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Pump Switching-Induced Transients in Water Distribution Networks—Preliminary Laboratory Experiments †

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Abstract: The Water Engineering Laboratory (WEL) of the University of Perugia hosts a real-scale water distribution network (WDN) with a service line comprising high-density polyethylene (HPDE) pipes and supplied by two pumps in series. The carried out unsteady-state tests show the WDN behavior during transients due to pump switching-on and -off. In particular, they underline the most pressure-stressed sections of the system. The obtained results can help water utility managers in protecting these sections with the aim to preserve the integrity of the WDN.

Keywords: water hammer; transient; pump switching; water distribution network

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1. Introduction

In water distribution networks (WDNs), transients repeatedly generated by maneuvers at regulation devices [1], end-users [2–4], supply lines [5], and pumps [6] pose a risk of pipe damage. Monitoring the dynamics of discharge in WDS supplied by pumps is crucial, not only to prevent potential risks of pipe damage due to transients, as highlighted by [6], but also to accurately account for the supplied water in the overall water mass balance in aqueducts. This is particularly important for aqueducts fed by aquifers, where the integration of soil moisture data from ERA5, water table measurements, discussed in [7] and the dynamics of water pumped from aquifers provides a comprehensive understanding of the recharge and discharge processes. In [8], to estimate the pressure stressing the pipes, field tests are carried out in two WDN districts: one with industrial end-users and the other interested by pump activity.

The aim of this paper is to study the effect of pump switching in the WDN installed at the Water Engineering Laboratory (WEL) of the University of Perugia (Italy). In particular, the focus is on the identification of the most stressed parts of the WDN, with the ultimate goal of driving water utility managers to enhance monitoring and maintenance operations at critical sections.

2. Experimental Setup

The experimental setup consists of a WDN, with all pipes made of high-density polyethylene (HDPE), supplied by two identical pumps arranged in series: the supply pump (SP) and the maneuver pump (MP). The pumping system draws water from a feeding tank as a supply source. The WDN consists of a DN110 42.30 m long supply line, with an internal diameter D = 93.3 mm, wall thickness e = 8.1 mm, and two loops. The first loop has four 100 m long pipes with DN75, D = 63.8 mm and e = 5.6 mm, while the second one has one pipe in common with the first, and the other three are 100 m long pipe with DN50, D = 42.6 mm and e = 3.7 mm. A DN25 service line (SL), with a length of 23.60 m,

D = 20 mm, and e = 3 mm, is installed at section 6 (Figure 1). At a downstream end of the SL, a ball valve is installed to regulate the discharge and simulate the end-user 6u. Pressure signals are acquired with a sampling frequency of 2048 Hz, with transducers located at sections 32 (32.3 m downstream of MP), 8, 6, and 6u. These measurement sections are chosen as they are the closest and the farthest to the pumping system, the junction with SL, and the end-user, respectively.

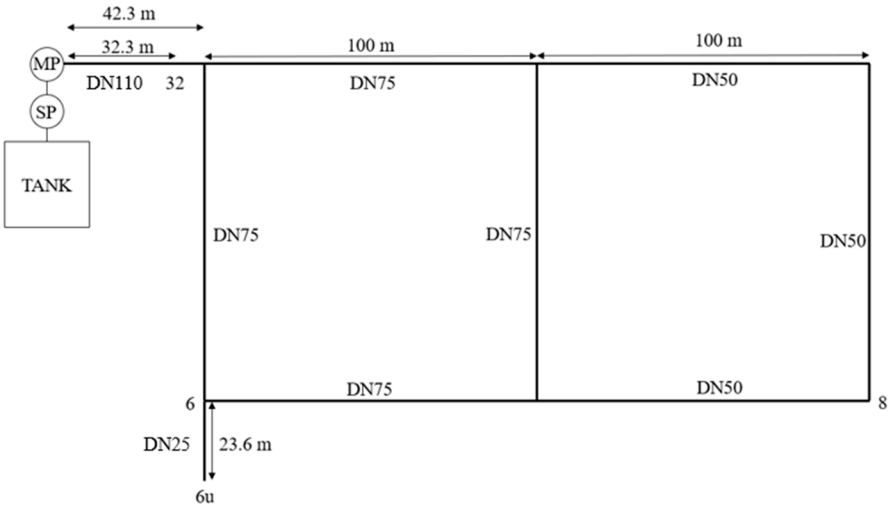


Figure 1. The experimental setup.

