RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**503-8641**
SRP Section:	**05.04.01.01 – Pump Flywheel Integrity (PWR)**
Application Section:	**5.4.1.1**
Date of RAI Issue:	**07/06/2016**

Question No. 05.04.01.01-7

Title 10 of the Code of Federal Regulations (10 CFR) Part 50, Appendix A, General Design Criterion (GDC) 4, "Environmental and dynamic effects design bases," states in part that structures, systems, and components important to safety shall be protected against environmental and dynamic effects, including the effects of missiles, that may result from equipment failure. Reactor coolant pump (RCP) flywheels have large masses and rotate at 1200 revolutions per minute (rpm) during normal reactor operation. A loss of flywheel integrity could result in high energy missiles and the safety consequences could be significant because of possible damage to the reactor coolant system, the containment, or the engineered safety features. Also, to meet GDC 1, "Quality Standards and Records," and 10 CFR Part 50.55a(a)(1), the adequacy of the RCP flywheel design, materials selection, fracture toughness, preservice and inservice inspection programs, and overspeed test procedures are reviewed to assure a quality product commensurate with the importance of the safety function to be performed.

In order for the staff to determine whether the APR1400 design meets these criteria with regard to RCP flywheel integrity to minimize the effects of missiles on components important to safety, the staff is requesting the following information.

In response to RAI 341-8410, question 05.04.01.01-1, your letter dated April 29, 2016, did not provide adequate justification that the flywheel material, 26NiCrMoV14-5, is equivalent to the steels specified in APR1400 FSAR Section 5.4.1.1.2 and NUREG 0800, Section 5.4.1.1, "Pump Flywheel Integrity (PWR)" in order to use an indirect method of determining the fracture toughness. Your response stated that the justification to use an indirect method of determining fracture toughness would be the use of American Society of Mechanical Engineers (ASME) Code Case N-631, "Use of Fracture Toughness Test Data to Establish Reference Temperature for Pressure Retaining Materials Other Than Bolting for Class 1 Vessels Section III, Division 1." This is unacceptable as ASME Code Case N-631 is applicable to the ferritic steels currently specified in the ASME Code. The flywheel material, 26NiCrMoV14-5, is not specified as an acceptable material in the ASME Code.

Revise the information in the APR1400 Design Certification Document to document an acceptable approach for determining the fracture toughness of the RCP flywheel materials used in the APR1400 design.

Response

It is confirmed that fracture toughness will be demonstrated by the direct test method, ASTM E-399-05, specified in NUREG 0800, Section 5.4.1.1. DCD Subsection 5.4.1.1 will be revised. Test reports will be available by November 30th 2016.

Impact on DCD

DCD Subsection 5.4.1.1 will be revised as indicated in the Attachment.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environment Report.

5.4.1.1.1 Material Selection and Fabrication

The material used to manufacture the flywheel is produced by a commercially acceptable process that minimizes flaws such as the vacuum melting and degassing process. The flywheel material is a quenched and tempered forging with the German material designation 26NiCrMoV14-5, which is a high strength ductile forged material. This material meets the requirements described in Subsection 5.4.1.1.2 and 5.4.1.1.3, and its mechanical properties are equal to or exceed SA-508 Class 2, which is a typical U.S. forged flywheel material. One of the attributes that led to selection of this material is its resistance to non-ductile-type failures. This provides adequate fracture toughness properties under operating conditions. No welding is performed on the flywheel. If the flywheel is flame cut, at least 13 mm (1/2 inch) of stock is left on the outer and bore radii for machining to final dimensions.

5.4.1.1.2 Fracture Toughness

, which will be demonstrated by the direct test method.

The K_{IC} of the flywheel material at the normal operating temperature of the flywheel is greater than 165 MPa√m (150 ksi√in). ~~Conformance is demonstrated by an indirect test.~~

~~Justification is provided to establish the equivalence of fracture toughness in the proposed flywheel material and certain steels (ASME SA-533-B Class 1, ASME SA-508 Class 2, ASME SA-508 Class 3, and ASME SA-516 Grade 65). The RT_{NDT} of the flywheel materials is determined in accordance with NB-2320 and NB-2330 of the ASME Section III.~~

5.4.1.1.3 Design

The flywheel is designed to withstand normal conditions, anticipated transients, loss of coolant accident with the largest mechanical pipe break remaining after application of leak before break as described in Subsection 3.6.3, and a safe shutdown earthquake (SSE) without loss of structural integrity. The flywheel integrity analysis is summarized in the technical report APR1400-A-M-NR-14001-P (Reference 4) which is performed for a stress analysis at standstill, normal and overspeed conditions and a fracture mechanics analysis to predict the critical speed for fracture of the flywheel.

