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ITB8646

Chapter VIII

Integrating Genetic Algorithms and Finite Element Analyses for Structural Inverse Problems

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ABSTRACT

A general method for integrating genetic algorithms within a commercially available finite element (FE) package to solve a range of structural inverse problems is presented. The described method exploits a user-programmable interface to control the genetic algorithm from within the FE package. This general approach is presented with specific reference to three illustrative system identification problems. In two of these the aim is to deduce the damaged state of composite structures from a known physical response to a given static loading. In the third the manufactured lay-up of a composite component is designed using the proposed methodology.

INTRODUCTION

Inverse analyses have a variety of applications in structural mechanics in which unknowns in a structure are determined using system identification techniques. These techniques allow the state of the structure to be deduced from the observed response to given inputs. Depending on the problem to be solved, the unknowns to be determined may be the material properties, applied loads, boundary conditions or even the geometry of the specimen.

In general, inverse system identification techniques involve updating an analytical model representing the structure, where the difference between some measure of analytical response and equivalent experimental response is minimised. In this sense, the inverse problem can also be considered an optimisation problem. Central to the analysis is the appropriate selection of an analytical model that can accurately predict the response of the structure, and an efficient and robust optimisation algorithm for updating the model. Both of these components can be programmed for specific problems, however the programming of an analytical model is largely problem dependent and can be cumbersome. This is particularly true of structures in which the geometry and to a lesser extent the material properties are complex. Therefore it is considered, beneficial to develop a robust tool that can be readily applied to a wide range of structural inverse problems without being concerned with the complexity of geometry and/or material properties.

The method described here exploits the versatility of the *LUSAS* finite element package (distributed by FEA Ltd., v13.3, 2001, www.lusas.com) by integrating it as an object within a genetic algorithm (GA). The principal advantage of this approach is that the broad functionality of the finite element application can be used to model many structural scenarios, without needing to know the exact form of the analytical model. It is sufficient to enter the geometry, the loading and the boundary conditions without explicitly stating the form of the analytical model. This is handled inside the FE code and effectively hidden to the analyst. It is expected that this work will provide the basis of future automated and robust inverse analysis in a wide range of applications.

The described method is applicable to many structural problems in which the state of the structure is unknown. GAs offer a powerful means of finding the global optima of functions, particularly those in which the solution space is irregular or discontinuous. One area in which system identification problems can be of considerable benefit is in damage detection and quantification. Another application is the design of the manufacturing lay-up for producing composites optimised for strength and/or lightweight rigidity. This chapter will pay particular interest to this latter application and will reference two examples of how the described method has been successfully applied in the former. Of particular benefit to this method is the fact that the result of the algorithm is an updated finite element model that represents the actual structure that can subsequently be used under in-situ loading conditions.

Early investigations into inverse damage detection were summarised by Hajela and Soeiro (1990), who considered damage in the analytical model to be represented by a local, reduced elastic modulus. The unknowns to be solved were

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