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Calibration of potential drop measuring and damage extent prediction by Bayesian filtering and smoothing

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Abstract

Fatigue related damage growth without feasibility of optical assessment can be monitored conveniently by means of the direct current potential drop method in laboratory experiments. By estimating the unknown damage extent of a structure indirectly via observed measurements, the need to relate both quantities, i.e. a calibration of damage extent and measurements, arises. In recent years, Bayesian inference has been applied with a special focus to such inverse problem formulations.

In the present paper, a novel approach to the calibration issue is proposed by employing Bayesian filtering and smoothing. A probabilistic state space model incorporating prior information about the damage extent and calibration parameters as well as process describing models is defined and subsequently used to infer the damage extent of fatigue-tested specimens from potential drop measurements. First, the obtained results in the form of joint conditional posterior distribution functions are exploited to facilitate an evaluation of a direct model calibration on the one hand and direct damage extent estimation on the other hand given persistent uncertainties. In a further step, the inferred damage extent estimations and associated uncertainties are propagated in time as to allow an assessment of decision-making-feasibility within the extended scope of structural health monitoring and damage prognosis. A thorough performance analysis in the light of actual damage extend data is undertaken, revealing accurate results.

Keywords: Probabilistic analysis, Fatigue crack growth, Fatigue test methods, Bayesian model calibration, Parameter estimation

1. Introduction

In certain engineering domains like aviation, materials that are to be employed have to meet various requirements regarding their properties. In order to specify the fatigue capability of a material, crack propagation testing is - among other testing procedures - commonly used. The direct current potential drop (DCPD) method, see Figure 1, is widely accepted as means to monitor fatigue-related crack initiation and growth, especially where an optical assessment of the defect is not possible. Within DCPD measuring, a direct current injected into a specimen is utilised to quantify the potential drop over a structural damage. Growing damage extents lead to an increased electrical resistance which in turn yields a higher potential drop. Unfortunately, for real-time measuring the DCPD method presupposes a calibration that facilitates the linkage of the measured potential drop to the actual damage size.

There are various ways to obtain a calibration which encompass experimental, analytical and numerical approaches: An experimental calibration can be achieved by obtaining reference potential changes via manually introduced, pre-defined damages and a consistent probe and electrode setup for following specimens [1] or by crack front marking techniques like heat tints [2] and beachmarks (frequency or stress ratio shifts) [3, 4] to allow a calibration after the test. Theoretical calibrations are based on solving the Laplace equation of an electrical potential for certain geometry and boundary conditions. For simple geometries like plane single-edge, double-edge and center cracks, [5] provides an analytical solution. However, it is not applicable to more complex geometries so that numerical methods like FEM have been employed [6, 7].

In model-based structural health monitoring and prognostics, Bayesian filtering has been widely applied in damage diagnosis and damage prognosis with the aim of predicting a system's remaining useful life, e.g. [8–12]. In a Bayesian framework, dynamic state estimation problems can be solved in a probabilistic fashion that allows to account for different kinds of variabilities and uncertainties [13, 14] which is why Bayesian filtering appears perfectly suited to the task of inferring the unknown extent of a

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