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A novel forced motion apparatus with potential applications in structural engineering

Key words: Forced motion apparatus; Coupled vibration; Stochastic vibration simulation; Aerodynamic force; Frequency multi-plication; Memory effects; Wind engineering; Potential applications

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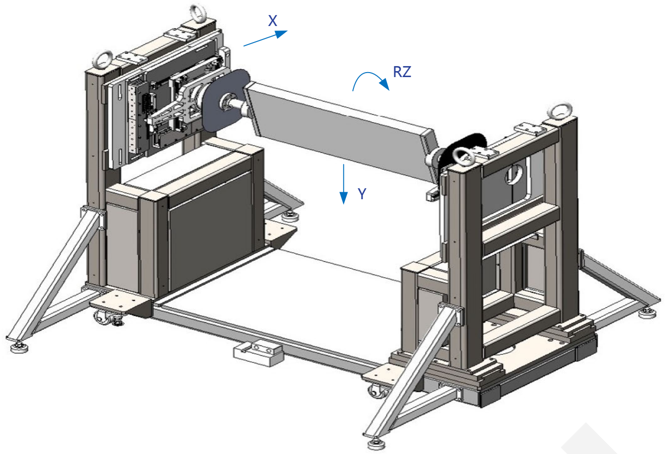
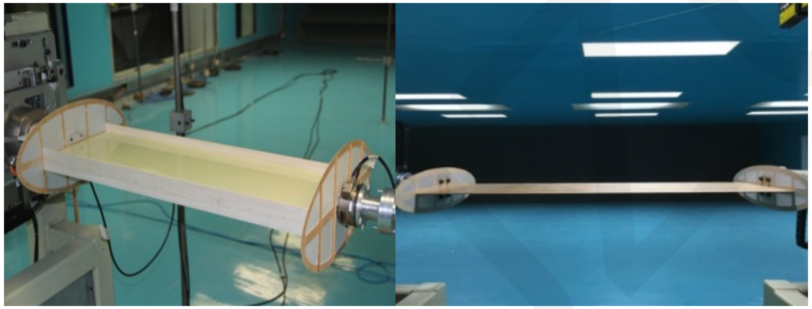
A novel forced motion apparatus

Introduction



a) Schematic of FMA



b) The H-shaped section model; The flat section model

Fig. 2 Images of the novel FMA

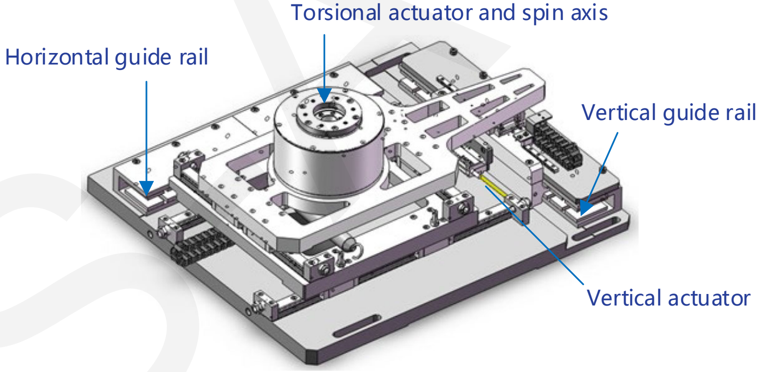


Fig. 3 Driving and decoupling systems of three DOFs

Property parameter	Value
Total weight	1t
Lateral displacement	±50mm
Vertical displacement	±50mm
Torsional displacement	360°
DOFs	Single or coupled
Displacement adjustment resolution	continuous
Frequency adjustment resolution	continuous
Time interval for reading signal	10ms
Motion type	Random

