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Theoretical and Experimental Investigations of the Transport of Chugging Loads Through the Small Model Wetwell

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Abstract

The paper deals with theoretical and experimental investigations of the transport of chugging loads through a small cylindrical wetwell simulating the BWR pressure suppression system in a LOCA situation. The experimental facilities used as well as the typical pressure and acceleration responses obtained are presented. Results calculated with the computer codes VOICE and EVA are compared with the corresponding experimental values.

1. Introduction

The response of BWR-pressure suppression systems to LOCA-induced chugging loads in the wetwell is the object of numerous investigations. Due to the complexity of the chugging phenomena and the presence of feedbacks, various simplifying approaches are generally used. The approach in our investigations is based on the convolution integral (1) interrelating the response of the wetwell $y(\vec{r}, t)$ and the so-called source function $x(t)$, induced during a single chugging event at the bottom of an individual vent pipe. The symbol $y(\vec{r}, t)$ generally denotes the pressure response in the pressure suppression pool as well as the dynamic response (e.g. acceleration, displacement or strain) of an adjacent wall of the pressure suppression confinement. The convolution integral reads

$$y(\vec{r}, t) = \int g(\vec{r}, t - \tau)\, x(\tau)\, d\tau \qquad (1)$$

and comprises the weighting function $g(\vec{r}, t - \tau)$ of the given response type. The source function $x(\tau)$ is defined as a time derivative of an oscillating water volume, displaced away at the lower end of the vent pipe during the steam condensation cycle /1/. Symbol $\vec{r}$ denotes the location in the wetwell where the response is measured. The weighting function $g(\vec{r}, t - \tau)$ is defined as a response of a given type (e.g. pressure or acceleration at the location $\vec{r}$) to a Dirac impulse of the source function $x(\tau)$. A two-step experimental procedure was used to verify the computer code VOICE /1/ developed to calculate the source function $x(\tau)$ from a set of N pressure responses $y(\vec{r}_j, t)$ $(j = 1, 2, \ldots, N)$ simultaneously measured at N pressure transducer locations $\vec{r}_j$ in the wetwell during a single chugging event /1/. A similar procedure has been started to verify the coupled fluid/ structure-interaction code SING-S capable to describe the corresponding dynamic response of the adjacent containment wall /2/. However, these investigations have not yet been completed (February 1985) and will therefore be reported elsewhere.

2. Experimental setups

Two different experimental setups were necessary to investigate the functions $y(\vec{r}, t)$, $g(\vec{r}, t - \tau)$ and $x(\tau)$; they are illustrated in fig. 1. Figure 1a shows a simplified pressure suppression system with a cylindrical wetwell (stainless-steel test cylinder ϕ 1000x3x1600 mm) partly filled with water (free water level at 1350 mm) and a single vent pipe (4.5 mm thick carbon steel pipe, ϕ 150x3700mm). The lower end of the vent pipe was located 400 mm above the bottom of the wetwell. Both axisymmetric and eccentric (eccentricity 100 mm) arrangements of the vent pipe in the wetwell were used. The wetwell was provided with an air injection gear facilitating adjustment in the water charge of different amounts of finely dispersed air bubbles, varying between the limits of 0 - 7 vol. %. A carbon steel surge tank (volume 1 m^3) was used to simulate the drywell; it was fed with saturated steam from a conventional steam supply network. To measure the chugging loads, the wetwell and the vent system were instrumented with 18 pressure transducers and 9 thermocouples; 36 miniature accelerometers were used to measure the response of the wetwell shell. This experimental setup was used to generate the chugging loads and to measure the corresponding responses in the wetwell. Typical time histories of temperature, pressure and accelaration measured in one chugging experiment are illustrated in fig. 1 b. The upper curves represent the time history of temperature in the upper (θ_{54}) and lower (θ_{42}) parts of the vent pipe, respectively, illustrating the filling of the vent pipe with water from the water charge. The third curve shows the quasi-periodic time history of pressure in the drywell (p_{63}). This pattern is substantially modified by superimposed chugging loads in the lower part of the vent pipe, which was quasi-periodically filled with water (p_{45}). The fifth curve (p_{36}) shows the time history of pressure measured at the inner side of the test cylinder shell at the level of the vent pipe outlet (400 mm). Each chugging event is accompanied by a sudden pressure decrease of several tenths of bar followed by a sharp pressure peak in the opposite direction; the rest of the cycle indicates the strongly damped pressure oscillations following these two pressure peaks. The last curve in fig. 1b illustrates the time history of acceleration response of the test cylinder shell (a_3) measured 600 mm above the bottom of the test cylinder. It resembles the pressure response but is more complicated due to the superposition of the responses of several modes.

Figure 1c illustrates the second experimental setup used in our experiments involving the same test cylinder as in fig. 1a, but instead of the vent pipe a ground hollow bronze cylinder (ϕ 150 mm) with an oscillating piston is employed. This setup was used to measure a frequency response function of pressure and acceleration in the wetwell, related to the acceleration of the oscillating piston. A Fourier-transformation of these functions, calculated with the computer code EVA /3/, yielded the weighting functions $g(\vec{r}, t - \tau)$ employed in the convolution integral (1).

