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Response Spectra and Expected Fatigue Reliability: A Look at Hydroelectric Turbines Behavior

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Abstract

When we look at the fatigue reliability of a structure, its dynamic response will be closely related to the sensitivity to material properties both in terms of crack propagation and limit state. In this paper, we have identified 2 types of response spectra for hydroelectric turbines. The type 1 spectrum is simpler and was the first encountered. The type 2 spectrum is more complex and contains more Low Cycle Fatigue (LCF) stress cycles compare to type 1. Hence, reliability decreases faster for similar parameters values. For each spectrum, 3 scenarios have been identified. In this paper, we first present the simple typical response spectra expected, the reliability model and its relation to life expectancy with regards for High Cycle Fatigue (HCF). Next, we propose families of response spectra based on the observed data from in situ measurements. This is followed by a discussion on the sensitivity to material properties. Finally, we suggest specific guidelines and recommendations. We believe that a better knowledge of the structure response spectra with respect to fatigue reliability will help turbine operators and manufacturers to maximize the overall reliability of their equipment.

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Keywords: Reliability; High Cycle Fatigue (HCF); Hydroelectric turbine; Response spectra

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Nomenclature

a	defect size
a_0	defect size at which the fatigue limit and the LEFM threshold cross
$f_X(x)$	joint density function
$g(x)$	limit state
n	number of blades
t	time
x	an n-dimensional vector of random variables
$Y(a)$	stress intensity correction factor for a given geometry
ΔK	stress intensity factor
ΔK_{th}	stress intensity factor of the LEFM threshold
ΔK_{onset}	stress intensity factor of the HCF onset
$\Delta\sigma$	stress cycle range
$\Delta\sigma_0$	fatigue limit
$\Delta\sigma_{LCF}$	stress cycle range of the LCF loading component
$\Delta\sigma_{HCF}$	stress cycle range of the HCF loading component
$\Delta\sigma_{Shutdown}$	stress cycle range of the shutdown transient
$\Delta\sigma_{SNL}$	stress cycle range of the regime change from maximum opening to SNL
$\Delta\sigma_{Startup}$	stress cycle range of the startup transient

1. Introduction

The response of a turbine runner to both transient events and steady operating conditions has an impact on the runner remaining life. We observe, when looking at the currently available experimental data, that each turbine has a unique dynamic behavior. This renders difficult the standardization of turbines response spectra. However, even if it is difficult to generalize the behavior of turbine runners with only one standard spectrum, we are able to distinguish families of typical behavior. The expected spectra dictate the sensitivity to material property which defines both the speed at which a defect propagates and the limit state in terms of fatigue reliability [1]. To evaluate risk, we have to work with a simplified representation of the real-world phenomena which means a tradeoff between model complexity and sufficiently detailed results [2]. We argue that based on available data, we need to differentiate response spectra families and that these spectra families have an influence on the sensitivity to materials properties. The previously used LCF/HCF loading model [3] might be too simple for our purpose. Given that the behavior of a runner belongs to one of these observed families of behavior, we hope to issue more relevant recommendations to maximize life and reliability.

For hydroelectric turbines, we define the reliability limit as the onset of High Cycle Fatigue (HCF). More specifically, the HCF onset is the contribution to crack propagation of small amplitude stress cycles which are different from the high amplitude cycles irrespective of their frequency as defined by Nicholas, 2006 [4]. The high amplitude cycles are thus considered the low cycle fatigue (LCF) component of the spectra. For a large turbine runner, this means that every steady operating condition should have a response spectrum below the HCF onset threshold at any given time [3]. This statement has far reaching implications regarding the relation between the response spectra of the runner and its fatigue reliability. Using measured strain data from Hydro-Québec turbine runners as reference, we intend to demonstrate that even if some response spectra are in accordance with current design specifications and practices, the behavior of some observed families of spectra might lead to counterintuitive results. This knowledge should help turbines operators and manufacturers to maximize the reliability of their equipment.

The paper is structured as follows. First, we present the typical type of response spectra expected, the reliability model and its relation to life expectancy. Next, we propose families of response spectra based on the observed data from in situ measurements followed by a discussion on the sensitivity to material properties. Finally, specific guidelines and recommendations are suggested.