

Optimization of the equivalent oscillator for VIV modelling

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SUMMARY:

The equivalent oscillator is an empirical model used to reproduce VIV (Vortex Induced Vibration). In the present paper, an optimization of the main parameters at the basis of the model using Genetic Algorithm is presented. Furthermore, a modal approach has been implemented in the model to simulate the response of flexible structures and a comparison with an experimental database from the Politecnico di Milano Wind Tunnel is presented for model validation. It is shown that the developed model is able to replicate the steady state conditions of both rigid and flexible cylindrical structure in terms of amplitude of vibration, lift coefficient and lock-in range.

Keywords: vortex induced vibration, equivalent oscillator model, Genetic Algorithm, circular cylinder, wind tunnel tests

1. INTRODUCTION

Vortex induced vibration (VIV) occurs when shedding vortices exert oscillatory forces on a bluff structure in the direction perpendicular to both the flow and the structure (Gabbai, 2004). Vortex shedding modelling is an open problem. Since it is a complex phenomenon, involving many fluid dynamics variables and non-linear fluid-structure interaction, it is difficult to mathematically represent all VIV features. While pure mathematical models are very difficult to formulate due to the complexity of the phenomenon and CFD models are not fully applicable due to limitations of the available computational capability, semi-empirical model like the equivalent oscillator represent the best trade-off between accuracy and computational cost. The main focus is to develop an engineering model applicable to like-cylindrical shape structures, such as HVTL conductors (Zanelli et al., 2022), to predict the VIV response and design suitable damping systems.

2. EQUIVALENT OSCILLATOR

The equivalent oscillator model considered in this work is based on the model described in (Argentini et al., 2023). It reproduces vortex shedding by considering the flow as an equivalent aerodynamic mass M_{aer} that moves together with the structure and is connected to a negative aerodynamic damping able to provide energy input to the system (Belloli et al., 2006). The connecting elements are used to reproduce the interaction between the structure and the flow.

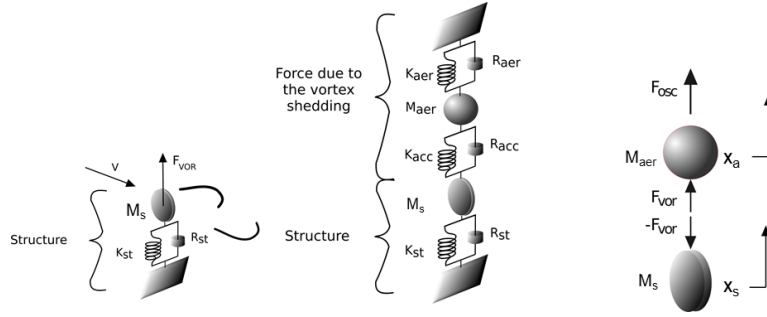


Figure 1. Equivalent oscillator model

The complete model reported in Fig. 1 consists of a two degree of freedom system, where x_a is the degree of freedom of the aerodynamic mass and x_s is the cylinder displacement. The vortex and oscillator forces (F_{vor} and F_{osc} in Fig.1) are modelled with hyperbolic functions (f_1, f_2, f_3, f_4) of the displacement and velocity to reproduce the self-generating and self-limiting mechanism of VIV as shown below:

$$f_i(x_i) = a_i [b_i + \tanh(c_i(\text{abs}(x_i) - d_i))] \quad (1)$$

The capability of the model to simulate VIV phenomenon is strictly related to a proper definition of the linear and non-linear parameters ($H_{kaer}, H_{raer}, H_{kacc}, H_{racc}, K_{kaer}, K_{raer}, K_{kacc}, K_{racc}$) presented in (Argentini et al., 2023) and of the formulation of the function f_1, f_2, f_3 and f_4 shown in equation (1). Since the fluid-structure energy exchange and interaction mechanism is highly dependent on these parameters, a big focus has been devoted to their optimization.

3. METHODOLOGY

The oscillator parameters for the rigid model have been optimized taking advantage of the experimental database collected at the Politecnico di Milano Wind Tunnel campaign (Muggiasca, 2006). In Table 1 mechanical and geometrical characteristics of the rigid cylinder employed in the tests are presented.

Table 1. Mechanical and geometrical characteristic of the rigid cylinder

Diameter [m]	Length [m]	Mass/Length [kg/m]	Natural frequency [Hz]
0.2	2	6.5	3.1

The rigid model structural damping is in the order of $1.5 * 10^{-3}$. The cylinder was also tested with increased level of damping introduced by means of eddy current dampers. This added damping effect has been used to test three different damping configurations (ξ_1, ξ_2 and ξ_3) adopting the same model. While the oscillator parameters optimization for ξ_1 case has already been discussed in (Argentini et al., 2023), in this paper the results obtained for the ξ_2 case is presented with the aim of extending the validity of the model to higher structural damping cases.

4. RESULTS AND DISCUSSION

4.1. Parameter optimization

Genetic Algorithm (GA) has been implemented to automatize the parameters optimization procedure. For this application the GA is used as a best fitting procedure between the experimental

dataset and the model results. The best parameters configuration is evaluated through the minimization of a cost function defined as the mean between the norm of the model and experimental amplitude of vibration and lift coefficient relative error.

