PHY/ENS 119 EXPERIMENT NO. 4: THE UNIFORMLY ROTATING LIQUID; A STUDY OF CIRCULAR MOTION

Introduction

In this laboratory exercise, we will study the dynamics of a uniformly rotating liquid, and in particular, determine the shape of the surface of the liquid, and how it depends on such factors as the rate of rotation and the acceleration due to gravity g.

As shown in Fig. 1, the apparatus consists of a cylindrical bowl of glycerin mounted on a turntable, whose rate of rotation is controlled by a variable power supply.

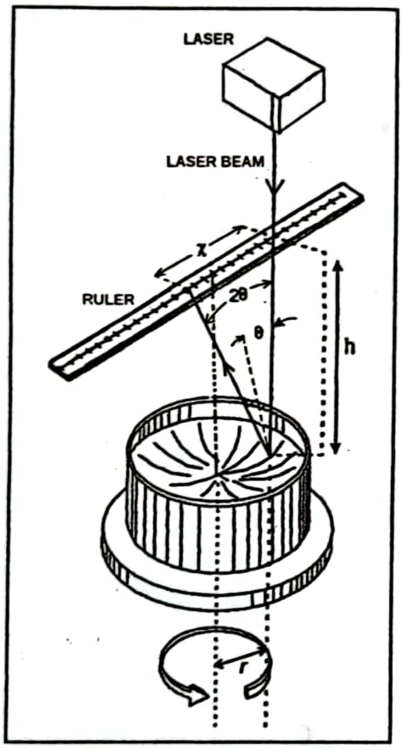

Figure 1. Overall Schematic Diagram of Apparatus

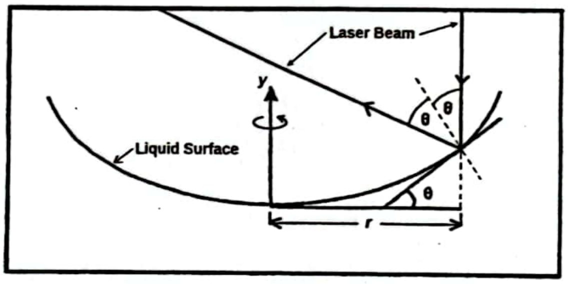

Figure 2. Cross-section of the Profile of the Rotating Liquid

In lecture, it was shown that the theoretical profile of a rotating liquid is given by

$$y = \omega^2 r^2 / (2g), \tag{1}$$

where y is the height of the liquid surface relative to its height at the center of rotation, ω is the angular velocity, r is the distance from the center of rotation and g is the acceleration due to gravity at the Earth's surface. The angular velocity ω has units of radians/second, and is related to the period of revolution T by $\omega = 2\pi/T$.

Procedure

1. With the turntable at rest, turn on the laser and adjust the beam and the ruler so that the beam passes through the ruler at the 15 cm mark, and that the beam reflects back from the motionless liquid and passes through the same point, assuring that the beam is vertical. Carefully move the turntable so that the vertical beam strikes the mark at the center of the glass container. Slightly loosen the clamp holding the laser to the bench and slide the laser back and forth, adjusting the ruler as needed to make sure the laser beam passes through the ruler at the same distance from the edge of the ruler at all points. When this is done, re-position the laser beam at the 15 cm mark and move the turntable (if necessary) so that the laser beam again hits the center of the glass container. **Measure the height *h* from the ruler to the surface of the liquid, and be sure that the ruler is horizontal.** (see Fig. 1)

2. Now turn on the green power supply and adjust the voltage control knob on the left until the turntable rotates at about 1 revolution per second. The current control knob on the right should be set at maximum, fully clockwise. If the laser beam passing through the 15 cm mark on the ruler is accurately spotted on the center of rotation, the reflected beam should return to exactly the same point on the ruler. If it does not, and you see the reflected spot wandering around, it means the turntable is not level. Ask your instructor for help in leveling the turntable.

3. Press the "Reset" button on the timer to measure the period T of rotation. Do this several times. You should get the same value each time, to within three significant figures. T should be about 1 second. Check to make sure your value is correct by using the "Snap-Time Pro" program on the computer to measure the time for 10 revolutions, as you did in the pendulum experiment. Now adjust the power supply until $T = 1.0$ sec. **Record your value of *T* to 3 significant figures, and keep it constant for steps 3-7 below.**

4. Now move the laser so that the incident beam crosses through the ruler at the 16 cm mark. You have now moved the incident beam so that it hits the liquid a distance r = 1.0 cm from the center of rotation, as shown in Fig. 1. **Record this value of r.**

5. Notice that the reflected laser beam also moves away from the center of rotation. Again referring to Fig. 1, we see that the reflected beam strikes the ruler a distance x from the point at which the incident beam strikes the ruler. **Record this value of x.** Repeat the measurement of x with the incident laser beam at the 14 cm mark, and **also record this value of x, which ideally should be the same in magnitude as the previous x.** If it is not, you will later take the average of the two x values.

6. Your values of x and h will be used to determine θ, the slope angle of the liquid a distance r from the center of rotation. From Fig. 1, we see that $\tan(2\theta) = x/h$. The reason the angle is 2θ can be seen from Figure 2. The slope angle θ of the rotating liquid can then be determined from

$$\theta = (\tfrac{1}{2})\tan^{-1}(x/h). \qquad (2)$$

7. **Repeat steps (3) through (5) for r = 2.0 cm, 3.0 cm, etc., until you reach the edge of the glass container. In every case, take r on both sides of center, and record the corresponding values of x.**

8. Repeat steps (3) through (7) for T = 1.5 sec and T = 2.0 sec.

9. For this part, set the laser so that the incident beam passes through the 10 cm mark (i.e., r = 5.0 cm), and slowly and carefully adjust the speed of the turntable until the reflected beam passes through the 15 cm mark. Then scan the laser back and forth across the rotating liquid. **What happens, and why does it happen?**

Analysis

For each fixed value of T, determine the slope angle θ as a function of r, using Eq. (2) in step (6) above. If the two values of x corresponding to values of r taken equal distances to the left and right of center do not match, take the average of the two values of x to calculate θ.

For each value of T, plot $\tan\theta$ (vertical axis) as a function of r (horizontal axis). According to theory,

$$\tan\theta = dy/dr = (\omega^2/g)\, r, \qquad (3)$$

so your plots of $\tan\theta$ vs r should give you straight lines with slope ω^2/g. Recall that $\omega = 2\pi/T$, so each plot will have a different slope. Note also that $\tan\theta$ is the slope of the rotating liquid, and so is equal to dy/dr, the derivative of the curve of the rotating liquid surface.

Discuss whether or not your data confirm the theory, and if they do, what can you say about the shape of the rotating liquid surface, i.e., what is y as a function of r?