International Conference on Engineering Vibrations
Aberdeen, Scotland, 14 – 16 December 2020

RESONANCE VIBRATIONS OF THE NON-IDEAL SYSTEM HAVING THE MISES GIRDER AS ABSORBER

Yuri Mikhlin[1], Anton Onizhuk[2]
[1] *National Technical University “KhPI”, Kharkiv, Ukraine,* Yuri.Mikhlin@gmail.com
[2] *A.Pidgorny Institute for Mechanical Engineering Problems, National Academy of Science, Kharkiv, Ukraine*

ABSTRACT

The systems with a limited power supply are characterized by interaction of source of energy and elastic sub-system which is under action of the source. Such systems are named also as the non-ideal systems (NIS). The most important effect observed in the NIS is the Sommerfeld effect [1], when the large amplitude regime is appeared in the elastic sub-system, and the large part of the vibration energy passes from the energy source to the resonance vibrations. Resonance dynamics of such systems was first analytically described by V.O.Kononenko [2]. Investigations on the subject were continued in different publications. In particular, overviews on numerous studies of the non-ideal systems dynamics can be found in [3,4]. Here a resonance behavior of NIS containing the source of energy, the linear sub-system and the nonlinear absorber (Fig.1), is analyzed by the multiple scales method. The snap-through truss is chosen as absorbers. Two resonance regimes of vibrations are considered, namely, the resonance between the linear sub-system and the motor, and the resonance between the absorber and the motor. The multiple scales method is used to describe the system resonance behavior. Corresponding frequency responses are constructed. The snap-through motions and outcome from the resonance behavior in the system are considered too.

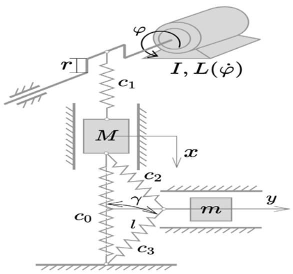


Figure 1: Non-ideal system having Mises girder as absorber

Keywords: Non-ideal system, Mises girder, Resonance vibrations...

[1] Zommerfeld, A. 1902 Beitrage zum dynamichen ausbau der festigkeitslehe*. Physical Zeitschr.* 3: 266-286.

[2] Kononenko, V.O. 1969 *Vibrating Systems with Limited Power Supply*. London: Illife Books.

[3] Eckert, M. 1996 The Sommerfeld effect: theory and history of a remarkable resonance phenomenon. *European J. of Physics* 17 (5), 285-289.

[4]Balthazar, J.M. 2018 An overview on the appearance of the Sommerfeld effect and saturation phenomena in non-ideal vibrating systems (NIS) in macro and micro scales. *Nonlinear Dynamics* 93 (1), 19-40.

[5]Mikhlin, Yu., Onizhuk, A., and Awrejcewicz, J. 2020 Resonance behavior of the system with a limited power supply having the Mises girder as absorber. *Nonlinear Dynamics* 99 (1), 519-536.

International Conference on Engineering Vibrations
Aberdeen, Scotland, 18 – 21 August 2020

VORTEX-INDUCED VIBRATIONS OF RISERS IN OCEANS CURRENTS

Victoria Kurushina[1,2], Ekaterina Pavlovskaia[3]
[1] *Centre for Perspective Research and Innovative Development, Industrial University of Tyumen,*
38 Volodarskogo Street, Tyumen, 625000, Russia, kurushinava@tyuiu.ru
[2] *School of Engineering, Newcastle University, Newcastle-upon-Tyne, United Kingdom, NE1 7RU,*
victoria.kurushina@newcastle.ac.uk
[3] *Centre for Applied Dynamics Research, University of Aberdeen, King's College, Aberdeen, AB24 3FX,*
United Kingdom, e.pavlovskaia@abdn.ac.uk

ABSTRACT

Dynamic behaviour of structures of an increased aspect ratio in a fluid flow depends on the flow velocity profile along the length, and it is important to consider its possible variations. In this work, the model of vortex-induced vibrations of risers [1, 2] previously proposed to describe the structural dynamics in the uniformed flow is developed for non-uniformed flows. The considered structure, shown in Fig. 1a, has pinned connections and is free to oscillate in both in-line and cross-flow directions, subjected to both linear and nonlinear velocity profiles, as in Fig. 1b. The dimensionless vortex shedding frequency $\Omega_R(\zeta)$ is considered varying with the dimensionless coordinate ζ along the length and constant in time, or:

$$\Omega_R(\zeta) = St(U_R(\zeta) - K), \tag{1}$$

where $U_R(\zeta)$ is the height-dependent profile of the reduced velocity, St stands for the constant Strouhal number, and K is the empirically defined delay coefficient.

