Revision 1
August 1975

U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.14

REACTOR COOLANT PUMP FLYWHEEL INTEGRITY

A. INTRODUCTION

General Design Criterion 4, "Environmental and Missile Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires that nuclear power plant structures, systems, and components important to safety be protected against the effects of missiles that might result from equipment failures. This guide describes a method acceptable to the NRC staff of implementing this requirement with regard to minimizing the potential for failures of the flywheels of reactor coolant pump motors in light-water-cooled power reactors.

B. DISCUSSION

The flywheels on reactor coolant pump motors provide inertia to ensure a slow decrease in coolant flow in order to prevent fuel damage as a result of a loss of power to the pump motors. During operation at normal speed, a flywheel has sufficient kinetic energy to produce high-energy missiles and excessive vibration of the reactor coolant pump assembly if the flywheel should fail. Overspeed of the pump rotor assembly during a transient increases both the potential for failure and the kinetic energy of the flywheel. The safety consequences could be significant because of possible damage to the reactor coolant system, the containment, or other equipment or systems important to safety.

Methods of predicting the loss-of-coolant accident (LOCA) overspeed conditions are under continuing investigation. The limit on predicted pump overspeed in the event of a LOCA should be less than the calculated critical speed for failure of the flywheel. The conservatism inherent in the latter calculation, coupled with a realistic prediction of maximum rotational speed, is considered to provide adequate margin because of the low probability of occurrence of the specific LOCA conditions that would cause such overspeed. Methods of limiting potential pump overspeed are also under investigation.

If the flywheel of the reactor coolant pump is conservatively designed and made from suitable materials with closely controlled quality, if adequate design review of new configurations is provided, and if adequate inservice inspection is provided, the probability of a flywheel failure is sufficiently small that the consequences of failure need not be protected against.

Materials for pump flywheels should be manufactured by processes that minimize flaws and result in adequate fracture toughness in both the transverse and longitudinal rolling directions. Materials produced by vacuum melting and degassing or the electroslag remelting process are known to have improved cleanliness and toughness. Plate material should be cross rolled to a ratio of at least 1 to 3, sufficient to achieve acceptable isotropy. Fracture toughness is achieved more readily in thinner plates, and fabrication of laminated flywheels by assembling them from several plates is acceptable.

As an example, past evaluations have shown that ASME SA-533-B Class 1 and SA-508 Classes 2 and 3 materials generally have suitable toughness for typical flywheel applications provided stress concentrations are kept within reasonable limits and the reference temperature RT_{NDT}, determined in accordance with Article NB-2331(a) of Section III of the ASME Code,[1] is at least 50°C (90°F) below the lowest temperature at which operating speed is achieved. For other materials that may be considered for flywheels, the strength and toughness properties should be evaluated and justified for this application.

[1]Copies may be obtained from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York 10017.

The non-ductile fracture analysis called for in regulatory position C.2.d should be based on appropriate conservative assumptions for stress level, flaw size, temperature, and fracture toughness at the location of interest. The non-ductile fracture criterion used to predict the critical fracture speed should be based on initial instability of the flaw as defined in ASTM E-399. The justification for the stress analysis method used in the fracture analysis should describe the treatment of stresses arising from interference fits and thermal stresses when they are superimposed on the stresses caused by rotational forces. Justification for the flaw size estimate should consider it to be the maximum expected size of flaw that could conceivably escape detection, and should consider material thickness, method and frequency of nondestructive inspection, and analysis of flaw growth in fatigue if that is significant. The effect of cracks emanating from such structural discontinuities as keyways and bolt holes should be evaluated. Justification for the fracture toughness assumed for the material should describe the properties to be measured transverse to the rolling direction in the tests of each plate of material. The range of fracture toughness test temperatures should include the lowest service temperature at which overspeed could occur. If not, the basis used for any extrapolation should be justified.

In doing the fracture analysis described in regulatory position C.2.d, engineering judgment should be used to select for analysis only those locations that appear to have the most severe sets of conditions. Severity is a function of stress level, flaw size, and fracture toughness at the location of interest. Comparison of perhaps three or four cases in terms of K_I/K_{IC}, the ratio of the imposed stress intensity factor at some nominal speed to the material toughness, should locate to most severe sets of conditions. Evaluation of the critical speed for fracture, which may require techniques that go beyond linear elastic fracture mechanics, may then focus on one critical location.

Excessive deformation during overspeed of the flywheel is of concern because damage could be caused by separation of the flywheel from the shaft. For the purpose of this guide, excessive deformation means any deformation such as an enlargement of the bore that could cause such separation directly or could cause an unbalance of the flywheel leading to structural failure or separation of the flywheel from the shaft. The calculation of deformation should employ elastic-plastic methods unless it can be shown that stresses remain within the elastic range.

The geometry of the flywheel and pump motor design should facilitate preservice and inservice inspection of all high-stress regions (bore, keyway, and bolt hole regions) without the need for removal of the flywheel from its shaft and preferably without the need for removing the rotor from the motor assembly.

The desired results of the analyses described in regulatory positions C.2.c, d, and e are quantitative estimates of the margins against fracture or excessive deformation during overspeed because such estimates, coupled with adequate provisions against overspeed, provide the best basis for assurance that the probability of failure under normal and transient conditions is sufficiently small that the consequences of failure need not be protected against.

