Simulation Study on the Influence Law of Two-body Wear in Sliding Guide Ways

Shengfang Zhang, Qiang Hao, Zhihua Sha, Yu Liu*, Jian Yin, Fujian Ma and Dapeng Yang
School of Mechanical Engineering, Dalian Jiaotong University, Dalian, China 116028

*E-mail: liuyu_ly12@126.com

Abstract: In view of the typical two-body wear issue in sliding guide ways, this paper established the two-body wear simulation model of the guide ways by the finite element software. Based on the friction and wear mechanism, and the influence of friction conditions on the two-body wear of the guide ways was considered. The wear process of the guide ways was analysed, and the influence of load and sliding speed on the wear of the guide ways was researched. The simulation results showed that large sliding speed with the wear would accelerate and a large load would increase the wear of the guide ways.

Keywords: sliding guide ways, friction factor, two-body wear, finite element simulation

1. Introduction
The sliding resistance and energy consumption cause the two-body friction by the interaction of the two contact surfaces, and the two-body wear is a process in that the surface material changed the shape, size, structure and properties under two-body friction. Friction causes wear and friction occurs in the wear. Therefore, for the two-body friction and wear mechanism, the tribology community has conducted a lot of researches for many years.

Based on the idealized classical model, Rabinowicz laid the theoretical foundation for the qualitative analysis of wear[1]. Lee et al obtained an empirical formula for estimating the tool wear model by Archard model analysis[2]. Soerberg et al used the Archard wear model to describe the relationship between friction material wear rate and braking distance[3]. And the methods for wear research were not limited to theoretical analysis, but also focused on experimental research. Peterseim et al established a model for numerical simulation of pin-disc friction and wear tests, and its self-developed program is used to calculate wear volume and wear surface appearance parameters[4]. Mukras et al used a wear processor to simulate the dry friction process of the swing pin on the pivot[5]. However, the experimental research method consumes a lot of manpower and material resources, and the complexity of the system and different working conditions will cause some simulation test results to be not well used in practical engineering applications. Numerical simulation techniques can make up for these deficiencies. Bortoleto et al used finite element modelling to numerically simulate the stress field distribution and analysed the variation of the surface profile of the disc[6]. Shen et al used the Archard model to analyse the dynamic wear process of the bearing and learned the wear between the contact surfaces by finite element simulation is that the discrete quasi-static model can be used to simulate the nonlinear wear process[7]. Ripoll et al used finite element analysis to analyse the effect of reciprocating sliding friction on the plastic deformation of the textured surface under different groove morphology and loading conditions[8].
The above researches mainly aim at the change of the friction performance of the friction pair, but
the material wear analysis and research are not deep enough. In this paper, the typical two-body wear
of sliding guide ways is studied by Deform-3D. The two-body wear simulation model of the guide
ways is to carry out finite element analysis, and the influence of friction condition on the two-body
wear is explored, which provides a theoretical basis for practical application.

2. Mechanism analysis of two-body wear
Wear is a process in that the surface materials continue removal in the relative motion of the objects in
contact with each other, which is an inevitable result of friction. The interaction of the two friction
surfaces can be either mechanical or molecular. Mechanical effects include elastic deformation, plastic
deformation, and furrowing effects. It can be caused by the direct mesh of the rough peaks between
the two surfaces, or it also can be caused by external abrasive particles. The surface molecular action
includes two kinds of attraction and adhesion effects, the former has a small force and the latter’s force
is large. When the friction pair slides, the rough peak of the soft surface is easily deformed, and a
smoother surface formed by the soft rough peak first breaks under load. Thus, the contact state is no
longer a rough peak versus a rough peak, but the rough peak of the hard surface slides on a relatively
smooth soft surface, and when the hard surface rough peak slides on the soft surface, the points on the
soft surface are subjected to a load, the surface shear deformation will occur and cause wear.

The relationship between various factors in the friction and wear process is very complicated. The
surface layer will undergo mechanical, structural, physical and chemical changes under the interaction
of the friction surface. The plastic deformation of the surface layer makes the metal cold. It hardens
and becomes brittle. If the surface is subjected to repeated elastic deformation, fatigue damage and
wear will occur. The high temperature of the surface contact caused by frictional heat can soften the
surface metal, and rapid cooling after contact will cause recrystallization or solid solution decomposition, these will cause wear.

3. Establishment of finite element model for two-body wear of guide ways
Based on friction and wear mechanism, a simplified model of the two-body wear of the rectangle
guide ways is established by using the finite element software Deform. The model is shown in Figure
1. In the simplified model, the sliding guide way length is \( L_1 = 10 \) mm, the width is \( l_1 = 20 \) mm, the height
is \( h_1 = 5 \) mm, the static guide way length is \( L_2 = 100 \) mm, the width is \( l_2 = 20 \) mm, and the height is \( h_2 = 5 \) mm.

