

Virtual Laboratory Work in the Course of Hydromechanics
«Measurement of Hydrostatic Pressure, Experimental Confirmation
of the Basic Hydrostatic Equation and Pascal's Law»

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.

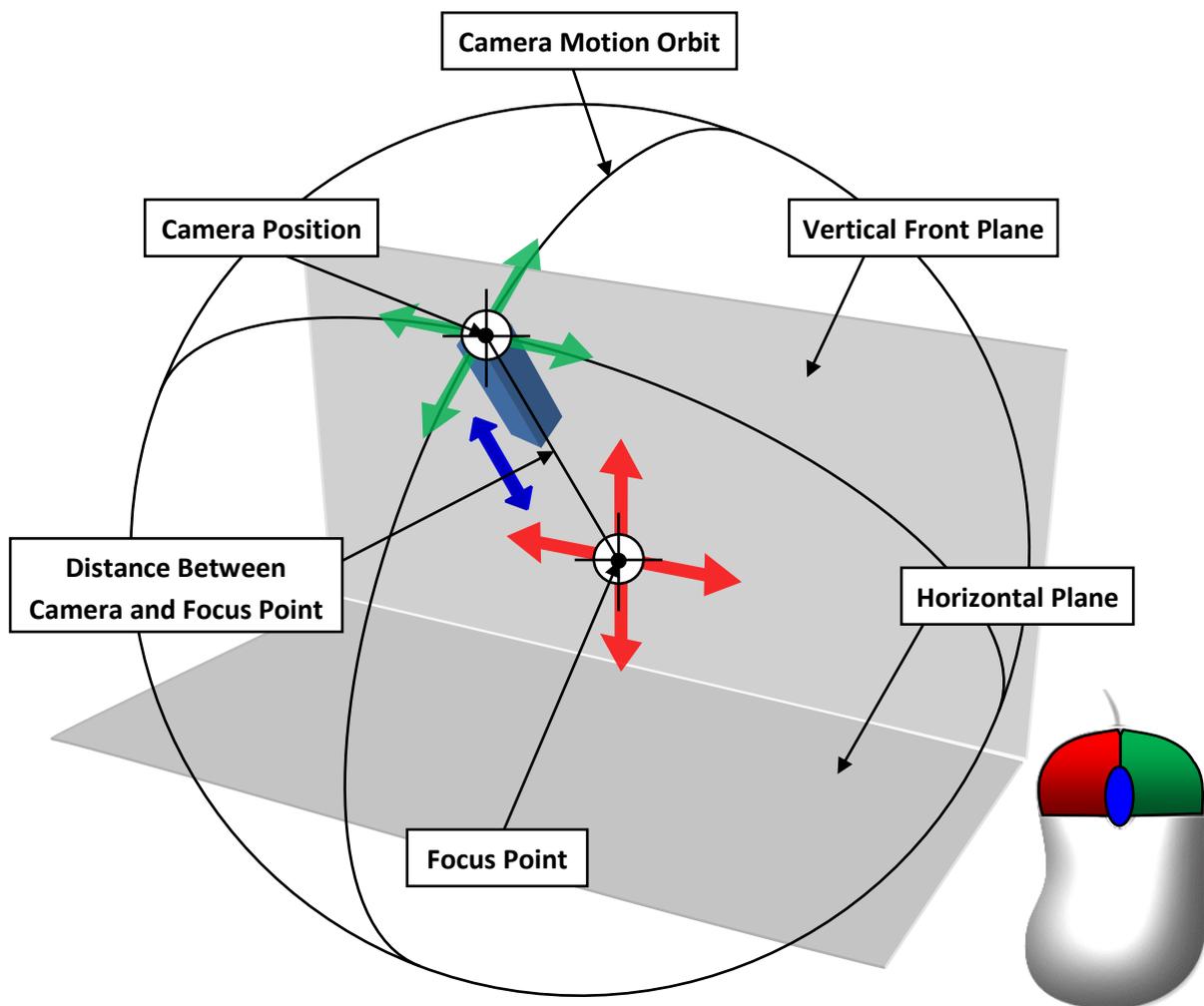


Figure 1 – Principle of the Camera Control in Free Mode

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 virlabs, 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

The laboratory equipment shown in figure 2 simulates a thick-walled steel cylinder (1) partially filled with water, the level of which is measured by a piezometric tube with a scale (2). The water supply to reservoir is carried out by opening the valve (3).