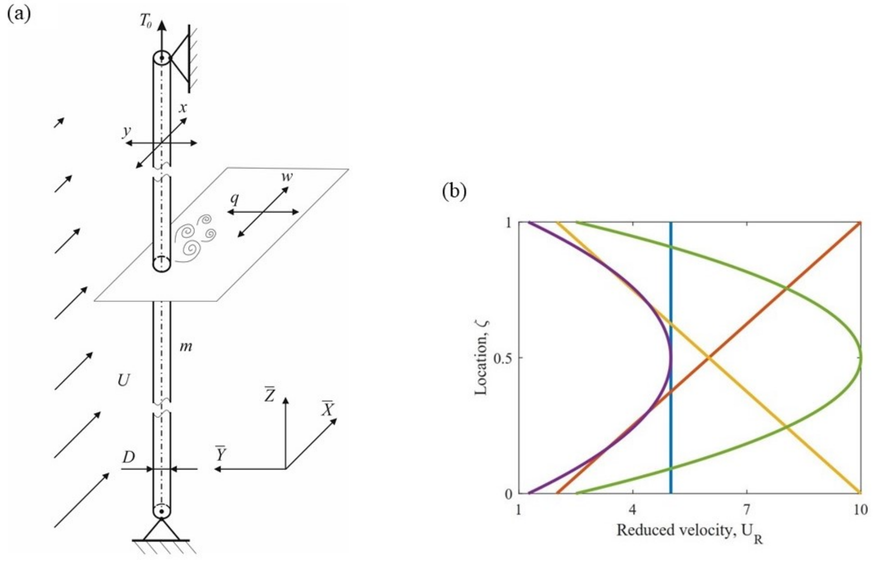


Figure 1: Flexible riser and sheared flow model: a) vortex-induced vibrations of flexible structure in sheared flow; b) reduced velocity variation along the axial coordinate ζ.

The integral of the velocity profile $U_R(\zeta)$ is incorporated into modal interaction coefficients obtained during the Galerkin procedure. The system of equations includes Krenk-Nielsen - van der Pol and van der Pol oscillators in order to model lift and drag force fluctuations coupled with the structural motion. The system is solved with the ode45 MATLAB solver, and the results show changes in the predicted dynamics of a flexible structure with a high aspect ratio related to the flow velocity variations and tension effects.

Keywords: Vortex-induced vibrations, Flexible risers, Pipeline dynamics, Ocean currents, Sheared flow

[1] Pavlovskaia, E. and Keber, M. and Postnikov, A. and Reddington, K. and Wiercigroch, M. 2016 Multi-modes approach to modelling of vortex-induced vibration. *International Journal of Non-Linear Mechanics* **80**, 40-51.

[2] Kurushina V., Pavlovskaia E., Wiercigroch M. 2020 VIVs of flexible structure in 2D uniform flow. *International Journal of Engineering Science* **150**, 103211.

SUPPRESSION OF RESONANCE VIBRATIONS OF RECTANGULAR PLATE INTERACTING WITH FLUID

Alexander Kamenskikh[1], Sergey Lekomtsev[1], Maksim Iurlov[1]
Institute of Continuous Media Mechanics, Ural Branch Russian Academy of Sciences, Acad. Korolev str., Perm, Russian Federation, 614013, lekomtsev@icmm.ru

ABSTRACT

Thin plates have found their application in modern engineering structures, which are in contact with a fluid or completely immersed in it. Often they are important components and operate under conditions of high loads, vibrations or seismic forces. The risk of resonance phenomena generates the need to monitor the current conditions of the object, and to control the occurring dynamic processes. This will prevent emergency situations causing instant or fatigue failure of the structure. For known and time-constant frequency of external excitation or self-exciting undamped vibrations, their effective suppression can be achieved by the application of oppositely directed external harmonic force or using piezoelectric shunt damping technology. The advantage of the last approach is the possibility of executing continuous control of the dynamic behavior of structures, including underwater constructions.

