Evaluation of Campbell diagrams for vertical hydropower machines supported with Tilting Pad Journal Bearings

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Long Abstract

Introduction

In usual horizontal turbomachines, the dynamical properties of the system are calculated around the static load due to dead weight. On the contrary, for vertical machines such as pumps and hydropower turbines, the rotor is subjected to unbalance loads that do not allow to calculate constant stiffness and damping coefficients for fixed operating conditions. Instead, the Reynolds equation is usually solved at each time step and the Campbell diagram is not available anymore due to the nonlinear equations of motion. However, from a technical point of view, it is necessary as a first step to obtain the Campbell diagram to evaluate critical designs for hydropower rotors. As a result, a first evaluation can be performed by assuming the bearing loads to be constant at each bearing position. A comparison with the frequency content of the sweep sine and random response for the nonlinear equation of motion is performed to investigate to which extend is this assumption valid. If not, a strategy to upgrade the Campbell diagram should be determine to evaluate in a correct way the natural frequencies and damping ratios of the system.

1. Methods

The model of the vertical hydropower unit used in this paper is a typical 45MW Kaplan turbine as seen in Fig. 1(a). The rotor is supported by three tilting pad journal bearings at the upper guide bearing (UGB), the lower guide bearing (LGB) and the turbine guide bearing (TGB).

1.1 Nonlinear model

For the nonlinear case, instead of using Reynolds equation to solve the bearing forces as suggested in [1], a simplified model of tilting pad bearings is used to simulate the stiffness and damping properties at each time-step. The concept is to model the bearing coefficient as function of the load angle, eccentricity and number of pads [2]. The variation of stiffness and damping is mainly due to the change of load direction. Indeed, the stiffness and damping properties will change depending if the load is on the pad (LOP) or between the pads (LBP) of the bearing as observed in Fig. 1(b). Since the stiffness and damping coefficients are calculated in the rotating frame, a transformation to the fix coordinate system has to be applied at each time-step. For simplicity, the cross-coupling coefficients are neglected. To compare the nonlinear case with the linear case, a slow sweep sine load is applied to the system to check the frequency content of the signals and investigate when higher vibrations occur. Since the damped natural frequencies of the system are close, simulations for backward whirl and forward whirl will be performed independently to obtain more clear results in maximum displacement curves.

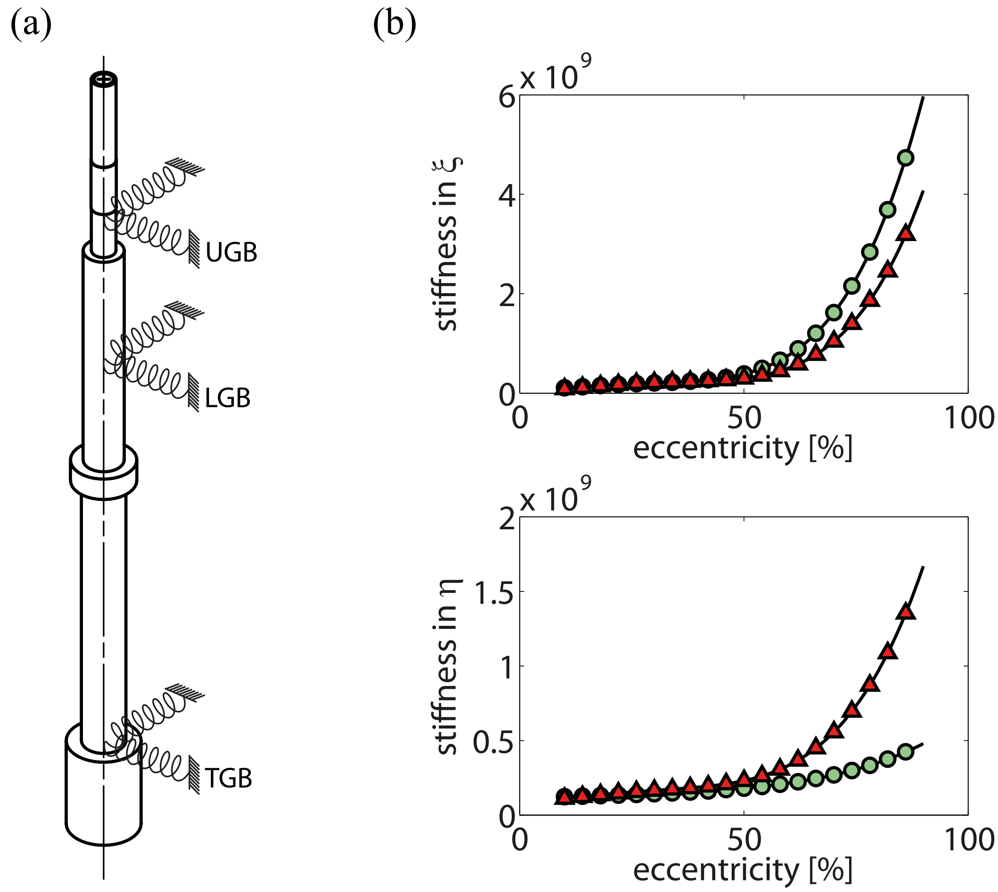

Figure 1. (a) Model of hydropower turbine supported by three tilting pad journal bearings (b) Bearing stiffness of the UGB for LOP (○) and LBP (△) in the ξ and η directions (rotating frame) as function of eccentricity for a rotating speed $\Omega = 2350$ RPM

1.2 Linear model

To obtain the Campbell diagram of the system, the first assumption is to consider the unbalance loads to be applied at the generator and runner positions. In this configuration, the load applied is almost equal at each bearing position. The unbalance load is determined in accordance to the balance quality grades such as G6.3 or G16. Moreover, the bearing loads are assumed to increase with the square of the rotating speed to calculate the stiffness and damping coefficients. As a first approximation, the bearing coefficients are assumed to be isotropic with the values of Load On Pad calculations. Even though this is not entirely representative of the bearing properties under unbalance operating conditions due to rotating stiffness and damping, it will allow to obtain the Campbell diagram as a first try and compare it with the nonlinear case.

References

[1] Maurice F White, Erik Torbergsen, and Victor A Lumpkin. Rotordynamic analysis of a vertical pump with tilting-pad journal bearings. *Wear*, 207(1–2):128 – 136, 1997.

[2] Mattias Nässelqvist, Rolf Gustavsson, and Jan-Olov Aidanpää. Experimental and numerical simulation of unbalance response in vertical test rig with tilting-pad bearings. *International Journal of Rotating Machinery*, 2014:10, 2014.