# DESIGN AND REALIZATION OF VORTEX-INDUCED VIBRATION CONVERTER


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**ME420- Mechanical Engineering Individual Research Project**

**ES81**

June, 2025

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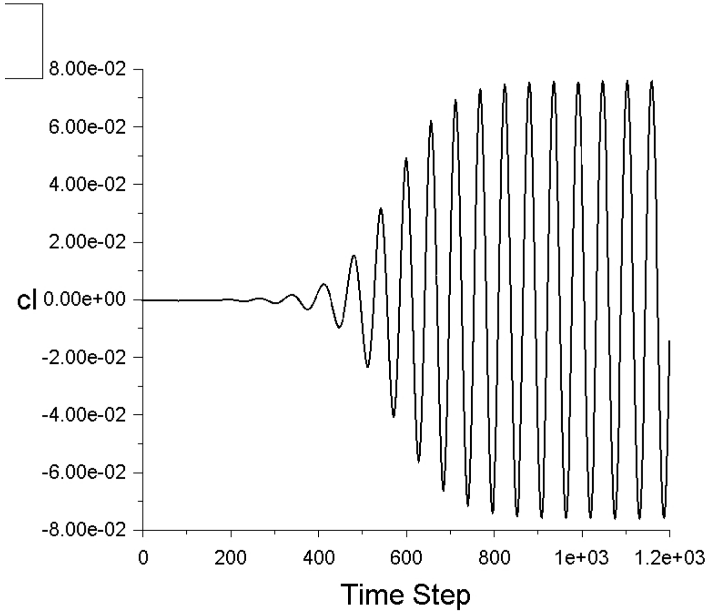
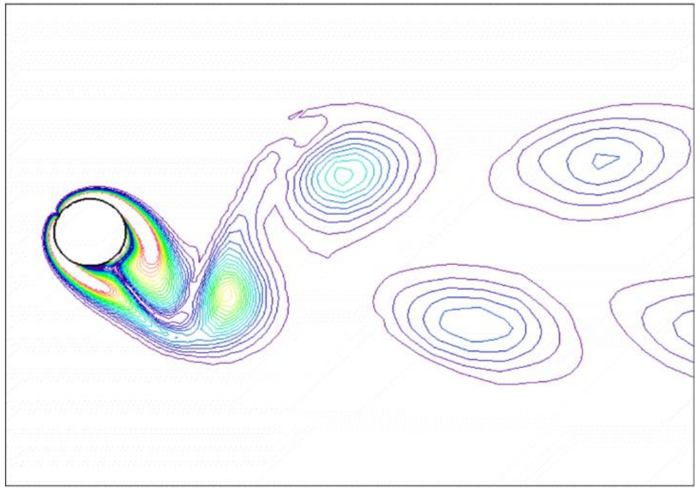
# INTRODUCTION

- When a fluid flows past a bluff body, such as a cylinder vortex shedding occurs and it generate oscillating transverse force component on the cylinder.
- If the cylinder is free to oscillate/vibrate, vortex induced vibrations occurs.

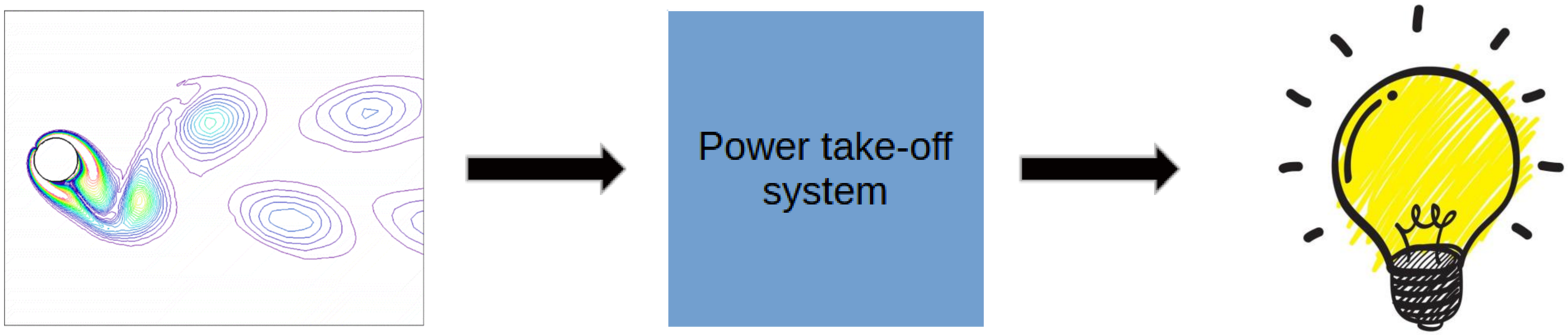



Variation of the lift coefficient on the cylinder with time



# INTRODUCTION

What is vortex induced vibration converter?

