Influence of the Valve - Pull-down Equipment on the Area of High Pressure Peaks in Long Pipelines

Fedor V. Rekach, Svetlana L. Shambina, Evgeny K. Sinichenko, Yuri V. Belousov

Abstract— The pipeline system is usually destroyed by the high internal pressure in the tubes due to development of water hammers. Also the possibility of continuous pressure oscillations causing vibration of external piping is dangerous, because it leads to loosening and destruction of the supports. One of the effective methods to protect a long pipeline is the possibility of removing liquid from the pipeline. The paper deals with the calculation of similar valve-pull-down unit by the numerical method of characteristics.

Keywords: Valve-pull-down unit; Water hammer; Pressure fluctuations

I. INTRODUCTION

There are some reasons that can cause serious accidents in pipelines such as damage of equipment and typical faults, violating the conditions of its normal use and safe operation [1], [2], [3]:

1) mechanical destruction of water pumps, pipe-lines and structures when internal pressure changes, ex-ternal forces increase, corrosion conditions and tempera-ture change;

2) breakage of components such as pumps, com-pressors, fans and mixers;

3) malfunction in the control systems (pressure, temperature, level indicators, flow meters, control devic-es);

4) malfunction in the safety system (safety valves, pressure relief system, neutralization systems, safety bursting disks);

5) violation of welded assemblies and connecting flanges.

2. Main part

Analysis of emergencies in pipelines of various purposes shows that practically each of these mentioned above events can cause a major accident which may occur as a result of changes in pressure due to wave and shock processes [4].

Among the modern ways of dealing with a sharp increase of pressure in the hydraulic systems due to wa-ter hammer, emergency situations, turning on of devices, suddenly stopping the movement of fluid, etc. is the pressure stabilizer [5]. When branched scheme of the pipeline system is considered it is needed to have a pres-sure stabilizer of high volume. A similar calculation was given earlier [6]. However, for large hydraulic schemes with great volumes of fluid, the size of such devices may be so great that its use becomes economically disadvan-tageous. In these conditions, if fluid release to the atmos-phere or reservoir is possible, it may be advantageous to use the device which discharges fluid.

One of the varieties of this device is the valve-discharging unit (VDU). The valve is selected so that when pressure doesn`t exceed the pressure under stationary fluid motion p_{sm} then discharge of liquid from the pipeline system does not occur; in case of exceeding of the specified pressure p_{sm} the valve moves and the liquid outflows.

The manufacturer in the certificate of VDU can give the following parameters: t_{vm} - the minimum time for which the valve opens totally; d_v- the diameter of the valve; Q_v - liquid discharge when the pressure is equal to Hv and $h_v=0$ where h_v - the excess pressure over the pressure at a stationary mode H_{sm}, not causing opening of the valve, $h_v=0\text{-}20$ *м* ; the parameter h_v can be regulated when installing the valve VDU.

Let us assume the following hypotheses for the analysis model:

I. Hydraulic resistance ζ_v of the VDU at fully opened valve is considered to be constant.

II. The water discharge of liquid increases from 0 to Q_{of} during time t_{vm} according to the square law.

III. If pressure falls below H_{sm} the device closes immediately.

In accordance with hydraulic formulas:

$$H_v = \zeta_v \frac{v_v^2}{2g} = \zeta_v \frac{(Q_v/\omega_v)^2}{2g} \qquad (1)$$

where v_v is the average velocity of the liquid through the valve.

Therefore,

$$\zeta_v = \frac{2H_v g}{(Q_v / d_v)^2} = const. \qquad (2)$$

Relying on the second hypothesis II (see the formula (1)), we get:

$$Q_{of} = a_v \sqrt{\frac{2gH_P\omega_v^2}{\zeta_v}}$$

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where $H_P = \Delta H - h_v$ (ΔH is the difference of pressures in the pipeline and the external environment)

$$a_v = \begin{cases} (t/t_{vm})^2 & when \ \ \mathrm{t < t_{vm}}, \\ 1 & when \ \ \mathrm{t \geq t_{vm}}. \end{cases}$$

Time is measured since the start of the opening of the VDU. If at time t_0 , $H_P < H_{sm}$, then the valve closes instantly.

