Virtual Laboratory Work in the Course of Hydromechanics «The Experimental Study of the Direct Water Hammer in Pressure Pipe»

PRINCIPLES OF INTERACTION WITH THE VIRTUAL MODEL OF THE LABORATORY EQUIPMENT

The simulation model of the laboratory equipment is an interactive geometric structure placed in a virtual three-dimensional space. Observation of objects is carried out using a virtual camera. In the basic (free) mode, the camera can rotate around the focus point (figure 1). The focus point of the camera can move in the vertical frontal plane. In addition, the camera can distance itself relative to the focus point for an arbitrary distance bounded by the dimensions of the work space of 3D scene.

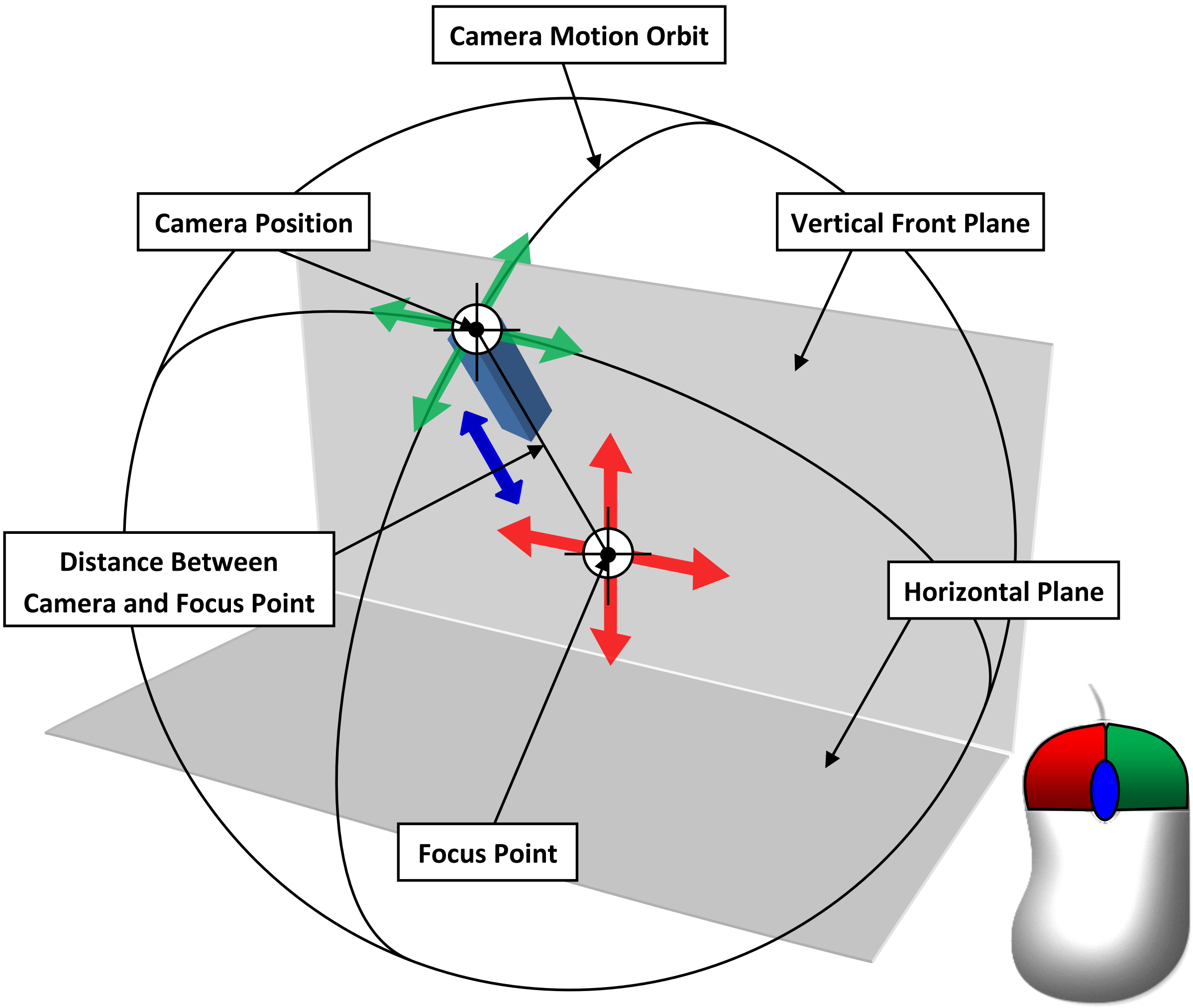


Figure 1 – Principle of the Camera Control in Free Mode

Basic manipulations with the camera in a free mode are carried out using a computer mouse. Herewith pressing and holding the left mouse button with the accompanying movement of the mouse moves the focus point of the camera in the frontal plane of work space. Clicking and holding the right mouse button while moving the mouse causes the camera to rotate relative to the focus point. The angles of rotation (azimuth and elevation) of the camera are limited by the dimensions of the 3D work space. The distance between camera and focus point is changing by rotating the mouse scroll wheel in the forward and reverse directions.

Note: in some virtlabs, the focus point may move in a horizontal plane!

In addition to the free mode, the camera can switch to individual elements of the laboratory equipment. Switching the camera to the individual object is performed by hovering the mouse over the object with a subsequent single click of the left mouse button. In this case, the camera can take a static position or be able to move in a vertical plane by hovering the mouse pointer to the edges of the screen or using the keyboard arrow keys. The clicking on an arbitrary area of the screen is return of the camera to basic mode.

The interaction with the control elements of the simulational laboratory equipment is carried out by hovering the mouse over the object and then pressing (or a single click) the left (or right) mouse button. Specific of the control for different elements may vary. For example, continuously regulating elements (flow control valves, etc.) require holding the left or right mouse button to change their state. Elements of discrete action (gates or latches) require a single click of the left mouse button.

At the moment of hovering the mouse pointer over the object, manipulations with the camera are temporarily unavailable. Similarly, when manipulating the camera, it is not possible to perform actions on the controls elements of the lab equipment.

VIRTUAL MODEL OF THE LABORATORY EQUIPMENT

A simulation model of a laboratory equipment (Figure 2) includes a pressure tank (1), the water supply to which is regulated by a valve (2), and the water level is maintained at a constant level during the experiment. A horizontal steel pipe (3) is connected to the tank. At the end of the pipeline there is a spring manometer (4), with which the pressure in the liquid is measured before and at the time of closing the shutter (5), which allows the pipeline to be closed almost instantly. The water flow is regulated by the valve (6). To measure water flow, a measuring tank (7) equipped with a water measuring tube with a scale and a stopwatch are used.

The main characteristics of the laboratory equipment are presented in the diagram (Fig. 3).

