Indian Institute of Technology Gandhinagar

Universal Joint

ME 352 : Mechanical Engineering Lab 2

Lab Report - Experiment 4

Group - 8

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OBJECTIVE

To design and fabricate a universal joint which can transmit motion between two inclined shafts.

ABSTRACT

The universal joint, also known as a "U-joint," is a mechanical device that attaches two rotating shafts at an angle to one another while retaining their ability to rotate and transmit torque. It consists of two hinges with a 90-degree orientation close to each other. The idea of a constant velocity joint is the basis for the U-operating joint's principle.

Universal joints are designed to allow some degree of misalignment between the two shafts and some flexibility to absorb shock and vibration. It is a flexible and reliable mechanism that has been used for many years in various applications. It's simple design and ease of use make it a popular choice for many different types of machinery and equipment. They are commonly used in automotive and industrial applications, such as in the driveshafts of cars and trucks, to transmit power from the transmission to the rear wheels.

EXPERIMENTAL DESIGN

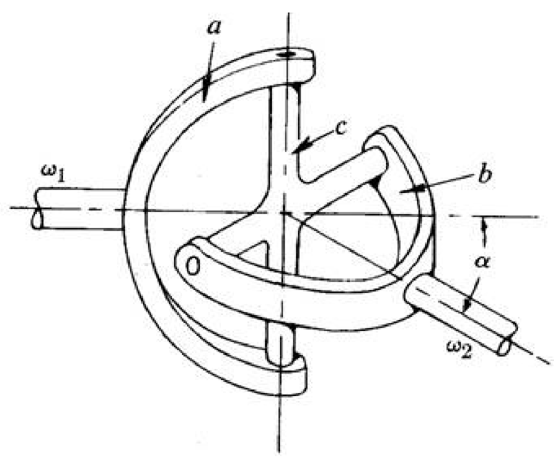

Figure 1 : Schematic of Setup

The essential components of a universal joint include:

1. Yoke: U-shaped component that connects the two shafts (first and second) to be joined. These are designed to transmit torque and power from one end to the other perpendicular end of the cross.
2. Cross: Four-armed piece that sits in the centre of the yoke. Each arm of the cross is attached to a bearing, which is used to mount the cross on the arms of the yoke.
3. Ball Bearings: Used to support the arms of the cross and allow them to rotate freely.
4. Motor: Connected to the first shaft to give the input as constant angular velocity.
5. Optical encoder: Connected to the second shaft to read the output.
6. Shafts: Used to connect one yoke with the motor(which gives the input as constant angular velocity) and another yoke to the optical encoder(which provides the output as variable angular velocity).

The basic operation of a universal joint is as follows: as one shaft rotates, the cross rotates with it, and the yoke and second shaft rotate, providing the output. The cross can pivot within the yoke, accommodating angles between the shafts. The angular offset between the two shafts creates a speed difference between the input and output shafts, resulting in the cross's non-uniform motion. This non-uniform motion can cause vibration and noise, as well as wear and tear on the joint.