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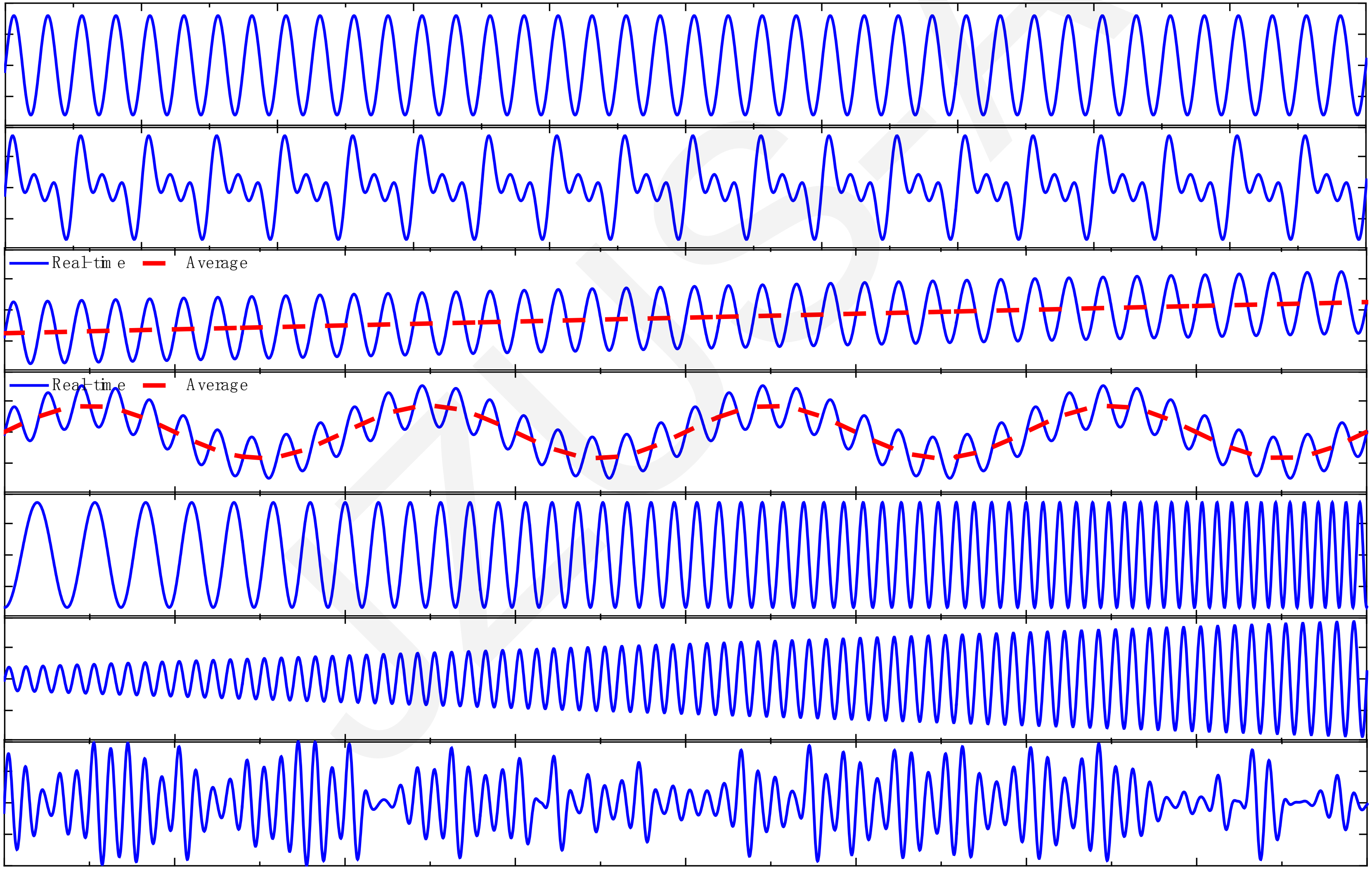
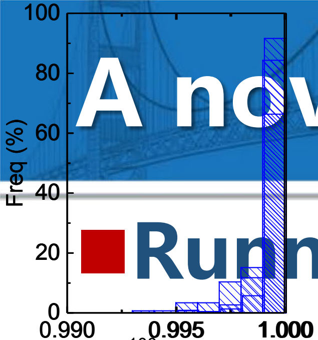
■Motion types





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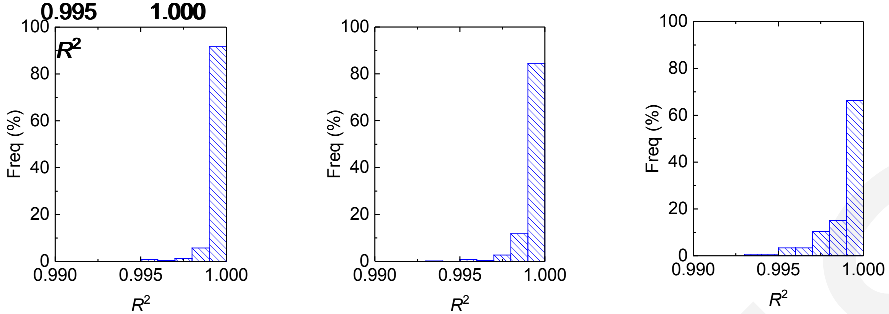
Running accuracy



