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Procedia Engineering 119 (2015) 1030 – 1038

Procedia Engineering

www.elsevier.com/locate/procedia

13th Computer Control for Water Industry Conference, CCWI 2015

Transient effects of self-adjustment of pressure reducing valves

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Abstract

Pressure control strategy through Pressure Reducing Valves (PRV) has been deeply investigated as management strategy, aimed at water leakages reduction avoiding very expensive pipe replacement programs. On the contrary, few experimental data are available in literature, with regard to PRV transient behavior in terms of its response to incoming pressure waves, as well as the time required for achieving the pressure set point. In this paper, the results of some experimental tests are presented. The PRV is installed in a single high density polyethylene pipe and transients are generated by operating the downstream end valve. Two types of tests are considered: a partial valve closure and opening simulating a water demand decrease and increase, respectively. The analysis of the experimental pressure traces points out the valuable effects of the PRV on transient characteristics with respect to the case of a partially closed in-line valve with a constant opening degree.

Peer-review under responsibility of the Scientific Committee of CCWI 2015

Keywords: pressure reducing valve, pressurized pipes, transients

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1. Introduction

In pipe systems pressure reducing valves (PRV) are used to manage flow conditions quite differently from those considered in the design. As an example, the fulfillment of peak demands – which occur in a limited interval of time indeed – is associated with a pressure regime leading to huge leakage and possibly gives rise to pipe bursts in the long period. The key function of a PRV is to disconnect two parts of a pipe system by: i) maintaining a given pressure value downstream of it in spite of the upstream value, and ii) avoiding reverse flow (Simpson,1999). As a consequence, if the outlet pressure would be larger than the requested value because of the upstream condition, the PRV adjusts its opening degree – i.e., it partially closes – giving rise to an appropriate local head loss. On the contrary, if the downstream pressure is too small, the PRV opens completely. In the case of a downstream overpressure, the PRV fully closes by isolating the two parts of the system to prevent a reverse flow. Moreover, PRV can be used to supply a constant discharge irrespective from the difference between the upstream and downstream pressure. Thus in many cases pressure reducing valves behave as a sort of panacea for unforeseen functioning conditions. According to such a crucial role, literature offers a great many contributions about their optimal location and number to reduce

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Peer-review under responsibility of the Scientific Committee of CCWI 2015
doi:10.1016/j.proeng.2015.08.999

leakage in water distribution networks (WDN) within quite different approaches. An exam of literature concerning the steady-state effects of PRV in pipe systems is beyond the aim of this paper and for an in-depth literature review the interested reader may refer to the recent paper by Sivakumar and Prasad(2015). Surprisingly, less attention has been devoted to the actual behavior of PRV and particularly to their reaction to fast variations of pressure regime as during transients caused by changes in functioning conditions (i.e., due to an increase or decrease of water demand). Main contributions are due to Ulanicki and co-workers who examined the performance of PRV from both the experimental and modeling point of view. Precisely, their dynamical behavior has been simulated in Prescott and Ulanicki(2003) where several models – to be used in network simulation – with a different complexity have been checked by means of laboratory runs executed on a short pipe system. Transient tests – simulated by means of a rigid column model – concerned an increase of the PRV set point followed by a partial closure of an upstream valve, a change in the downstream valve setting, and a decrease in the PRV set point. The efficiency of a pressure control with the possibility of automatically adjusting the set point of a PRV according to the flow through it – the so called flow modulation – is evaluated in Abdel Meguid et al.(2011). Finally, the precise cause for the instability at low flows (small valve openings) of PRVs has been identified and the measures to improve the robustness of the generic pressure control schemes have been proposed in Ulanicki and Skworcow(2014). A numerical analysis of unwanted interaction between PRV and network transients with possible propagation of large pressure peaks and related water quality problems is presented in Prescott and Ulanicki(2008). The negative feedback in terms of water quality – with persistent reports of red water – have been observed also during transient tests executed on a real pipe system and due to the fast closure of a PRV (Karney and Brunone,1999). The possibility of evaluating the actual flow rate of PRV as well as other parameters of transient governing equations (e.g., pressure wave speed, decay coefficient of unsteady friction) by means of few field tests within an inverse transient analysis is shown in Brunone and Morelli(1999).

