Analysis of the development of friction and wear testing machine based on complex working conditions

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Abstract. Friction is one of the three main factors leading to the failure of metal materials. In order to improve the service life of machinery and reduce unnecessary losses in industrial production, it is necessary to study the friction and wear properties of industrial materials. Simultaneously in order to explore the impact of various environmental conditions on material properties, friction and wear testing machine war born as the times require. This paper mainly introduces the experimental principles and application scenarios of several universal friction and wear testing machines. At the same time, this paper also explores the situation of several special friction and wear testing machines that adapt to complex environments by organizing the industrial needs generated by the rapid development of technology. This paper collects and organizes literature on the current status and development of friction and wear testing machine in recent years. The paper has found that adding or improving special equipment to the special type of friction and wear testing machine on the basis of the universal model can better meet the needs of actual working conditions.

Keywords: Friction and wear, Magnetic field, Corrosion, Vacuum

1. Introduction

Tribology is the study of surface interactions between objects in relative motion. The term tribology originated from the Greek word “tribos”, which means rubbing. The content covered by this word is diverse, including research on friction, wear, lubrication, lubricant, and bearing [1]. During the operation of mechanical equipment, friction and wear between various parts are difficult to avoid. The unnecessary friction and wear can lead to material deformation, thereby damaging the service life of mechanical equipment [2].

The friction and wear testing machine is the instrument for conducting tribological experiment. The friction and wear testing machine evaluates materials by measuring the Coefficient of Friction (COF) and Wear Rate (WR) between materials. According to different working conditions, friction and wear testing machine is divided into two categories: universal friction and wear testing machine and special friction and wear testing machine. Because special friction and wear testing machine is born to adapt to complex actual working conditions. Universal type is usually divided into five subcategories, namely four ball type, pin disc type, ring block type, reciprocating type, and multifunctional friction and wear testing machine [2, 3]. However, with the exploration and development of aerospace and other high-tech fields, the actual operating conditions have become increasingly complex, such as high temperature, low

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temperature, high pressure, vacuum, strong corrosion, strong magnetic field, strong current, high-speed etc. The universal friction and wear testing machine on the market was no longer able to meet the requirements. Therefore, a special friction and wear testing machine that can meet complex working conditions was born [2, 4].

This paper introduces the experimental principles and application scenarios of several universal friction and wear testing machines. It also collects and organizes literature on the current status and development of friction and wear testing machine in recent years. This paper explores the future research directions of friction and wear testing machines based on practical application requirements. These studies provide a reference for the optimization of friction and wear testing machines in the future.

2. Universal friction and wear testing machine

2.1. Four ball friction and wear testing machine

The four ball friction and wear testing machine is a machine that measures the performance of lubricating oil under sliding friction in the form of point contact. The main indicators tested are maximum sintering load, maximum non jamming load, and lubricating oil friction coefficient. These indicators directly reflect the performance of lubricating oil. The principle of the four ball friction and wear testing machine is shown in Figure 1. Its friction pair consists of three fixed specimens that are compressed below and one rotating specimen above [5].

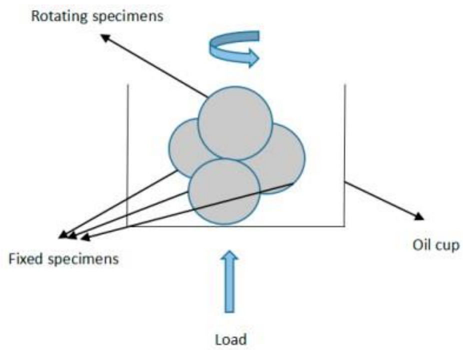

Figure 1. Schematic diagram of the four ball friction and wear testing machine [3]

When conducting friction and wear experiment on lubricating oil on the four ball friction and wear testing machine, the experimenter only needs to pour the tested lubricating oil into an oil cup and then run the testing machine. After the experiment, the experimenter can compare the condition of the components before and after wear based on the load displayed by the instrument during the experiment. In this way, the tribological properties of the tested lubricating oil can be obtained [5].

2.2. Pin disc friction and wear testing machine

Pin disc type friction and wear testing machine is a friction and wear testing machine used to detect surface contact, which is used to measure the friction and wear performance of metal and non-metallic materials (such as plastic, nylon, etc.). It is usually a tabletop model with simple manufacturing and easy operation. It is used to measure the friction coefficient of various materials in surface contact sliding friction and wear tests, as well as the wear status of various materials at different temperatures, loads, and speeds [2, 3].

