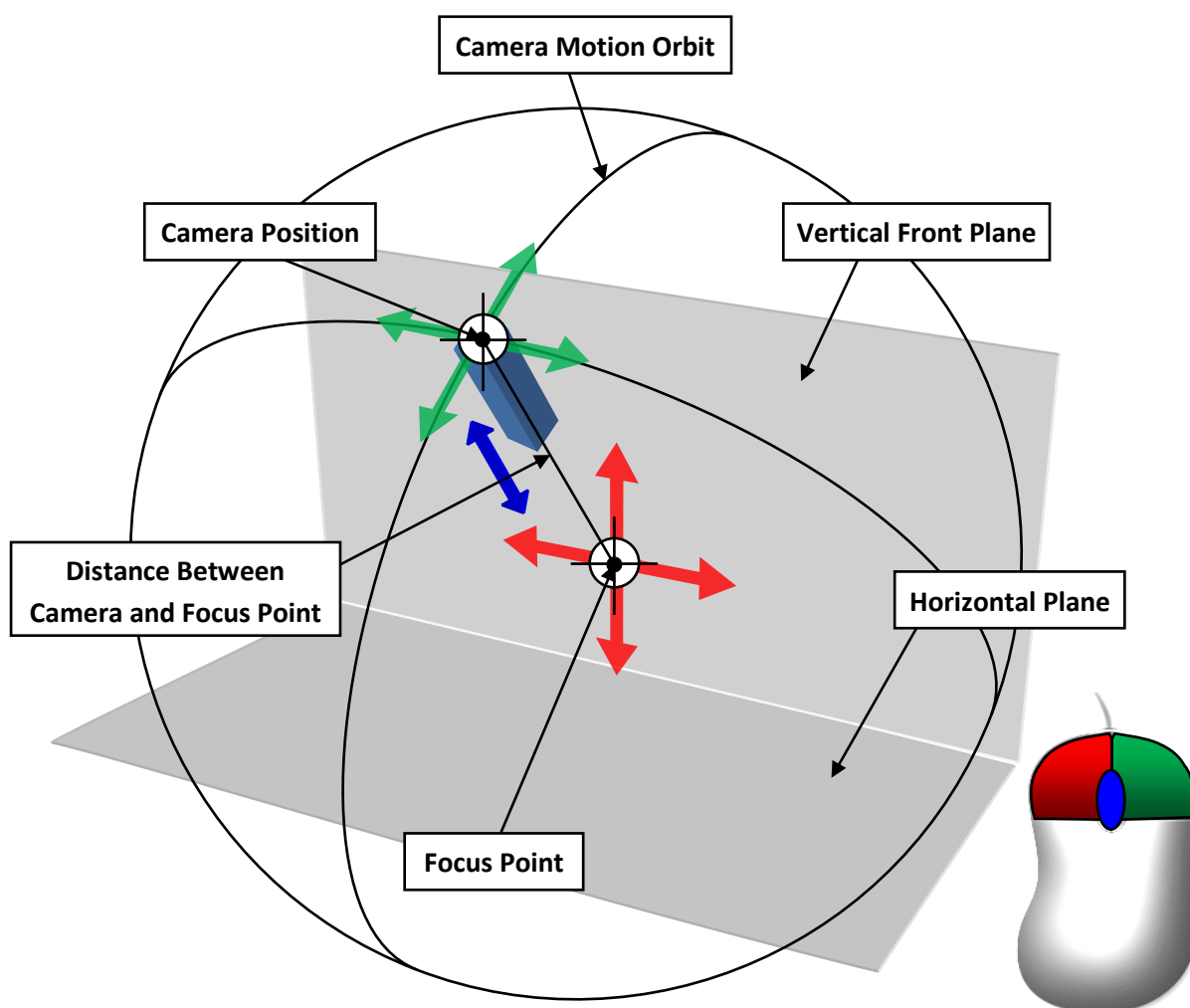


**Virtual Laboratory Work in the Course of Hydromechanics**  
**«The Study of the Relative Rest of the Fluid During Rotational Motion»**

