CONTACT STRESSES - MODELS AND METHODS OF COMPUTATIONS

A. Zmitrowicz
Institute of Fluid-Flow Machinery, Gdańsk, Poland

1. Introduction

Contact stresses are forces acting between contacting bodies or between the body and a foundation. They are identified as normal pressure and tangential traction. A potential contact area between two bodies can be divided into the following states: separation (non-contact), sticking and slipping. In the most cases the contact stresses, the size of the contact region, the distribution of contact zones of slip and adhesion cannot be predicted a priori.

There has been little progress toward general models for contact phenomena. The reason for this lies in the significant complexity of the phenomenon. Descriptions applied in classical mechanics are very simple and they do not include present experimental facts. The purpose of this contribution is to review general and simplified forms of constitutive laws of normal traction and friction, and to review computational methods used in calculations of the normal pressure and friction [5]. They are described in the framework of continuum mechanics, FEM and other methods.

2. The normal traction

Mechanics considers two models of mechanical interactions i.e. forces and analytical relations describing restrictions of deformations, i.e. geometrical and kinematical constraints. Unilateral contact constraints are as follows: two contacting bodies cannot penetrate each other, cannot pull on each other and are either separated or pressed on each other (so-called Signorini conditions). To reduce the computational effort for contact pressure computation, in some problems, contact stresses are formulated directly from kinematical considerations. The contact conditions are frequently modeled by nonlinear springs (and viscous dampers) which connect solids (e.g. Winkler-type contact laws). Such model may, however, correspond to severely ill-conditioned system of motion equations since very stiff springs must then be used to simulate no-slip and no-clearance gap conditions. Other methods are following: stiffness approach, flexibility approach, normal compliance, normal damped response, bond or gap elements, interfaces materials, etc.

3. The tangential traction

The tangential components of the contact traction (shear traction) are governed by friction laws. Friction forces depend on motions of the bodies, and they are not known in advance. For vanishing sliding velocity (case of sticking), the tangential traction is a resting force governed by the equation of equilibrium. The law of Amontons and Coulomb is commonly taken as the friction law in the case of slipping.

4. Development of ideas and modeling of friction

It should be noticed that many identically significant reasons have an influence on friction. We take into account the following parameters: normal pressure, sliding velocity, surface temperature, time of contact, surface roughness, presence of wear debris, extreme environments. There are materials and ranges of the contact parameters, especially for their extreme values, whose constitutive relations for friction should be considered as various nonlinear functions with respect to the parameters. Friction plays a crucial role for many mechanical systems. In special applications, more sophisticated models are desirable to accurately model the contact phenomena, e.g. in vibrating systems, in materials processing, in rubbers and polymers, in geomechanics, in bioengineering, in living systems.

The genesis of friction is not clearly known. Mechanical and atomistic theories of the origins of friction are used at present, and friction modeling is based on observations from macro- to micro-scale. In the subject literature, there are phenomenological, micromechanical, atomic-level and multi-scale friction models. In [2,3,4] a family of non-classical friction laws have been proposed. These friction laws include anisotropy and heterogeneity effects. Anisotropy means that there are distinguished directions of sliding. Heterogeneity means that there are distinguished points at the contact surface. Kinematics of sliding can initiate microstructural and frictional changes in the surface and near-surface material (self-organization and structural adaptation). As in continuum mechanics the central topic for the friction constitutive models are conditions of material objectivity, the Second Law of Thermodynamics and conditions of symmetry.

5. Predictions of contact stresses

Different approaches can be applied to calculations of contact stresses and to satisfaction of kinematic contact constraints on displacements of the contacting bodies. Since both forces and displacements in the contact area are unknown, additional relations are needed to describe them. Powerful formulations of problems with constraints on certain solution variables (e.g. unilateral and contact problems) can be obtained by utilization of the classical variational formulations and the following techniques: Lagrange multipliers, penalty function, perturbated Lagrangian method, augmented Lagrangian method [1]. They are so called active strategies. These methods are designed to fulfill the constraint equations in normal direction to the contact area. For the tangential part we need constitutive equations. Most standard finite element codes use two active strategies i.e. the Lagrange multipliers and the penalty method [1].

6. Adhesion and impacts mechanics

Adhesion is the phenomenon that occurs when a normal tensile force must be done to separate two surfaces from contact (after being compressed together). The adhesive normal force depends on the initially normal pressure and a coefficient of adhesion (the law of Rabinowicz and Frémond). Impacts occur if the solids come into contact among each other or against the foundation. Short-time impacts, one can describe using an impulse model for impacts. The colliding solids change their velocities discontinuously (the law of Newton and Poisson). Wave theory is appropriate for the description of collisions against flexible structures.

7. References

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