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U.S. NUCLEAR REGULATORY COMMISSION
STANDARD REVIEW PLAN
OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 5.4.1.1 PUMP FLYWHEEL INTEGRITY (PWR)

REVIEW RESPONSIBILITIES

Primary - Materials Engineering Branch (MTEB)

Secondary - None

I. AREAS OF REVIEW

General Design Criterion 4 (Ref. 1) requires that structures, systems, and components of nuclear power plants important to safety be protected against the effects of missiles that might result from equipment failures. Because flywheels have large masses and rotate at speeds of 900 rpm or 1200 rpm during normal reactor operation, a loss of flywheel integrity could result in high energy missiles and excessive vibration of the reactor coolant pump assembly. The safety consequences could be significant because of possible damage to the reactor coolant system, the containment, or the engineered safety features.

General Design Criterion 1 (Ref. 1) and 10 CFR Part 50, §50.55a(a)(1) require that structures, systems, and components important to safety shall be designed, fabricated, erected and tested to quality standards which shall be identified and evaluated to determine their adequacy to assure a quality product in keeping with the required safety function.

The following areas relating to reactor coolant pump flywheel integrity are reviewed by MTEB:

1. Materials Selection

   Reactor coolant pump flywheels are of a simple geometric shape, and are made of ductile material. Their quality can be closely controlled and their service conditions are not severe; therefore, the use of suitable material, coupled with adequate design and inservice inspection can provide a sufficiently small probability of a flywheel failure that the consequences of failure need not be protected against.

USNRC STANDARD REVIEW PLAN

Standard review plans are prepared for the guidance of the Office of Nuclear Reactor Regulation staff responsible for the review of applications to construct and operate nuclear power plants. These documents are made available to the public as part of the Commission's policy to inform the nuclear industry and the general public of regulatory procedures and policies. Standard review plans are not substitutes for regulatory guides or the Commission's regulations and compliance with them is not required. The standard review plan sections are keyed to the Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants. Not all sections of the Standard Format have a corresponding review plan.

Published standard review plans will be revised periodically, as appropriate, to accommodate comments and to reflect new information and experience.

Comments and suggestions for improvement will be considered and should be sent to the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, D.C. 20555.

Information in the applicant's safety analysis report (SAR) on materials selection and the procedures used to minimize flaws and improve mechanical properties is reviewed to establish that sufficient information is provided to permit an evaluation of the adequacy of the flywheel materials.

2. <u>Fracture Toughness</u>

The fracture toughness of the materials, including materials tests, correlation of Charpy specimens to fracture toughness parameters, or the alternate use of a nil-ductility transition reference temperature (RT_{NDT}), are reviewed to establish that the flywheel materials will exhibit adequate fracture toughness at normal operating temperature (Ref. 2).

3. <u>Preservice Inspection</u>

The descriptive information is reviewed to verify that the bore of the flywheel is machined to final dimensions if it is flame cut, and that ultrasonic and surface inspections are performed on all finished machined surfaces.

4. <u>Flywheel Design</u>

The flywheel design information including allowable stresses, design overspeed considerations, and shaft and bearing design adequacy, is reviewed.

5. <u>Overspeed Test</u>

The applicant's overspeed test procedures are reviewed to establish their adequacy.

6. <u>Inservice Inspection</u>

A description of the preservice and postoperational phases of the inservice inspection program, including types of inspections, areas inspected, frequencies of inspection, and flaw acceptance criteria, is reviewed.

The review for quality assurance is coordinated and performed by the Quality Assurance Branch (QAB) as part of its primary review responsibility for Standard Review Plan Sections 17.1 and 17.2. The acceptance criteria necessary for the review and the methods of application are contained in the referenced SRP section.

II. <u>ACCEPTANCE CRITERIA</u>

The MTEB acceptance criteria are based on meeting the relevant requirements of the following regulations:

A. General Design Criterion 1 and 10 CFR Part 50, §50.55a(a)(1), as they relate to pump flywheel design, materials selection, fracture toughness, preservice and inservice inspection programs, and overspeed test procedures to determine their adequacy to assure a quality product commensurate with the importance of the safety function to be performed.

B. General Design Criterion 4, as it relates to protecting safety-related structures, systems, and components of nuclear power plants from the effects of missiles that might result from reactor coolant pump failure. The following regulatory guide provides positions acceptable to the staff in meeting the requirements listed above: Regulatory Guide 1.14 which describes a method of minimizing the potential for failures of the flywheels of reactor coolant pump motors in light-water-cooled power reactors.

