Seismic Performance Analysis of Emergency Diesel Engine Retarder in Nuclear Power Plant

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Abstract. The finite element analysis is used to study the seismic performance of the emergency diesel worm gear retarder in nuclear power plant. By modal analysis of the structure, it is concluded that the first natural frequency is higher than 33 Hz. Then the seismic analysis is performed both on the horizontal and vertical conditions. The analysis results show that under the equivalent earthquake acceleration 4.5g, the stress is low for the retarder case and other components of the worm retarder, and fulfills the material strength requirement. It can be considered that the structure of the retarder is stable and has excellent anti-seismic performance, meeting the seismic requirement for class 3 nuclear safety equipment.

1. Introduction

The worm gear retarder is an important part of the emergency equipment of the nuclear power plant, which consists of box, top capper, transitional sleeve, worm gear, capper, output disk, worm, input disk, bearings, seal gaskets and bolts [1]. The whole geometry model is shown in Figure 1.

This article analyzes the stress and displacement of the retarder under the equivalent seismic acceleration of 4.5g by quasi-static method, and evaluates the seismic analysis results [2]. The purpose of the seismic analysis is to prove that the retarder can remain its structure integrality during and after the Operation Base Earthquake (OBE) and Safety Shutdown Earthquake (SSE).
2. Seismic analysis of the worm gear retarder

The material of the box, worm gear, output disk, capper and input disk is spheroidal graphite iron QT500-7, the material of the top capper is gray iron HT200, the material of the capper is carbon steel Q235A, and the material of the transitional sleeve and the worm is carbon steel 45#. According to the Mechanical design manual [3], the material properties are shown in Table 1.

| Material   | Young’s modulus $E$ ($10^5$ MPa) | Poisson’s ratio | Tensile strength $\sigma_s$, $S_s$ (MPa) | Yield strength $\sigma_y$, $S_y$ (MPa) | Density $(x10^3$ kg / mm$^3$) |
|------------|----------------------------------|----------------|----------------------------------------|--------------------------------------|--------------------------------|
| QT500-7    | 1.76                             | 0.3            | 500                                    | 320                                  | 7.7                            |
| HT200      | 1.60                             | 0.27           | 300                                    | 200                                  | 7.7                            |
| Q235A      | 2.03                             | 0.3            | 430                                    | 235                                  | 7.8                            |
| 45#        | 2.1                              | 0.3            | 650                                    | 360                                  | 7.8                            |

According to the regulation of class 3 components in ASME-ND[4], the normal operation condition belong to level A series limit, while OBE condition belong to Level B Series and SSE condition belongs to Level D series. ASME ND-3321 specified the stress limitations of class 3 equipments under A, B, D operation limit.

Two loads are considered in this analysis, one is gravity and the other is seismic loads. According to the Required Input Motion (RIM), the peak value of the acceleration is about 4.5g. Because the frequency of first mode of the retarder is higher than 33Hz, the quasi-static analysis method is available in this analysis. For conservative consideration, the peak acceleration of the RIM, 4.5g, is used as the equivalent seismic acceleration in this analysis. The worm gear retarder can be either horizontally or vertically located in different places, so horizontal and vertical conditions are both analyzed in this article.

There are worm, worm gear, transitional sleeve in the retarder. The worm is positioned by two GB/T27308E bearings. The worm drives the worm gear. The worm gear is axial positioned by retarder case and output disc in the retarder case. The rotation angle of worm gear is restricted by 2 socket head cap flat-end holding screws. The worm gear drives the transitional sleeve. The transitional sleeve is axial positioned by worm gear and cruciform slot sunk screws on the output disc.

Retarder case is the important component of retarder. As it is the foundation support of rotation parts, retarder should have enough strength and rigidity. In the analysis in this article, all the mass of
upper end capper, capper, worm, worm gear and transitional sleeve is uniformly distributed on the retarder case, while their rigidity is neglected. This kind of simplification is conservative and safe.

3. Analysis Results

3.1. Modal analysis of whole retarder body

The static components of the worm gear retarder include upper end capper, capper, retarder case, input disc and output disc. The upper end capper, capper, input disc and output disc are connected to retarder by bolts separately. The input part is usually connects to electric actuating mechanism, while the output part usually connects to valve.

As the mass of upper end capper and capper is little, and only inertia load acts on them, this article doesn’t calculate them separately. The mass of upper end capper and capper is uniformly distributed on retarder case, while their rigidity is neglected.

During the modal analysis, the displacement relation is neglected between contact surfaces of retarder case and input disc, between contact surfaces of retarder case and output disc. That is to say there are only connection bolts between these contact surfaces. For this reason, the rigidity of worm gear retarder in modal analysis is lower than that of real structure.

The displacement constrain is defined on the surface of bolts which connect the output disc and flange surfaces of valve. The analysis model of retarder is shown in Figure 2.