To measure the hydrostatic pressure above the free surface of the liquid at point 1 and at points 2 and 3, recessed by the values of depth of h_2 and h_3 , mechanical manometers are connected, respectively M_1 (4), M_2 (5) and M_3 (6).

Compressed air from the compressor (7) can be supplied to the space above the free surface through a pipeline (8) by opening the valve (9). Overpressure is discharged from the upper part of the tank by means of a valve (10).

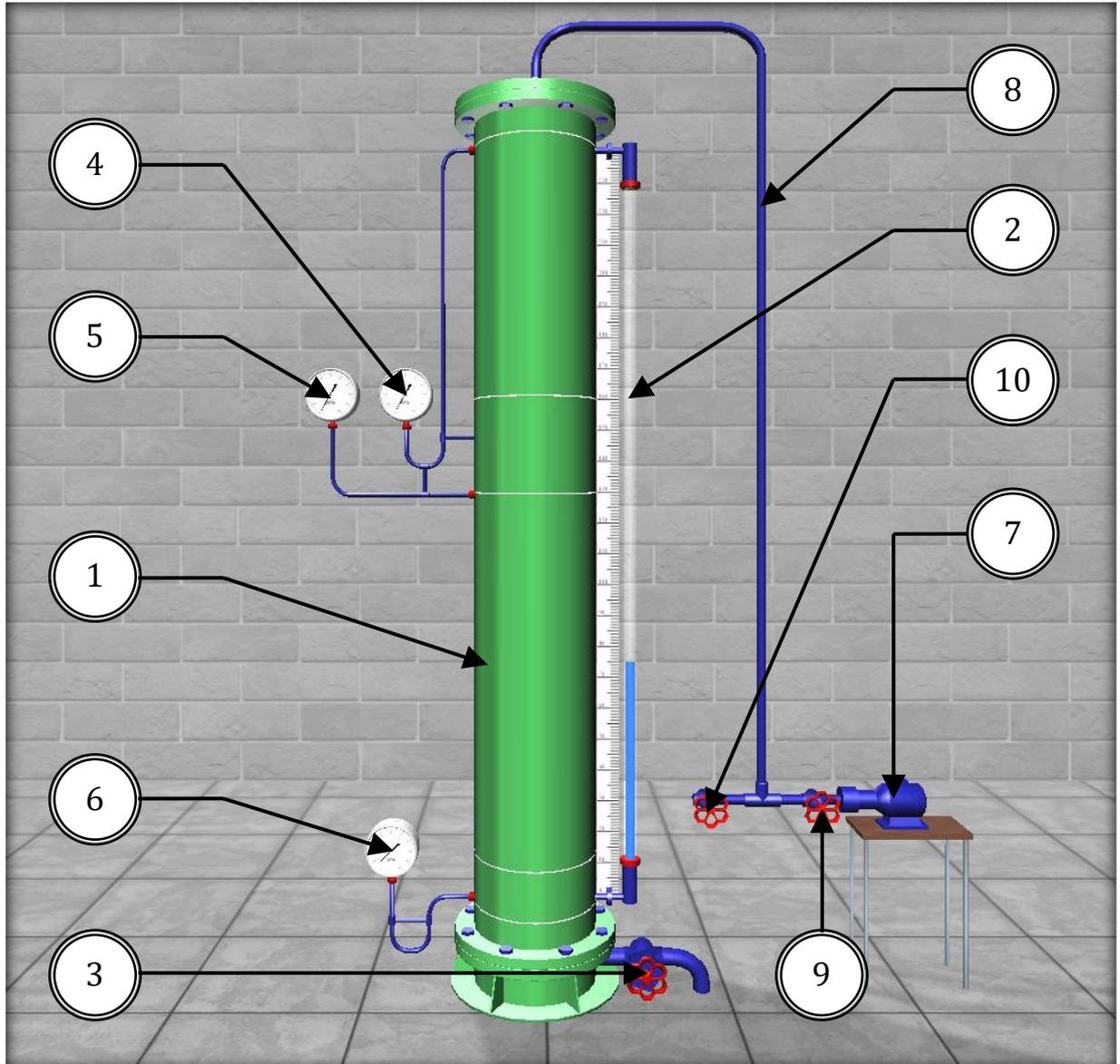


Figure 2 – Image of a Simulation Laboratory Equipment for Experimental Confirmation of the Basic Hydrostatic Equation and Pascal's Law

PHYSICAL PROCESS DESCRIPTION

Hydrostatic pressure p is the normal compressive stress that occurs in a stationary liquid under the action of surface and mass forces:

$$p = \lim_{\Delta S \rightarrow 0} \frac{\Delta F}{\Delta S}, \quad (1)$$

where ΔF – elementary resultant of surface and mass forces (hydrostatic force), N; ΔS – elementary area of action, m^2 .

From formula (1) it can be seen that the hydrostatic pressure p is the limit of the ratio of the elementary hydrostatic force ΔF to the elementary area ΔS , when the latter tends to zero.

The unit of measurement of hydrostatic pressure is taken to be uniformly distributed pressure of one Pascal (Pa), that is, created by a force of 1 N over an area of 1 m², or $p = 1 \text{ Pa} = 1 \text{ N} / \text{m}^2$.

Hydrostatic pressure, measured from absolute zero, is called absolute (p_{abs}), and measured from atmospheric (p_{atm}) – overpressure (p_{over}), therefore:

$$p_{\text{abs}} = p_{\text{atm}} + p_{\text{over}} , \quad (2)$$

It's obvious that:

$$p_{\text{over}} = p_{\text{abs}} - p_{\text{atm}} \quad (3)$$

In hydraulic calculations, the value of normal atmospheric pressure is considered equal $p_{\text{atm}} = 98100 \approx 10^5 \text{ Pa}$.