At the same time, the material properties are added to the sliding guide way and the static guide way, as shown in Table 1.

| Material                        | Density (kg/m³) | Yield stress (MPa) | Elastic Modulus (GPa) | Poisson's ratio | Hardness |
|---------------------------------|-----------------|--------------------|-----------------------|-----------------|----------|
| the static guide way (cast iron)| 7200            | 270                | 148                   | 0.3             | HRC17    |
| the sliding guide way (45 # steel)| 7800            | 355                | 210                   | 0.3             | HRC26    |

In the simulation process, the initial mesh of the model will be distorted and degraded. In order to
avoid the problem of reduced accuracy or non-convergence caused by severe distortion of the mesh,
the adaptive mesh re-division technique to Deform is adopted. Encryption and automatic
compensation of the lost mesh volume not only ensures the accuracy of the local deformation, but also saves the solution time and memory consumption.

Figure 2. Finite element model of the guide ways wear.

The boundary conditions of the sliding guide way and the static guide way are set separately. The wear process is achieved by relative sliding, so that the sliding guide way needs to apply a speed in the $Y$ direction while the upper surface of the sliding guide way applies a load in the negative direction of the $Z$ axis. In the actual working condition, the static guide way is fixed, and full constraint is applied to the bottom surface of the static guide way to control the movement of the static guide way. The model is shown in Figure 2. It is assumed that the heat exchange coefficient between the friction surfaces is 45N/sec/mm/C, the friction coefficient is 0.1, and the friction coefficient does not change with temperature. Set the environment temperature to 20°C. In the simulation process, the wear calculation is based on the Archard wear calculation formula, which is:

$$ W = \int K \cdot \frac{P^a \cdot v^b}{H^c} \, dt $$

(1)

Where, $W$ is wear depth, $P$ is the interface pressure, $v$ is sliding velocity, $H$ is material hardness, $K$, $a$, $b$, and $c$ are experimentally calibrated coefficients.

The simulation control increment is 0.01s/step, and the reading is saved every 20 steps. The time step setting cannot be too large, otherwise the solution accuracy will be reduced, and will result in mesh distortion or even non-convergence. The heat transfer and deformation are selected in the simulation model, and the international unit system will be chosen. The conjugate gradient method is used to increase the solution accuracy. The wear process under different parameters is simulated by a single variable method, and the influence of different friction conditions on the wear of the two-body of the guide ways is analysed.

4. Simulation results and analysis

4.1. Analysis of two-body wear process of guide ways

When the load is 1000N and the sliding speed is 5mm/s, the sliding guide way slides from point $A$ to point $B$ on the static guide way through the simulation of the finite element software Deform, the nephogram of wear can be obtained, as shown in Figure 3.
Figure 3. Nephogram of the static guide way wear in different time.

It can be seen from Fig.3(a) that the wear value of the contact area between the static guide way and the sliding guide way is generally $1.89 \times 10^{-6}$mm when the sliding guide way starts to slide, and the wear value on both sides is below $8.78 \times 10^{-7}$mm. It shows the tendency that the middle area wear is large and various, and wear of both ends are small. As the sliding guide way continues to slide, the middle area wear of the static guide way is continuously expanded, and the area with small wear at both ends remains basically unchanged. In Fig.3(f), the middle portion of the static guide way wears relatively uniformly, and the both ends area wears very small. And the material of the edge region is not supported, and the stress concentration caused by the extrusion, and the material strength is low and easily broken. The maximum wear values at both ends of the static guide way are $1.84 \times 10^{-6}$mm, and the maximum wear value in the middle is about $3.58 \times 10^{-6}$mm. This is because the sliding guide way are in the initial sliding and ending sliding state, the contact friction area is small. When it is at both ends of the static guide way, the wear of the static guide way is small.

4.2. Effect of load on the wear of the static guide way
The static guide way is subjected to different loads, and the degree of wear will change accordingly. In order to study the relationship between wear and load, the simulation loads are selected to be 1000N,
1300N and 1600N respectively when the sliding speed is 5mm/s. By extracting 100 nodes data uniformly distributed from the point \( A \) to point \( B \) on the static guide way, the curves of the single-wear surface appearance of the static guide way under different loads are plotted, as shown in Fig.4.

