Approximate model of flat ribbon vibrations in the wind

Martins Irbe[*], Janis Viba[*], Grigory Panovko [**] and Alexander Gouskov [***]

[*]*Riga Technical University, Riga, Latvia*

[**]*Mechanical Engineering Research Institute of RAS, Moscow, Russia*

[***]*Bauman Moscow State Technical University, Moscow, Russia*

Abstract. This work proposes an approximate analytical method for engineering calculations of thin ribbon motion. The axially stretched ribbon model is simplified to a system of three degrees of freedom. The local forces of interaction between the plate and the air are described by the boundary layer momentum exchange and by the change in the moment of the momentum against the centre of mass. As a result, after the reduction of interactions, three integral-differential equations are obtained for centre of mass of the plate and in the rotation around it. The study obtained analytical formulas for the analysis, optimization and parametric synthesis of the simplified ribbon model. The model allows to optimize the system in a space of given parameters. A case for oscillation power analysis is considered if an electrodynamic generator is used as a oscillation damper. In addition, model validation experiments were performed in the Armfield wind tunnel.

Introduction

One of the most complex objects in the calculation of nonlinear dynamics in nature, technics and everyday life is the model of straight flat ribbon motion in airflow [1 – 3]. The difficulty in the study of the object can be explained by the fact that the mechanical system has infinitely many degrees of freedom. It involves the movement of an air (fluid) around an elastic deformable ribbon, which also moves and deforms [3]. Recently, time-space programming methods have been used in the analysis of such systems. However, when using such numerical methods, it should be understood that they are also approximate, with a very large work capacity and require prior knowledge of all system parameters [4, 5]. This work proposes an approximate analytical method for engineering calculations, in which the axially stretched ribbon model is simplified to a system of three degrees of freedom (x, y, φ) in the following way (Fig.1.).

In the center of the system C is a reduced symmetric rigid non-deformable rectangular plate; the axial and rotational deformations of the ribbon are replaced by elastic and damping interactions; the airflow interaction is divided into two zones, one on the pressure side and the other on the suction side. The local forces of interaction between the plate and the air with velocity V0 are described by the boundary layer momentum exchange and by the change in the moment of the momentum against the canter of mass in complete motion. This allows the calculations to take into account the airflow rate and the local point velocities of the plate in compound motion. As a result, after reduction of interactions, three integral-differential equations are obtained for the centre of mass of the plate and in the rotation around it.

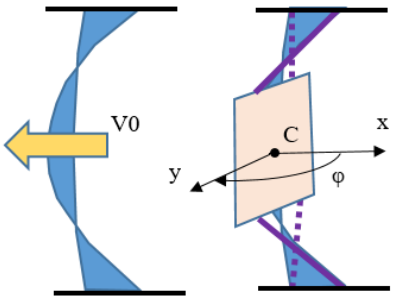

Figure 1: Approximate model.

Results and discussion

Differential equations of the developed model, as examples, are numerically modelled in the space of the given parameters. In particular, values of critical air flow rate as a function of ribbon tension were obtained. Model validation experiments were performed in the Armfield wind tunnel.

The approximate analytical method proposed in this work for wind and ribbon interaction calculations and dynamics analysis can be applied in the analysis of vibrations of existing objects as well as in the synthesis of new mechatronic systems with application in energy extraction from fluid (wind) flow.

This research is funded by the Russian Science Foundation, project No. 18-19-00708 and supported by Riga Technical University's Doctoral Grant programme.

References

[1] Bryant M, Garcia E. (2011) Modelling and testing of a novel aeroelastic flutter energy harvester. *J Vibration and Acoust.*133(1):011010.

[2] Afanaseva A.A., Gouskov A.M., Panovko G.Y. (2020) Nonlinear dynamics of a thin narrow ribbon in an airflow. *Vibroengineering Procedia* 32:105-110.

[3] Tipans I., Viba J., Irbe M., Vutukuru S.K. (2019) Analysis of Non-Stationary flow interaction with simple form objects. *Agronomy Research*17(1): 1227-1234.

[4] Vutukuru S.K., Tipans I, Viba I, Irbe I. (2020) Form optimization and interaction analysis of plane symmetry prism in air. *Engineering for rural development*. 739. – 746.