DESIGN OF TRANSIENT TESTS FOR THE DIAGNOSIS OF TRANSMISSION MAINS

BRUNO BRUNONE\(^{(1)}\), SILVIA MENICONI\(^{(1)}\), CATERINA CAPPONI\(^{(1)}\), & MARCO CIFRODELLI\(^{(1)}\)

\(^{(1)}\) Department of Civil and Environmental Engineering, The University of Perugia, via G. Duranti 93, 06125 Perugia, Italy
bruno.brunone@unipg.it

ABSTRACT

In the last two decades, increasing attention has been paid to the Transient Test-Based Techniques (TTBTs) for the diagnosis of long transmission mains (TMs). In fact, the usual distrust – which derives from the misunderstanding that reliable results could be achieved only if large and, therefore, potentially dangerous, pressure waves are generated – has been overcome. As a matter of fact, pressure waves can be very small as long as they are sharp, and applications of TTBTs increased, because of the simplicity and shortness of the tests, as well as the modest cost of the necessary instruments. For these reasons, TTBTs are undoubtedly competitive with the techniques – quite invasive – which involve the insertion of probes in the pipelines, or the realization of “points of listening” for the leak a few hundred meters away from each other. This paper illustrates the possible methods for generating suitable transients for a reliable diagnosis of TMs without compromising their integrity. For each method, the main characteristics are highlighted as well as limits and potential weaknesses are discussed. Moreover, the results of some experimental tests carried out at the Water Engineering Laboratory (WEL) of the University of Perugia (Italy) are reported.

Keywords: Transient test-based techniques, fault detection, transient generation.

1 INTRODUCTION

In the last two decades the literature (for an exam of the most important contributions, see Colombo et al., 2009; Xu & Karney, 2017; Ayati et al., 2019) has been enhanced with numerous contributions on the use of transients for the diagnosis of transmission mains (TMs), the so-called Transient Test-Based Techniques (TTBTs). The simplicity and the short duration of the transient tests, as well as the moderate cost of the necessary instrumentation, represent an undoubted value of the TTBTs compared to other techniques (Liu & Kleiner, 2013). This is the case of the in-line techniques which involve the insertion of sensors in the pipeline (see, for example, the technique described in www.puretechltd.com) or the continuous monitoring at measurement sections situated next to each other, i.e., at a distance of a few hundred meters (see, for example, the technique described in www.echologics.com). Despite the intense research activity, in-depth studies are needed to make TTBTs fully operational.

One of the most investigated aspects of TTBTs is the technique used to analyze the pressure signal acquired during the transient test. In fact, this may be executed both in the time and frequency domain, depending on the type of transient and the system examined (Colombo et al., 2009; Xu & Karney, 2017; Ayati et al., 2019). On the contrary, one of the aspects that merit further investigation is the choice of the suitable transient test, i.e., the procedure of generating pressure waves that allows the diagnosis of the system without compromising its integrity. In literature, although there are several contributions at this regard (e.g., Brunone et al., 2008; Gong et al., 2018; Shucksmith et al., 2012; Stephens et al., 2011; Taghvaei et al., 2010), the question of a general validity methodology remains open. It is also worthy of noting that the choice of the transient test depends on: (i) the characteristics of the system and its devices, (ii) the operating conditions and, last but not least, (iii) the water utility manager requirements.

With regard to TMs – in which the use of TTBTs is more appropriate – firstly it is the case of distinguishing between gravity flow pipe systems and systems with pumping stations. In the former, in fact, the closure of a regulation/sectioning valve constitutes the first working hypothesis. In the latter, on the other hand, the switching on/off of the pumps is the most evident procedure to generate transients.

In this paper, for the sake of brevity, only the first type of TMs is considered. The possible methods for the generation of transients are analyzed, highlighting the main characteristics and discussing their limits and potential weaknesses. It should also be noted that for all the techniques examined and discussed in this work it is necessary that the execution of the transient tests is preceded by a phase of stationary conditions in order to avoid the overlapping of pressure waves due to the transient tests with the pre-existing ones.

