Shakedown Analysis for the Hydraulic Nut Device of Reactor Vessel

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1. Introduction

The hydraulic nut system is a tensioning system that is a direct retrofit for any existing tensioning system currently used on the reactor vessel. The system itself is of a modular design tensioner and integrated mechanical lock ring to retain load generated through the use of hydraulics. The hydraulic nuts allow for 100% tensioning of all studs simultaneously, so reduction in critical path time and radiation exposure for both installation and removal laborers can be achieved by adopting this device.

Structural analyses for the hydraulic nut device which will be applied to the Nuclear Power Plant reactor vessel have been performed to evaluate the effect of the replacement on the structural integrity of both the reactor vessel closure head area and the hydraulic nuts. Shakedown analyses have been performed because the primary plus secondary (P+Q) stress intensity limit of the hydraulic nut is exceeded in several locations. It is concluded that shakedown will occur and structural integrity of the reactor vessel closure head area will be maintained with the application of the hydraulic nut system.

2. Methods and Results

Because the hydraulic nut device is categorized as a class 1 component by the ASME B&PV code [1], structural analyses should be performed per ASME code, Section III, NB-3200.

The geometry of the hydraulic nut device is shown in Fig. 1 and operating mechanism of the nut is shown in Fig. 2.

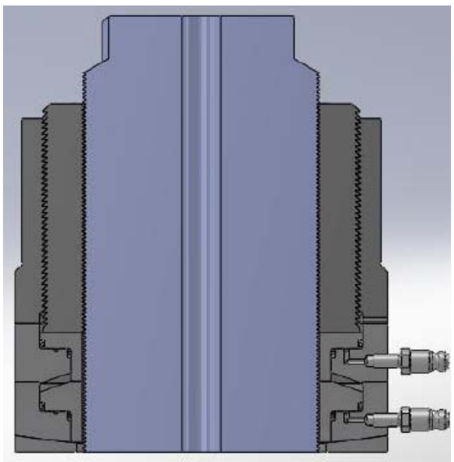

Fig. 1. Geometry of the hydraulic nut device

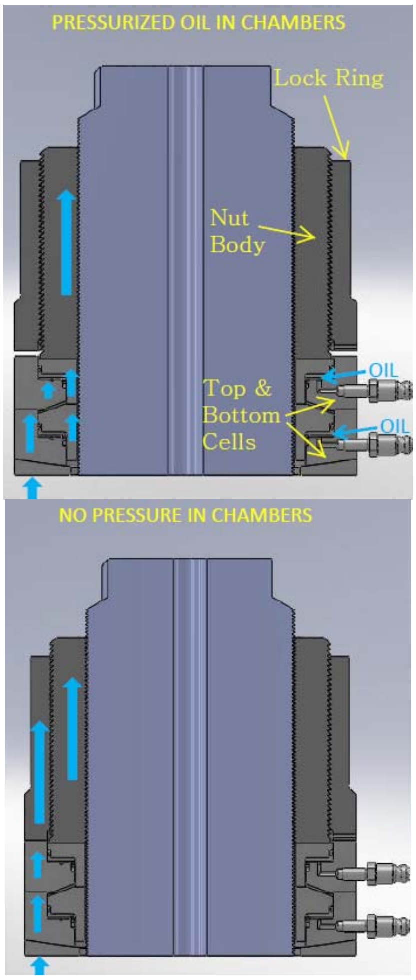

Fig. 2. Operating mechanism of the nut

As shown in Fig. 2, the stud is lifted when the hydraulic pressure is applied to two chambers located under the nut body and this tensioning load can be retained by turning the lock ring down. The nut body, lock ring, and top and bottom load cells keep the tensioning load during plant operation. Simplified FEM models of the hydraulic nut device with its boundary condition for the axial loading and pressure loading are shown in Fig. 3. The pressure and the axial loading case simulate the tensioning stage and the operation stage, respectively. The lock ring and the nut body are excluded in the FEM model because the top and bottom load cells are the limiting components. This makes sense because the lock ring and nut body are fastened by threads and this threaded connection distributes stresses to the two components.

Material of the hydraulic nut is SA-540, Grade B24, Class 3 and its material property is shown in Table I.

