Methodology of optimization of layout of shell structure reinforcement

Jerzy Małachowski[1], **Krzysztof Damaziak**[2] **and Tomasz Szafrański**[3]

[1]*Department Of Mechanics And Applied Computer Science, Military University of Technology*
Kaliskiego 2, 00-908 Warsaw, Poland
e-mail: jerzy.malachowski@wat.edu.pl

[2]*Department Of Mechanics And Applied Computer Science, Military University of Technology*
Kaliskiego 2, 00-908 Warsaw, Poland
e-mail: krzysztof.damaziak@wat.edu.pl

[3]*Department Of Mechanics And Applied Computer Science, Military University of Technology*
Kaliskiego 2, 00-908 Warsaw, Poland
e-mail: tomasz.szafranski@wat.edu.pl

Abstract

This paper presents a process optimization of a light shell diffuser reinforced with frame intended for a small wind turbine (rated power of 3kW). The diffuser structure consists of multiple beams and metal sheets. This kind of structure is suitable for an optimization in terms of selection of pipes quantity, dimensions, sheet thickness etc. The optimisation approach assumes the reduction of the amount of work to be done between the optimization process and the final product design. The optimization methodology is using genetic algorithm to generate the optimal reinforcement layout. The obtained results are the base to modify the existing Small Wind Turbine (SWT) design.

Keywords: optimization, genetic algorithm, wind energy, diffuser, FEM, SWT, DAWT

1. Introduction

Wind power is rapidly developing sector of energy industry. Unfortunately, wind conditions in most areas in Poland are unfavourable for utility scale wind turbines.

Small wind turbines (SWTs) dedicated to individual customers could create a grid which can increase the share of renewable energy in the energy balance of Poland. Unfortunately the great majority of existing wind turbines operates inefficiently in typical polish wind conditions and the return of investment time is too long to make it attractive for individual customers [1].

There is a need for a small wind turbine which could operate efficiently and could be available to purchase at a reasonable price. A project carried out by universities from Poland and Norway resulted in development of a prototype of a diffuser augmented wind turbine (DAWT) characterised by rated power of 3.5 kW. The developed turbine is equipped with a diffuser which enhances its efficiency at all wind speeds The use of the diffuser also allows the turbine to operate at a lower wind speed than non-diffuser turbines.

The diffuser shape has been optimized by means of aerodynamic efficiency of the turbine [5]. The resulting shape is challenging for a structural design. The centre of the mass is shifted far beyond the mounting point, which leads to high bending moments in the centre node. That is why the mass of the diffuser and the turbine is a significant parameter and it has to be optimized. Preliminary analysis reviled that the fully composite diffuser – technology of first choice – will be much heavier or significantly more expensive than the metal frame with sheet coating. The diffuser structure consists of multiple beams forming stringers and ribs and sheet metal. This kind of structure is suitable for an optimisation in terms of selection of beams quantity, dimensions, sheet thickness etc.

2. Object of optimization

2.1. Geometry preparation

The object of study and its simplification level is presented in Fig. 1. As it was stated above, the main dimensions of the diffuser (length and diameters) remains unchanged, while the specific layout of stiffeners and thickness of skin has to be found.

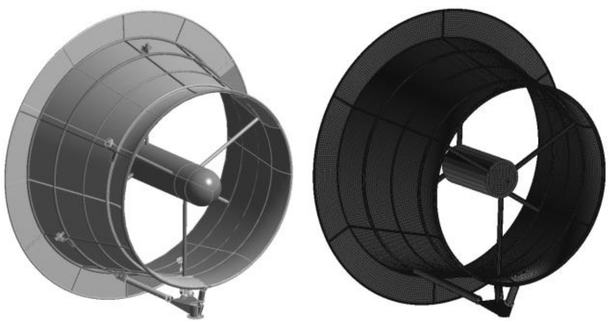

Figure 1: Comparison of detailed FEM model (left) and simplified FEM model (right)

The optimization of the diffuser structure is based on automatic, parametric, generation of turbine geometry in MSC.Patran software. The optimization algorithm generates population of different reinforcement layouts using parametrized MSC.Patran script. The developed model is based on shell and beam elements, which greatly reduce the time of model generation and computation time.