**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!**

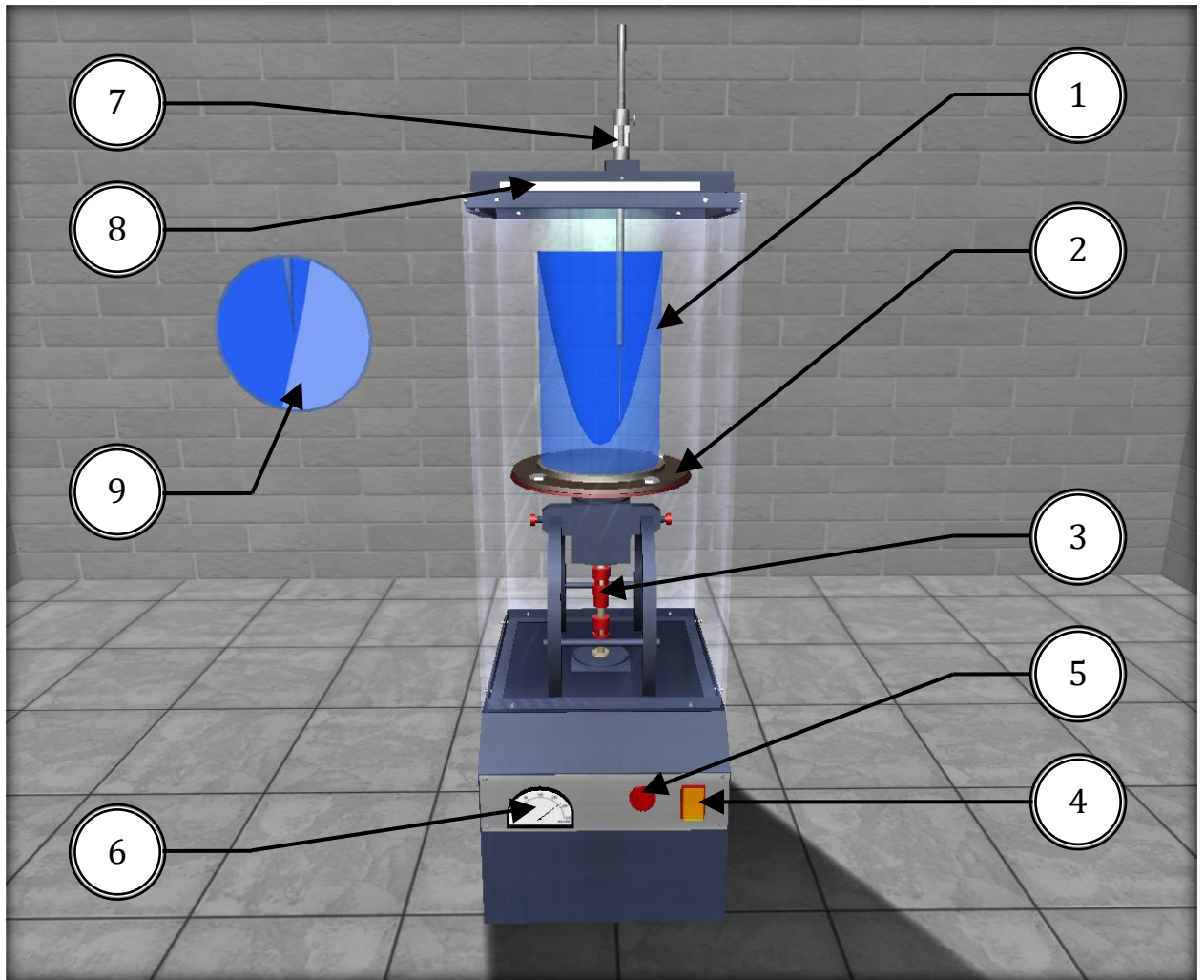
In addition to the free mode, the camera can switch to individual elements of the laboratory equipment. Switching the camera to the individual object is performed by hovering the mouse over the object with a subsequent single click of the left mouse button. In this case, the camera can take a static 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 an open vertical cylindrical vessel with water (1), mounted on a rotating platform (2). The platform is connected via a shaft (3) to an electric motor in the lower part of the stand. The electric motor is switched on using the toggle switch (4). The rotation velocity of the platform is changed using the regulator (5). Current shaft revolutions are monitored using a tachometer (6). To determine the coordinates  $x$  and  $z$  of the points of the free surface of the rotating fluid, the stand is equipped with a horizontal ruler (8) and a vertical measuring needle (7), which is a level gauge that allows you to accurately fix the height position of the points of the free surface. The touch of the needle and the free surface of the liquid is monitored using the enlarged area on the screen (9).



