.0[c]	4.6[c]
40-41	-	-	-	-	-	-	.25[e]	.25[f]	.25[f]	.25[d]	3.1[d]	3.1[d]	3.1[d]	3.3[d]	4.1[d]
41-42	-	-	-	-	-	-	-	-	-	-	-	1.8[c]	1.8[c]	1.8[c]	4.8[c]
42-43	-	-	-	-	-	-	-	-	-	-	-	2.8[c]	2.8[c]	4.1[c]	4.3[c]
43-44	-	8.6	10.2	10.2	10.2	10.2	10.2	10.2	11.2	11.4	12.2	12.2	12.2	12.2	12.2
44-45	-	-	-	-	-	-	-	5.3[c]	5.6[c]	5.6[c]	5.6[c]	6.4[c]	6.6[c]	6.6[c]	6.6[c]
45-46	-	-	-	-	-	-	-	-	-	-	6.6[c]	6.6[c]	6.6[c]	6.9[c]	6.9[c]
46-47	-	-	-	-	-	.25[e]	.25[e]	5.3[f]	10.2[d]	10.2	10.2	10.4	10.4	10.4	10.4
47-48	-	-	-	-	-	-	-	-	-	-	5.6[c]	5.6[c]	8.1[c]	8.1[c]	8.1[c]
48-49	-	-	-	-	4.9[c]	5.4[c]	5.7[c]	5.7[c]	5.7[c]	5.7[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	7.1[c]
49-50	10.2	10.2	10.2	10.2	10.4	10.4	10.4	10.4	11.2	11.2	11.2	11.2	11.4	11.7	11.7
50-51	-	-	-	-	-	-	-	-	-	-	4.8[c]	4.8[c]	4.8[c]	5.1[c]	5.1[c]
51-52	-	-	-	-	-	-	-	-	-	-	-	1.3[c]	3.1[c]	3.1[c]	5.3[c]
52-53	-	-	-	.25[d]	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.7	11.2	11.2
53-1	-	-	-	-	-	-	-	4.8[c]	5.6[c]	5.6[c]	5.6[c]	7.1[c]	7.1[c]	7.1[c]	7.1[c]

Table 29 (cont.)

Crack Location[a]	Crack Length at Given Cycle, mm[b] 4025	4525	5025	5525	6025	6525	7025	7525	8025	8525	9025	9525	10,025
1-2	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]
2-3	11.7	11.7	11.9	11.9	11.9	11.9	11.9	11.9	12.2	12.4	12.4	12.4	12.7
3-4	6.4[e]	6.4[e]	6.4[e]	6.4[e]	7.9[e]	7.9[e]	7.9[e]	7.9[e]	7.9[e]	7.9[e]	7.9[e]	7.9[e]	7.9[e]
4-5	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	7.1[c]	7.1[c]	7.1[c]	7.1[c]	7.1[c]	7.1[c]	7.1[c]	7.1[c]
5-6	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]
6-7	13.0	13.0	14.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.5	15.5	17.5
7-8	5.8[c]	5.8[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.6[c]
8-9	6.1[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	9.7[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]
9-10	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
10-11	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.2[h]	10.9[h]
11-12	4.6[e]	4.8[e]	4.8[e]	4.8[e]	5.1[e]	5.6[e]	5.6[e]	5.6[e]	5.6[e]	5.6[e]	6.4[e]	6.4[e]	6.4[e]
12-13	5.1[c]	5.3[c]	5.3[c]	5.3[c]	5.3[c]	5.3[c]	5.3[c]	5.6[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]
13-14	11.2	11.2	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.9	12.7	12.7	12.7
14-15	2.0[c]	2.0[c]	2.0[c]	2.0[c]	2.0[c]	3.3[c]	3.3[c]	3.3[c]	3.3[c]	3.3[c]	3.3[c]	3.3[c]	3.3[c]
15-16	4.3[c]	6.1[c]	6.1[c]	6.4[c]	6.4[c]	6.4[c]	7.4[c]	7.4[c]	7.4[c]	7.4[c]	7.4[c]	7.4[c]	7.4[c]
16-17	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	11.4	11.4	11.4
17-18	3.6[c]	3.6[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	3.8[c]	9.4[c]	9.4[c]	9.4[c]	9.4[c]
18-19	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	7.1[c]	7.1[c]	7.1[c]	7.1[c]
19-20	5.8[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	6.4[c]	6.4[c]	6.4[c]	6.9[c]	7.1[c]	7.1[c]	7.1[c]
20-21	15.0	15.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	18.0	19.6
21-22	5.3[c]	5.3[c]	5.3[c]	5.3[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]	5.6[c]
22-23	8.9[d]	9.7[d]	9.7[d]	9.7[d]	9.7[d]	9.7[d]	10.2[d]	10.2[d]	10.2[d]	10.2[d]	10.2[d]	10.2[d]	10.2[d]
23-24	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]
24-25	6.6[c]	6.9[c]	6.9[c]	6.9[c]	6.9[c]	6.9[c]	7.1[c]	8.9[c]	9.1[c]	9.1[c]	9.1[c]	9.1[c]	9.7[c]
25-26	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.7	12.7
26-27	8.4[c]	9.9[c]	9.9[c]	10.2[c]	10.2[c]	10.2[c]	10.9[c]	10.9[c]	10.9[c]	10.9[c]	10.9[c]	10.9[c]	11.2[c]
27-28	7.6[i]	7.6[i]	7.6[g]	7.6[g]	7.6[g]	7.6[g]	7.6[g]	7.6[g]	7.6[g]	7.6[g]	7.6[g]	7.6[g]	7.6[g]
28-29	6.6[c]	6.6[c]	6.6[c]	6.6[c]	6.6[c]	7.1[c]	8.6[c]	8.6[c]	8.9[c]	8.9[c]	8.9[c]	8.9[c]	8.9[c]
29-30	11.2	11.2	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.9	11.9	12.2
30-31	5.3[c]	5.3[c]	7.1[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]
31-32	4.1[c]	4.1[c]	4.1[c]	4.1[c]	4.1[c]	4.1[c]	5.6[c]	5.6[c]	5.6[c]	6.4[c]	6.4[c]	6.4[c]	6.9[c]
32-33	11.9	11.9	11.9	12.2	12.2	12.2	12.2	12.7	12.7	12.7	13.2	14.0	14.0
33-34	9.1[c]	9.1[c]	9.1[c]	9.1[c]	9.1[c]	9.7[c]	9.7[c]	9.7[c]	9.7[c]	9.7[c]	9.7[c]	9.7[c]	9.7[c]
34-35	4.1[g]	6.1[g]	6.1[g]	6.1[g]	6.1[g]	6.1[g]	6.1[g]	6.1[g]	6.4[g]	6.4[g]	6.4[g]	7.1[g]	7.1[g]
35-36	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.4	10.4	10.9	10.9	10.9
36-37	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.1[c]	6.4[c]	6.4[c]	6.4[c]
37-38	5.3[c]	5.3[c]	5.8[i]	5.8[i]	5.8[i]	5.8[i]	5.8[i]	5.8[i]	5.8[i]	5.8[i]	5.8[i]	5.8[i]	5.8[i]
38-39	14.0	14.2	14.2	14.2	14.5	14.5	14.5	14.5	16.0	16.0	16.0	16.5	17.0
39-40	4.6[c]	4.6[c]	4.6[c]	4.8[c]	4.8[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]	5.1[c]	5.6[c]
40-41	5.8[d]	6.4	6.6	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
41-42	4.8[c]	4.8[c]	4.8[c]	4.8[c]	4.8[c]	5.1[c]	5.1[c]	5.1[c]	5.6[c]	5.6[c]	5.6[c]	6.6[c]	6.6[c]
42-43	5.1[c]	5.1[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	5.8[c]	6.4[c]	6.6[c]	6.6[c]
43-44	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.4	12.4	13.2	13.2	13.7
44-45	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]	8.4[c]
45-46	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]
46-47	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	11.4
47-48	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]
48-49	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]	8.1[c]
49-50	11.7	11.7	11.7	12.2	12.2	12.2	12.2	12.2	12.7	12.7	13.2	13.2	13.7
50-51	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]
51-52	5.3[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	6.4[c]	7.1[c]
52-53	11.2	11.2	11.4	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.9	12.2	12.7
53-1	7.1[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	7.6[c]	8.1[c]

[a]Location with reference to blades numbered clockwise from the reference mark.

[b]All cracks extend across the disk at the blade root except where noted.

[c]Root cracks not present.

[d]Root crack 1/2 disk thickness from shaft side to disk side.

[e]Root crack 1/4 disk thickness from shaft side to disk side.

[f]Root crack 1/3 disk thickness from shaft side to disk side.

[g]Root crack 1/3 disk thickness from disk side to shaft side.

[h]Root crack 2/3 disk thickness from shaft side to disk side.

[i]Root crack 1/4 disk thickness from disk side to shaft side.

Table 30

CRACK INITIATION AND PROPAGATION FOR POCKETED WHEEL P4

Crack Location[a]	Crack Length at Given Cycle, mm[b]										
	25	50	100	200	300	500	700	1000	1500	2000	2500
1-2	-	-	-	-	3.1[c]	8.1[c]	8.6[c]	8.6[c]	8.6[c]	8.6[c]	8.6[c]
2-3	-	-	-	-	-	.25[d]	9.4[d]	9.4[d]	9.4[d]	9.4[d]	9.9[d]
3-4	.25[e]	.25[f]	.25[f]	.25[f]	9.1[f]	9.4[f]	9.4[f]	9.4[f]	9.4[f]	9.4[f]	9.7[f]
4-5	4.3	10.2	10.4	10.4	10.4	10.4	11.4	11.4	11.9	12.7	12.7
5-6	-	-	-	-	-	-	-	-	-	5.6[d]	5.6[d]
6-7	-	-	-	-	-	6.1[g]	C.4[g]	8.4[f]	8.4[f]	9.4[f]	9.4[f]
7-8	-	-	-	.25[e]	.25[e]	6.1[c]	9.1[c]	9.1[c]	10.4[c]	10.4[c]	10.4
8-9	-	-	-	-	-	-	-	-	-	7.1[d]	7.1[d]
9-10	-	-	-	-	-	-	-	-	5.3[d]	5.6[d]	5.6[d]
10-11	9.7	10.2	10.2	10.2	10.2	10.2	11.7	12.4	12.4	12.7	13.0
11-12	-	-	-	-	-	-	-	-	-	5.3[d]	5.3[d]
12-13	-	-	-	-	-	-	-	2.0[d]	4.3[d]	5.1[d]	5.1[d]
13-14	-	-	-	-	-	-	-	6.4[e]	6.4[e]	10.2[c]	10.2[c]
14-15	-	-	-	-	-	-	-	3.3[d]	3.6[d]	5.3[d]	5.6[d]
15-16	9.9	10.4	10.4	10.4	10.4	10.4	11.4	11.7	11.9	12.4	12.4
16-17	-	-	-	-	-	8.4[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]
17-18	-	-	-	-	-	-	-	-	-	3.6[d]	3.6[d]
18-19	-	-	-	.25[e]	7.6	10.2	10.2	10.2	10.2	11.4	11.4
19-20	-	-	-	-	-	4.8[d]	8.4[d]	8.4[d]	8.9[d]	8.9[g]	8.9[g]
20-21	-	-	-	-	-	-	-	-	-	6.6[d]	6.6[d]
21-22	-	-	-	-	6.4[d]	7.6[d]	7.9[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]
22-23	9.9	10.2	10.4	10.4	10.4	10.4	11.7	11.7	12.2	12.2	13.0
23-24	-	-	-	-	-	-	-	-	-	4.6[d]	4.8[d]
24-25	-	-	-	-	-	-	-	-	4.8[d]	4.8[d]	4.8[d]
25-26	.25	1.5	4.1	10.2	10.2	10.2	11.2	11.2	11.4	11.7	12.4
26-27	-	-	-	-	-	-	-	4.8[d]	4.8[d]	4.8[d]	4.8[d]
27-28	-	-	-	-	-	-	-	-	-	4.8[i]	4.8[i]
28-29	-	-	-	-	-	.25[h]	.25[h]	4.1[h]	4.8[e]	7.1[e]	7.4[e]
29-30	-	-	-	-	-	-	-	-	-	-	-
30-31	10.4	10.4	10.4	10.4	10.4	10.4	11.7	12.2	12.2	13.0	13.0
31-32	-	-	-	-	-	-	-	-	-	-	1.5[d]
32-33	-	-	-	-	-	-	-	-	3.1[d]	4.1[d]	4.6[d]
33-34	-	-	-	-	-	-	-	-	4.1[d]	4.1[d]	4.6[d]
34-35	.25[e]	6.1[e]	9.1	10.2	10.2	10.2	11.2	11.4	11.7	11.9	12.2
35-36	-	-	-	-	-	-	-	4.1[d]	5.6[d]	5.6[d]	5.6[d]
36-37	-	-	-	-	-	-	-	.25[h]	.25[e]	9.9[e]	9.9[e]
37-38	-	-	-	-	-	.25[h]	.25[h]	3.6[e]	7.6[e]	10.2[e]	10.2[e]
38-39	-	-	-	-	-	-	-	4.6[d]	5.1[d]	5.1[d]	5.6[d]
39-40	10.2	10.2	10.2	10.2	10.2	10.2	10.4	10.9	11.2	11.4	11.7
40-41	-	-	-	-	-	-	-	-	5.3[d]	5.8[d]	6.1[d]
41-42	-	-	-	-	-	-	-	-	2.3[d]	7.6[d]	7.6[d]
42-43	-	-	-	-	-	-	-	4.8[d]	5.6[d]	10.2[d]	10.2[d]
43-44	9.1	10.2	10.2	10.2	10.2	10.2	11.4	11.7	11.7	12.4	12.4
44-45	-	-	-	-	-	-	4.3[d]	5.8[d]	6.9[d]	7.1[d]	7.1[d]
45-46	-	-	-	-	9.1[g]	9.1[g]	9.1[g]	9.1[g]	9.4[f]	9.9	10.2
46-47	-	-	-	-	-	-	.25[c]	8.6[c]	8.6[c]	10.2[c]	10.2[c]
47-48	-	-	-	-	-	-	-	-	-	7.6[d]	7.6[d]
48-49	-	-	-	-	-	-	5.6[d]	5.6[d]	6.9[d]	7.6[d]	7.6[d]
49-50	9.1	10.2	10.2	10.2	10.2	10.2	11.7	12.7	12.7	12.7	13.2
50-51	-	-	-	-	-	-	-	-	.76[d]	2.5[d]	2.5[d]
51-52	-	-	-	-	-	-	-	.25[e]	2.0[c]	10.2[c]	10.2[c]
52-53	-	-	-	.25[f]	.25[f]	.25[f]	.25[f]	.25[f]	9.1[f]	9.4[f]	9.7[f]
53-1	-	-	.25[d]	5.3[d]	6.4[d]	7.4[d]	7.4[d]	7.4[c]	9.9[c]	10.2[c]	11.2[c]

Table 30 (cont.)

