Ansys Mechanical Linear and Nonlinear Dynamics

Module 01: Introduction

Release 2022 R2

Please note:
- These training materials were developed and tested in Ansys Release 2022 R2. Although they are expected to behave similarly in later releases, this has not been tested and is not guaranteed.
- The screen images included with these training materials may vary from the visual appearance of a local software session.

Ansys

Welcome!

- Welcome to Ansys Mechanical Linear and Nonlinear Dynamics.
- This course covers the use of Ansys Mechanical to perform several different types of dynamic analyses. It is intended for users who already have experience performing analysis in Ansys Mechanical.
- Objectives:
  - General understanding of the different types of dynamic analyses available in Ansys Mechanical.
  - Understanding of procedures for performing each type of dynamic simulation, including modal, harmonic, random vibration, response spectrum, and transient structural analyses.
- Prerequisites:
  - Ansys Mechanical Getting Started

Module 01 Learning Outcomes

- After completing this module, you will:
  - Understand the difference among the types of dynamic analyses available in Ansys Mechanical.
  - Be able to recognize the type of dynamic analysis associated with various types of excitation inputs.
  - Have a fundamental knowledge of the underlying equations used when performing dynamic simulations.

Module 01 Topics

A. Definition & Purpose
B. Types of Dynamic Analyses
   - Modal Analysis
   - Harmonic Analysis
   - Response Spectrum Analysis
   - Random Vibration Analysis
   - Transient Analysis
C. General Equation of Motion
D. Basic Concepts and Terminology

A. Definition & Purpose

Static Structural Analysis:

Might ensure that the design will withstand steady-state loading conditions, but it may not be sufficient, especially if the load varies with time.

Dynamic Structural Analysis:

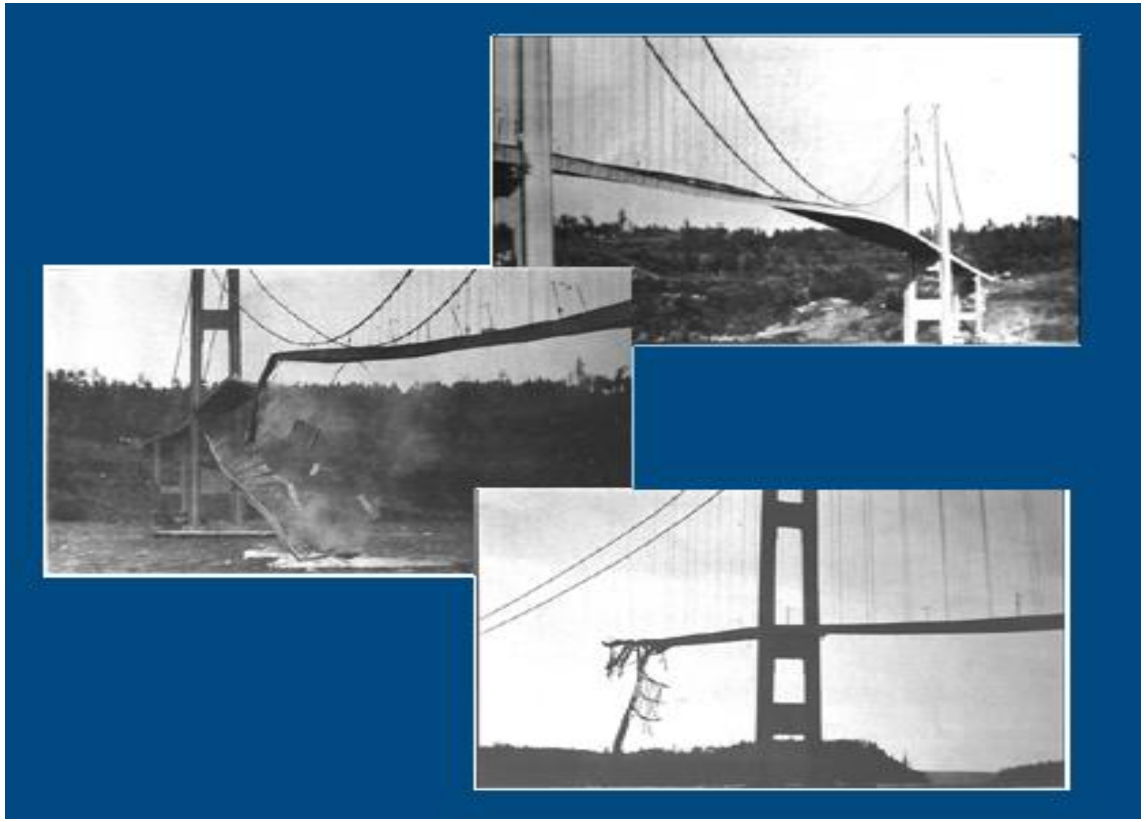
- Used to determine the behavior of structures subjected to loads that vary with time or frequency.
- *Inertia*, and possibly *damping*, of the structure play an important role.
- Dynamics also includes the study of free vibrations, i.e., the oscillations of a structure after the force causing the motion has been removed.