![Figure 4. Chart of parameters with different loads.](image)

It can be seen from Fig.4 that the static guide way wear tends to increase at the node 1-10, and the wear value at the node 10 reaches a maximum of \( 2.75 \times 10^{-3} \)\( \mu \)m, and the wear value of the middle portion is substantially unchanged. At the node 88, the static guide way wear value begins to decrease, and the wear value decreases to zero when the sliding guide stops. When the load is 1000N, the wear depth in the middle of the static guide way is \( 2.75 \times 10^{-3} \)\( \mu \)m. When the load is increased to 1300N, the wear depth in the middle of the static guide way increases to \( 3.58 \times 10^{-3} \)\( \mu \)m. When the load is 1600N, the middle of the static guide way wear depth is \( 4.40 \times 10^{-3} \)\( \mu \)m. When the hardness, sliding speed and friction coefficient of the guide way material are constant, the increase of the load will increase the wear depth of the static guide way. The increase in wear at both ends of the static guide way also increases as the load changes. The larger the load, is the more inclined the curves, is which means that the degree of material wear is greater.

4.3. Effect sliding speed on the wear of static guide way
The sliding speed of the sliding guide way is one of the factors that affect the wear of the static guide way. In order to study the influence of different sliding speeds on the wear of the static guide way, other friction parameters were assumed unchanged, and the sliding speeds were selected as 2.5mm/s, 5mm/s and 7.5mm/s respectively for finite element simulation. The post-simulation processing results are extracted, and the curves of the single-wear surface appearance of the static guide way at different sliding speeds are shown in Fig.5.

![Figure 5. Chart of parameters with different sliding speed.](image)
It can be seen from Fig.5 that the trend of the surface appearance wear depth contrast curves of the static guide way is similar to Fig.4. When the sliding speed of the sliding guide way is 2.5\text{mm/s}, the wear value of the middle portion of the static guide way is maintained at 3.02 \times 10^{-3} \mu m. At a speed of 5\text{mm/s}, the wear depth in the middle area will increase to 3.58 \times 10^{-3} \mu m, and when the sliding speed is 7.5\text{mm/s}, the wear depth in the middle area will stabilize at 3.99 \times 10^{-3} \mu m. When the hardness, friction coefficient and load are constant, there is not always a linear relationship between the sliding speed and the wear depth. In the specific sliding speed range, the sliding speed increases, while the wear of the static guide way becomes large, but the sliding speed effects the wear of the sliding guide way not obviously.

5. Conclusions
In this paper, based on the Archard wear calculation model, the load of the static guide way and the sliding speed of the sliding guide way are considered in the friction pair. The simplified finite element model of the two-body wear of the guide ways is established, and the wear process is studied. The results show that the friction condition has a certain influence on the wear of the guide ways. The middle area of the surface of the static guide way wears uniformly, and the wear at both ends is light. Within a certain range, the wear of the static guide way is severe with the increase of the load, and when the sliding speed of the sliding guide way becomes large, the wear of the static guide way aggravates.

Acknowledgments
The research work is supported by National Natural Science Foundation of China under Grant No. 51475066 and No. 51675075 and Natural Science Foundation of Liaoning Province under Grant No. 2015020114.

References
[1] Rabinowicz E, Tanner R I 1995 Friction and Wear of Materials J. Journal of Applied Mechanics 33(2) pp 606-611
[2] Lee H C, Lee Y and Lee S Y 2008 Tool life prediction for the bolt forming process based on high-cycle fatigue and wear J. Journal of Materials Processing Tech 201(1) pp 348-353 (in Chinses)
[3] Söderberg A and Andersson S 2009 Simulation of wear and contact pressure distribution at the pad-to-rotor interface in a disc brake using general purpose finite element analysis software J. Wear 267(12) pp 2243-2251
[4] Peterseim J, Elsing R and Deuerler F 1998 Simulation of sliding wear of hard-phase-containing metallic compound materials J. Metall 52(10-11) pp 643-651
[5] Mukras S, Kim N H and Sawyer W G 2009 Numerical integration schemes and parallel computation for wear prediction using finite element method J. Wear 266(7–8) pp 822-831
[6] Bortoleto E M, Rovani A C and Seriacopi V 2013 Experimental and numerical analysis of dry contact in the pin on disc test J. Wear 301(1–2) pp 19-26
[7] Shen X, Liu Y and Cao L 2012 Numerical Simulation of Sliding Wear for Self-lubricating Spherical Plain Bearings J. Journal of Materials Research & Technology, 1(1) pp 8-12 (in Chinses)
[8] Ripoll M R, Podgornik B and Vižintin J 2011 Finite element analysis of textured surfaces under reciprocating sliding J. Wear 271(5) pp 952-959