Crack Location[a]	Crack Length at Given Cycle, mm[b]										
	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000
1-2	8.9	9.4	9.7	9.7	9.7	10.2	10.2	10.2	10.2	10.2	10.2
2-3	9.9[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]	9.9[d]
3-4	9.7[f]	9.7[f]	9.9[j]	9.9[j]	9.9[j]	9.9[j]	9.9[j]	9.9[j]	9.9[j]	9.9[j]	9.9[j]
4-5	12.7	13.0	13.0	13.0	13.0	13.2	13.2	14.0	14.0	14.7	15.0
5-6	5.6[d]	5.6[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]
6-7	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]
7-8	10.4	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7
8-9	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]
9-10	5.6[d]	6.4[d]	6.4[d]	6.6[d]	6.6[d]	6.6[d]	6.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]
10-11	13.2	13.2	13.2	13.2	14.0	14.2	14.2	14.5	14.7	15.7	15.7
11-12	5.6[d]	5.8[d]	6.6[d]	6.6[d]	6.6[d]	6.6[d]	6.6[d]	6.6[d]	7.1[d]	7.1[d]	7.6[d]
12-13	6.1[d]	9.7[d]	9.7[d]	9.7[d]	9.7[d]	9.9[g]	9.9[g]	9.9[g]	9.9[g]	9.9[g]	9.9[f]
13-14	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]
14-15	5.6[d]	5.6[d]	5.6[d]	5.8[d]	5.8[d]	5.8[d]	5.8[d]	5.8[d]	5.8[d]	5.8[d]	5.8[d]
15-16	12.4	12.4	12.4	12.4	14.0	14.0	14.0	14.7	14.7	14.7	14.7
16-17	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]	8.6[d]
17-18	3.8[d]	3.8[d]	5.3[d]	5.6[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]
18-19	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.9	11.9	11.9	11.9
19-20	8.9[g]	8.9[g]	8.9[g]	8.9[g]	8.9[g]	8.9[g]	9.7[g]	9.7[g]	9.7[g]	9.7[g]	9.7[g]
20-21	6.9[d]	6.9[d]	7.1[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]
21-22	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]
22-23	13.0	13.0	13.0	13.0	13.5	13.5	13.7	13.7	13.7	14.2	14.2
23-24	4.8[d]	5.1[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.6[d]
24-25	5.1[d]	5.3[d]	5.3[d]	6.4[d]	6.4[d]	6.4[d]	6.9[d]	6.9[d]	7.1[d]	7.1[d]	7.1[d]
25-26	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.7	12.7	13.0
26-27	4.8[d]	5.1[d]	5.1[d]	6.1[d]	6.1[d]	6.1[d]	6.1[d]	6.1[d]	6.1[d]	6.1[d]	6.1[d]
27-28	4.8[i]	6.6[i]	6.6[i]	6.6[i]	6.6[i]	7.1[i]	7.1[i]	7.1[i]	7.1[i]	7.1[i]	7.1[i]
28-29	7.6[f]	7.9[f]	8.1[f]	8.1[f]	8.1[f]	8.1[f]	8.1[f]	8.1[f]	8.1[f]	8.1[f]	8.1[f]
29-30	2.5[d]	2.5[d]	2.5[d]	2.5[d]	2.5[d]	2.5[d]	5.1[d]	5.1[d]	5.8[d]	5.8[d]	5.8[d]
30-31	13.0	13.0	13.0	13.0	14.5	14.5	14.5	14.5	16.0	16.0	16.0
31-32	3.1[d]	3.6[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]
32-33	4.8[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	5.3[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]	6.4[d]
33-34	4.6[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]	5.1[d]
34-35	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	13.5	14.7	14.7
35-36	5.6[d]	5.6[d]	5.6[d]	5.6[d]	6.9[d]	6.9[d]	6.9[d]	6.9[d]	6.9[d]	6.9[d]	6.9[d]
36-37	9.9[e]	9.9[e]	9.9[e]	9.9[e]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9[c]	9.9
37-38	10.2[e]	10.2[e]	10.2[e]	10.2[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]	10.4[c]
38-39	6.4[d]	6.4[d]	6.9[d]	7.1[d]	7.1[d]	7.1[d]	7.1[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]
39-40	11.7	11.9	11.9	11.9	12.4	12.4	12.4	12.4	12.7	13.5	13.7
40-41	6.4[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	7.6[d]	8.1[d]
41-42	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]
42-43	10.4[d]	10.4[h]	10.4[h]	10.4[h]	10.4[h]	10.4[h]	10.4[h]	10.4[h]	10.4[h]	10.4[h]	10.4[c]
43-44	12.4	12.7	12.7	12.7	13.7	13.7	13.7	13.7	14.0	14.0	14.0
44-45	7.1[d]	8.9[d]	9.1[d]	9.1[d]	9.1[d]	9.1[d]	9.1[d]	9.1[d]	9.1[d]	9.1[d]	9.1[d]
45-46	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
46-47	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]
47-48	7.6[d]	7.6[d]	7.6[d]	7.6[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]
48-49	8.1[d]	8.4[d]	8.4[d]	8.4[d]	8.9[d]	8.9[d]	8.9[d]	8.9[d]	8.9[d]	8.9[d]	8.9[d]
49-50	13.5	13.5	13.5	13.5	13.5	13.5	15.2	15.2	15.7	16.0	16.0
50-51	3.3[d]	3.3[d]	7.6[d]	7.6[d]	7.9[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]	8.1[d]
51-52	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]	10.2[c]
52-53	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]	9.7[f]
53-1	11.2[c]	11.2[k]	11.2[k]	11.2[k]	11.2[k]	11.2[k]	11.2[k]	11.4[k]	11.4[k]	11.4[k]	11.4[k]

[a]Location with reference to blades numbered clockwise from the reference mark.

[b]All cracks extend across the disk at the blade root except where noted.

[c]Root crack 1/2 disk thickness from shaft side to disk side.

[d]Root crack not present.

[e]Root crack 1/3 disk thickness from shaft side to disk side.

[f]Root crack 1/2 disk thickness from disk side to shaft side.

[g]Root crack 1/4 disk thickness from disk side to shaft side.

[h]Root crack 1/4 disk thickness from shaft side to disk side.

[i]Root crack 1/3 disk thickness from disk side to shaft side.

[j]Root crack 3/4 disk thickness from disk side to shaft side.

[k]Root crack 3/4 disk thickness from shaft side to disk side.

Table 31

CRACK INITIATION AND PROPAGATION FOR POCKETED WHEEL P5

Crack Location[a]	Crack Length at Given Cycle, mm[b]															
	25	50	100	200	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1-2	-	-	-	5.8	5.8	6.4	7.6	7.6	7.6	7.6	7.6	8.1	8.1	8.1	8.1	10.2
2-3	-	-	-	-	-	-	1.3	1.3	1.8	3.3	3.6	3.6	3.8	3.8	3.8	3.8
3-4	-	-[c]	-[c]	-[d]	-[d]	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	10.8	10.8	10.8
4-5	-	-	-	-	-	-	.76[f]	2.8[f]	5.6[f]	5.6[f]	5.6[f]	5.8[f]	5.8[f]	5.8[f]	5.8[f]	6.6[g]
5-6	-	-	-	-	-	-[d]	1.3[d]	1.3[d]	1.8[d]	1.8[d]	1.8[d]	1.8[d]	3.6[d]	3.6[d]	3.8[d]	3.8[d]
6-7	-	-	-	-	-	1.5	1.5	1.5[c]	4.1[c]	5.3[c]	5.3[c]	5.3[c]	6.4[c]	6.4[c]	7.1[d]	7.1[d]
7-8	-	-	-	-	-	3.8	3.8	3.8	4.1	4.1	4.6	4.6	4.6	4.6	5.1	5.1
8-9	-	8.4	8.4	8.4	8.4	8.4	8.4	10.3	11.3	12.0	12.5	13.5	13.8	14.6	17.6	18.4
9-10	-	-	-	-	-	.76	.76	.76	1.3	1.3	1.3	1.3	3.6	3.8	3.8	3.8
10-11	-	-	-	-	-	-	1.3	1.3	2.0	2.0	2.0	2.8	2.8	2.8	3.1	3.1
11-12	-	-[d]	8.4	8.4	8.4	8.4	8.4	10.3	10.8	11.3	11.5	11.8	12.0	12.5	12.5	13.0
12-13	-	-	-	-	1.5	3.3	3.3	4.1	6.6	6.6	6.6	7.1[c]	7.1[c]	7.1[c]	7.1[c]	7.1[d]
13-14	-	-	-	-	-	-	-	-	3.8	3.8	3.8	5.1	5.1	5.1	5.1	5.1[f]
14-15	-	-	-	-	-	-	1.0	1.0	3.8	3.8[f]	5.3[f]	5.3[f]	5.3[f]	5.3[f]	7.6[g]	7.6[g]
15-16	-	-	-	.76	1.8	2.0[c]	5.1[c]	5.8[c]	8.4[c]	8.4[c]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.4[d]	8.6[d]
16-17	-	-	-	2.5	4.3	5.3	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.6
17-18	-	-	8.6	8.6	8.6	8.6	10.5	10.7	11.7	12.2	13.0	13.3	14.0	14.3	14.8	18.3
18-19	-	-	-	-	-	4.6	4.6	5.1	6.4	6.9	6.9	6.9	7.6	7.6	7.6	7.6
19-20	-	-	-	-	-	-	1.8	1.8	4.8	5.1	5.1	5.1	5.1	5.3	5.3	5.3
20-21	-	-	-	-	-	.76[c]	4.1[c]	6.4[c]	8.4[c]	8.4	8.4	8.4	8.4	8.4	8.4	8.4
21-22	-	2.5	5.6	6.4	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	8.4	8.4	8.4	8.4
22-23	-	2.5	3.3	4.6	5.1	6.4	6.4	6.4	6.9	6.9	6.9	6.9	6.9	7.1	7.1	7.1
23-24	8.1	8.1	8.4	8.[illegible]	8.4	8.4	10.3	11.0	11.3	11.5	12.3	12.5	12.8	13.3	14.1	15.1
24-25	-	-	3.1	4.6	5.3	6.1	6.4	6.4	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
25-26	-	-	3.1	3.3	3.8	3.8	3.8	3.8	3.8	3.8	3.8	7.4	7.4	7.4	7.4	7.4
26-27	-	-	-	8.4[d]	8.4	8.4	8.4	8.4	10.3	10.3	10.8	10.8[e]	10.8	10.8	10.8	10.8
27-28	-	-	-	-	-	-	3.1	6.4	6.4	6.4	6.4	6.9[c]	6.9[c]	7.1[c]	7.1[c]	7.1[c]
28-29	-	-	-	-	-	-	-	-	-	-	-	3.6	3.6	3.8	4.1	4.1
29-30	-	-	-	-	-	-	-	2.3	3.8	4.6	4.6	4.6	5.1	5.1	5.1	6.6
30-31	-	-	9.7	9.9	10.2	10.2	10.2	10.2	11.2	11.7	11.7	13.2[e]	13.5	13.5	13.5	16.0
31-32	-	-	-	-	-	-	-	-	-	-	.51	2.8	3.6	3.6	3.6	3.6
32-33	-	-	-	-	-	-	-	-	-	-	-	.76	1.3[f]	2.5[f]	2.5[f]	4.6[f]
33-34	-	-	-	-	-	-	-	-[c]	-[c]	-[c]	1.3[c]	2.3[c]	3.1[c]	3.1[c]	3.1[c]	3.8[c]
34-35	-	-	-	-	-	-	2.8	3.1	3.8	3.8	4.6	5.8	6.4	6.4	6.4	6.4
35-36	8.1	8.6	9.7	9.7	9.7	9.7	10.2	10.2	11.4	11.9	12.7	12.7[e]	12.7	12.7	12.7	14.0
36-37	-	-	-	-	-	6.4	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
37-38	-	-	-	-	-	-	-	-	-	-	-	.51	1.3	1.3	2.0	2.5
38-39	-	-	-	-	-	-	-	-	-	-[f]	7.1[f]	9.7[f]	9.7	9.9	9.9	9.9
39-40	-	-	-	-	-	-	-	5.1[d]	6.1[d]	6.6[d]	6.6[d]	7.1[d]	7.1[d]	7.6[d]	9.9[d]	9.9[d]
40-41	-	-	-	-	-	5.6	7.1	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
41-42	7.4[d]	9.9	9.9	10.2	10.2	10.2	10.2	10.2	10.2	10.9	11.2	11.2	11.2	11.2	11.2	13.0
42-43	-	-	-	-	-	7.6	7.6	7.6	7.6	7.6	7.6	8.4	8.4	8.4	9.1[c]	9.1[c]
43-44	-	-	-	-	-	-	-	-	-	-	-	3.3	3.3	4.1	4.1	6.1
44-45	-	-	-	-	-	9.7	9.9	10.2	10.2	10.2	10.2	10.2	10.7	10.7	10.9	11.4
45-46	-	-	-	-	-	-	-	-	-	-	-	5.1	6.4	6.4	7.1	8.1
46-47	-	-	-	-	-	2.5	3.1	3.1	3.1	3.1	5.1	5.1	5.1	6.4	6.4	7.1
47-48	9.7	10.2	10.2	10.2	10.2	10.2	10.2	10.9	10.9	10.9	11.9	12.7	12.7	12.7	12.7	14.0
48-49	-	-	-	6.4	6.4	7.6	8.9	8.9	8.9	9.4	9.4	9.4	9.4	9.4	9.4	9.4
49-50	-	-	-	-	-	-	1.5	2.5	3.1	3.8	4.6	5.1	5.1	5.1	5.1	6.9
50-51	-	-	-	-	-	-	6.4	6.4	7.6	7.6[f]	8.4[f]	10.2	10.2	10.2	10.2	10.2
51-52	-	-	-	-	-	-	-	3.1[c]	10.7[c]	10.7[d]	10.7[d]	10.7[d]	10.7[d]	10.7[d]	10.7[d]	10.7[d]
52-53	-	-	-	-	-	6.4	6.9	7.4	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
53-1	-	-[d]	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.9	11.4	11.7	11.9	11.9	12.7	13.7

