Analysis of Vortex Rope Frequencies in the Draft Tube Cone of Francis-type Turbines

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Abstract: Pressure pulsations at Francis-type turbines, especially at off-design operation, are caused due to interaction between the helical vortex rope with the draft tube elbow. If the vortex rope frequency in such cases is close to the system's natural frequency, resonance conditions are met and this can lead to undesired high pressure and, subsequently, power oscillations. Voith Hydro (VH) has therefore determined the frequency range of the helical vortex rope from model tests at VH laboratories with respect to the specific speed of the machine at its optimum. Subsequently, VH has investigated the potential benefit of air admission during such part-load operation in order to reduce the occurring pressure pulsations. This paper presents the results of the research carried out, introducing individual frequency bands for the vortex rope with respect to specific speed at optimum and the impact of air admission on pressure amplitudes. Results are verified using a 1-D simulation approach and by comparison with prototype commissioning data.

1. Introduction

During part load operation of Francis-type turbines pressure pulsations in the hydraulic system are noticed. These pressure pulsations are caused due to interaction between the helical vortex rope with the draft tube elbow and lead to an excitation of the hydraulic system. This excitation results in high pressure pulsations, especially if the vortex rope frequency is close to a natural frequency of the hydraulic system.

The critical part-load operation area investigated in this paper is the higher part load area within a range of Q/Q_{opt} = 70% to Q/Q_{opt} = 80%, however, lower part-load operation down to and below Q/Q_{opt} = 50% may also yield significant pressure pulsations. During this range of operation earlier research by Dörfler et al. [1] amongst others, suggested that the frequency of the rotating vortex rope f [Hz] related to the nominal frequency f_n [Hz] is expected in the range of:

$$f/f_n = 0.2 \text{ to } 0.4 \quad (1)$$

Resonance will then occur , if the first natural frequency f_{sys} [Hz] of a system falls within the expected range of the vortex rope frequency stated in equation (1). The IEC [2] recommends the calculation of the first natural frequency of a hydraulic system based on an infinite reservoir downstream, a turbine runner with infinite hydraulic resistance, a mean cross-sectional area A_{DT} [m²] and a length L_{DT} [m] as:

$$f_{sys} = 1/(2 * \pi) * (g * A_{DT}/(L_{DT} * C_{DT}))^{0.5} \quad (2)$$