.... Definition & Purpose

It is crucial to understand the vibration characteristics (free vibration analysis) of a system

"The famous Tacoma Narrows bridge (Galloping Gertie) collapsed under steady wind loads during a 42-mph windstorm on November 7, 1940, just four months after construction"

Vibration characteristics!



…. Definition & Purpose

- A dynamic analysis usually takes into account one or more of the following:
  - free vibrations
    - natural vibration frequencies and shapes
  - forced vibrations
    - e.g. crank shafts, other rotating machinery
  - seismic/shock loads
    - e.g. earthquake, blast
  - random vibrations
    - e.g. rocket launch, road transport
  - general time-varying loads
    - e.g. car crash, hammer blow
- Each situation is handled by a specific type of dynamic analysis.

B. Types of Dynamic Analyses

- <u>Modal Analysis</u>

Modal analysis is used to determine a structure's vibration characteristics, i.e., natural frequencies and mode shapes.

Consider the following examples:

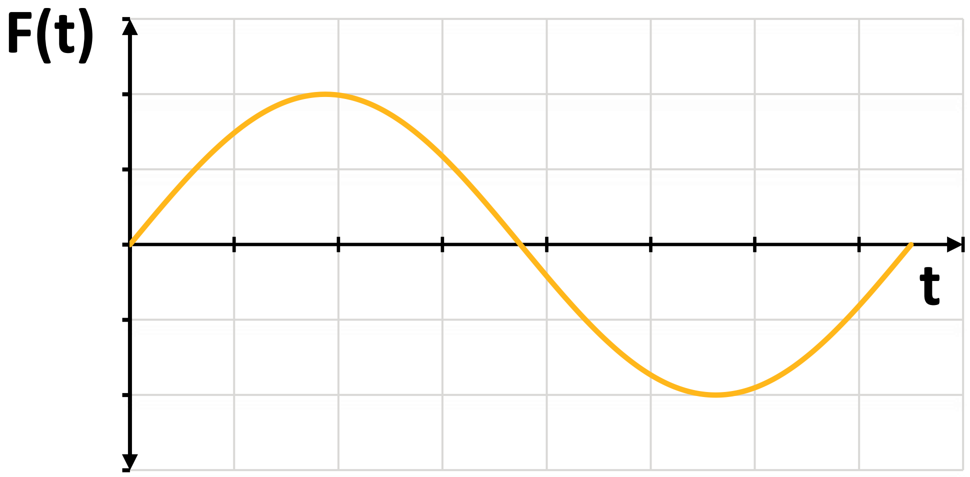
- An automobile tailpipe assembly could shake apart if its natural frequency matched that of the engine. <u>*How can you avoid this?*</u>
- A turbine blade under stress (centrifugal forces) shows different dynamic behavior. <u>*How can you account for it?*</u>

…. Types of Dynamic Analyses

- <u>Harmonic Analysis</u>

The harmonic-response analysis is used to determine a structure's response to steady, harmonic (sinusoidally varying) loads.

Rotating machines exert steady, alternating forces on bearings and support structures. These forces cause different deflections and stresses depending on the speed of rotation.



…. Types of Dynamic Analyses

- <u>Response Spectrum Analysis</u>

A response-spectrum analysis can be used to determine how a component responds to earthquakes.

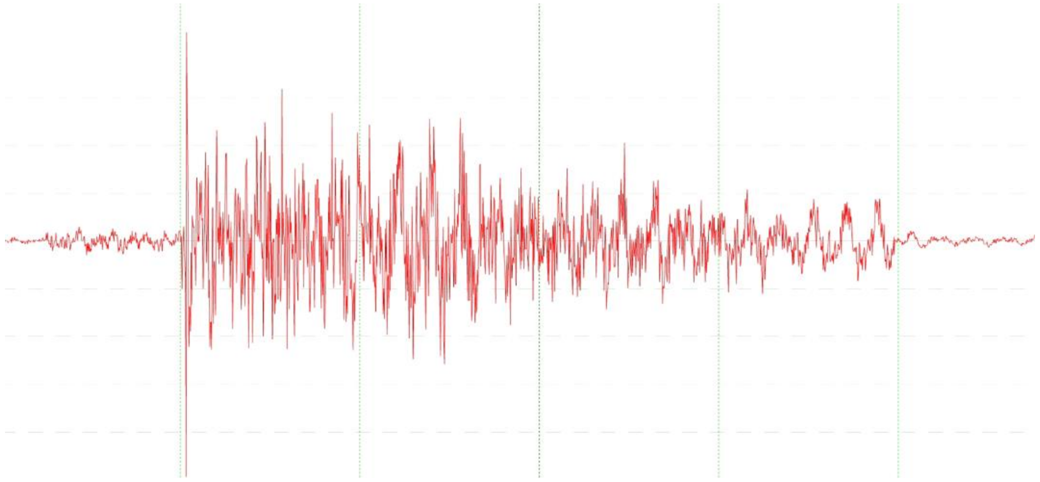
Skyscrapers, power-plant cooling towers, and other structures must withstand multiple short-duration transient *shock/impact loadings*, common in seismic events.

