1 Pohl's Pendulum

where	Building 49, Rm 309
when	Oct-14, 9:00-11:30 am

1.1 Objective

- Understand the concept: forced oscillation and damped oscillation.
- Understand the concept: characteristic frequency and resonance.
- Learn how to achieve/reduce resonance.
- Measure the resonance and represent your data as tables and graphs.
- Explain the physical content of Resonance.

1.2 Theory and background

Oscillation, as a form of motion, can be commonly observed in many situations every day. After we learned the fundamental of physics, we know there are several quantities to quantify different oscillations. They are amplitude, period or angular frequency and phase as shown in Equation 1.

$$x(t) = A\cos(\omega t + \phi) \tag{1}$$

A is the amplitude of the oscillation and it tells people how significant the oscillation is. ω is the angular frequency which can be obtained from the period. It tells how frequent the oscillation is. ϕ is the phase; it tells where the oscillation starts, from the equilibrium point or somewhere else.

Almost every oscillator has its own "characteristic frequency", a frequency depends on the oscillator itself. This applies to all oscillators such as the spring-mass systems, the Pohl's pendulums, swings and etc.

For better illustration, let's consider the period of a swing.

Figure 1: A swing picture from Wikipedia (left) and the giant bell stick (right)for the Fahua Bell (25 ton, 4.5m high), located in Fagu Temple, Taiwan, China.

If you push a swing once and let it oscillate, you will find a period of the swing. Pushing the swing harder doesn't reduce the oscillation period. If you time the swing while it oscillates, the period for each oscillation seems to be the same. The period (the natural interval) is regarded to the "characteristic frequency". When the swing is built up, the characteristic frequency is fixed until some structure changes are made.

As the swing oscillates, the amplitude decrease due to the energy loss by the fraction and the oscillation is in fact a damped oscillation. The amplitude of such oscillation decreases exponentially.

Can we change the oscillation? Yes, of course. You can push the swing any time in your pattern, the period you defined. If you push the swing in the period you defined continuously, the period of the swing will be the period you defined. And the oscillation is a Forced Oscillation.

We all know how to push the swing to go higher and higher in time with the natural interval. Thinking of swing a heavy bell stick as shown in Figure 1. If people follow the characteristic frequency, their efforts add up and make the stick move to hit the bell. In this case, the frequency of the force matches the characteristic frequency. Thus the resonance happens.

What happens when the two doesn't match in a forced oscillation? The force sometimes needs to go against the swing. In this case, the force stops swing first and then accelerate it in the opposite direction. Therefore, the energy is wasted in changing the motion direction of the swing.

So keeping the driving force the same frequency as the characteristic frequency is helpful in accumulating the energy and yields a large amplitude.

In general, the frequency of the driving force changes the amplitude of the oscillation. The maximum amplitude appears only when the driving frequency matches the characteristic frequency.

If the driving force has a smaller frequency than the characteristic frequency, the force has to change the direction of motion of the oscillator before it changes by itself. Such difference of the change timing is the phase difference. See Figure 2 for details.

