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Prediction of the Nuclear Fuel Rod Abrasion in the Probability Sense

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Abstract: The paper deals with the upper and lower limits estimation of the friction work and fretting wear in the contact of nuclear fuel rods with fuel assembly (FA) spacer grid cells. The friction work is deciding factor for the prediction of the fuel rod cladding abrasion caused by FA vibration. Design and operational parameters of the FA components are understood as random variables defined by mean values and standard deviations. The gradient and three sigma criterion approach is applied to the calculation of the upper and lower limits of the friction work and fretting wear in particular contact surfaces between the fuel rod cladding and some of spacer grid cells.

Introduction

The friction forces in the contact of nuclear fuel rods with FA spacer grid cells, caused by flexural vibration of fuel rods (FR), produce the FR cladding abrasion. The goal of this contribution, in direct sequence at deterministic interpretation of FR abrasion [1,2], is a presentation of the probabilistic method [3] for the estimation of the upper and lower limits of the work of friction forces and fretting wear of the FR cladding in the contact surfaces. The chosen fuel rod (Fig. 1) is surrounded by three spacer grid cells (Fig. 2) on every level of spacer grid g. Elastic properties of cells can be expressed by three springs with identical stiffnesses k between cell centres and contact points [2].

The dynamic contact forces $F_{i,g},\ i = 1, 2, 3$ between fuel rod and cells at the level of spacer grid g in the course of FA vibration can be expressed by means of cell centres displacements $x_{i,g}, y_{i,g}$, $(i = 1, 2, 3)$ and lateral displacements ξ_g, η_g of the chosen FR. Fuel rod lateral displacements are generalized displacements of the FA global mathematical model presented in [2]. The *total contact*

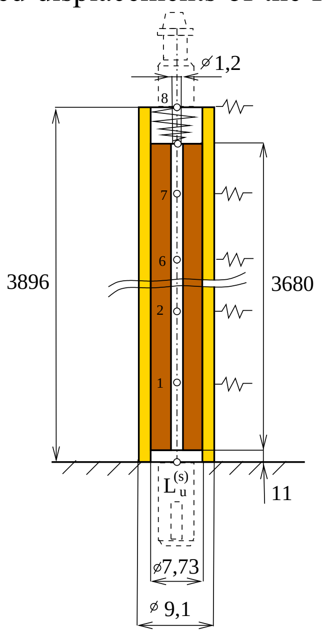

Fig. 1: Model of the fuel rod

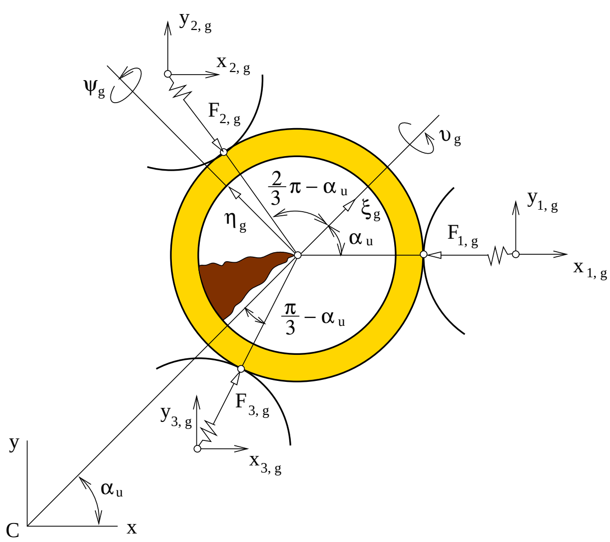

Fig. 2: Section of the fuel rod at the level of spacer grid g

forces between fuel rod and the spacer grid cells at the level $g = 1, \dots, G$ are determined by the sum of the static contact force F_{st} after fuel rods installation into the load-bearing skeleton with spacer grids and the dynamic contact forces caused by vibration $N_{i,g}(t) = [F_{st}+F_{i,g}(t)]H(F_{st}+F_{i,g}(t)), i = 1, 2, 3$. H is Heaviside function (for $F_{st} + F_{i,g}(t) < 0$, when contact is interrupted, $H = 0$).

Estimation of works of friction forces

The criterion of the FR cladding fretting wear can be expressed using the work of friction forces during the representative time interval $t \in \langle t_1, t_2 \rangle$ in contact surfaces as

$$W_{i,g} = \int_{t_1}^{t_2} f_0 \, |N_{i,g}(t)\dot{z}_{i,g}(t)| \, \mathrm{d}t \, , \; i = 1, 2, 3 \, , \; g = 1, \dots, G \tag{1}$$

where f_0 is the computational friction coefficient and $\dot{z}_{i,g}$ are vertical sliding velocities. Let us assume dependence of FA mathematical model on stochastical independent random design parameters $\boldsymbol{p}_d = [p_j] \in R^s$ defined by mean values $\overline{p}_j$ and diagonal covariance matrix $\Sigma_{\boldsymbol{p}_d} = \mathrm{diag}[\sigma_j^2] \in R^{s,s}$. Using the gradient method and on condition that standard deviations σ_j are relatively small we can write [3] the approximate relation for the covariance matrix of the works of friction forces (further *friction works*) in all contact surfaces in the form

$$\Sigma_W \doteq \left[\frac{\partial \boldsymbol{w}(\boldsymbol{p}_d)}{\partial \boldsymbol{p}_d^T} \right]_{\boldsymbol{p}_d = \overline{\boldsymbol{p}}_d} \Sigma_{p_d} \left[\frac{\partial \boldsymbol{w}(\boldsymbol{p}_d)}{\partial \boldsymbol{p}_d^T} \right]^T_{\boldsymbol{p}_d = \overline{\boldsymbol{p}}_d} . \tag{2}$$

Friction works are compiled in the vector $\boldsymbol{w}(\boldsymbol{p}_d) = [\dots, W_{i,g}(\boldsymbol{p}_d), \dots], i = 1, 2, 3 \, , \; g = 1, \dots, G$ of dimension $3G$. Diagonal elements $\sigma^2_{W_{i,g}}$ of the covariance matrix Σ_W can be used for the upper and lower limits calculation of the friction works in all contact surfaces. Similarly to friction works limits, the limits of fretting wear of the FR cladding are calculated using experimentally obtained loss of FR cladding mass in contact surface generated by the friction work $W = 1$[J] and friction coefficient [4].

Summary

As described analytical-numerical method enables to investigate the limits of the friction work and fretting wear of the nuclear Zr FR cladding in contact surfaces with FA spacer grid cells. The FA vibration is caused by spatial motion of the fuel assembly support plates investigated on the global reactor model. FA design and operational parameters are understood as random variables defined by mean values and standard deviations or relative ranges of values. The presented method was applied on the Russian TVSA-T fuel assembly in the VVER 1000 type reactor in NPP Temelín.

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