3. Results of investigations

Typical results relating to the experimental setup with the oscillating piston (fig. 1c) are presented in figs. 2 and 3. Figure 2 shows the frequency response function $H_{a_{K}, p_{36}}(f)$ of the pressure, measured (solid line) at the pressure location p_{36} (at the inner side of the test cylinder shell 400 mm above the bottom). The measurement was performed with an axisymmetric arrangement (e = 0) of the vent pipe in the wetwell by an adjusted air fraction in the water charge $\alpha = 5.0$ vol. %. The dashed line shows the same function, obtained by Fourier transformation of the theoretical weighted function $g_{a_{K}, p_{36}}(t)$ calculated with the computer code VOICE. This comparison shows that both curves follow a similar course in the low-frequency domain, a small deviation of approx. 7 % between the calculated and measured natural frequency values of the fundamental mode ($f_1 \approx 29$ Hz), as well as a deviation of approx. 30 % between the calculated and measured critical damping ratios of the same mode ($\zeta_1 \approx 8$ %). Considerable deviations between the theoretical and experimental curve can be observed in the high-frequency domain. They are caused by a general neglect in the mathematical model of the computer code VOICE of the high-frequency shell modes. Figure 3 shows the theoretical weighting function of pressure $g_{a_K, p_{36}}$ (t), mentionned above, in comparison with the corresponding experimental curve, obtained by Fourier transformation of the experimental frequency response function plotted in fig. 2. Good mutual agreement can be found only in the time interval 0 - 10 ms, which includes the first response peak. Due to this agreement, satisfactory estimates of the maximal loading values can be calculated with the computer code VOICE. With increasing time, considerable deviations between calculated and real loading values can be observed. Figure 4 illustrates the time history of the source function x (t), related to one isolated chugging event of one particular steam quenching experiment, performed with an axisymmetric arrangement (e = o), an adjusted air fraction $\alpha = 5.0$ %, the initial water temperature $\theta_{OW} = 32^{o}$ C, and a mean steam flow rate of 0.5 kg/s. The solid line shows the source function x (t) obtained by numerical deconvolution of eq. (1), using the measured pressure response $y\ (\vec{r},\ t) = p_{36}$ (t) (see fig. 5) and the experimental weighting function $g\ (\vec{r},\ t - \tau) = g_{a_K, p_{36}}$(t) from fig. 3. This numerical deconvolution was performed with the computer code EVA. The dashed line was calculated with the computer code VOICE using three simultaneously measured pressure responses as the input. The comparison of both curves shows a good agreement in the general trend, accompanied by local deviations up to 25 % FS, attributable to the same phenomenon as above (neglection of high-frequency modes). Figure 5 illustrates the degree of correctness of the numerical calculations performed. The solid line shows the pressure response, measured at the pressure transducer location p_{36} during the same chugging event as indicated above; the same response was used as the input for the numerical calculations of the source function x (t), performed with the computer code EVA. The dotted/dashed line illustrates the reconstructed response calculated with the computer code EVA from the corresponding functions $g_{a_K, p_{36}}$(t) and x(t). (t). The dashed line illustrates the same quantity, reconstructed similarly with the computer code VOICE. Full accordance of all three curves is expected a priori; the minor deviations found are caused by errors in the measurements and calculations.

4. Conclusions

The results obtained demonstrate the usefulness of eq. (1) for calculating the response to particular chugging events in the wetwell. The computer code VOICE proved helpful for the calculation of the source function x (t), especially if air bubbles are present in the wetwell water charge.

References

/1/ Class, G.: Analyse von kondensationsbedingten Druckpulsationen im LWR-Druckabbausystem-Rechenprogramm VOICE. KfK 3921, Kernforschungszentrum Karlsruhe, März 1985

/2/ Krieg, R., Göller, B., Hailfinger, G.: Transient, three-dimensional potential flow problems and dynamic response of surrounding structures. Part II: Simultaneous coupling between fluid and structural dynamics (computer code SING-S). Journal of Computational Physics 34, 164 - 183, 1980

/3/ Eberle, F., Kadlec, J.: Extraction of Eigenfrequencies, Mode Shapes and Critical Damping Ratios of HDR Core Barrel Mockup from Step Relaxation Response Signals Measured in the Snapback Test Series V59. KfK 3408, Kernforschungszentrum Karlsruhe, Oct. 1982

