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Young's Modulus and Poisson's Ratio Estimation Based on PSO Constriction Factor Method Parameters Evaluation

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ABSTRACT

The knowledge of materials' mechanical properties in design during product development phases is necessary to identify components and assembly problems. These are problems such as mechanical stresses and deformations which normally cause plastic deformation, early fatigue or even fracture. This article is aimed to use particle swarm optimization (PSO) and finite element inverse analysis to determine Young's Modulus and Poisson's ratio from a cantilever beam, manufactured in ASTM A36 steel, subjected to a load of 19.6 N applied to its free end. The cantilever beam was modeled and simulated using a commercial FEA software. Constriction Factor Method (PSO variation) was used and its parameters were analyzed in order to improve errors. PSO results indicated Young's Modulus and Poisson's ratio errors of around 1.9% and 0.4%, respectively, when compared to the original material properties. Improvement in the data convergence and a reduction in the number of PSO iterations was observed. This shows the potentiality of using PSO along with Finite Element Inverse Analysis for mechanical properties evaluation.

KEYWORDS

Constriction Factor Method, Finite Element Method, Mechanical Properties Estimation, Optimization Methods, Performance Optimization, Robotic Manipulators

INTRODUCTION

Most of materials in service are subjected to loads. In this context, it is necessary to know the material's mechanical properties to avoid excessive deformations, early fatigue or even fracture. Mechanical behavior of materials depends on its response to the load in which the material is subjected. Some of the main properties that associate elastic deformation with stress are the Young's modulus, shear modulus, thermal expansion coefficient, and Poisson's ratio (Callister, 2007).

Strain and stress distributions in materials subjected to loads can be obtained through experimental techniques or numerical analysis which depend on specific material properties,

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mainly Poisson's ratio and Young's modulus. Finite Element Analysis (FEA) is the most common method known for mechanical behavior simulation, which is normally used for stress, strain and displacement analysis (Yildiz & Duzgun, 2010; Celik, Rennie, & Akinci, 2011; Sabik & Kreja, 2013; Sánchez, De la Torre Ibarra, Mendoza Santoyo, Saucedo, & Reyes R, 2014; Cardelli, 2013).

The measurement of mechanical properties is performed through experiments in accordance with standards conditions. For this type of analysis, the methods applied can be dynamic, applying vibrations with small amplitudes of deformation (Kang, Kim, & Lee, 2007; Akhter, Jung, Chang, & Kim, 2009), or static, that submits the test body to a known load and simultaneously measures the induced deformation (Martínez-Celorio et al., 2010). In addition, non-destructive techniques, such as Particle Image Velocimetry (PIV) (Adrian, 1991; Magalhaes, Braga & Barbosa, 2015), Digital Image Correlation (DIC) (Brynk, Molak, Janiszewska & Pakiela, 2012; Zhang et al., 2012) and Robotic Arm (Dias, Magalhães, Ferreira & Vitoriano, 2016) can be applied to perform displacement measurements on the material.

Magalhães et al (2015) and Magalhães et al. (2017) proposed similar methods using Particle Swarm Optimization (PSO) together with FEA. In these researches, parameters from cantilever beam and human cornea, respectively, have been analyzed. However, in these works, PSO parameters were not well investigated and explored.

In the other hand, displacements evaluation assisted by a Robotic Arm (Dias et al., 2016) can be considered a precision technique and has a large use in industries. One of the advantages of this technique when compared to an articulated arm coordinated measured machines (AACMM) (Gao, Wang, Lin, & Chen, 2009) is that it does not require a dedicated robotic arm to perform displacement measurements from a body.

Conventional methods are commonly used for mechanical properties estimation (Young's modulus and Poisson's ratio). When analytical approaches do not guarantee a global solution for linear and nonlinear systems, stochastic search algorithms, such as PSO, may provide a promising alternative to these approaches.

PSO was firstly proposed by Kennedy and Eberhart (1995). This is a stochastic search algorithm based on socio-psychological principles, which are inspired by swarm intelligence. PSO offers understanding into social behavior and it has contributed for diverse engineering applications (Marwala, 2010). PSO formulation has been applied in many areas such as Biomedical (Xu, Wunsch & Frank, 2007), Power Systems (Esmin, Lambert-Torres & Zambroni de Souza, 2005; Vlachogiannis & Lee, 2006), Robotics (Mehdi & Boubaker, 2011; Chatterjee, Pulasinghe, Watanabe & Izumi, 2005) and Neural networks (Song, Chen & Yuan, 2007).

Researches normally perform experimental studies and develop empirical model and then apply non-traditional algorithms for obtaining better results. In this study, it was performed experiments to determine Young's modulus and Poisson ratio and these results were used as input to numerical analysis. Since numerical analysis is an approximation, an optimization method combining PSO and FEA is proposed in order to identify Young's Modulus and Poisson's ratio from a cantilever beam. Displacements evaluation assisted by a Robotic Arm was used to provide PSO input data. Commercial software based on FEA was used to generate the values for the objective function and to return the Sum Square Error (SSE) between experimental and simulated data. In this case, PSO was used for searching optimal parameters.

This paper is organized as follows: Section 2 provides a description of the displacement technique used. Section 3 introduces the PSO method combined with a summary of the framework developed. Section 4 provides a brief introduction to the PSO-FEA identification technique. Results and parameters identification are presented in Section 5 and concluding remarks are given in Section 6.

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