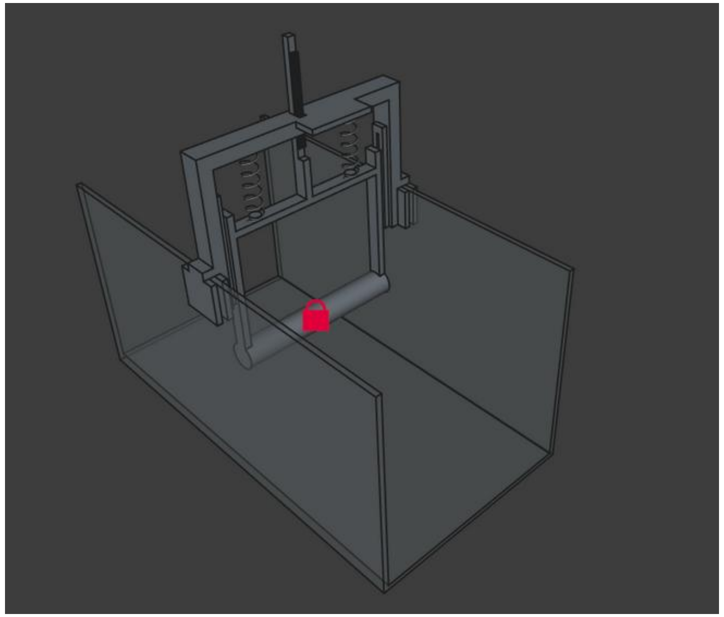


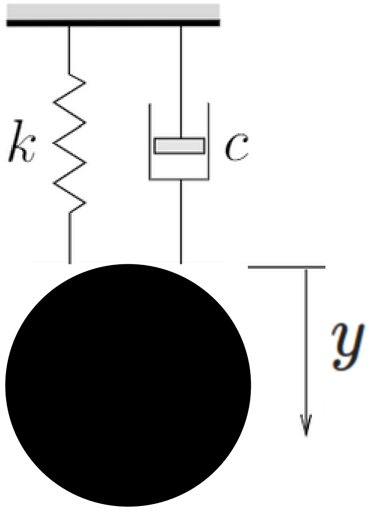
# OBJECTIVES

- Obtain a conceptual understanding of the phenomenon and review existing models.
- Design a mathematical model to analyze the performance of a vortex-induced vibration converter.
- Design a lab-scale prototype.
- Fabricate the prototype
- Validate the prototype.
- Calculate design specifications for different application scales.

# UPTO PREVIOUS EVALUATION

- Literature survey about the existing models.
- Mathematical model was developed to simulate the amplitude response of the device.
- Basic 3D model was developed.






$$(m+m')\ddot{y}+c_1\dot{y}+c_2|\dot{y}|\dot{y}+ky=F_L$$

$$c_2=\frac{1}{2}\rho C_D D|\dot{y}|$$

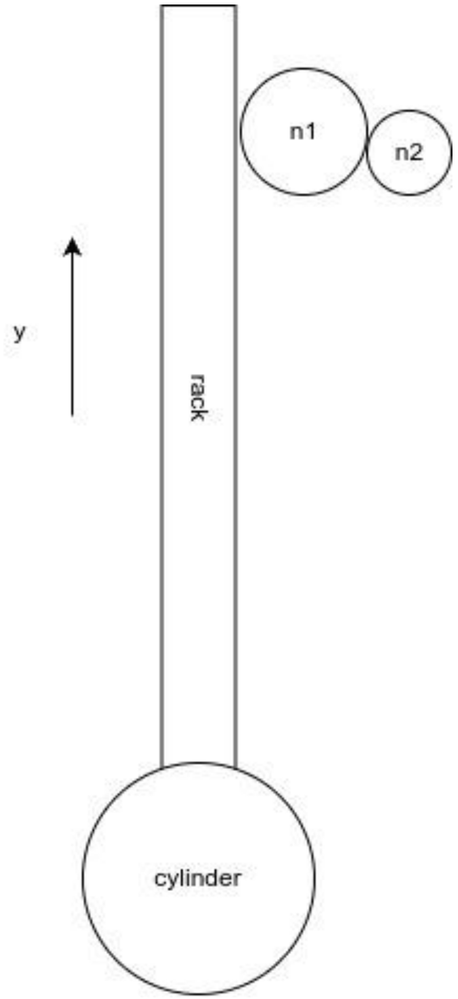
$$F_L=\frac{1}{2}\rho C'_F D U^2_{stream}$$

$$C'_L=\sqrt{2}C_{L,rms}sin(\omega_v t)$$

Variation of the lift coefficient on the cylinder with time

# UPTO PREVIOUS EVALUATION

Basic PTO design with rack and pinion mechanism




if the motor is mounted to the n2 gear shaft, angular velocity of n2 shaft,

$$\omega_2 = -\frac{y_m}{r_2}\omega_{cyl}cos(\omega_{cyl}t + \phi)$$

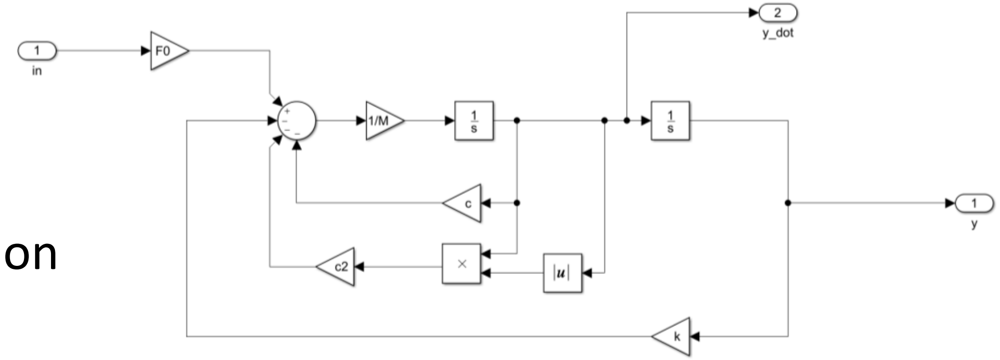
If separately excited DC generator is used, generated terminal voltage,