FABRICATION DETAILS

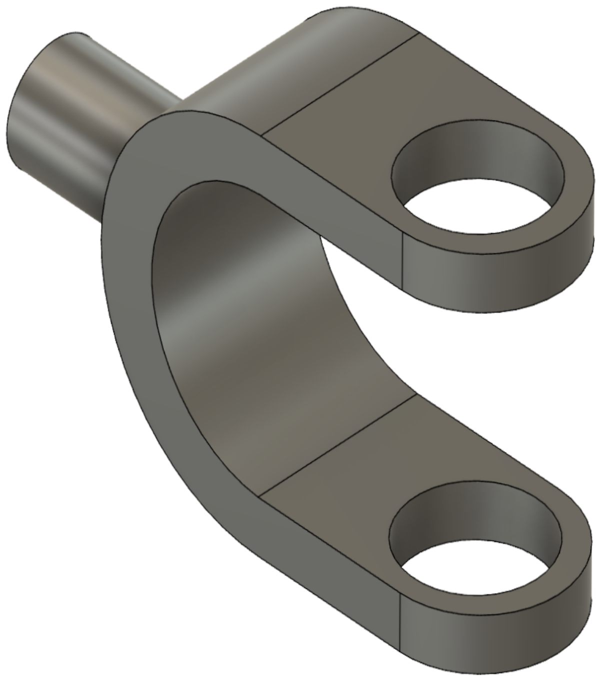

Figure 2 : CAD model of yoke

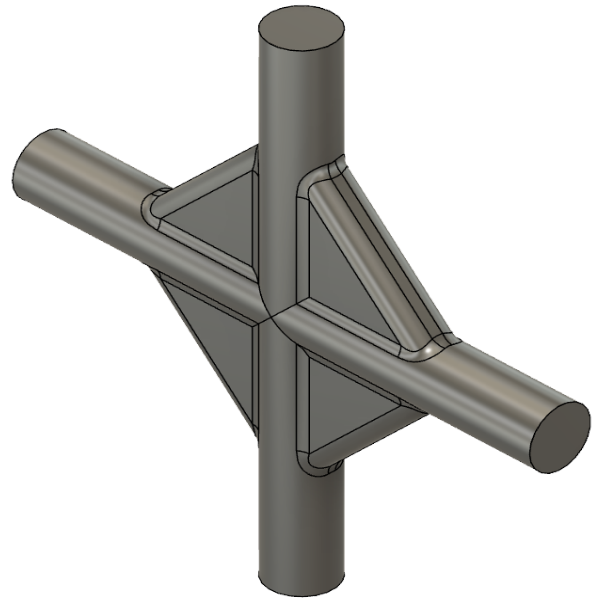

Figure 3 : CAD model of cross

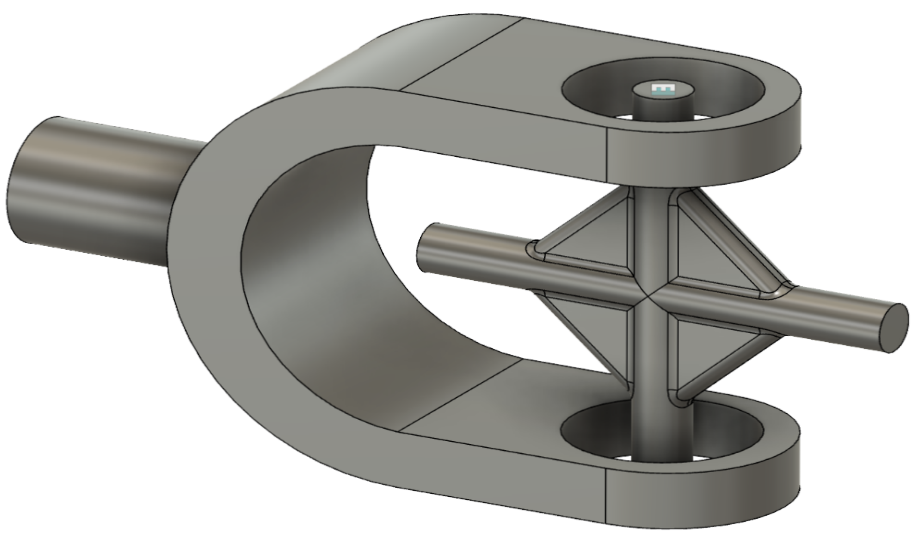

Figure 4 : CAD model of the yoke and cross attached with each other using ball bearings

The joint was first designed in CAD model and then 3d printed. Ball bearings were used to ensure smooth motion. Aluminum shafts were used to transmit rotation. The entire setup was planted on a wooden base.