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Application Section:	**5.4.1.1**
Date of RAI Issue:	**07/06/2016**

Question No. 05.04.01.01-8

In response to RAI 341-8410, question 05.04.01.01-1, your letter dated April 29, 2016, provided operating experience of the proposed flywheel material. However, it is unclear whether the operating experience cited is directly applicable to the flywheel material proposed in the APR1400 design, with a yield strength of 92,825 lbs/in^2. Therefore, the NRC staff needs the following clarifications:

☐ The operating experience cited for the material includes spare flywheels that have not seen service or plants that have not been operated. It is unclear how this information is relevant to demonstrating the performance of the proposed flywheel material under APR1400 operating conditions. Please clarify.

☐ The operating experience cited to justify the use of the specific material cited in the APR1400 design (26NiCrMoV14-5, that has a yield strength of 92,825 lbs/in^2) should be specific to flywheels manufactured from that particular material. If operating experience is cited for a flywheel of similar design but different material (or this material in a different flywheel design), provide justification as to why that operating experience is relevant to the review of the ARP1400 flywheel design.

Response

The operating experience table in response to RAI 341-8410, question 05.04.01.01-1 is revised as follows, with only the relevant flywheels and their respective period of successful operating experience. The flywheels are made of 26NiCrMoV14-5 with specifications that require minimum Sy = 640 MPa to740 MPa, and minimum Su = 800 MPa.

Connection to Grid	Country	Site	Number of motors	Years in operation	Flywheel Material	Flywheel Experience
1974	ARG	Atucha A	2	42	26NiCrMoV14-5	No known integrity issue for the time in operation
1973	NDL	Borssele	2	43	26NiCrMoV14-5	No known integrity issue for the time in operation
1972	GER	Biblis A	4	44	26NiCrMoV14-5	No known integrity issue for the time in operation
1977	GER	Brunsbüttel	4	39	26NiCrMoV14-5	No known integrity issue for the time in operation
1974	GER	Biblis B	4	42	26NiCrMoV14-5	No known integrity issue for the time in operation
1978	GER	Unterweser	4	38	26NiCrMoV14-5	No known integrity issue for the time in operation
1979	SWZ	Gösgen 1	3	37	26NiCrMoV14-5	No known integrity issue for the time in operation
1984	GER	Grohnde	4	32	26NiCrMoV14-5	No known integrity issue for the time in operation
1985	GER	Philipsburg	4	31	26NiCrMoV14-5	No known integrity issue for the time in operation
1982	BRA	Angra 1	4	34	26NiCrMoV14-5	No known integrity issue for the time in operation
2000	BRA	Angra 2	4	16	26NiCrMoV14-5	No known integrity issue for the time in operation
1986	GER	Brokdorf	4	30	26NiCrMoV14-5	No known integrity issue for the time in operation
1988	GER	Isar 1	4	28	26NiCrMoV14-5	No known integrity issue for the time in operation
1988	GER	Isar 2	5	28	26NiCrMoV14-5	No known integrity issue for the time in operation
plan: 2014	ARG	Atucha 2	2	2	26NiCrMoV14-5	No known integrity issue for the time in operation
1988	GER	Emsland	4	28	26NiCrMoV14-5	No known integrity issue for the time in operation
1994	CHN	Qin Shan 1	2	22	26NiCrMoV14-5	No known integrity issue for the time in operation
1989	GER	GKN	4	27	26NiCrMoV14-5	No known integrity issue for the time in operation
1995/96	KOR	Yeonggwang 3/4 (Hanbit 3/4)	8	20	26NiCrMoV14-5	No known integrity issue for the time in operation
1998/99	KOR	Ulchin 3/4 (Hanul 3/4)	8	17	26NiCrMoV14-5	No known integrity issue for the time in operation
2002	KOR	Yeonggwang 5/6 (Hanbit 5/6)	8	14	26NiCrMoV14-5	No known integrity issue for the time in operation
2004/05	KOR	Ulchin 5/6 (Hanul 5/6)	8	11	26NiCrMoV14-5	No known integrity issue for the time in operation
2011/12	KOR	Shin Kori 1/2	8	4	26NiCrMoV14-5	No known integrity issue for the time

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environment Report.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

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Application Section:	**5.4.1.1**
Date of RAI Issue:	**07/06/2016**

Question No. 05.04.01.01-9

In response to RAI 341-8410, question 05.04.01.01-3, your letter dated April 29, 2016, did not provide a sufficient basis for using the design acceptance criteria of one-third ultimate strength in lieu of one-third yield strength for the flywheel design stress limit. The use of one-third of the yield strength as a design acceptance criteria has been documented by the NRC in SRP 5.4.1.1 and RG 1.14 as providing an acceptable level of safety for this component. The use of one-third of the ultimate strength of the material as the basis for the flywheel design stress limit is unacceptable absent a technical basis demonstrating why the use of such a criteria will provide for an acceptable level of safety against flywheel failure. Revise the APR1400 Design Certification to apply a RCP flywheel stress limit of one-third of the yield strength of the material, or provide a technical justification regarding why the use of one-third of the ultimate strength as the design stress limit will provide an acceptable level of safety against potential failure of the flywheels.