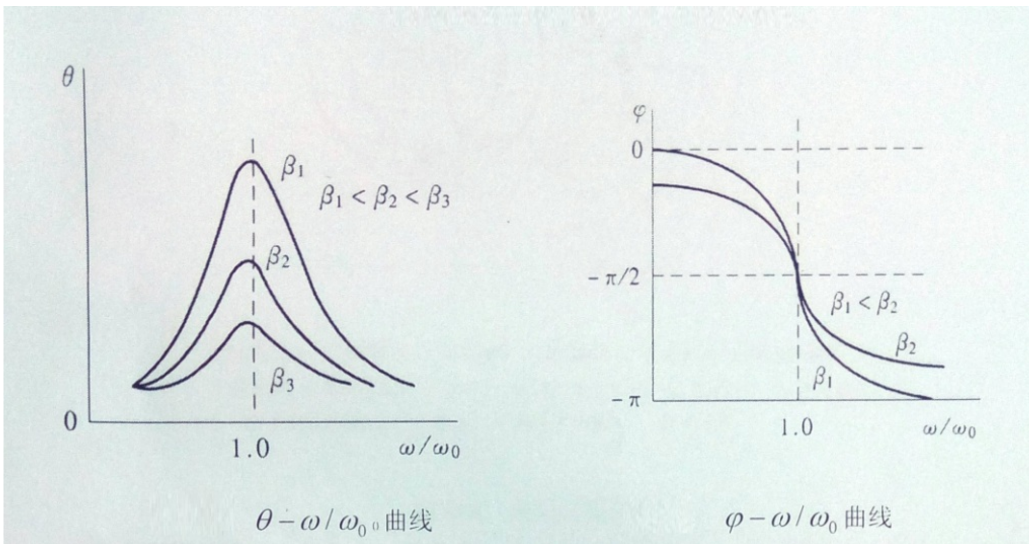

Figure 2: Driving frequency-amplitude curve (left) and driving frequency-phase difference curve(right).

1.3 Experiment Design

In this experiment, we use Pohl's Pendulum for our measurement. The Pohl's Pendulum is also called Pohl's wheel. It can be used to study the resonance, phase shift and even chaos (a modern physical concept). The equipment in our lab are digital equipment with built-in meters and power sources. The equipment is shown in Figure 3. The larger wheel is the pendulum which is attached to the base via a spiral torsion spring. The smaller wheel is a phase meter disc which is attached to the motor.

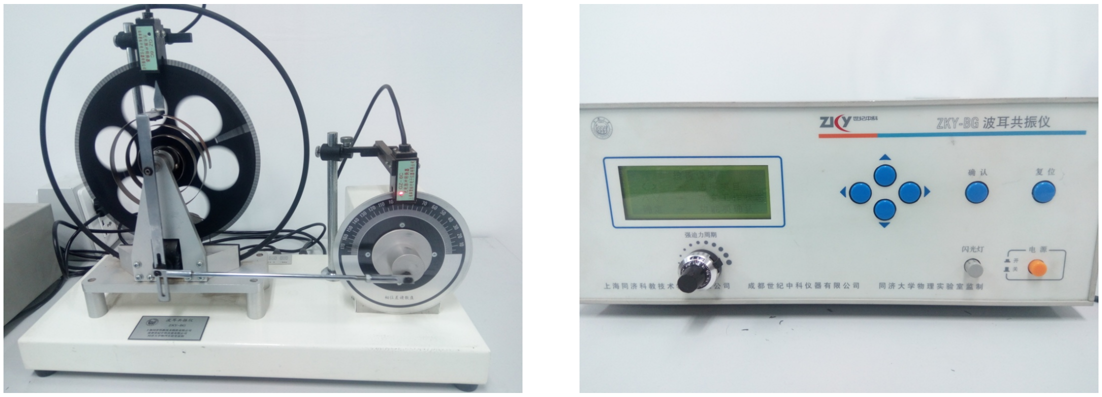

Figure 3: Pohl's wheel (left) and meter (right).

The panel of the meter is shown in Figure 4. The switches are on the panel are used for the control of the pendulum and the power source. Use the direction buttons to highlight different selections and use "OK" button to choose. The 3 operation modes are: "Free Oscillation", "Damped Oscillation" and "Forced Oscillation". Our experiment will be done using the 3 modes.

Figure 4: The panel of the meter (left) and the 3 operation modes (right).

Free Oscillation

First, we perform a measurement for the "Free Oscillation". Please Focus on the period value and take them as your record. In this mode, the driving force and the magnetic break are turned off. So the only friction is from the wheel and the spring. Therefore, we can find the amplitude slowly decrease from the screen. We can use the direction button to highlight the "measurement" and use "up" button to turn on the recorder. As long as the recorder is turned on, the meter measures and saves the measurement of the period for each cycle. Here we can make multiple measurements.

