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Design of pressure vessels using shape optimization: An integrated approach

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Previous papers related to the optimization of pressure vessels have considered the optimization of the nozzle independently from the dished end. This approach generates problems such as thickness variation from nozzle to dished end (coupling cylindrical region) and, as a consequence, it reduces the optimality of the final result which may also be influenced by the boundary conditions. Thus, this work discusses shape optimization of axisymmetric pressure vessels considering an integrated approach in which the entire pressure vessel model is used in conjunction with a multi-objective function that aims to minimize the von-Mises mechanical stress from nozzle to head. Representative examples are examined and solutions obtained for the entire vessel considering temperature and pressure loading. It is noteworthy that different shapes from the usual ones are obtained. Even though such different shapes may not be profitable considering present manufacturing processes, they may be competitive for future manufacturing technologies, and contribute to a better understanding of the actual influence of shape in the behavior of pressure vessels.

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1. Introduction

In the pressure vessel literature, the optimization of nozzle and heads has been conducted independently. Although this is a practical and widely used approach, it leads to undesirable problems such as thickness variation from nozzle to head (among others) and, as a consequence, reduces the optimality of the final result (which may also be influenced by the adopted boundary conditions). Thus, this work investigates the optimization of pressure vessels considering a model of the entire vessel. A multi-objective function based on a p-root of summation of p-exponent terms of von-Mises stress values is defined in order to minimize the tank maximum von-Mises stresses. Mechanical and thermal loads are considered. Shape optimization techniques are applied, and the design optimization procedure is implemented by combining the commercial finite element analysis system ANSYS with our MATLAB optimization algorithm. Although composite tanks have a strength/weight ratio higher than steel tanks, they have a higher manufacturing cost. Thus, this work emphasizes homogeneous tanks, and focuses on CNG (Compressed Natural Gas) tank design by means of shape optimization techniques.

This paper is organized as follows. The literature review and related work are presented in Section 2. The formulation and numerical implementation of the optimization problem for the pressure vessel is described in Sections 3 and 4, respectively. In Section 5, the optimized shapes for the entire pressure vessel are presented and the results are discussed. Finally, in Section 6, some conclusions are inferred.

2. Related work

The design of pressure vessels is an important and practical topic which has been explored for decades. Even though optimization techniques have been extensively applied to design structures in general, few pieces of work can be found which are directly related to optimal pressure vessel design. These few references are mainly related to the design optimization of homogeneous and composite pressure vessels.

A pioneering work on optimization techniques for designing pressure vessels was presented by Middletown and Owen [1], who

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