Specific criteria necessary to meet the relevant requirements of GDC 1 and 4 and 10 CFR Part 50, §50.55a(a)(1) are as follows:

1. Materials Selection

   The applicant's selection of flywheel material is acceptable if it is in accordance with the following criteria:

   The flywheel material must be produced by a process (such as vacuum melting or degassing) that minimizes flaws in the material and improves its fracture toughness properties. The material must be examined and tested to meet the following criteria:

   a. The nil-ductility transition (NDT) temperature of the flywheel material, as obtained from dropweight tests (DWT) performed in accordance with the specification ASTM E-208 (Ref. 3), should be no higher than 10°F.

   b. The Charpy V-notch (C_v) upper-shelf energy level in the "weak" direction (WR orientation in plates) of the flywheel material should be at least 50 ft-lbs. A minimum of three C_v specimens should be tested from each plate or forging, in accordance with ASTM A-370 (Ref. 4).

2. Fracture Toughness

   The following fracture toughness criteria are derived from Regulatory Guide 1.14, C.1.c, and the ASME Boiler and Pressure Vessel Code (hereafter "the Code"), Section III, Appendix G. The pump flywheel fracture toughness properties are acceptable if they are in compliance with the following criteria:

   The minimum static fracture toughness of the material at the normal operating temperature of the flywheel should be quivalent to a critical stress intensity factor, K_{Ic}, of at least 150 ksi $\sqrt{in.}$ Compliance can be demonstrated by either of the following:

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

   b. Determining that the normal operating temperature is at least 100°F above the RT_{NDT}.

3. Preservice Inspection

   The following preservice inspection criteria are derived from Regulatory Guide 1.14, C.1.d, C.1.e, and C.1.f. The applicant's preservice inspection program including finish machining and ultrasonic and surface inspections is acceptable if in compliance with the following criteria:

a. Each finished flywheel should be subjected to a 100% volumetric examination by ultrasonic methods using procedures and acceptance criteria specified in Code Section III, NB-2530 for plates, and NB-2540 for forgings.

b. If the flywheel is flame cut from a plate or forging, at least 1/2 inch of material should be left on the outer and bore radii for machining to final dimensions.

c. Finish machined bores, keyways, splines, and drilled holes should be subjected to magnetic particle or liquid penetrant examination.

4. Flywheel Design

The following flywheel design criteria are derived from Regulatory Guide 1.14, C.2. The applicant's flywheel design is acceptable if in compliance with the following criteria:

The flywheel should be designed to withstand normal conditions, anticipated transients, the design basis loss of coolant accident, and the safe shutdown earthquake without loss of structural integrity.

The design of the pump flywheel should meet the following criteria:

a. The combined stresses at the normal operating speed, due to centrifugal forces and the interference fit of the wheel on the shaft, should not exceed 1/3 of the minimum specified yield strength or 1/3 of the measured yield strength in the weak direction of the material if appropriate tensile tests have been performed on the actual material of the flywheel.

b. The design overspeed of a flywheel should be at least 10% above the highest anticipated overspeed. The anticipated overspeed should include consideration of the maximum rotational speed of the flywheel if a break occurs in the reactor coolant piping in either the suction or discharge side of the pump. The basis for the assumed design overspeed should be submitted to the staff for review.

c. The combined stresses at the design overspeed, due to centrifugal forces and the interference fit, should not exceed 2/3 of the minimum specified yield strength, or 2/3 of the measured yield strength in the weak direction if appropriate tensile tests have been performed on the actual material of the flywheel.

d. The shaft and the bearings supporting the flywheel should be able to withstand any combination of loads from normal operation, anticipated transients, the design basis of loss-of-coolant accident, and the safe shutdown earthquake.

5. Overspeed Test

The following overspeed test criterion is taken from the Regulatory Guide 1.14, C.3. The applicant's commitment to perform an overspeed test is acceptable if each flywheel assembly is to be tested at the design overspeed of the flywheel.

6. Inservice Inspection (ISI)

The following inservice inspection program criteria are derived from Regulatory Guide 1.14, C.4. The applicant's ISI program is acceptable if in compliance with the following:

a. A volumetric examination by ultrasonic methods of the areas of higher stress concentration at the bore and keyway at approximately 3-1/3 years intervals, during the refueling or maintenance shutdown coinciding with the inservice inspection schedule as required by the Code, Section XI. Removal of the flywheel is not required.

b. A surface examination by liquid penetrant or magnetic particle methods of all exposed surfaces, and 100% volumetric examination by ultrasonic methods at approximately ten-year intervals, during the plant shutdown coinciding with the inservice inspection schedule as required by the Code, Section XI. Removal of the flywheel is not required.

c. A preservice baseline inspection incorporating all the procedures of a. and b. above, which should establish initial flywheel conditions, accessibility, and practicality of the program.

d. Examination procedures and acceptance criteria should be in conformance with the requirements specified in subsection II.3.a of this SRP Section.