Your response also stated that the "NRC staff used an approximate conversion factor of 1 MPa = 145 psi to arrive at the value of 800/3 MPa = 38,667 psi." The NRC did not convert the units from metric to standard, but simply used the flywheel material ultimate strength (standard units) specified in the flywheel analysis report of 116,000 psi, and divided it by three to obtain 38,667 psi. Therefore, if the use of the one-third ultimate strength criteria is to be justified as noted above, the acceptance criteria should be revised to specify 38,667 psi in the technical report APR1400-A-M-NR-14001-P, "KHNP APR 1400 Flywheel Integrity Report," Revision 0, dated November 24, 2014.

Response

The flywheel material, 26NiCrMoV14-5 was tested to have Sy = 816 MPa and KIC = 168 MPa√m. The tensile test was performed for the weak direction of the specimen according to the SRP 5.4.1.1. Test reports will be available by November 30th 2016. Technical Report APR1400-A-M-NR-14001-P will be revised by November 30th 2016.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Technical Report APR1400-A-M-NR-14001-P will be revised.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

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Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**503-8641**
SRP Section:	**05.04.01.01 – Pump Flywheel Integrity (PWR)**
Application Section:	**5.4.1.1**
Date of RAI Issue:	**07/06/2016**

Question No. 05.04.01.01-10

In response to RAI 341-8410, question 05.04.01.01-3, your letter dated April 29, 2016, did not provide an analysis of the hub nor an acceptable justification for the fatigue crack growth rates used for the flywheel as was previously requested in RAI 341-8410, question 05.05.01.01-3. The use of fatigue crack growth rates from ASME Code, Section XI, Appendix A, Paragraph A-4300 for the proposed flywheel material is unacceptable, as those fatigue crack growth rates are for SA-533 Grade B, Class 1 and SA-508, Class 3 steels, and no justification has been provided for using them for high alloy 26NiCrMoV14-5 material.

Revise the technical report to include an appropriate analysis of the hub, including an appropriate fatigue evaluation for the applicable hub material, and revise the technical report to use appropriate fatigue crack growth rates for the proposed flywheel material.

Response

Although ASME XI A-4200 KIC curve is specific for SA-533 Grade B Class 1, SA-508 Class 2, and SA-508 Class 3 Steels, the ASME XI A-4300 crack growth rate is generic. Figure A-4300-1 is titled, “Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels Exposed to Air Environments (Subsurface Flaws)”. Therefore, ASME XI A-4300 is applicable for 26NiCrMoV14-5. A separate stress plot of the hub itself will be added in the technical report APR1400-A-M-NR-14001-P by November 30th 2016, showing the hub is in compression; therefore, the hub has no risk of flaw propagation.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Technical Report APR1400-A-M-NR-14001-P will be revised.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

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Application Section:	**5.4.1.1**
Date of RAI Issue:	**07/06/2016**

Question No. 05.04.01.01-11

In response to RAI 341-8410, question 05.04.01.01-4, your letter dated April 29, 2016, did not revise the APR1400 FSAR to specify the maximum flaw size used as the acceptance criteria for the preservice inspection and that it is bounded by the flaw size used in determining the critical flaw size in Technical Report APR1400-A-M-NR-14001-P as was previously requested in RAI 341-8410, question 05.04.01.01-4. Revise the APR1400 FSAR to include this information.

Response

DCD Subsection 5.4.1.1 will be revised to include an inspection acceptance criteria.

Impact on DCD

DCD Subsection 5.4.1.1 will be revised as indicated in the Attachment.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environment Report.

e. A surface examination of all exposed surfaces and a 100 percent volumetric examination by ultrasonic methods are conducted at approximately 10-year intervals during the plant shutdown coinciding with the inservice inspection schedule as required by ASME Section XI.

f. Each flywheel receives a preservice baseline inspection that incorporates the methods defined above for an inservice inspection. Examination procedures and acceptance criteria are determined in accordance with ASME Section III.

g. The observed flaw depth from flywheel and hub inspections shall be limited to less than 12.7 mm (0.5 inch).