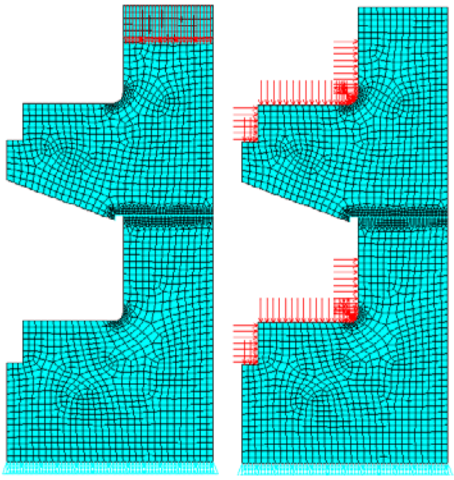

Fig. 3. Axial loading boundary condition (Left), Pressure loading boundary condition (Right)

Table I. Material Property of SA-540, Gr. B24, Cl. 3

Temp. (ºF)	Young's Modulus (ksi)	Thermal Expansion ($x10^{-6}$ in/in/ºF)
70	27800	6.4
400	26100	7.1
625	25100	7.5

Temperature of 625ºF is applied to the model for the consideration of the thermal expansion during normal operating conditions. Analysis results for each loading condition are shown in Fig. 4 and a summary of P+Q evaluation results is in Table II. It shows that P+Q stress intensities of the pressure loading can't meet the ASME code allowable value of 3Sm.

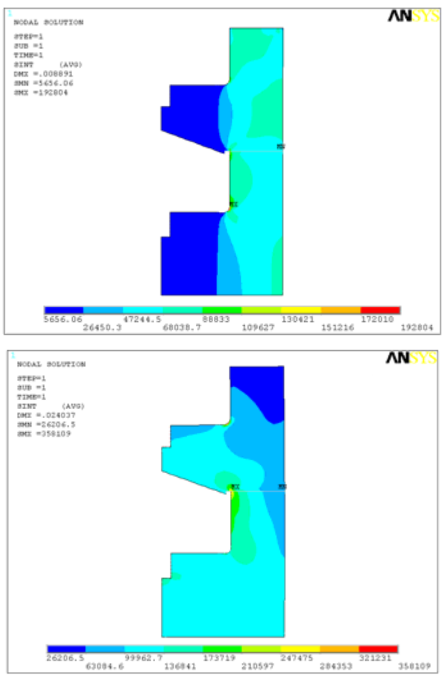

Fig. 4. Analysis results,
Axial loading (Top), Pressure loading (Bottom)

Table II. Summary of P+Q evaluation

Loading Case	P+Q (ksi)	Allowable (ksi)
Axial	91.43	106
Pressure	192.9	129.9

Relaxation from the P+Q stress limits is permitted per NB-3228[1] if a plastic analysis is performed. Because the ratio of yield to tensile strength for the nut is greater than 0.80, the simplified elastic plastic analysis per 3228.5 [1] is not applicable. Therefore the shakedown analysis is performed in accordance with NB-3228.4 [1].

The loading sequence scenario is developed by using the plant transient loading data with a conservative combination. It consists of twenty four (24) transient loadings from tensioning to de-tensioning and it is repeated for twenty (20) cycles. Shakedown analysis results reveal that shakedown occurs as shown in Fig. 5.

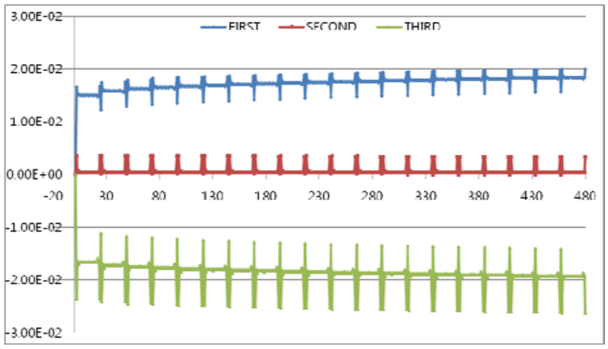

Fig. 5. Shakedown analysis result (Principle strain)

3. Conclusions

The structural analysis for the hydraulic nut device is performed per the ASME B&PV code, Section III, Subsection NB [1]. In primary plus secondary (P+Q) stress intensity evaluations, the stress intensity limit is exceeded for the pressure loading condition, so the shakedown analysis is performed to relax the P+Q stress limit. It is shown that shakedown occurs and it can be concluded that primary plus secondary stress intensities of the hydraulic nut device meet the ASME Code [1] criterion for the Class 1 component.

REFERENCES

[1] ASME Boiler & Pressure Vessel Code, 1998 Edition, with 1999 and 2000 Addenda, Division 1, Rules for Construction of Nuclear Power Plant Components.

[2] B. E. Heald, D. P. Molitoris, J. V. Gregg Jr., E. E. Heald, D. H. Roarty, Elastic-Plastic Shakedown Evaluation using ASME Code Section III and Section VIII Methods, ASME PVP 2010 Conference, PVP2010-25669.