X Y RZ

Fig. 6 R^2 value distributions under various types of motion

$$R^2 = 1 - \frac{\sum_{i=1}^{n} \left(y_{u=0,i} - \widehat{y}_{u=U,i} \right)^2}{\sum_{i=1}^{n} \left(y_{u=0,i} - \overline{y}_{u=0} \right)^2},$$

$$\overline{y}_{u=0} = \frac{1}{n} \sum_{i=1}^{n} y_{u=0,i},$$

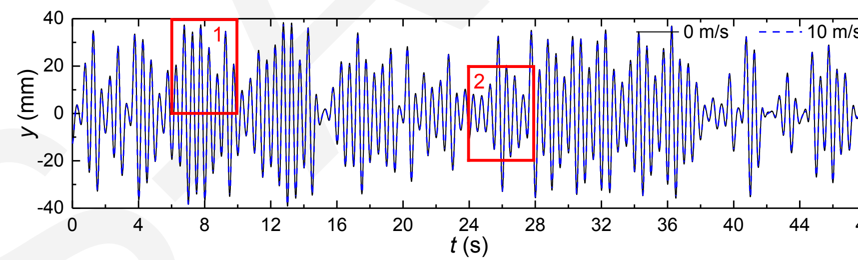


Fig. 7 Running accuracy under different wind velocities

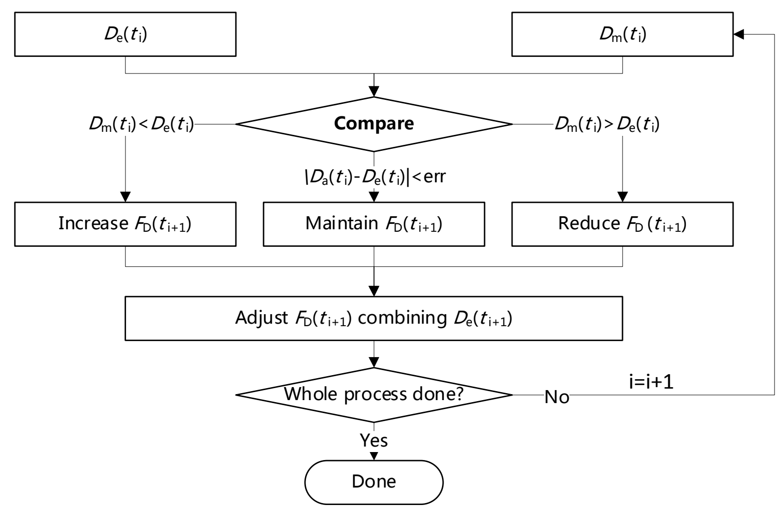
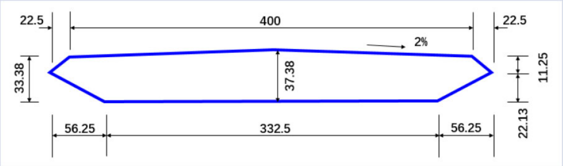


Fig. 5 Closed-loop PID feedback system for running accuracy

Identification of flutter derivatives

■Running accuracy

Table 3 Criteria, confidence interval and comparison objects of flutter derivatives (unit: mm)

Section type	The lower limit of R^2	Confidence interval	Comparison objects	Comparison section
Box girder	0.90	95%	Wind tunnel tests Chen(Yang et al., 2005)	
			Wind tunnel tests (Niu, 2007)	
			CFD (Ying, 2017)	

