Numerical and Analytical Estimation of the Hydrodynamic Coefficients of a Radial Seal under Whirling Vibrations

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Abstract. Turbulent leakage flow passes through the radial seals and side chambers of turbine runners. A small deviation of the rotor changes the radial seal flow, inducing a strong pressure gradient. Reaction fluid forces act on the rotor which hence whirls. These forces are modeled by dynamic force coefficients on the shaft-line dynamics. We determine those coefficients to predict whirl vibrations. The radial and tangential forces are written as quadratic and linear polynomials of the whirl frequency. The polynomial coefficients correspond to the rotor dynamic coefficients. A computational fluid dynamics (CFD) simulation computes these forces for different whirl frequencies of a disk-like structure. Harmonic analyses on a vibroacoustic finite element model (FEM) yield the same forces, which are interpolated to obtain the dynamic coefficients. These numerical models are compared with an analytical potential flow theory model for a plain annluar seal geometry. CFD considers more physics than the other methods as it includes the fluid shear. Parametric studies on a clearance-and-side-chamber geometry highlight that hydrodynamic coefficients vary with rotor frequency, axial mass flow rate, rotor angular frequency and radial seal clearance. The resulting rotor dynamic coefficients improve the shaft line analysis, as more physical phenomena are considered on a real geometry.

1. Introduction

In Francis turbines, undesirable and sometimes unacceptable self-excited vibrations can occur due to the flow in hydrodynamic seals [1]. Staubli [2] points out that hydrodynamic seals are designed to reduce leakage flow, to minimize its deleterious effect on efficiency in large machines such as Francis and pump-turbines. A narrow radial seal surrounds the rotor band in the radial side chambers, through which a turbulent flow passes axially in addition to a circumferential shear flow driven by the rotor rotation.

Under external excitations the rotor is off-centered by a distance of ϵ, and the deformed seal has a smaller and a larger gap of width $C_0 - \epsilon$ and $C_0 + \epsilon$ respectively, as shown in Figure 1.a. Nishimura et al. [3] explain that the flow is squeezed in the narrow passage, generating a strong pressure gradient that causes radial and tangential excitation forces on the rotor. The perturbation in the circumferential flow which stems from the rotor rotation and from the whirling motion, and perturbation of the inertia of the axial leakage flow, both contribute to the pressure gradient. These forces can promote rotor instability. A radial force in the direction