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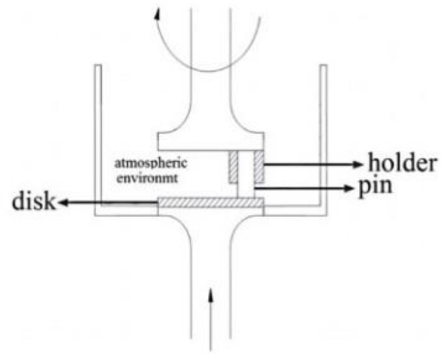

Figure 2. Schematic diagram of the pin disc friction and wear testing machine [3]

As shown in Figure 2, the tested component is fixed by a holder and driven by a spindle to rotate at a uniform speed. The friction and wear disc is subjected to a vertical load from the other axis, causing the specimen to slide and friction through rotational motion on the disc. Then, the friction and wear performance of the specimen can be obtained by comparing the load measured by the sensor during the experiment and the wear status of the tested components before and after the experiment [2-3,6].

2.3. *Ring block type friction and wear testing machine*

Ring block friction and wear testing machine is the friction and wear testing machine used for measuring line contact. The schematic diagram of the ring block friction and wear testing machine is shown in Figure 3. The friction pair of the testing machine is composed of a rotating standard rotating ring and a rectangular block in contact with the ring. The clamping mechanism and loading mechanism of the block are combined together. The loading mechanism is connected to the crossbar. The friction coefficient between the ring and the block can be measured by the rotation of the circular ring. By measuring the thickness and width of wear marks on the block under different speeds and loads, as well as the magnitude and coefficient of friction between the block and the ring. In this way, the friction and wear performance of the tested component can be measured [3].

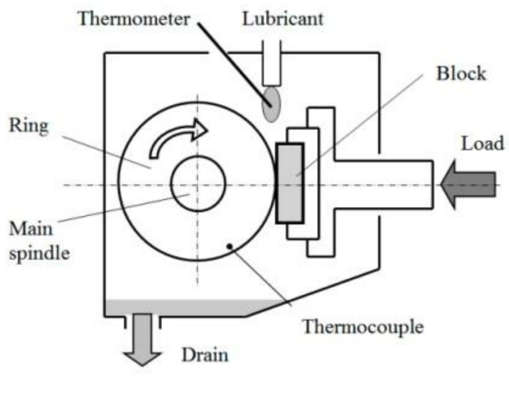

Figure 3. Schematic diagram of ring block friction and wear testing machine [3]

2.4. *Reciprocating friction and wear testing machine*

The reciprocating friction and wear testing machine is used to conduct experiments on mechanisms and components that undergo reciprocating motion through reciprocating surface contact, such as bearing, gasket, and piston ring, etc. As shown in Figure 4, the tested component is loaded onto the slider through a fixture and then driven by a connecting rod. This causes the component to move back and forth on the execution guide rail. The other friction pair is fixed under the loading device. The loading device controls the load between two friction pairs by increasing or decreasing weights [3, 5].

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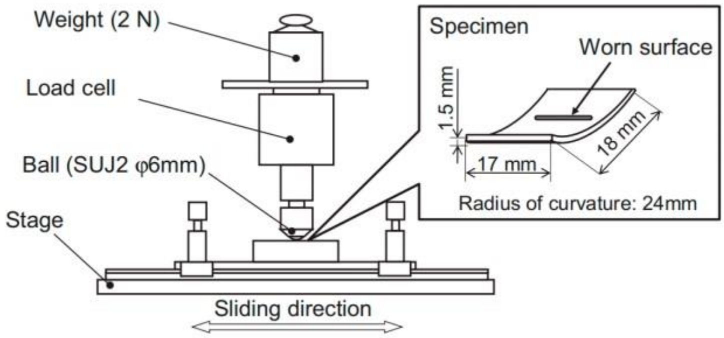

Figure 4. Schematic diagram of reciprocating friction and wear testing machine [3]

3. New types of friction and wear testing machine adapted to complex working conditions

With the continuous development of high-tech fields such as aviation and aerospace, the demand for materials used in machinery is increasing rapidly, especially in terms of friction and wear of mechanical materials. Because friction and wear performance directly affect the service life of machinery and the safety of users' lives. And the usage environment of materials is becoming increasingly extreme, such as high magnetic field, low temperature, high temperature, strong corrosion, high vacuum, high-speed, etc. Generally speaking, commercial universal friction and wear testing machines are no longer able to meet many complex requirements for simulating complex working conditions and conducting material performance testing research. Therefore, people focus on these complex operating conditions. Designers have designed and developed the special friction and wear testing machine that adapts to the environment one by one [4].

3.1. Vacuum friction and wear testing machine

To meet the needs of the aerospace industry, friction and wear testing machine that can simulate vacuum environments are essential. There are some vacuum friction and wear testing machines that have been commercialized, such as the VTR and HVT high vacuum friction and wear testing machines of CSM company in Switzerland. The commonly used testing machine in experiments is the VFBT-4000 high vacuum four ball friction and wear testing machine. The tester is designed and manufactured by the State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics. The VFBT-4000 high vacuum four ball friction and wear testing machine is mainly used to test the performance of lubricating oils and greases under aerospace conditions. The testing machine achieves a vacuum environment through a vacuum pump. And it uses magnetic rotation technology to make three moving balls move. Finally, it collects and records the relationship curve between the vacuum degree and the friction and wear performance of the experimental material through sensors [4].

