Parallel and distributed computations in evolutionary and immune optimization of laminates

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Abstract

The paper deals with the application of the parallel and distributed calculations for global optimization of composite structures. Evolutionary Algorithm and Artificial Immune System are employed as global optimization methods. The aim of the optimization is to find the best stacking sequence of laminates for given criteria. To reduce the computational time parallel versions of global optimization algorithms are used. Computational grid is used to perform distributed computations. A boundary-value problem for laminates is solved by means of Finite Element Method commercial software. Numerical examples presenting efficiency of proposed attitude are attached.

Keywords: optimization, parallel computing, laminates, artificial intelligence, finite element method

1. Introduction

Laminates state a group of composites which are characterized by very high strength-to-weight ratio. They are also materials which properties can be tailored by manipulating several parameters like: components material, stacking sequence, fibres orientation or layer thickness.

Typically, all layers in laminates are composed of the same material. In some applications more than one laminate material is used forming hybrid laminates. In the following paper interply hybrid laminates are optimized [1]. The interply hybrid laminates consist of core layers built of a weaker but less expensive material while external layers are composed of a high-stiffness. It is also assumed that all considered structures are made of symmetrical laminates. As a result, there is no coupling between shield and bending states in laminate structure [4].

The aim of the paper is to find an optimal stacking sequence for hybrid laminate structures and to reduce the computational time by means of parallel and distributed computations. To find the optimal properties of laminate global optimization methods are employed. In order solve the boundary-value problem for laminate structures Finite Element Method (FEM) commercial software MSC.Patran/Nastran is employed [7].

2. Global optimization of laminate structures

The aim of the optimization is to find an optimal stacking sequence of the laminate structures for given criteria. Different criteria connected with stiffness and modal properties of laminates are taken into account. The computation of the objective function gradient is often hard to obtain and the objective function is typically a multimodal one in such problems. As a result, gradient optimization methods can not be used.

Artificial Intelligence methods allow avoiding mentioned problems. In the present paper global optimization methods in form of the Evolutionary Algorithm (EA) and the Artificial Immune System (AIS) have been used to solve optimization tasks. Both methods work on a set of possible solutions of the problem and both are non-deterministic metaheuristics.

3. Parallel and distributed computations

In many practical optimization problems calculation of the objective function is the most time-consuming part of the computations. It is especially noticeable if the population-based optimization methods, like EAs or AISs, are employed. To reduce the computational time one can use parallel and distributed computations. In the present paper a parallel versions of the EA and AIS as well as grid-based EA and AIS working on Alchemi framework are used.

3.1. Computing speedup

The speedup of distributed computations depends on the number of simultaneously processed possible solutions n (chromosomes in EA or B-cells in AIS) and the number of processors. The number of possible parallel jobs is equal to n. The wall time t_1 of computation for one generation of the evolutionary algorithm using one processor is equal to:

$$t_1 = t_f \cdot n \tag{1}$$

where t_f – objective function computation time;
If the n_p processors are used the wall time t_{np} is equal to:

$$t_{np} = t_f (n \setminus n_p + r) \tag{2}$$

where "\" denotes integer division (the fractional part of the result is abandoned), and the r is equal to:

$$r = \begin{cases} 0 & \text{if } n \mod n_p = 0 \\ 1 & \text{otherwise} \end{cases} \tag{3}$$

The speedup can be calculated as [6]:

$$s = \frac{t_1}{t_{np}} = \frac{n}{n \setminus n_p + r} \tag{4}$$

3.2. Parallel global optimization algorithms

The parallel EA (PEA) and parallel AIS (PAIS) are global optimization algorithms which are able to calculate the objective function on many processors [5].

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Table 1: Numerical results – computational speedup (for 3 iterations of PEA)

Number of processes	~ 12 000 DOF 2 computers		~ 50 000 DOF 2 computers		~ 12 000 DOF 1 computer		~50 000 DOF 1 computer	
	time [s]	speedup	time [s]	speedup	time [s]	speedup	time [s]	speedup
1	484	1.00	2426	1.00	484	1.00	2426	1.00
2	260	1.86	1296	1.87	289	1.67	1626	1.49
4	253	1.91	724	3.35				
8	230	2.1	521	4.65				

In the employed version of the PEA and PAIS the number of processing units can be theoretically up to the number of solutions in one iteration (chromosomes in PEA and B-cells in PAIS). Specialised process manages sending tasks to the processing units in order to calculate the objective function value.

3.3. Alchemi based computational grid

The grids give the opportunity to use distributed resources in time-consuming engineering applications. The grids can be built on top of computational resources connected by fast networks. The resources shared among partners, e.g. universities, allow to obtain powerful resources and to use resources in a efficient way. The Alchemi framework [2], one of the grid software, is used to implement the global optimization algorithms. The grid-enabled PEA and PAIS are used in this approach. The optimization algorithms are modified in objective function evaluation stage. The objective function evaluation is performed with use of grid. The programs and data files are submitted to the grid. The objective function values are returned from grid to the optimization algorithms. The global optimization algorithms have been implemented using Alchemi framework API in C# language.

4. A numerical example – computing speedup

The beam-box structure of varying cross-section is optimized (Figure 1). The wider end of the structure is fixed. Each of 4 walls of the structure is composed of the same hybrid, symmetric laminate with the same stacking sequence. The thickness of each ply is h_i = 0.2e-3 m. External laminas are made of graphite-epoxy material while internal layers are built of glass-epoxy material. It is assumed, that ply angles can vary continuously or in discrete way.

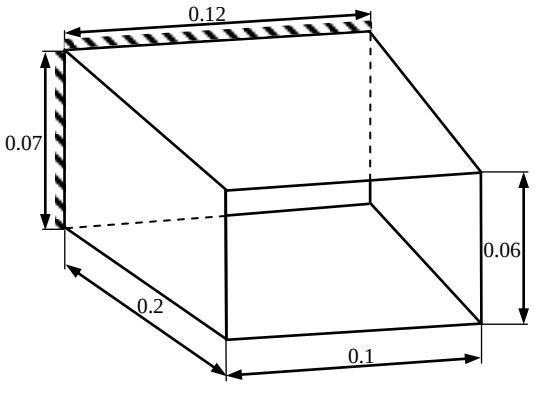

Figure 1: Box beam – dimensions and bearing

The aim is to maximize fundamental eigenfrequency of the structure and to reduce the computational time. The PEA is employed to parallel computations. The details and the results of the optimization performed by PAIS are presented in [3].

The computations with a different number of processing units were performed. To show the dependency between computing speedup and the single objective function calculation time, two different FEM meshes, resulting in different number of degree of freedom (DOF) for considered structures are proposed.

Two computers with two quadcore processors Intel Xeon E5345 each were used in experimental tests. The tests were performed with two computers and one computer for different number of parallel processes. The computational time was measured after 3rd iteration of PEA. The measured speedups are collected in Table 1.

5. Final conclusions

The application of the artificial intelligence methods in optimization of laminate structures is presented. Parallel versions of Evolutionary Algorithm and Artificial Immune System as well as the computational grid are employed to reduce the computational time.

It can be observed that better computing speedup is obtained, if the computational time for calculation of the objective function value is longer. The reason is that the time necessary for communication in parallel calculations is relatively shorter. The computations with use of two computers and the same number of processes give better results. The main reason is that a disk sharing is avoided.

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