IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Recent developments in unsteady pipe flow experimentation at the University of Montenegro

To cite this article: R Branin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **405** 012019

IOP Conf. Series: Earth and Environmental Science **405** (2019) 012019 doi:10.1088/1755-1315/405/1/012019

Recent developments in unsteady pipe flow experimentation at the University of Montenegro

R Brđanin[1,6], U Karadžić[2], A Bergant[3,4] and J Ilić[4]

[1] University of East Sarajevo, Production and Management Faculty Trebinje, 89101 Trebinje, Bosnia and Herzegovina
[2] University of Montenegro, Faculty of Mechanical Engineering, 81000 Podgorica, Montenegro
[3] Litostroj Power d.o.o., 1000 Ljubljana, Slovenia (Full-Time)
[4] University of Ljubljana, Faculty of Mechanical Engineering, 1000 Ljubljana, Slovenia (Part-Time)
[5] University of Belgrade, Faculty of Mechanical Engineering, 11000 Belgrade, Serbia

[6] Corresponding author's e-mail address: radislav.brdjanin@fpm.ues.rs.ba

Abstract. This paper presents recent experimental results of pressure measurements during filling and emptying of a relatively small-scale pipeline at the University of Montenegro. Experimental setup for investigation of water hammer and its special effects (unsteady friction, cavitation, column separation, trapped air, fluid-structure interaction - FSI), and pipeline filling and emptying is installed at the Faculty of Mechanical Engineering. It consists of an upstream end high-pressurized tank, horizontal steel pipeline (total length: 55.37 m, inner diameter: 18 mm, pipe wall thickness: 2 mm), four valve units positioned along the pipeline including the end points, and a downstream end outflow tank. The setup was upgraded in 2018 with the installation of new piezoresistive pressure transducers and pipe displacement sensors as well as additional electro-pneumatically operated ball valve at the upstream end of the pipeline. The filling of an initially empty pipeline is performed by a sudden opening of the valve positioned at the high-pressurized tank filled with water. The pipeline emptying process is accomplished by high-pressurized air supplied from the air reservoir installed in the air supply line. The high-pressurized tank is closed, and the downstream end valve is opened. Experimental runs have been performed with different initial values of pressure in the upstream end high-pressurized tank (filling) and air supply line (emptying). Results of new pressure measurements are analyzed and commented, with a reference to the previous experiments presented at 6th IAHR WG Meeting in Ljubljana, 2015.

1. Introduction

Rapid filling and emptying of pipes is commonly encountered in water supply and sewer systems, during which pressure transients may cause unexpected large pressure events [1]. Pipeline filling is an essential part of the operation of water systems. In order to avoid large pressure surges, slow filling is usually adopted in engineering applications. However, rapid filling sometimes occurs due to valve failure, which may result in severe transient flows [2]. Emptying pipelines can be critical in many water distribution networks because sub atmospheric pressure pulses could cause considerable damage to the system due to the consequent expansion of entrapped air [3]. Thus, the filling with liquid of an initially empty pipeline and the emptying of an initially liquid-filled pipeline should be investigated both experimentally [3], [4], [5], [6] and numerically [1], [2], [3], [6] in order to ensure accurate prediction of transients in advance and consequently to avoid dangerous events.

This paper presents recent experimental results of pressure measurements during filling and emptying of a relatively small-scale pipeline at the University of Montenegro. Experimental runs have been performed for similar initial conditions as for the experiments presented at 6th IAHR WG Meeting in Ljubljana, 2015 [5]. New results are analysed, commented and compared with previous experiments.

2. Experimental setup

A small-scale pipeline apparatus for investigation of water hammer events including column separation, fluid-structure interaction, unsteady friction, and pipeline filling and emptying has been constructed at the Faculty of Mechanical Engineering [5] and upgraded in 2018. The apparatus is comprised of a horizontal pipeline that connects the upstream end high pressurized tank to the outflow tank (steel pipe of total length L = 55.37 m; internal diameter D = 18 mm; pipe wall thickness e = 2 mm) – figure 1.