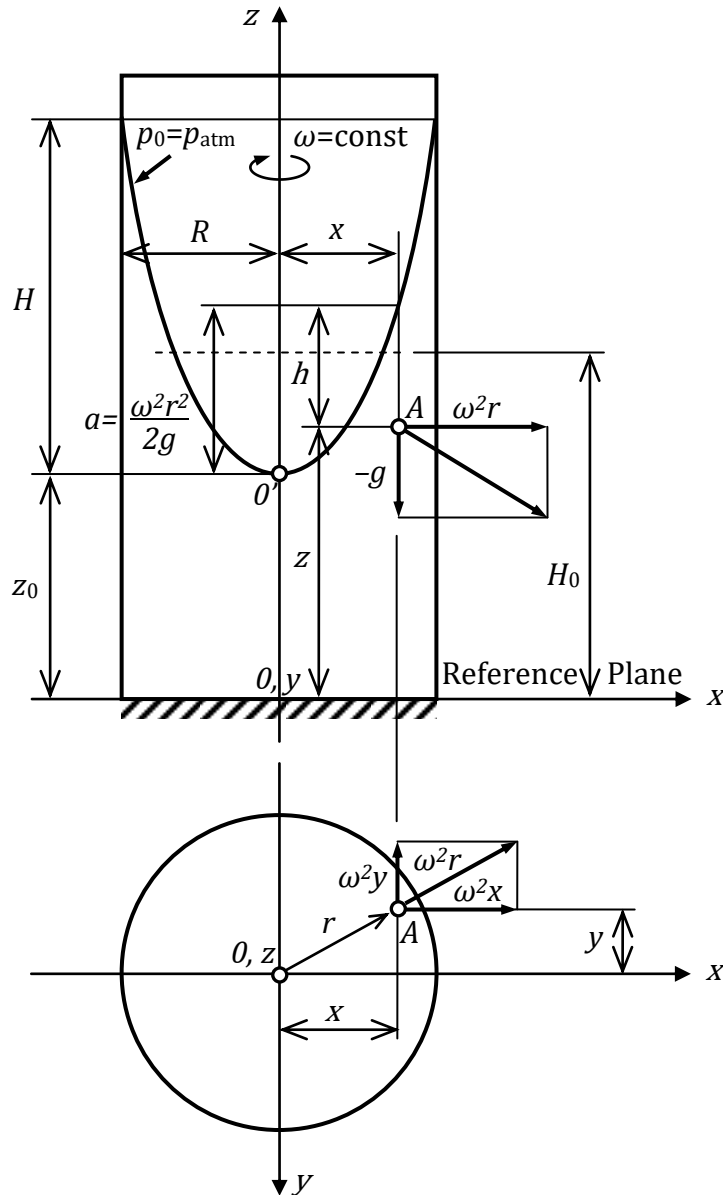
**Figure 2** – Image of a Simulation Laboratory Equipment for Experimental Study of the Relative Rest of the Fluid During Rotational Motion

### PHYSICAL PROCESS DESCRIPTION

In this lab work, we consider the case when a fluid in an open cylindrical vessel rotates with a constant angular velocity  $\omega$  about vertical axis. The walls of a rotating cylinder, due to the frictional forces, first cause the closest fluid layers to rotate, and then, due to the viscosity of the fluid, its entire mass. Thus, after some time, all the particles of the liquid begin to rotate at the same angular velocity  $\omega$  as the walls, i.e., the entire mass of the liquid relative to the rotating cylinder will be motionless (it will be in relative rest).

In this case, two mass forces act on each fluid particle: gravity, which creates acceleration  $g=9,81 \text{ m/s}^2$ , and centrifugal force, which creates acceleration  $\omega^2 r$ . Here  $r$  – the radius of rotation of the fluid particle;  $\omega = \pi n / 30$  – angular velocity of rotation of the vessel,  $\text{s}^{-1}$ , where  $n$  – frequency of rotation of the vessel, rpm.

Due to the action of centrifugal forces, the free surface of the rotating fluid in a cylindrical vessel takes the form of a rotation paraboloid. The curve formed from the intersection of this paraboloid with a vertical plane is a quadratic parabola (Figure 3).



**Figure 3** – Scheme of the Relative Rest of Liquid in a Rotating Cylindrical Vessel

For the case of relative rest considered in the work, the distribution law of the hydrostatic pressure  $p$  in the liquid (the basic hydrostatic equation) has the form

$$p = p_0 + \rho g(z_0 - z) + \frac{\rho g(\omega r)^2}{2g} \quad (1)$$

where  $p_0$  – the external pressure (in our case  $p_0 = p_{\text{atm}}$ ;  $z_0$  and  $z$  – the excesses, respectively, of the vertex of the rotation paraboloid (point  $O'$ ) and an arbitrary point  $A$  of the rotating fluid over the reference plane  $xOy$ .