5.4.1.2 Description

Table 5.4.1-1 lists the principal parameters of the reactor coolant pumps, and Figure 5.4.1-1 depicts the arrangement of the pump and motor. Reactor coolant pump supports are described in Subsection 5.4.15. The flow diagram for the reactor coolant pump is given in Figure 5.1.2-2.

The four reactor coolant pumps are vertical, single stage, bottom suction, horizontal discharge, motor-driven centrifugal pumps. The pump impeller is splined and locked to its shaft. Pump shaft alignment is maintained by a water lubricated radial bearing within the pump and by radial and thrust bearings located in the motor stand. The pump and motor shafts are directly connected by a coupling.

The pump rotating assembly is mounted in a diffuser-type pump casing. The pump casing is a one-piece design in accordance with applicable sections of ASME Section III. The one-piece casing reduces the ASME Section XI examination requirements.

The pressure boundary materials used for the reactor coolant pump assembly are listed in Table 5.2-2, are compatible with the reactor coolant addressed in Subsection 5.2.3.2.1.

The shaft seal assembly consists of two face types, mechanical seals in series, with a controlled leakage bypass to provide the same pressure differential across each seal. The seal assembly is designed for the pressure differential of 175.8 kg/cm^2 (2,500 psi) and to reduce the leakage pressure from the RCS pressure to the volume control tank pressure. A third, face-type, low-pressure vapor seal at the top is designed to withstand system operating pressure when the pumps are not operating. The leakage past the second

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Application Section:	**5.4.1.1**
Date of RAI Issue:	**07/06/2016**

Question No. 05.04.01.01-12

In response to RAI 341-8410, question 05.04.01.01-5, your letter dated April 29, 2016, did not revise the APR1400 FSAR to include that the hub will be inspected for both pre-service inspection (PSI) and in-service inspection (ISI) in the same manner as the flywheel. In addition, the applicant's response also stated that the hub has oil channels that would make it difficult to perform UT inspection.

Revise APR1400 FSAR Section 5.1.1.1.4 to state that the hub will be inspected for both PSI and ISI in the same manner. In addition, provide a discussion on the extent and acceptance criteria of UT inspections that could be performed or other alternatives of performing in-service inspections given these geometric interferences (oil channels).

Response

Without disassembling of the flywheel, the outer wheel and hub interface prevents accurate UT readings. Additionally, even if it is disassembled, the presence of oil channels would mask many areas from a meaningful reading. Due to this reason, KHNP proposes a dye penetrant test (PT) or magnetic particle test (MT) instead of UT. As indicated in the response to Question No. 05.04.01.01-10, KHNP will show the hub is in compression with a separate stress plot in the technical report APR1400-A-M-NR-14001-P. The risk of flaw propagation in the hub is negligible.

Impact on DCD

DCD Subsection 5.4.1.1 and Table 1.9-1 will be revised as indicated in the Attachment.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environment Report.

The design overspeed of flywheel is 125 percent of the synchronous speed of the RCP motor. The design overspeed is at least 10 percent greater than the highest anticipated overspeed of the pump. The highest anticipated overspeed is predicted for loss of coolant accident with the largest break size remaining after the application of leak before break, as described in Subsection 3.6.3. The largest break size remaining after the application of leak before break that may affect the maximum overspeed of the RCP is a 10.16 cm (4 in) pressurizer spray line.

The shaft and bearings supporting the flywheel are able to withstand any combination of the loads of normal operation, anticipated transients, loss of coolant accident with the largest mechanical pipe break remaining after application of leak before break as described in Subsection 3.6.3, and an SSE.

The flywheel is accessible for 100 percent in-place volumetric ultrasonic inspections. The flywheel-motor assembly is designed to allow such inspection with a minimum of motor disassembly.

5.4.1.1.4 Test and Inspection

a. Each flywheel [and hub] is tested at the design overspeed.

b. The flywheel [and the hub are] is subjected to a magnetic particle or liquid-penetrant examination per ASME Section III before final assembly. ~~The inspection is performed on areas of high stress concentrations.~~

c. Each finished flywheel [and its hub] is subjected to a 100 percent volumetric ultrasonic inspection from the flat surface as per ASME Section III. ~~This~~ [The flywheel] inspection is performed ~~on the flywheel~~ after final machining and the overspeed test. ~~[The hub inspection is performed before final machining.]~~ [The ultrasonic inspection for the hub is performed before final machining. Post final machining, the hub is inspected by dye penetrant test or magnetic particle test.]

