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# Research on macro-mesoscopic normal dynamic characteristics of sliding joint surface

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ABSTRACT

The dynamic characteristics of the sliding surface will affect the dynamic properties of the mechanical structure in a great degree. For the sliding surface in lubricating condition, the normal equivalent stiffness and normal equivalent damping mathematical analysis model of the joint surface were deduced based on the fractal theory and the mean flow generalized Reynolds equation with boundary lubrication. After simulation analysis, the equivalent normal stiffness of the solid portion, oil film portion and the comprehensive stiffness, and the comprehensive normal equivalent damping were obtained when the lubrication is on the partial film state. The results show, the contact stiffness and contact damping of the joint surface will be in an ideal state when their actual contact area ratio reached a certain value. At the same time, the dynamic and static stiffness and damping parameters of the sliding guide rail experimental device under the condition of lubrication were identified. The results show that the normal stiffness and normal damping of the guide rail will be in good state under the appropriate normal load. It is consistent well with the simulation analysis results of the mesoscopic dynamic characteristics of the sliding surface under lubrication condition.



## 1. Introduction

Sliding surface is widely used in machine tools, such as tool slide ways and dovetail slides and so on, with the development of modern machine tool to high speed, heavy load and high precision, It is of significance to study the dynamic characteristics of the sliding surface. From the view of the mesoscopic scales, the joint surface of mechanical structure is rough plane in certain degree, rather than an absolutely smooth plane. It shows numerous asperities under a certain scale. The contact behavior of the real surface will significantly affect their mechanical properties, such as the friction and wear, lubrication and seal, stiffness and damping, assembly and connection, and so on.

The statistical parameters of the rough surface such as the r.m.s. height, slope and curvature, which are conventionally used to characterize surface roughness, are scale-dependent [1]. In order to avoid the scale effect of statistical parameters and the non-uniqueness of the model, study on the micro contact characteristics of the joint surface is mostly based on the fractal contact model, which include elastic, elastic-plastic and plastic fractal contact models [2–6], and the normal and tangential contact stiffness has been studied [7–10]. A number of studies have been made on the dynamic characteristics of the joint surfaces considering surface friction factors [11,9,12,13]. From the macroscopic point of view, studies on sliding guide rail surface are mainly focus on the parameter identification of the equivalent stiffness and damping [14,15]. And the

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equivalent spring damping model was used to establish the dynamic model of the system [16,17]. But the research literatures on the relationship between the macroscopic dynamic characteristics with the mesoscopic morphology and mesoscopic dynamic characteristics of the sliding joint surface are rarely reported. At the same time, most of the mesoscopic contact models do not consider the lubrication between the joint surfaces. In fact, almost all kinds of the sliding surfaces are often in lubrication when working. When two joint surfaces sliding against each other, under the influence of surface roughness and ripple, the dynamic pressure lubrication phenomena will be generated on the mesoscopic surface of the joint surface, and the mesoscopic dynamic pressure oil film will be generated. Until now, many valuable results have been obtained for the study on the squeeze film problem of the ideal smooth surface. However, the research on the squeeze film problem of the real joint surfaces especially the effect of partial fluid squeezing film on the sliding surface are limited.

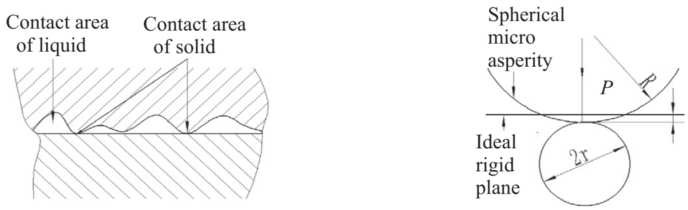
The squeeze oil film of the sliding surfaces is often in the state of partial film, which is the roughness peaks of one surface are directly contact with another surface when the oil film is relatively thin [18,19]. Studies have shown that when the contact gap between the two surfaces is small to a certain level, the molecules regular arrangement of the restricted liquid will occur, and the liquid will has a certain property of the solid. The solid-like micro oil film elastic supports are formed; this is similar to the increase of the actual contact area between the surfaces [20]. Therefore, the contact dynamic characteristics of the lubrication joint surfaces are different from the joint surfaces of the dry friction state. Aiming at this phenomenon, the normal contact stiffness and normal contact damping model of the sliding contact surface under the condition of lubrication will be established based on the fractal theory and generalized Reynolds equation with average flow model [21,22]. And on this basis, the experimental verification study is carried out to investigate the correlation between the macroscopic and mesoscopic dynamic characteristics of the joint surface. This work will provide the foundation to establish the multi scale contact model of the joint surface and to reveal the micro mechanism of the joint surfaces which in the actual working conditions.

The contact of two rough lubrication contact surface was divided into two parts in this paper, that are the solid contact and the liquid contact, and the two parts are in parallel connection. The equivalent contact stiffness and the equivalent contact damping fractal models are derived based on the Hertz contact theory and fractal theory. According to the mean flow generalized Reynolds equation, the equivalent contact stiffness and the equivalent contact damping models of the equivalent oil film between the joint surfaces are obtained. Then, the normal dynamic characteristic of the rough lubrication contact surface will be studied to obtain the relationship between the normal dynamical characteristic and the rough surface parameters, the contact parameters with the normal load. In order to study the relationship between the mesoscopic and macroscopic dynamic characteristics of the lubrication joint surfaces, a physical experiment device of sliding track was set up. And the parameter identification experiment will be finished to get the contact stiffness and contact damping parameters of the sliding guide rail under the condition of lubrication. The results of the theory analysis will be compared that of experiment.

## 2. Parallel contact model of the sliding surfaces

In the process of contact, the higher convex peaks of the joint surface will contact first. Then, under the action of normal force, the elastic deformation of the micro convex peak will occur, even with plastic deformation. At the same time, the lubricant contained within the rough surface is partially leaking out with the change of the space volume. The leaked lubricant will filled into the concave valley of the surface, and then leak out at the contact boundary. Right now, the normal load between joint surfaces will be undertaken by the two contact regions of the solid and the liquid. So the stiffness and damping of this joint surfaces considering lubrication include the stiffness and damping of the asperities of the two contact surfaces and those of the squeeze oil film between the asperities.

It is assumed that the roughness of the rough surfaces is statistically isotropic and that during contact, the interactions between neighboring asperities, work hardening due to plastic-elastic transition, variation of material hardness with depth from the surface and the frictional forces between deforming asperities are negligible. And the two rough joint surfaces can be simplified to a rough surface and an ideal rigid plane. And Fig. 1a is the simplified diagram. And one of the micro asperities on the rough surface is approximately equivalent to a hemisphere with a curvature radius $R$. When the hemisphere contact with the ideal rigid plane under the action of the normal force $P$, the size of the contact deformation in normal direction is $\delta$, which shown in Fig. 1b.




(a) The simplified diagram of the surface contact (b) The contact deformation sketch of the micro asperities

**Fig. 1.** The sketch of the micro contact of the joint surfaces.