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U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

10.2.3 TURBINE DISK INTEGRITY

REVIEW RESPONSIBILITIES

Primary - Materials Engineering Branch (MTEB)

Secondary - None

I. AREAS OF REVIEW

General Design Criterion 4 requires that structures, systems, and components important to safety shall be appropriately protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. Because turbine disks have large masses and rotate at relatively high speeds during normal reactor operation, failure of a disk may result in the generation of high energy missiles and cause excessive vibration of the turbine rotor assembly. Measures taken by the applicant to assure turbine disk integrity and reduce the probability of turbine disk failure satisfy the relevant requirements of General Design Criterion 4.

The purpose of this section of the SRP is to review and evaluate the information submitted by the applicant to assure turbine disk integrity and a low probability of turbine disk failure with the generation of missiles.

The following areas of the applicant's safety analysis report (SAR) relating to turbine disk integrity are reviewed:

1. Materials Selection

   The low-pressure turbine rotor assembly usually consists of a rotor shaft with shrunk-on disks. Low-pressure disk stresses are due to thermal gradients, the interference fit, and centrifugal forces. These stresses are relatively high. The low-pressure turbine operates at lower temperatures than the high-pressure turbine. Thus, it is particularly important that low-pressure disks be made of a tough material. The use of suitable design, materials, and inservice inspection can greatly reduce the probability of a turbine disk failure.

The materials properties, including descriptions of the procedures to minimize flaws and improve fracture toughness, are reviewed to establish that sufficient information is provided to permit an evaluation of the adequacy of the low-pressure disk materials.

Included in this information are:

a. A discussion of the ductile-brittle transition temperatures (FATT or NDT) of the materials and the tests and standards used to determine them.

b. The Charpy V-notch test program used to establish minimum upper-shelf energies of the disk materials.

c. The fracture toughness test program used to establish minimum upper-shelf toughness of the disk materials.

2. Fracture Toughness

The fracture toughness of the materials and the materials tests or correlations of Charpy and tensile data to toughness properties are reviewed to establish that the turbine disk materials exhibit adequate fracture toughness at normal operating temperature and during startup.

3. Preservice Inspection

The preservice inspection program information is reviewed to verify that the disk forgings are first machined with minimum excess stock prior to heat treatment, that visual and surface inspections are performed on all finished machined surfaces, and that a 100% volumetric (ultrasonic) examination is performed.

4. Turbine Disk Design

The low-pressure turbine rotor design information, including allowable stresses, temperature distributions, and design overspeed considerations, is reviewed.

5. Inservice Inspection

Descriptions of the baseline and inservice phases of the inservice inspection program, including types of inspections, areas to be inspected, frequencies of inspection, and acceptance criteria, are reviewed.

II. ACCEPTANCE CRITERIA

MTEB acceptance requirement is based on meeting the relevant requirements of General Design Criterion 4, "Environmental and Missile Design Bases," as it relates to structures, systems, and components important to safety being appropriately protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. The specific criteria necessary to meet the relevant requirements of GDC 4 to reduce the probability of failure of the turbine disk are as follows:

1. Materials Selection

The turbine disk should be made from a material and by a process that tends to minimize flaw occurrence and maximize fracture toughness properties, such as a NiCrMoV alloy processed by vacuum melting or vacuum degassing. The material should be examined and tested to meet the following criteria:

a. Chemical analysis should be made for each forging. Elements that have a deleterious effect on toughness, such as sulfur and phosphorus, should be controlled to low levels.

b. The fracture appearance transition temperature (50% FATT) as obtained from Charpy tests performed in accordance with specification ASTM A-370 should be no higher than 0°F for low-pressure turbine disks. Nil-ductility transition (NDT) temperature obtained in accordance with specification ASTM E-208 may be used in lieu of FATT. NDT temperatures should be no higher than -30°F.

c. The Charpy V-notch (C_v) energy at the minimum operating temperature of each low-pressure disk in the tangential direction should be at least 60 ft-lbs. A minimum of three C_v specimens should be tested in accordance with specification ASTM A-370.

2. Fracture Toughness

The low-pressure turbine disk fracture toughness properties are acceptable if in compliance with the following criteria:

The ratio of the fracture toughness (K_{Ic}) of the disk material to the maximum tangential stress at speeds from normal to design overspeed should be at least two $\sqrt{in.}$, at minimum operating temperature. Bore stress calculations should include components due to centrifugal loads, interference fit, and thermal gradients. Sufficient warmup time should be specified in the turbine operating instructions to assure that toughness will be adequate to prevent brittle fracture during startup. Fracture toughness properties can be obtained by any of the following methods:

a. Testing of the actual material of the turbine disk to establish the K_{Ic} value at normal operating temperature.

b. Testing of the actual material of the turbine disk with an instrumented Charpy machine and a fatigue precracked specimen to establish the K_{Ic} (dynamic) value at normal operating temperature. If this method is used, K_{Ic} (dynamic) shall be used in lieu of K_{Ic} (static) in meeting the toughness criteria above.

c. Estimating of K_{Ic} values at various temperatures from conventional Charpy and tensile data on the disk material using methods presented by J. A. Begley and W. A. Logsdon in Westinghouse Scientific Paper 71-1E7-MSLRF-P1 (Ref. 5). This method of obtaining K_{Ic} should be used only on materials which exhibit a well-defined Charpy energy and fracture appearance transition curve and are strain-rate insensitive. The test data and the calculated toughness curve should be submitted to the staff for review.

d. Estimating "lower bound" values of K_{Ic} at various temperatures using the equivalent energy concept of F. J. Witt and T. R. Mager, ORNL-TM-3894 (Ref. 6). Load-displacement data from the compact tension specimens and the calculated toughness data should be submitted to the staff for review.