The aim of this paper is to investigate the effect of self-adjustment of PRV due to a change in water demand. Particularly two different scenarios are examined: a reduction of the flow rate through the PRV – with a different speed – and a sudden increase. The experimental data are compared with numerical simulations to analyze the overlapping of two transients: the one due to the change of water demand and the second generated by the automatic adjustment of the PRV according to the set point.

2. Experimental setup

The high density polyethylene (HDPE) pipe at the Water Engineering Laboratory of University of Perugia has an internal diameter D = 93.3 mm, a nominal diameter DN110, a length L = 199.30 m, and is supplied by a pressurized tank; at the downstream end section a maneuver valve – ball valve DN50 – is placed (Fig. 1). A PRV (CLA-VAL ECO 90-35) with a nominal diameter DN80 is installed at a distance L_1 = 129.59 m downstream of the supply tank (Fig. 2). This PRV is a double stage pressure reducing valve: nominally the range of the low pressure set point is between 1.0 bar and 5.3 bar; the range of the high pressure set point is from 1.4 bar to 7.2 bar. During tests, the high pressure set point is disconnected and the low pressure set point is fixed at 1.0 bar. Transient tests are generated by maneuvering the end valve. Pressure signals, H, are acquired by piezoresistive transducers with a frequency acquisition of 1000 Hz at: section V, placed immediately upstream of the maneuver valve, section D, at a distance of 0.78 m downstream of the PRV, section U, at a distance of 0.79 m upstream of the PRV, as well as at the supply tank (T). The steady-state discharge is measured by means of a magnetic flow meter at a distance of 23.78 m from the tank.

3. Transients simulating a demand decrease

The first transient is generated by the fast partial closure of the end valve: the initial value of the flow rate is Q_0 = 3.32 l/s and the final one is Q_e = 0.13 l/s as shown in Fig. 3b, with the subscripts 0 and e indicating the pre-transient and final conditions, respectively. In Fig. 3a the pressure signals acquired at sections V, D, U, and T are reported. Experimental traces of Fig. 3a indicate that the system takes about 12 s to settle to the new steady state. During the pre-transient steady-state condition, the PRV is partially closed. In fact, the value of the pressure at section U ($H_{U,0}$ = 20.5 m) is larger than the fixed set point and the pressure at section D is automatically set by the PRV to $H_{D,0}$ = 10.44 m. It is worthy of noting that a small difference occurs between the value of the pre-transient set point and the final one ($H_{D,e}$ = 12.71 m). As a preliminary remark, it can be noticed that the pressure signals downstream of the PRV

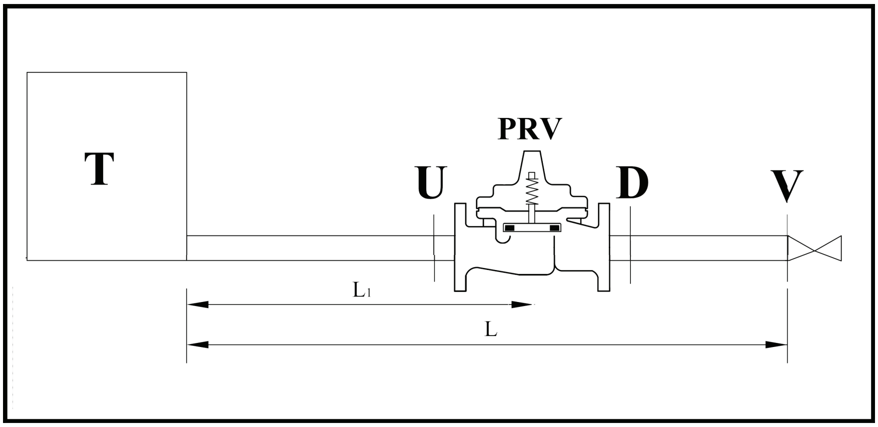

Fig. 1. Experimental set-up (T = supply tank, U = measurement section at 0.79 m upstream of the PRV, D = measurement section at 0.78 m downstream of the PRV, V= measurement section immediately upstream of the end valve).