…. Types of Dynamic Analyses

- Random Vibration Analysis

A random-vibration analysis can be used to determine how a component responds to random vibrations.

Spacecraft and aircraft components must withstand random loading of varying frequencies for a sustained time period.



…. Types of Dynamic Analyses

- <u>Transient Analysis</u>

A transient analysis can be used to calculate a structure's response to time-varying loads.

Consider the following examples:

- An automobile fender should be able to withstand low-speed impact, but deform under higher-speed impact.
- A tennis racket frame should be designed to resist the impact of a tennis ball and yet flex somewhat.

…. Types of Dynamic Analyses

Choosing the appropriate type of dynamic analysis depends on the type of input available and the type of output desired.

Type	Input	Output	Nonlinear
Modal	none	• natural frequencies and corresponding mode shapes • stress/strain profile	No
Harmonic	sinusoidally-varying excitations across a range of frequencies (“sine sweep”)	• sinusoidally-varying response at each frequency • min/max response over frequency range	No
Spectrum	spectrum representing the response to a specific time history (Amplitude/Hz)	• maximum response if the model were subjected to the time history	No
Random	Power spectrum representing probability distribution of excitation (PSD, $\text{Amplitude}^2/\text{Hz}$)	• probability distribution of response	No
Transient	time-varying loads (seconds, ms)	• time-varying response	Yes

…. Types of Dynamic Analyses

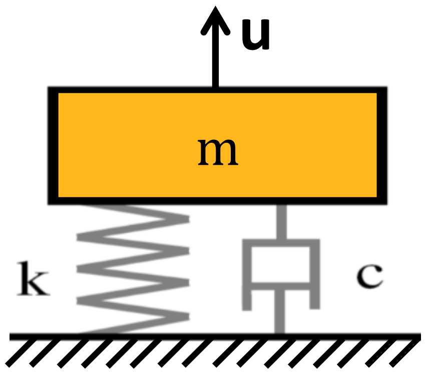
Below are three general categories (Shock, Vibration, and Free Vibration) that we often hear of referring to Dynamics, along with typical keywords. We can usually determine the proper Ansys analysis from these keywords…

Category	Keywords	Analysis Type
Shock	• G's • G-Loads • RMS G's	Static Analysis
	• Drop test • Rail impact • Drop shock • 30ms half sine	Transient Analysis
Vibration	• Earthquake • Seismic • SRSS • Spectrum • Response Spectrum	Response Spectrum Analysis
	• Sine Sweep • Frequency Sweep • Rotating Imbalance	Harmonic Analysis
Free Vibration	• Resonance • Modes • Mode Shapes • Fundamental Frequency • Natural Frequency	Modal Analysis

C. General Equation of Motion

- The non-linear governing equation for the Transient Dynamic Analysis is:

$$\underbrace{[M]\{\ddot{u}\}}_{F_{\text{inertia}}}+\underbrace{[C]\{\dot{u}\}}_{F_{\text{damping}}}+\underbrace{[K(u)]\{u\}}_{F_{\text{stiffness}}}=\underbrace{\{F(t)\}}_{F_{\text{applied}}}$$



[M]: is structural mass matrix

[C]: is structural damping matrix

[K]: is structural stiffness matrix

{F}: is the load vector

$\{\ddot{u}\}$: is nodal acceleration vector

$\{\dot{u}\}$: is nodal velocity vector

{u}: is nodal displacement vector

(t): is time

…. General Equation of Motion

$$\overbrace{[M]\{\ddot{u}\}}^{F_{\text{inertia}}}+\overbrace{[C]\{\dot{u}\}}^{F_{\text{damping}}}+\overbrace{[K(u)]\{u\}}^{F_{\text{stiffness}}}=\overbrace{\{F(t)\}}^{F_{\text{applied}}}$$

Nonlinearity

- Sources of Nonlinearity
  - large deflection
  - nonlinear contact
  - material nonlinearity

- Nonlinearity is allowed only in a *full transient* analysis.