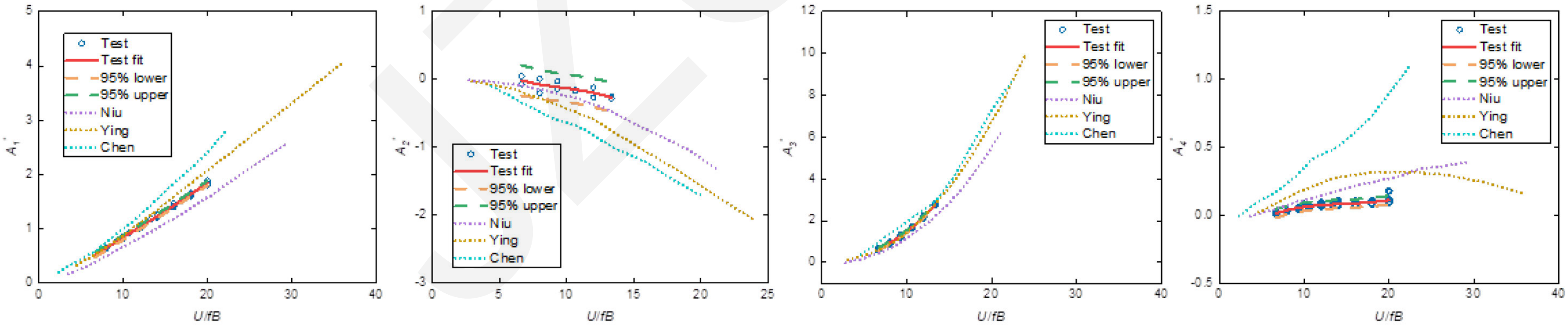


Fig. 8 Identification results of flutter derivatives of a typical box girder section

Extended application

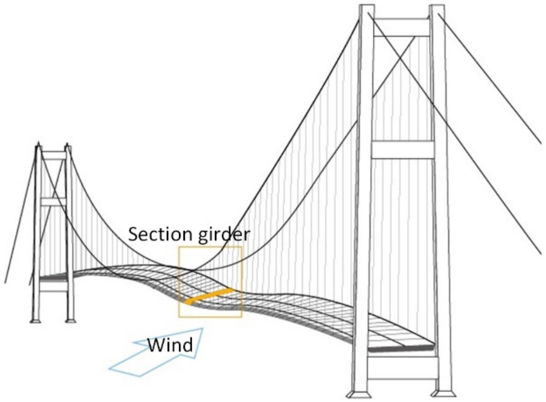


Fig. 9 Amplitude-dependent aerodynamics of a long-span bridge under a stochastic wind field