[a]Location with reference to blade numbered clockwise from reference mark: 1.6 mm drilled holes **located at 53-1 thru 26-27.**

[b]No cracks present at base of blades except where noted.

[c]Root crack 1/4 disk thickness from shaft side to disk side.

[d]Root crack 1/2 disk thickness from shaft side to disk side.

[f]Root crack 1/4 disk thickness from disk side to shaft side.

[g]Root crack 1/3 disk thickness from disk side to shaft side.

Table 32

CRACK INITIATION AND PROPAGATION FOR POCKETED WHEEL P6

Crack Location[a]	Crack Length at Given Cycle, mm[b] 25	50	100	200	300	500	700	1000	1500	2000	2500	3000	3500	4000	4500	5000
1-2	-	-	-	-	-	-	1.0	1.0	1.0	1.0	1.3	1.8	1.8	2.0	2.0	2.0
2-3	8.1	8.1	8.1	8.1	8.1	8.1	10.2	10.2	10.7	10.7	10.7	11.2	12.2	12.2	12.8	14.1
3-4	-	-	-	-	-	-	-	-	-	.76	1.0	1.0	2.8	2.8	3.3	3.3
4-5	-	-	-	-	-	-	.51	.51	.51	.51	.51	1.0	1.0	1.0	1.5	1.5
5-6	6.1	8.1	8.1	8.1	8.1	8.1	10.2	10.2	10.5	10.5	10.5	11.0	11.7	12.8	12.8	12.8
6-7	-	-	-	-	-	-	-	-	-	-	1.3	1.3	1.3	1.5	2.0	2.0
7-8	-	-	-	-	-	.76	.76	1.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
8-9	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	10.0	10.0	10.0	10.5	11.0	11.0	11.2	11.7
9-10	-	-	-	-	-	.76	.76	.76	1.8	1.8	1.8	2.0	2.3	2.3	2.5	2.5
10-11	-	-	-	-	-	-	.51	.51	2.0	2.0	2.5	2.8	3.6	3.6	3.6	3.8
11-12	8.4	8.4	8.4	8.4	8.4	8.4	10.6	10.6	10.6	10.9	10.9	11.4	11.9	11.9	12.1	12.4
12-13	-	-	-	-	-	-	.51	.51	.51	.51	1.3	1.3	3.1	3.1	3.1	3.1
13-14	-	-	-	-	-	-	1.3	1.3	1.3	1.5	1.5	2.5	2.5	2.5	2.5	2.8
14-15	8.4	8.4	8.4	8.4	8.4	8.4	10.2	10.5	11.0	11.3	11.3	11.5	12.3	13.1	13.6	18.1
15-16	-	-	-	-	-	-	.76	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
16-17	-	-[d]	-[d]	-[d]	-[e]	-[e]	.76[e]	.76[e]	2.0[e]	2.0[e]	2.5[e]	2.5[e]	3.3[e]	3.6[e]	3.6[e]	3.8[e]
17-18	3.6[f]	7.6[f]	7.9[g]	7.9	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	10.6	10.6	10.6	10.9
18-19	-	-	-	-	-	-	.51	.51	2.0	2.0	2.0	2.5	2.5	2.5	2.5	2.5
19-20	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	10.0	10.0	10.3	10.3	11.1	11.1	11.6	12.3
20-21	-	-	-	-	-	-	-	-	1.5	1.5	1.5	1.5	2.5	2.5	2.5	3.3
21-22	-	-	-	-	-	-	-	-	1.3	1.3	1.8	1.8	1.8	1.8	1.8	3.3
22-23	8.1	8.1	8.1	8.1	8.1	8.1	10.2	10.2	10.5	10.5	10.8	11.1	11.1	11.1	11.3	12.3
23-24	-	-	-	-	-	-	.25	.51	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
24-25	-	-	-	-	-	-	.51	.51	.51	.76	.76	.76	1.0	1.0	1.0	1.3
25-26	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	10.2	10.5	10.5	11.0	11.2	11.5	11.7	12.8
26-27	-	-	-	-	-	-	-	-	.51	.51	.51	.51	1.8	1.8	1.8	1.8
27-28	-	-	-	-	-	-	.51	1.3	1.3	1.8	1.8	1.8	1.8	1.8	1.8	2.3
28-29	7.4	8.4	8.9	8.9	9.7	9.7	9.7	9.7	11.2	11.2	11.4	11.4	11.7	11.7	11.9	12.7
31-32	8.9	8.9	8.9	8.9	9.7	9.9	10.4	10.4	11.4	11.4	11.4	11.9	11.9	12.2	12.2	13.7
32-33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.76	.76
34-35	-[f]	5.6[g]	8.6	8.6	9.4	9.4	9.4	9.4	9.9	10.2	10.2	10.2	11.2	11.2	11.7	12.4
35-36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.76
37-38	7.6	8.9	9.7	9.7	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	11.7	11.7	11.7	12.4
38-39	-	-	-	-	-	-	-	-	-	-	-	-	2.0	3.6	4.1	4.1
39-40	-	-	-	-	-	-	-	-	-	-	-	-	2.8	4.1	4.1	4.1
40-41	7.9	8.4	9.7	9.9	9.9	9.9	10.2	10.2	10.9	11.2	11.4	11.9	11.9	11.9	12.2	13.7
43-44	7.4	8.6	9.4	9.4	9.7	9.7	9.7	9.7	10.2	10.2	10.2	10.2	11.2	11.4	11.4	12.4
44-45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3
45-46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.76
46-47	7.4	8.6	9.7	9.7	10.2	10.2	10.2	10.2	10.9	10.9	10.9	11.4	11.7	11.7	12.2	12.4
47-48	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	1.5	1.5
48-49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3
49-50	7.6	8.1	8.6	8.9	9.4	9.4	9.9	9.9	9.9	9.9	9.9	11.2	11.7	11.7	11.7	12.7
52-53	7.6	8.9	9.7	9.7	9.9	9.9	9.9	9.9	9.9	9.9	10.2	10.7	11.4	11.4	12.2	12.4

[a]Location with reference to blade numbered clockwise from reference mark: 1.6 mm drilled holes in pockets **located at 53-1 thru 26-27.**

[b]No cracks present at base of blades except where noted.

[d]Root crack 1/4 disk thickness form shaft side to disk side.

[e]Root crack 1/2 disk thickness from shaft side to disk side.

[f]Root crack 1/4 disk thickness from disk side to shaft side.

[g]Root crack 1/2 disk thickness from disk side to shaft side.

Table 33

BLADE CRACK INITIATION AND PROPAGATION FOR POCKETED WHEEL P1

Crack Location[a]	Crack Length at Given Cycle, mm										
	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10,000
					Wheel P1						
8	No Cracks	.25	.25	.25	.25	.25	.25	.25	.25	.51	.51
25		-	-	-	-	-	-	-	-	.25	.25
28		-	-	-	-	.25	.25	.25	.25	.25	.25
31		-	-	-	-	.25	.25	.25	.25	.25	.25
34		-	-	-	.25	.25	.25	.25	.25	.25	.25
46		-	-	-	-	-	-	-	-	.25	.25

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 34

BLADE CRACK INITIATION AND PROPAGATION FOR POCKETED WHEELS P2 AND P3

Crack Location[a]	Crack Length at Given Cycle, mm										
	5025	5525	6025	6525	7025	7525	8025	8525	9025	9525	10,025
					Wheel P2						
19	No Cracks	.25	.25	.25	.25	.25	.25				
24		-	-	-	-	.25	.25				
30		-	-	-	-	-	.25				
48		-	-	-	-	-	.25				
					Wheel P3						
1		-	-	-	.25	.25	.25	.25	.25	.25	.25
4		-	-	-	-	-	-	-	-	-	.51
15		-	-	-	.25	.25	.51	.51	.51	.51	.51
37		-	-	-	.25	.25	.51	.51	.51	.51	.51
38		.25	.25	.25	.25	.25	.25	.25	.51	.51	.51
41		-	-	-	-	-	-	-	-	-	.51
42		.25	.25	.25	.25	.51	.51	.51	.51	.51	.51

[a]Location with reference to blade numbered clockwise from the reference mark.

Table 35

BLADE CRACK INITIATION AND PROPAGATION FOR POCKETED WHEELS P4, P5, AND P6

Crack Location[a]	Crack Length at Given Cycle, mm 2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000
							Wheel P4						
1							No Cracks	-	.25	.25	.25	.25	.25
4								-	-	-	-	.25	.25
5								-	-	-	.25	.25	.25
6								-	-	-	-	.25	.25
15								.25	.25	.25	.25	.25	.25
16								.25	.25	.25	.25	.25	.25
36								-	-	-	1.0	1.0	1.0
							Wheel P5						
2	No Cracks	-	-	.51	.51	.51	.51						
6		-	-	.25	.25	.25	.25						
7		-	-	-	-	.25	.25						
10		-	.25	.25	.25	.25	.25						
11		.25	.25	.25	.25	.25	.51						
13		-	-	.25	.25	.25	.51						
14		-	-	-	-	-	.25						
15		-	-	-	-	-	.25						
18		-	-	.25	.25	.25	.25						
20		-	-	-	-	.25	.25						
23		-	-	-	-	-	.25						
32		-	-	.25	.25	.25	.25						
							Wheel P6						
1	No Cracks	-	-	-	-	-	.25						
7		-	-	.25	.25	.25	.25						
11		-	-	.25	.25	.51	.76						
21		-	-	-	.25	.25	.25						
22		-	-	.25	.25	.25	.25						
24		-	-	-	-	.25	.51						
25		-	.25	.25	.25	.25	.25						
26		-	-	-	-	-	.25						
36		-	-	-	-	.25	.25						
39		-	-	-	.25	.25	.25						
41		.25	.25	.25	.25	.25	.76						

[a]Location with reference to blade numbered clockwise from the reference mark.