3. Transient Tests

During the transient tests, the SP was maintained in continuous operation, supplying a discharge Q_{SP}; the successive switching-on and -off maneuvers executed at the MP led the discharge to Q_{MP} and then again to Q_{SP}, respectively. In this work, as a representative example of the carried-out transients, and for lack of space, the results of the test characterized by Q_{SP} = 0.42 L/s and Q_{MP} = 0.62 L/s are presented. For this test, pressure signals, H, acquired at the selected measurement sections are shown in Figure 2. This plot indicates that, after a time interval Δt_1 = 54 s, the MP is switched on until the new steady-state conditions are reached, both pumps are on, and Q_{MP} = 0.62 L/s. Such a transient takes more than 1 min to damp (Δt_2 = 96 s). Successively, the MP is switched off to restore to the initial conditions (Δt_3 = 70 s). It is worth noting that the pressure signal acquired at section 6u reaches 90 m with both the pumps switched on, whereas its value is about 45 m when only the SP is operating.

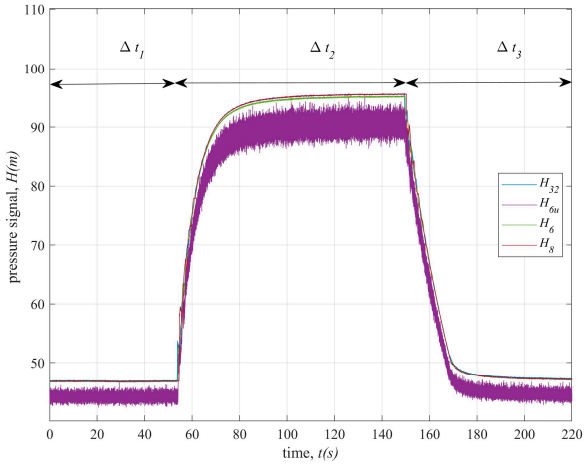


Figure 2. Pressure signals, H, acquired at the measurement sections 32, 6u, 6, and 8.

4. Results

The first phases of the transients induced by both switching-on and -off are reported in Figure 3a,b, respectively, as enlargements of the pressure signals of Figure 2. For the sake of clarity, the first pressure variations at each measurement section are marked by a double arrow and the symbol δ, followed by a subscript indicating the corresponding measurement section. The pressure variation due to the pump switching on (Figure 3a) reaches section 32 at t = 53.66 s, with an amplitude δ_{23} equal to 53.87 m. When such a wave arrives at sections 6 and 6u at a t equal to 53.96 s and 54.07 s, respectively, it is reduced to δ_6 = 52.63 m and δ_{6U} = 51.36 m. This reduction is due to the interaction of the pressure waves with the WDN junctions. It is worth noting that during the first phase of the transient, the most excited section is node 8 (δ_8 = 54.73 m), irrespective of if it is the farthest section from the transient generation point. This feature can be ascribed to the topology of the considered WDN that implies the almost simultaneous arrival of three pressure waves at node 8.

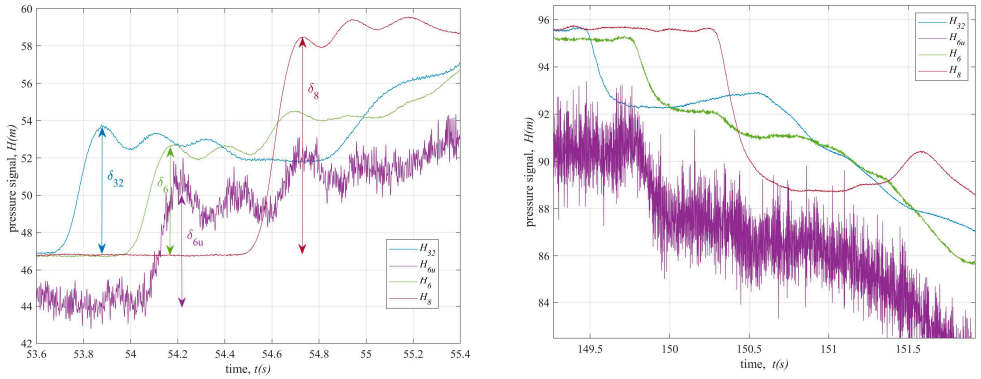


Figure 3. Transient response of the WDN at sections 32, 6, 6u, and 8: (**a**) the first overpressures during MP switching-on, and (**b**) the first depressions during MP switching-off.

During the first phases of the transient due to the pump switching off (Figure 3b), it can be noted that smoother pressure variations occur.

5. Conclusions

This paper presents the preliminary results of the tests carried out at the Water Engineering Laboratory (WEL) of the University of Perugia (Italy), with the aim to investigate the transient response of a two-loop water distribution network (WDN) to pump switching-on and -off.

The acquired pressure signals show that, during the first phases of the transient due to the pump switching-on, sharp pressure waves are generated, and the pressure extreme values are achieved at the farthest section from the pumping system. On the contrary, the transient due to the pump switching off is characterized by smoother pressure waves.

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