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Water Hammer Model Sensitivity Study by the FAST Method

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Abstract

Appearance of water hammer in thermal-hydraulic systems was widely studied employing different state of-the-art thermal-hydraulic codes. Before carrying out the water hammer analysis, it is very important to match the model and to perform the analysis of its sensitivity. The paper presents an analysis of the water hammer experimental test performed at the Fraunhofer UMSICHT Institute using the RELAP5/Mod3.3 thermal hydraulic code. The model sensitivity study was performed by using the Fourier amplitude sensitivity test (FAST) method. The FAST method aims to determine the most important input parameters that are major contributors to the model output uncertainty. Such information can be used further for a more detailed system study and development of improvements or preventive actions.

Keywords: Water hammer; UMSICHT; RELAP5 model; sensitivity analysis; FAST

1. Water hammer model sensitivity study

Pressure surges occurring in pipeline systems may be caused by fast control interference, start-up and shut-down processes and operation failure, as well as flow rate fluctuation. They lead to water hammer upstream the closing valve and cavitational hammer downstream the valve, which may cause considerable damages to the pipeline and the support structures. Appearance of water hammer in thermal-hydraulic systems was widely studied employing different state-of-the-art thermal-hydraulic codes: TREMOLO, TRACE, CATHARE, ATHLET, TRAC, FLOWMASTER, RELAP5. Because the phenomena of water hammer are specific, not all the codes are verified for simulation of water hammer fast transients. Therefore, it is very important to verify a model developed using these codes and to carry out a model sensitivity study.

In this work, as an illustration, RELAP5 analysis of a water hammer test performed at the Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT), Germany is considered. This UMSICHT facility, whish is described by Dudlik (2005), simulates the piping system and associated supports that are typical of a nuclear power plant. A centrifugal pump produces steady-state flow into the circuit from the pressurized vessel into the test pipe section of 110 mm inner diameter and back to the vessel. When at t = 0 sec the valve closes rapidly while the pump is still running, pressure waves are induced in the whole pipe system. During the first phase of the

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transient, a rarefaction wave is traveling inside the pipe towards the downstream reservoir. As a consequence, cavitation occurs downstream the valve, and a vapor bubble is formed. The generated pressure wave oscillates between the vessel and the vapor bubble until the cavitation condenses, inducing a cavitational hammer. The modeling of water hammer experiment performed in the UMSICHT test facility has been performed by employing RELAP5/Mod3.3 code model (RELAP5 Code Development Team, 1995). The results of calculations have shown that the first calculated pressure peak matches very well the measured value of pressure. The prediction of the first cavitation hammer is most important. The value attained during the first pressure peak is the highest therefore most dangerous in comparison with the successive pressure peaks and can lead to damages of the equipment (valves, pumps, pipe bends) or leakages in the piping. Therefore, the further analysis was carried out only for investigation of the first (peak) pressure increase.

The model sensitivity study was performed by using the extended Fourier amplitude sensitivity test (FAST) method (Saltelli et al., 1999). At first, based on the experience of previous analyses (Kaliatka et al., 2004), were selected parameters, having influence on the results of deterministic calculation. These parameters compound two groups: (1) the initial conditions of the system: (X1) water pressure in the pump header, (X2) water temperature in the system, (2) model parameters: (X3) valve closing rate, (X4) pipe wall roughness, (X5 – X7) flow energy loss coefficients in different piping segments. The generation of the FAST sample and the computation of the sensitivity indices was performed by using the SIMLAB software tool (Ispra, 2005). The total sample size used was 1463, which corresponds to about 20 runs per parameter and is considered to be a good enough sample size for an extended FAST method (Saltelli et al., 1999).

The sensitivity analysis results indicate that the energy flow loss coefficient (X6) in a pipe component downstream the fast-acting valve is the most important parameter with the highest contribution to the variance of the estimated pressure peak. It is followed by the wall roughness (X4) and the pressure at the pump header (X1) parameters whose importance is similar, but significantly lower than that of the energy flow loss coefficient in the pipe component downstream the fast-acting valve. The importance of the energy flow loss coefficient in the pipe component downstream the fast-acting valve can be explained from physical point of view because this piping segment is just downstream the closing valve, and there the most significant pressure increase is formed. The analysis has indicated that the interactions among the parameters are not very strong; however, in quantitative terms, they are of almost equal magnitude for all the parameters. As a consequence, none of the parameters can be excluded as having an-insignificant effect on the model output, even if some first-order indices suggest so. The investigation of the interaction effect and its quantitative magnitude is the unique feature of the extended FAST method, and it cannot be obtained by the conventional random sample-based sensitivity methods. The low level of parameter interactions also implies another important practical result: a corresponding change in the value of the energy flow loss coefficient in the pipe component downstream the fast-acting valve (parameter X6) would enable to reduce the pressure peak value in the most efficient way.

2. References

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