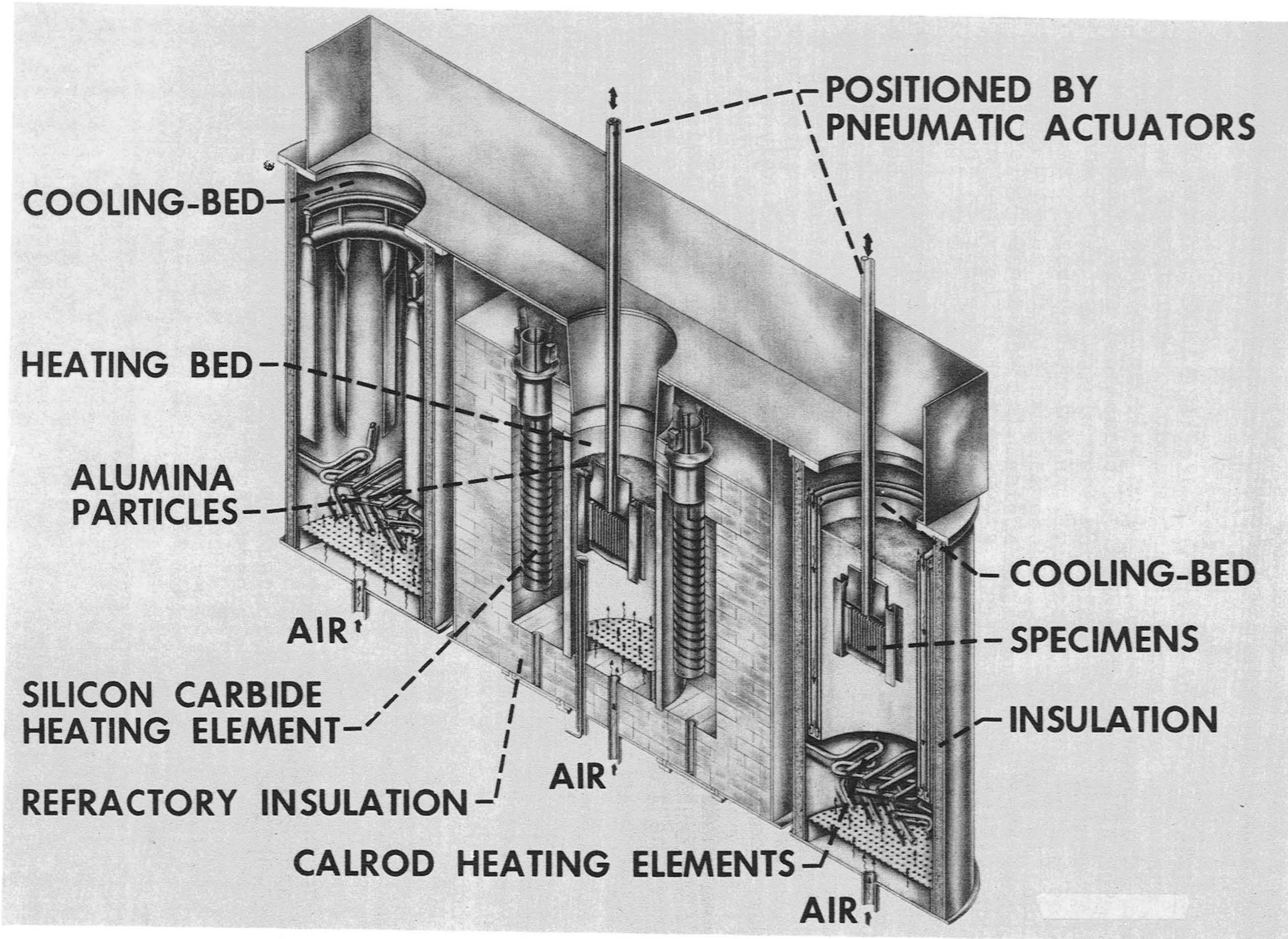
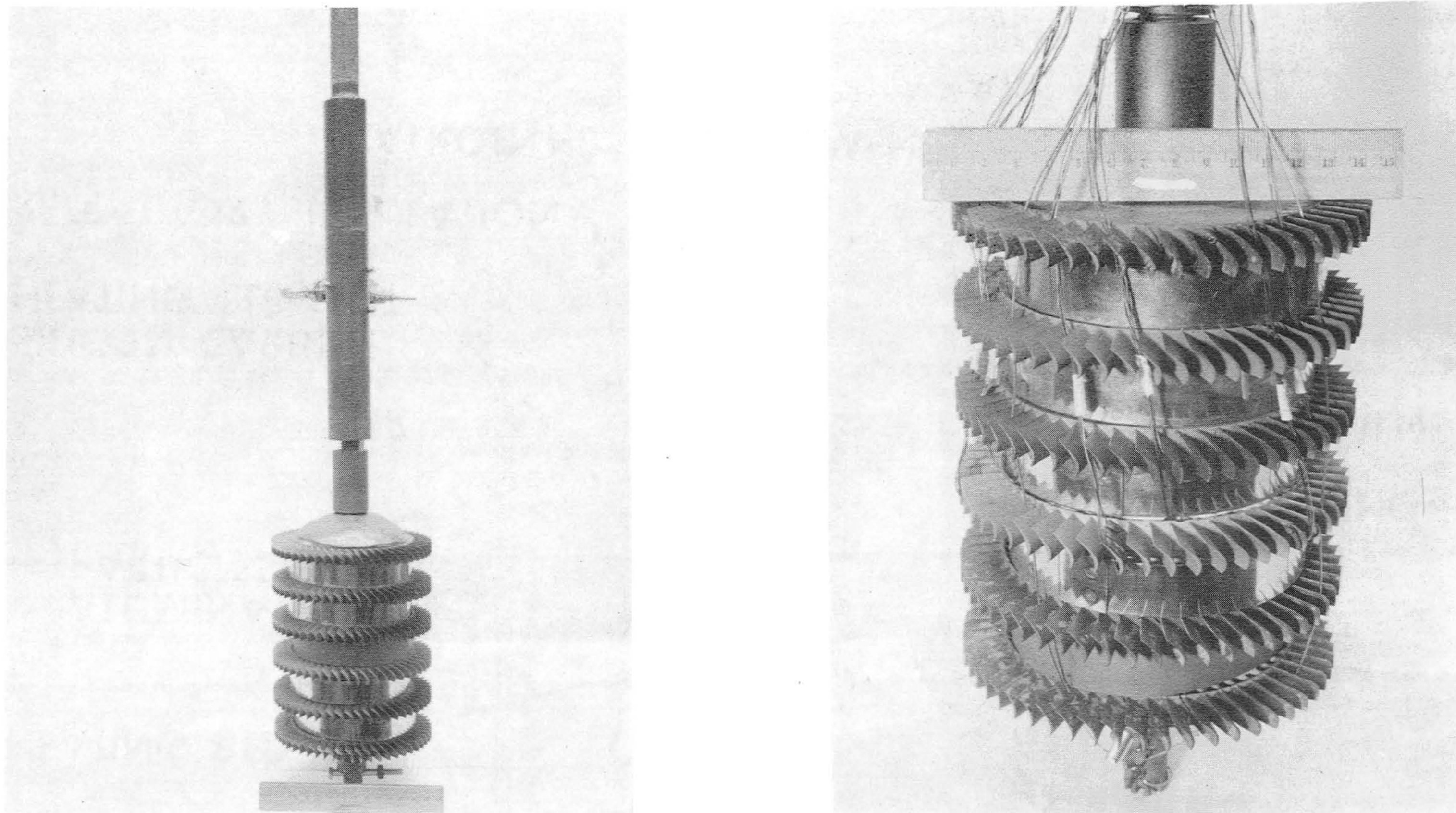


Figure 1
Fluidized Bed Thermal Fatigue Facility



Neg. No. 51534 1/4X

(a) Test stack in fixture

Neg. No. 51516 1X

(b) Thermocouple installation

Figure 2

Fixture for Thermal Fatigue Testing and Thermocouple Attachment
for Temperature Calibration

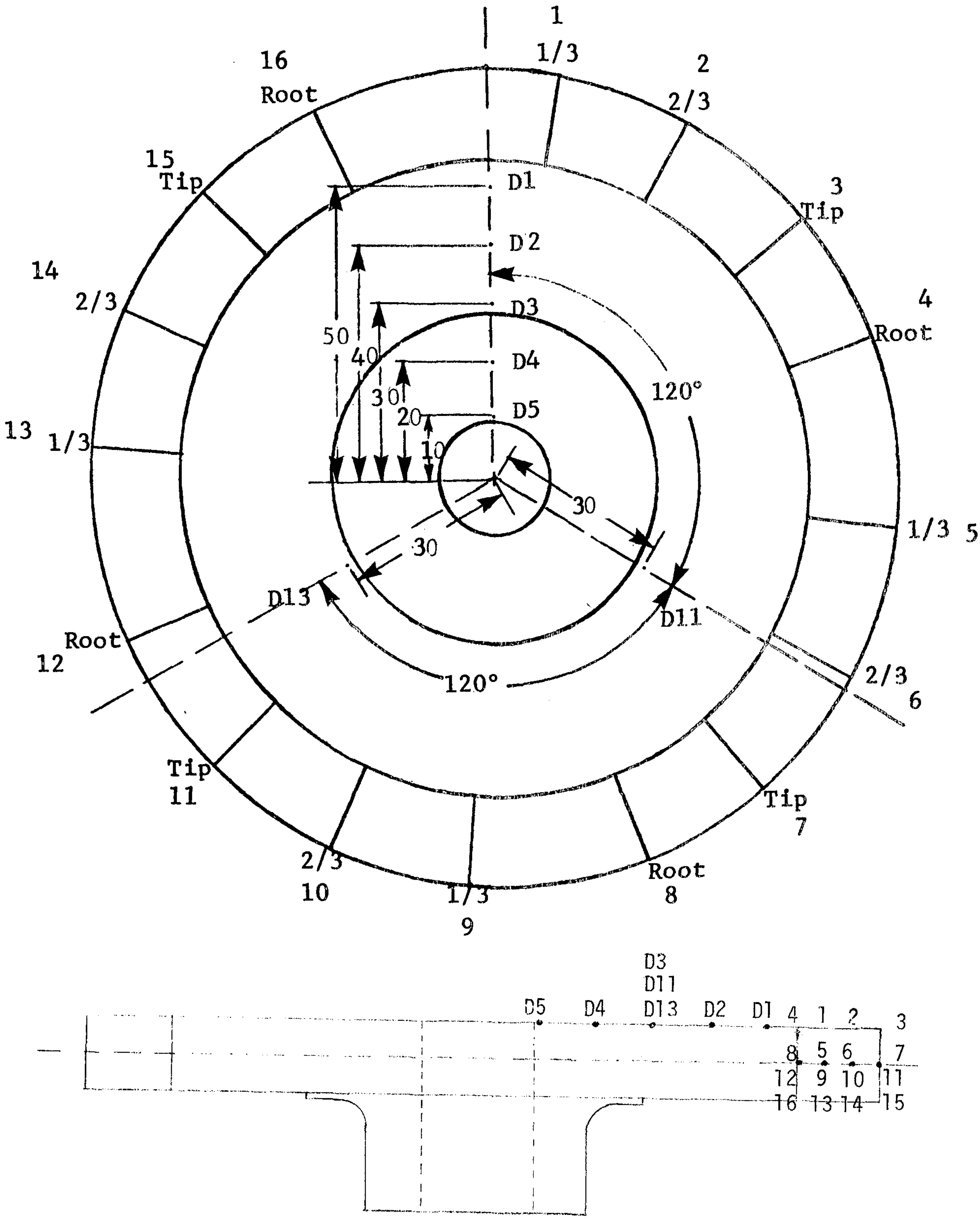


Figure 3

Thermocouple Locations on Disk Side (D) of Automotive Turbine Wheel During Calibrations 1 and 2.
(All dimensions in mm.)

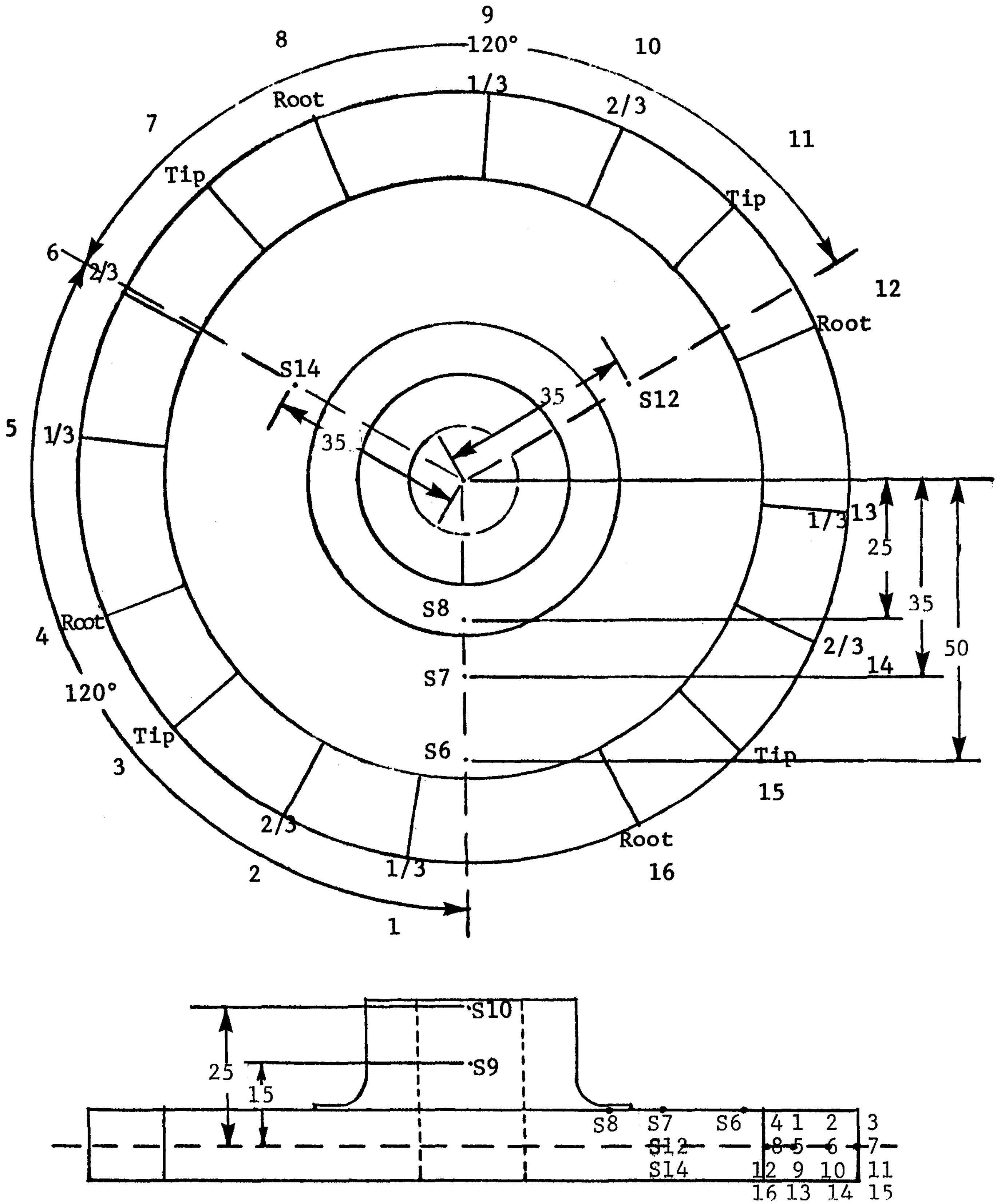


Figure 4

Thermocouple Locations on Shaft Side (S) of Automotive
Turbine Wheel During Calibrations 1 and 2.
(All dimensions in mm.)