The effect of the added mass and dissipative mechanism arising from the hydroelastic interaction can significantly affect the dynamic processes occurring in the structures. In this work, the influence of the above factors on the efficiency of damping the resonance vibrations of a rectangular plate interacting with quiescent fluid is studied experimentally. The vibrations are excited by an electromagnetic force, which is generated by the interaction of a light neodymium magnet glued to the bottom surface of the plate and a coil located in the neighborhood. To reduce the amplitude of resonant vibrations we used the piezoelectric element glued to the opposite (underwater) surface of the plate and connected to the electrical impedance in the form of external passive electric circuit. The study was carried out in several steps. First, we determined the natural frequencies of the structure vibrations for the operating modes of the piezoelectric element with open-circuited and short-circuited electrodes. Then, the results of numerical simulation [1] or analytical calculations [2] were used to select the values of the resistance and inductance parameters of the external *RL*-circuit, which provided the most effective damping of harmonic vibrations at a given frequency. The physical coil in the shunt circuit was replaced by a compact inductance equivalent circuit — a gyrator. Its main function is to make the input voltage and current of the circuit behave like the voltage and current in an inductor using for this purpose a capacitor and operational amplifiers. At the final stage, forced harmonic vibrations of the plate were excited. The Polytec PDV-100 laser vibrometer was used to measure the velocity at a reference point on the surface of the structure before and after the piezoelectric element was connected to a shunt circuit.

The experimental studies have shown that the resonant vibrations of the plate interacting with fluid layer cannot be completely suppressed by means of a piezoelectric element connected to an external passive electric circuit. The efficiency of damping decreases more than twice as the height of the fluid layer increases. The variants of attaching different types of piezoelectric elements to the structure surface are analyzed. It has been found that the application of a thin layer of viscous glue eliminates most of the positive effect. As an alternative, we consider the case when a piezoelectric element is connected to an alternating voltage source rather than to a shunt circuit. By selecting its amplitude at a frequency known in advance or determined by the device, it is possible to achieve almost complete suppression of vibrations.

The study was supported by the grant of the Russian Scientific Foundation (project No. 18-71-10054).

Keywords: Fluid-structure interaction, Vibrations damping, Plate, Shunted piezoelectric element.

[1] Matveenko, V. P., Iurlova, N. A., Oshmarin, D. A., Sevodina, N. V. and Iurlov, M. A. 2018 An approach to determination of shunt circuits parameters for damping vibrations. *International Journal of Smart and Nano Materials* **9**, 135–149.

[2] Hagood, N. W. and von Flotow, A. H. 1991 Damping of structural vibrations with piezoelectric materials and passive electrical networks. *Journal of Sound and Vibration* **146**, 243–268.

International Conference on Engineering Vibrations
Aberdeen, Scotland, 18 – 21 August 2020

NUMERICAL BIFURCATION ANALYSIS OF AN OSCILLATING AEROFOIL UNDER NOISE-LOAD

Sandor Beregi[1,2], David A. W. Barton[1], Djamel Rezgui[1], Simon A. Neild[1]
[1] *Faculty of Engineering, University of Bristol*
[2] *sandor.beregi@bristol.ac.uk*

ABSTRACT

Tracing steady-state solutions in nonlinear experiments or stochastic numerical models is a challenging task as the standard techniques of bifurcation analysis, such as numerical continuation, cannot be directly employed. Furthermore, the random perturbation may result in a loss of information about the underlying deterministic system.

In our study, we employ control-based continuation (CBC) to investigate the dynamics of a numerical model of an aerofoil with pitch and heave degrees-of-freedom [1]. This model is capable to capture the self-excited oscillations associated with aeroelastic flutter and can predict the critical airspeed corresponding to the stability boundary. It can also feature a subcritical Hopf bifurcation, generating a region of airspeeds where two coexisting stable steady-state solutions occur for the same set of parameters: an equilibrium and a large amplitude limit cycle.

Since flutter involves a highly unsteady airflow around the aerofoil, often considerable process noise occurs in experiments. In our numerical model, this is emulated by considering a Langevin-type stochastic moment acting on the aerofoil.