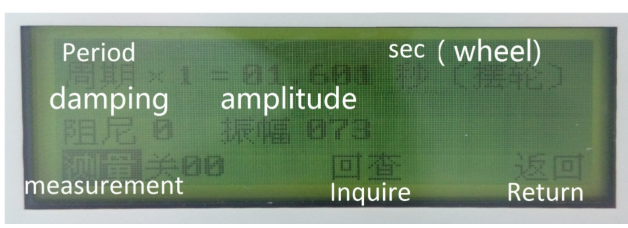

Figure 5: Snapshot for the measurement of the "Free Oscillation" mode.

Damped Oscillation

Second, we turn on the magnetic break to study the "Damped Oscillation". To turn the damping on, return to the mode selection and choose "Damped Oscillation". Here we measure the period and the amplitude. Note that the period does not change much, but the amplitude decrease significantly. In this mode, we need to measure several consecutive cycles for amplitude. The recorder is automatically turned on. So we can retrieve the result when we see there are enough measurement values are collected.

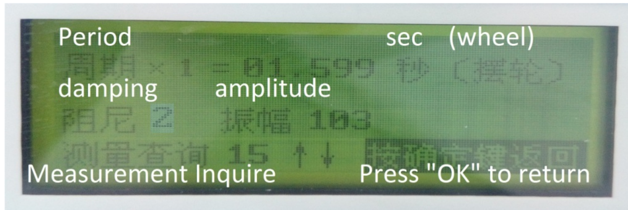

Figure 6: Snapshot for the measurement of the “Damped Oscillation” mode.

Forced Oscillation

The last measurement is for the “Forced Oscillation”. Go to the mode selection and choose “Forced Oscillation”. When the driving force is turned on, the wheel will be driven and the period may change until the periods of the wheel and the motor are the same. If they are different, please wait until they matches each other. In this part, we use different period of the motor and find the corresponding amplitude and phase different of the wheel. Each amplitude value will be a single time collection from the screen. The phase different can be collected using the flash light. To do that, hold the “flash light” button on the meter and face the light to the meter wheel (the smaller wheel in front of the motor). When the oscillation starts, the light flashes when the wheel turns its rotating direction. At the moment, a bright pointer will be lit. And please collect the number for that particular moment. Try multiple times if you are not sure. Or only record the ones you are confident with.

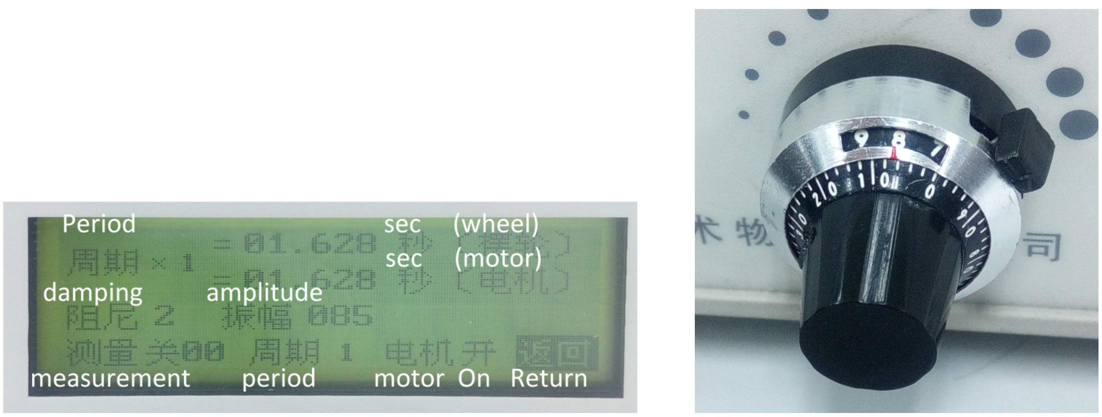

Figure 7: Snapshot for the measurement of the “Forced Oscillation” mode (left) and the adjusting knob (right).

