Experimental Detection of an Unauthorized Connection to a Pipeline

Sergejs Nazarovs[1], Talis Juhna[2],
Andrei Kolyshkin[3], [1-3]*Riga Technical University*

***Abstract* – Transient events e.g. valve closures, initiate pressure oscillations in the pipeline with specific frequency and damping rate. It is known that a lateral disturbance of the flow such a leak causes a noticeable attenuation of transients. In this study we have experimentally tested if analyses of changes of transient damping rate and damping modes can be used for detection of intrusion location and size. Results showed that both the frequency and the decay rate were influenced by the intrusion. Opening of the intrusion port and pumping liquid into the system results in change of frequency, regardless of intrusion rate. However, intrusion flow rate also has an effect on damping of oscillations – they decay faster at higher intrusion rates.**

***Keywords* – intrusion detection, transient events, water distribution system protection**

I. Introduction

Drinking water distribution systems (DS) are vulnerable to contamination, which may be accidental and, of more recent concern, intentional due to terrorism. The intentional contaminations of DS by terrorists have already occurred in the past [1, 2, 3, 8], thus there is a risk for such events in future by intentionally injecting chemical, biological or radioactive contaminants. The consequences of such an action can be grim and the risk of casualties, social disruptions and disarray is high. Therefore, water distribution systems are to be protected from unauthorized access and constantly be under the surveillance to allow instant detection an intrusion or an unauthorized connection.

It is a challenge to secure a comprehensive surveillance of such a complex system as water distribution network. Therefore, alternative monitoring methods are necessary. Several authors addressed the issue. Quesson et al. [6] investigated the possibilities to detect and recognize sounds produced by pumps, drills and other tools used to intrude into a distribution system. A demonstration device was developed and tested on an operational DS. Krause et al. [4] considered methods of optimal sensor placement for the most effective detection of contamination. A Fuzzy rule-based modeling method is offered by Sadiq et al. [7] for estimation of risk of contaminant intrusion.

Transient flow analysis is found to be useful in analyzing different problems in water distribution networks. Wang et al. [9] offered an interesting method of leak detection in the pipelines that is based on analysis of fluid transients. Unsteady flow in a pipeline arises from events like a valve closure. Such events generate pressure waves in the system that decay with time. Wang et al. [9] demonstrated that if there is a lateral disturbance of the flow (e.g. a leak), a noticeable attenuation of transients is observed. It is shown that analysis of transient damping rate and damping modes enables to determine the occurrence of a leak as well as location and size of the leak.

The assumptions made by Wang et al. [9] are analyzed by Nixon et al. [5] where the range of validity of the method is investigated. The method was found to show promising results for the simple, single pipeline case. An intrusion into a pipe and an injection of a contaminant, as well as a leak, most likely, will cause a disturbance to the flow. As a result, there is a reasonable probability that the transient damping method can be applied to determine unauthorised connections and intrusions into the system.

The aim of this study was to investigate experimentally whether intrusion into a water distribution pipe has an effect on damping of transients and whether this method can be applied for detection of an unauthorized connection to a pipeline.

II. Materials and Methods

A pilot device was built for the analysis of transients and experimental determination of the effect of an intrusion on pressure oscillations after a valve closure. The pilot device consisted of 35m long aluminum pipe with internal diameter of 16 mm, a pressurized water supply tank, pressure gauges, valves, solenoid valves to produce a transient, an intrusion port with a pump to inject a contamination and an electronic pressure measurement system.

In the experiment water flowed from the pressurized tank to the open reservoir. Pressure in the system was about 3 bar (0.3 MPa). The main flow was adjusted with restrictor to a flow rate of about 1.5 litres per minute which corresponds to flow velocity of 0.12 m/s. Transient event was generated by shutting off the solenoid valve that blocks the main flow. Side discharge valve was closed all the time. Closure of the main solenoid valve results in greater pressure oscillations than the closure of side discharge solenoid valve. The side discharge valve provides similar effect, but at smaller scale. Intrusion flow rate in our experiments ranged from 0.1 to 0.7 litres per minute that is 7-47% of the main flow rate. Right after the main solenoid valve was closed, the pressure oscillations were recorded by oscilloscope. Oscillations were characterized by frequency and damping rate.

