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Comparative analyses of torsional fretting, longitudinal fretting and combined longitudinal and torsional fretting behaviors of steel wires

Xiangru Wang[a], Dagang Wang[a,b,*], Xiaowu Li[a], Dekun Zhang[c], Shirong Ge[a], José Alexander Araújo[d]

[a] School of Mechatronic Engineering, China University of Mining and Technology, Xuzhou 221116, China
[b] Jiangsu Key Laboratory of Mine Mechanical and Electrical Equipment, China University of Mining & Technology, Xuzhou 221116, China
[c] School of Materials Science and Engineering, China University of Mining and Technology, Xuzhou 221116, China
[d] Faculty of Technology, University of Brasilia, Brasilia 70910-900, Brazil

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ABSTRACT

Comparative analyses of torsional fretting, longitudinal fretting, and combined longitudinal and torsional fretting behaviors of steel wires were investigated in the present study. Hysteresis loops of tangential force versus displacement and torque versus torsion angle were explored employing the self-made test apparatus. Wear scars were quantitatively compared using the three-dimensional white light interferometer. Morphologies of wear scars of steel wires were comparatively analyzed to investigate their wear mechanisms employing the scanning electron microscope. Wear coefficients in all three cases were calculated and compared. The results show that the combined longitudinal and torsional fretting presents the largest relative slip (longitudinal and circumferential) and area of hysteresis loop. The wear scar size and wear coefficient of fatigue wire present the largest values in the case of combined longitudinal and torsional fretting as compared to the smallest values during torsional fretting. Meanwhile, combined longitudinal and torsional fretting exhibits the most severe damage at the contact surface.

1. Introduction

In China, 53% of proven coal resources are buried in km deep stratum. Vertical multi-rope friction hoist systems (Fig. 1), widely employed in km deep coal mine hoisting, are responsible for lifting and lowering the coal, equipment and personnel. The hoisting rope, as the key transmission component of a multi-rope friction hoist system, connects the hoist and containers [1]. Therefore, the reliability of hoisting ropes greatly affects the safe production of coal mines and the safety of personnel.

During hoisting, the hoisting rope is subjected to dynamic tensile, bending and torsional loads. During the shallow coal mine hoisting, the torsional stress of hoisting rope can be neglected, while the torsional stress greatly affects the rope life in the km deep coal mine hoisting [2]. For example, hoisting ropes in km deep Zhangjiakou and Dongguashan coal mines in China have the averaged service life of 3–6 months (far smaller than two years' service life according to coal mine safety regulation) attributed to the torsion effects [3]. Those loads will cause the longitudinal fretting [4,5], torsional fretting (cyclic torsion at a constant tension), and combined longitudinal and torsional fretting of steel wires in the rope, which all induce the fretting wear between contacting wires and thus accelerate the rope failure. Therefore, it is of great importance to explore torsional fretting, longitudinal fretting and combined

* Corresponding author at: School of Mechatronic Engineering, China University of Mining and Technology, Daxue Road #1, Xuzhou 221116, PR China.
E-mail address: wangdg@cumt.edu.cn (D. Wang).

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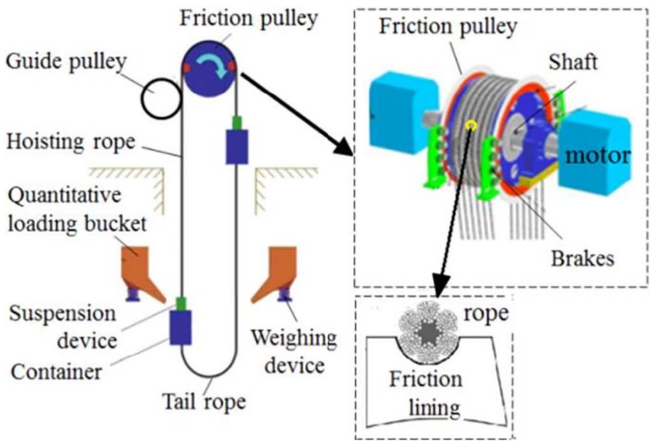

Fig. 1. Vertical multi-rope friction hoist system [10].

longitudinal and torsional fretting behaviors.

In recent years, many scholars have performed researches on longitudinal fretting of steel wires. Wang et al. [6] investigated dynamic wear evolution and the crack propagation behavior of steel wires during fretting fatigue, and found that an increase of relative displacement induces better anti-wear properties of wires. Shen et al. [7] studied the effect of contact load on fretting wear behavior of steel wires, and found that the contact stress and probability of contact fatigue increased with increasing contact load. Zhang et al. [8] explored fretting fatigue behaviors of steel wires under different strain ratios. He found that a decrease of strain ratio causes the fretting regime changed from partial slip regime to mixed regime and slip regime, shorter fretting fatigue life and higher wear coefficient. Cruzado et al. [9] estimated the fatigue coefficients of steel wire using four methods and found Manson's method and medians method gave lives closer to those obtained from fretting wear tests in thin steel wires. Previous studies mainly focused on longitudinal fretting behaviors of steel wires. However, comparative analyses of torsional fretting, longitudinal fretting and combined longitudinal and torsional fretting behaviors of steel wires are not yet reported, and damage degrees of steel wires in these cases are not clear.

Therefore, the objective of the present study was to compare torsional fretting, longitudinal fretting and combined longitudinal and torsional fretting behavior of steel wires. A self-made combined longitudinal and torsional fretting test rig is introduced in Section 2. Section 3 presents evolutions of hysteresis loops of tangential force versus displacement amplitude and torque versus torsion angle of steel wires, and dissipated energy at distinct fatigue cycles in three cases. The size of wear scars and wear morphologies in distinct cases were investigated. Wear coefficients in all cases were calculated.

2. Experimental details

2.1. Multiaxial longitudinal fretting test rig

A self-made multi-axial longitudinal fretting test rig for steel wires (Fig. 2) is introduced to carry out torsional fretting at a constant tension, longitudinal fretting and combined longitudinal and torsional fretting tests. The fatigue wire (7) is axially loaded employing the servo electric cylinder (10), and the fatigue load is recorded by the tension sensor (9). The cyclic torsion of fatigue wire is applied using step motor *A* (2); the torsion angle and torque of fatigue wire can be measured by the angular displacement sensor (1) and torque sensor (3), respectively. Left and right loading wires are fixed to left and right fixtures (17 and 15) with certain radii of curvature, respectively. The role of weight (13) causes the close contact between loading wires and fatigue wire. The contact load between contacting wires is equal to the gravity of weight, and the tangential force can be measured by the tangential force transducer (14). The crossing angle between contacting wires can be adjusted by the step motor *B* (6). The inverter is applied to control the step motor *A* in order to realize longitudinal fretting or fatigue tests with distinct crossing angles.

2.2. Test parameters

Steel wires of hoisting ropes have the diameter of 1 mm and length of 400 mm. Those wires are manufactured by the cold drawing process of high quality carbon structural steel. The chemical composition (in wt%) of the wire material is 98.71 Fe, 0.39 Mn, 0.87 C, 0.02 Si, 0.01 Ni, 0.001 S, $<$ 0.001 P. The wires have the ultimate strength of 1700 MPa, offset 0.2% yield strength of 1150 MPa, an elastic modulus of 203 GPa, and elongation of 1.9% after wire failure. Tables 1 and 2 show chemical compositions of steel wires and test parameters, respectively. Those wires were gently grinded using fine sandpaper and then cleaned using alcohol before the tests.