summary

The amplitude and the phase difference for the Pohl’s wheel can be described as the following equations:

$$\theta = \frac{m}{\sqrt{\left(\omega_0^2 - \omega^2\right)^2 + 4\beta^2\omega^2}} \tag{2}$$

$$\phi = \tan^{-1}\frac{2\beta\omega}{\omega_0^2 - \omega^2} \tag{3}$$

1.4 Experiment

1. Warm up the meter by plug the power cable to the outlet and Turn it on after 5 minutes.
2. Press “OK” button until you see the mode selection screen (Figure 4).
3. Select the “Free Oscillation mode” and you can see the screen as shown in Figure 5. Then highlight the “measurement” and press “up” button to turn on the recorder.
4. Turn the wheel counterclockwise by about 150 degree and release. The wheel then starts oscillating and the recorder starts collecting data.
5. Highlight the “Inquire” and press “OK” button after you collect 28 values. Fill Table 1 by looking up the values in the recorder.
6. Select the “Damped Oscillation mode” and then select the “damping 2” option. Then the screen looks like Figure 6.
7. Turn the wheel counterclockwise by about 150 degree and release. This time the recorder starts automatically. Collect data after you have 10 values recorded.
8. Adjust the meter disc (smaller wheel) and make sure it is on the upright position (0 on the left and 180 on the right).
9. Select the “Forced Oscillation mode” and then select the “damping 2” option as the previous case. Then turn on the motor.
10. Twist the black knob until you see “7 8 9” in the small window (Figure 7) and start your measurement from the period.
11. Wait till the period of the wheel catches up with the motor and take down the period and amplitude. Hold the flashlight button and face the flashlight to the meter disc. Read the phase angle when the flashlight lit a bright pointer.
12. Decrease the force period by untwisting the black knob and repeat the data collection until you have 20 data sets.

1.5 Data

Here is a sample table for you to organize your data collection. Please collect 28 entries and only record the ones indicated in the table. Note the angular frequency can be calculated by $\omega_0 = 2\pi/T_0$

Measurement	Period (s)
1	
4	
7	
10	
13	
16	
19	
22	
25	
28	

T_0 (s)	
ω_0 (1/s)	

Table 1: Data collection for the period measurement in the “Free Oscillation” mode.

Measurement of the damping factor β. We need the averaged period and the averaged difference of the natural logs of the amplitude. The damping factor can be calculated as $\beta = \overline{\ln(\theta_i) - \ln(\theta_{i-5})}/(5\bar{T})$.

Measurement: i	Amplitude:θ (degree)	Period: T (s)	$\ln(\theta_i) - \ln(\theta_{i-5})$
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

$\bar{T}$ (s)	
$\overline{\ln(\theta_i) - \ln(\theta_{i-5})}$	
β	

Table 2: Data collection for the period measurement in the "Damped Oscillation" mode.

Here we need to collect data for the amplitude-frequency curve

Measurement: i	Period:T (s)	ω/ω_0	Amplitude:θ (degree)	Phase difference:ϕ (degree)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Table 3: Data collection for the period measurement in the "Forced Oscillation" mode.

1.6 Results and Summary

Free Oscillation

The measurement shows the period for the free oscillation is ________________ s. So the angular frequency is ________________ 1/s.

The last digit on the screen of the meter is in fact the "extra digit". The meter is designed to provide the digit for us and we don't have to measure by ourselves.

Damped Oscillation

The damping factor in the "damped oscillation" mode with damping #2 is ________________ 1/s.

Forced Oscillation

Using the collected data from the "Forced Oscillation" mode to plot curves. Curve 1 ω/ω_0 - amplitude.

Curve 2 ω/ω_0 - phase difference.

Discuss what is the characteristic frequency of the Pohl's pendulum and how to achieve its resonance. Try to describe how the resonance amplitude changes with the damping factor.