$$E_a = -\frac{K\phi y_m}{r_2}\omega_{cyl}cos(\omega_{cyl}t + \phi)$$

# PROGRESS

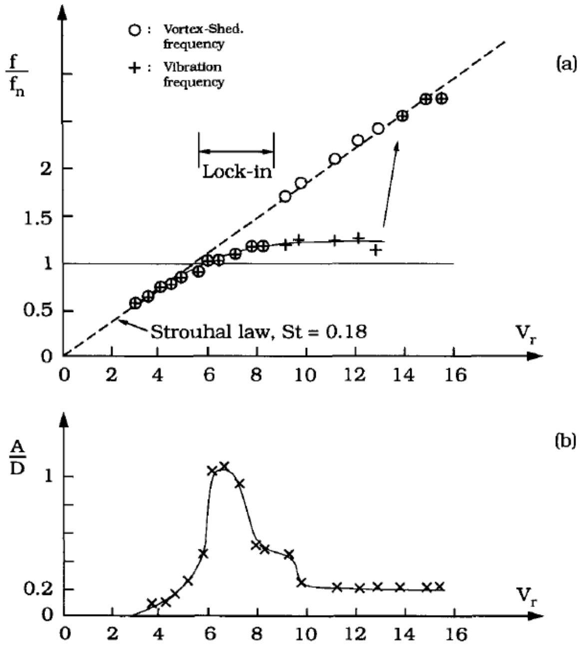
# Mathematical model limitations

- Inability to simulate the synchronization region.
- Cannot simulate lift force magnification with cylinder motion

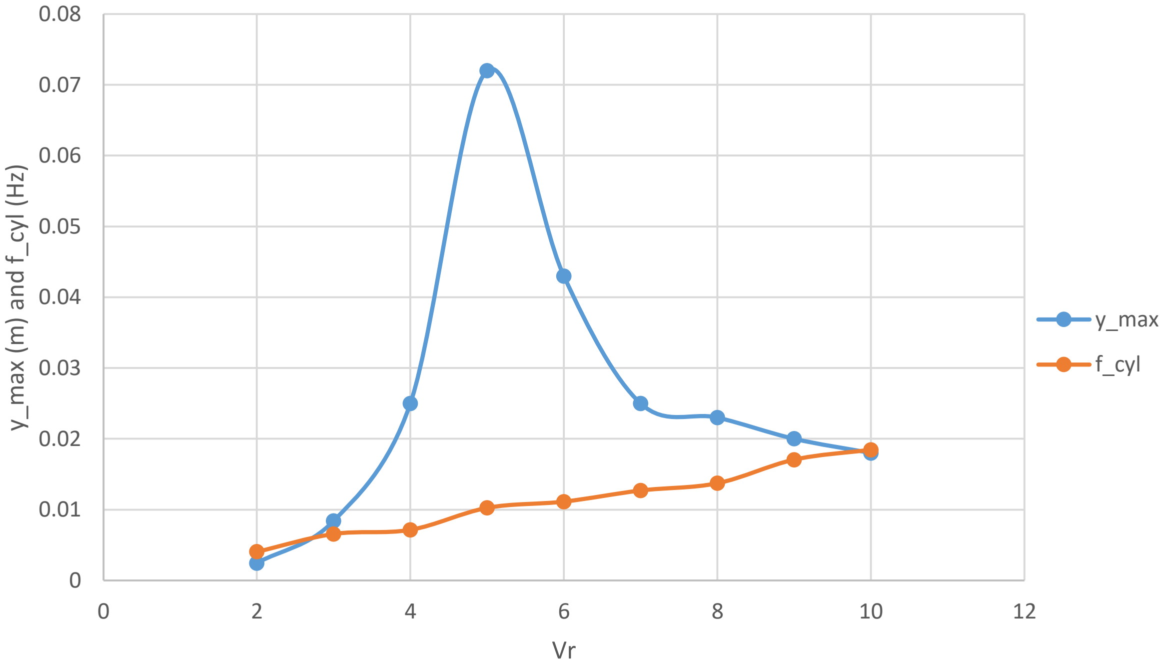



$$\text{reduced velocity}(V_r) = \frac{U}{fD}$$

Simulink implementation




Response of cylinder in a steady fluid flow
(Anand 1985 - from Sumer & Fredsoe)




Variation of the lift coefficient on the cylinder with time

# Wake-Oscillator model

- Initially introduced 1953 introduced by Garett Brikoff. Many developments have made throughout the years.
- Wake's behavior and cylinder's behavior is modeled using 2 coupled differential equations.
- In most cases Wake is modeled as Van Der Pole oscillator.

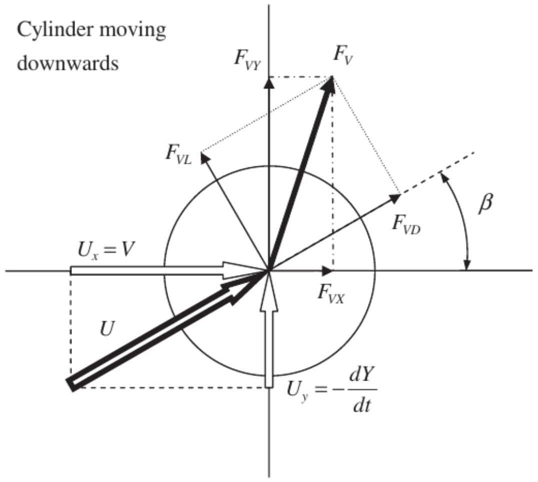
- Facchinetti (2004) model

$$\frac{d^2y}{dt^2} + 2\zeta\omega_n\left(\frac{dy}{dy}\right) + \omega_n^2 y = \frac{\frac{1}{2}\rho DLV^2 C_{VY}}{(m+m_a)}$$

