An active learning strategy to study the flow control of a stationary cylinder with two asymmetrically attached rotating cylinders

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ABSTRACT

We numerically investigate the flow control problem of the flow passing a stationary cylinder at a fixed Reynolds number 500 using two attached control cylinders with different rotation rates. Compared to the traditional uniform (lattice) sampling method, we developed an active learning strategy based on Gaussian Process Regression (GPR), drastically reducing the number of simulations and accelerating the scientific findings. We also discussed the effects of parameters on different hydrodynamic coefficients, and verified the feasibility of this strategy. The mechanism of this asymmetric flow control model was also further studied by analyzing flow patterns.

KEY WORDS: Active Learning; Flow Control; Numerical Simulation;

INTRODUCTION

Fatigues and vibrations due to dynamic marine environment, like Vortex-Induced Vibration (VIV), are fairly severe that the analysis of fluid and structure interaction (FSI) for offshore structures are important. Since almost all of these structures have crucial components such as piles and stacks that could be modeled as cylinders in fluid domain, we narrow our focus on the flow around the cylinder, one representative type of bluff body, where there exists well-known studies having figured out the mechanism of oscillations (Sarpkaya, 1979) and the crucial effect of Reynolds number (Pasto, 2008) of this FSI problem, as well as different wake modes of two side-by-side circular cylinders at low Reynolds numbers (Sangmo, 2003) and fluid characteristics of rotating cylinders next to a wall (Cheng et al., 2007; Rao et al., 2011). Almost all these studies aim at how to enhance the hydrodynamic properties of target bodies, promoting a vivid flow control field consisting of various active (Jahanmiri, 2010) and passive control strategies (Kumar et al., 2008), with related studies (Sakamoto et al., 1994) on their mechanism and the nature of the controlled wake. However, though extra energy is needed, active flow control, with Moving Surface Boundary-Layer Control (Modi, 1997) as the most frequently used method, has been regarded to be more robust and flexible than its counterpart. One model incorporating this methodology is to use two attached rotating cylinders (Muddada et al., 2010), which is also the prototype of our improved model. Specifically, With an objective of drag reduction and focusing on the mean drag coefficient ($C_{D,MEAN}$), this model could achieve higher energy efficiency of underwater vehicles, while their maneuverability could be improved with the mean lift coefficient ($C_{L,MEAN}$) studied. Similarly, When this method used in wave energy generation with Root-Mean-Square (RMS) values of the drag and the lift force ($C_{D,RMS}$, $C_{L,RMS}$) targeted, the productivity of energy harvest device could be improved by magnifying vibration amplitudes.

Previous studies have figured out a few effects of some parameters in this model. For example, the lift-to-drag ratio could be obviously improved with small control cylinders rotating at a rate higher than one, normalized by the upcoming fluid velocity (Modi, 1997), while the flow separation of the target main cylinder could be delayed even with two stationary small cylinders (Kuo et al., 2007). Besides, with two symmetrically attached counter-rotating cylinders at same rates, the critical range of the normalised gap value ($g/D$, where $g$ is the gap from small control cylinders to the main cylinder whose diameter is $D$) was found (Mittal, 2001, 2003), the mechanism behind which is its key effects on the length of recirculation zone, thereby affecting the hydrodynamics of the target body. From this analysis, the normalized gap in our study is determined as 0.1, neither too narrow to place sufficient grids nor too wide to deteriorate the performance of actuators. Furthermore, the control mechanism of this model is found to be viscous (Schulmeister et al., 2017), which means the crux of achieving flow control is to delay the separation point, which basically locates around 90° with respect to the downward stream at Reynolds number 500. Therefore, this relative angle ($\theta$) in our study was selected from 30° to 120°. Apart from the relative location of control cylinders, the proportional relationship between the diameter ratio ($d/D$, diameter of small cylinders over that of the main cylinder) and the control effects is