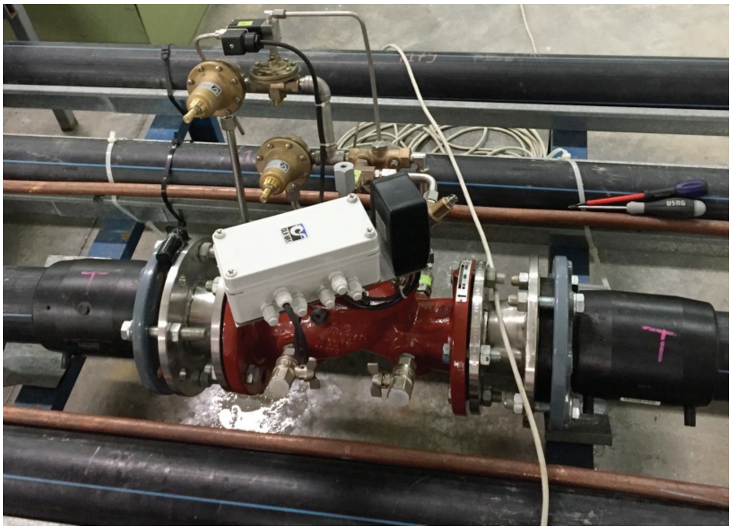

Fig. 2. The CLA-VAL ECO 90-35 installed at the Water Engineering Laboratory of the University of Perugia

do not show any periodicity, whereas clear oscillations take place in the branch of pipe upstream of the PRV. In other words, in some phases of the transients, the PRV behaves as a discontinuity, splitting the system into two parts.

Wavelet analysis – used to point out the discontinuities of the pressure signal (Ferrante et al.,2007) – identifies the first discontinuity at section V due to the maneuver at t = 0.07 s; the second one can be presumably ascribed to the arrival in the measurement section of the wave reflected by the PRV, at t = 0.47 s (Fig. 4). By associating such a discontinuity to the PRV the resulting value of the pressure wave speed, a is 356.23 m/s. This value is compatible with the geometrical and mechanical characteristics of the pipe. By considering such a value of a, the first discontinuity of the pressure signal at section D and U due to the maneuver should happen at t = 0.195 s and t = 0.199 s, respectively; such values are confirmed by wavelet transform of H_D and H_U, respectively (Figs. 5b and 6b).

Furthermore, if the opening degree of the PRV were constant, at section V the third singularity should be at t = 0.79 s due to the arrival of the second pressure wave reflected by the PRV. Moreover, the fourth discontinuity should occur at t = 1.12 s associated to the arrival of the pressure wave reflected by the tank. By analyzing Fig. 4b, it can be noticed that at such instants of time no singularity can be found in the pressure signal. On the contrary, in H_V (Fig. 4a) a gradual decrease in the pressure – starting at t = 0.64 s – can be observed, presumably caused by the self-adjustment

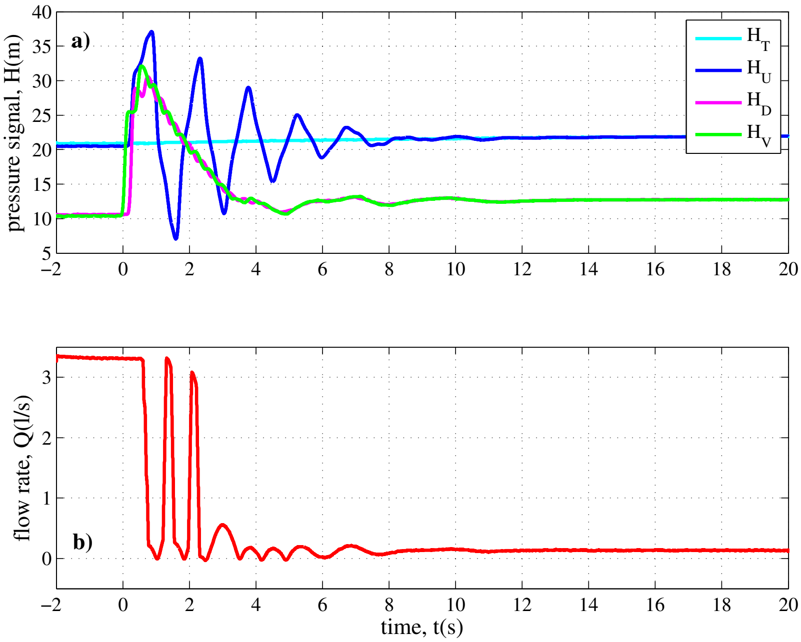

Fig. 3. Transient due to the fast partial closure of the end valve: a) pressure signals; b) flow rate (initial flow rate = 3.32 l/s, final flow rate = 0.13 l/s).