Figure 5 : Final Setup

MATHEMATICAL MODELLING

Let AB be the driver yoke and CD be the driven yoke. Since AB is rotating at a constant angular speed, CD and AB will trace a circle. However, from the front view, it will seem like CD is following an elliptical path as it is inclined at an angle α with AB.

Let AB rotates angle θ in a counterclockwise direction, and the new position is A'B'. So, CD will also rotate angle θ in the front view. But, this is not the true angle rotated by CD. The actual angle rotated by CD is ϕ which is shown in figure(6).

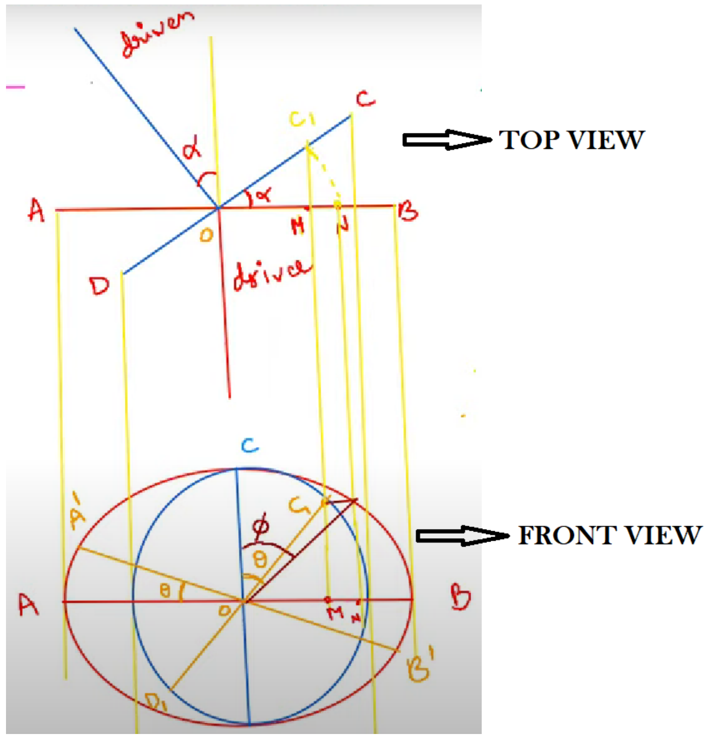

Figure 6 : Top and front view for path traced by the driver and driven shafts

$Here,\ \theta = Angle\ turned\ by\ driver\ shaft\ (or\ yoke)$

$$\omega = \frac{d\theta}{dt} = \ Angular\ velocity\ of\ driver\ shaft$$

$$\phi = Angle\ turned\ by\ driven\ shaft\ (or\ yoke)$$

$$\omega_1 = \frac{d\phi}{dt} = \ Angular\ velocity\ of\ driven\ shaft$$

$$\alpha = Angle\ between\ driven\ and\ driver\ shaft$$

From ΔOC_1M, we have:

$$tan\theta = \frac{OM}{C_1M} \quad (1)$$

$$OM = ON\ cos\alpha \quad (2)$$

From ΔOC_2M, we have:

$$tan\phi = \frac{ON}{C_1N} = \frac{ON}{C_1M} \quad (3)$$

Using equation (1),(2) and (3), we get:

$$\frac{tan\theta}{tan\phi} = \frac{OM}{ON} = cos\alpha$$

$$\Rightarrow tan\theta = tan\phi\, cos\alpha \tag{4}$$

By differentiating equation (4), we get:

$$sec^2\theta \frac{d\theta}{dt} = cos\alpha\, sec^2\phi \frac{d\phi}{dt}$$

$$\frac{\omega}{\omega_1} = \frac{sec^2\theta}{cos\alpha\, sec^2\phi} \tag{5}$$

Using equation (4) and (5), we get:

$$sec^2\phi = 1 + tan^2\phi$$

$$\Rightarrow sec^2\phi = 1 + \frac{tan^2\theta}{cos^2\alpha} = \frac{cos^2\theta\, cos^2\alpha + sin^2\theta}{cos^2\theta\, cos^2\alpha} = \frac{cos^2\theta(1 - sin^2\alpha) + sin^2\theta}{cos^2\theta\, cos^2\alpha}$$

$$\Rightarrow sec^2\phi = \frac{1 - cos^2\theta\, sin^2\alpha}{cos^2\theta\, cos^2\alpha} \tag{6}$$