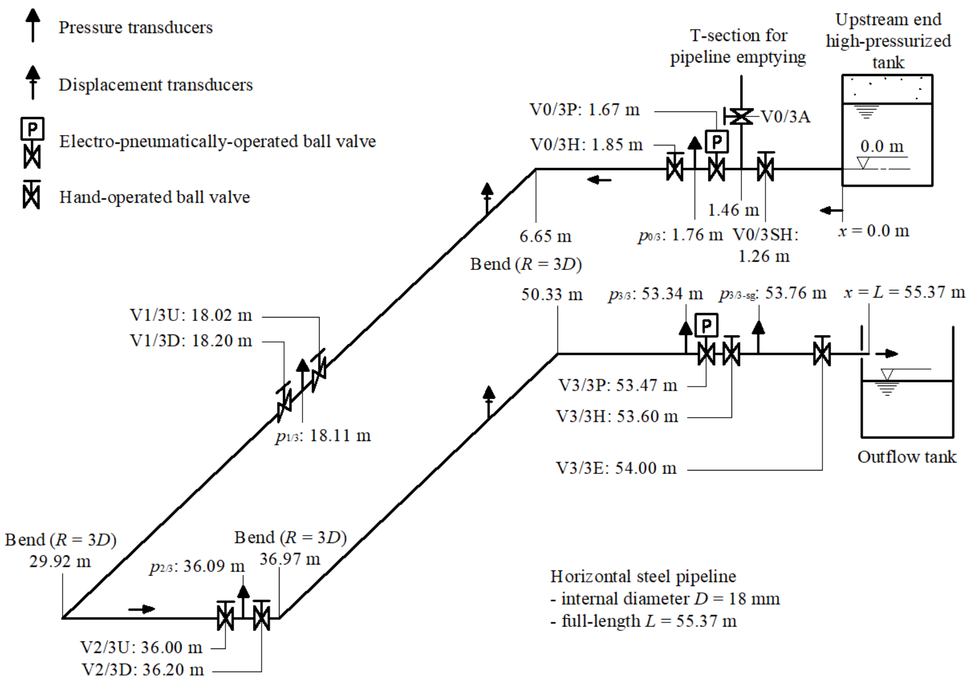

Figure 1. Layout of small-scale pipeline apparatus at University of Montenegro.

Four valve units are positioned along the pipeline including the end points. The valve units at the two tanks (positions 0/3 and 3/3) consist of an electro-pneumatically operated ball valve and hand-operated ball valve. Valve units at the two equidistant positions along the pipeline (positions 1/3 and 2/3) consist of two hand-operated ball valves. All units are connected to the intermediate pressure transducers block. A T-section at the upstream end unit serves for pipeline filling and emptying experiments. There are four bends (90°) on the pipeline with radius R = 3D. The pipeline is fixed against axial displacement in 37 points (near the valve units and bends). The air pressure in the upstream end tank can be adjusted up to 800 kPa. The pressure in the tank is kept constant during each experimental run by using a high-precision fast-acting air pressure regulator (precision class: 0.2 %) in the compressed air supply line. The fast closing electro-pneumatically operated ball valves (V3/3P and V0/3P) are controlled with filtered compressed air which is supplied through a plastic pipeline from the pressure regulator, in which the pressure is independent from the rest of the system. The transient event can be triggered by fast closure or opening of the end valves, using either the V3/3P or V0/3P. In addition, transients can be induced by closure or opening of hand-operated ball valves (valves V0/3H, V3/3H and V3/3E; Vi/3U and V*i*/3D; *i* =1, 2). The hand operated ball valve V3/3E is currently used for adjustment of the initial pipe discharge.

