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Chugging occurs intermittently with bubble collapse in time periods of 1 to 2 s. Pressure time history, due to chugging, observed on the pool boundary consists mostly of two parts, i.e., a part including the impulsive pressure peak and a part showing the sinusoidal trend. The former is due purely to steam bubble collapse and can be treated in a statistical way. The latter corresponds to the system response, which can be described by a deterministic approach. Therefore, the chugging forcing function is assumed to have an impulsive nature, and we simulate its shape by a narrow-banded triangle with its width and height varied.

The model is divided into two submodels, the vent acoustic model and the fluid-structure interaction model, which includes the pool acoustic effect. In the vent acoustic model, a nonlinear wave equation is solved by the method of characteristics.<sup>1</sup> The three-dimensional linear wave equation and the elastic equation are coupled to express the fluid-structure interaction. The finite element method is incorporated as a numerical method.

The following boundary conditions are used on the interfaces. On the steam-water interface, the pressure is specified from the vent model calculation. On the fluid-structure interface, free-slip fluid motion is assumed in the tangential direction to the interface, and in the normal direction, the following equation is set to link the two media<sup>2</sup>:

$$\rho \frac{\partial^2 u_n}{\partial t^2} = -n \cdot \nabla P,$$

where

$u_n$  = normal component of structure displacement

$P$  = fluid pressure at the interface

$\rho$  = fluid density

$t$  = time.

The whole system is related in this way, and once the forcing function is imposed at the steam-water interface, the system response can be obtained on the pool boundary.

The procedure used to derive the representative chugging forcing function is as follows:

1. obtain the power spectral density function (PSD) from pressure measurements
2. bound the PSD obtained using the average and the variance
3. determine the shape of the simulated forcing function that produces the best fit to the PSD obtained above.

## THERMAL-HYDRAULIC ASPECTS OF CONTAINMENT DESIGN

All Papers Invited

### 2. Evaluation of Chugging Load Coupled with System Response, M. Utamura (Hitachi ERL-Japan), T. Horiuchi (Hitachi Ltd-Japan), O. Oyamada (Hitachi Works-Japan)

Steam condensation in water is a key phenomenon related to hydrodynamic load on boiling water reactor suppression systems during a loss-of-coolant accident. Hence, extensive efforts, through both experiments and analyses, have been made to better understand the loading characteristics. However, a difficulty still remains in establishing a definition of the forcing function, because (a) the steam bubble collapse follows a more or less stochastic process due to highly transient heat transfer through the steam-water interface, and (b) the pool boundary load is a combination of the forcing function and the excited system response. The purpose of the present study is to propose a numerical method to derive a reasonable forcing function for chugging mode condensation.

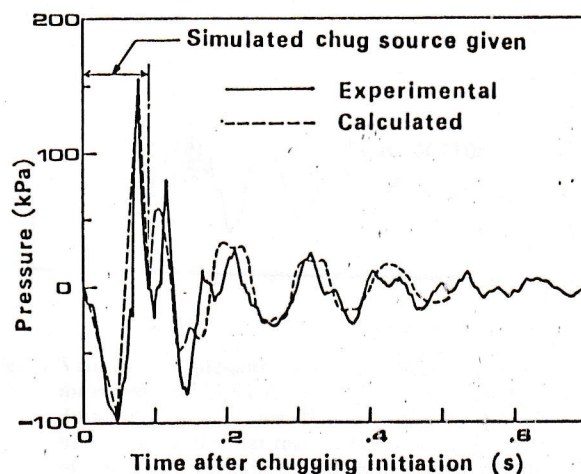


Fig. 1. Pressure transient at vent exit.

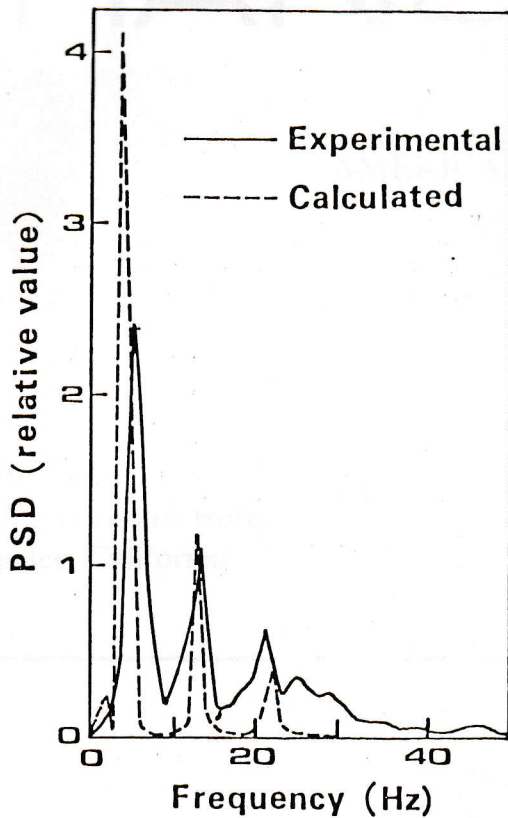


Fig. 2. PSD on pool boundary.

