NDT&E International 46 (2012) 7–13

Contents lists available at SciVerse ScienceDirect

NDT&E International

journal homepage: www.elsevier.com/locate/ndteint

Nondestructive and quantitative evaluation of wire rope based on radial basis function neural network using eddy current inspection

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ARTICLE INFO

Article history:
Received 8 November 2010
Received in revised form
16 September 2011
Accepted 20 September 2011
Available online 20 October 2011

Keywords:
Wire rope
Eddy current testing
Basis function neural network

ABSTRACT

Wire ropes have been widely used in elevators, lifting machinery, passenger aerial ropeways, and other related fields. Such ropes often deteriorate during their lifetime due to external or internal corrosion and abrasion, and dynamic mechanical stresses. Nondestructive evaluation methods are being increasingly applied to monitor wire ropes. In this paper, an adjustable, annular testing device, consisting of probes arranged in radial symmetry, is designed using low frequency transmission eddy current testing. The testing device is designed to overcome the usual limitations of eddy current techniques, namely the lift-off effect, edge effect, and skin effect. Peak-to-peak difference and phase difference of the response signal to the excitation signal are used as signal features, and are extracted using a numerical algorithm. A radial basis function neural network (NN) is proposed for the identification of broken wires within a wire rope. The NN models are established by offline training, with three different rope types and signal features being NN inputs, and number of wire-breaks being the output. The experimental eddy current sensor and computer measuring system has been developed to obtain characteristic data for rope samples made in our laboratory. The characteristic data are indentified by the RBF network, and the identification results show the proposed evaluation method to test if wire ropes is feasible and practical.

1. Introduction

Wire rope is a type of flexible load bearing structure widely used in many applications including coal mining, transportation, construction, and tourist attractions. Operational safety problems have recently become the focus of attention, making nondestructive testing (NDT) of wire rope an important area of research. The detection of damage within wire rope is usually accomplished by NDT methods such as the classical electromagnetic method [1], the ultrasonic method [2], and the acoustic emission test method [3].

Electromagnetic detection technology has been applied by a number of researchers [4–6] for achieving automatic online detection of breakages in wire rope. Wang et al. [4] designed a detection system that used a personal computer and eddy current sensor as its core, and then used pattern recognition technology to detect the damage. Hu et al. [5] introduced filters and a data smoothing algorithm to suppress disturbances in the measurement signal. A range of signal characteristics were described, including absolute peak value, peak-to-peak difference, area of wave, and self-adaptive threshold adjustment to quantitatively analyze defects. Gu and Chu [6] also presented a group of signal characteristics for rope damage, however, they utilized a fuzzy identification method to detect and quantify different types of defects quantitatively. In more recent years, Basak et al. [7] provided a method for the non-destructive evaluation of haulage ropes. The method presented by Basak et al. [7] improved the reliability of the initial identification of the location of significant degradation along a rope.

One technique offering great potential for use in wire rope damage detection is neural networks [11–18]. A neural network (NN) is a non-linear dynamic system that can perform large-scale parallel distributed processing and self-adaptive learning, including the reconstruction of patterns [8]. Neural networks have been shown to be an efficient means of solving electric and/ or magnetic inverse problems to estimate material properties [9,10]. It was demonstrated by Gao et al. [11] that the performance of wire rope inspection is significantly improved with the use of a neural network-based technique in comparison to conventional methods.

Neural networks have been employed in a wide variety of nondestructive testing and damage detection applications ranging from planar structures to welded joints. Multilayer perceptron neural networks were used by Rekanos et al. [12] in order to evaluate the conductivity profile of a layered planar structure.

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doi:10.1016/j.ndteint.2011.09.015

Upadhyaya et al. [13] developed robust neural networks with low probability of misclassification for flaw depth estimation in steam generators based on eddy current test data analysis. A novel combination of neural networks and finite element modeling was presented by Song and Shin [14] to provide a systematic approach for flaw characterization in tubes. Of particular interest in their work is the use of two different paradigms of neural networks: probabilistic neural networks for flaw classification, and back propagation neural networks for flaw sizing. Yusa et al. [15] proposed a generalization for the solutions of an eddy current inversion method based on an artificial neural network, which simulates mapping between eddy current signals and crack profiles. The use of a multi-layer feed-forward error-back propagation neural network was investigated by Rao et al. [16] for on-line eddy current testing of austenitic stainless steel welds. The developed technique was able to detect and characterize longitudinal and transverse surface-breaking notches, despite the presence of disturbance variables (such as the weld microstructure). Dolapchiev and Brandisky [17] adopted Radial Basis Function (RBF) neural networks to measure crack width and depth using the pulsed eddy current technique and finite element method. Despite the large range of applications and success of neural networks in NDT and damage detection, there has been limited use in the evaluation of wire ropes. Tian et al. [18] proposed a back propagation network method to test for broken wires in steel rope.