D. Basic Concepts and Terminology

Free Vibration:

takes place when a system oscillates in the absence of external forces.

Natural Frequency:

a system under free vibration will vibrate at one or more of its natural frequencies. A natural frequency is a property of the dynamic system established by its mass and stiffness distribution.

Forced Vibration:

vibration that takes place under external forces.

…. Basic Concepts and Terminology

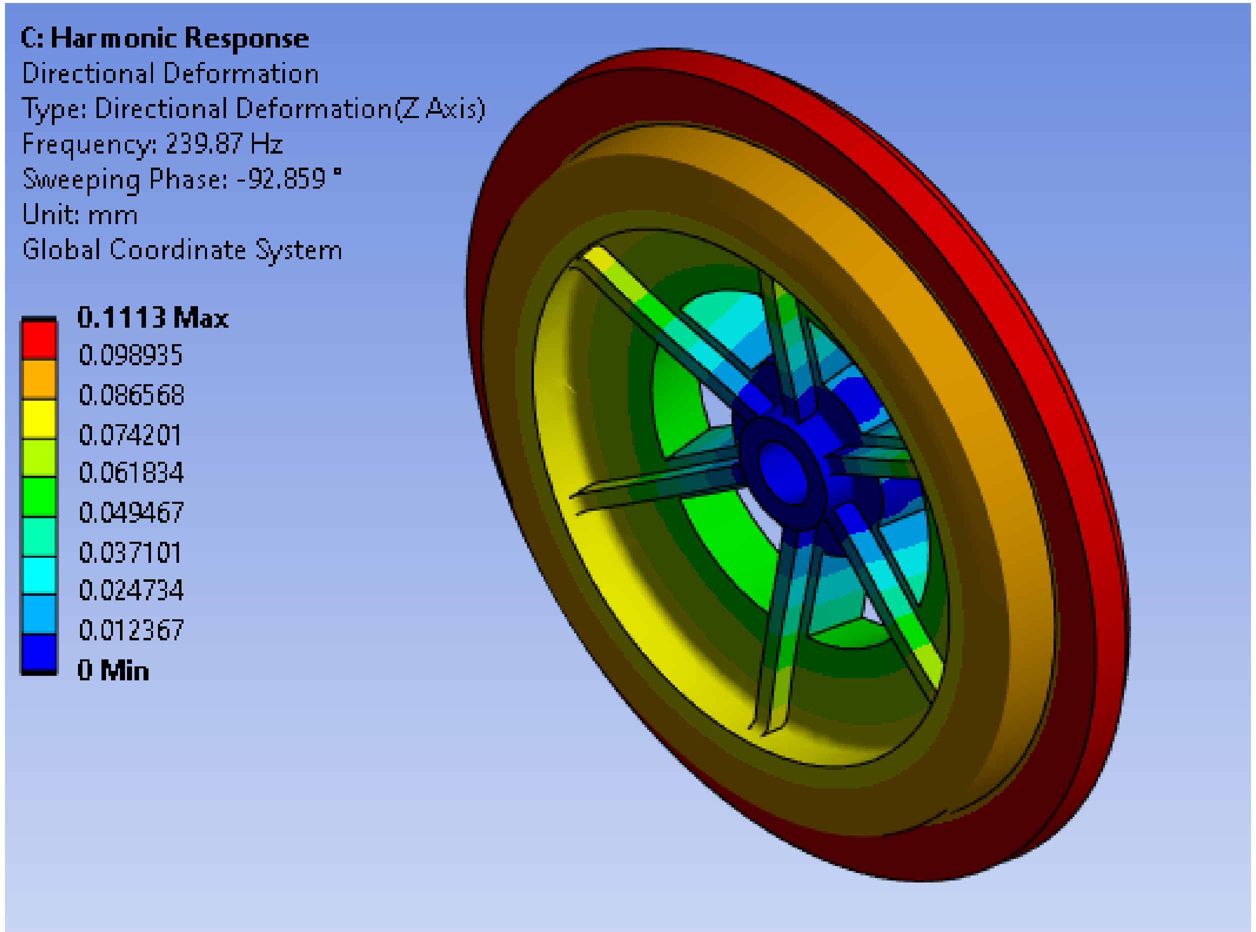
Resonance:

in forced vibration, when the force is oscillatory, the system is forced to oscillate at the excitation frequency. If the frequency of excitation coincides with one or more of the natural frequencies, resonance occurs.

Damping:

is an energy-dissipation mechanism that causes vibrations to diminish over time and eventually stop. If damping is small, it has very small influence on the natural frequencies.

Workshop 01.1: Flywheel



Ansys

End of presentation