Water Hammer Modelling

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Water Hammer is a physical phenomenon that occurs due to sudden stopping of flow in a pipeline system which causes a sudden large pressure rise mimicking the hammering effect. It is considered one of the worst nightmare for hydraulic engineers due to its potential of causing widespread damage to property and lives. Therefore, numerical estimation of water hammer pressure is crucial for the design, operation, and risk analysis of pipeline systems. Generally, the traditional Method of Characteristics (MOC) is preferred by modellers worldwide due to its simplicity and usability. However, due to high shock generation during large water hammer event in pipeline, Finite Volume Method (FVM) has a clear advantage because of its desirable attribute of conserving mass, momentum compared to traditional MOC Schemes. Further, modelling of the water hammer phenomenon for dynamic characteristics within a turbine is impossible using the classical 1D MOC or 1D FVM schemes, and such applications require more extensive 3D grids and turbulence models. Several commercial pieces of software for turbulence modelling available today can be effectively used for this type of study. Some well-known and well-applied turbulence models currently in use are FLUENT and CFX (https://www.ansys.com(accessed on 1 June 2021)).

Keywords: water hammer ; computational fluid dynamics ; MOC ; FDM ; FVM ; pipe network

1. Introduction

Increases in computational power create an opportunity for analysts to better understand many complex phenomena, including water hammer. In essence, water hammer events involve hydraulic shock waves generated in a pipeline by rapid changes in one or more boundary values, such as valve closure. As per Toro [1], shock waves of strong character are a very rapid transition of a physical quantity (i.e., pressure, density, or temperature). Water hammer problems with a rapid boundary change characterized, for example, by a valve closure time that is less than the wave return time over the entire system length, produce such rapid changes of pressure and velocity that the motion is typically characterized as a mathematical discontinuity.

What makes the finite volume (FV) approach special is that it evaluates the conservative forms of the governing partial differential equations (PDEs) in the algebraic form [1][2]. Indeed, the FVM is developed by considering a small volume surrounding each nodal point in a geometric mesh, and then relating the volume integral to the surface integrals using the divergence theorem. The resulting surface integrals act as fluxes at the boundaries of each finite volume, and the whole formulations enable the tracking of the evolution of a system’s state.

2. Future Research Directions for Water Hammer Modelling

Water hammer responses are now being used for leak detection and state assessment of pipe conditions in water pipeline systems. Nevertheless, the MOC approaches have notable disadvantages already introduced, such as non-conservation of mass momentum for non-unity and non-uniform courant numbers, and difficulty in including the convective acceleration term. Besides these concerns, complex device characteristics (e.g., for pumps and turbines), and even unsteady friction—not to mention certain air-water interactions—can be thought of as hints that simplified models themselves have limitations that can confound 1D analysis. However, the application of FVM methods has been limited due to their complexity and comparative newness when applied to water hammer problems.

The recent advances in genetic algorithms (GAs) and other evolutionary codes have created a huge opportunity for hydraulicians in their application to various unsteady flow problems. The GA method can achieve high efficiency in modelling optimization problems due to its ease of application and its controlled computational effort. Tang and Karney [3] successfully applied GA techniques using data from two pump trip tests and estimated wave speed and roughness factors. In addition, extensive analysis of pressure histories at various locations of pipe systems can be useful for the rehabilitation of pipes, calibration of pipe networks, leakage, and blockage detection by applying inverse analysis, which is also gaining interest.

Parallel computing techniques are gaining increased attention due to their potential to reduce computational time and costs. With the increasing availability of supercomputers, parallel computing has become progressively easier, cheaper, and more widely applied. [4] found GPUs to be up to 156 times faster than traditional CPU approaches. [5] successfully completed parallel integration of the MOC with GPUs, thus confirming its attractiveness for this application.

Third-order accuracy can be achieved by applying the piecewise parabolic method (PPM) technique, which may allow a more precise parabolic reconstruction for solving the water hammer problem using Godunov's scheme. This model requires further investigation in terms of computational speed, reliability, and applicability. A flexible error-detection technique is needed for higher-order schemes to achieve excellent results. In addition, the feasibility and the usefulness of FVM schemes for their applicability in currently available commercial software need to be extensively studied for the advancement of software capabilities.

Future development in numerical techniques has the potential to reduce extensive and expensive testing. Efficient numerical models may enable leakage and blockage detection, and knowledge of whether to assess deposit thickness, rehabilitation needs in pipes, and loss of non-revenue water (NRW) or pipe wall condition. Possible problems such as pipe incrustation, wall erosion, and water contamination in water networks should be better analyzed, so that suitable preventive and rehabilitation measures can be taken. Thus, the further advancement of numerically more accurate models continues to have the potential to save costs and avoid trouble in the pressing pipe design, management, and operational domains.

References

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