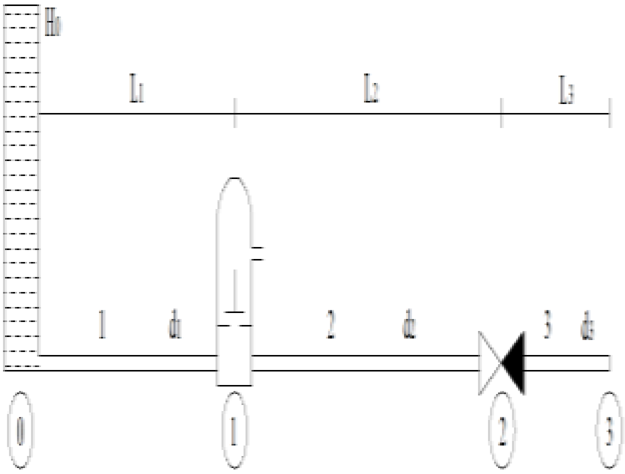

Figure 1: Scheme of the pipeline, including VDU

Calculation of pipeline schemes, including the valve-pull-down equipment (Figure 1) was analyzed numerically by the method of characteristics and was described before [6]. As main characteristics are adopted flow discharge $Q = F \cdot v$ and hydrodynamic pressure H (expressed in meters of water column), where F - the cross - sectional area of the pipe $[m^2]$, v - average flow rate of the living cross - section.

$$\frac{\partial}{\partial x}\left(gFz + gFH + \frac{Q^2}{2F}\right) + \frac{\partial Q}{\partial t} + \qquad (3)$$
$$+ \frac{\zeta}{2DF} Q|Q| = 0, \quad \left[m^3/\sec^2\right];$$
,

$$\frac{Q}{F}\frac{\partial H}{\partial x} + \frac{\partial H}{\partial t} + \frac{c^2}{gF}\frac{\partial Q}{\partial x} = 0, \qquad (4)$$
$$[m/\sec]$$

where g -acceleration of gravity; z - geometric height; t -time; ζ -the coefficient of hydraulic friction along the length; D - diameter of pipe; c -the speed of propagation of pressure waves. The numerical method is realized in the language $C++$, a graphical representation in the visual language of MAPLE.

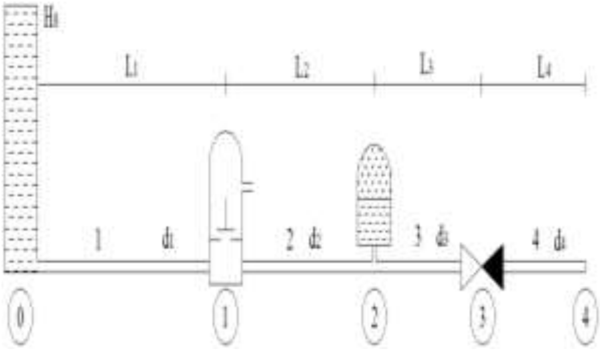

Figure 2: Scheme of the pipeline, including VDU and PS

The hydraulic schemes of the pipe are shown in Figure1 and Figure 2 (with pressure stabilizer).

Under stationary mode, the water due to the pres-sure difference moves with constant speed from node 0 to node 3. The latch installed in the node 2 (Figure 1) is opened and closed when after the motion has become steady-state. With the development of the water hammer the valve-discharge equipment, installed in node 1 opens and releases the water.

Under the above conditions to the pipeline scheme is added pressure stabilizer (Figure. 2) consisting of an air cap, working together with perforations uniformly distributed over the surface area of the pipe.

III. RESULTS & DISCUSSIONS

Data: $H_0=10m$; $H_3=0$; $l_1=10000m$; $l_2=10m$; $l_3=10m$; $c=1000m/s$; $d_1=d_2=d_3=1m$; hydraulic tubes resistance $\lambda=0.02$; $H_v=50m$; $h_v=5m$; $d_v=0.3$; $dx=10m$.

Pressure stabilizers of different volumes changes from $4m^3$ [notation PS (4/2)] to $60m^3$ [PS (60/30)].

Results 1

Series of calculations with given initial data and different time of full opening of the valve 0.5; 1; 2 seconds was made.

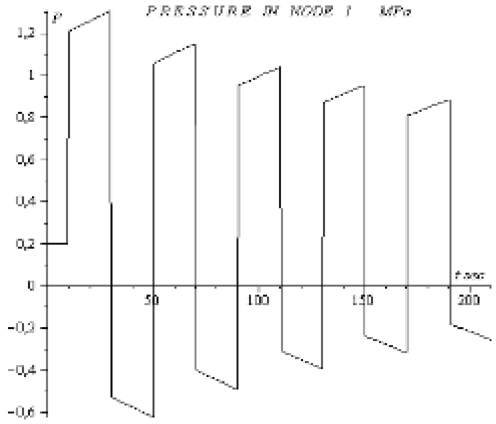

Figure 3: Pressure in node 1 without VDU

Figure 3 shows the pressure P in the hydraulic sys-tem without VDU in node 1. Max pressure is 1.1 MPa (110 m water column).

