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Investigation of a novel rolling contact fatigue/wear competitive life test machine faced to surface coating

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ABSTRACT

A novel rolling contact fatigue (RCF)/wear competitive life test machine based on double-roll mechanism was designed to investigate the RCF/wear failure mode and predict the competitive life regularity of surface coatings. The test machine was designed for variable slip ratio to simulate the complex service conditions. The failure can be monitored using signals which are acquired from acoustic emission (AE) of the contacting rollers. In the experimental studies, the typical morphologies of RCF damage such as pits, surface abrasion, and delamination were observed. The effectiveness of the AE signals used as a RCF failure monitoring tool was analyzed. The *P–N* and *P–S–N* plots were established to predict the life regularity of surface coatings.

1. Introduction

Rolling contact fatigue (RCF) and wear are the most common failure modes of mechanical components and engineering structural parts such as shafts, gears, cams, and rollers, etc. RCF and wear can cause a huge economic loss and restrict the service property of equipments. Wear is mainly in the form of surface material removal caused by plow and adhesion under slip contact condition. RCF often occurs on the surface of friction pairs under rolling contact condition. It is a persistent damage process which involves the crack initiation, crack propagation and crack induced fracture due to the generated shear stress in the superficial layer under the action of alternating load. RCF and wear are both subject to the surface material failure with a common characteristic of contact, friction, and surface accumulative damage.

Thermal spraying as a kind of convenient and high efficient technology is often used to prepare surface coatings with high bonding strength and hardness for repairing the failure parts due to RCF and wear, which has attracted extensive attention of researchers in the field of tribology [1–3]. The wear-resistance and contact fatigue resistance properties are the key indicators to evaluate the quality and durability of the repairing coatings [4–6]. However, it should be noted that surface coatings have multicomponent composition and high irregular metastable structure, which endows surface coatings special characteristics-high free energy and multi-interface different from those of homogeneous materials. High free energy contributes to the improvement of the wear-resistance property, while multi-interface tends to induce the initiation of micro-cracks and reduce the RCF life. Therefore, the life evolution laws of surface coatings are nonlinear, which leads to the complexity of life prediction. Under the "slip-rolling" complex condition, the failure mode of surface coatings is determined by the competition between RCF and wear. Therefore, it has great scientific significance to research competitive life of surface coatings under "slip-rolling" mode which is close to real serving condition.

A novel RCF/wear competitive life test machine was designed to simulate the real contact condition i.e. "slip-rolling" of surface coating. Acoustic emission (AE) technology was selected to monitor the failure of the surface coating, especially RCF failure. The energy and amplitude of acoustic emission signals can monitor sensitively the stress wave which is generated from the fracture of materials due to fatigue crack propagation [7–11]. Moreover, acoustic emission signals can prewarn the failure occurrence ahead of the commonly used vibration signals. This contributes to reduction of human attention and human error, and accurate determination of failure point as well.

2. RCF/wear competitive life test machine

2.1. Design criteria

The novel RCF/wear competitive life test machine was designed to simulate the complex service condition and provide a reliable

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test platform. It should meet the requirement of the following criteria [12]:

(a) The friction pairs contact with each other as a line contact mode to simulate the service condition of gears, rollers, and cams.
(b) The test machine should have controllable drive device to run the friction pairs to achieve any desired speed and realize accelerated life tests with high efficiency.
(c) The relative motion state between the friction pairs can switch conveniently among pure slip, slip-rolling, and pure rolling.
(d) The test machine should have reliable loading facility to give a contact pressure up to 2.6 GPa.
(e) The test machine should have sensitive system to monitor failure process accurately, and realize automatic stop when determining failure point.

2.2. Modules of the test machine

The test machine was designed in the form of modules. Fig. 1 shows the schematic diagram of the test machine. The test machine consists of a mechanical system and a measurement and control system. The mechanical system includes roller assembly module, drive module, loading module, and lubrication module. The measurement and control system is composed of measurement module and data acquisition and processing module.