2.1. Instrumentation

Pressures at $p_{0/3}$, $p_{1/3}$, $p_{2/3}$ and $p_{3/3}$ are measured within the valve units along the pipeline including the end points (figure 1). Dynamic pressures are measured by Dytran 2300V4 high-frequency piezoelectric absolute pressure transducers (pressure range: from 0 MPa to 6.9 MPa; resonant frequency: 500 kHz; acceleration compensated; discharge time constant: 10 seconds (fixed)). Due to the fixed time constant (inability to measure very slow varying pressure [5]) four piezoresistive absolute pressure transducers Keller PAA-M5 HB (pressure range: from 0 to 30 bar, sensitivity: 10 mV/0.03 bar, precision ± 0.1%) were mounted next to Dytran transducers in 2018. The datum level for all pressures measured in the pipeline and at the tank is at the top of the horizontal steel pipe (elevation 0 m in figure 1). Two displacement transducers (HBM K-WA-L010W-32K, measuring range: 0 to 10mm, precision ± 0.2%) are placed on their own supports, so they can be moved to different positions along the pipeline. Valves V3/3P and V3/3H are equipped with a fast-response displacement transducer (measurement range: 0° to 90°, frequency response: > 10 kHz) which measures the change of the valve angle (α) during its closing or opening. At the upstream end high-pressurized tank and at the downstream end of the pipeline, two E+H PMP131 strain-gauge pressure transducers ($p_{0/3\text{-sg}}$ and $p_{3/3\text{-sg}}$; pressure range: from 0 MPa to 1 MPa, uncertainty: ±0.5 %) are installed. These transducers are used for the evaluation of the initial conditions in the system. The initial discharge (velocities larger than 0.3 m/s) is measured by the electromagnetic flow meter (uncertainty: ±0.2 %). All measured data are collected by the programmable logic controller (compact DAQ platform by National Instruments) connected to a PC, with software that is also used for control of the two electro-pneumatically operated ball valves.

2.2. Pipeline filling procedure

Procedure for the pipeline filling is as follows. The pressure in the upstream end high-pressurized tank is adjusted to a desired value using a high precision air pressure regulator. The downstream end emptying valve V3/3E is opened to appropriate position. The upstream end service valve V0/3SH is closed. All valves of the four valve units are fully opened. The air inlet valve V0/3A is closed (isolation of the compressed air supply line). The filling of the initially empty pipeline is initiated by quickly opening the valve V0/3SH. When steady state condition is achieved, the final flow velocity (V_f) is measured using an electromagnetic flowmeter.

2.3. Pipeline emptying procedure

The pipeline is emptied using compressed air supplied from the air reservoir connected with a high precision air pressure regulator. The air pressure for the pipeline emptying is firstly adjusted to a desired value with the air inlet valve V0/3A closed (isolation of T-section). All valves of the four valve units and the upstream end service valve V0/3SH are fully opened. The downstream end emptying valve V3/3E is closed and then the high-pressurized tank is isolated from the system by shutting the upstream end service valve V0/3SH. After that the air inlet valve V0/3A is opened. The process of emptying is started by quickly opening the downstream end emptying valve V3/3E.

3. Experimental results

This section presents measured results from pipeline filling and emptying experimental runs with different initial values of the pressure in the high-pressurized upstream end tank (filling procedure: p_{HPT} = 100; 400 kPa) and air supply line (emptying procedure: p_{Air} = 100; 400 kPa). Some results from previous experiments [5] are given for comparison.

3.1. Pipeline filling
Figure 2 presents a comparison of heads at the downstream end of the pipeline (position 3/3 in figure 1) measured by Dytran 2300V4 piezoelectric pressure transducer and by E+H PMP131 strain-gauge pressure transducer. The pressure in the upstream end tank is p_{HPT} = 400 kPa (head H_{HPT} = 39.2 m), the control needle valve is fully opened, and the final flow velocity in the pipe after the filling process is V_f = 2.21 m/s. It can be seen that the E+H transducer, after the filling process is completed, shows the steady state (actual) value of the pressure, which is not the case with the Dytran transducer (step-like pressure pulse). Results in figure 2 are from the experimental setup with control needle valve installed (previous experiments [5]) which acts as an orifice. In recently modified setup the control needle valve was removed and the results from new measurements are given in figure 3.