Studying a periodically forced oscillator, Schilder et al. [2] addressed the challenges of tracing periodic solutions in the presence of noise by making their algorithm robust against random perturbations while they perform continuation directly on the noise-polluted experiment. In contrast, our aim is to use a representative surrogate model of the stochastic process and to include parameter identification as part of the continuation algorithm. Thus, we perform nonlinear root finding on a deterministic model, regularly updated to ensure accordance with the modelled process instead of directly using the noise-polluted time-profiles from the simulation of the stochastic system.

As shown in Fig. 1, the presence of noise affects the bifurcation diagram by resulting in a drift from the deterministic equilibria and limit cycles. Having a deterministic surrogate model of the stochastic process can help to capture the deterministic response more accurately while it may also reveal more information about the solutions by determining their stability or identifying bifurcations, which may not be possible to extract robustly based on the noise-polluted time-profiles.

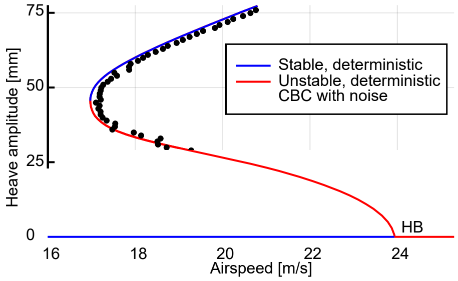


Figure 1: Bifurcation diagram of the deterministic and stochastic models of aeroelastic flutter.

Keywords: control-based continuation, flutter, process noise, surrogate model, bifurcation analysis.

[1] Dimitriadis, G. 2017 *Introduction to Nonlinear Aeroelasticity*, Chichester: John Wiley & Sons.

[2] Schilder, F., Bureau, E., Santos, I.F., Thomsen J.J. and Starke J. 2015 Experimental bifurcation analysiscontinuation for noise-contaminated zero problems. *Journal of Sound and Vibration* **358**, 251–266.

International Conference on Engineering Vibrations
Aberdeen, Scotland, 18 – 21 August 2020

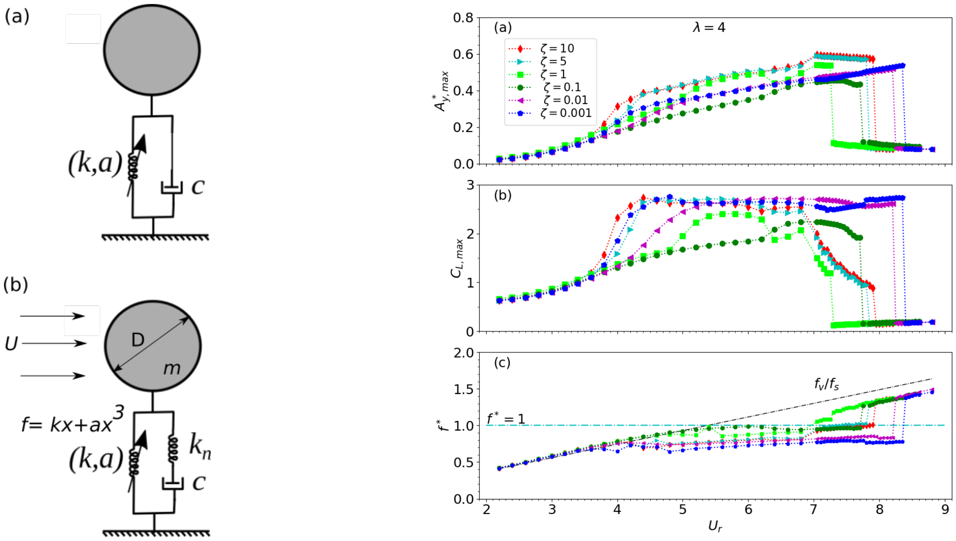
EFFECT OF DAMPING ON VORTEX-INDUCED OF A CIRCULAR CYLINDER ON THE NONLINEAR SPRING SUPPORT

Rahul Mishra [1],[2], Rajneesh Bhardwaj[1], Salil S. Kulkarni[1], Mark C. Thompson[2]
[1] *Department of Mechanical Engineering, IIT Bombay, Mumbai, Maharashtra, 400076, India*
[2] *Department of Mechanical and Aerospace Engineering, Monash University, Clayton 3800, Australia*

