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Fatigue life prediction for welding components based on hybrid intelligent technique

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ABSTRACT

This paper details the fatigue life prediction model for welding components based on hybrid intelligent technology. We make use of the capabilities and advantages of rough set theory, particle swarm optimization (PSO) algorithm and BP neural network for establishing of the fatigue life prediction model. Firstly, rough set theory was used to deal with the original fatigue sample data; the minimum fatigue feature subset was obtained. Secondly, improved PSO algorithm was used to optimize the initial weighs and thresholds of the BP neural network, which resolves such problems as local extremum and slow convergence that exist in the traditional BP neural network. At last, minimum reduced subset was inputted into the optimized BP neural network to construct the novel fatigue life prediction model for welding components by the continuous training and adjusting. Sample data of the titanium alloy welded joints was used to verify the correctness and validity of the novel fatigue life prediction model, simulation results show that the fatigue life prediction model proposed in this paper has better fault tolerance, higher precision, and can fitting fatigue life value more accurately than traditional BP model. Consequently, the model based on hybrid intelligent technology can provide an effective new approach to predict the fatigue life of welded joints.

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1. Introduction

Welded structures are one of the main connection methods in industrial production nowadays. Due to the influence of the welding residual stress, residual plastic deformation, heat affected zone and stress concentration effect, the fatigue life of the welding components is far lower than that of the parent metal, thus fatigue fracture generally first occur in the welding components. According to statistics, 70–90% of the welded structures invalidation accidents in the past several years were caused by fatigue failure. These accidents not only caused great damage to national economy, but also seriously threatened the safety of people's life. Therefore, the research of fatigue analysis and optimization design method for welding components is urgent.

Up to now, a lot of domestic and foreign experts have devoted themselves into the research of the fatigue analysis and optimization design method for welding components, and plentiful fatigue analysis methods for welding components have been obtained. Generally speaking, there are two categories of fatigue analysis methods. One is the S–N curve method; the other is the fracture mechanics method [1]. The S–N curve method mainly includes three kinds of methods: the normal stress method [1], the surface extrapolation hot spot stress method [2, 3] and the nodal force based structural stress method [4, 5]. The S–N curve method is most widely used in the actual engineering application nowadays, for example, Rao et al. [6] present a generalized procedure for estimating probabilistic fatigue life of steel plate railway bridge girders with welded connections, considering plate breathing and a loading spectrum by combining the probabilistic S–N curve with Palmgren–Miner's fatigue damage accumulation rule; Cheng et al. [7] propose an efficient method for time-dependent fatigue reliability assessment of mechanical components under random loadings based on median S–N curve and P–S–N curve. Although it has been most widely used, there are such flaws that cannot be overcome as finite element model is difficult to build, stress is hard to calculate and selection of the S–N curve is uncertain in this method. The fracture mechanics method focuses mainly on the research of the development of the fatigue damage, including

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measuring crack growth rate, determining the relationship between crack propagation rate (crack propagation length) and the parameter of external load stress. Up to now, it has also been successfully used, for example, Anoop et al. [8] use a fracture mechanics based procedure to determine the fatigue life of steel plate girders of two railway bridges with welded connections; Mohammadzadeh et al. [9] develop a method for reliability analysis of spring clips type SKL14, based on fracture mechanics approach, and a linear limit state function based on fracture mechanics is derived in terms of random variables. Although it has been successfully used, the application of fracture mechanics method for the design of welding components is limited to some small number of key components with high security requirements, and it has not been widely used for the design of common welding components yet.

Artificial intelligence technology is to simulate the complex thinking process and intelligent behavior (such as learning, reasoning, thinking, planning, etc.) by using computer and to make a new kind of reaction similar to human intelligence; it is more suitable for solving the fatigue life prediction problem that is influenced by complex physical rules and a large quantity of uncertainty factors. In this paper, by integrating rough set theory, neural network technology and PSO algorithm, the fatigue life prediction model for welding components based on hybrid intelligent technology was established. In the model, rough set theory was used for knowledge reduction and for determining the core factors among a large quantity of factors which influence the fatigue life of the welding components; improved PSO algorithm was used to optimize the initial weights and thresholds of the BP neural network; the reduced minimum subset of the attributes was used as the input of the optimized neural network to fitting the fatigue life of the welding components. To verify the correctness and validity of the novel method, fatigue data of the titanium alloy welded joints is used in the experiment.