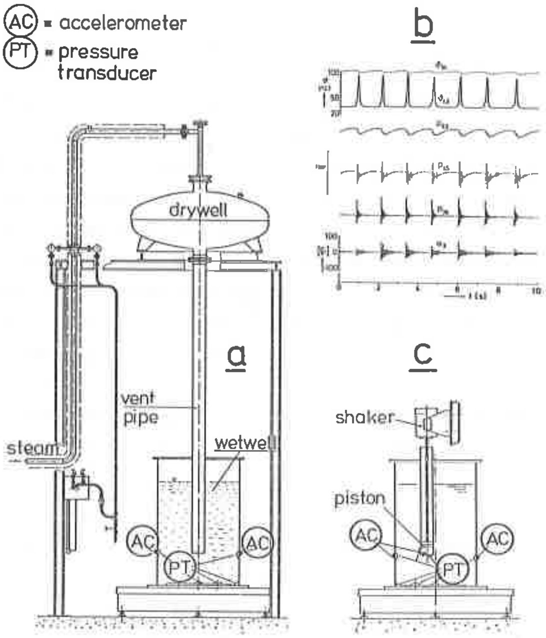

Fig. 1: Experimental setups (a-pressure suppression system mockup, b-typical response signals, c-setup with oscillating piston)

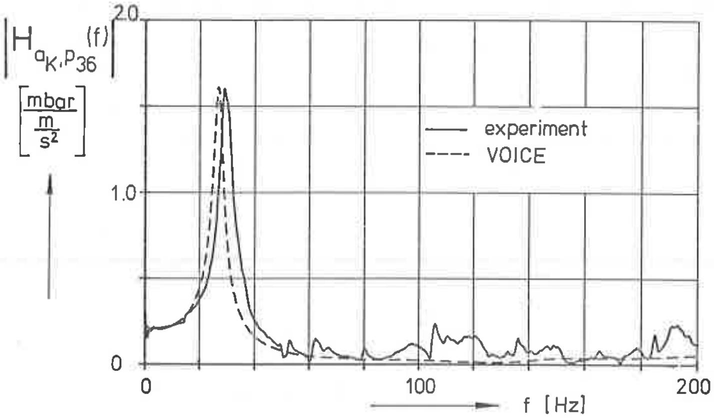

Fig. 2: Frequency response function of pressure in the wetwell (measuring position p_{36}, α=5.0‰, e = 0)

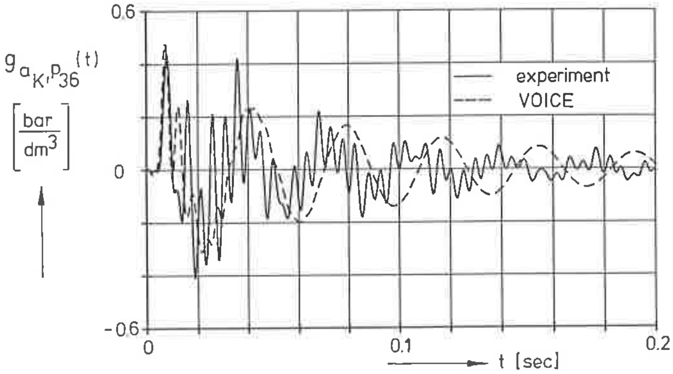

Fig. 3: Weighting function of pressure in the wetwell (measuring position p_{36}, α =5.0‰, e = 0)

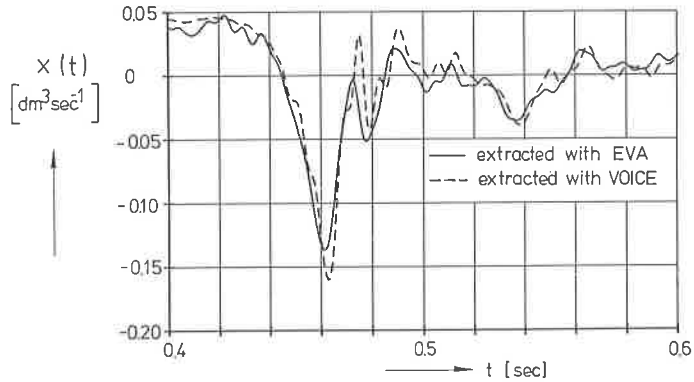

Fig. 4: Typical source function x (t) ($\underline{e}_1$= 0, α =5.0‰, θ_{OW}= 32° C, mean steam flow rate 0.5 kg sec^{-1})

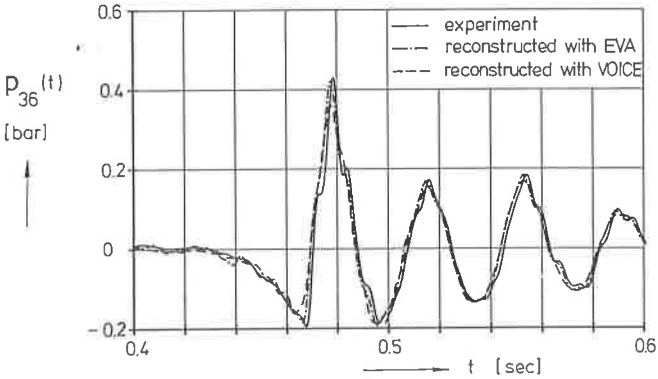

Fig. 5: Comparison of the measured and reconstructed pressure response in the wetwell