THE ACCOUNTING OF SURFACE ROUGHNESS IN CONTACT OF ARBITRARY SHAPED BODIES USING FEM

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Summary The universal method of accounting the surface roughness in contact of arbitrary shaped bodies is developed. Procedure of computation of the contact stiffness and real contact area using finite element method are considered. Some results are presented.

INTRODUCTION

There are two principal approaches for modeling contact of rough bodies. The first one represents the rough surface of a body as a set of simple figures (columns, spheres, etc) with normally distributed heights. The analytical Hertzian solution of the contact problem for single asperity extends to all the asperities. In many cases it is assumed that there is no influence between neighboring contacts. This approach is detailed in, e.g. [1], [2], [3]. In the second approach the surfaces are considered as a set of finite elements and the shape of asperities is based on profilometric data of real surface and contact problem is solved numerically [4]. The last method is discussed in the paper. Methods using the first approach give good results when contact stiffness is investigated but they cannot be used in case of arbitrary shaped bodies or evaluation the stress-strain state for real asperities. Numerical methods are free of mentioned disadvantages. That is why there is the need for developing numerical methods for solving a contact problem for real rough bodies.

OBTAINING THE DISCRETE CONTACT PARAMETERS

General approach

The first approach for finite element modeling the contact of rough bodies is to build a FEM model of the whole bodies describing both the shape of each body and surface microgeometry. It is possible when contact areas are small and there are no heavy gradients of stresses. However, in some cases the contact area is comparable with size of bodies and the discrete pattern of contact caused by surface roughness requires fine finite element model so the dimension of a problem may be inadmissible large. Another way is to build a FEM model of a small part of rough surfaces of real machine elements in order to compute the contact stiffness parameters and then apply them to the contact problem for the whole bodies. A model of small parts of bodies also allows investigating the real contact area and stress-strain state of asperities. Numerical methods allow solving contact problem for rough surfaces with accounting of elastic-plastic deforming of material.

Finite element model forming

To obtain information about geometry of surface roughness a profilometer is used. Machine elements surfaces with Ra = 0.1-2.5 μm and Sm = 100 μm are typical. For surfaces with such parameters a model length 800-1000 μm containing 8-10 asperities and width 250-300 μm are appropriate. The typical size of finite element adjoining the contact surface equal to 5 μm provides enough accuracy of modeling. The height of the model providing the decay of stress peaks caused by contacts of asperities is 150 μm. The size of model is very small comparing with the size of bodies so the surfaces of models are assumed to be nominally flat. We consider a normal load of bodies only. Constraints are imposed normally to all lateral faced of a model. Ad hoc contact elements controlling mutual penetration and sliding of contact nodes are placed between nodes of upper and lower parts of model. Model contains 74532 elements (Figure 1).

model with loads and constraints   rough surface of the model   fragment of the lower part of the model

Figure 1. Finite element model of small parts of rough bodies in contact

Procedure of contact stiffness computation

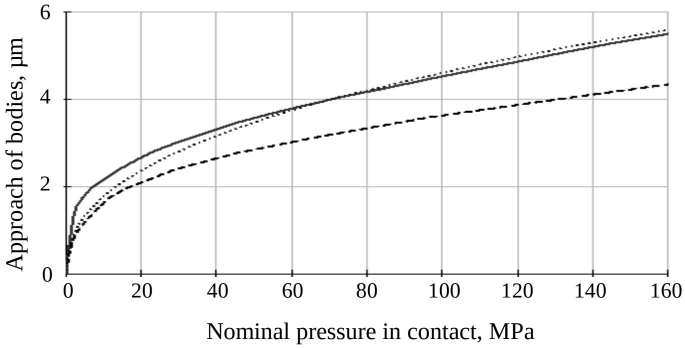
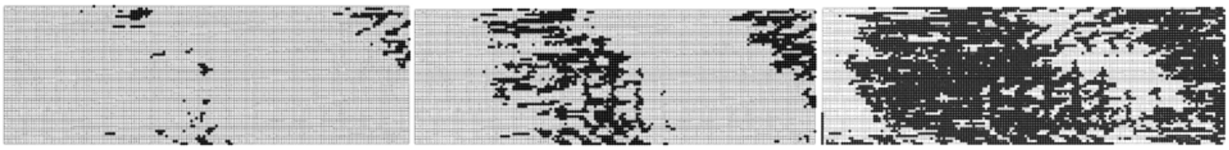


Figure 2. Approach of bodies with rough surfaces (Ra=0.41 µm, Sm=100.9 µm for both surfaces)

In order to realize kinematic load the upper face of a model is displaced down vertically. Step by step loading allows obtaining detailed information about bodies approach and changing the contact spots distribution during load increment. The accounting of elastic-plastic strain is based on yield theory with using plastic stress-strain matrix described in [5]. All of the computations were performed using a program package DSMFem (www.dsmsoft.ru) [6]. The main result of the contact problem solving is dependence of the bodies approach α on nominal pressure p_n at the contact surface, i.e. computation of the contact stiffness (Figure 2). The expression $p_n = c\alpha^x$ approximates the numerical result with average relative error 1%. Here c and x are parameters. The solid curve is the result of elastic-plastic solution of the contact problem, the dot one is its analytic approximation, and the dash one is the result of elastic solution shown for comparing. The analytic approximation is applied to solving the contact problem for arbitrary shaped real bodies further. In accomplish a behavior of contact areas during load increment was investigated (Figure 3). Each dark point is a node of a model where contact is occurred. The total number of nodes at the contact surface is 8965. Values of the nominal pressure and the real contact area A_r are given for 3 of 32 intermediate stages of load.



p_n =3.57 MPa, A_r =3.10% p_n =20.73 MPa, A_r =19.25% p_n =63.15 MPa, A_r =59.75%

Figure 3. Real contact area during load increment

APPLICATION

The curves describing the contact stiffness obtained for small parts of rough bodies can be applied to computing the contact parameters of arbitrary shaped bodies. It has been shown in [2] that the contact pressure distribution most depends on surface roughness in case of small load. The railway wheelset with differential rotation was chosen as an appropriate object, which has an extensive area of conformal contact between the wheel center and the bandage with typical value of nominal contact pressure 10-20 MPa [7]. A finite element model of the wheel was formed and the contact problem was solved for it. The obtained values of contact stiffness of rough layer were used in this computation as parameters. The accounting of surface roughness leads to 41-60% reducing of contact pressure in contact between the wheel center and bandage and 62-103% growth of nominal contact area for considered rough surfaces. Therefore, despite the displacements due to rough layer presence are small comparing to typical size of bodies, the value and distribution of the contact pressure can depend significantly on a surface roughness in some contact problems.

CONCLUSIONS

The universal method described in this paper allows accounting the surface roughness in contact of arbitrary shaped bodies using finite element method. They also allow investigation of the contact of rough surfaces.

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