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UNCERTAINTY REPRESENTATION AND PROPAGATION IN THE PREDICTION OF STRUCTURAL RESPONSE: A COMPARISON OF DIFFERENT APPROACHES

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ABSTRACT

Prognosis is an important and challenging task in structural analysis for reliability and quality assurance. The goal of a prognostic system is to estimate the Time To Failure of a structure, i.e. the lifetime remaining between the present and the point in time where it can no longer perform its function. The estimation can usually be based on a set of measurements of parameters representative of the degradation process.

To be effective, the predictive task must adequately account for the uncertainty associated to the future behaviour of the structure. Sources of uncertainty derive from: (1) randomness due to inherent variability in the structure behavior (aleatory uncertainty) and (2) imprecision due to lack of knowledge and information on the parameters used to model the degradation process (epistemic uncertainty).

This work investigates two methods for the representation and propagation of uncertainties: (1) a pure probabilistic method and (2) an hybrid Monte Carlo and Possibilistic method. In the context of the pure probabilistic approach, both epistemic and aleatory uncertainties are represented in terms of probability distributions and a double-randomization Monte Carlo simulation is carried out in which epistemic variables are sampled in the outer loop and aleatory variables are sampled in the inner loop, to propagate the uncertainty through the model onto the prediction of the Time To Failure [1]. By so doing, the method obtains a different cumulative distribution of the Time To Failure for each realisation of the epistemic variables, thus maintaining separated the two types of uncertainty. This leads to the positive fact that all the information on the uncertainty in the Time To Failure is preserved, but the interpretation of such information may not be straightforward in practical terms. Furthermore, resorting to a probabilistic representation of the epistemic uncertainty may not be possible when sufficient data is not available for statistical analysis, even if one adopts expert elicitation procedures to incorporate diffuse information into the corresponding probability distributions, within a subjective view of probability.

To overtake some of the limitations of the pure probabilistic approach, an hybrid method has been explored in which the aleatory variables are represented by probability distributions while the epistemic variables are represented by possibility distributions. Monte Carlo sampling of the random variables is repeatedly performed to process the

aleatory behavior of the structure and fuzzy interval analysis is carried out at each sampling to process the epistemic uncertainty in the possibilistic variables. The method leads to the computation of a fuzzy random variable representing the Time To Failure for each considered realization of the aleatory variables. Finally, the obtained fuzzy sets can be combined (1) into a set of limiting cumulative distributions characterized by different degrees of confidence [2] or (2) accordingly to the Dempster-Shafer Theory into Belief and Plausibility measures that can be interpreted as "rational averages" of the above mentioned limiting cumulative distributions [3].

In principle, the hybrid method seems to provide a more satisfactory characterization of the epistemic uncertainty in cases of lack of information or knowledge and an effective way for jointly propagating the aleatory and epistemic uncertainties through the model. However, the interpretation of the results in the form of limiting cumulative distributions requires the introduction of a degree of confidence that is not easy to asses. On the contrary, the introduction of Belief and Plausibility measures provides average information on the limiting cumulative distributions which give a more synthetic, albeit less informative, representation of the uncertainty in the predicted Time To Failure.

The investigation of the two methods is carried out with reference to a case study regarding the prediction of the remaining useful lifetime of a non repairable component which is randomly degrading in time. The degradation is assumed to evolve according to a simplified, stochastic fatigue crack growth process of literature [4]; the maximum accepted level of degradation is considered to be affected by epistemic uncertainty. This degradation process is typical of, for example, components in the pressure boundaries of a nuclear power plant [5] and may initiate from the foundry flaws which are always present in large cast components subject to fatigue loading caused by allowed power variations or incidental transients; once initiated, the degradation process can propagate under stressful operating conditions, up to limits threatening the components' structural integrity [6].

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