Analytical solution and numerical study on water hammer in a pipeline with an elastically attached valve

Slawomir Henclik, Department of Hydropower, Institute of Fluid-Flow Machinery,
Polish Academy of Sciences, Gdansk, Poland

Long Abstract

Introduction

The influence of dynamic fluid-structure interaction [1] onto water hammer [2] run can be significant, especially in non-rigid pipeline system [3]. The reason of this behavior is the transfer of liquid energy to the structure which is of importance for elastic structures and can be negligible for rigid ones. In general, one can expect lowering of transient pressure changes due to energy outflow from the liquid. However, as pointed by scientists (e.g. [4]), this effect is not unambiguous and a temporary pressure increase may also happen. This is due to the wave effects and frequency characteristics of the piping system. An important element of the current problem is that, the energy transfer from the liquid to the structure is in general reversible and the energy flowing out of the liquid to the structure may return back within a specific timescale. However, because dissipation and spreading of the energy in the structure takes place it should result in faster decaying of the liquid transient and can be regarded as positive effect in majority of hydraulic systems.

1. Methods

In the paper a model of such behavior is analyzed. A straight pipe fixed rigidly to the floor is assumed. The initial steady flow is driven by the pressure vessel at the beginning. The transient is generated by the quickly closed valve installed at the end of the pipeline. The fluid-structure interaction (FSI) effects are assumed to be present at the valve which is attached with a spring-dashpot system. This model is presented in figure 1. In fact, it can be a physical model of a true design applicable in practice [2].

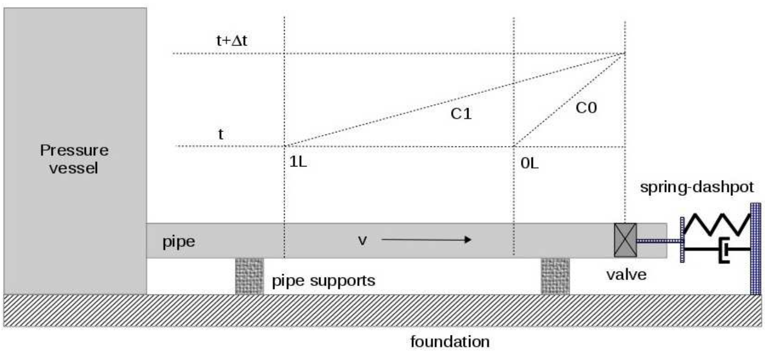

Figure 1. Physical model of the pipeline with viscoelastic valve attachment

Analyses of the WH run, especially transient pressure changes, for various viscoelastic parameters (Kelvin-Voigt model of the spring characteristics is assumed) of the valve attachment is presented in the paper. The solutions are found in two ways – analytically and numerically. Analytical solution is developed and presented for the valve spring without damping. Damping is taken into account within a numerical study. The four equations model of water hammer with fluid structure interaction [1] is assumed and numerical analyses with the use of a own computer program [5] is performed. The detailed solution of the boundary condition at the valve fixed with viscoelastic attachment presented in [6] and applied in a numerical scheme has been used for the analyses. In order to focus on the influence of the parameters of the valve attachment, the Poisson effect and the liquid pipe-wall friction are neglected.

2. Results and conclusions

Analytical solutions were found with the classical method of separation of variables for the assumed boundary condition at the valve. The results are presented as a sum of weighted eigenfunctions. They approaches classical WH solution for rigid closed-end and a harmonic oscillator solution for small stiffness of the valve spring. The selected, computed pressure records and valve axial displacements for various stiffness and no damping of the valve spring are presented in figure 2.

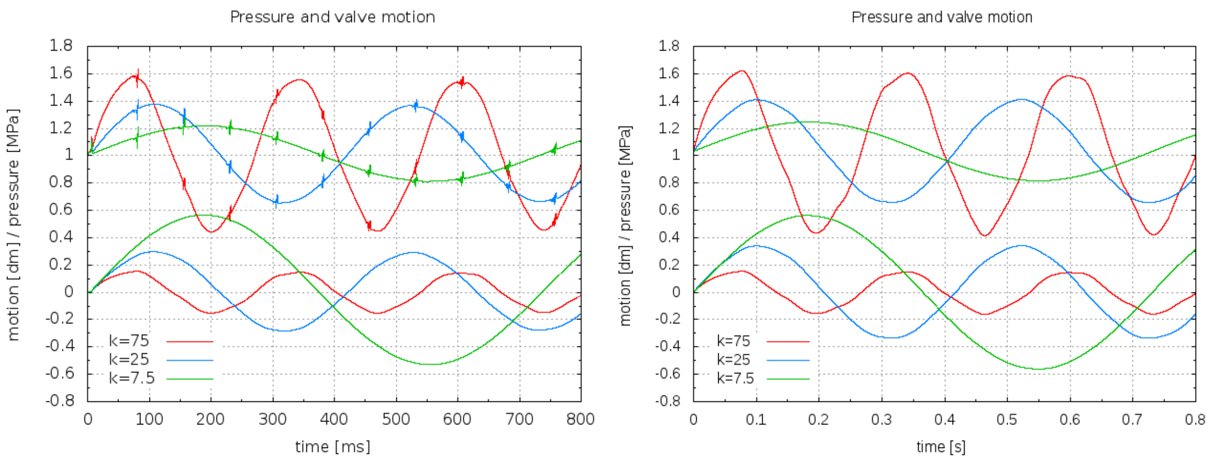

Figure 2. Numerical (left) and analytical (right) results of the pressure records (upper plots) and axial valve motions (lower plots) for small stiffness (k) of the valve spring

One can observe there is no significant difference between numerical and analytical results. The results for higher stiffness will also be presented and discussed. To test the influence of damping, numerical investigations were done with the use of the method described above. The results for various stiffness and damping coefficients of the valve spring will be presented, discussed and concluded. It was found that the influence of damping varies with the spring stiffness and detailed analyses will be presented. Finally, the applicability of the results and conclusions of the current work in real engineering systems will be stated.

References

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