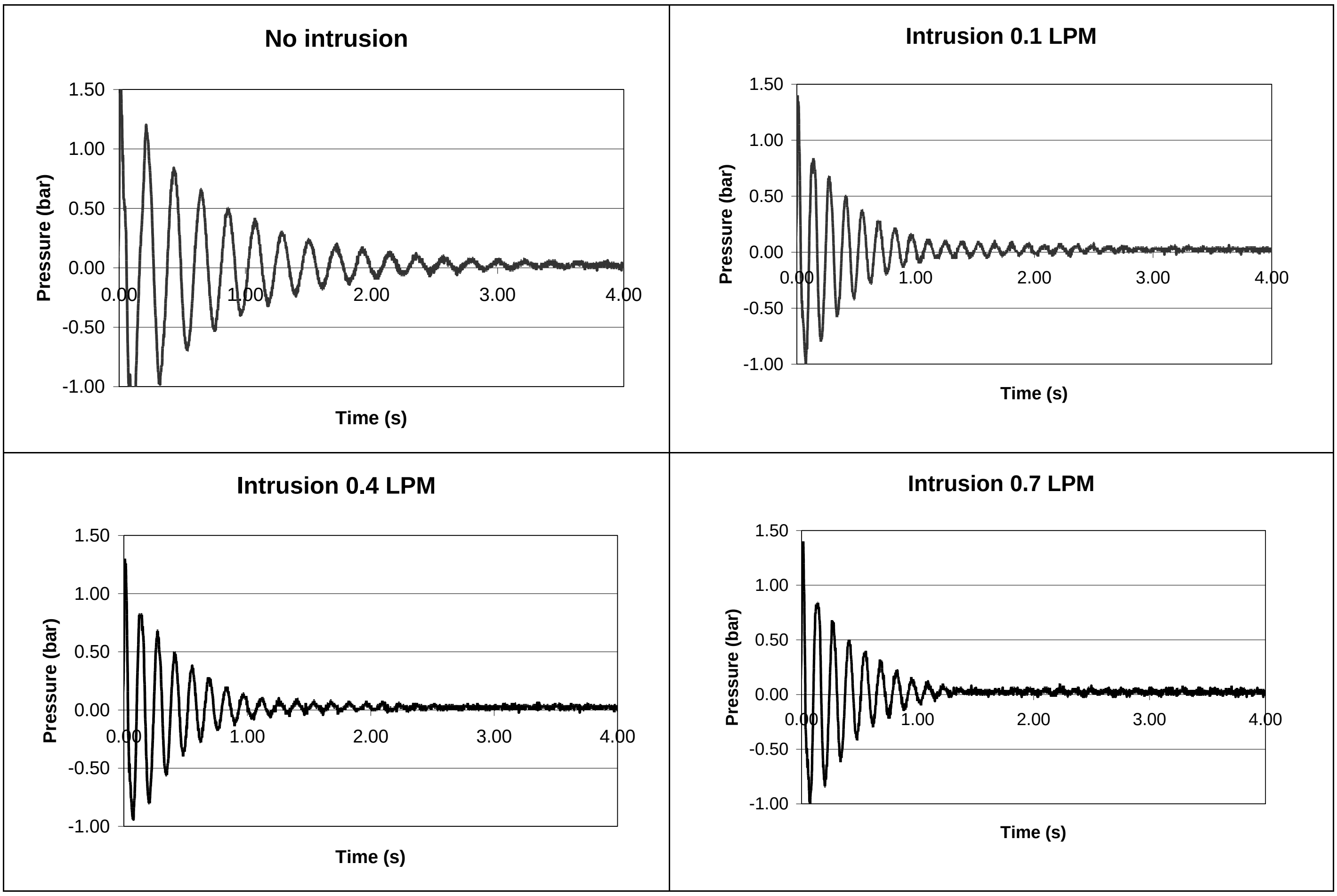
A honeywell 26PCFFM6G pressure sensor was used to measure pressure oscillations following a transient event (main valve closure). The sensor is capable to measure relative pressure up to 6.9 bar (0.69 MPa). The sensitivity of the sensor is about 1 mV/psi and response time is about 1 ms. The signal of the sensor was amplified and adjusted to 1 V/bar. In the laboratory tests presented in the paper of Wang et al. (2002), a typical period of pressure oscillations is 56 ms while the amplitude is 0.2 bar. As the length of the pipe used in present experiments is close to the length of the pipe used by Wang et al. [9] and assuming the wave speed of the pressure wave is the same, the period of oscillations should be no less than 50 ms. So, sensor response rate of 1 ms is considered to be sufficient.

The intrusion was simulated by opening the intrusion port and switching on the intrusion pump. The intrusion pump is the diaphragm pump with 1 L reservoir used for damping of pressure vibrations. The intrusion pump injected the contamination with pressure of 4 bar and flow rate ranging from 0.1 L per minute to 0.7 L per minute. Each time right after the main solenoid valve was shut, the pressure wave was detected by the pressure sensor and recorded by the oscilloscope. The pressure waves were recorded for the non-intrusion case and for the cases when injection of the contaminant takes place at the flow rates of 0.1 L/min, 0.4 L/min and 0.7 L/min.