Using equation (5) and (6), we get:

$$\frac{\omega_1}{\omega} = \frac{1}{cos^2\theta\, cos\alpha} \times \frac{cos^2\theta\, cos^2\alpha}{1 - cos^2\theta\, sin^2\alpha}$$

$$\Rightarrow \frac{\omega_1}{\omega} = \frac{cos\alpha}{1 - cos^2\theta\, sin^2\alpha} \qquad (ratio\ of\ angular\ velocity) \tag{7}$$

For maximum and minimum angular speed of driven shaft:

ω_1 will be maximum at $cos\theta = 1 \Rightarrow \theta = 0^o$

$$\left(\omega_1\right)_{max} = \frac{\omega}{cos\alpha}$$

ω_1 will be minimum at $cos\theta = 0 \Rightarrow \theta = 90^o$

$$\left(\omega_1\right)_{min} = \omega\, cos\alpha$$

For the same angular speed of driven and driver shaft:

$$\frac{\omega_1}{\omega} = \frac{cos\alpha}{1 - cos^2\theta\, sin^2\alpha}$$

$$\Rightarrow cos\alpha = 1 - cos^2\theta\, sin^2\alpha \qquad (\text{as } \omega = \omega_1)$$

$$\Rightarrow cos^2\theta = \frac{1 - cos\alpha}{sin^2\alpha} = \frac{1}{1 + cos\alpha}$$

$$\Rightarrow cos^2\theta + cos^2\theta\, cos\alpha = 1 = cos^2\theta + sin^2\theta$$

$$\Rightarrow tan^2\theta = cos\alpha$$

$$\Rightarrow tan\theta = \pm\sqrt{cos\alpha} \tag{8}$$

Equation (8), will give four value of θ and α when $\omega = \omega_1$.

