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Finite Element Prediction Model of Surface Temperature Rise Based on Fractal Theory ⋆

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Abstract

The prediction of surface temperature induced by frictional heating is of significance for evaluating the serious thermal wear, erosion and lubrication failure for industrial application and design. Temperature prediction model was established with two steps. Local temperature was calculated firstly with the real contact area based on the fractal analysis. Then, the finite element prediction model were established with the above value of local temperature, on the basis of wavelet finite element. Finally, the whole temperature of the fractal engineering surface were demonstrated and simulation results were shown. Moreover, orthogonal simulations were conducted to study the influence of the input parameters of fractal dimension, fractal characteristic length and material thermal properties. Results with different cases demonstrated that all the temperature decreased gradually from the contact surface to the bottom and the temperature increased with the rise of heat transfer properties, fractal dimension and fractal characteristic length for the same position. However, heat transfer properties had the most obvious influence on the temperature rise, and the following one was fractal dimension.

Keywords: Finite Element Model; Surface Temperature Prediction; Fractal Theory; Wavelet Finite Element Method

1 Introduction

There is a long history to study the temperature rise induced by friction on the surface of friction pair material [1, 2]. High temperature has negative influence on the lubrication and wear performance which would directly decide the running condition and service life of the engineering machinery [3, 4]. Calculation models of frictional surface temperature have been reported about the instantaneous high temperature on different contact model of friction surfaces and average temperature that contained the influence of surface topography, frictional condition and their hardness in [5–7]. On the surface of real engineering machinery with fractal characterization, it is not ideally absolute smooth but contains many micro-bulges. From the viewpoint of

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micro-contacts, the frictional temperature rise is the accumulation of each contact micro-bulges. Therefore, the real contact area and contact stress distribution are of importance to be calculated firstly, which is the decisive factors for the frictional temperature rise, and then the calculation model for temperature rise would be studied based on the relationship between the temperature rise and the condition of real contact area.

The finite element theory has been widely used in the calculation of various physical fields, especially shows great advantage in solving differential equations to give the numerical solution with the help of computer. However, the traditional finite element method might come into being numerical oscillation or distortion during the process of solving the big gradient filed function. The wavelet finite element methods were proposed by Morlet [8] with multi-resolution property to improve the shortage of traditional finite element method. Wavelet finite element has been approved as an effective method application to solve the big gradient and strange problems in a wide variety of practical problems [9–11]. Wu and Zhao [12,13] simulated the temperature distribution by using wavelet finite element method to avoid the phenomenon of numerical distortion, but their discussion only based on the macroscopical temperature change, lack of consideration of micro-contact states which are significant for the variation of temperature on the practical engineering surface.

In this paper, friction temperature rise of engineering surface with fractal characterization would be calculated with different contact states of micro-bulges based on the analytical calculation of fractal theory. Then, temperature rise with thermal transmission is simulated with the help of wavelet finite element method, about the whole surface under macro-scale.

2 Frictional Temperature Calculation Based on Fractal Theory

Three contact states of elastic contact, elastic-plastic contact and plastic contact exist with the increasing normal press stress. When the contact state is fully plastic contact as a big stress more than the yield limit is applied, the contact stress p_p is given in Eq. (3). Then the real contact area increases to the elastic-plastic state and the contact stress p_{e-p} is given in Eq. (2). Moreover, the contact stress p_e in the elastic state is shown in Eq. (1),

$$p_e(a) = \frac{4EG^{(D-1)}(a)^{(3-D)/2}}{3\sqrt{2\pi}} \tag{1}$$

$$p_{e-p}(a) = \frac{a\sigma_y}{3}\left\{2 + \ln\left[\frac{2\sqrt{\pi}EG^{(D-1)}}{3\sigma_y} + \frac{(1-D)\ln(a)}{2}\right]\right\} \tag{2}$$

$$p_p(a) = \frac{1.1K_f\sigma_y a}{2} \tag{3}$$

where, G is the fractal characteristic length, σ_y is the yield strength of the softer material between the two contact surface, E is the integrated elasticity modulus of the two surface, K_f is the parameter to adjust the friction coefficient. The friction temperature rise can be described as the temperature diffusivity from the heat source of semi-infinite solid. Gennaro et al. [4] gave the