d. The inservice inspection program includes ultrasonic examinations ~~of the areas of high stress concentration at the bore and keyway~~ [of the flywheel, excluding the hub,] at about three and one-third year intervals, during the refueling or maintenance shutdown coinciding with the inservice inspection schedule as required by ASME Section XI (Reference 5). Removal of the flywheel [or hub] is not required. [The hub is inspected by dye penetrant test or magnetic particle test.]

e. A surface examination of all exposed surfaces and a 100 percent volumetric examination by ultrasonic methods are conducted at approximately 10-year intervals during the plant shutdown coinciding with the inservice inspection schedule as required by ASME Section XI. This examination is limited to the flywheel, excluding the hub.

f. Each flywheel receives a preservice baseline inspection that incorporates the methods defined above for an inservice inspection. Examination procedures and acceptance criteria are determined in accordance with ASME Section III.

5.4.1.2 Description

Table 5.4.1-1 lists the principal parameters of the reactor coolant pumps, and Figure 5.4.1-1 depicts the arrangement of the pump and motor. Reactor coolant pump supports are described in Subsection 5.4.15. The flow diagram for the reactor coolant pump is given in Figure 5.1.2-2.

The four reactor coolant pumps are vertical, single stage, bottom suction, horizontal discharge, motor-driven centrifugal pumps. The pump impeller is splined and locked to its shaft. Pump shaft alignment is maintained by a water lubricated radial bearing within the pump and by radial and thrust bearings located in the motor stand. The pump and motor shafts are directly connected by a coupling.

The pump rotating assembly is mounted in a diffuser-type pump casing. The pump casing is a one-piece design in accordance with applicable sections of ASME Section III. The one-piece casing reduces the ASME Section XI examination requirements.

The pressure boundary materials used for the reactor coolant pump assembly are listed in Table 5.2-2, are compatible with the reactor coolant addressed in Subsection 5.2.3.2.1.

The shaft seal assembly consists of two face types, mechanical seals in series, with a controlled leakage bypass to provide the same pressure differential across each seal. The seal assembly is designed for the pressure differential of 175.8 kg/cm^2 (2,500 psi) and to reduce the leakage pressure from the RCS pressure to the volume control tank pressure. A third, face-type, low-pressure vapor seal at the top is designed to withstand system operating pressure when the pumps are not operating. The leakage past the second

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Table 1.9-1 (2 of 38)

the ultrasonic inspection for the hub is performed before final machining. Post final machining and during service, the hub is inspected by dye penetrant test or magnetic particle test.

NRC Regulatory Guide	Revision / Issue Date	Conformance or Summary Description of Deviation	DCD Tier 2 Section
1.8 Qualification & Training of Personnel for Nuclear Power Plants	Rev. 3 05/2000	Not applicable (COL)	N/A
1.9 Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants	Rev. 4 03/2007	The APR1400 conforms with this NRC RG.	8.1.3.3, 8.3.1.2.2
1.11 Instrument Lines Penetrating Primary Reactor Containment	Rev. 1 03/2010	The APR1400 conforms with this NRC RG.	3.6.2.1.4.2, 6.2.4.1
1.12 Nuclear Power Plant Instrumentation for Earthquakes	Rev. 2 03/1997	The APR1400 conforms with this NRC RG.	3.7.4.1
1.13 Spent Fuel Storage Facility Design Basis	Rev. 2 03/2007	The APR1400 conforms with this NRC RG.	9.1.1.1, 9.1.1.3, 9.1.2.1, 9.1.3.3.3, 9.1.4.3, 9.1.5.2.1, 9.1.5.3, 9.4.2.1
1.14 Reactor Coolant Pump Flywheel Integrity	Rev. 1 08/1975	~~The APR1400 conforms with this NRC RG.~~	5.4.1.1
1.20 Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial S	Rev. 3 03/2007	The APR1400 conforms with this NRC RG with the following exception:	3.9.2.4, 14.2.7.1.6
1.21 Measur Radioa Effluen			11.5, 12.3.4, TS Part 3, 5.0
1.22 Periodi Actuati			7.1.2.38, Table 7.1-1, 7.2.2.5, 7.2.3.3, 7.3.2.5, 7.3.3.5, 8.1.3.3
1.23 Meteorological Monitoring Programs for Nuclear Power Plants	Rev. 1 03/2007	Not applicable (COL)	N/A

The APR1400 conforms with this NRC RG with the following exception:

- The flywheel hub has small oil channels which prevents accurate ultrasonic test (UT) inspection. Due to this reason, ~~the hub is only inspected before machining.~~ Since the flywheel was analyzed using the maximum tensile stress at the outer wheel inner diameter surface, the hub is bounded. The outer wheel will be inspected after machining and during service as indicated in RG 1.14.