For the GA simulation, 16 populations with 10 generations are specified as initial parameters.

The comparison between the model with the optimized parameters and the experimental results from ξ_2 case is shown in Fig.2.

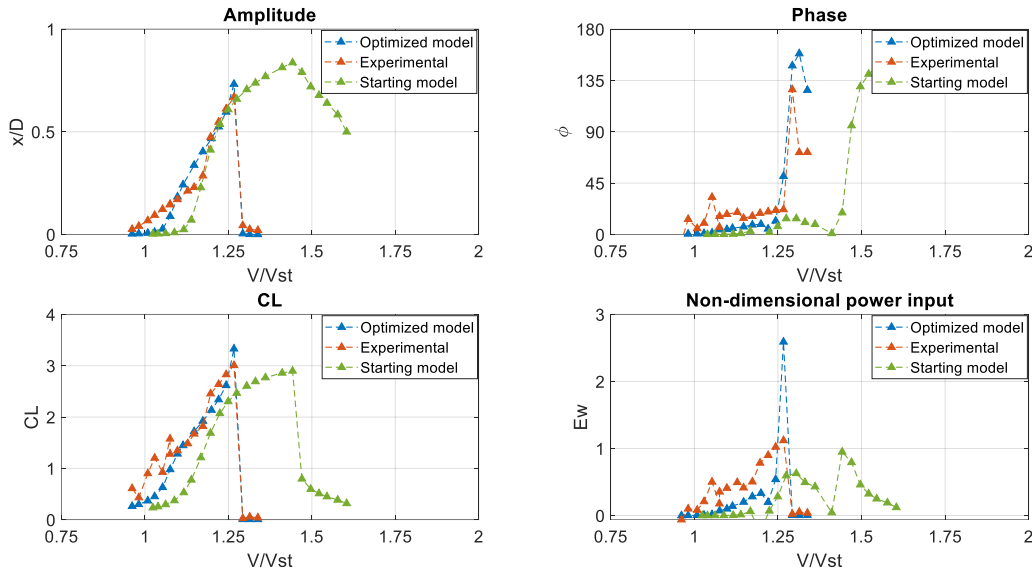


Figure 2. Comparison between the results obtained with the starting parameters model, the optimized parameters model and the experimental database in terms of non-dimensional amplitude of vibration x/D , lift coefficient C_L , phase ϕ and non-dimensional power input E_w as a function of the non-dimensional wind speed V/V_{st}

4.2. Flexible model

The equivalent oscillator model has been implemented with a modal approach to simulate the response of flexible structures subject to VIV. Equivalent fluid oscillators are lumped at each node of the model and their forcing contribution is then composed into the modal term so that only one equation of motion must be solved for each mode of the cylinder. The model validation has been performed through the comparison with an experimental campaign on flexible cylinders in the Politecnico di Milano Wind Tunnel as described in (Belloli et al., 2008).

This analysis is focused on the simulation of modes *II*, *III* and *IV* for which the experimental modal damping has been obtained from testing. In Fig. 3 of the comparison between results from the model with ξ_2 parametrization and experimental antinode amplitude of vibration for the three modes is shown.

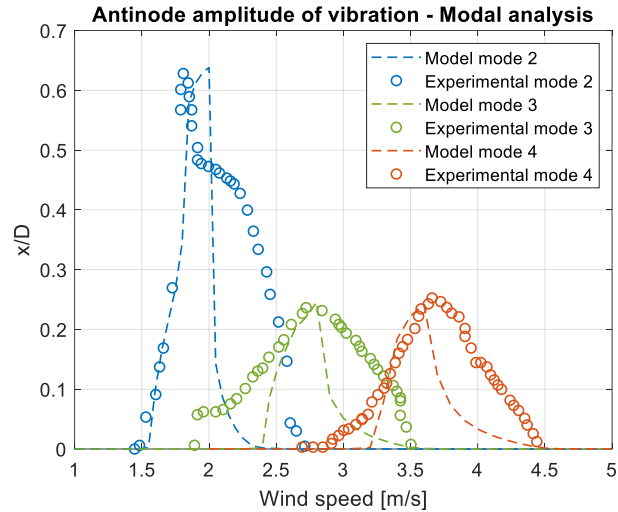


Figure 3. Comparison between the model and experimental antinode amplitude of vibration in steady-state conditions as a function of the wind speed

It is shown, then, that the model can correctly replicate the most important engineering features of VIV, especially the maximum amplitude of vibration at each mode and the lock-in range width. However, the numerical model is still not able to simulate accurately the complete shape of the lock-in curve, especially the second branch due to its fluid-dynamic complexity.

5. CONCLUSION AND FUTURE DEVELOPMENT

In this paper, the oscillator parameters optimization for an elastically suspended rigid cylinder is shown. The aim is to extend the validity and flexibility of the model to different structural damping configurations. The equivalent oscillator has also been implemented with a modal approach to simulate the behaviour of flexible structure subject to VIV. Future works will be to extend the database for model training and generalization through further wind tunnel tests. A future development of the model will focus, moreover, on the turbulence implementation that will allow to perform VIV simulations aimed at design damping systems to suppress vibrations in different scenarios, as in the field of HVTL conductors.

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