3. Preservice Inspection

The applicant's preservice inspection program is acceptable if in compliance with the following criteria:

a. Disk forgings should be rough machined prior to heat treatment.

b. Each finished disk should be subjected to 100% volumetric (ultrasonic), surface, and visual examinations using procedures and acceptance criteria equivalent to those specified for Class 1 components in the ASME Boiler and Pressure Vessel Code, Sections III and V.

c. Finish machined bores, keyways, and drilled holes should be subjected to magnetic particle or liquid penetrant examination. No flaw indications in keyway or hole regions are allowable.

d. Each turbine rotor assembly should be spin tested at the maximum speed anticipated during a turbine trip following loss of full load.

4. Turbine Disk Design

The applicant's design is acceptable if in compliance with the following:

The turbine assembly should be designed to withstand normal conditions, anticipated transients, and accidents resulting in a turbine trip without loss of structural integrity. The design of the turbine assembly should meet the following criteria:

a. The design overspeed of the turbine should be 5% above the highest anticipated speed resulting from a loss of load. The basis for the assumed design overspeed should be submitted to the staff for review.

b. The combined stresses of low-pressure turbine disk at design overspeed due to centrifugal forces, interference fit, and thermal gradients should not exceed 0.75 of the minimum specified yield strength of the material, or 0.75 of the measured yield strength in the weak direction of the materials if appropriate tensile tests have been performed on the actual disk material.

c. The turbine shaft bearings should be able to withstand any combination of the normal operating loads, anticipated transients, and accidents resulting in turbine trip.

d. The natural critical frequencies of the turbine shaft assemblies existing between zero speed and 20% overspeed should be controlled in the design and operation so as to cause no distress to the unit during operation.

e. The turbine disk design should facilitate inservice inspection of all high stress regions, including bores and keyways, without the need for removing the disks from the shaft.

5. Inservice Inspection

The applicant's inservice inspection program is acceptable if in compliance with the following criteria:

The inservice inspection program for the steam turbine assembly should provide assurance that disk flaws that might lead to brittle failure of a disk at speeds up to design speed will be detected. The inservice inspection program for the turbine assembly should include the following:

Disassembly of the turbine at approximately 10-year intervals, during plant shutdown coinciding with the inservice inspection schedule as required by ASME Boiler and Pressure Vessel Code, Section XI, and complete inspection of all normally inaccessible parts, such as couplings, coupling bolts, turbine shafts, low-pressure turbine blades, low-pressure disks, and high-pressure rotors. This inspection should consist of visual, surface, and volumetric examinations, as required.

III. REVIEW PROCEDURES

For each area of review, the following review procedures are followed:

1. Materials Selection

The materials properties and the procedures to minimize flaws and improve fracture toughness, as described by the applicant, are reviewed and compared with the requirements of subsection II.1 of this SRP section. If a new material not used in prior licensed cases is utilized, the applicant's materials selection is reviewed and evaluated to establish its acceptability. Such an evaluation is based on the acceptance criteria of subsection II of this SRP section.

2. Fracture Toughness

The fracture toughness properties of the low-pressure turbine disk material, including specimen test data, where applicable, are reviewed and compared with the requirements of subsection II.2 of this SRP section. The applicant is permitted any of three alternates for deriving the fracture toughness of the disk materials.

3. Preservice Inspection

The preservice inspection program, including finish machining, ultrasonic inspection, surface inspection, visual inspection, and spin testing, is reviewed and compared with the requirements of subsection II.3 of this

SRP section. The extent to which the ultrasonic inspections and the acceptance criteria in the SAR agree with ASME Boiler and Pressure Vessel Code, Section III, NB-2530 for plate materials or NB-2540 for forgings, is reviewed.

4. Turbine Disk Design

The design and stress analysis procedures used for the low-pressure turbine disks are reviewed including the following areas:

a. Load combinations at normal operating speed and allowable stresses.

b. Design overspeed and basis for selection of design overspeed.

c. Load combinations at design overspeed and allowable stresses.

The SAR data are compared and evaluated against subsection II.4 of this SRP section.

5. Inservice Inspection

The inservice inspection program described by the applicant, including areas to be inspected, methods of inspection, frequency of inspection, and acceptance criteria, is reviewed and compared with the requirements of subsection II.5 of this SRP section.

IV. EVALUATION FINDINGS

The staff concludes that the integrity of the turbine disk is acceptable and meets the relevant requirements of General Design Criterion 4 of 10 CFR Part 50. This conclusion is based upon the following:

The applicant has met the requirements of General Design Criterion 4 of 10 CFR Part 50 with respect to the use of materials with acceptable fracture toughness and elevated temperature properties, adequate design, and the requirements for preservice and inservice inspections. The applicant has described his program for assuring the integrity of low-pressure turbine disks by the use of suitable materials of adequate fracture toughness, conservative design practices, and preservice and inservice inspections. The staff concurs that these provisions provide reasonable assurance that the probability of failure with missile generation is low during normal operation, including transients up to design overspeed.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plan for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specific portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with the Commission regulations.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Design Bases."

2. ASME Boiler and Pressure Vessel Code, Sections III, V, and XI, American Society of Mechanical Engineers.

3. ASTM E-208, "Standard Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels," Annual Book of ASTM Standards, Part 31, American Society for Testing Materials.

4. ASTM A-370, "Standard Methods and Definitions for Mechanical Testing of Steel Products," Annual Book of ASTM Standards, Parts 1, 2, 3, 4, or 31, American Society for Testing Materials.

5. J. A. Begley and W. A. Logsdon, Scientific Paper 71-1E7-MSLRF-P1, Westinghouse Electric Corp., July 26, 1971.

6. F. J. Witt and T. R. Mager, ORNL-TM-3894, Oak Ridge National Laboratory (1972).