Figure 2. Finite Element Model of Modal Analysis

The calculated former five natural frequencies are shown in Table 2. It can be seen from Table 2, the first natural frequency is higher than 33 Hz, so the above model build method is conservative.

Table 2. Former Five Natural Frequencies of Retarder (Hz)

| Modal No. | 1   | 2   | 3   | 4   | 5   |
|-----------|-----|-----|-----|-----|-----|
| Natural frequency | 70.3 | 85.7 | 408.5 | 582.0 | 689.8 |

3.2. Seismic analysis of retarder

After modal analysis, the seismic analysis can be proceeded based on basic structure dynamic properties. The analysis model of whole retarder is shown in Figure 3. The model includes 835774 four nodes tetrahedron elements, 189085 nodes, 1 concentrate mass elements, 24 rigid element, 2 couple of contact surfaces, 4 couple of multi points constrain surface, and 1 displacement constrain surface.
3.2.1. Seismic analysis of worm gear when it is vertically installed

The equivalent seismic acceleration 4.5g is defined in the direction of axis X, -Y and Z, and the gravity acceleration is 1g in the direction of axis X, which is the same as the direction of the vertical earthquake acceleration. Under this kind of seismic load, the box, input disc, output disc and bolts mainly bear tensile force. The retarder case, input disc, output disc, and connection bolts are all made from spheroidal graphite iron, which can bear compress force instead of tensile force.

The maximum strain of retarder is 0.20552mm, locating at the concentrating mass point of electric actuating mechanism, as shown in Figure 4. The maximum principal stress is about 100.77MPa, locating at central discontinuous area of retarder case, shown in Figure 5. The strain is consistent with the load direction.

The maximum principal stress of retarder is about 100.77MPa, locating at the discontinuous area between open cores on input disc and output disc. The area is very small. The stress of whole retarder case is low, which is under 30MPa, shown in Figure 6. The maximum principal stress of input disc is about 68.214MPa, locating at the bolt gasket which connects to electric actuating mechanism. The area is very small. The stress of whole input connection disc is low, which is under 40MPa, shown in Figure 7. The maximum principal stress of output connection disc is about 29.235MPa, locating at boundary of boss which connects with the valve. The stress of whole output connection disc is low, which is under 20MPa, shown in Figure 8.
3.2.2. Seismic analysis of worm gear when it is horizontal installed.

The equivalent seismic acceleration 4.5g is defined in the direction of axis -X, -Y and -Z, and the gravity acceleration is 1g in the direction of axis -Z, same as the direction of the vertical earthquake acceleration. The calculation results are as follows.

The maximum strain of retarder is 0.2097mm, locating at the concentrating mass point of electric actuating mechanism, as shown in Figure 9. The maximum principal stress is about 86.119MPa, locating at bolts connecting the input disc and electric actuating mechanism, shown in Figure 10. The strain is consistent with the load direction.

The maximum principal stress of retarder case is about 69.452MPa, locating at boundary of bolt hole connecting the retarder case and input disc. The area is very small. The stress of whole retarder case is low, which is under 30MPa. The maximum principal stress of input disc is about 41.51MPa, locating near the chamfer. The area is very small. The stress of whole input disc is low, which is under 40MPa. The maximum principal stress of output disc is about 27.28MPa, locating at boundary of boss which connects to the valve. The stress of whole output disc is low, which is under 20MPa.
3.3. Stress Evaluation

For nuclear safety class 2 and 3 equipment, the first strength theory, maximum principal stress theory, is adopt in our article [4-7]. The calculated stress is the maximum principal stress of given points. Sum up above calculation results, the maximum principal stress and allowable stress of components in retarder are given in Table 3.

The inner parts in the retarder, such as upper end capper, transitional sleeve, worm, capper, worm gear, almost bear no other load except their own inertia load. Comparing with the retarder, input disc and output disc, the inner parts load is much lower, so these inner parts is much safer.

Table 3. Stress Evaluation of Retarder Parts (MPa)

| Name of Component       | Material   | Allowable Stress | Maximum Principal Stress |
|-------------------------|------------|------------------|--------------------------|
| Gear case               | QT500-7    | 125              | 100.77                   |
| Input connection disc   | QT500-7    | 125              | 68.214                   |
| Output connection disc  | QT500-7    | 125              | 29.235                   |

4. Conclusions

Through seismic analysis on the emergency diesel worm gear retarder in nuclear power plant, it can be concluded as follows: according to earthquake response spectrum specification in “Certification on safe class valve driven device in nuclear power plant”, under the equivalent earthquake acceleration 4.5g, the stress is low for the retarder case and other components of the worm retarder, and fulfills the material strength requirement. It can be considered that the structure of the retarder is stable and has excellent anti-seismic performance, meeting the seismic requirement for class 3 nuclear safety equipment.

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