Dividing equation (1) by  $\rho g$  and moving  $p_0$  to the left side, we obtain an expression for determining the depth  $h$  of the considered point of the rotating fluid under the free surface:

$$\frac{p - p_0}{\rho g} = (z_0 - z) + \frac{(\omega r)^2}{2g} = h \quad (2)$$

where  $\frac{(\omega r)^2}{2g} = a$  – the excess of the point of the free surface located at a distance  $r$  from the axis of rotation over the vertex  $O'$  of the paraboloid.

Taking into account the expressions for  $h$  and  $a$ , the law of distribution of hydrostatic pressure in a rotating fluid (1) takes the same form as for the case of absolute rest:

$$p = p_0 + \rho g(z_0 + a - z) = p_0 + \rho g h \quad (3)$$

The equation of the free surface of a rotating fluid, obtained from equation (2), for  $p = p_0 = p_{\text{atm}}$  has the form

$$z = z_0 + \frac{(\omega r)^2}{2g} \quad (4)$$

For  $r = R$  (here  $R$  – the internal radius of the cylinder) from equation (4) we obtain the expression for determining the height  $H$  of the rotation paraboloid:

$$H = \frac{(\omega R)^2}{2g} \quad (5)$$

Dependence (4) underlies the operation of liquid tachometers - devices for measuring the number of revolutions of the shaft of various machines. And the phenomenon of fluid relative rest is used, for example, in centrifugal pipe molding.

## LABORATORY WORK DESCRIPTION

### Laboratory Work Objectives:

1. Observe the process of establishing fluid relative rest in an open cylinder rotating with a constant angular velocity  $\omega$  about a vertical axis, paying particular attention to the nature of the free surface; measure the  $x$  and  $z$  coordinates of its five points located from the axis of rotation at distances  $x$  equal to  $1,00R$ ;  $0,75R$ ;  $0,50R$ ;  $0,25R$  и  $0,00R$ .
2. Measure the rotation paraboloid height  $H_{\text{exp}}$ , compare it with the theoretical  $H$ , calculated by formula (5) and determine the relative deviation.
3. Construct from experimental data on a scale a rotation paraboloid and two diagrams of manometric pressure (along the liquid depth, at a distance  $R$  from the axis of rotation and along the bottom of the cylinder).

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

1. Measure the  $z$  coordinate of the bottom of the cylinder with a measuring needle.
2. Turn on the electric motor, observe the rotating fluid and, making sure that the rotation paraboloid has taken a stable position, measure the number of revolutions per minute  $n$  of rotation of the cylinder with a tachometer, and (using the horizontal ruler and a measuring needle) the  $x$  and  $z$  coordinates of the five points of the free surface of the rotating fluid.

3. Record the measurement results in table 1, and then turn off the motor.
4. Perform all the calculations provided by table 1.
5. According to the table, construct a scale rotation paraboloid and manometric pressure diagrams along the bottom of the cylinder and along the height of its wall, that is, at a distance  $R$  from the axis of rotation.
6. Give a conclusion of the results of the work.

**Table 1** – Results of Measurements and Calculations

№	Measured and Calculated Values	Units	Experimental Results
1	Inner radius of the cylinder $R$	m	
2	Cylinder rotation velocity $n$	rev./min	
3	Cylinder rotation angular velocity $\omega = \pi n / 30$	1/s	
4	The x and z coordinates of the points on the free surface of a rotating fluid	$x_1=1,00R; z_1=...$	m
		$x_2=0,75R; z_2=...$	m
		$x_3=0,50R; z_3=...$	m
		$x_4=0,25R; z_4=...$	m
		$x_5=0,00R; z_5=...$	m
5	Coordinate $z_6$ of the bottom of the cylinder	m	
6	Excess of the rotation paraboloid vertex above the bottom of the cylinder $z_0 = z_6 - z_5$	m	
7	Rotation paraboloid height (experimental) $H_{\text{exp}} = z_5 - z_1$	m	
8	Rotation paraboloid height (theoretical) $H = (\omega R)^2 / 2g$	m	
9	The relative deviation of the rotation paraboloid height $E_H = \frac{ H - H_{\text{exp}} }{H} \cdot 100$	%	