ABSTRACT

Vortex-induced vibration (VIV) occurs when shedding vortices (a von Karman vortex street) exert oscillatory forces on a cylinder in the direction perpendicular to both the flow and the structure. Effect of damping on vortex-induced vibration of circular cylinder supported on non-linear spring have been studied numerically for the fixed mass ratio ($m^* = 2.546$) at Reynolds no, $Re = 150$. For the classic case where structure support is made of spring and damper in parallel (fig. 1(i) (a)), this study consider two spring and one damper system as shown in fig. 1(i) (b), motivated by SLS (standard linear solid) model of viscoelastcity [1]. The non linear structural system is governed by the following three parameters: (a) the ratio of springs constant ($R = k_n/k$), (b) damping ratio ($\zeta = c/\sqrt{km}$), and (c) non-linearity strength($\lambda = -D/\sqrt{-k/a}$) [2]. The VIV response of a circular cylinder in uniform flow is characterized by the Reynolds number ($Re = UD/\nu$), the mass ratio, the damping ratio and the reduced velocity($U_r = U/f_sD$), where f_s is the natural frequency of nonlinear structural system. The damping effect on VIV response shows the non-monotonic variation with ζ.

Fig. 1(ii) (a) shows amplitude of cylinder displacement, $A^*_{y,max}$ increases continuously upto maximum value and suddenly drop with U_r, the location of peak amplitude non-monotonically vary with ζ. The peak amplitude for $\zeta = 0.001$ occurs at $U_r = 8.4$, decreases to $U_r = 7.2$ for $\zeta = 1$, and further increases to $U_r = 8$ for $\zeta = 10$. Fig. 1(ii) (b) shows the peak lift coefficient, $C_{L,max}$ with U_r. Peak lift coefficient is nearly constant for higher amplitude region and the range of U_r corresponding to peak vary non monotonically with ζ. Fig. 1(ii) (c) shows the the normalised frequency (f^*_y), ratio of vibration frequency to the natural frequency of nonlinear damped system. The range of U_r for $f^*_y \approx 1$, is known as the lock-in region. The results show the maximum amplitude, peak lift coefficient and constant frequency value is non-monotonic with damping, contrary to the classic case of VIV (fig. 1(i) (a)) where these parameters monotonically decreases with damping.



(i) Schematic of the structural model

(ii) (c) Amplitude of displacement, $A^*_{y,max}$; (d) Peak lift coefficient, $C_{L,max}$;(e) Normalised frequency, f^*.

Figure 1: Structural model and VIV response

Keywords: Fluid-Structure Interactions, Vortex-induced vibration, Cubic stiffness non-linearity, Damping

[1] Mishra, R., Kulkarni, S. S., Bhardwaj, R., Thompson, M. C., 2019 Response of a linear viscoelasticsplitter plate attached to a cylinder in laminar flow. *Journal of Fluids and Structures* **87**, 284–301.

[2] Mackowski, A., Williamson, C., 2013. n experimental investigation of vortex-induced vibrationwith nonlinear restoring forces. *Physics of Fluids* **25** **(8)**, 087101.

International Conference on Engineering Vibrations
Aberdeen, Scotland, 18 – 21 August 2020

INVARIANT MANIFOLD FOR THE ANALYSIS OF FLEXIBLE CYLINDERS UNDER VORTEX-INDUCED VIBRATIONS

Guilherme J. Vernizzi[1,2], Stefano Lenci[2], Guilherme R. Franzini[3]

[1] *Offshore Mechanics Laboratory - LMO, Escola Politécnica, University of São Paulo, Brazil, guilherme.jorge.lopes@usp.br*

[2] *Università Politecnica delle Marche, Ancona, Italy, lenci@univpm.it*

[3] *Offshore Mechanics Laboratory - LMO, Escola Politécnica, University of São Paulo, Brazil, gfranzini@usp.br*