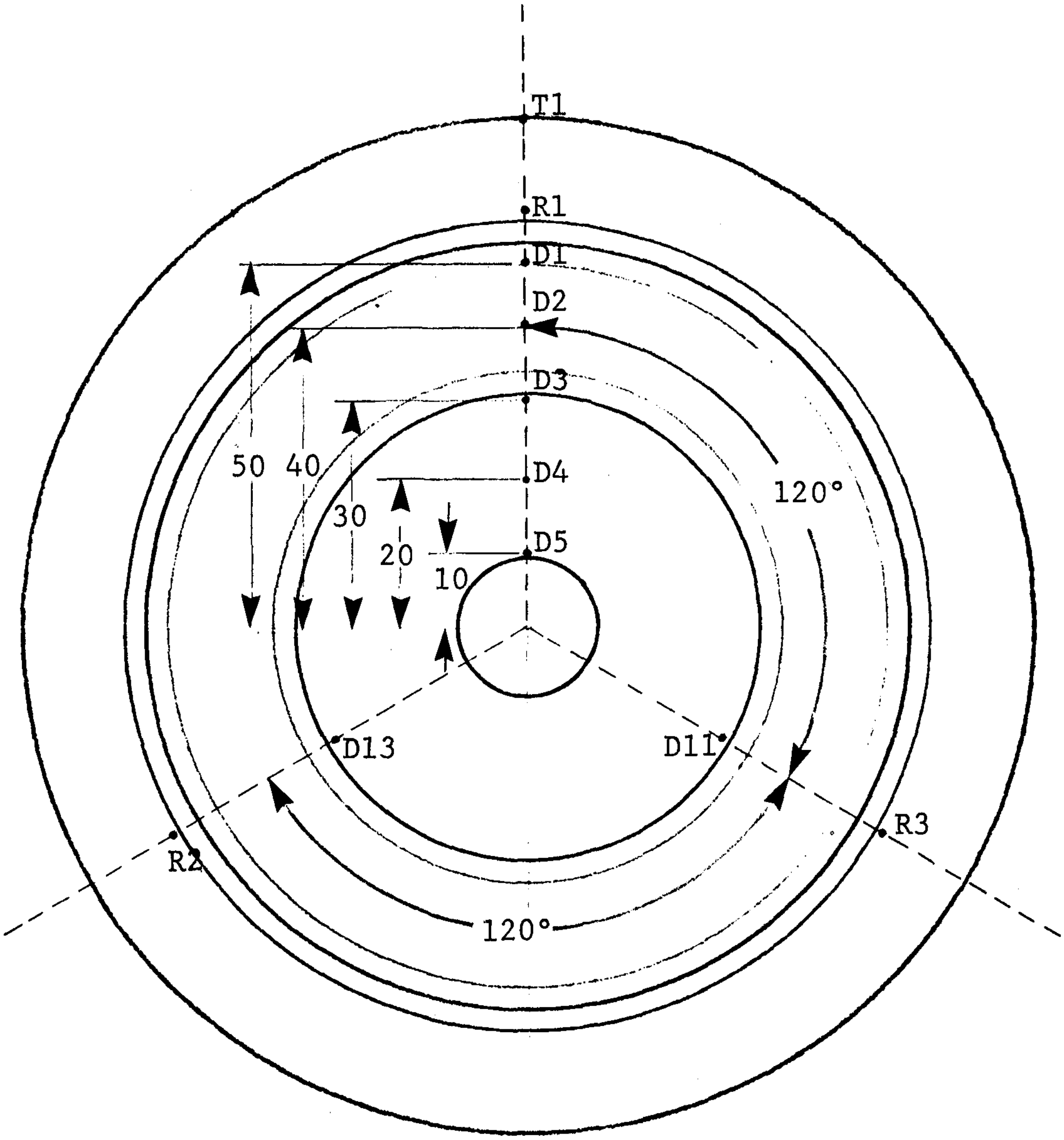


Figure 5

Thermocouple Locations on Disk Side of Turbine Wheel During Calibration 3. (All dimensions in mm.)

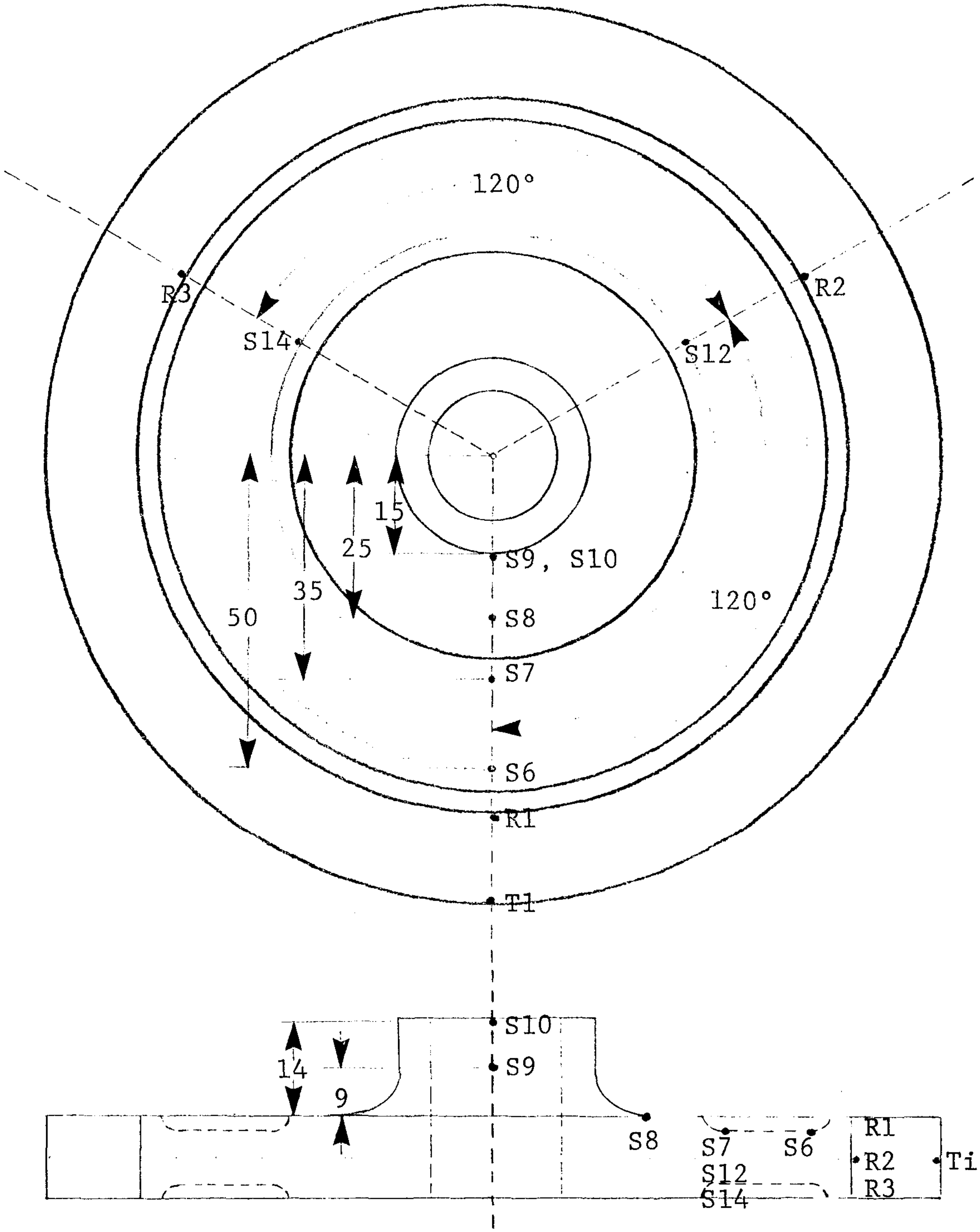
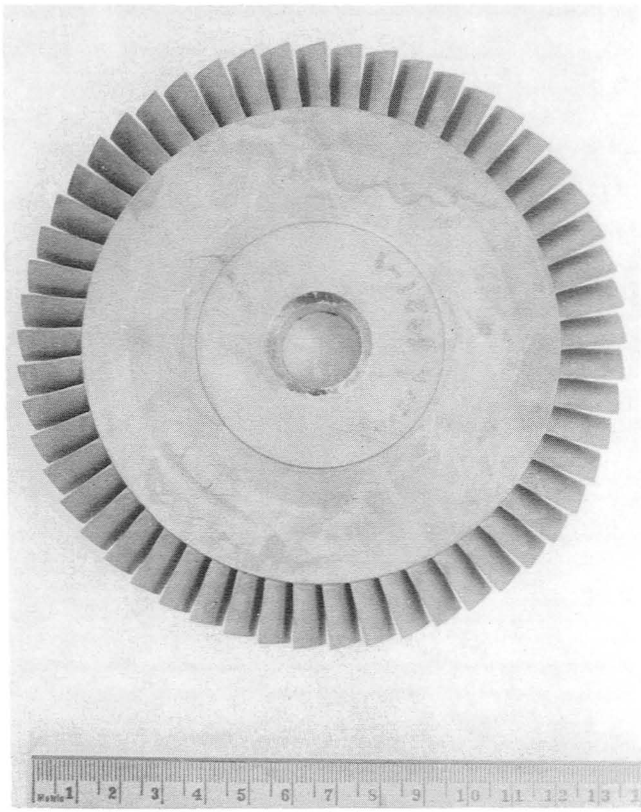


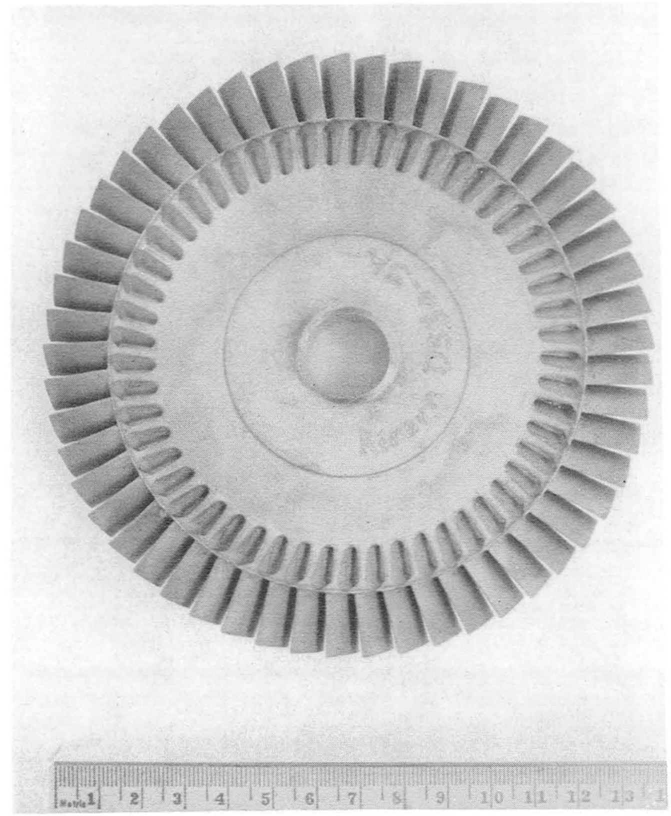
Figure 6

Thermocouple Locations on Shaft Side of Turbine Wheel During Calibration 3. (All dimensions in mm.)



Neg. No. 43789 3/4X

(a) Unpocketed (U1)

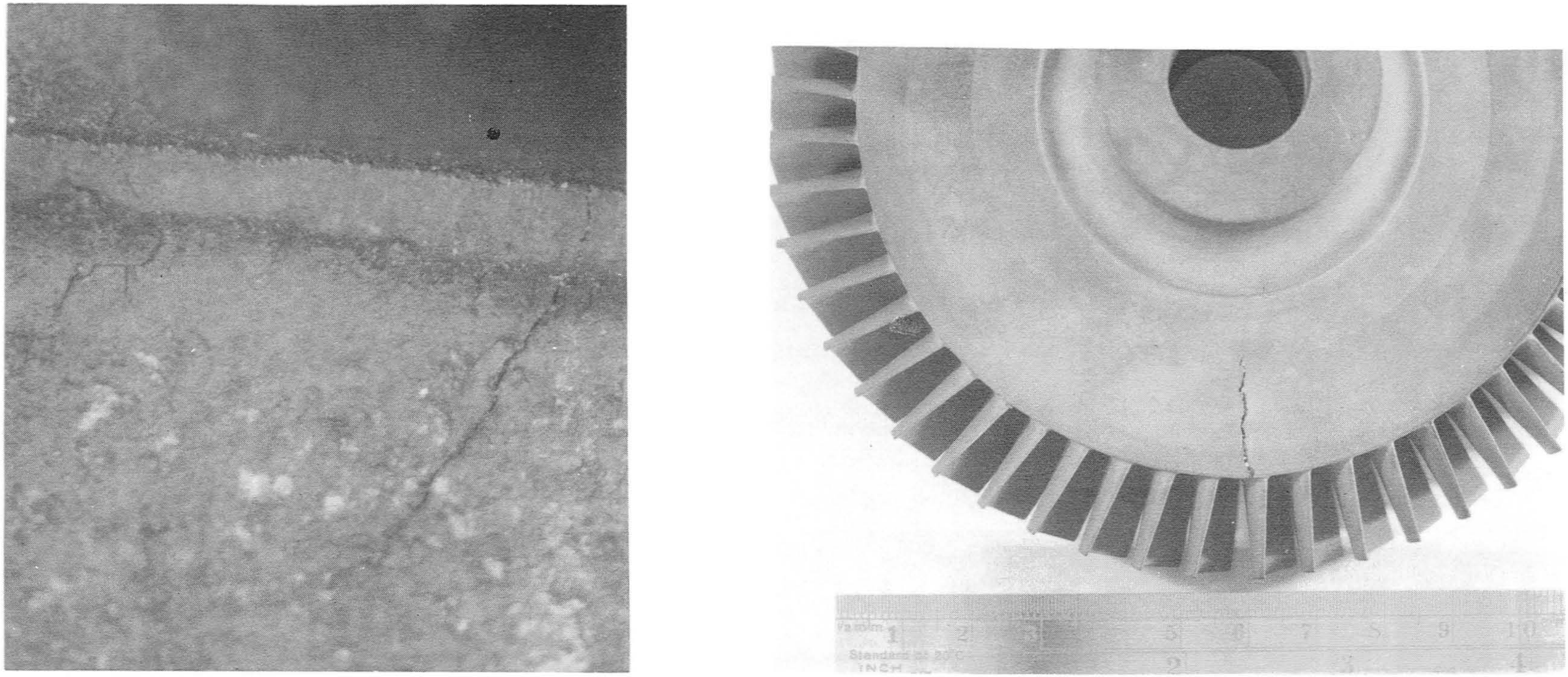


Neg. No. 43790 3/4X

(b) Pocketed (P1)