From the formula (3) it can be seen that, depending on the ratio between the p_{abs} and the p_{atm} , the overpressure p_{over} can be both positive and negative. Positive overpressure is called manometric pressure, and negative overpressure is called vacuumetric pressure. Devices used to measure $+p_{\text{over}}$ and $-p_{\text{over}}$ are called, respectively, manometers and vacuum gauges. According to the principle of operation, manometers and vacuum gauges are divided into two groups: liquid and mechanical.

The liquid manometer (piezometer) is a glass tube, the upper end of which is open to the atmosphere, and the lower end is connected to the point where the gauge pressure is measured.

Manometric pressure p_{over} , expressed in piezometer indications:

$$p_{\text{over}} = \rho g h_{p_{\text{over}}} , \quad (4)$$

where $\rho g = \gamma$ is the volumetric weight of the liquid; $h_{p_{\text{over}}}$ – piezometric height, i.e. height measured from the connection point of the piezometer to the level of the liquid in it.

The operation of mechanical devices is based on the deformation of the elastic element (spring or membrane) under the influence of pressure. Note that the spring manometer shows the pressure at the point of the liquid at the level of the axis of rotation of its arrow. If the height position of the axis of rotation of the arrow and the connection point of the manometer does not match, a correction ($\pm \rho g y_m$) is entered into the indications of the pressure gauge (p_m):

$$p_{\text{over}} = p_m \pm \rho g y_m , \quad (5)$$

where y_m is the excess of the axis of rotation of the arrow of the manometer above its connection point, m.

In this laboratory work, the measurement of the manometric pressure by spring manometers is provided.

When only gravity acts on a resting fluid, the distribution of hydrostatic pressure p over depth h is described by the basic hydrostatic equation:

$$p = p_0 + \rho g h , \quad (6)$$

where p is the hydrostatic pressure in a fluid at a depth h , Pa; p_0 – the external pressure, i.e. hydrostatic pressure on the free surface of the liquid, Pa; h – depth of the considered point, m; ρgh – the weight pressure, i.e. the hydrostatic pressure created by the weight of the liquid column with height h , Pa.