ABSTRACT

Vortex-induced vibration (VIV) is a self-induced and self-sustained resonant phenomenon that can be commonly observed in the very slender structures found in the offshore engineering. A review of some topics of research concerning VIV can be found in [1]. From the mathematical point of view, a possible way to model VIV is by coupling a wake-oscillator to the equations of motion of the structure. In the present work, the wake-oscillator model presented in [2] is used in an extended manner, being applied to flexible cylinders. The goal of this paper is to derive invariant manifolds for the system of ordinary differential equations of motion of the problem, obtained from a Galerkin procedure over the equations of motion in the continuum. In [3], the invariant manifold approach is applied to the structural part of the equations of motion only. In [4], VIV of a rigid and elastically mounted cylinder is investigated and a manifold is obtained to represent the wake-oscillator, however being limited to very high structural damping ratios. The present work is an extension of those previous developments. In Fig. 1, the results obtained using the invariant manifold for the wake variable and a direct integration of the system of equations are compared to show the agreement. It is possible to see that the results are in good agreement in the amplitude of response, with a small difference in the oscillation frequency. Further results can then be explored using the invariant manifolds.

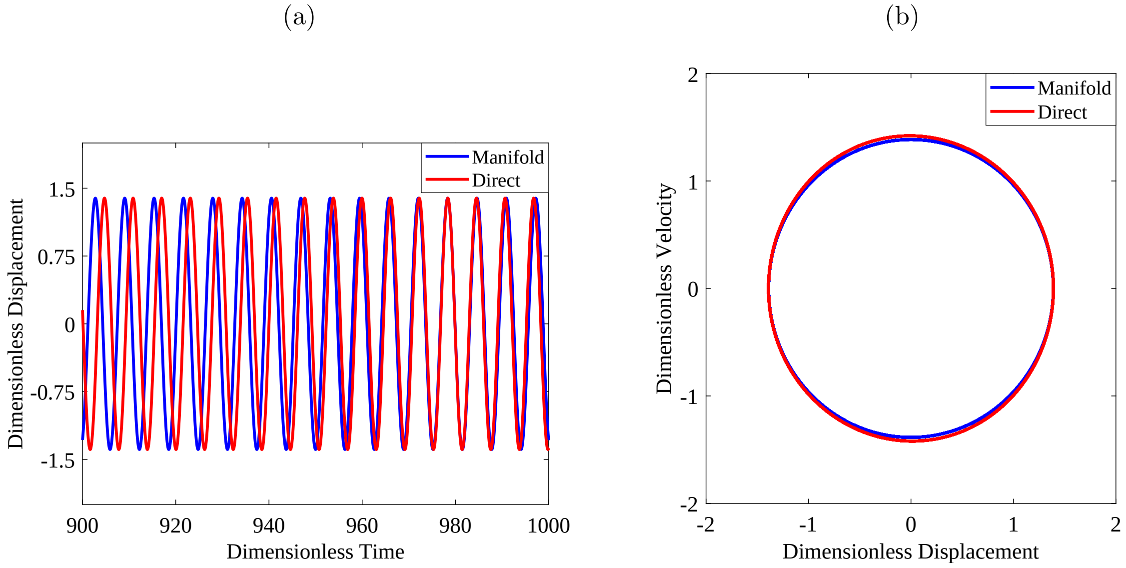

(a) (b)

Figure 1: (a) Comparison of the time-series of the transversal displacement of the cylinder. Direct integration of the differential equations and manifold solution; (b) Comparison of the phase space for the transversal displacement and velocity of the cylinder. Direct integration of the differential equations and manifold solution

Keywords: Invariant manifolds, Flexible slender cylinder, Vortex-induced vibration.

[1] Wu, X., Ge, F., Hong, Y. 2012 A review on recent studies of vortex-induced vibrations of long slender cylinders, *Journal of Fluids and Structures*, **28**, 292-308.

[2] Facchinetti, M.L., de Langre, E., Biolley, F. 2004 Coupling of structure and wake oscillators in vortex-induced vibrations, *Journal of Fluids and Structures*, **19**, 123-140.

[3] Keber, M., Wiercigroch, M. 2008 Dynamics of a vertical riser with weak structural nonlinearity excited by wakes, *Journal of Sound and Vibration*, **315**, 685-699.

[4] Vernizzi, G.J., Franzini, G.R. 2019 Vortex-induced vibration analysis using invariant manifolds, *XVIII International Symposium on Dynamic Problems of Mechanics*, Brazil.