3.2. High corrosion type friction and wear testing machine

Corrosion and wear are the three main factors leading to metal failure. If the wear of machinery is reduced in a corrosive environment, the service life of the machinery can be greatly increased. In this way, it can reduce unnecessary mechanical losses. According to different environments, there are two main types of corrosion to machinery, namely gas corrosion and liquid corrosion. There are many corrosive environments, such as the mining water environment of mining institutions, the seawater environment of deep-sea institutions, and some strongly corrosive gas environments [4, 7].

Due to the different corrosive environments, the corrosion mechanism, namely the corrosion chamber, used to simulate the environment in highly corrosive friction and wear testing machines also varies. The friction and wear testing machine for gas corrosion can simulate the environment by injecting corrosive gas into the vacuum box. For example, a vacuum friction and wear testing machine designed and developed by Pei Zhaohui's team from Wuhan Institute of Material Protection can not only achieve a vacuum environment and introduce corrosive gases, but also adjust the temperature and humidity during the experiment. At the same time, the machine has a simple structure, high sensitivity, and is easy to operate. The friction and wear testing machine for liquid corrosion can add an intermediate mechanism, namely the liquid corrosion chamber. The corrosion solution can be added to the liquid corrosion chamber according to the actual working condition ratio. Afterwards, the specimen can be tested in a liquid corrosion chamber. The testing machine collects the friction coefficient and magnitude of friction between two friction pairs through sensors [4,7].

3.3. Low temperature friction and wear testing machine

There are many high-temperature friction and wear testing machines on the market. However, low-temperature friction and wear testing machine is rare on the market. Most low-temperature friction and wear testing machines on the market can just only maintain a minimum temperature of -30 ℃. Although this temperature can meet many experimental conditions. This temperature can't meet the requirements for some extreme situations, such as the polar environment and space environment. The experimental team of Kun Yang et al. developed an ultra-low temperature friction and wear testing machine that adapts to polar climates, which meets the needs of simulating low-temperature environments. The testing machine adopts a German-developed ultra-low temperature heating and cooling circulator. This testing machine can control the experimental temperature at -70 ℃. This temperature meets the experimental needs of polar and low-temperature environments very well [2].

3.4. Stable magnetic field friction and wear testing machine

With the rapid development of industry, the presence of magnetic fields in actual working conditions is not uncommon. From the perspective of tribology, the presence or absence of a magnetic field has a significant impact on the coefficient of friction and fluctuation coefficient of friction in machinery. Due to the presence of magnetic fields in industrial environments, the losses of mechanical components under magnetic fields are also increasing rapidly. According to the research conducted by Guo et al. from Anhui University of Science and Technology, it was found that the introduction of a magnetic field significantly increases the wear of pure iron under low loads between friction pairs. However, when there is a high load between the friction pairs, the introduction of a magnetic field has a relatively small impact on their wear. It indicates that the magnetic field can greatly affect the friction performance of pure iron, especially under low loads [8]. According to the tribological experiments conducted by Li et al. from Chongqing University of Posts and Telecommunications in China, it was found that under magnetic field conditions, the elastic modulus and surface roughness of magnetorheological elastomer (MRE) are affected. They do not vary linearly with the strength of the magnetic field [9].

In order to reduce the wear of these materials in magnetic field environment, the friction and wear testing machine with a stable magnetic field is essential. Wu et al. from Qingdao University designed and developed a new environmentally controllable friction and wear testing machine. The testing machine creates a stable magnetic field environment by connecting wire coils. The magnetic field strength is controlled by connecting the microcontroller to the upper computer. The upper computer uses the collected voltage signal to cause the constant current source module to output a certain amount of current to the coils. Then it causes a stable change in the size of the magnetic field [10].

4. Conclusion

This paper mainly explains the universal types of friction and wear testing machines, as well as the types of special friction and wear testing machines based on complex actual working conditions. This paper concludes that adding or improving special equipment to the special type of friction and wear testing machine on the basis of the universal model can better meet the needs of actual working conditions. By summarizing those types of friction and wear testing machine, it is believed that it will play a good role in future practical applications. The paper has not yet delved into the working conditions under the influence of multiple factors.

People have made tremendous achievements in the field of friction and wear testing machine. However, the actual operating conditions will become increasingly complex, and the requirement for

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experiments will also become higher and higher. Therefore, the development of friction and wear testing machine in the future should focus on the following aspects: Using high-precision measurement and control systems; Using high-performance, automated, and easily controlled motion and loading systems; Adding replaceable intermediate components or multifunctional mechanical components; Strengthening the Application of Artificial Neural Network (ANN) and Machine Learning (ML) Models in Friction and Wear Experiments.

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