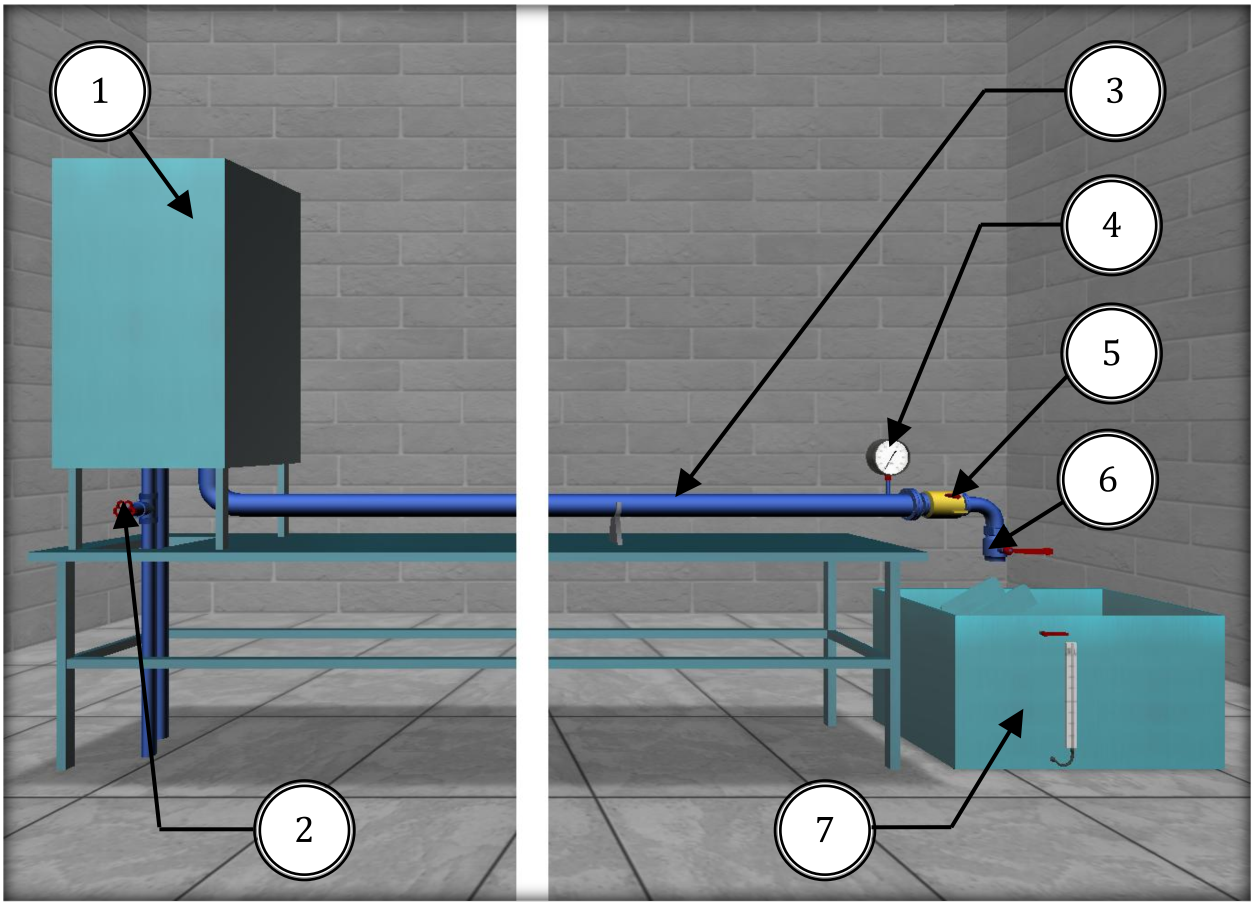
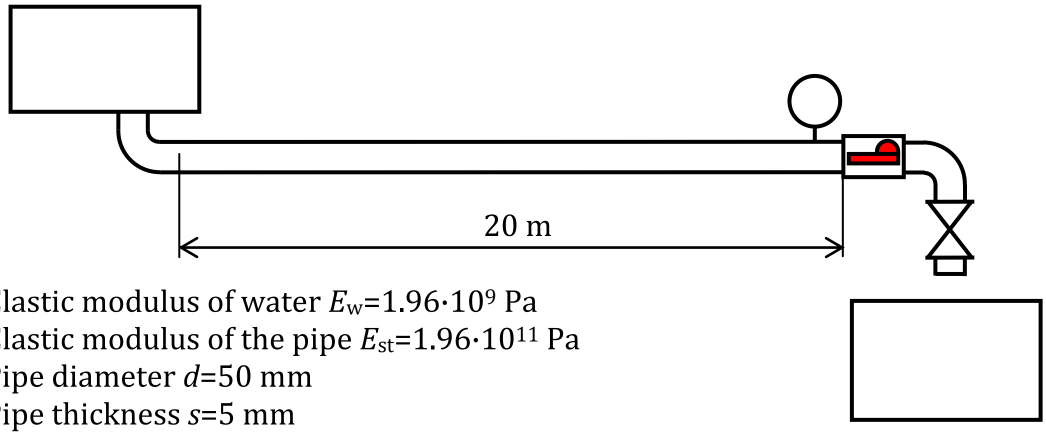


Figure 2 – Image of a Simulation Laboratory Equipment
for Experimental Study of the Direct Water Hammer in Pressure Pipe



Elastic modulus of water E_w=1.96·10^9 Pa
Elastic modulus of the pipe E_{st}=1.96·10^{11} Pa
Pipe diameter d=50 mm
Pipe thickness s=5 mm

Figure 3 – Main Features of a Simulation Laboratory Equipment

PHYSICAL PROCESS DESCRIPTION

Water hammer refers to a change (increase or decrease) in pressure in the head pipe during a sudden change in the fluid velocity (for example, as a result of a sudden closing or opening of the valve). The increase in pressure from a water hammer can be so large that it can cause the pipeline to break.

When the shutter closes quickly, not all of the fluid mass enclosed in the pipeline will stop at first, but only a part of it located immediately in front of the shutter. This is due to the inertia and elastic properties of the fluid and the material of the pipe (the stopped mass of the fluid is somewhat compressed, the pipe expands, and the pressure in the fluid increases suddenly). Then the pressure increase spreads very quickly through the pipeline from the valve to the tank. The propagation velocity of the increase in pressure is called the propagation velocity of the shock wave C. After the pressure in the entire pipeline rises, the fluid begins to leave the pressure zone back into the tank, and the pressure in the pipeline begins to decrease. Then, fluid from the tank will again enter the reduced pressure zone, and the pressure will rise again. Due to the elastic properties of the fluid and the walls of the pipeline, this process decays rather quickly. The most dangerous is the first increase in pressure.