where,

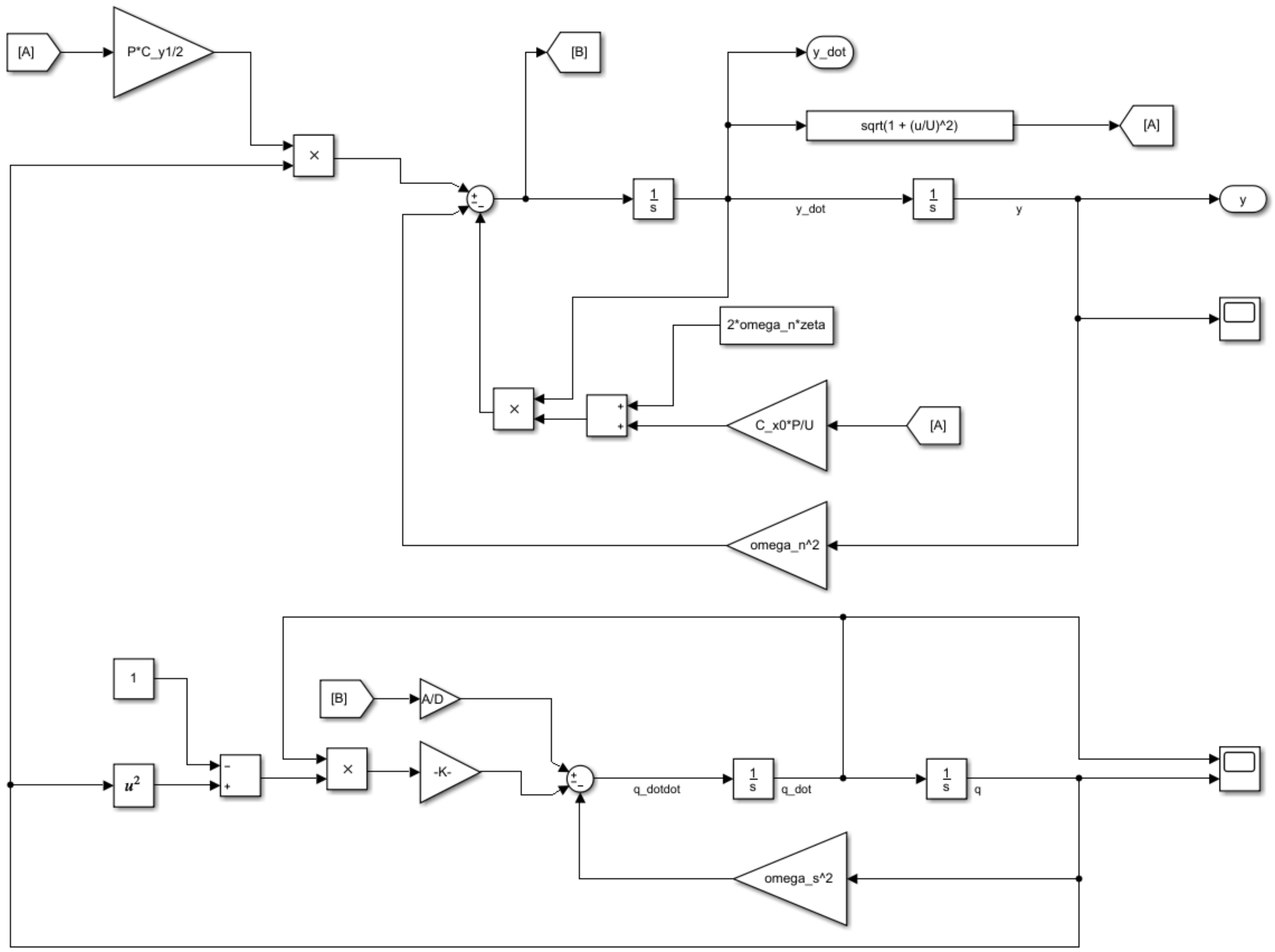
$$c_{VY} = \left[\frac{q}{2}C_{LO} - \frac{\frac{dy}{dt}C_{DO}}{V}\right]\sqrt{1+\left(\frac{dy}{dx}\times\frac{1}{V}\right)^2}$$

$$\frac{d^2q}{dt} + \epsilon\omega_v(q^2-1).\frac{dq}{dt} + \omega_V^2 q = \frac{A}{D}\ \ddot{y}$$



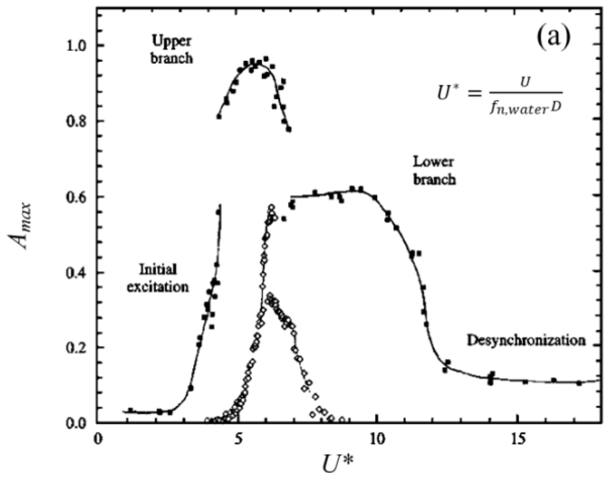

From Ogink and Metrikine (2010)