From equation (6) it can be seen that at $p_0 = const$ and $\rho g = const$, the pressure p changes linearly with a change in the value of h , which is to be confirmed by experiments. By calculating the pressure p at two points, deepened by different values of h , using equation (6), we can construct a diagram of the distribution of hydrostatic pressure over the depth, called the hydrostatic pressure epure.

It also follows from equation (6) that the external pressure p_0 in a fluid at rest is transmitted to all points of its volume without change. This consequence is called Pascal's law: «The external pressure applied to the surface of a fluid that is in equilibrium in a closed vessel is transmitted to all points of the fluid without change».

The validity of this law will be tested empirically in this work.

LABORATORY WORK DESCRIPTION

Laboratory Work Objectives:

1. Measure the hydrostatic pressure at three points (1, 2, 3), recessed by a different depth h under the level of the liquid, which is in absolute rest under the action of gravity.
2. Confirm the basic hydrostatic equation and Pascal's law on the basis of experimental data.
3. Plot the epure of manometric pressure on the cylinder wall at a depth h on the basis of experimental data.

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

It is necessary to perform two experiments, providing in the first $p_0=0$, and in the second $p_0>0$.

Experiment №1. Open the water supply valve, fill the tank to the level specified by the teacher, and measure with a piezometric tube immersion depth h_2 and h_3 of points 2 and 3, as well as exceeding the y_2 and y_3 of rotation axes of the arrows of manometers M_2 and M_3 above their connection points. Then measure the indications of all manometers (M_1 , M_2 and M_3). Record the results of measurement into table 1.

Experiment №2. Close the overpressure relief valve and open the compressed air supply valve and turn on the compressor. Bring p_0 to the value specified by the teacher, then turn off the compressor. Measure the indications of the M_1 , M_2 and M_3 manometers. Record the results of measurement into table 1.

Perform all calculations in table 1. Give a conclusion of the results of the work. Plot the epure of manometric pressure on the cylinder wall at a depth h according to the data of experiments №1 and №2.

Table 1 – Results of Measurements and Calculations

Nº	Measured and Calculated Values	Units	Exp. Results		Notes	
			Exp. 1	Exp. 2		
1	Manometers Indications M_1, M_2, M_3	$p_{M_1} \approx p_0$	Pa			$h_1 = \text{___ m}$ $h_2 = \text{___ m}$ $h_3 = \text{___ m}$ $y_{m2} = \text{___ m}$ $y_{m3} = \text{___ m}$ $\rho = 1000 \text{ kg/m}^3$ $g = 9,81 \text{ m/s}^2$
		p_{M_2}	Pa			
		p_{M_3}	Pa			
2	Hydrostatic Overpressure at Points 1, 2, 3	$p_1 \approx p_{M_1} \approx p_0$	Pa			
		$p_2 = p_{M_2} + \rho g y_{m2}$	Pa			
		$p_3 = p_{M_3} + \rho g y_{m3}$	Pa			
3	Hydrostatic Overpressure Increment	$\Delta p_1 \approx \Delta p_0 = p_{0_2} - p_{0_1}$	Pa			
		$\Delta p_2 = p_{2_2} - p_{2_1}$	Pa			
		$\Delta p_3 = p_{3_2} - p_{3_1}$	Pa			
4	Average Hydrostatic Overpressure Increment	$\Delta p_{av} = \frac{\Delta p_0 + \Delta p_2 + \Delta p_3}{3}$	Pa			
5	Relative Differences in Pressure Increments at Points 1, 2, 3 with an Average Value	$E_{\Delta p_0} = \frac{(\Delta p_{av} - \Delta p_0)}{\Delta p_{av}} \cdot 100$	%			
		$E_{\Delta p_2} = \frac{(\Delta p_{av} - \Delta p_2)}{\Delta p_{av}} \cdot 100$	%			
		$E_{\Delta p_3} = \frac{(\Delta p_{av} - \Delta p_3)}{\Delta p_{av}} \cdot 100$	%			