III. Results and Discussion

Each measurement was made at least three times. No significant differences were noticed between the three replicates. Results of pressure wave measurements corresponding to the cases of no intrusion and 0.1, 0.4, 0.7 L/min intrusions are shown in Table 1. We observed that opening of an intrusion port significantly altered frequency of oscillations, however, frequency did not depend on intrusion flow rate. On the other hand it was noticed that the higher intrusion flow rate, the smaller the number of oscillations before returning to steady state. The change in frequency due to presence of intrusion is outlined in Fig. 1, where Fourier spectrum of oscillations is shown. To measure the frequency shift due to opening of intrusion port more clearly, Fourier analysis of the oscillations was performed and the frequency spectrum was obtained.

TABLE I
Pressure Oscillation Curves



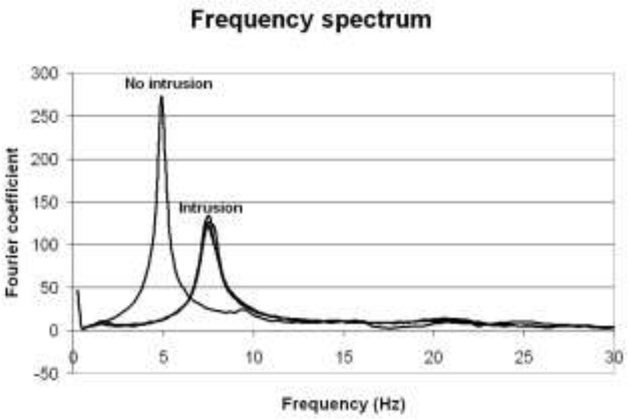


Fig. 1. Frequency spectrum of oscillations

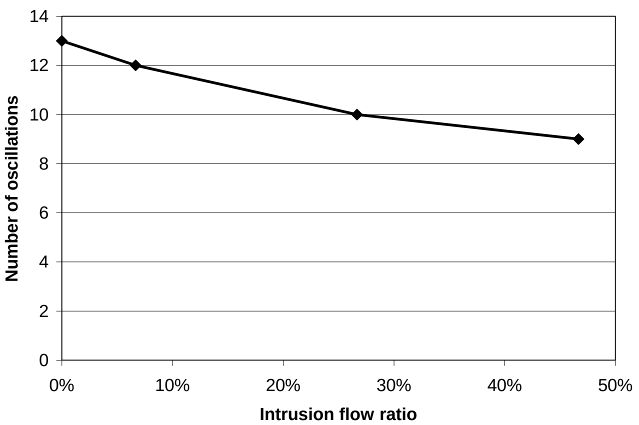


Fig. 2. Duration of pressure oscillations for different intrusion rates (ratio between intrusion rate and flow rate in %)

This data processing showed that when the intrusion port was opened the oscillation frequency shifted from approx. 5 Hz to 8 Hz. Thus, the frequency was dependent only on whether port is opened or not, but it did not depend on intrusion rate.

Besides of the change of frequency, intrusion lead to higher decay rate of oscillations. The higher is the intrusion flow rate, the smaller the number of pressure oscillations observed till full decay. Fig. 2 plots the correlation between intrusion rate and the number of pressure oscillation periods till signal-to-noise ratio of the peak-to-peak amplitude falls below 4. According to this chart, intrusion flow affects decay rate of oscillations, namely, at higher intrusion rates oscillations decay was faster.

The probability of attack to a water supply system is not high, thus occurrence of such even is rare. So, investing in sensors for detection of specific compounds that might not be activated during their lifetime could be less attractive than using pressure sensors which would provide useful data also for other routinely maintenance of water supply networks (e.g. calibration of hydraulic model, control of leakage, optimization of pumping). Measurements of water pressure changes can be useful for everyday operations, for example to optimizes performance of the plant (to save energy), validation of hydraulic models etc. Moreover, the price for pressure sensors is very low and installation can be done without stopping water supply system operation. This study showed that closing of the valve (in side and on main flow) and measuring pressure oscillation over the time can be simple but useful strategy to protect networks from intrusion. In this study, the experiments were done in a singe pipe where consumption was constant, however in the real branched networks the oscillation noise would come from transient event generated by consumers opening and closing taps and other devices. In such cases long-term data about water usage patterns would be needed to distinguish between the intrusion and transients generated by normal operation of the systems.