Figure 7

Appearance of Disk Side of Typical Unpocketed (U1) and Pocketed (P1) Turbine Wheel As-Received



Neg. No. 47525 25X

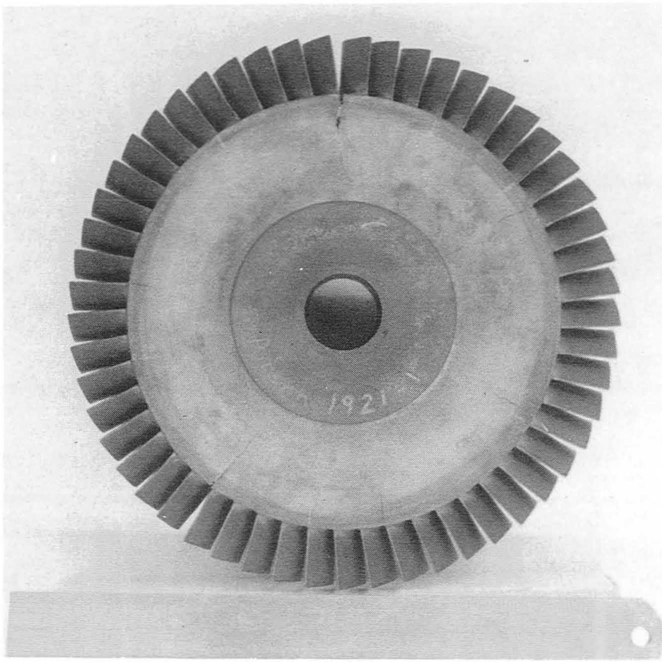
(a) Crack initiation (300 cycles)

Neg. No. 47657 1X

(b) Crack propagation (1000 cycles)

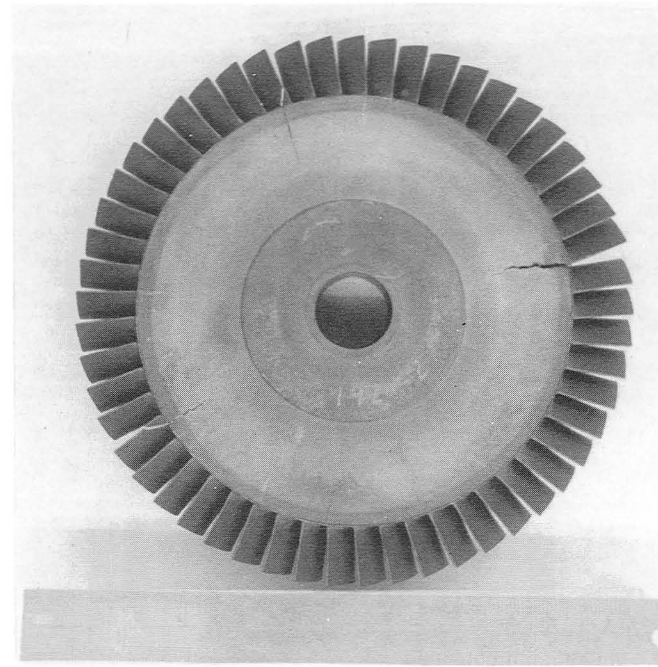
Figure 8

Illustration of Typical Crack Initiation and Propagation for Unpocketed Turbine Wheels (Specimen U5) Originating Between Blades at Blade Root Flange



Neg. No. 48260 1/2X

(a) U1

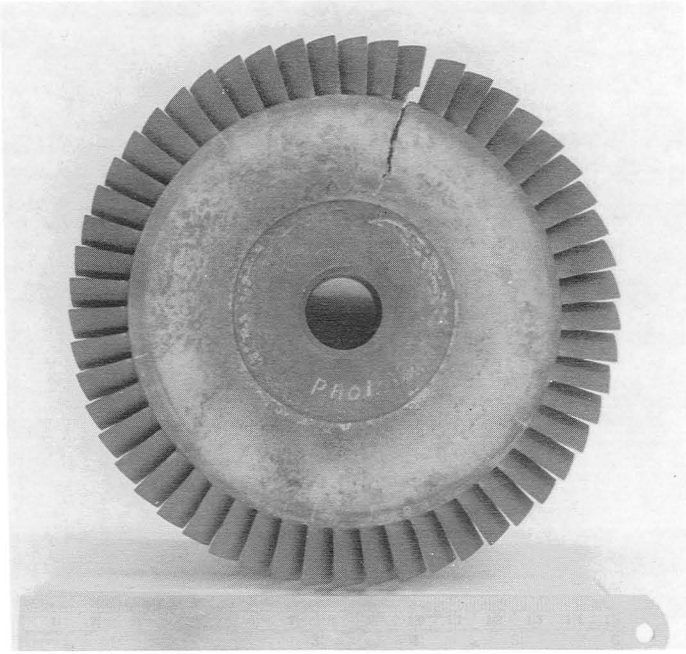


Neg. No. 48261 1/2X

(b) U2

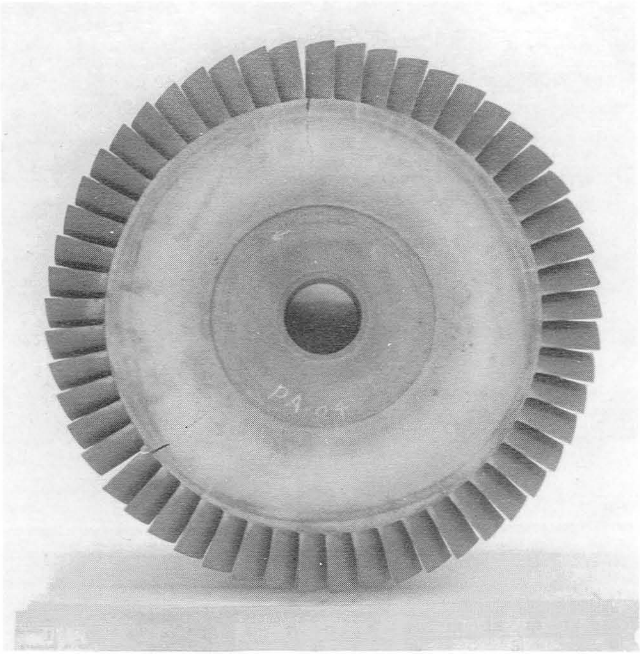
Figure 9

Appearance of Disk Side of Unpocketed Wheels U1 and U2 after 5000 Accumulated Thermal Cycles at 935°/50°C



Neg. No. 48259 1/2X

(a) U4

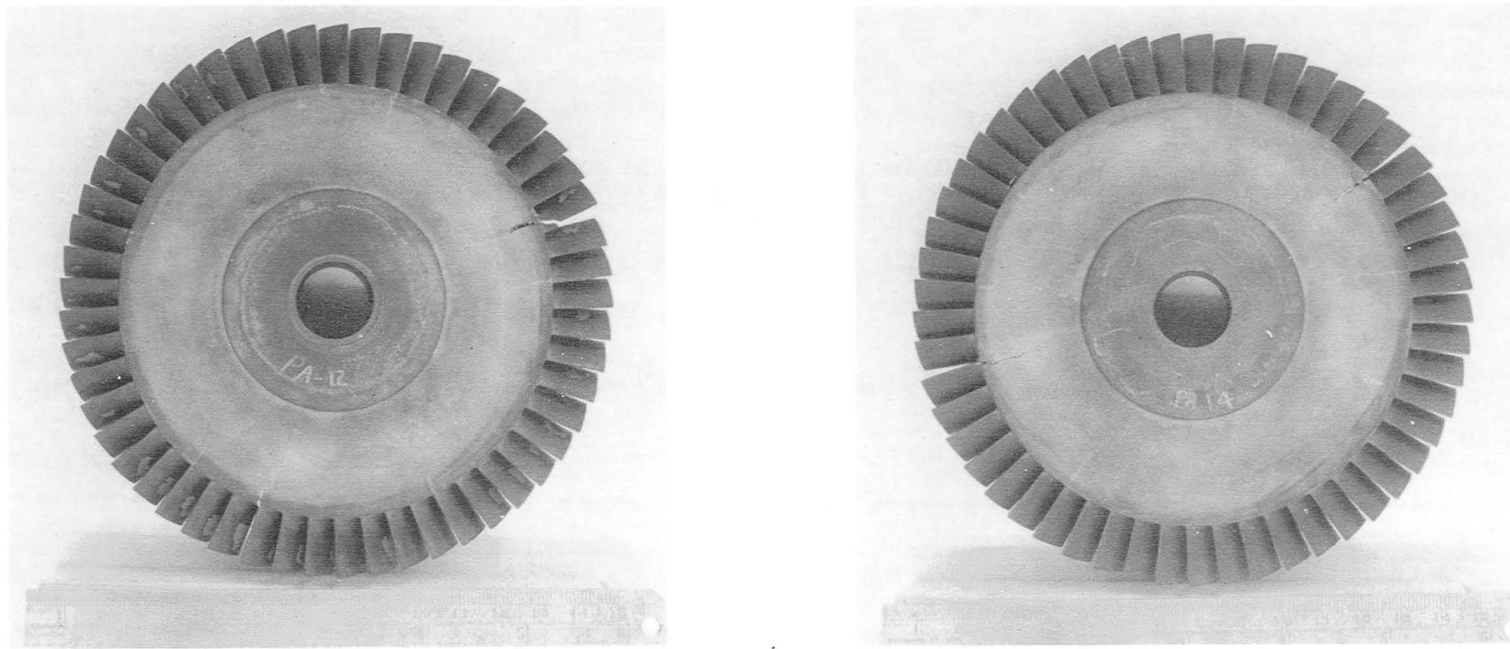


Neg. No. 48252 1/2X

(b) U5

Figure 10

Appearance of Disk Side of Unpocketed Wheels U4 and U5 after 1000 Accumulated Thermal Cycles at 935°/50°C



Neg. No. 48254 1/2X

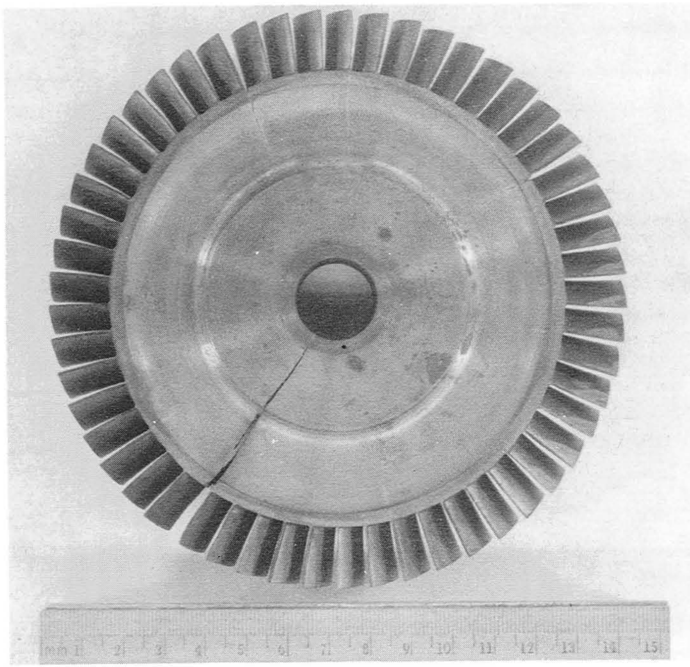
(a) U6

Neg. No. 48256 1/2X

(b) U7

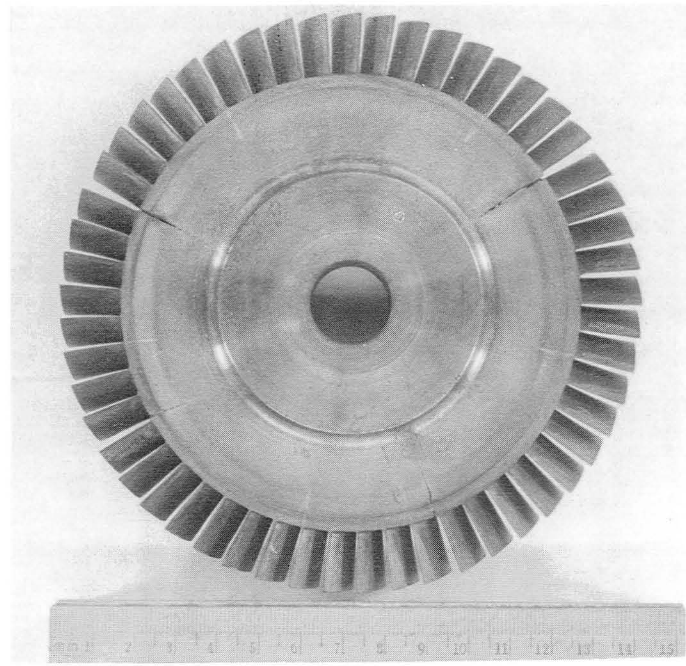
Figure 11

Appearance of Disk Side of Unpocketed Wheels U6 and U7 after 4000 Accumulated Thermal Cycles at 935°/50°C