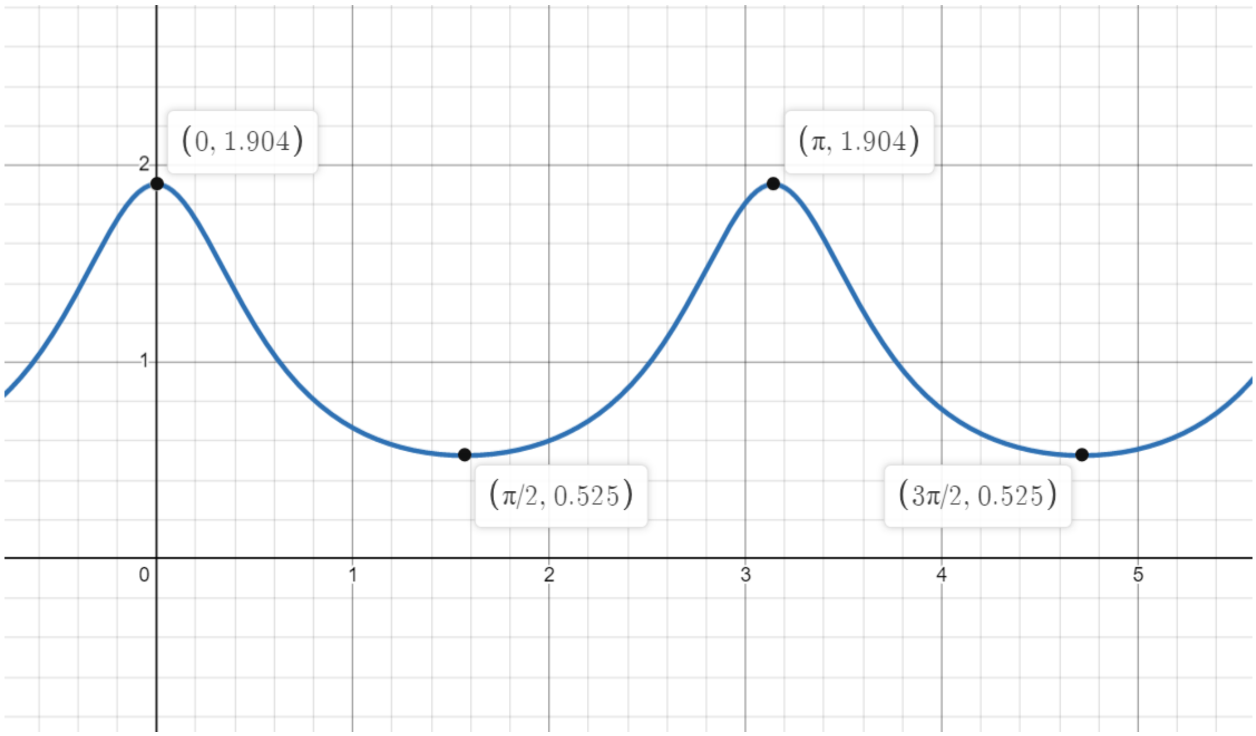

Figure 7 : $\frac{\omega_1}{\omega}$ v/s θ at $\beta = 45^{\circ}$

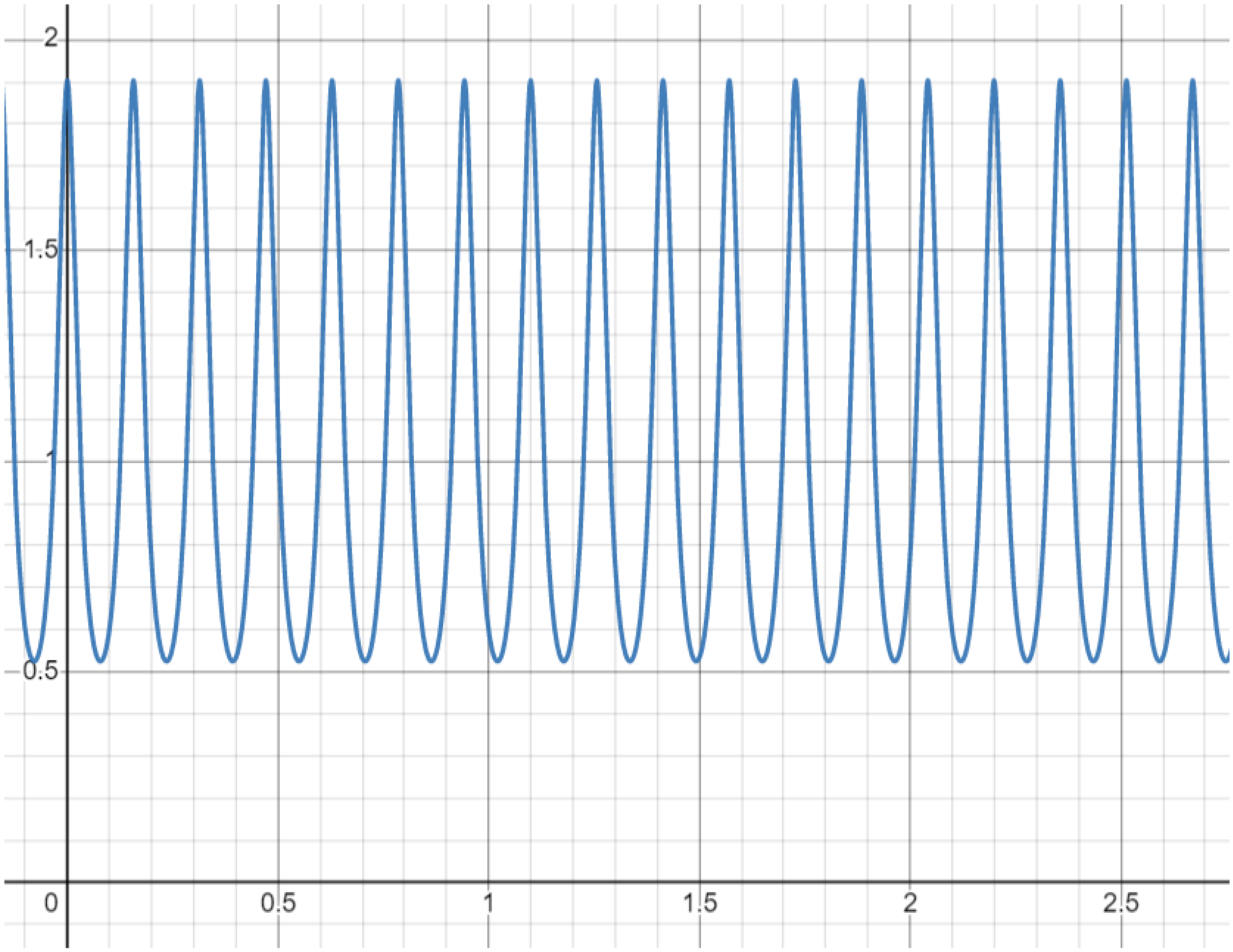

Figure 8 : $\frac{\omega_1}{\omega}$ $v/s\ time$

RESULTS

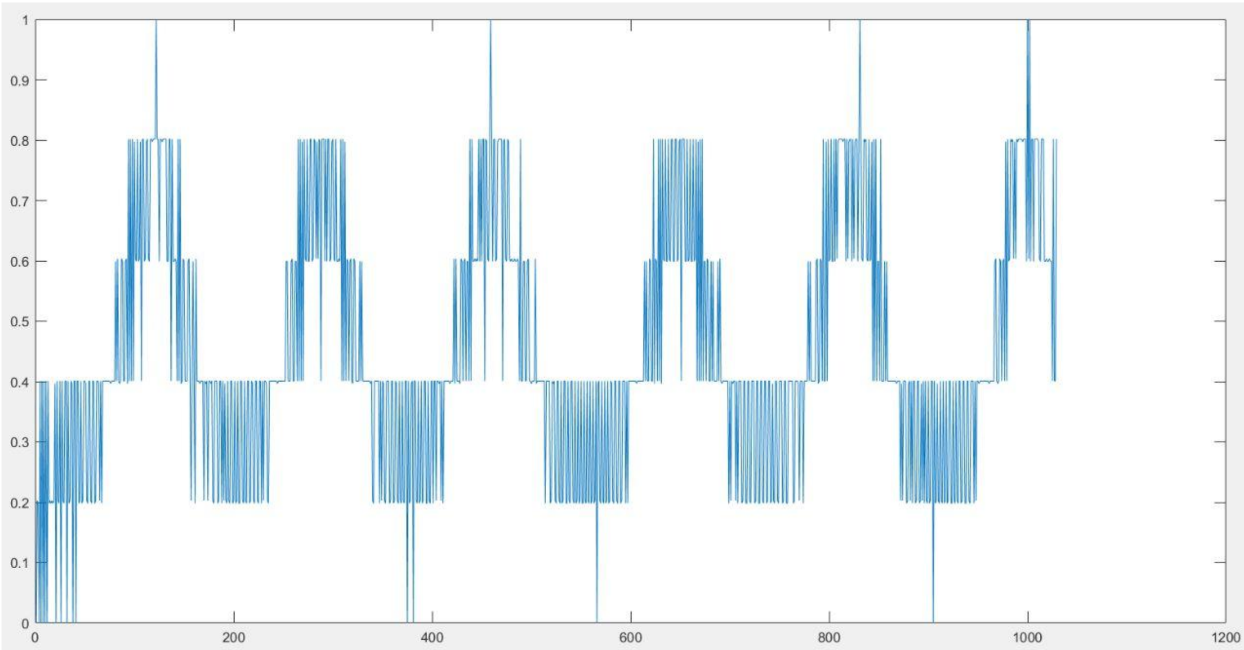

Figure 9 : Graph of frequency v/s time

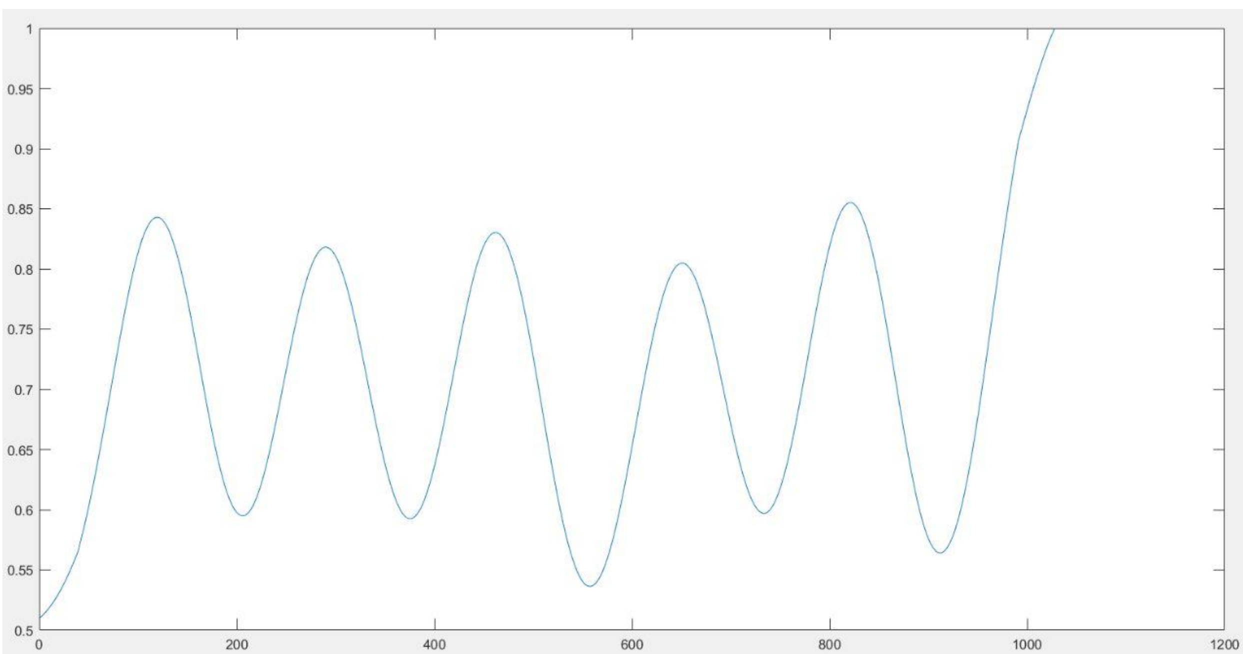

Figure 10 : Curve Fitted Graph of the experimental output

The experimental graph plotted doesn't match with the one obtained from the theoretical one. The nature and the phase of the graph matches but there is an issue with the amplitude of the two graphs.

REASONS FOR MISMATCHING

- Errors while taking measurements
- Sliding between the shafts and joints
- Inaccuracy in setting the angle of inclination
- The weight of the 3D printed parts (both yokes and cross) causes bending in the shafts. This causes irregularities in the readings.

SCOPE OF IMPROVEMENT

- We can fix the rotary encoder and shaft so that they don't change their position and support the weight of the joints.
- If we use durable material like steel, we can run the experiment at higher rpm and get more accurate results.

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