Advances in Engineering Software 90 (2015) 11–21

Contents lists available at ScienceDirect

Advances in Engineering Software

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

Computer-aided modeling of wire ropes bent over a sheave

W. Ma, Z.C. Zhu*, Y.X. Peng, G.A. Chen

School of Mechanical and Electrical Engineering, China University of Mining and Technology, Xuzhou 221008, China

ARTICLE INFO

Article history:
Received 8 April 2015
Revised 26 May 2015
Accepted 14 June 2015
Available online 26 June 2015

Keywords:
Wire rope
Helical wires
Serret–Frenet frame
Variable section sweep
Helically twisting surface
Proe

ABSTRACT

In the paper, two methods for building a 3-dimensional geometry of a wire rope bent over a sheave in Proe™ are presented. In order to obtain the centroidal axes of the wires, the first method is associated with deriving their coordinate equations based on the Serret–Frenet frame and the second method is characterized by using the 'Variable Section Sweep' tool in Proe™ to generate a helically twisting surface around the centroidal axis of the king wire or a strand with the two boundary curves being the centroidal axes of two double or triple helical wires. Finally, both methods use the 'Variable Section Sweep' tool to generate the geometries of the wires. The two methods can be applied to any helical-strand wire rope.

1. Introduction

There are many actual cases of wire ropes bent over a sheave, such as in a wire rope-pulley system or in a multi-rope friction hoist system, which is composed of a large hoisting sheave, wire ropes, guide sheaves and containers, as shown in Fig. 1(a). It utilizes the friction between wire ropes and friction linings inserted onto the periphery of the hoisting sheave to lift coal, devices and personnel. Wire ropes are bent over the hoisting sheave in Fig. 1(b) and guide sheaves in Fig. 1(c).

In the case of a wire rope being bent over a sheave, there are triple helices among the centroidal axes of the wires, which increase the difficulty and complexity in terms of analytical and geometrical modeling. So far, most of the related studies have been limited to straight wire ropes and their mechanical behavior has been the research interest. Experimental research is time-consuming and expensive, and in most time cannot be conducted because of limited resources, etc. Some scholars [1–9] have been engaged in theoretical studies on wire ropes' mechanical behavior or response based on the Love's rod theory [10] and others [11–15] used finite element (FE) models. Most of these studies are related to analytical and geometrical modeling of straight wire ropes or straight strands, which are involved in deriving the coordinate equations of the wires' centroidal axes which are single helices or double helices.

Usabiaga et al. [8] derived the parametric equations of the double-helical wires under undeformed and deformed status based on the Serret–Frenet frame and used the recursive and wire-by-wire modeling approach to model straight helical-strand wire ropes subjected to tensile and torsional loads more precisely. Elata et al. [9] proposed a new model for simulating the mechanical response of a wire rope with an independent wire rope core (IWRC) and analytically obtained the theoretical mechanical response of the rope subjected to both an axial load and an axial torque, which is in agreement with experimental results. Jiang et al. [11] developed a concise FE model for a simple straight strand which takes full advantage of the helical symmetry features, further developed an accurate bending symmetric boundary condition to make finite element analysis (FEA) of a straight strand under pure bending [12], and also extended their study to three-layered straight helical wire ropes under axial loads [13]. Nawrocki et al. [14] and Páczelt et al. [15] respectively proposed a reliable FE model of a simple straight strand which allows for all the possible internal motions among the wires. In Ref [14], the role of the contact conditions in pure axial loading and in axial loading combined with bending was investigated and in Ref [15], the contact and friction of the wires were taken into account and the contact stress and deformation were calculated based on the Hertz theory and the developed nonlinear spring element.

Actually, it is difficult to conduct an analytical investigation on mechanical behavior of stranded wire ropes because the kinematics of double-helical wires is very complex [9]. In recent years, scholars would make use of FE packages to simulate the mechanical behavior of wire ropes in the actual applications. It consists of building a 3-dimensional (3-D) geometry of a wire rope. Many scholars made FEA on mechanical behavior of wire ropes by virtue of Ansys™ and Abaqus™. Stanova et al. [16] used the method of geometric transformations to have derived the coordinate equations of the

* Corresponding author.
E-mail address: zhuzhencai@cumt.edu.cn (Z.C. Zhu).