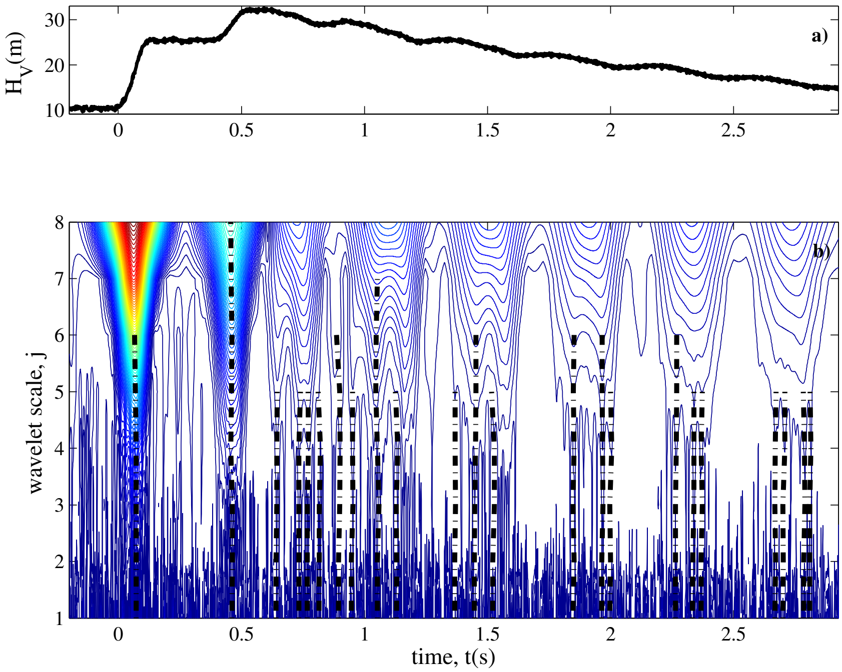

Fig. 4. Transient due to the fast partial closure of the end valve of Fig. 3: a) pressure signal at section V; b) corresponding wavelet transform.

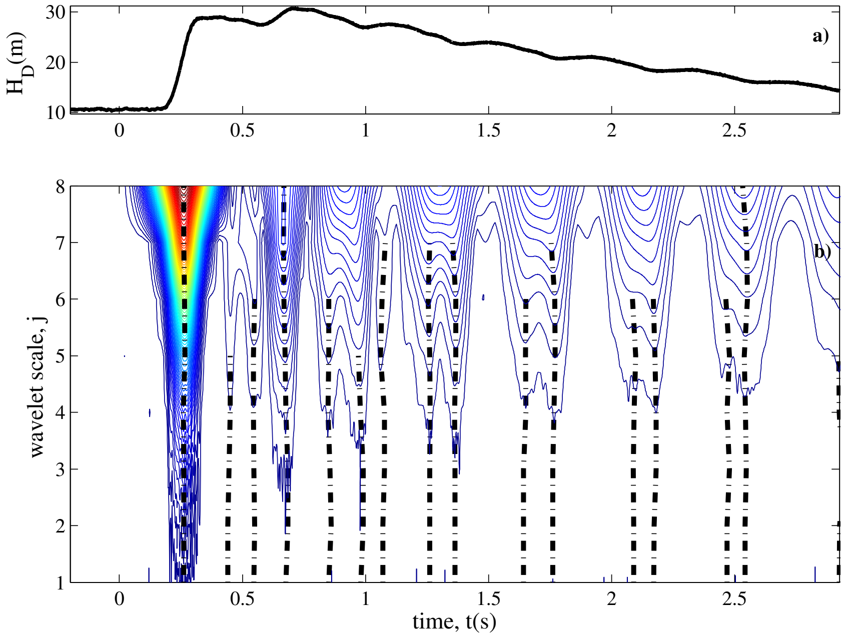

Fig. 5. Transient due to the fast partial closure of the end valve of Fig. 3: a) pressure signal at section D; b) corresponding wavelet transform.