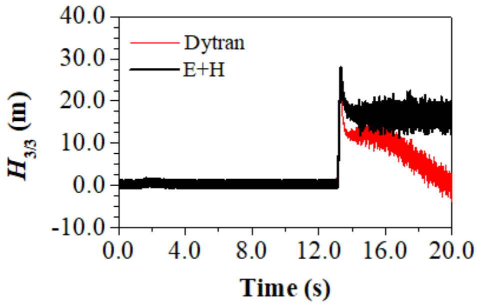

Figure 2. Comparison of heads at the position 3/3 measured by Dytran piezoelectric and E+H strain-gauge pressure transducers: pipeline filling [5].

Figure 3 shows a comparison of heads at positions 1/3 (figure 1), measured by Dytran piezoelectric and Keller piezoresistive pressure transducers, and 3/3 (figure 1), where E+H strain-gauge pressure transducer is added, for the case of pipeline filling with two different values of pressure in the upstream end high-pressurized tank: p_{HPT} = 100; 400 kPa (head H_{HPT} = 11.1; 41.5 m). The downstream end emptying valve is fully open and the final water flow velocity in the pipe is V_f = {1.43; 2.74} m/s for p_{HPT} = {100; 400} kPa, respectively.

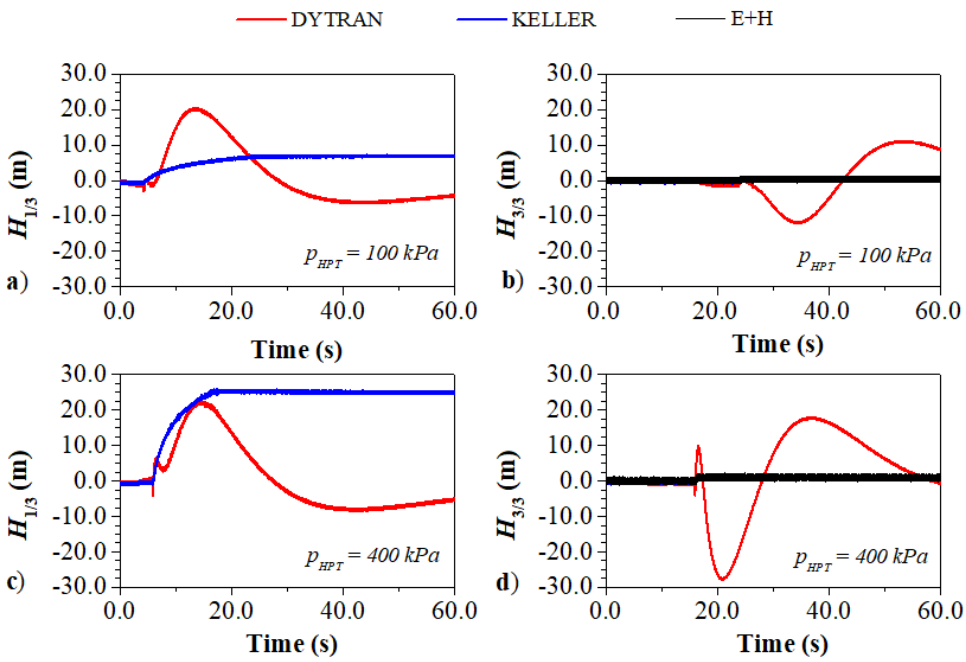

Figure 3. Comparison of heads at positions 1/3 and 3/3 for different initial conditions: pipeline filling.

