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Acoustic Standing Waves in Primary Circuit of NPPs with WWER 1000 MW

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Abstract: Acoustic standing waves in primary circuit of the NPPs with WWER 1000 MW reactor is possible classify as in whole primary circuit or only in reactor pressure vessel with partial penetration in the hot leg. Typical feature of these waves is the dependence on the coolant temperature which increase or decrease during increasing or decreasing of the reactor power. Exact solution of the eigenvalue problem represents the six order determinant. The first (lowest) frequency is influenced by the water volume in the pressurizer. To obtain the analytical solution the Whittaker method is applied to the original six order determinant. As the result we obtain the two order one and finally the very simply but exact equation is obtained.

Introduction

Acoustic standing waves represent special type of exciting forces acting on the reactor internals. As a important part of the reactor diagnostic this ones are detected using installed pressure sensors on the cold and hot legs. To explain some specific features of this phenomenon basic theory is derived and numerical results presented.

Basic theory

Simplified schema of the loop with pressurizer is illustrated in the Fig.1. In the upper part of the reactor pressure vessel is supposed small volume of steam. In normal operation conditions in pressurizer is certain volume of coolant and above is the steam. The height of the coolant volume depend on the coolant temperature and as the result the value of first acoustic frequency changed. The same is valid for steam volume in reactor pressure vessel.

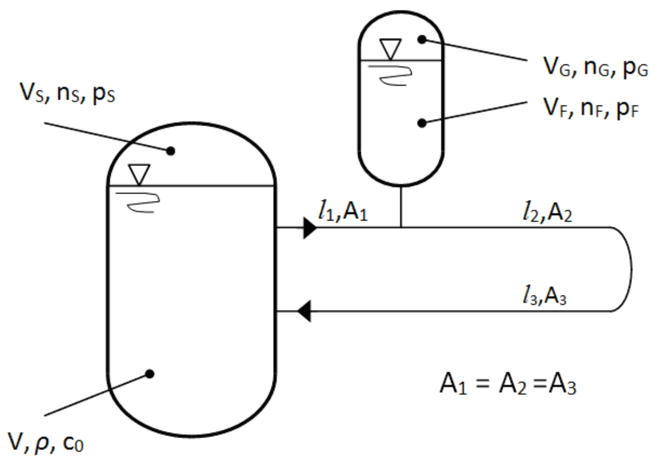

Fig.1: Scheme of the loop with pressurizer

The basic theory is published in paper [1], resulting determinant of the system of equations takes the form:

$$0 = \begin{vmatrix} \cos\frac{\Omega_n l_1}{c_0} & \sin\frac{\Omega_n l_n}{c_0} & -\frac{A_2}{A} & 0 & -1 & 0 \\ -\sin\frac{\Omega_n l_1}{c_0} & \cos\frac{\Omega_n l_1}{c_0} & 0 & -1 & 0 & 0 \\ 0 & 0 & \cos\frac{\Omega_n l_2}{c_0} & \sin\frac{\Omega_n l_2}{c_0} & 0 & -1 \\ 0 & 0 & -\sin\frac{\Omega_n l_2}{c_0} & \cos\frac{\Omega_n l_2}{c_0} & 0 & -\frac{A_2}{c_0\rho(\frac{V_G}{n_G P_G}+\frac{V_f}{c_0\rho})\Omega_n} \\ -1 & \frac{1}{A}(\frac{V}{c_0}+\frac{\rho c_0 V_s}{n_s p_s})\Omega_n & 0 & \sin\frac{\Omega_n l_3}{c_0} & \cos\frac{\Omega_n l_3}{c_0} & 0 \\ 0 & -1 & 0 & \cos\frac{\Omega_n l_3}{c_0} & -\sin\frac{\Omega_n l_3}{c_0} & 0 \end{vmatrix} \qquad (1)$$

For assessment of first (lowest) frequency it is realistic to suppose $l_1 \doteq 0$. After application of the Whittaker method t we obtainas the resul the two order determinant and the resulting equation

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{1}{\frac{\rho l_2}{A_2}+\frac{\rho l_1}{A_1}}\left(\frac{1}{\left(\frac{V_g}{n_G p_G}+\frac{V_f}{\rho c_0^2}\right)}+\frac{1}{\left(\frac{V_S}{n_S p_S}+\frac{V+A_3 l_3}{\rho c_0^2}\right)}\right)} \qquad (2)$$

First term in the bracket represents influence of the pressurizer and second one the influence of steam in reactor pressure vessel.

Numerical results

The input data in normal operation conditions are as followes

$V = 148.3 m^3$; $V_f = 55 m^3$; $V_g = 24 m^3$

$l_1 = 6.86$ m; $l_2 = 25.1$ m; $l_3 = 53.39$ m;

$A_1 = 0.567 m^2$; $A_2 = 0.094 m^2$;

Results of numerical calculations are illustrated in tables 1 and 2

Table 1: Influence of increasing water volume in pressurizes

$V_s [m^3]$	55	60	65	70	75	79
f [Hz]	0.76	0.768	0.792	0.836	0.937	1.23

Table 2: Influence of steam in % of V in reactor pressure vessel

V_s[%]	0.1	0.5	2	4	6	8	10
f_1 [Hz]	0.751	0.724	0.647	0.585	0.543	0.514	0.49

Summary

Theoretical analysis of the acoustic pressure pulsations has been performed. Eigenvalues of the six order determinant represent frequency spectrum of this problem. Special attention has been paid to obtain the lowest eigenfrequency. Simple formula has been derived. Using numerical sensitivity analysis we can conclude that this one represent diagnostic symptom describing upset operation states of the primary circuit.

References

[1] L. Pečínka, Exact Solution of the coolant Resonant States in the Primary Circuit of the Reactor, Dynamic of Machines, National Colloquium with International. Participation, February 7-8,2006, Prague, in Czech Language only