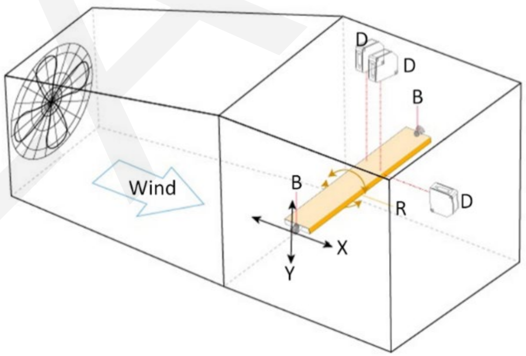


Fig. 10 Application to the study of aerodynamic forces on a bluff body

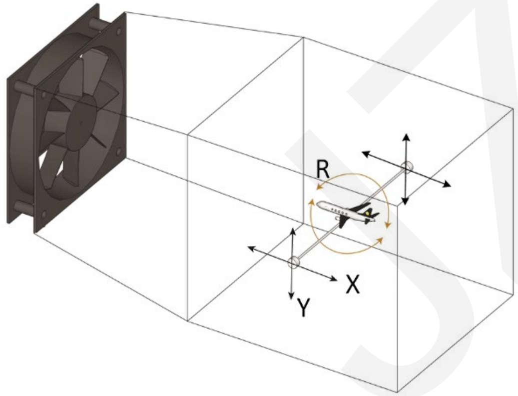


Fig. 11 Application to the study of the aerodynamics of flying aircraft

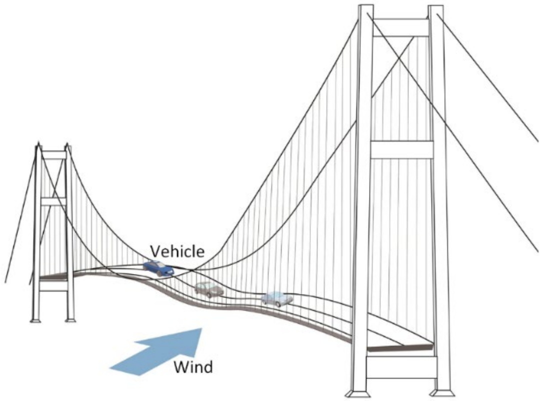


Fig. 14 Vehicle-bridge-wind coupling problem

Extended application

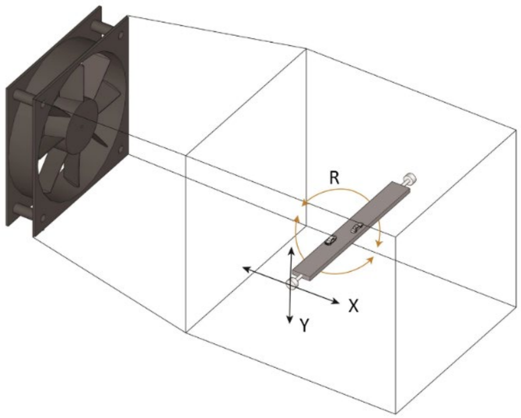


Fig. 15 Application to vehicle-bridge-wind coupling analysis

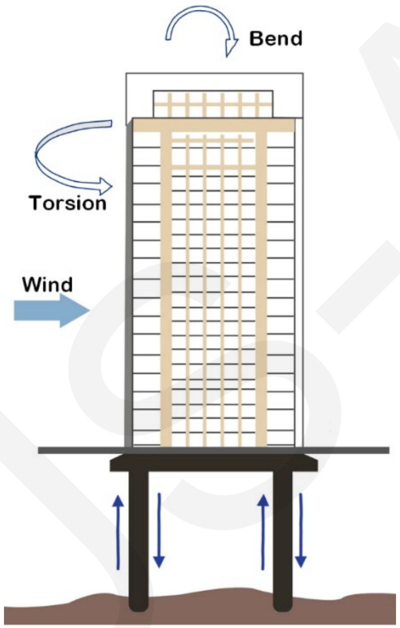


Fig. 16 Pile-soil interaction considering wind effect simulation excitation

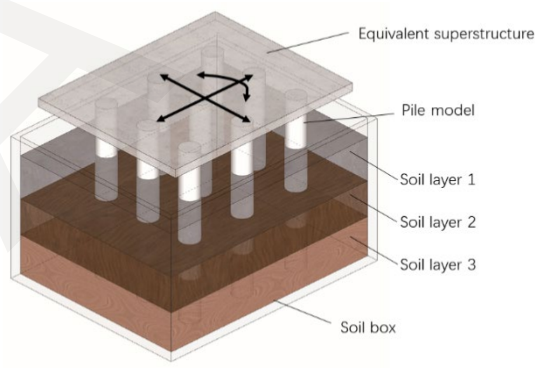


Fig. 17 Application to the study of pile-soil interaction under simulation excitation

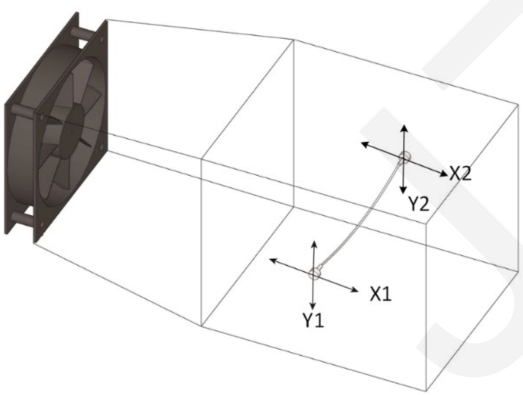


Fig. 19 Application to line-tower coupled vibration considering boundary simulation movement

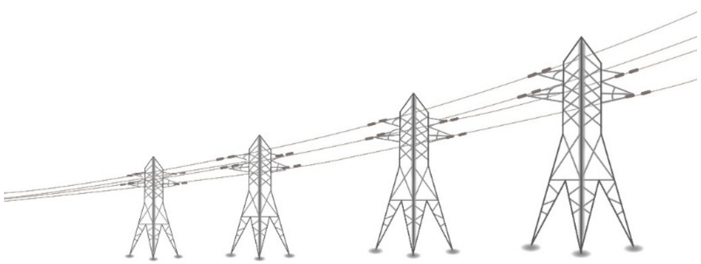


Fig. 18 Interaction between transmission towers and lines

Conlusions

- An FMA has been developed based on the PID control algorithm to simulate different forms of wind-induced vibrations.
- Various motion types are realized in individual DOFs and coupling three DOFs, including stationary and nonstationary DOFs.
- Running accuracy is verified under different external obstructions by tests for a variety of wind loads and different driven weights.
- The rationality of the application of the FMA in the wind engineering field has been verified by identifying and comparing the flutter derivatives of a box girder section.
- Simulation of various motion types paves the way for its application in structural wind engineering, including nonstationary aerodynamic forces, vehicle-bridge-wind coupling vibration, pile-soil interaction and line-tower coupled vibrations.