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ANALYSIS OF STEADY WEAR STATES FOR MONOTONIC AND PERIODIC SLIDING

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1. Introduction

In many practical industrial applications it is very important to predict the form of wear shape and the related contact stress distribution. The wear process on the frictional interface of two bodies in a relative sliding motion induces shape evolution. In the earlier paper [1] it was shown that the contact shape evolution tends to a steady state. The steady state conditions were specified for both monotonic and periodic sliding motion. In the case when the contact zone is fixed on body B_1 and translates on body B_2 in monotonic sliding, then the rigid body velocity of B_1 specifies the wear rate form of B_1 and the related contact pressure, satisfying the minimum principle of the wear dissipation power. In this work a fundamental assumption has been introduced, namely, *in the steady state the wear rate vector is collinear with the rigid body wear velocity of body* B_1 allowed by the boundary constraints. Similarly, for the periodic sliding motion the steady state satisfies the periodicity condition and the accumulated wear in one cycle is compatible with the rigid body motion of B_1. The numerical simulation of the contact shape evolution is based on time integration of the modified Archard wear rule expressed in terms of relative slip velocity and contact pressure.

Several classes of wear problems are distinguished and discussed for specified loading and support conditions for two bodies in the relative sliding motion: *Class 1.* The rigid body wear displacements are constrained by the boundary supports and the steady state corresponds to vanishing contact pressure[1]. *Class 2.* The contact zone S_c does not evolve in time and is specified. The rigid body wear velocity is compatible with the specified boundary conditions. The steady state condition is reached when the contact pressure distribution corresponds to the wear rate proportional to the rigid body velocity [1]. *Class 3.* The contact surface S_c evolves in time due to wear process, for instance, in the case of a spherical indenter sliding on a substrate with varying size of the contact domain $a = a(t)$. The stress distribution and the shape of contact zone are then dependent on the size parameter $a(t)$. In this case the quasi-steady distribution of contact pressure and the surface shape can then be specified for the selected values of the size parameter [2]. *Class 4.* Similarly as for *Class 2* the contact surface S_c is specified but the wear process occurs for periodic sliding motion. The periodic solution for one cycle remains steady for consecutive cycles [1, 3]. *Class 5.* Similarly to *Class 3*, the contact zone S_c evolves during consecutive cycles of sliding or loading and the periodic quasi-steady state depends on the contact size parameter [2].

2. Wear rule and variational method applied to steady state conditions

The modified Archard wear rule [1] specifies the wear rate $\dot{w}_{i,n}$ of the i-th body in the normal contact direction. Following the previous work [1] it is assumed that

$$(1)\quad \dot{w}_{i,n} = \beta_i(\tau_n)^{b_i}\|\dot{\boldsymbol{u}}_\tau\|^{a_i} = \beta_i(\mu\, p_n)^{b_i}\|\dot{\boldsymbol{u}}_\tau\|^{a_i} = \beta_i(\mu\, p_n)^{b_i} v_r^{a_i} = \tilde{\beta}_i\, p_n^{b_i}\, v_r^{a_i}, \qquad i = 1, 2$$

where μ is the friction coefficient, β_i, a_i, b_i are the wear parameters, $\tilde{\beta}_i = \beta_i \mu^{b_i}$, $v_r = \|\dot{\boldsymbol{u}}_{R,\tau}^{(s)}\|$ is the relative sliding velocity. The shear stress at the contact surface is denoted by τ_n and calculated in terms of the contact pressure p_n by using the Coulomb friction law $\tau_n = \mu\, p_n$. Assuming existence of J contact zones in Body 1, it can proved that for the wear problem of *Class 2* the minimization of the following wear dissipation power

(2) $$D_w = \sum_{j=1}^{J} \sum_{i=1}^{2} \left(\int_{S_c^{(j)}} (\boldsymbol{t}_i^c \cdot \dot{\boldsymbol{w}}_i)\, dS \right) = \sum_{j=1}^{J} \sum_{i=1}^{2} C_i^{(j)}$$

with the equilibrium constraints of body B_1: $\boldsymbol{f} = \boldsymbol{0}$, $\boldsymbol{m} = \boldsymbol{0}$, provides the contact pressure

(3) $$p_n^{(j)\pm} = \left(\frac{1}{K^{(j)}} \left(\dot{\boldsymbol{\lambda}}_F \cdot \boldsymbol{\rho}_c^{\pm} + \left(\dot{\boldsymbol{\lambda}}_M \times \boldsymbol{r} \right) \cdot \boldsymbol{\rho}_c^{\pm} \right) \frac{1}{Q} \right)^{1/b} \qquad x \in S_c^{(j)}$$

where $K^{(j)} = \sum_{i=1}^{2} (\tilde{\beta}_i\, v_r^{a_i})^{(j)}$, $Q = 1 \pm \mu\, \tan\chi\, \cos\chi_1 + \mu_d \tan\chi\, \sin\chi_1$, $\dot{\boldsymbol{\lambda}}_F$ and $\dot{\boldsymbol{\lambda}}_M$ are the vectors induced by wear, briefly called *rigid body wear velocities*. The solution is valid if $p_n^{(j)\pm} \geq 0$ at each point $x \in S_c^{(j)}$. The contact traction can now be written as follows $\boldsymbol{t}^c = \boldsymbol{t}_1^c = -\boldsymbol{t}_2^c = -p_n^{\pm} \boldsymbol{\rho}_c^{\pm}$, where the vector $\boldsymbol{\rho}_c^{\pm} = \boldsymbol{n}_c \pm \mu\, \boldsymbol{e}_{\tau 1} + \mu_d\, \boldsymbol{e}_{\tau 2}$ specifies the orientation and magnitude of the traction on S_c referred to the contact pressure $p_n^{\pm}$. The friction coefficients μ and μ_d specify the shear stresses in sliding and transverse directions [1]. The non-linear equations can be solved by applying Newton-Raphson technique.

3. Periodic sliding motion

During a periodic reciprocal sliding, the steady wear state is expressed in terms of contact pressure in progressive and reverse sliding semi-cycles [1, 3], that is $p_n^{+} + p_n^{-} = 2p_m = \text{const}$. Using this fact the optimization problem for calculation of the contact shape of body B_1 is stated and an analytical method is formulated for prediction of the number of cycles to reach the periodic steady wear state.

4. Numerical experiments

The lecture will present numerous examples for different classes of wear problems with neglect or account for the generated temperature field. The presented examples demonstrate that the thermal distortion affects essentially the optimal contact shape in the steady state and for periodic sliding motion it affects also the contact pressure distribution.

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