As it may be seen in figure 3, the removal of the needle valve generates different results. At position 1/3 Keller piezoresistive transducer exhibits smooth pressure rise (ΔH = 7.1; 25.5 m for p_{HPT} = {100; 400} kPa, respectively) much larger than at position 3/3 where only a small head rise may be noticed (ΔH = 0.6; 1.8 m for p_{HPT} = {100; 400} kPa, respectively). Keller piezoresistive transducer shows good agreement with E+H strain gauge pressure transducer at position 3/3, while from comparison at both positions (1/3 and 3/3) it may be seen that Dytran piezoelectric transducer gives inaccurate results due to low discharge time constant which is fixed and it cannot be adjusted.

3.2. Pipeline emptying

Figure 4 shows a comparison of heads at the downstream end of the pipeline (position 3/3 in figure 1) measured by Dytran 2300V4 piezoelectric pressure transducer and by E+H PMP131 strain-gauge pressure transducer. The pressure in the air supply line is p_{Air} = 400 kPa (head H_{Air} = 39.2 m). Again, the results shown in figure 4 are from the experimental setup with a control needle valve installed (previous experiments [5]). New measurements obtained with the control needle valve removed from the setup are given in figure 5.

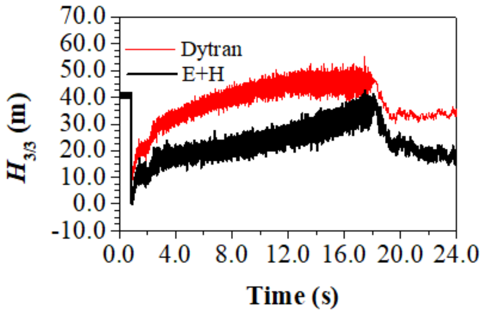

Figure 4. Comparison of heads at the position 3/3 measured by Dytran piezoelectric and E+H strain-gauge pressure transducers: pipeline emptying [5].

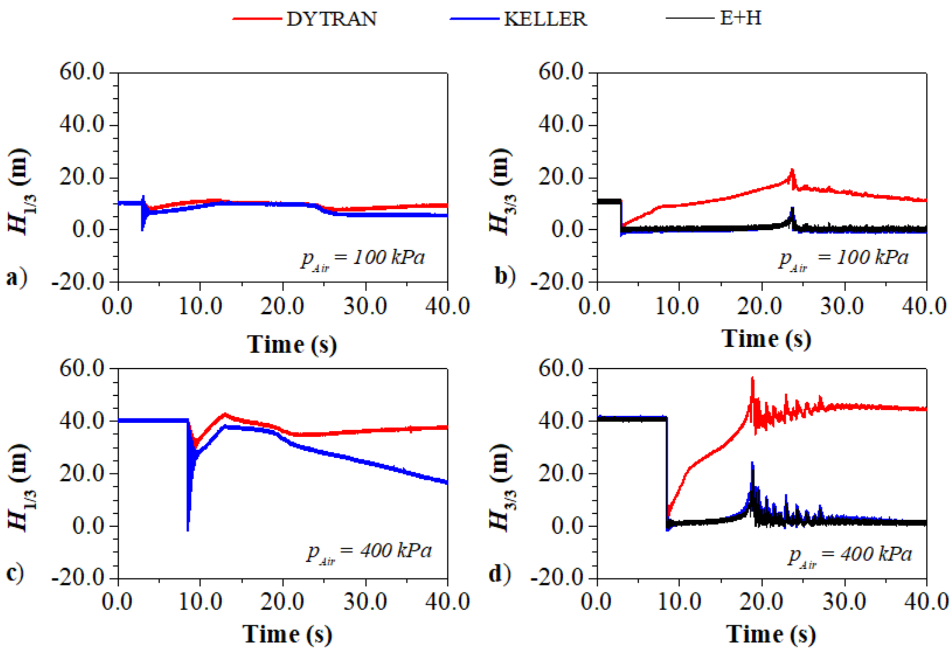

Figure 5. Comparison of heads at positions 1/3 and 3/3 for different initial conditions: pipeline emptying.