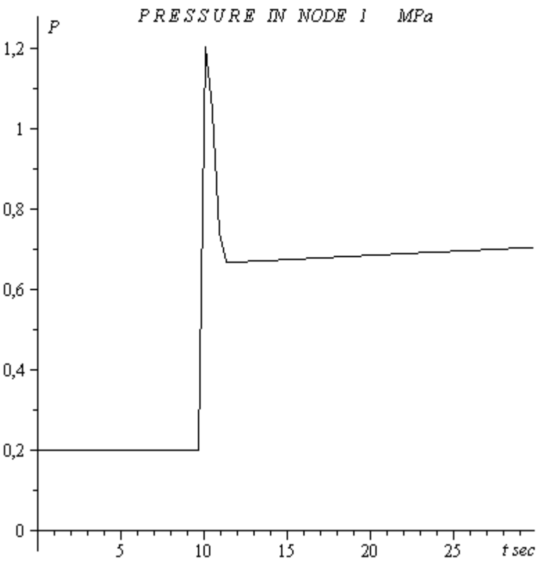

Figure 4: Pressure in node 1 with VDU

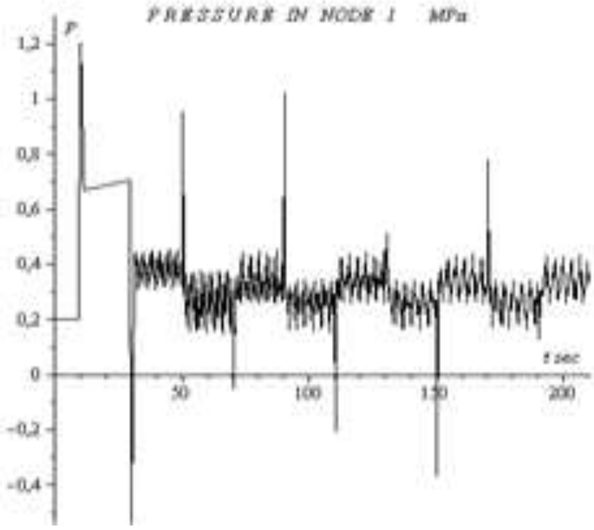

Figure 5: Pressure in node 1 with VDU

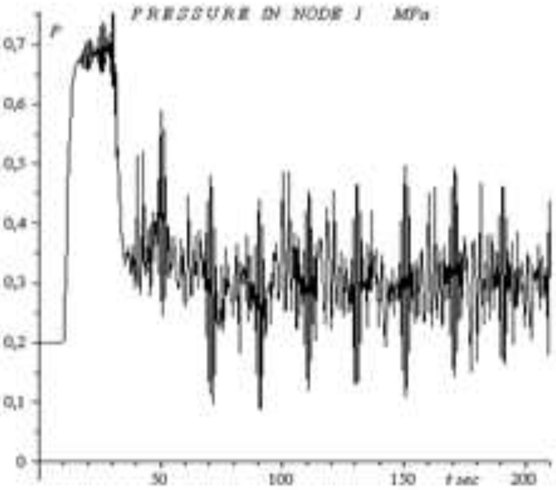

Figure 6: Scheme with VDU and PS (4/2)

Figure 4 shows pressure at and . Figure 5 shows pressure when and in a wide period of time.

Results 2.

Series of calculations are made when and . Transition to unsteady motion of the fluid is at the time moment when the latch instantly closes in node 2.

4. CONCLUSIONS

1) As numerical results showed, the valve-pull-down unit doesn`t totally stop the peak of overpressure even during the momentary opening of the valve – Figure 3, the height of the peak is 0.1 MPa. The peak width depends on : the more , the wider area of high pressure. There were some at-tempts to decrease the step dx to 0.5 m (with =0) but it didn`t let to a qualitative change of the picture: the peak of high pressure remained; with a substantial reduction in the step of graphical output, has expanded over several points.

2) If we change , the value of the peak of overpressure does not change (1 MPa), but pressure step the lower, the more is . When , ; if , then .

3) Under large calculation does not give good re-sults, as much liquid flows out of the tube forcedly and the numerical solution gets harmful oscillations. In this case, we need to specify other boundary con-ditions (e.g., pressure equal to zero at node 1 of in-stalling VDU.

4) A small peak of high pressure can be removed when pressure stabilizer of small capacity is included into the scheme (W=4m3), and a further increase in stabi-lizer does not change the pressure.

5) Numerical experiments have shown that to reduce the pressure to the level of 0.75 MPa is required pressure stabilizer of a large volume .

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