Repetitive Impact Response of Multiple Beam Structures Through Constraint and Modal Mapping Methods

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MFDL

Executive Summary

This work analytically investigates the repetitive impact dynamics of two orthogonal pinned-pinned beams subjected to base excitation at specified frequency and acceleration.

MOTIVATION

Applications:

Mechanical components in such industries as

- nuclear (steam generator tubes, reactor rods)
- petroleum (drillstrings, piping systems)
- biomedical (artificial heart valves)
- automotive (transmission gear sets)

Consequences:

Mechanical, thermal, or chemical damage as noise, wear, damage, fracture, fatigue, collapse through fretting, adhesion, abrasion, spalling, pitting, and plastic flow

OBJECTIVES

- Examine impact-driven vibration
- Predict beam response
- Determine major response factors through parameter studies

METHODOLOGY

→ The vibration is described in a piecewise fashion as switching between the linear in-contact and not-in-contact states.

→ Compatibility conditions are applied at junctions.

→ The model is discretized through the subset of N modes Φ in each state such that

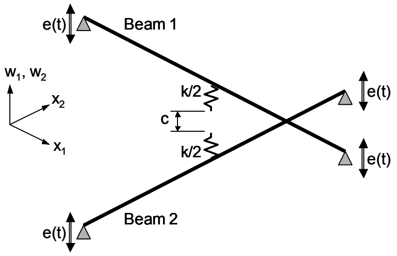
$$\underline{u}^{(j)}(x,t) \approx \sum_{m=1}^{N} \eta_m^{(j)}(t)\,\underline{\phi}_m^{(j)}(x)$$

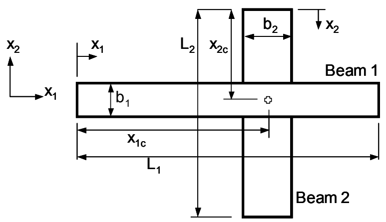
where

$$\ddot{\eta}_m^{(j)} + 2\xi^{(j)}\omega_m\dot{\eta}_m^{(j)} + \omega_m^2\eta_m^{(j)} = \langle \underline{f}, \underline{\phi}_m^{(j)} \rangle$$

MODEL

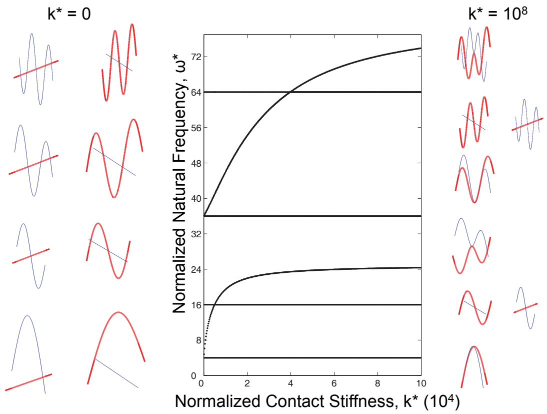
- 2 orthogonal Euler-Bernoulli beams
  - → Parameters b, h, A, E, I, L
  - → Deflection, w(x,t)
  - → Contact stiffness, k
  - → Deadband clearance, c
- Single point of linear spring contact
- Pinned end conditions
- Base excitation, $e(t) = e_o \sin \omega t$





CONJOINED MODE SHAPES

Natural Frequencies and Mode Shapes



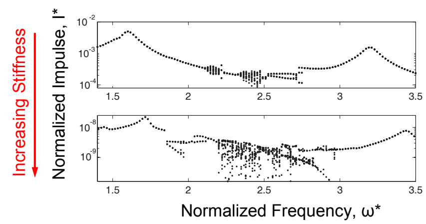
SIMULATION

- Numerical solution for response is calculated using MATLAB.
- Repetitive Impact Frequency Response Functions are generated for the steady-state motion by capturing the contact impulse.
- The minimum numbers of required modes to reach a relative convergence are used.

Sample Results

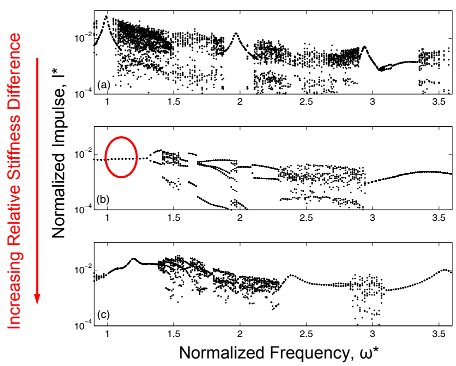
Contact Stiffness

→ As k increases, the structure of the repetitive impact frequency response functions also increases in sophistication.



Relative Beam Stiffness

→ For $E_1I_1/(E_2I_2)$ = ½, a minor anti-resonance exists, signifying passive vibration control targeted at specific excitation frequencies.



RESULTS AND CONCLUSIONS

- The responses will include such phenomena as
  - →system resonance
  - →harmonic resonance
  - →bifurcation
  - →grazing impact
  - →aperiodicity
- The response complexity is strongly affected by
  - →contact stiffness
  - →relative beam stiffness

  but weakly affected by
  - →damping
  - →clearance
  - →acceleration
- Proper selection of relative beam stiffness creates passive vibration control.

FUTURE WORK

- Experimental studies verifying trend behavior
- New numerical studies are also required to model experiment apparatus
- Expanded cases will be examined such as
  - →Shock and ballistic loading
  - →Parallel beams
  - →Composite materials

OUTCOMES

Publications

E. K. Ervin, “Repetitive Impact in Continuous Structures.” Mid-South Area Engineering & Sciences Conference, May 17-18, 2007, Oxford, MS, MAESC10050, 2007.

E. K. Ervin, “Repetitive Impact Between Two Orthogonal Beams.” 18th Engineering Mechanics Division Conference of the American Society of Civil Engineers, June 3-6, 2007, Blacksburg, VA.

E. K. Ervin, “Repetitive Impact Between Orthogonal Beams, Part I: Theory.” *ASCE Journal of Engineering Mechanics* (submitted).

E. K. Ervin, “Repetitive Impact Between Orthogonal Beams, Part II: Simulation.” *ASCE Journal of Engineering Mechanics* (submitted).

E. K. Ervin, planned paper, "Dynamics of Nonlinear Structures with Contact Interfaces," The 8th World Congress on Computational Mechanics, Venice, Italy, June 30 – July 5, 2008.

Proposals

1/24/07 National Science Foundation Major Research Instrumentation Program, “MRI: Acquisition of Equipment for the Multi-Function Dynamics Laboratory.” $1,103,110; Status: Declined.

2/2/07 Oak Ridge Associated Universities Ralph E. Powe Junior Faculty Enhancement Award, “Repetitive Impact Response of Multiple Beam Structures through Constraint and Modal Mapping Methods.” $10,000; Status: Awarded.

7/18/07 National Science Foundation CAREER Award, “CAREER: Research and Education in Coupled Motion through the Multi-Function Dynamics Laboratory.” $402,147; Status: Pending.