This paper investigates a quantitative evaluation method for the detection of breakages in wire rope based on a RBF neural network using eddy current sensors. The detection method is presented in Section 2, where it is shown how the current technique overcomes three adverse effects of eddy current testing. Section 3 discusses the feature extraction algorithm of the detection system, which is used to provide a means of identifying defects. The design of the RBF NN is detailed in Section 4. The network model is presented along with the procedure to identify defects that could lead to breakage of the wire rope. Section 5 develops an experimental system to demonstrate and validate the effectiveness of the method. Conclusions on the newly developed method for damage detection in wire rope are given in Section 6.

2. Eddy current detection technique

According to the literature reviewed above, many NDT methods have been applied to try and solve problems associated with the detection of defects in wire rope. This paper adopts the eddy current testing technology for detecting defects in the wire rope. The detection scheme is first outlined below followed by a discussion on ways of overcoming key limitations of the eddy current testing technology.

2.1. The detection scheme

Wire rope is a complex component usually consisting of many fine steel wires twisted together. This complex structure can create difficulties for quantitative damage detection. Added to this is the factor that in most applications, wire rope is exposed to harsh working environments where interference factors are numerous. The typical length of wire ropes makes offline inspection and maintenance inconvenient and expensive. Thus, any damage detection technique for wire ropes is required to be used online for long durations and preferably non-contact for ease of use in a variety of practical applications.

Eddy current testing technologies for NDT take the eddy current effect as the working principle, which has advantages of high sensitivity, high detection speed, non-contact, and can be automated. This method has been widely applied including defect detection, vibration measurement, parts counting, and thickness detection.

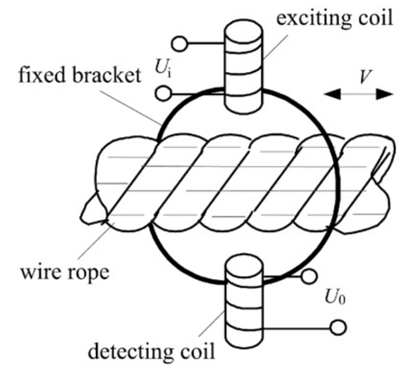

Fig. 1. Schematic of the eddy current detection setup.

The damage detection scheme developed for this work is designed to realize the long duration, online, and non-contact testing of wire ropes. A schematic of the eddy current system is shown in Fig. 1. The excitation coil and detecting coil are arranged in the radial symmetry way and are fixed on semi-circular combination brackets. The radial and circumferential location of the double coils can be adjusted by mechanically driven parts.

In Fig. 1, U_i is the excitation signal input and U_o is the sensing signal output. The wire rope moves at a finite speed, V, in either horizontal direction. When alternating electrical current passes through the excitation coil, an alternating magnetic field is generated in the space around the coil. The alternating magnetic field then creates eddy currents in wire rope, which affects the magnetic fields and the output from the detecting coil. A broken strand in the wire rope will change the characteristic parameters, which will affect the strength and distribution of the magnetic field. This means that the output of detecting coil will also change. All other relevant parameters remain unchanged when the wire rope moves in the testing system, therefore breakages at different locations will be reflected in the voltage signal of induction (detecting) coil. The output can be used to achieve quantitative detection of the broken wire rope through appropriate signal processing methods.

2.2. Design specifications to overcome key limitations

Generally, there are three key issues with eddy current testing systems, which are the lift-off effect, the skin effect, and the edge effect. These factors can have adverse impact on the precision of a testing system and must therefore be overcome. The specifications of the current test system to overcome these key limitations are detailed below.

2.2.1. Lift-off effect

Lift-off effect means that the impedance of the coil caused by the magnetic field of the eddy currents will change when the distance between the probes and object surface changes. The lift-off effect is mainly caused by shaking of the wire rope during the testing process.

Dual coils are fixed on the combined circular bracket in a symmetrical way within low-frequency testing devices (Fig. 1). The distance between the two probes should be adjusted to be larger than the diameter of the wire rope before working and then fixed to limit shaking of the rope during testing. The clearance is determined experimentally. In the work presented in this paper, the lift-off effect is overcome by adjusting the distance, or space, between the two probes.