Table 1 shows the technical parameters of the test machine. The significant features of the test machine are as follows:

(a) The test roller and standard roller are driven by respective servo-actuator to realize the accurate control of slip ratio (0–100%), where slip ratio is the ratio of velocity difference between test roller and standard roller to the velocity of standard roller. The rolling-slip contact condition can change conveniently by adjust the slip ratio randomly
(b) The convex part of the test roller was designed to make the machine specific for testing surface coatings.
(c) Hydraulic and lever loading device ensures the test machine can load continuously without interruption. The loading value can be controlled by computer.
(d) AE technique was introduced to make the test machine accurately judge the failure point. The typical AE waveforms and frequency spectra of different stages in RCF process can be extracted to judge the RCF failure.
(e) The test machine can realize automatic stop when the selected parameter (energy of AE signal, friction torque, and test time) is over the pre-set value.

2.2.1. Roller assembly module

Fig. 2 shows the schematic diagram of roller assembly module. The roller assembly module of the test machine mainly includes a test roller and a standard roller. The test roller and standard roller were assembled on respective main shaft, and both locked by a nut with the diameter of 35 mm. The main shaft of test roller was fixed on the working flat by a bearing block. The main shaft of standard roller was fixed on one side of the hydraulic and lever loading device. The parallelism between the two main shafts is relatively high to ensure the tight contact between the two rollers.

Fig. 3(a) and (b) show the configuration of the test roller and standard roller, respectively. The tested coating should be

Table 1
Technical parameters of the test machine.

Technical parameters	Values
Loading range of test force	1.2–30 kN (relative error≤ $\pm$ 0.5%)
Measurement range of friction torque	1–20 Nm (relative error≤ $\pm$ 1%)
Rotational speed	5–2000 r/min(infinitive variable)
Test time	1 s–9999 min
Measurement range of test revolution	0–999999999
Measurement range of temperature	−25–650 °C
Slip ratio	0–100%
Power of servo-actuator	5 kW
Torque output of servo-actuator	23 Nm
External dimensions	1690 × 960 × 1210 mm^3

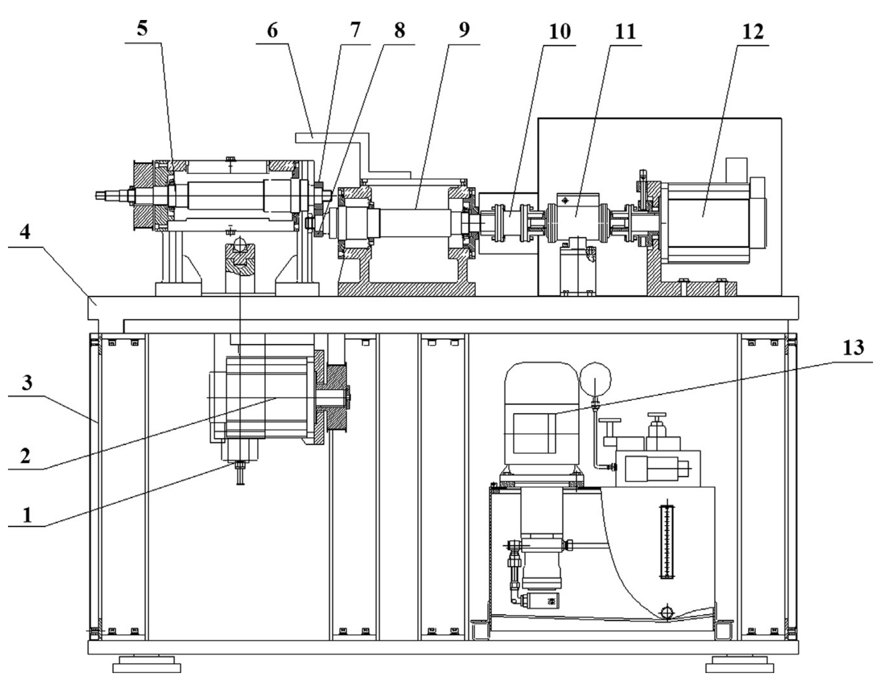

Fig. 1. Schematic diagram of RCF/wear competitive life test machine. (1) Hydraulic piston, (2) servo-actuator driving standard roller, (3) chest, (4) working flat, (5) main shaft of standard roller, (6) oil interceptor, (7) standard roller, (8) test roller, (9) main shaft of test roller, (10) flexible coupling, (11) torque sensor, (12) servo-actuator driving test roller, and (13) hydraulic station.