A note on optimal design of contact geometry in fretting wear

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1. Introduction

Fretting wear is a tribological process which occurs at the contact interface between mechanical component parts subjected to relative tangential movements of small amplitude [1,2]. Geometry design optimization of contacting surfaces subjected to wear is receiving an increasing attention due to both issues of safety [3] and reliability [4]. In particular, the contact geometry is found to influence the feature and behavior of the fretting wear in contact between the nuclear fuel rods [5]. Also, the fretting wear is very important for the structural integrity of steam generators in nuclear power plants [6].

One of the most important factors influencing the wear intensity is the contact pressure, which, in turn, essentially depends on the contact geometry [7]. During the wear process, the contact pressure evolves, since the geometry of contacting surfaces changes as well. The problem of the contact pressure evolution due to wear has been considered in a number of publications. The main analytical result is that the contact pressure tends to a uniform distribution [8]. It is interesting that the constant pressure pattern is shown to be, in a sense, optimal, provided that the wear coefficient is constant. In a series of works, the optimal shapes generated by wear process were analyzed by postulating minimization of the wear dissipation power and also the wear volume and the friction dissipation power.

It is clear that the optimal contact geometry design, which results in a uniform contact pressure, allows to avoid stress concentrations in the contact zone. From a design point of view, in order to get rid of singularities of the contact pressure beneath a punch with sharp edges, the latter should be rounded off [9,10]. It is known that a uniform contact pressure distribution can be obtained by minimizing the equilibrium potential energy under an isoparametric constraint. The minimized integral functional describing the discrepancy between the actual contact pressure and the required pressure distribution was utilized. From a practical point of view, the contact geometry optimization problem was considered by introducing a symmetrical punch with compound curvature as the basis for possible optimal contact designs, which are easy to manufacture.

In the present paper, we revisit the corresponding optimization problem using two different approaches.

2. Body of abstract

A two-parametric geometry optimization problem for a symmetrical punch with compound curvature in frictionless contact with and an elastic half-plane is considered. An almost constant pressure distribution is sought for by means of least-square method. Another sub-optimal solution, which equalizes the three local maximum peaks (one at the center, and two at either side of the contact interval), is constructed using an asymptotic modeling approach and compared with the exact solution known in the literature

3. A two-parametric optimization problem for a symmetrical punch with compound curvature

Consider the smooth compound contact geometry with a convex central region, $-b<x<b$, of constant curvature $1/R$ and two symmetric outer regions with the same curvature radii R_1, such that the gradient of the contact surface is continuous at the transition points (see Fig. 1).

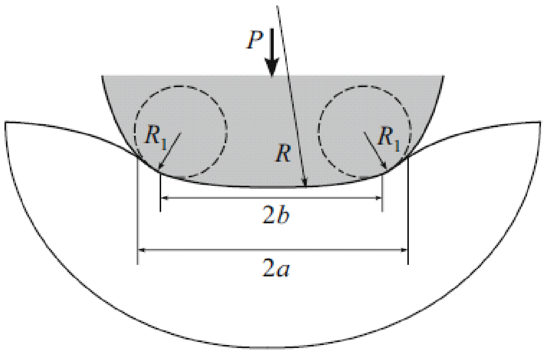

Fig. 1 Schematic of the normal contact of a compound curvature punch with an elastic half-plane

Under the action of a normal load, P, the punch establishes contact over an interval, $-a<x<a$. Contact pressure beneath the absolutely rigid punch is described by the formula and the contact force is defined as an integration of contact pressure over the contact interval.

The contact pressure vanishes at the ends of the contact interval, which means that the ideally optimal solution of constant contact pressure is not achievable. Therefore, we will look for a sub-optimal solution, which minimizes the maximum contact.

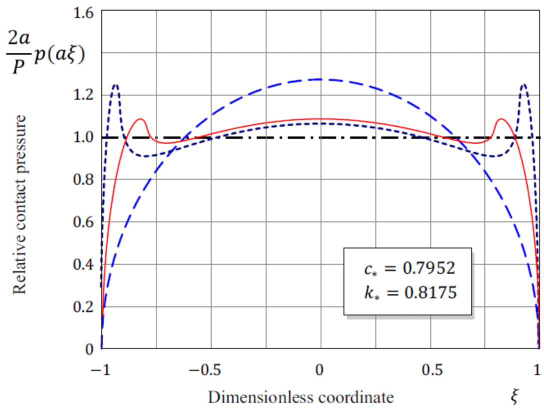

Fig. 2 Optimal contact pressure distribution (red line) under the punch with compound curvature

4. A least mean square error approximate solution – application of asymptotic modeling

To construct an approximate solution of the contact problem for a punch with rounded edges, we apply the method of matched asymptotic expansions based asymptotic modeling approach developed in Argatov [10]. By considering the minimizing the mean squared error, ideally optimal contact solution could be found.

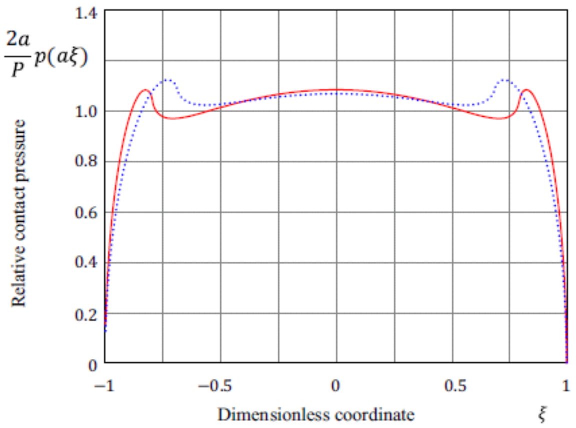

Fig. 3 Optimal contact pressure distribution (red line) under the punch with compound curvature

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