Although the change of the flow rate – caused, for example, by pump switching off or valve closing – constitutes, also for historical reasons, the most frequent cause of pressure wave generation, the inverse
option, i.e., the change of pressure that causes a change of flow, should be taken into account. This is the case of the Portable Pressure Wave Maker (PPWM) device refined at the Water Engineering Laboratory (WEL) of the University of Perugia, Italy.

The description of the techniques of generation of transients is followed by some examples of tests executed at WEL.

2 METHODS OF GENERATION OF TRANSIENTS

In gravity flow pipe systems (Fig. 1), at least two valves are usually installed: the first valve (IV) is located immediately downstream of the supply reservoir (SR) and it is used for disconnecting SR when it must be maintained; the second valve (EV) is immediately upstream of the end reservoir (ER) and it allows regulating the discharge as well as disconnecting ER.

Operating the IV valve has to be excluded in order to avoid the generation of potentially dangerous negative pressure waves. On the contrary, the EV valve can be used even if it is necessary to proceed preliminarily to its slow partial closure, especially for large diameter pipes. The aims of this operation are: (i) to reduce the velocity from the initial value \( V_0 \), which corresponds to the ordinary functioning condition of the system to \( V' \) that implies an acceptable value of the pressure wave, \( \Delta p \), generated by the fast total closure; and (ii) to carry out a closing maneuver as fast as possible. The EV valve and its actuator are, in fact, designed to avoid fast maneuvers that may cause excessive pressure variations. In this configuration the measurement section M is generally placed immediately upstream of the EV (Fig. 1).

![Figure 1. Single pipe: transient generated by closing the end valve EV.](image)

In principle, the described procedure could be a working hypothesis. However, it is difficult to achieve it without significant and costly adjustments of the valve actuator and control system. In fact, the EV cannot be maneuvered at will for the mentioned safety reasons; the following alternative solutions can be adopted for generating a transient:

- maneuvering a side discharge valve (SDV), and
- connecting the Portable Pressure Wave Maker (PPWM) device.

2.1 Maneuvering a side discharge valve (SDV)

Due to the frequent impossibility of maneuvering the EV valve with the necessary rapidity, a small and sharp pressure wave can be generated by means of a side discharge valve (SDV) of small diameter. For this configuration, two alternatives are possible depending on whether or not the EV valve can be closed.

Assuming that the EV valve can be completely closed, the SDV can be installed immediately upstream of it (Fig. 2). Once the EV valve has been closed and the SDV has been opened, and once stationary conditions have been reached in the system, with a suitable velocity \( V''_0 \), it is possible to proceed to the rapid closure of the SDV, because of its small size. During the period necessary to reach stationary conditions, the discharge through the SDV can be conveyed to the ER, for example, by means of a short plastic pipe. In this configuration the measurement section M can be set immediately upstream of the SDV (Fig. 2).

On the contrary, if, due to service requirements, it is not possible to close the EV and/or install the SDV immediately upstream of the EV, to avoid interference between the positive wave generated by the closure of the SDV and the negative one, reflected by ER or SR, it is necessary to install the SDV at a distance \( L_2 \) upstream of ER. The optimal value of \( L_2 \) depends on the duration of the SDV closing maneuver, \( \tau \), and...
pressure wave speed, $c$. For example, for a metallic pipe (with $c = 1000$ m/s) and a typical closing time of small diameter valves ($t = 0.05$ s), $L_2$ must be greater than 25 m according to the following relationship:

$$L_2 \frac{c}{2} > L_2 \frac{c}{2}$$

[1]

Figure 2. Single pipe: transient generated by closing the SDV with the end valve closed.

2.2 Connecting the Portable Pressure Wave Maker (PPWM)

A possible option is to install the PPWM downstream of the SR (Fig. 3) in order to reduce the pressure regime inside the device with consequent lower cost and greater safety during the tests.

The PPWM device (Fig. 4) consists of a steel vessel filled with water and air that can be placed under pressure by means of a standard compressor. The PPWM and test pipe are connected by a short length conduit with a small diameter connection valve (CV) at the end section. At the beginning of the test, after disinfecting the device and refilling it with water from the test pipe, the inside pressure, $H_{PPWM0}$, is fixed larger of a given amount than the pressure inside the pipe.