# Wake-Oscillator model Implementation



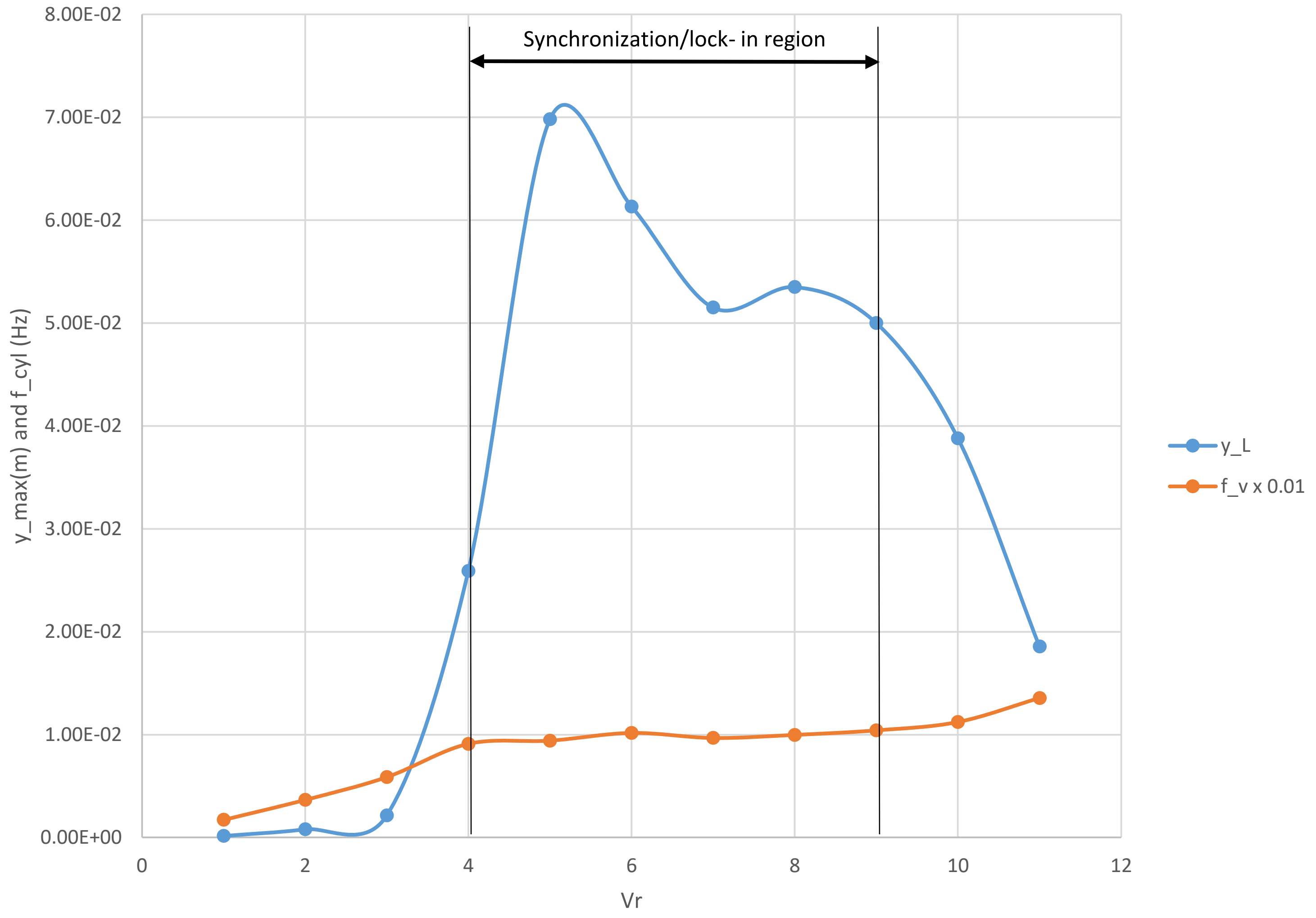

Model parameters ($\epsilon$ $and$ $A$) , values proposed by Ogink and Metrikine (2010) were used

| Upper branch | Lower branch |
|---|---|
| $\hat{C}^0_{x0} = 1.1856,$ | $\hat{C}^0_{x0} = 1.1856,$ |
| $\hat{C}^0_{y1} = 0.3842,$ | $\hat{C}^0_{y1} = 0.3842,$ |
| $\mathrm{St} = 0.1932,$ | $\mathrm{St} = 0.1932,$ |
| $A = 4.0,$ | $A = 12.0,$ |
| $\varepsilon = 0.05,$ | $\varepsilon = 0.7.$ |




Amplitude vs Reduced velocity plotted for a smooth cylinder in water (black dots) - (Williamson & Roshko 1988)