Neg. No. 51547 1/2X

(a) U8

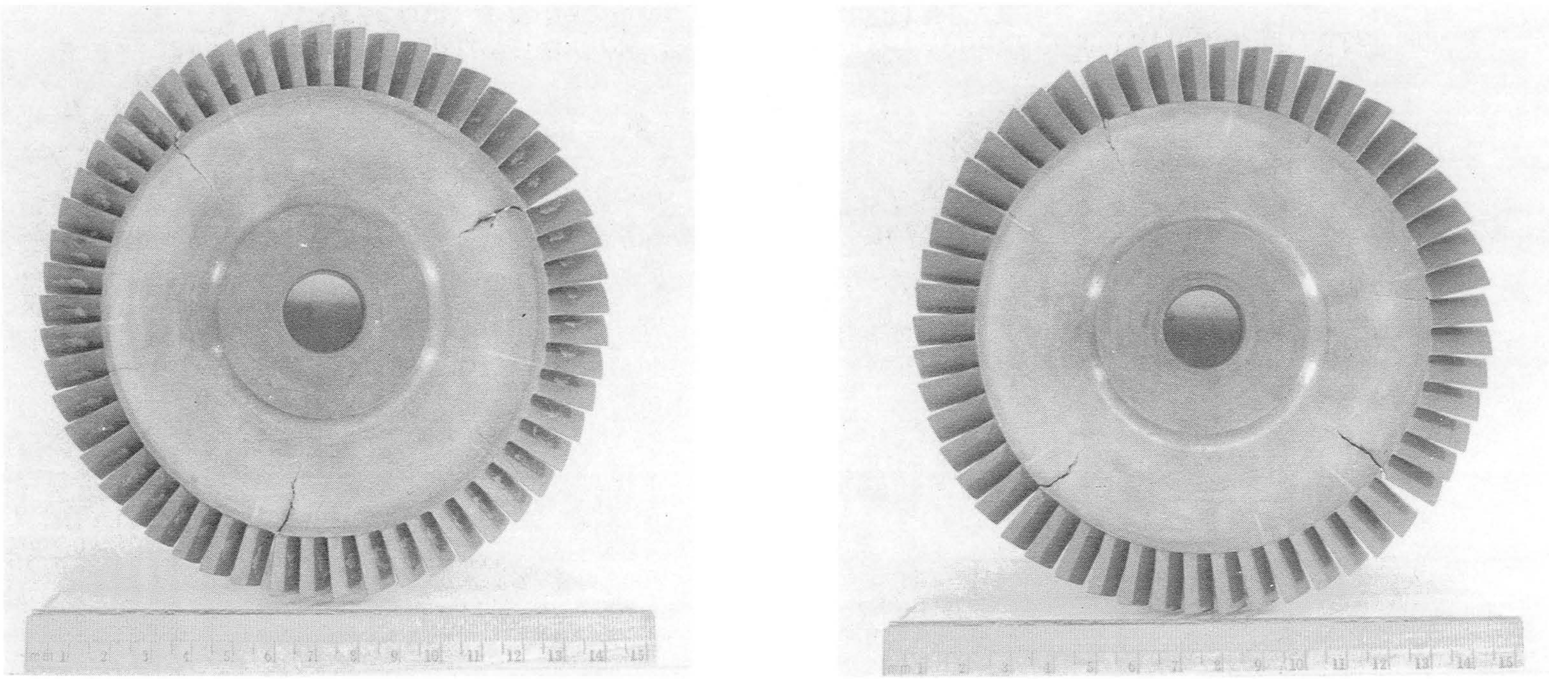


Neg. No. 51546 1/2X

(b) U9

Figure 12

Appearance of Disk Side of Unpocketed Wheels U8 and U9
after 2000 Accumulated Thermal Cycles at 935°/50°C



Neg. No. 50327 1/2X

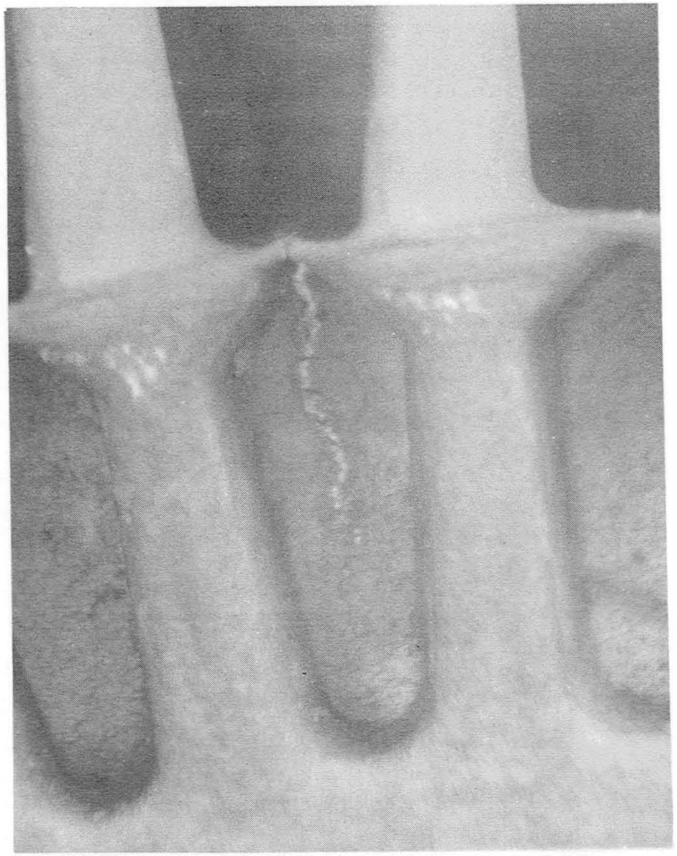
Neg. No. 50326 1/2X

(a) U11

(b) U12

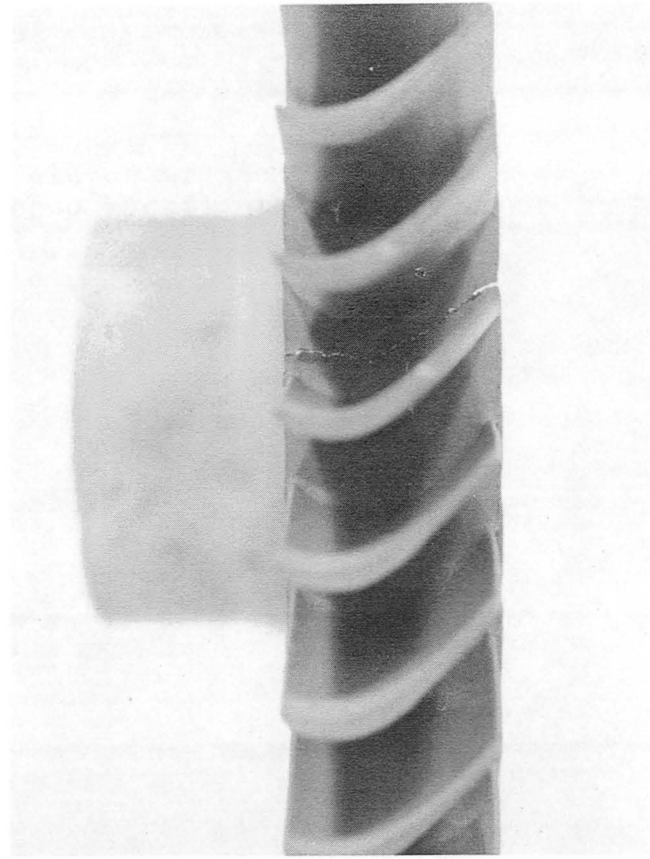
Figure 13

Appearance of Disk Side of Unpocketed Wheels U11 and U12
after 5000 Accumulated Thermal Cycles at 935°/50°C



Neg. No. 47449 7X

(a) Pocket crack

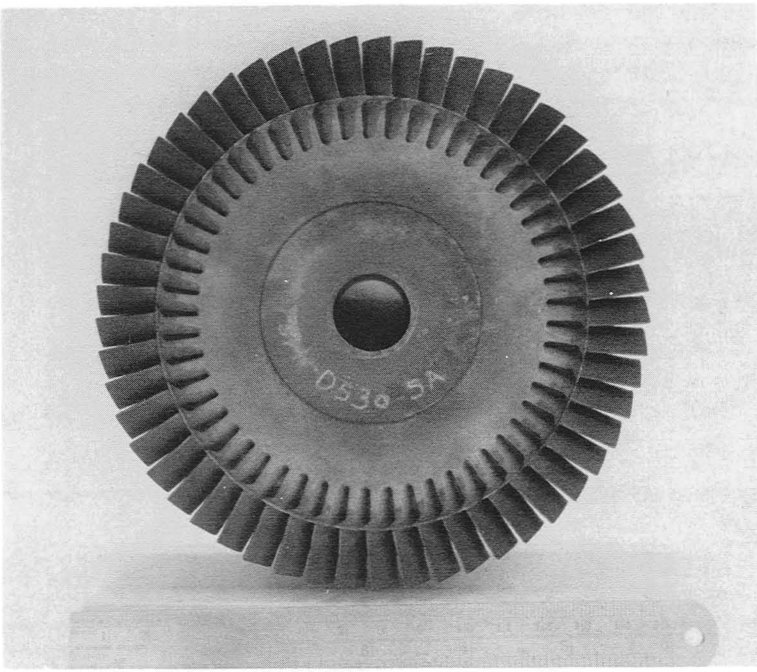


Neg. No. 47451 2.5X

(b) Cross section

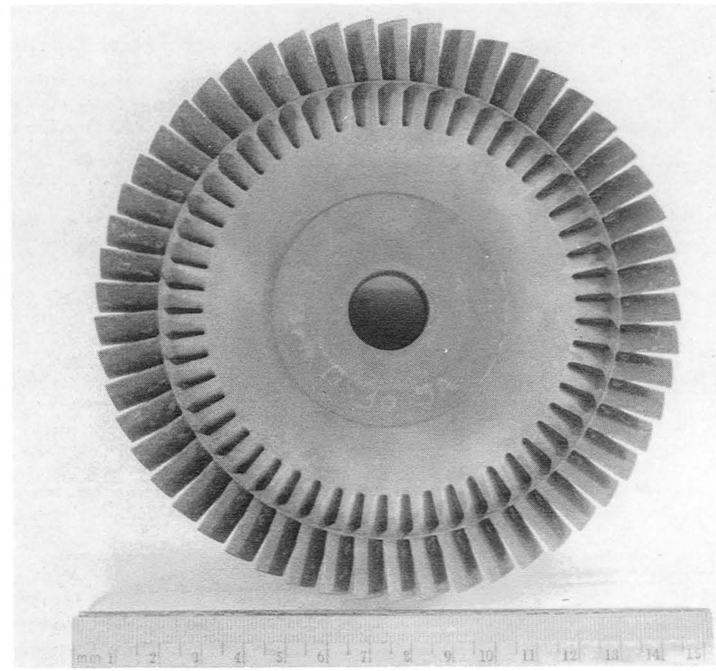
Figure 14

Illustration of Typical Crack Initiation for Pocketed Turbine Wheels Originating Between Blades at Blade Root Flange