The calculated pressure at the vent exit is compared with measurements,<sup>3</sup> as shown in Fig. 1. Good agreement is obtained with respect to both frequency and damping trends, which verifies the vent acoustic model. The damping trend is caused by the existence of drywell, which serves as an energy sink.

Figure 2 shows the PSD on the pool boundary. The highest peak and the following one express the fundamental and the second modes of the vent acoustics, respectively. The third peak shows the fluid-structure interaction. General agreement is obtained between calculations and measurements, confirming the validity of the present method.

1. V. L. STREETER and E. B. WYLIE, *Hydraulic Transients*, McGraw-Hill Book Co., New York (1977).
2. O. C. ZIENKIEWICZ, *The Finite Element Method*, 3rd ed., McGraw-Hill Book Co., New York (1977).
3. Y. KUKITA et al., "Statistical Evaluation of Dynamic Loads by Condensation Oscillation and Chugging in Suppression Pool," JAERI-M 9665, Japan Atomic Energy Research Institute (1980).

### 3. Chugging Desynchronization Effects on Multivent Pressure Suppression Pool Loads, Y. Kukita, K. Namatame, I. Takeshita, M. Shiba (JAERI-Japan)

#### INTRODUCTION

In evaluating the loss-of-coolant accident (LOCA)-induced hydrodynamic loads in the boiling water reactor

(BWR) pressure suppression pool, it is convenient to take into account the decreasing trend of the chugging steam condensation loads with increasing number of vent pipes, which has been identified through comparisons of experimental data for different numbers of vent pipes. The trend is primarily due to the interactions of the pressure waves transmitted out-of-phase from the individual vent pipe outlets where condensation of steam bubbles takes place.

The test data obtained from the Japan Atomic Energy Research Institute (JAERI) full-scale seven-vent test<sup>1</sup> have clearly demonstrated, through comparisons with the General Electric single-vent data, the multivent load reduction trend for the full-scale Mark II geometry.<sup>2</sup> This paper describes the results of analysis on the multivent load reduction effects involved in the JAERI seven-vent test data.

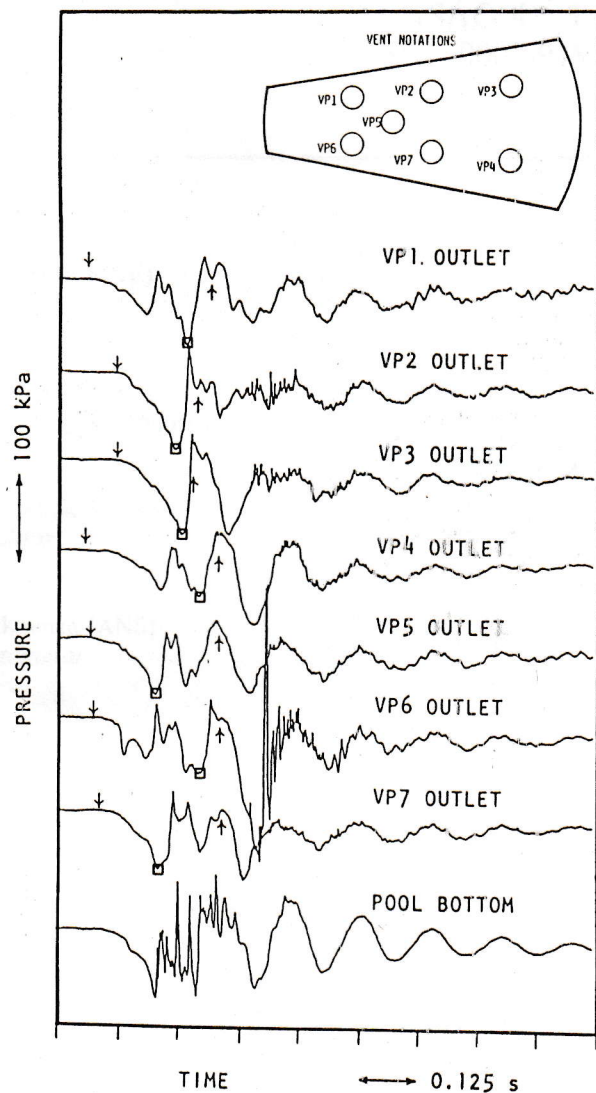


Fig. 1. Vent outlet pressures and pool boundary pressure measured in JAERI full-scale seven-vent test facility during typical chugging. Here, ↓ = time of vent clearing, ↑ = time of water reentry into vent, and □ = time of peak-under-pressure during presence of steam bubble at vent outlet.