The shock wave will pass through the entire pipeline (from the shutter to the tank) in a time $t=L/C$ (here L – the length of the pipeline). The time of one cycle, including increasing and decreasing pressure, is called the shock phase $T=2L/C$.

If the closing time t_{close} of the shutter is less than or equal to the phase of the hammer T ($t_{close} \leq T$), the water hammer is called direct.

Water Hammer may occur, for example, when the pump that delivers water through the pressure pipe to the tank suddenly shuts down. After the pump is turned off, the fluid will inertia move for some time, and a reduced pressure will appear in the pipeline. Then, the fluid will move back from the reservoir to the low pressure area in the pipeline, and the pressure will increase here, as was observed with a direct impact.

From the foregoing, it is clear that the parameters of fluid motion during hydraulic shock change over time. Therefore, with a hydraulic shock, the fluid motion is unsteady.

To determine the increase in pressure Δp during direct water hammer, the formula is used

$$\Delta p = \rho C \upsilon \ , \tag{1}$$

where ρ – the density of the fluid; C – the shock wave propagation velocity; υ – the average fluid velocity in the pipeline until the shutter closes (with steady motion).

The value of C is calculated by the formula

$$C = \frac{\sqrt{E_w/\rho}}{\sqrt{1+\left(E_w d / E_{st} s\right)}} \ , \tag{2}$$

where E_w and E_{st} – the elastic modules of the fluid and pipeline material, respectively; ρ – the fluid density; d – the inner diameter of the pipeline; s – the wall thickness of the pipeline.

The values of the elastic modulus of the fluid and its density determine the velocity of sound propagation in the fluid C_{snd}:

$$C_{snd} = \sqrt{E_w / \rho}\ , \tag{3}$$

Taking into account (3):

$$C = \frac{C_{snd}}{\sqrt{1 + \left(E_w d / E_{st} s \right)}}\ , \tag{4}$$

In water, the sound propagation velocity C_{snd}~1425 m/s.

LABORATORY WORK DESCRIPTION

Laboratory Work Objectives:

Determine experimentally the amount of pressure increase Δp_{exp} at a direct water hammer in the head pipeline, compare it with the value of the Δp, calculated by the formula (1), and calculate the relative deviation between them.

The Order of the Work and the Processing of Experimental Data:

1. Measure the pressure in the pipeline using a manometer before water hammer (with the control valve closed) and record the measurement results in table. 1.
2. Having opened (not fully) the control valve, ensure that a certain water flow passes through the pipeline.
3. Measure the water flow Q using a measuring tank and a stopwatch. In this case, the measured volume of water should be at least 50 liters.
4. Block the shutter and measure the maximum pressure upon water hammer using a manometer.
5. Record the data obtained during measurements in the table.
6. Make two more similar experiments with other water consumption.
7. Process the experimental data according to the paragraphs of the table. 1.
8. Give a conclusion of the results of the work.

Table 1 – Results of Measurements and Calculations

№	Measured and Calculated Values	Units	Experimental Results		
			Exp. 1	Exp. 2	Exp. 3
1	Pipeline inside diameter d	m			
2	Pipe wall thickness s	m			
3	Pipeline cross-section area $S=\pi d^2/4$	m^2			
4	Measuring tank volume W	m^3			
5	Tank filling time t	s			
6	Water flow $Q=W/t$	m^3/s			
7	Average water velocity in the pipeline (before water hammer) $\upsilon=Q/S$	m/s			
8	Shock wave velocity $C=\frac{1425}{\sqrt{1+\left(\frac{E_w d}{E_{st} s}\right)}}$	m/s			
9	Hammer pressure increase $\Delta p=\rho C\upsilon$	Pa			
10	Pipe pressure before water hammer (by manometer) p_1	Pa			
11	Maximum pressure in the pipeline during water hammer (by manometer) p_2	Pa			
12	Hammer pressure increase (experimental) $\Delta p_{exp}=p_2-p_1$	Pa			
13	Relative deviation $E_p=(\lvert\Delta p-p_{оп}\rvert\ /\ \Delta p)\cdot 100$	%			