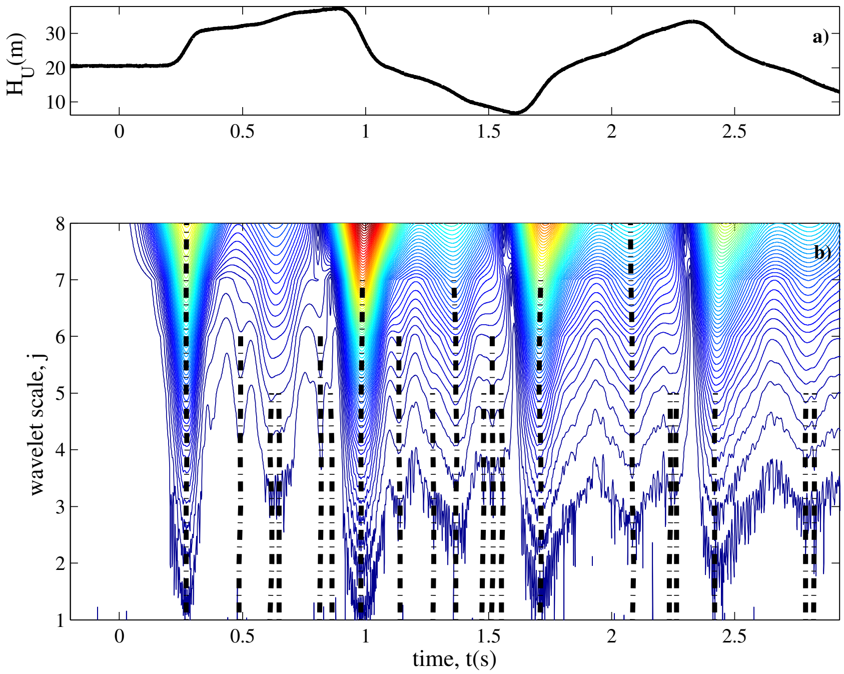

Fig. 6. Transient due to the fast partial closure of the end valve of Fig. 3: a) pressure signal at section U; b) corresponding wavelet transform.

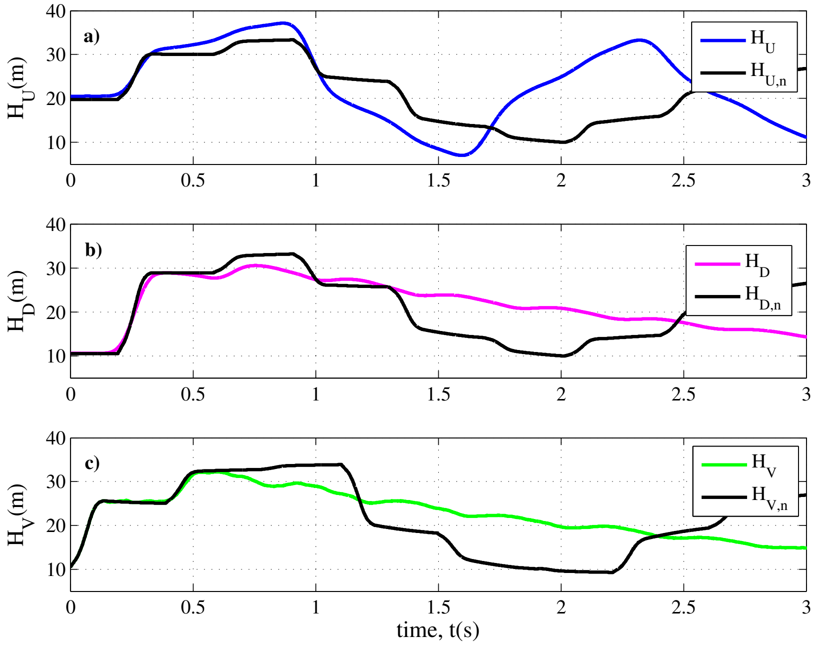

Fig. 7. Transient due to the fast partial closure of the end valve of Fig. 3: numerical simulation vs. experimental data at sections: a) upstream of the PRV, U; b) downstream of the PRV, D; and c) immediately upstream of the end valve, V. In the Figure, the subscript *n* indicates the numerical simulation.

of the PRV (i.e., a closure of the PRV).