2.2. Loads and boundary conditions

Loads acting on the diffuser structure were obtained using the CFD analysis [2]. Assumed wind speed was 33m/s which corresponds the maximum value accordingly to the proper normative. The FEM model load case consists of a gravitational load, the torque and axial force from the turbine operation as well as the pressure field acting on the diffuser. The detailed pressure field designated from the CFD analysis was simplified. Local changes of the pressure field, which have minor influence on the global turbine response were neglected. Boundary conditions consist of constrain (translation and rotation) for chosen nodes in the mounting flange.

2.3. Optimization methodology

The optimisation is based on genetic algorithm presented in figure 2. The genetic optimisation algorithm is a nature inspired method of achieving the best outcome of a given operation while satisfying certain restrictions. In comparison to conventional optimisation methods, the genetic algorithm is based on a probability and it is less prone to finding a local optima instead of the global one.

During the optimization process, population of different diffuser reinforcement layouts is automatically generated based on parameters chosen by genetic algorithm. Each layout is subject to FE analysis utilizing pre-defined loads and boundary conditions. Obtained results are used by genetic algorithm to make decision on stiffeners distribution and skin thickness.

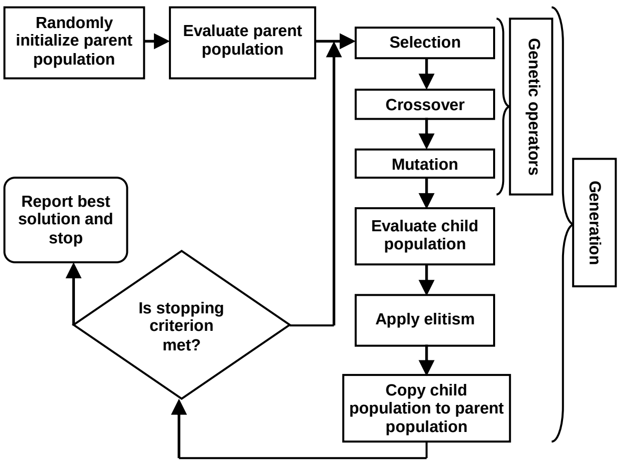

Figure 2: Genetic optimisation algorithm

The main assumption behind of the adopted methodology is that the result of optimisation has to closely reflect technologically justified product. The majority of articles describing optimisation problems of reinforced shell structures, are focused on topology optimisation problem [3, 4, 6]. In such approach, the result of optimisation can only be used as a general guideline of reinforcement layout and not even as the starting point of an engineering design process. Considering the above, authors focused on reducing the amount of work to be done to make results of optimisation process practically usable.

2.4. Design variables, objective function, constraints.

In the described methodology, we define combinatorial optimization problem, which means that all design variables are discrete The design variables can be divided into three groups.

The first group represents non-dimensional parameters in the model such as the number of stiffeners in the frame.

The second group represents modifications of location of the main support frame nodes. The variables in this group have dimensions (i.e. millimetres, degrees) and again contains only integer values.

The last group consist of the properties of particular parts of the diffuser, for example, characteristic dimensions of cross sections, thickness of sheets, material properties. Values in this group have dimensions and they correspond to normalised billets and materials.

Each variable was defined as a table. The variables limits are set as end of variable range. The minimal and maximal values are chosen based on the author’s experience in design of prototype version of the diffuser.

The objective function is based on the minimum mass criterion. This simple criterion meets many technological demands. Lower mass will lead to the use of thin walled beam sections, thin sheets, and lower number of elements.

The constraints consist of maximal displacements of chosen nodes in the model. The proper choice of these points and their allowable displacements values will fulfil demands of a high stiffness and acceptable stress in crucial parts of the structure.

3. Summary

The presented methodology allows for development of an optimal and technically justified variant of SWT diffuser. Unlike in case of typical topology optimization, the obtained result i.e. optimal diffuser design, can be directly used to develop specific, technologically feasible solution.

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