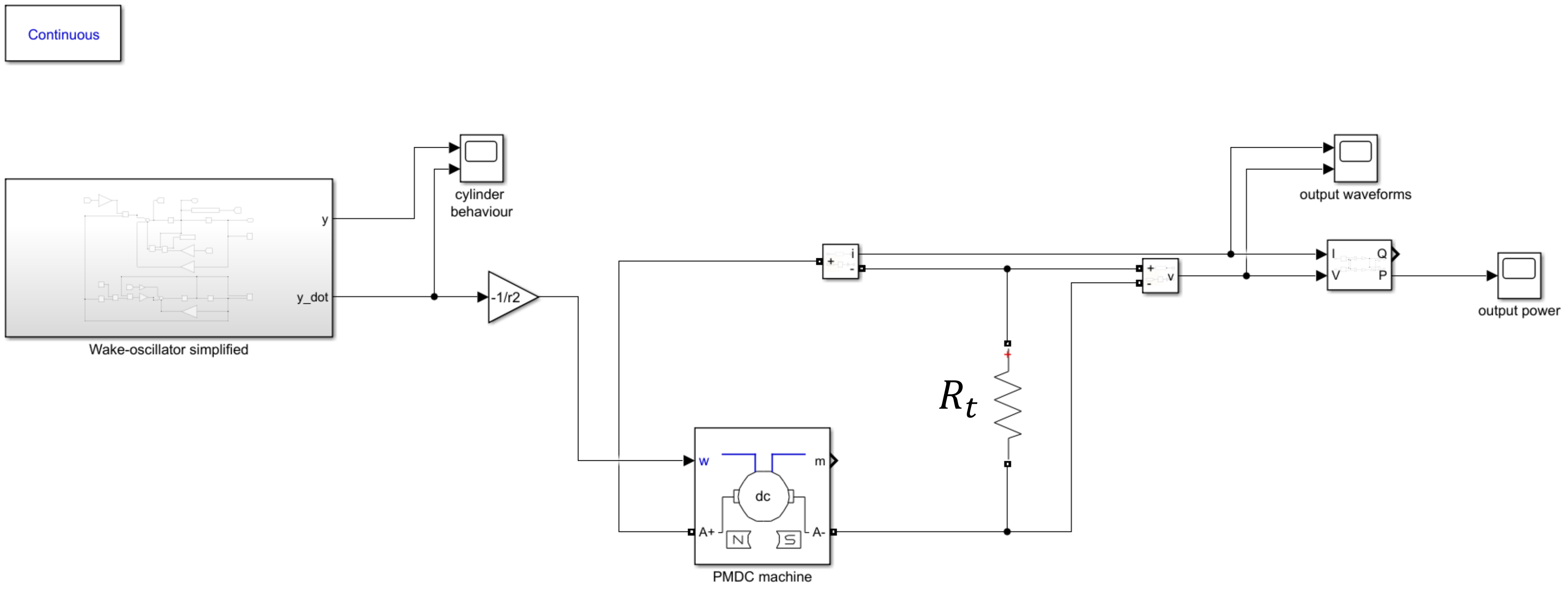
# Wake-Oscillator model response




Maximum amplitude and frequency variation with reduced velocity

# PTO System Implementation

## Implementation in MATLAB



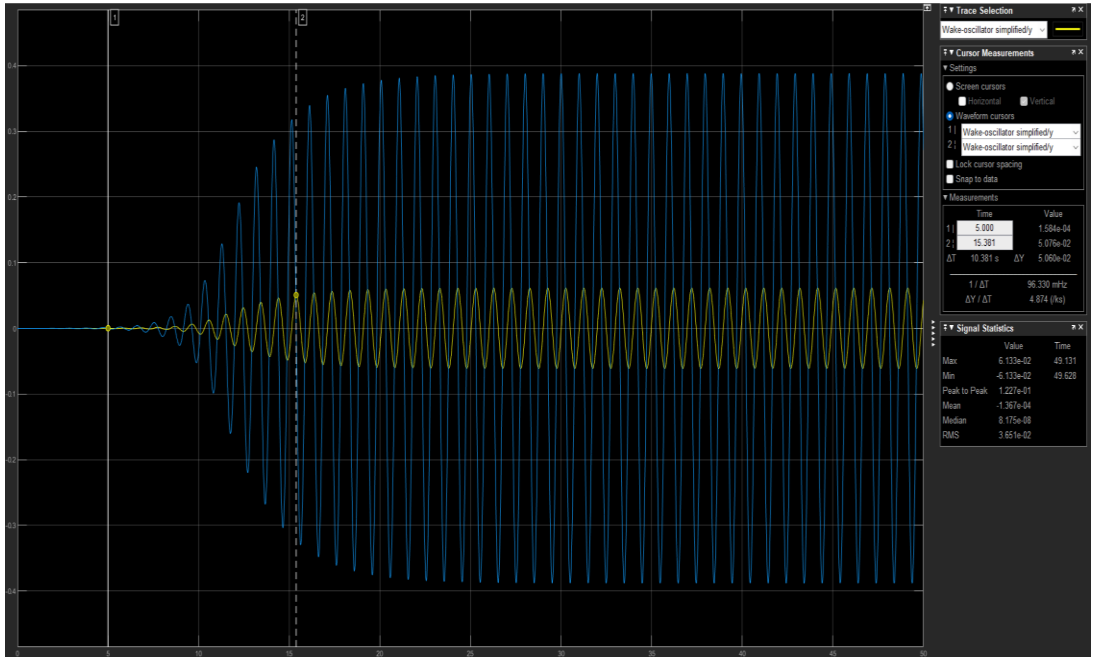

Damping induced by the DC generator on the oscillator,

$$c_{gen} = \frac{k^2}{r^2 R_T}$$

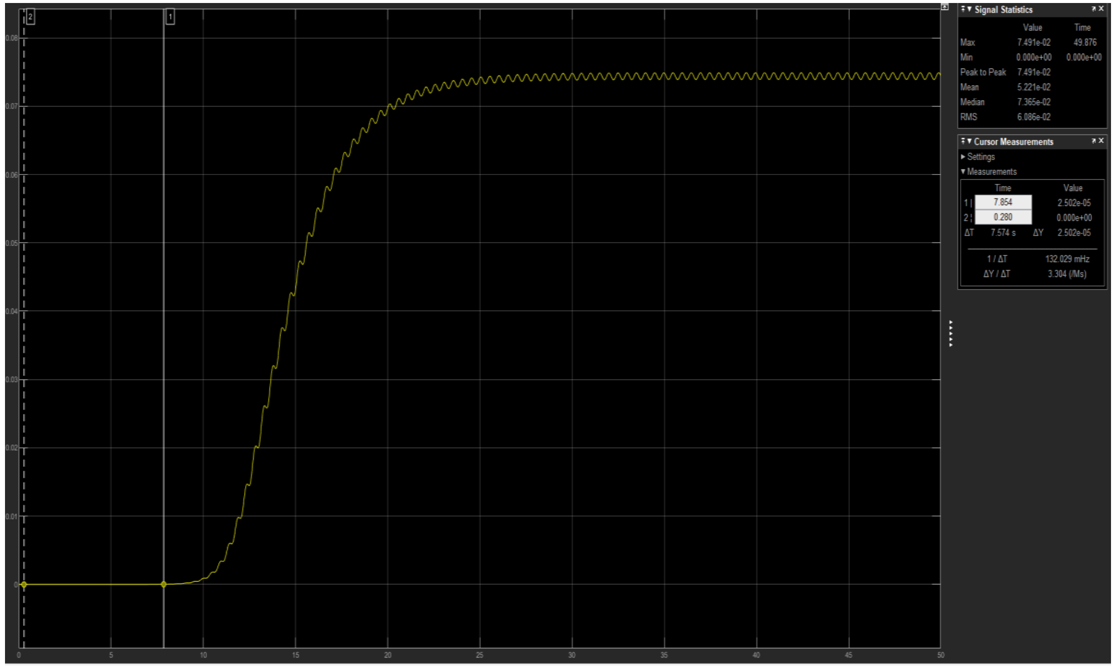
RS755 12V DC motor has k=0.1, $R_t = 100$ and $r = 0.01$ then,

$$c_{gen} = 0.1$$

# Power output




Cylinder motion




Power generation

According to the simulation with the RS775 motor 75 mW power can be generated at the resonance frequency.