At section D the second singularity – a pressure increase – should be at t = 0.67 s due to the arrival of the pressure wave reflected by the PRV and the end valve. But in the pressure signal – as pointed out by wavelet analysis (Fig. 5b) – such a discontinuity is preceded by a gradual and small decrease in pressure starting at t = 0.44 s, due to the gradual closure of the PRV. Such a behavior corresponds to the one happening at section V at t = 0.64 s.

With regard to section U, analysis of Fig. 6b shows that the time interval occurring between pressure extreme values is constant and equal to the characteristic time of the branch of pipe upstream of the PRV (= $\frac{2L_1}{a}$ = 0.72 s). This means that the PRV remains closed in the time period analyzed by the wavelet transform.

Even if mainly from the qualitative point of view, an idea of the effect of the PRV in the pressure signals is given in Fig. 7. In such a figure the experimental traces are compared with the results of a numerical model (Meniconi et al.,2012a,b,Pezzinga et al.,2014), in which a partially closed in-line valve with a fixed value of the opening degree is considered instead of the self-adjusting PRV (Meniconi et al.,2011). It is worthy of noting that in the very first part of the transient the good correspondence between numerical and experimental data is due to the fact that the PRV does not adjust; afterwords, the primary effect of the PRV is a sort of smoothing of the pressure waves.

In Fig. 8 the same type of transient, i.e., a partial closure of the end valve, but due to a slower maneuver, is reported. Inspection of Figs. 3 and 8 shows that the system takes a shorter period of time – about 9 s vs. 12 s — to reach a new steady-state condition. Moreover, experimental pressure traces exhibit a smoother behavior; also in this case a difference in the value of H_D can be noticed between the pre-transient (= 10.44 m) and the final condition (=12.05 m).

4. Transients simulating a demand increase

Transient shown in Fig. 9 is generated by the fast partial opening of the end valve. The final (initial) flow rate is substantially equal to the initial (final) flow rate of the previous transient: in fact, also H_D varies in about the same

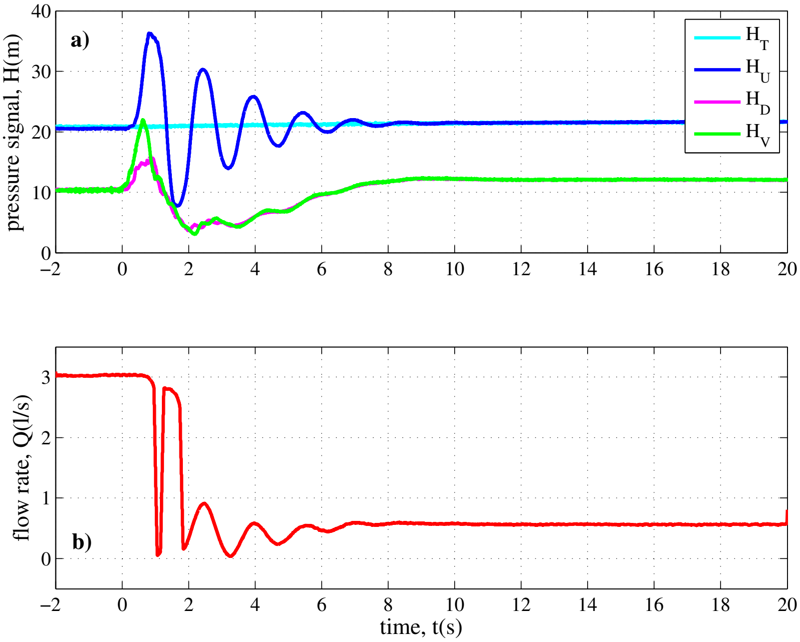

Fig. 8. Transient due to the slow partial closure of the end valve: a) pressure signals; b) flow rate (initial flow rate = 3.03 l/s, final flow rate = 0.56 l/s).