C. REGULATORY POSITION

1. Material and Fabrication

a. The flywheel material should be of closely controlled quality. Plates should conform to ASTM A20 and should be produced by the vacuum-melting and degassing process or the electroslag remelting process. Plate material should be cross-rolled to a ratio of at least 1 to 3.

b. Fracture toughness and tensile properties of each plate of flywheel material should be checked by tests that yield results[2] suitable to confirm the applicability to that flywheel of the properties used in the fracture analyses called for in regulatory positions C.2.c, d, and e.

c. All flame-cut surfaces should be removed by machining to a depth at least 12 mm (1/2 inch) below the flame-cut surface.

d. Welding, including tack welding and repair welding, should not be permitted in the finished flywheel unless the welds are inspectable and considered as potential sources of flaws in the fracture analysis.

2. Design

a. The flywheel assembly, including any speed-limiting and antirotation devices, the shaft, and the bearings, should be designed to withstand normal conditions, anticipated transients, the design basis loss-of-coolant accident, and the Safe Shutdown Earthquake loads without loss of structural integrity.

b. Design speed should be at least 125% of normal speed but not less than the speed that could be attained during a turbine overspeed transient. Normal speed is defined as the synchronous speed of the a.c. drive motor at 60 hertz.

c. An analysis should be conducted to predict the critical speed for ductile fracture of the flywheel. The methods and limits of paragraph F-1323.1(b) in Section III of the ASME Code are acceptable. If another method

[2]These results should be included as part of the FSAR.

is used, justification should be provided. The analysis should be submitted to the NRC staff for evaluation.[3]

d. An analysis should be conducted to predict the critical speed for nonductile fracture of the flywheel. Justification should be given for the stress analysis method, the estimate of flaw size and location, which should take into account initial size and flaw growth in service, and the values of fracture toughness assumed for the material. The analysis should be submitted to the NRC staff for evaluation.[3]

e. An analysis should be conducted to predict the critical speed for excessive[4] deformation of the flywheel. The analysis should be submitted to the NRC staff for evaluation.[3]

f. The normal speed should be less than one-half of the lowest of the critical speeds calculated in regulatory positions C.2.c, d, and e above.

g. The predicted LOCA overspeed should be less than the lowest of the critical speeds calculated in regulatory positions C.2.c., d, and e.

3. Testing

Each flywheel assembly should be spin tested at the design speed of the flywheel.

4. Inspection

a. Following the spin test described in regulatory position C.3, each finished flywheel should receive a check of critical dimensions and a nondestructive examination as follows:

(1) Areas of higher stress concentrations, e.g. bores, keyways, splines, and drilled holes, and surfaces adjacent to these areas on the finished flywheel should be examined for surface defects in accordance with paragraph NB-2545 or NB-2546 of Section III of the ASME Code using the procedures of paragraph NB-2540. No linear indications more than 1.6 mm (1/16 inch) long, other than laminations, should be permitted.

(2) Each finished flywheel should be subjected to a 100% volumetric examination by ultrasonic methods using procedures and acceptance criteria specified in paragraph NB-2530 (for plates) or paragraph NB-2540 (for forgings) of Section III of the ASME Code.

[3] The analyses outlined in regulatory positions C.2.c, d, and e should preferably be submitted in topical reports rather than on a case-by-case basis for those flywheel designs that will have multiple applications.

[4] As defined in the Discussion.

b. Inservice inspection should be performed for each flywheel as follows:

(1) An in-place ultrasonic volumetric examination of the areas of higher stress concentration at the bore and keyway at approximately 3-year intervals, during the refueling or maintenance shutdown coinciding with the inservice inspection schedule as required by Section XI of the ASME Code.

(2) A surface examination of all exposed surfaces and complete ultrasonic volumetric examination at approximately 10-year intervals, during the plant shutdown coinciding with the inservice inspection schedule as required by Section XI of the ASME Code.

(3) Examination procedures should be in accordance with the requirements of Subarticle IWA-2200 of Section XI of the ASME Code.

(4) Acceptance criteria should conform to the recommendations of regulatory position C.2.f.

(5) If the examination and evaluation indicate an increase in flaw size or growth rate greater than predicted for the service life of the flywheel, the results of the examination and evaluation should be submitted to the staff for evaluation.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the staff's plans for utilizing this regulatory guide.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the positions of this guide will be used by the NRC staff as follows.

1. The recommendations of regulatory positions C.1, C.2, C.3, and C.4.a will be used in evaluating submittals for construction permit applications docketed on or after January 1, 1976. If an applicant wishes to use the recommendations of regulatory positions C.1, C.2, C.3, and C.4.a of this regulatory guide in developing submittals for an application docketed before January 1, 1976, the pertinent portions of the application will be evaluated on the basis of this guide.

2. The recommendations of regulatory position C.4.b will be used in evaluating procedures used in inservice inspections conducted on all plants after January 1, 1976. If a licensee wishes to use the recommendations of regulatory position C.4.b of this

regulatory guide in performing the inspection before January 1, 1976, the pertinent portions of the inspection procedures will be evaluated on the basis of this guide. Where requirements of Section XI are recommended, examinations conducted during each 40-month inspection period should meet the code edition and all addenda that were in effect per paragraph (b) of 10 CFR § 50.55a 6 months prior to the inspection period. If a licensee wishes to use editions and addenda that subsequently become effective per paragraph (b) of § 50.55a for any portion of the inspection, the pertinent portions of the inspection procedures will be evaluated on the basis of those editions and addenda.

3. The recommendations of this guide will be used in evaluating all topical reports on flywheel integrity after January 1, 1976.