MEASURED LOAD UNCERTAINTY QUANTIFICATION AND FINITE ELEMENT MODEL HYPOTHESIS TESTING

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ABSTRACT

A method is presented for estimating the load measurement uncertainty for dynamic machine test events. The measurement uncertainty is then propagated through a linear-elastic finite element model of the structure to produce a time-varying distribution of possible strain response. The observed strain response at that location is examined for plausible membership in this distribution via principles of hypothesis testing.

The method for estimating the load measurement uncertainty involves the projection of the original as-measured external load histories into the null space of a matrix that enforces Newton's laws of motion for the body of interest. The projected values at each moment in time are then regarded as the instantaneous "mean" parameters of an assumed Gaussian measured load uncertainty distribution. The standard deviation of the measurement uncertainty distribution can then be estimated from the history of the changes that were made to the original as-measured loads as they were projected into the null space of the dynamic equilibrium matrix.

Unit load analyses of the inertia-relief finite element model can yield an influence coefficient matrix that relates strain to external applied load. The entries in this matrix can then be used to propagate the measured load uncertainty through the model (via the basic laws for linear transformations of random variables) to yield an instantaneous mean and standard deviation of calculated strain that is consistent with the measured load uncertainty. The changes in the loads as they are projected into the null space can also be propagated through the influence coefficient matrix to produce a random "chatter" in calculated strain which can in turn be used to associate a normalized autocorrelation function with the calculated strain distribution.

Finite element model validation can then be approached from a hypothesis testing paradigm. Here, the null hypothesis is that any disagreement between calculated mean strain and measured strain can be plausibly explained by the measured load uncertainty. The measured strain at some chosen response point on the body can be standardized by subtracting off the mean calculated strain and dividing by the standard deviation of the calculated strain. What remains should be a standard normal Gaussian signal with a certain anticipated autocorrelation function, as mentioned above. Statistical analyses on the standardized measured strain signal will yield 95% confidence intervals for the mean and standard deviation. If those confidence intervals contain zero and one, respectively, then the null hypothesis regarding the finite element model is not rejected.