range of pressure ($H_{D,0}$ = 12.07 m and $H_{D,e}$ = 10.39 m). The system takes a larger period of time – about 18 s — to reach a new steady-state condition with a larger flow rate. These characteristics of the maneuver reflect in the pressure signals: in H_V the fist two singularities (at t = 0.07 s and t = 0.47 s) are due to the maneuver and the reflection at the PRV which has not adjusted yet. Then the successive PRV self-adjustment implies a gradual pressure increase till t =7.07 s when a partial closure of the PRV happens to fulfill the set point (almost the same applies to the H_D pressure signal). Smaller pressure changes occur at section U, because of the action of the PRV that almost isolates the upstream branch of pipe in practice.

5. Conclusions

In this paper the effect of transients on a self-adjusting PRV is studied. Generated transients simulate a change in water demand by reducing or increasing the flow rate through the PRV. Pressure signals are acquired downstream and upstream of the PRV and immediately upstream of the maneuver valve. The case of the fast decrease of demand is analyzed in depth and the other transients are shown as a comparison with the first one. Particularly, the experimental pressure signals are analyzed by means of wavelet transform to point out the time instants in which pressure waves pass through the measurement sections. Moreover, experimental traces are compared with the transient numerical simulations in which a partially closed in-line valve with a fixed value of the opening degree is considered instead of the self-adjusting PRV. This comparison allows isolating the effect of the transient that causes the change of water demand and the transient generated by the automatic adjustment of the PRV according to the set point.

Acknowledgements

This research has been supported by the Italian Ministry of Education, University and Research (MIUR) — under the Projects of Relevant National Interest “Advanced analysis tools for the management of water losses in urban

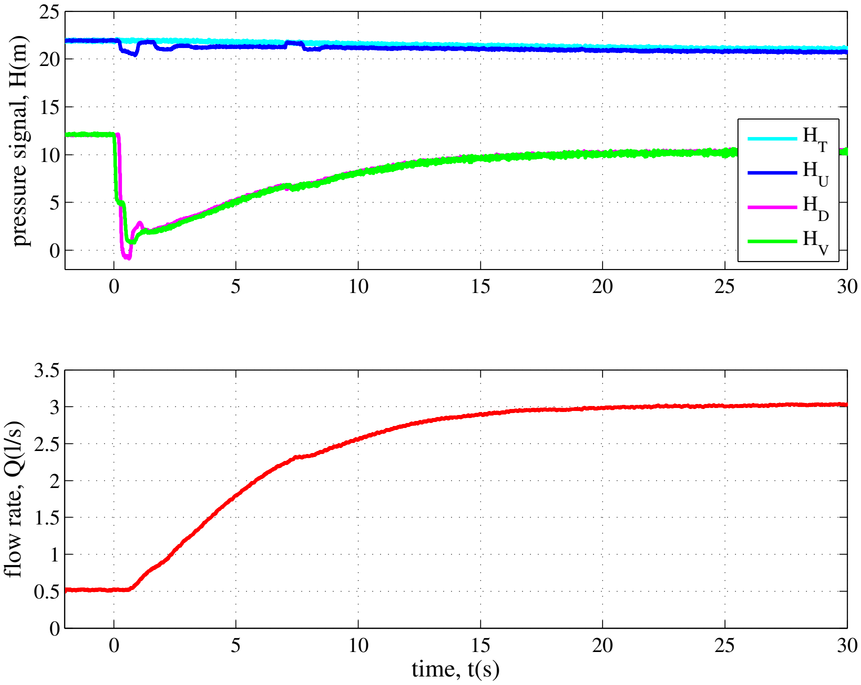

Fig. 9. Transient due to the fast partial opening of the end valve: a) pressure signals; b) flow rate (initial flow rate = 0.52 l/s, final flow rate =3.03 l/s).

aqueducts" and "Tools and procedures for an advanced and sustainable management of water distribution systems" — and Fondazione Cassa Risparmio Perugia, under the project "Hydraulic and microbiological combined approach towards water quality control (no. 2015.0383.021)".

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