III. REVIEW PROCEDURES

The reviewer will select and emphasize material from the procedures described below, as may be appropriate for a particular case.

For each area of review, the following review procedure is followed:

1. Materials Selection

The materials selection, including the procedures to minimize flaws and improve mechanical properties described by the applicant, are reviewed and compared with the requirements of subsection II.1 of this SRP Section. If it is a new material not used in prior licensing cases, the materials selection is reviewed and evaluated to establish its acceptability. Based on past evaluations, the following materials are suitable for pump flywheels provided that they meet all the criteria listed in subsection II.1 and II.2 of this SRP section: ASME SA-533-B Class 1, ASME SA-508 Class 2, and ASME SA-516 Grade 65 (Ref. 2).

2. Fracture Toughness

The fracture toughness properties of the flywheel materials, including test data where applicable, are reviewed and compared with the requirements of subsection II.2 of this SRP section. Two alternative methods for deriving the fracture toughness of the flywheel materials are acceptable. The value of the critical stress intensity factor is based on fracture mechanics testing, while the use of the reference temperature approach is based on the stated normal operating temperature of the flywheel and the actual reference nil-ductility transition temperature of the materials, if an operating license review, or as specified, if a construction permit review.

3. Preservice Inspection

The preservice inspection program, including finish machining, and ultrasonic and surface inspections described by the applicant is reviewed and compared with the requirlements of subsection II.3 of this SRP section. The extent to which the ultrasonic inspections proposed and the acceptance criteria in the SAR agree with Code Section III, NB-2530 for plate materials or NB-2540 for forgings, are reviewed.

4. Flywheel Design

The design and stress analysis procedures used for the flywheel 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 or design overspeed and allowable stresses.

d. Shaft and bearing load combinations.

The information given in the SAR is compared and evaluated against subsection II.4 of this SRP section.

5. Overspeed Test

The applicant should confirm that an overspeed test will be run in compliance with subsection II.5 of this SRP section.

6. Inservice Inspection

The inservice inspection program described by the applicant in the plant technical specifications, including areas to be inspected, methods of inspection, frequency of inspection, and acceptance criteria, is reviewed and compared with the requirements of subsection II.6 of this SRP section.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided in accordance with the requirements of this SRP section, and that his evaluation supports conclusions of the following type, to be included in the staff's safety evaluation report:

> The staff concludes that the precautions taken to assure the integrity of the reactor coolant pump flywheels are acceptable and meet the requirements of General Design Criteria 1 and 4 and 10 CFR Part 50, §50.55a(a)(1). This conclusion is based on the following:
>
> 1. The applicant's selection of materials, fracture toughness tests, design procedures, preservice overspeed spin testing program, and inservice inspection program for the reactor coolant pump flywheels have been reviewed and found to meet the requirements for GDC 1 and 10 CFR Part 50, §50.55a(a)(1) with respect to providing adequate assurance of a quality product commensurate with the importance of the safety function.
>
> 2. The applicant has met the requirements of GDC 4 complying with the guidance of Regulatory Guide 1.14 in using suitable materials with adequate fracture toughness, and conservative design procedures, and by providing a preservice testing, and inservice inspection program for flywheels of reactor coolant pump motors which provides reasonable assurance of the structural integrity of the flywheels in the event of design overspeed transients on postulated accidents.

V. IMPLEMENTATION

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

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

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guide.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," (General Design Criterion 1, "Quality Standards and Records," General Design Criterion 4, "Environmental and Missile Design Bases)."

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

3. ASTM E-208-69, "Standard Method for Conducting Drop-Weight Tests to Determine NilDuctility Transition Temperature of Ferritic Steels," Annual Book of ASTM Standards, Part 31, American Societly for Testing and Materials.

4. ASTM A-370-72, "Methods and Definitions for Mechanical Testing of Steel Products," Annual Book of ASTM Standards, Part 31, American Society for Testing and Materials.

5. Regulatory Guide 1.14, "Reactor Coolant Pump Flywheel Integrity" (originally Safety Guide 14).