IV. Conclusions

Valve closure initiates pressure oscillations in the system. The oscillations have a specific frequency and decay rate. Both the frequency and the decay rate are influenced by the intrusion. Opening of the intrusion port and pumping liquid into the system results in change of frequency, regardless of intrusion rate. However, intrusion flow rate also has an effect on damping of oscillations – they decay faster at higher intrusion rates.

So, the experiment demonstrates that it is possible to detect an unauthorized connection by analyzing pressure oscillations after a transient event. If an intrusion is taking place, a frequency shift is observed. The intrusion rate may be evaluated by analyzing the decay rate of the pressure oscillations.

It is possible to conclude that the transient analysis method proposed by Wang et al. [9], although initially developed for the leak detection, probably may be used for detection of an unauthorized connection. It is clearly seen that pressure oscillations decay in a different way when a connection to the system is present. Presence of intrusion can be detected by observing change in frequency and the intrusion rate can be evaluated by analyzing the decay rate of the oscillations.

V. Acknowledgements

This work has been undertaken as a part of the research project SECUREAU (Nr. 217976) which is supported by the European Union within the 7th Framework Programme. There hereby follows a disclaimer stating that the authors are solely responsible for the work. It does not represent the opinion of the Community and the Community is not responsible for any use that might be made of data appearing herein.

References

[1] Y. Alamanos, V. Maipa, S. Levidiotou, E. Gessouli, "A community waterborne outbreak of gastro-enteritis attributed to Shigella sonnei," Epidemiol. Infect., vol. 125, pp. 499-503, 2000.

[2] H. G. Circirello, K. S. Kehl, D. G. Addiss, M. J. Chusid, R. I. Glass, J. P. Davis, P. L. Havens, "Cryptosporidiosis in Children During a Massive Waterborne Outbreak in Milwaukee, Wisconsin: Clinical, Laboratory and Epidemiologic Findings," Epidemiol. Infect., vol. 119, pp. 53-60, 1997.

[3] P. Gleik, "Water and terrorism," Water policy, vol. 8, pp. 481-503, 2006.

[4] A. Krause, J. Leskovec, C. Guestrin, J. VanBriesen, C. Faloutsos, „Efficient Sensor Placement Optimization for Securing Large Water

Distribution Networks,“ Journal of Water Resources Planning and Management, vol. 134(6), pp. 516-526, 1997.
[5] W. Nixon, M. S. Ghidaoui, A. A. Kolyshkin, “Range of Validity of the Transient Damping Leakage Detection Method,” Journal of Hydraulic Engineering, vol. 132(9), pp. 944-957, 2006.
[6] B. A. Quesson, M. K. Sheldon-Robert, I. N. Vloerbergh, J. H. G. Vreeburg, “Acoustic Monitoring of Terrorist Intrusion in a Drinking Water Network,” Proceedings of the 10th Annual Water Distribution Systems Analysis Conference, WSDA, 2009.
[7] R. Sadiq, Y. Kleiner, B. Rajani, „Estimating Risk of Contaminant Intrusion in Distribution Networks Using Fuzzy Rule-based Modeling,“ Proceedings of the NATO Advanced Research Workshop on Computational Models of Risks to Infrastructure, Primosten, Croatis, pp. 318-327, 2006.
[8] B. Said, F. Wright, G. L. Nichols, M. Reacher, M. Rutter, “Outbreaks of Infectious Disease Associated with Private Drinking Water Supplies in England and Wales 1970-2000,” Epidemiol. Infect., vol. 130, pp. 469-479, 2003.
[9] X. J. Wang, M. F. Lambert, A. R. Simpson, J. A. Liggett, J. P. Vitkovsky, “Leak Detection in Pipelines using the Damping of Fluid Transients,” Journal of Hydraulic Engineering, vol. 128(7), pp. 697-711, 2002.

Sergejs Nazarovs has a MSc degree in medical physics and Doctor degree in mathematical modelling (2008).
S. Nazarovs is a researcher at Riga Technical University. Currently he works as a researcher at the Environment Modelling Centre, which is a part of the Faculty of Computer Science and information Technology of Riga Technical University.
His main scientific interests are treatment of drinking water and wastewater, protection of water distribution systems from deliberate contamination.
E-mail: nazarow@yahoo.com.