The rest of this paper is organized as follows. Section 2 describes the related artificial intelligent method for predicting the fatigue life for welding components in recent decades. Section 3 briefly introduces hybrid intelligent technology, including rough set theory, PSO algorithm and PSO-BP neural network. Section 4 presents the fatigue life prediction model for welding components based on hybrid intelligent technology. Section 5 details the experiments. Finally, the conclusions are discussed in Section 6.

2. Related works

In recent years, many welding experts used artificial intelligence methods (such as neural network, expert system, fuzzy computing, rough set theory, evolutionary algorithm, etc)to predict the fatigue life. Mohanty et al. [10] design multi-layer perceptron artificial neural network (ANN) architecture in order to predict the fatigue life along with different retardation parameters under constant amplitude loading interspersed with mode-I overload. Bezazi et al. [11] discuss the use of ANN implemented by both conventional maximum likelihood and Bayesian evidence based training algorithms to estimate fatigue lifetime of a sandwich composite material structure subjected to cyclic three-point bending loads. Sohn et al. [12] proposed the fatigue life prediction method using artificial neural network for spot-welded joints. Liu et al. [13] develop an expert system to realize an appropriate combination of material database, condition database and knowledge database for life prediction and management of cracked high temperature structures. Zou et al. [14] present a VPRS (variable precision rough set) modeling method for fatigue life prediction of welded joints of aluminum alloy. Experimental analysis based on this model using the small quantity of the laboratory data was conducted and the experimental results show that the model has a certain noise tolerance and a high accuracy and coverage.

With the rapid development of science and technology, the fatigue life prediction for welding components are becoming too complicated to obtain the much satisfactory results by using the single artificial intelligent method. So it is necessary to utilize hybrid intelligent technique to predict the fatigue life of welding components. The hybrid intelligent method is to utilize the single intelligent method of complementary advantages and the value-added information to overcome the insufficiencies of the single intelligent method in order to enhance the correctness of the complex fatigue life prediction for welding components problem. Many fatigue researchers presented some personalization hybrid intelligent methods according to the practical problems on the applications. Chandrasekhar and Vasudevan [15] proposed an intelligent model combining artificial neural network and genetic algorithm for achieving the desired depth of penetration and weld bead width during Activated Flux Tungsten Inert Gas Welding (A-TIG) welding. Huang and Chen [16] proposed a fuzzy modeling method based on support vector machine (SVM) and fuzzy logic for the arc welding process. SVM provides a mechanism to extract support vectors for generating fuzzy IF-THEN rules from training data. In this method, SVM is used to extract IF-THEN rules; the fuzzy basis function inference system is adopted as the fuzzy inference system. Dhanunjaya and Dilip [17] proposed a method of neural network-based expert systems using the data collected through finite element analysis for online predictions of temperature distributions on electron beam-welded plates. The neural network-based expert systems could make the predictions in a fraction of a second. Fan et al. [18] proposed fatigue behavior evaluation and fatigue fracture mechanisms of cruciform welded joints.

Although these hybrid artificial intelligent methods are widely used for predicting the fatigue life of welding components, some insufficiencies exist for complex large-scale fatigue problems.

3. Hybrid intelligent technology

3.1. Rough set theory

Rough set theory [19] was founded in 1982 by polish mathematical professor Z. Pawlak, whose aim is to find the inner links of the massive, imprecise, incomplete and uncertain data. Rough set theory provides a framework in which discernibility-based methods can be formulated and interpreted, and also forms an appealing foundation for data mining and knowledge discovery. Rough set theory is characterized by simple structure, easy implementation and fast speed when dealing with practical problems. At present, rough set theory has become an important tool to study granular computing theory [20]. The basic concepts of rough set theory including information systems, indiscernible relations, approximation sets, rough degree of membership, and significance of attribute and reduction of attribute are firstly introduced as below.

3.1.1. Information system

The basic vehicle for data representation in the rough set framework is an information system. An information system is in this context a single flat table. We thus define information system as a 4-tuple $S=(U, A, V, f)$, where U is a non-empty finite set of objects called the universe, $A=C\cup D$ is a non-empty finite set of attributes, C is a non-empty finite set of condition attributes, and D is a non-empty finite set of decision attributes, where $C\cap D=\phi$. Each attribute $a\in A$ can be viewed as a function that maps elements of U into

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