After closing the EV and keeping the IV open or partially open, once stable stationary conditions are reached, the abrupt opening of the CV determines a pressure wave that propagates in the pipe. Since the CV can be actuated very fast and the pressure wave generated by the PPWM, $\Delta p_{PPWM}$, can be controlled with reasonable precision (Brunone et al. 2008), by using such a device most of the mentioned weak points of the TTBTs can be eliminated. In this configuration the measurement section M is generally located immediately downstream of the connection to the PPWM (Fig. 3).

Figure 3. Single pipe: transient generated by the PPWM.
3 EXPERIMENTAL RESULTS

Experiments have been carried out at the Water Engineering Laboratory (WEL) of the University of Perugia, Italy, in a high-density polyethylene (HDPE) pipe with an internal diameter $D = 93.30$ mm, DN110, wall thickness $e = 8.1$ mm, and a total length $L = 189$ m, supplied by an upstream-pressurized tank, T (Fig. 5). At the downstream end section of the pipe, the valve EV is completely closed. Transient tests are generated by the total and fast closure of a side discharge valve, which is a pneumatic ball valve with nominal diameter DN32. Two tests have been carried out: (test #1) the SDV1, and the corresponding measurement section M1, are located at a distance $L_2 = 170.80$ m from EV; (test #2) the SDV2, and the corresponding measurement section M2, are located immediately upstream of the EV. In both cases, by monitoring the pressure it can be stated that the time necessary for reaching stationary conditions is about 20 minutes.

Pressure signal, $H$, is acquired by piezoresistive transducers with an acquisition frequency of 2048 Hz. The discharge is measured by means of an electromagnetic flow meter, located immediately upstream of M1.

Figs. 6a and 6b show the pressure signals acquired during test #1 and test #2, respectively. It is worth noting that the generated pressure wave is approximately the same with $\Delta H_{M1} = 10.35$ m and $\Delta H_{M2} = 10.59$ m, notwithstanding a very different steady-state discharge through the SDV: in fact, for test #1 $Q_{0,SDV1} (= 3.78$ L/s), is approximately the double of $Q_{0,SDV2} (= 1.93$ L/s) of test #2. This is due to the particular position of SDV1 for which the Allievi-Joukowsky overpressure splits in two pressure waves, the former travelling upstream of SDV1 towards T and the latter travelling downstream of SDV1 towards EV. Moreover, it has to be pointed out that, for test #1, even if the initial discharge is larger, the damping of pressure signal is faster with very small pressure oscillations after 5 s. This is due again to the particular position of SDV1. In other words, notwithstanding the value of the steady-state discharge, the larger $L_2$, i.e., the smaller the distance to T, the faster the damping of pressure peaks.
Figure 6. a) test #1 – pressure signal at section M1 and transient generated by the fast total closure of SDV1 ($Q_{0,SDV1} = 3.78$ L/s); b) test #2 – pressure signal at section M2 and transient generated by the fast total closure of SDV2 ($Q_{0,SDV2} = 1.93$ L/s).

4 CONCLUSIONS

The simplicity and the short duration of the transient tests, as well as the moderate cost of the necessary instrumentations, represent an undoubted value of the Transient Test-Based Techniques (TTBTs) compared to other more invasive techniques (the in-line techniques). One of the aspects of TTBTs that merit further investigation is the choice of the suitable transient test, i.e., the procedure of generating pressure waves that allows the diagnosis of the system without compromising its integrity.

In this paper the possible methods for generating suitable transients for a reliable diagnosis of TMs without compromising their integrity are illustrated. For the sake of brevity, attention is focused on gravity flow pipe systems where the closure of a regulation/sectioning valve constitutes the first working hypothesis. As reliable alternative options the transients generated by maneuvering a side discharge valve (SDV) or connecting the Portable Pressure Wave Maker device are examined. For both techniques, the main characteristics are highlighted as well as limits and potential weaknesses are discussed. Moreover, the results of some experimental tests carried out at the Water Engineering Laboratory (WEL) of the University of Perugia (Italy) are reported.

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