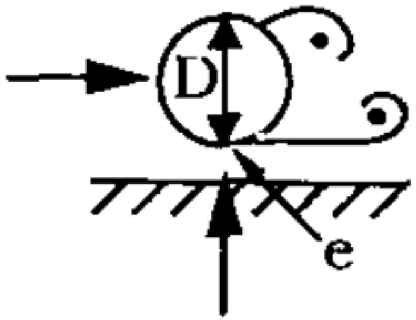
# Prototype Development

# Constraints

- According to the requirements and availability device can be tested in towing tank or in a Flume.
- To observe vortex shedding $Re \in (300, 3 \times 10^5)$.
- Amplitude of the oscillation depends on the cylinder diameter. ( high D => high amplitudes).
- Span-wise length of the cylinder should be according to the table below.
- VIV amplitude get significantly effected if bottom gap ratio, $\frac{e}{D} < 0.7$.

| Reynolds number | Correlation length | Source |
|---|---|---|
| $40 < Re < 150$ | (15–20)D | Gerlach and Dodge (1970) |
| $150 < Re < 10^5$ | (2–3)D | Gerlach and Dodge (1970) |
| $1.1 \times 10^4 < Re < 4.5 \times 10^4$ | (3–6)D | El-Baroudi (1960) |
| $\geq 10^5$ | 0.5D | Gerlach and Dodge (1970) |
| $2 \times 10^5$ | 1.56D | Humphreys (1960) |

from Sumer and Fredsoe (2006)



# 20m Flume check

- Dimensions
    - Width = 400mm
    - Maximum water level = 380mm
- Flume Velocity profile was tested using current meter. Maximum possible velocity (stable) is 0.47 m/s

| Distance from the bottom (cm) | Velocity (m/s) |
|---|---|
| 3 | 0.457 |
| 6 | 0.468 |
| 16 | 0.451 |
| 27 | 0.446 |
| 34 | 0.426 |
| 37 | 0.446 |

# Prototype Scaling

- Cylinder diameter = 80mm
- Maximum obtainable Reynold's number,

$$Re_{max} = 0.45 \times \frac{0.08}{10^{-6}} = 3.6 \times 10^4$$

- Cylinder length = 330 mm (table #)
- Vortex shedding frequency,

$$f_{v,max} = St \times \frac{U}{D} = 1.125\ H_z$$

- $f_n < f_{n,max}$ to observe synchronization.

$$1.125 > \frac{1}{2\pi}\sqrt{\frac{k}{m + m_a}}$$

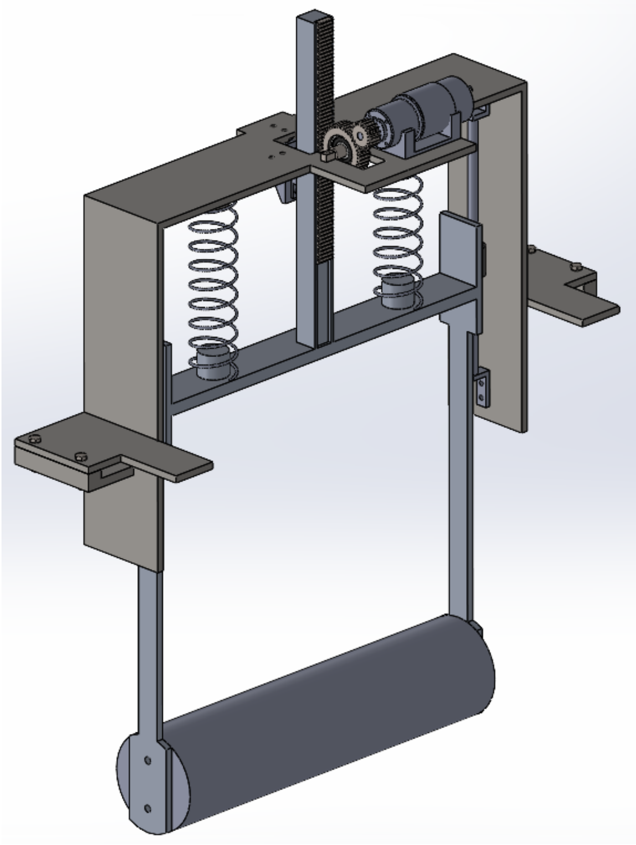
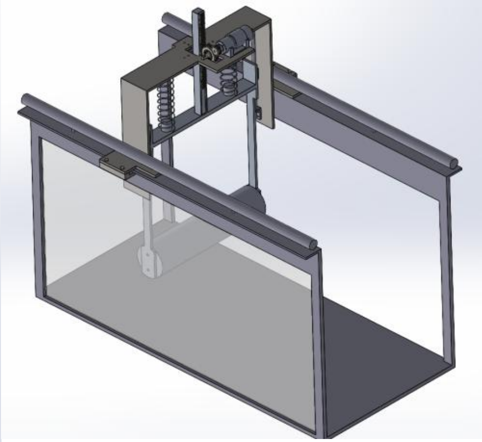
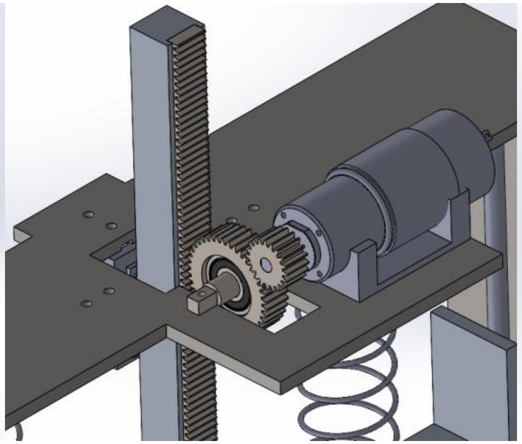
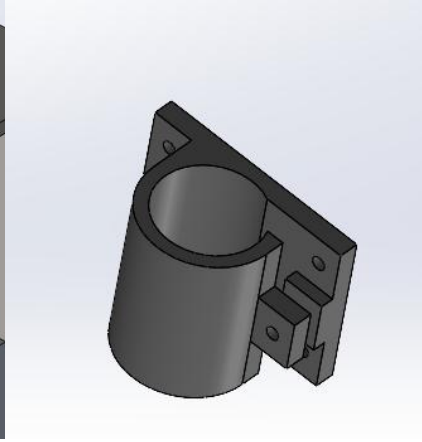
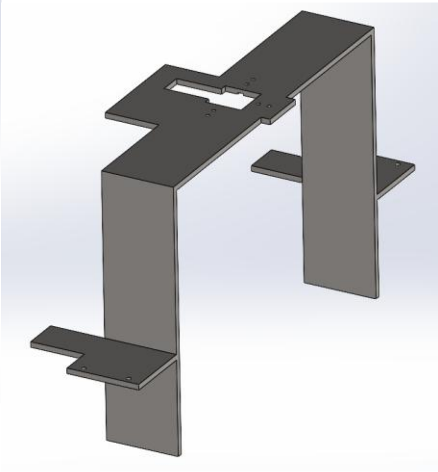
$$k < (1.125 \times 2\pi)^2\ (m + m_a)$$

