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Research on friction coefficient of nuclear Reactor Vessel Internals Hold Down Spring: Stress coefficient test analysis method

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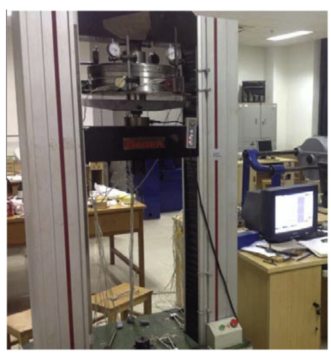
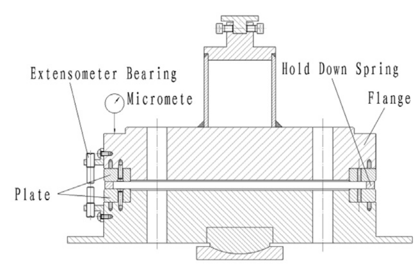
HIGHLIGHTS

- This paper performs mathematic deduction to the physical model of Hold Down Spring (HDS), establishes a mathematic model of axial load *P* and stress, stress coefficient and friction coefficient and designs a set of test apparatuses for simulating the pretightening process of the HDS for the first time according to a model similarity criterion.
- The mathematical relation between the load and the strain is obtained about the HDS, and the mathematical model of the stress coefficient and the friction coefficient is established. So, a set of test apparatuses for obtaining the stress coefficient is designed according to the model scaling criterion and the friction coefficient of the K1000 HDS is calculated to be 0.336 through the obtained stress coefficient.
- The relation curve between the theoretical load and the friction coefficient is obtained through analysis and indicates that the change of the friction coefficient *f* would influence the pretightening load under the condition of designed stress. The necessary pretightening load in the design process is calculated to be 5469 kN according to the obtained friction coefficient. Therefore, the friction coefficient and the pretightening load under the design conditions can provide accurate pretightening data for the analysis and design of the reactor HDS according to the operations.

GRAPHICAL ABSTRACT

HDS stress coefficient test apparatus.





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ABSTRACT

This paper performs mathematic deduction to the physical model of Hold Down Spring (HDS), establishes a mathematic model of axial load P and stress, stress coefficient and friction coefficient and designs a set of test apparatuses for simulating the pretightening process of the HDS for the first time according to a model similarity criterion. By carrying out tests and researches through a stress testing technique, P–σ curves in loading and unloading processes of the HDS are obtained and the stress coefficient k_f of the HDS is obtained. So, the friction coefficient f of the K1000 HDS are further calculated to be 0.336 by stress coefficient k_f. It is very important that the research method of friction coefficient put forward by this paper for the first time. The method can provide an exact basis for HDS design and structure selection and can provide a guarantee for the safe operation of the reactor.

1. Foreword

Reactor Vessel Internals (RVI) consists of four parts, including a compress component (reactor core upper supporting components), a core barrel components (reactor core lower supporting components), irradiation surveillance capsules and RVI accessories (Ehrnstén et al., 2013; Choi et al., 2013). The compress parts consist of a compress supporting structure, a guide tube, RVI temperature measuring device, a Hold Down Spring (HDS), a supporting plate and an adjusting shim (Sigrist et al., 2006).The HDS is an annular large-diameter compress spring with a Z-shaped cross section, is located between core barrel flange and reactor internals flange as show in Fig. 1. When a reactor pressure vessel head is closed and pretightened, the HDS is subjected to axial compression, simultaneously reactor core upper and lower supporting structures are pressed against a supporting step of the pressure vessel, deformation caused by changes such as of pressure, temperature or material thermal expansion in the vessel is compensated during operation, and the RVI are guaranteed to be pressed and stably located between the upper and lower flanges of the reactor pressure vessel (Zhang and Xue, 2013; Fang et al., 2014). The first role of the HDS is to compensate flange machining errors and the second role is to provide enough pressing force to the internal lower components. The interface contact between a core barrel assembly and two flange interfaces is to be too loose if the pretightening force of the HDS is too small. This will result in large flow-induced vibration of core barrel assembly under normal operating conditions (Kaoa et al., 2011; Fang et al., 2014; Yamano et al., 2011). At the same time, the pre-loading force of the HDS cannot be too large beyond the elastic range, resulting in spring-back deformation amount of the HDS is reduced, and for a long time will cause amplitude increased and frequency decreased of the flow-induced vibration of the core barrel assembly (Chen et al., 2014; RCC-M, 2007).

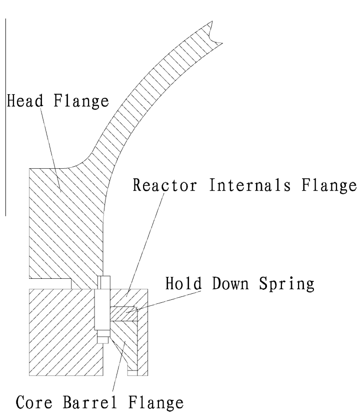

Fig. 1. Installation diagram of Hold Down Spring.

In the design and analysis of the HDS, it is found that the friction force between contact surfaces of the HDS and the upper and lower flange would directly affects the axial rigidity of the HDS. When the friction force increased, the axial rigidity value will be increased correspondingly, such that the axial pretightening force needed under the same initial deformation conditions is increased and the stress value in the ring is also increased. Since the actual friction coefficient cannot be obtained from the analysis, the experimental study should be carried out in order to obtain the friction coefficient, so as to provide an exact basis for the design and installation of HDS, and to ensure that the stress strength of the HDS under the maximum pre-loading force load controlled within permissible range required by ASME-NG (1989).

2. HDS stress analysis

When the HDS with a rectangular section is under the effect of the uniform moments M along the centerline thereof, the rectangular section would produce a tiny rotating angle φ without producing other deformations, such that circumferential stress is produced on the circumference. During stress analysis of the HDS, the HDS can be deemed to have torsion caused by the moment uniformly distributed along the centerline of the ring. The $h/2$ thickness of the ring is the r axis, and the coordinate system is established. It is cross-sectional as shown in Fig. 2.

where R_0 is outside diameter of ring; R_i is inside diameter of ring; R is medium diameter of ring, equal to $(R_0 + R_i)/2$; h is the thickness of the ring; (r_1,z) is the point coordinates of A.

2.1. Equilibrium differential equation

A unit with an included angle of $d\theta$ is taken along the diameter direction of the HDS, as shown in Fig. 3. Under the effect of an external moments M, an equilibrium equation is established as follow:

$$MRd\theta - 2M_\theta \sin\frac{d\theta}{2} = 0 \quad (1)$$

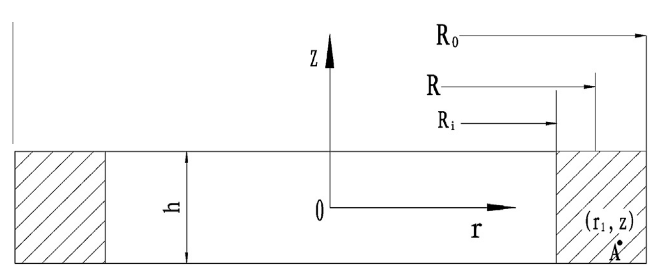

Fig. 2. Sectional dimension diagram of HDS.