Talis Juhna has a Doctor degree in engineering science (2002).
T. Juhna is a professor at Riga Technical University. Currently he works as a researcher in the Water Research Laboratory, which is a part of the Department of Water Engineering and Technology at the Faculty of Civil Engineering of Riga Technical University.
His main scientific interests are - drinking water treatment, removal of natural organic matter, bacterial growth in water distribution networks, rapid methods for identification of pathogens in drinking water.
E-mail: talis.juhna@rtu.lv

Andrei Kolyshkin has a Doctor degree in physics and mathematics (1981).
A. Kolyshkin is a professor at Riga Technical University, Department of Engineering Mathematics of the Faculty of Computer Science and Information Technology.
His main scientific interests are - stability problems in fluid mechanics with applications to hydraulics, mathematical modelling of non-destructive testing.
A. Kolyshkin is a member of the Latvian Mathematical Society.
E-mail: akolis@cs.rtu.lv.

Sergejs Nazarovs, Tālis Juhna, Andrejs Koliškins. Nesankcionētas pieslēgšanas pie ūdensvada eksperimentāla noteikšana
Sakarā ar pieaugošo risku ļaunprātīga vai nejauša ūdensvada piesārņojuma iespēju, ir nepieciešamība izstrādāt metodi piesārņojuma avota noteikšanai. Tā kā tāda notikuma varbūtība ir zema, ir vēlams detektēšanai izmantot tādu parametru analīzi, kas jau tiek kontrolēti normālas ūdens sistēmās ekspluatācijas laikā. Tādi parametri vārētu būt, piemērām, hlora koncentrācija un hidrauliskais spiediens. Pārejas procesi, tādi ka vārstu slēgšana, veido spiediena svārstības ūdensvadā ar noteikto frekvenci un rimšanas koeficientu. Ir zināms, ka laterāla plūsma, kas veidojās, piemērām, noplūdes gadījumā, veic pārejas procesu ātrāko rimšanu, ko var izmantot noplūdes detektēšanai. Šajā pētījumā eksperimentālā veidā pārbaudīts, vai pārejas procesu analīze var tikt izmantota intrūzijas vietas un lieluma noteikšanai. Eksperimenti tika veikti izmantojot vienu cauruli (garums 35 m, diametrs 16 mm) un intrūzijas plūsmas no 0.1 līdz 0.7 l/min, kas sastāda 7-47% no pamatplūsmas. Pārejas procesi tika iniciēti, aiztaisot ciet vārstu, kas kontrolē pamatplūsmu. Rezultāti liecina, ka intrūzija ietekmēja spiediena oscilāciju frekvenci un rimšanas ātrumu. Intrūzijas porta atvēršana mainīja oscilāciju frekvenci neatkarīgi no intrūzijas plūsmas ātruma. Intrūzijas plūsmas ātrums, savukārt, ietekmēja oscilāciju rimšanas ātrumu. Tātad var secināt, ka spiediena svārstību analīze var tikt izmantota intrūzijas vietas un lieluma noteikšanai.

Сергей Назаров, Талис Юхна, Андрей Колышкин. Экспериментальное определение факта несанкционированного подключения к водопроводу
В связи с возрастающей опасностью возможности случайного или намеренного загрязнения систем водоснабжения, возникает необходимость в разработке метода быстрого определения источника загрязнения. Так как вероятность загрязнения каждой отдельной системы не очень высока, для определения факта подключения к водопроводу с целью загрязнения его, предпочтительно использовать анализ параметров, которые контролируются в ходе нормальной эксплуатации систем водоснабжения. Такими параметрами являются, к примеру, концентрация хлора или гидравлическое давление. Переходные процессы, возникающие при закрытии клапана в системе водоснабжения, сопровождаются колебаниями давления с определенной частотой и скоростью затухания. Известно, что поперечные потоки в трубе (например, такие, которые возникают при наличии утечки) вызывают значительно более быстрое затухание переходных процессов, и этот факт может быть использован для определения несанкционированного подключения. В данной работе была произведена экспериментальная проверка, может ли анализ затухания переходных процессов быть использован для определения места несанкционированного подключения и скорости потока загрязняющего вещества. Экспериментальное устройство представляло собой трубу (длина 35 м, диаметр 16 мм), в которую закачивалась загрязняющая жидкость со скоростью 0.1 – 0.7 литров в минуту, что составляло 7-47% от основного потока. Переходные процессы создавались с помощью клапана, перекрывающего основной поток. Результаты свидетельствуют, что частота и коэффициент затухания колебаний меняются в случае наличия несанкционированного подключения. Скорость потока загрязняющей жидкости не оказывает влияния на частоту. Однако скорость потока оказывает влияние на затухание колебаний. Чем выше скорость потока загрязняющей жидкости, тем быстрее затухают колебания давления после закрытия клапана. Итак, можно сделать вывод, что с помощью анализа переходных процессов после закрытия клапана можно определить место несанкционированного подключения и скорость потока загрязняющей жидкости.