http://dx.doi.org/10.1016/j.advengsoft.2015.06.006
0965-9978/

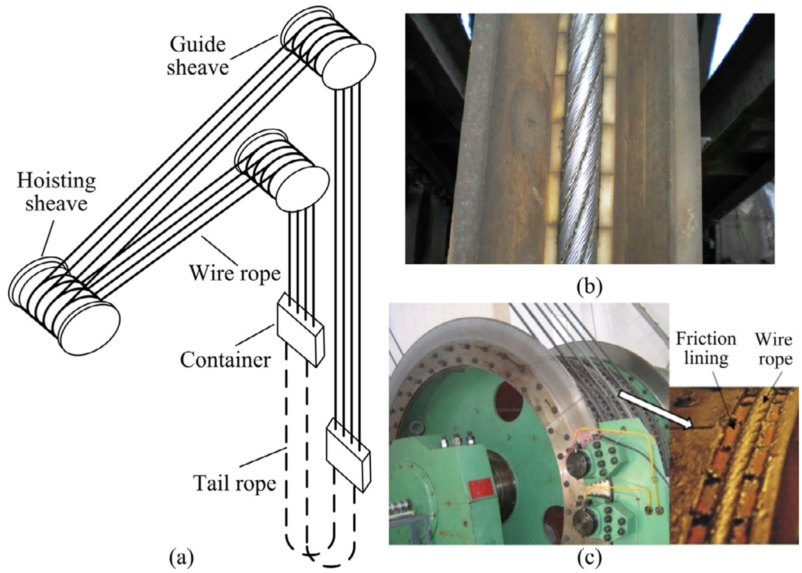

Fig. 1. (a) Schematic diagram of a multi-rope friction hoist system and its main components: (b) A hoisting sheave and (c) A guide sheave.

centroidal axes of the wires in a simple helical-strand wire rope and built its 3-D geometry in CATIA V5 software; and further imported a geometry of a multi-layered strand generated in this way into Abaqus™ and then made FEA on its mechanical behavior under axis load [17]. Erdönmez et al. [18,19] derived the parametric equations of the centerlines of the single and double-helical wires in a 7∗7-typed IWRC, used a developed code of Matlab™ to generate the control nodes of these centerlines, then constructed each wire with the meshed form in HyperMesh™ and finally in Abaqus™ assembled them into the IWRC and made FEA. Ma et al. [20] directly created the centroidal axes of all the wires in a basic 6×19 wire rope and subsequently built a geometric model for the 6×19 wire rope in ANSYS™ by virtue of the 'B-Spline' and 'Extrude' functions, and then made FEA to obtain the distribution of axial stress and axial strain along the length direction of the wire rope.

There are few studies on analytically modeling of a wire rope wound around a drum or bent over a sheave. In such cases, there are triple helices among the wires' centroidal axes, which increase the difficulty in modeling bent wire ropes precisely. Lee et al. [21,22] carried out a more comprehensive study into wire rope geometry. They gave the coordinate equations of the centroidal axis of an outer wire of a helical strand in a rope wound around a drum. The centroidal axis is in triple-helix from. The geometrical analysis presented in this paper applies to any rope with axisymmetric strands. Hobbs and Nabijou [23] studied the changes in curvature of single and double helixes in a straight wire rope as it is bent over a sheave. The analysis was applied to examine bending strains of wire ropes.

It can be seen that studies on mechanical behavior of bent wire ropes are limited to making use of geometrical analysis and prediction. In order to analyze mechanical behavior of bent wire ropes, it is better to turn to a FEA package, such as Ansys™ and Abaqus™. So it is necessary to build 3-D geometrical model in a CAD package or even in a FE package directly. Proe™ is one of the competent CAD software. It can generate a 3-D geometry and output a common-pattern file containing the geometry information, which can be imported into Ansys™ or Abaqus™.

So, the paper is aimed at building the 3-D geometry of a helical-strand wire rope bent over a sheave in Proe™. Actually, the outer wires of the helical strands in a rope bent over a sheave take on the form of a degenerate triple helix, because it can be seen as a case of a wire rope being wound around a drum with a lay angle of 0° [22]. Although in Ref [22], the coordinate equations of a triple-helix wire in a wire rope wound around a drum were directly presented in the Appendix section, it is still not easy for an engineer to build a 3-D geometry of a bent wire rope.

The present paper is organized as follows. Firstly, we present the basic assumptions and the definitions of some important geometrical parameters of a wire rope. Secondly, we derive the coordinate equations of the centroidal axes of all the wires in a 7∗7–wire strand core (WSC) stranded wire rope, which is one of the most interesting study objects [8], based on the Serret–Frenet frame like many scholars' work [8,14,21,22]. The derivation is recursive and does not involve any theoretical limitation for developing parametric equations of curves of higher twisting level. In the third part, we describe how to generate a 3-D geometry of the wire rope by the joint use of Matlab™ and Proe™. Finally, we will present another method for directly building the 3D geometry in Proe™, which does not involve analytical modeling and can be easily mastered by an engineer.

2. Basic assumptions and definitions of geometrical parameters of wire rope

2.1. Assumptions

The coordinate equations of the wires' centroidal axes of the 7∗7-WSC wire rope are obtained on the basis of the following assumptions:

(a) Any section normal to the centroidal axis of a wire is circular both before and after being bent over a sheave, as stated in the Assumptions section of Ref [22].
(b) The shape of the centroidal axis of a wire is a helix, which may be in the form of single helix, double helix, or triple helix.
(c) In addition, it is assumed that some terms related to wire rope, which are not explained in the paper, are known by readers. If not, please refer to Ref [22].

2.2. Definitions of the geometrical parameters of a 7∗7-WSC wire rope

The geometrical nomenclature of the 7∗7-WSC helical-strand wire rope used in this paper is provided in Fig. 2, to which reference should be made when reading the definitions of some terms, which, in accordance with those in [22], are specified as follows:

(a) Wire helical radius R_w
It is defined as the perpendicular distance from the centroidal axis of an outer wire to that of the parent strand.