Wind Turbine Mechanics

C. Static and Dynamic Modeling of Wind Turbines

2. Dynamic Modeling

WHY IS DYNAMIC MODELING IMPORTANT?

- TEMPORAL VARIATIONS OF LOADS ARE IMPORTANT FOR FATIGUE
- STABILITY OF DESIGN
- DESIGNING CONTROL STRATEGY

FOR DYNAMIC MODEL, MUST INCLUDE INERTIA

NEGLECTED IN STATIC ANALYSIS

UNSTEADY AERODYNAMICS IS NOW NEEDED

- UNSTEADY BEM FOR INSTANCE
- UNSTEADY WIND MODEL

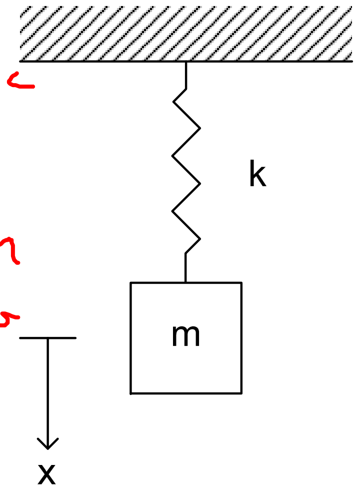
COUPLE

Wind Turbine Mechanics

C. Static and Dynamic Modeling of Wind Turbines

2. Dynamic Modeling

WHAT IS THE BASIS OF A DYNAMIC MODEL?



CONSIDER A SIMPLE DYNAMIC SYSTEM
MASS SUSPENDED ON A SPRING

CONSIDER STATICS

$$\Sigma F = 0 = mg - kx$$

SOLUTION FOR x YIELDS EQUILIBRIUM VALUE

NOW CONSIDER DYNAMICS

$$\Sigma F = ma = m\ddot{x} \qquad m\ddot{x} = mg - kx$$

RESTORING FORCE

$$m\ddot{x} + kx = mg$$

GRAVITY

DAMPING FORCES CAN BE ADDED
→ TEND TO DAMPEN OR RESIST ANY MOTION
PROPORTIONAL TO $\dot{x}$

Wind Turbine Mechanics

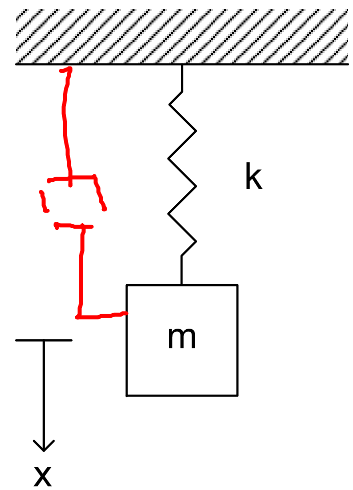
C. Static and Dynamic Modeling of Wind Turbines