- Hence for stiffness of single spring,

$$k_s = \frac{k}{2}$$

# Prototype design

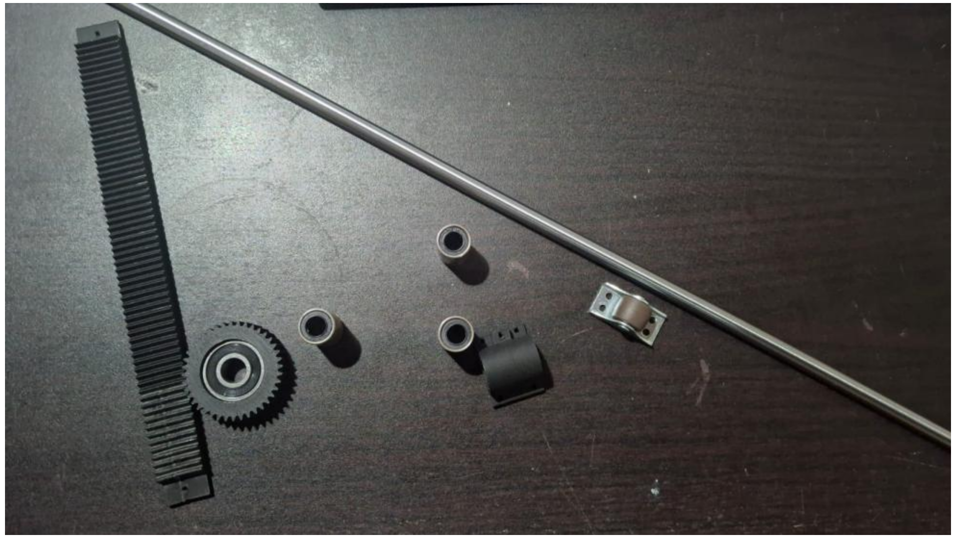
- Prototype was developed in SolidWorks

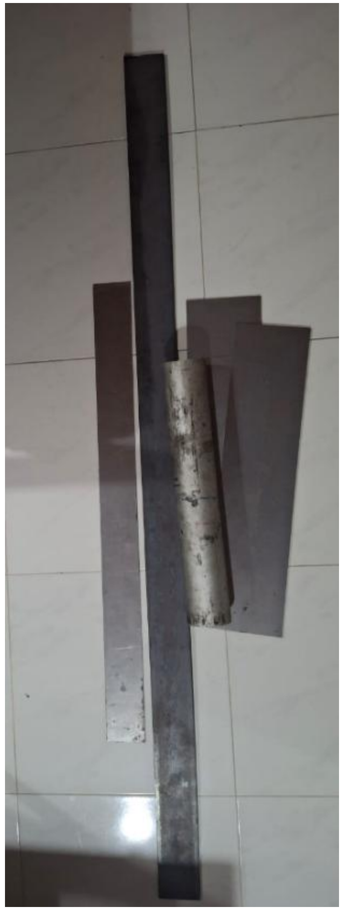






# Ongoing Fabrication

- Materials have selected and purchased.

| Item | size/quantity | Total price (Rs) |
|---|---|---|
| Steel strips | 5' x 3" x 1/4" | 1580 |
| Al tube | D = 80mm<br>L = 450 mm | 980 |
| Steel (other) | 3.5 kg | 900 |
| Linear bearings | 2 | 600 |
| 6000RS bearing | 1 | 850 |
| 3D printing | | 1400 |
| **Total price** | | **6310** |





# References

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Thank you !