Figure 5 depicts comparison of heads at positions 1/3, measured by Dytran piezoelectric and Keller piezoresistive pressure transducers, and 3/3 with E+H strain gauge pressure transducer added, for the case of pipeline emptying with two different values of pressure in the air supply line: p_{Air} = 100; 400

kPa (head H_{Air} = 11.1; 41.5 m). Similarly as for the case of pipeline filling, without the needle valve, different results are obtained for pipeline emptying. At position 1/3, after the V3/3E valve is opened, pressure fluctuations may be noticed. The maximum measured head at position 1/3 (figure 5a) has a higher value (H_{max} = 12.9 m) than the initial head in the air supply line: p_{Air} = 100 (head H_{Air} = 11.1 m). At position 3/3 Keller piezoresistive pressure transducers shows head rise (ΔH = 8.5; 24.4 m for p_{Air} = {100; 400} kPa, respectively) induced by compressed air. Keller piezoresistive and E+H strain gauge pressure transducers show good agreement, as well as Dytran piezoelectric transducer when considering pressure fluctuations during water expulsion by the air column. After the pipeline emptying Dytran piezoelectric transducer gives nearly initial values of the pressure in the pipeline. Due to the nature of pressure pulses, Dytran transducer exhibit better behaviour in the case of the pipeline emptying in contrast to the case of pipeline filling [5].

4. Conclusions

Experimental setup for investigation of water hammer and its special effects, and pipeline filling and emptying has been recently modified including the installation of new piezoresistive pressure transducers and pipe displacement sensors as well as an additional electro-pneumatically operated ball valve at the upstream end of the pipeline. The downstream end control needle valve has been removed from the setup. New measurements show different results in comparison with previous experiments with the control needle valve. The piezoresistive and strain-gauge pressure transducers show good agreement for both cases, pipeline filling and emptying, as well as the piezoelectric transducer when considering pressure fluctuations during water expulsion by the air column for the case of pipeline emptying. Nevertheless, from comparison of all three transducers it may be seen that the piezoelectric transducer behaves inaccurately at very slow varying pressure due to the fixed low discharge time constant.

Acknowledgements

The authors gratefully acknowledge the support of the Ministry of Science of Montenegro and of the Ministry of Education, Science and Technological Development of Republic of Serbia through the project „Research and development of improved measures for protection of hydropower plants during hydraulic transients in order to increase their reliability and energy efficiency“. In addition, the support from ARRS conducted through the project P2-0126 „Transient two-phase flows“ is gratefully acknowledged as well.

References

[1] Li L, Zhu D Z and Huang B (2018) Analysis of pressure transient following rapid filling of a vented horizontal pipe *Water* **10** 1698

[2] Wang L, Wang F and Lei X (2018) Investigation on friction models for simulation of pipeline filling transients *J. Hydraul. Res.* **56** 888-95

[3] Fuertes-Miquel V S, Coronado-Hernández O E, Iglesias-Rey P L and Mora-Meliá D (2019) Transient phenomena during the emptying process of a single pipe with water–air interaction *J. Hydraul. Res.* **57** 318-26

[4] Apollonio C, Balacco G, Fontana N, Giugni M, Marini G and Ferruccio Piccinni A (2016) Hydraulic transients caused by air expulsion during rapid filling of undulating pipelines *Water* **8** 25

[5] Karadžić U, Strunjaš F, Bergant A, Mavrič R, Buckstein S (2015) Developments in pipeline filling and emptying experimentation in a laboratory pipeline apparatus *Proc. of the 6th IAHR Meeting of the Working Group Cavitation and Dynamic Problems in Hydraulic Machinery and Systems*, September 9-11, Ljubljana

[6] Maddahian R, Cervantes M J and Bucur D M (2019) Numerical investigation of entrapped air pockets on pressure surges and flow structure in a pipe *J. Hydraul. Res*. **57** 1-13