2. Dynamic Modeling

$$m\ddot{x} + c\dot{x} + kx = mg$$

THIS IS THE EQUATION FOR THE "FREE" SYSTEM

$c\dot{x}$ IS DAMPING FORCE

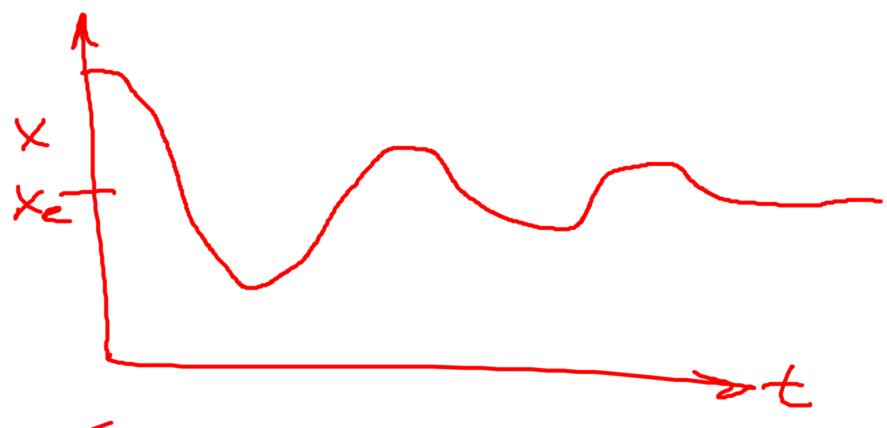


IF SOLVED, THE SOLUTION FOR A MASS DISPLACED FROM EQUILIBRIUM IS DETERMINED $\rightarrow$ A DECAYING OSCILLATION

$\omega_n = \sqrt{\frac{k}{m}}$ $\Rightarrow$ NATURAL FREQUENCY

$\zeta = \frac{c}{2m\omega_n}$ $\Rightarrow$ DAMPING RATIO

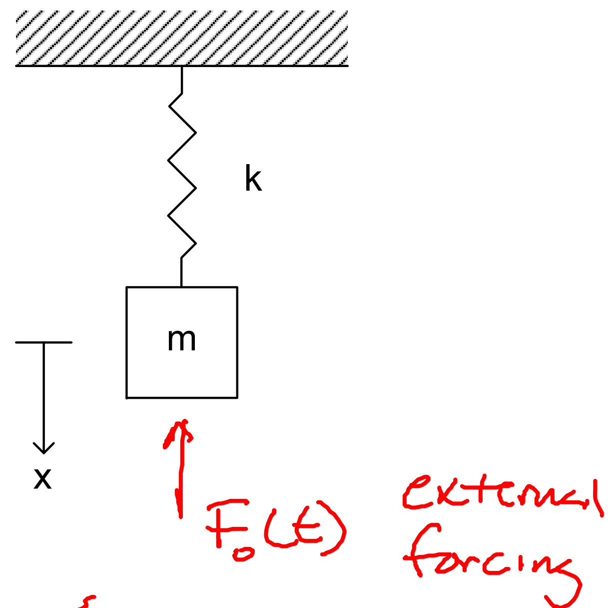
$\Rightarrow$ CHARACTERIZE OSCILLATION



Wind Turbine Mechanics

C. Static and Dynamic Modeling of Wind Turbines

2. Dynamic Modeling



WHAT HAPPENS IF UNSTEADY FORCE ACTS ON THE SYSTEM

$$m\ddot{x} + c\dot{x} + kx = F_o(t)$$

IT IS THE INTERACTION OF THE FORCING & THE SYSTEM THAT YIELD THE RESULTING MOTION

CONSIDER A SINUSOIDAL FORCING

$$F_o(t) = A\sin(\omega t)$$

WHAT IS SYSTEM RESPONSE

Wind Turbine Mechanics

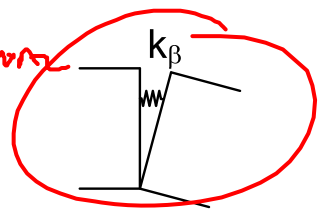
C. Static and Dynamic Modeling of Wind Turbines

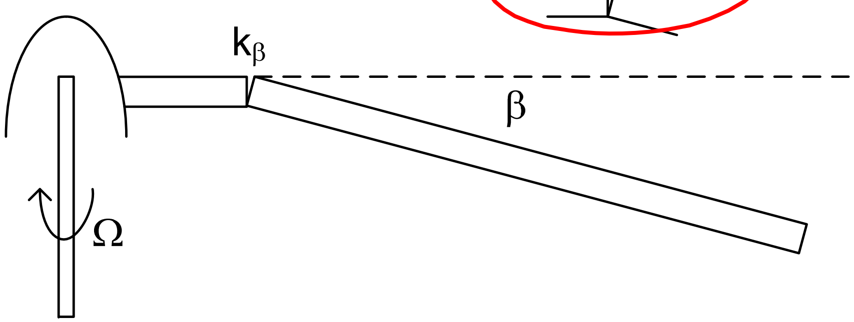
2. Dynamic Modeling

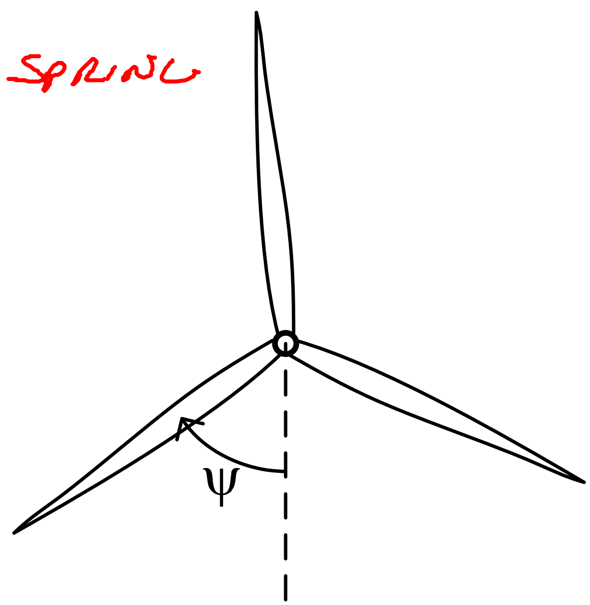
CONSIDER APPLYING SIMPLE CONCEPTS DEVELOPED TO A TURBINE BLADE } HINGE-SPRING MODEL IS SIMPLEST

IN ITS SIMPLEST FORM

- BLADE HAS UNIFORM CROSS SECTION
- BLADE IS RIGID
- COMPLIANCE IS REPLACED BY A SPRING
- CONSTANT ROTATIONAL SPEED







Wind Turbine Mechanics

C. Static and Dynamic Modeling of Wind Turbines

2. Dynamic Modeling

GENERAL FORM OF DYNAMIC EQUATION

$$\underbrace{\ddot{\beta}}_{\text{INERTIA}} + \underbrace{C\dot{\beta}}_{\text{DAMPING}} + \underbrace{K\beta}_{\text{RESTORING}} = \underbrace{F(t)}_{\text{FORCING}}$$

AFTER ACCOUNTING FOR FORCES WE'VE DISCUSSED

$$\underbrace{\beta'' + \left[\underbrace{1+\epsilon}_{\text{CENTRIFUGAL}} + \underbrace{\frac{G}{\Omega^2}\cos\psi}_{\text{GRAVITY}} + \underbrace{\frac{k_\beta}{\Omega^2 I_b}}_{\text{BLADE SPRING}}\right]\beta}_{\text{FREE RESPONSE}} = \underbrace{\underbrace{\frac{M_\beta}{\Omega^2 I_b}}_{\text{AERODYNAMIC LOAD}} - \underbrace{2\bar{q}\cos(\psi)}_{\text{YAW MOTION}}}_{\text{FORCING}}$$