Neg. No. 48253 1/2X

(a) 5000 cycles

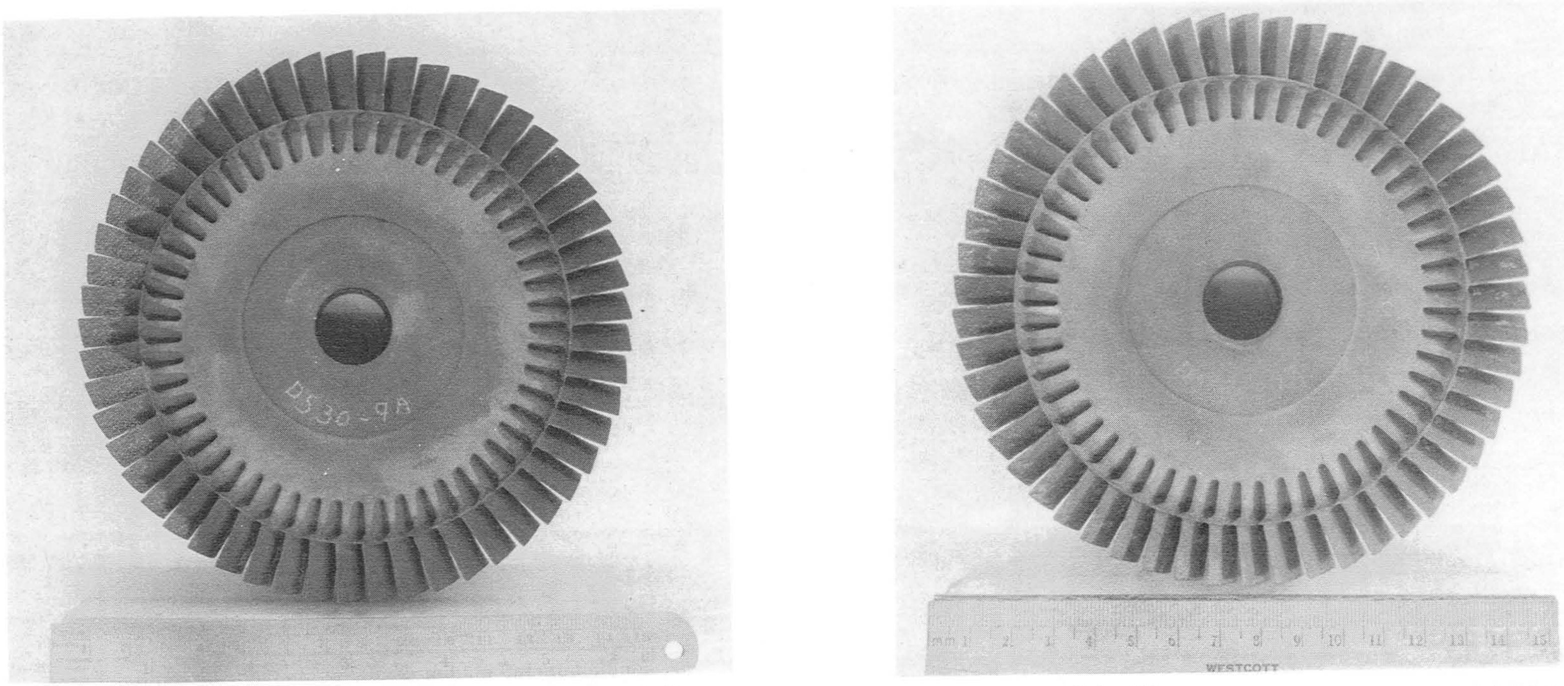


Neg. No. 50325 1/2X

(b) 10,000 cycles

Figure 15

Appearance of Disk Side of Pocketed Wheel P1 after 5000 and 10,000 Thermal Cycles at 935°/50°C



Neg. No. 48255 1/2X

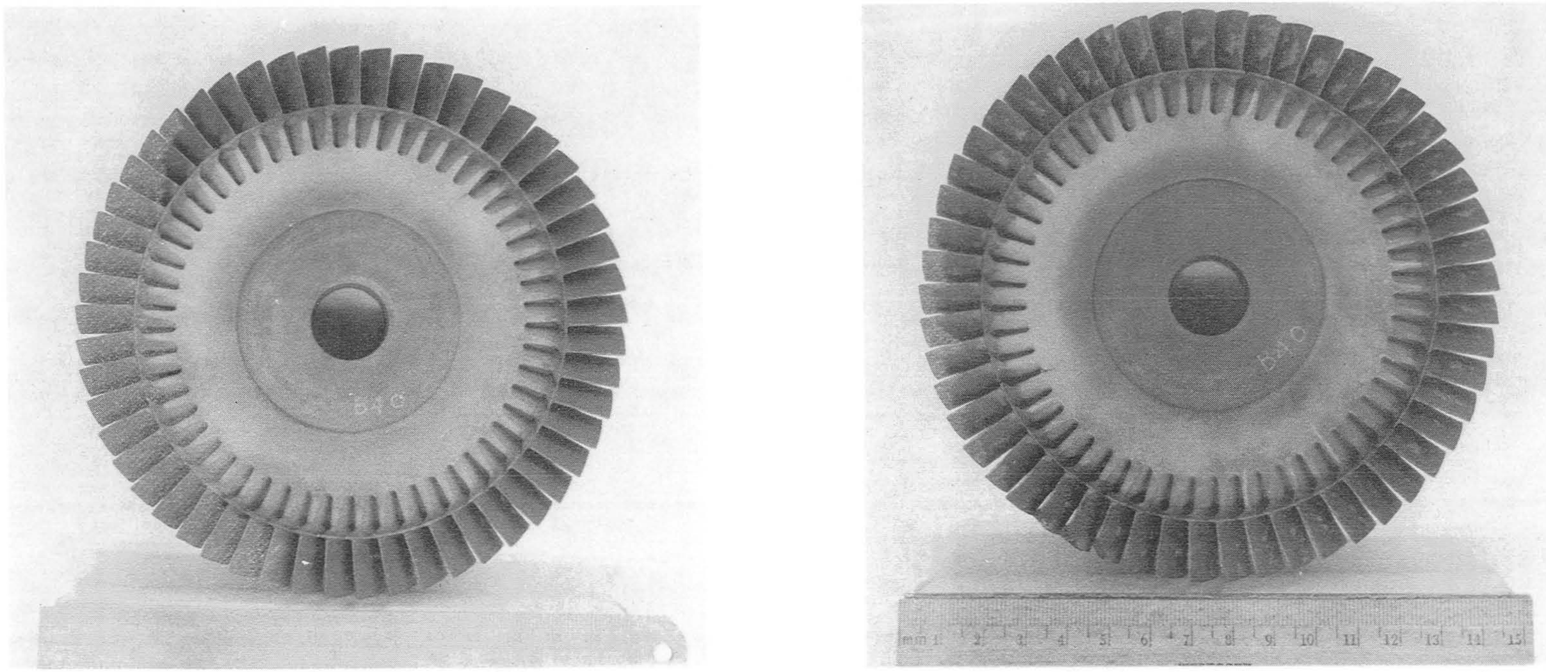
(a) 5000 cycles

Neg. No. 50324 1/2X

(b) 8000 cycles

Figure 16

Appearance of Disk Side of Pocketed Wheel P2 after 5000 and 8000 Thermal Cycles at 935°/50°C



Neg. No. 48258 1/2X

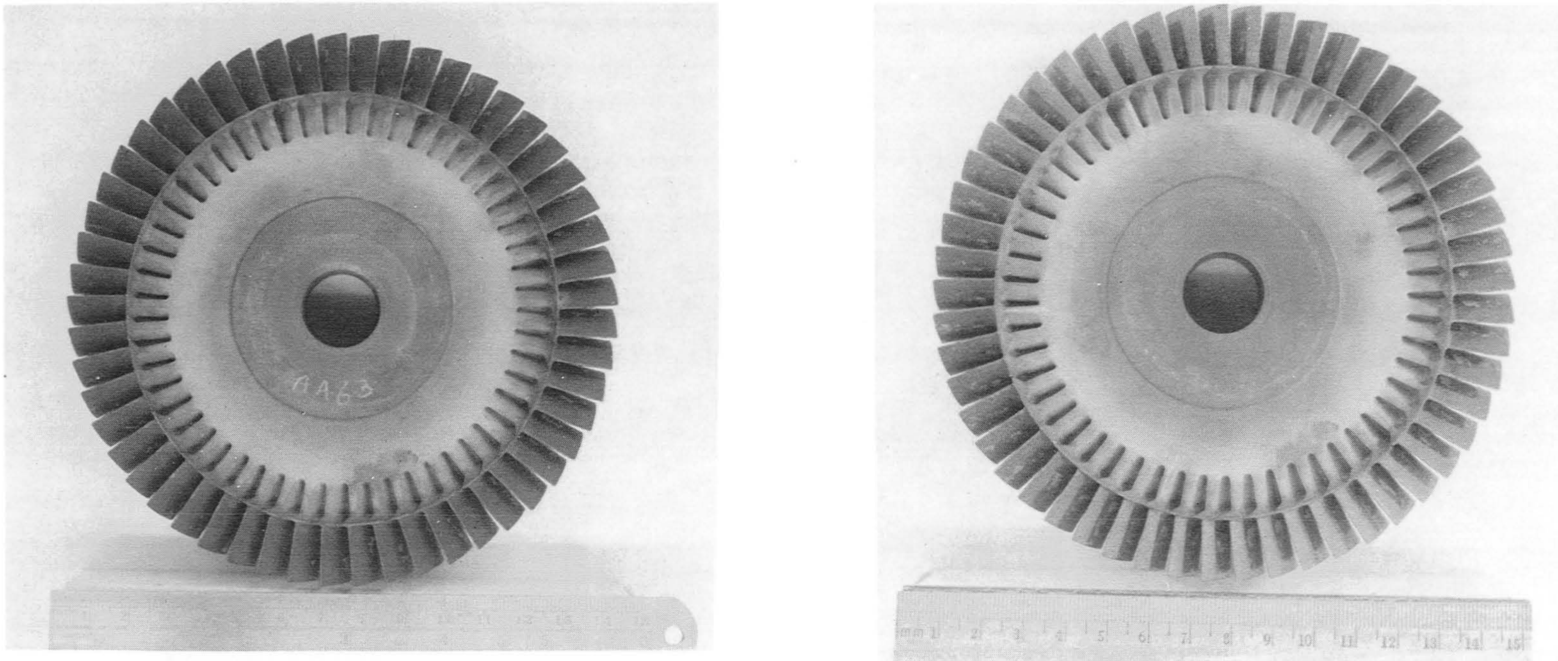
(a) 5000 cycles

Neg. No. 50321 1/2X

(b) 10,000 cycles

Figure 17

Appearance of Disk Side of Pocketed Wheel P3 after 5000 and 10,000 Thermal Cycles at 935°/50°C



Neg. No. 48257 1/2X

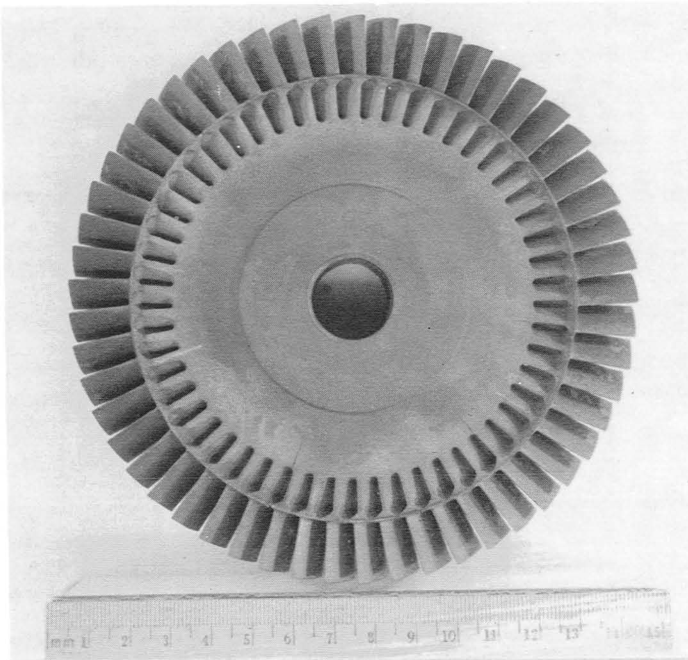
(a) 5000 cycles

Neg. No. 50320 1/2X

(b) 8000 cycles

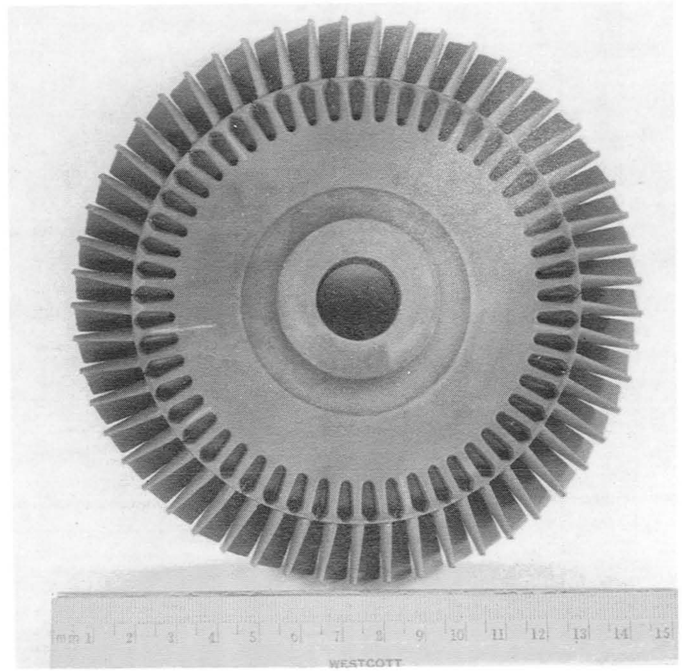
Figure 18

Appearance of Disk Side of Pocketed Wheel P4 after 5000 and 8000 Thermal Cycles at 935°/50°C



Neg. No. 50323 1/2X

(a) P5



Neg. No. 50333 1/2X

(b) P6

Figure 19

Appearance of Disk Side of Pocketed Wheels P5 and P6 after 5000 Thermal Cycles at 935°/50°C

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16. Abstract

Fluidized bed thermal fatigue testing was conducted on 16 integrally cast automotive turbine wheels for 1000-10,000 (600 sec total) thermal cycles at $935^{0}/50^{0}$ C. The 16 wheels consisted of 14 IN-792 + 1% Hf and 2 gatorized AF2-1DA wheels; 6 of the IN-792 + Hf wheels contained crack arrest pockets inside the blade root flange. Temperature transients during thermal cycling were measured in three calibration tests using either 18 or 30 thermocouples per wheel. Thermal cracking based on crack length versus accumulated cycles was greatest for unpocketed wheels with pocketed wheels developing cracks in 8-13 cycles compared to 75-250 cycles for unpocketed wheels. However, pocketed wheels survived up to 10,000 cycles with crack lengths less than 20 mm, whereas two unpocketed wheels developed 45 mm long cracks in 1000-2000 cycles.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Thermal fatigue; Nickel alloys; Heat-resistant alloys; Thermal resistance; Fluidized bed; Temperature measurement; Automotive; Turbine wheels	Unclassified - unlimited STAR Category 39 DOE Category UC-25

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