ON THE SHIFT OF LOOSE MATERIALS OVER SURFACES

P. N. Platonov and V. S. Poltorak

UDC 621.867.8

A comparative analysis is made of the processes of friction between solid surfaces and of the shift of loose materials over surfaces. The authors arrive at the opinion that the mechanism of these processes is distinct and express a hypothesis about the mechanism of the shift of a loose material over a surface.

Processes associated with contact between loose materials and solid surfaces and their mutual displacement are disseminated extremely widely. The transporation, storage and reprocessing of loose materials must be encountered in the majority of branches of the national economy. In these processes the loose materials make contact with the working members of the transporting and reprocessing machines and with the confining surfaces. Hence, the resistive forces of loose materials to being shifted over surfaces, the character of the relative shift process, and its peculiarities exert great influence on the technological process as a whole, on its efficiency, power consumption and wear of the equipment, the structural and strength peculiarities of the equipment.

The science of the relative shift of solid surfaces is presently at a sufficiently high level because of the accumulation and generalization of experimental data. Since it is impossible to describe the regularities inherent in the process of friction by using Coulomb's law, investigations have been conducted on the influence of diverse factors on the friction coefficient, and the various phenomena accompanying the friction process. Various hypotheses on the mechanism of the friction process [1, 2] have been constructed as a result of investigations, which explain the peculiarities of this process and its inherent regularities more or less convincingly. This permits conducting further investigations more expediently, as well as regulation of the magnitude of the friction in a sufficiently broad range of variation of the shift mode and the selection of different pairs of materials, which is quite important in practical respects. In some cases, there is the possibility of determining a sufficiently exact value of the friction force analytically.

The correct answer to the question of whether the processes of the relative shift of solid surfaces and the shift of loose materials over surfaces are similar or have essential differences is quite important. In the former case, the regularities inherent in the shift of surfaces can be carried over to the shift of loose materials over surfaces by using accumulated experimental data to insert some correction coefficients in available regularities without trying to expose the mechanism of the process. In the opposite case, new regularities inherent to precisely this process can be expected, which we shall be able to explain by knowing just the nature, the mechanism, of the process.

Let us examine two solid surfaces, or a loose material and a surface in contact and let us compare them:

a) Two surfaces come into contact only at a small quantity of elementary areas. An increase in the quantity of individual, independently loaded, elements comprising the common friction surface will result in all cases in a significant increase in the actual contact area, and therefore, in a rise in the friction coefficient [3]. For a loose material in contact with a solid surface there is a very large quantity of individual elements comprising the total friction surface, each of which is loaded by a certain force independently of the others.

b) If only sliding friction can occur during the relative shift of two solid surfaces on separate contact areas, then during the contact between loose material and a surface each particle contiguous to the surface has the opportunity, depending on different conditions, of being displaced relative to the surface with sliding, swinging, and spinning.

M. V. Lomonosov Odessa Technological Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 20, No. 5, pp. 822-826, May, 1971. Original article submitted July 2, 1970.

c) The contact is discrete when two solid surfaces or a loose material and a surface touch. But if the discrete character of the contact between solid surfaces is due to the waviness and roughness of the surfaces, the discrete character of the contact between a loose material and a surface is due mainly to the large quantity of elements comprising the common contact surface.

d) The condition responsible for the external friction of solid surfaces is localization of the strains in a very thin surface layer whose thickness is a fraction of a micron or microns. As a loose material shifts over a surface the strains are propagated to a considerable depth [4].

e) If the character of the displacement in the deformable zone is of wave nature during the external friction of solid surfaces, then both a wave displacement of the particles and a transfer of motion from one layer of loose material to another will occur during the shift of a loose material over a surface. The motion of the individual particles in the zone near the wall hence occurs both along, and at different angles to, the relative velocity vector. Consequently, a relative displacement and mixing of particles occurs in the near-wall zone.

f) If the magnitude of the preliminary displacement corresponding to the total rest friction is a fraction of a micron or microns during the friction of solid bodies, then the displacement corresponding to the maximum resistance of loose material to shift is 0.01-0.1 m during the shift of loose material over a surface. The displacement is hence jumplike.

We therefore see that there are essential differences between the relative shift of two solid surfaces and of a loose material and a surface. This permits the assumption that the mechanism of these processes is indeed distinct.

Unfortunately, until recently researchers considered the shift of loose material over a surface as the shift of solid surfaces in approaching the process as a whole while remarking on some peculiarities in the process. This is reflected also in many experimental papers [5, 6], when the layer of loose material contiguous to the surface was related to, and therefore transformed into a second solid body.

The differences between the relative shift of two solid surfaces and of a loose material and a surface are indubitably due to the mobility of the particles of loose material characterized by the packing density. A number of researchers [7] mention that the packing density of loose material is far from the maximum in the general case. The least value of the packing density has been observed on the boundary of the surface – loose material; the packing density rises gradually with recession from the surface, and reaches a constant value at some distance therefrom.

Therefore, it can confidently be assumed that the particles of loose material in the boundary domain form some structural formations: the particles in these structural formations are in some equilibrium position, and a force of a definite magnitude must be applied to carry them over into another position. Normal and tangential forces act on an individual particle at its points of contact with the surface and the adjacent particles. As the force tending to shift the surface relative to the loose material appears, additional tangential forces originate at the contacts between the particles and the surface, which add up to the resistance of the loose material to shift over the surface. The redistribution and alteration of the normal and tangential forces occur simultaneously on the contacts between the particles of the first layer and the others, which are directed towards canceling the effect of the tangential forces on contacts with the surface and preventing possible structural changes. Therefore, the effect of the tangential forces appearing on the contacts of the first layer of material with the surface is propagated a definite depth within the loose material, whose value depends on the frictional properties of the material and on its structure in the near-wall layer.

Until the shifting force reaches a definite value, the relative displacement of particles in the structural formations does not occur. But the structural formations possess some elasticity. Hence, the displacement of the bounding surface relative to the loose material which occurs at this time will occur because of the elastic properties of the material particles, and mainly its structure in the near-wall layer, and can reach a considerable magnitude. Hence, the displacement is elastic in nature in this phase of the shift process.

As the shifting force grows further, a time arrives when the friction forces on the contacts between particles of the first layer and the other particles cannot oppose the passage of some particles in the structural formations to a more equilibrium position. This process is certainly statistical in nature since the rearrangement of some particularly unstable structural formations can occur so much earlier. But these local rearrangements are almost never reflected in the nature of the displacement in this period by just increasing the fraction of the residual strains in the initial displacement.

When the shifting force reaches some value, rupture of a significant quantity of near-wall structural formations occurs. The particles emerging from previously existing structural formations go over into a new equilibrium position characterized by a large quantity of contacts with the surrounding particles and the surface.

During the structural rearrangements, a specific number of particles acquires the possibility of performing rotational motion under the effect of the applied additional tangential force. Since the rocking friction is very much less than the sliding friction, then this should result in a sharp diminution in the total force of resistance to shift, whereupon a sharp rise occurs in the displacement of the surface relative to the loose material, a jump in the displacement. A still greater quantity of near-wall structural formations is hence ruptured. Therefore, the jump in displacement should involve structural rearrangement on the loose material in the near-wall zone towards increasing the packing density of the material. The number of particles capable of performing rocking friction during shift diminishes sharply, it is replaced by sliding friction; the structure of the loose material acquires great strength relative to the shift forces; an increase occurs in the actual area of contact between the material and the surface.

Such a considerable increase in the resistance force of the loose material to shift occurs as a result of such transformations that the surface motion over the material ceases.

In contrast to the elastic character of the displacement in the previous shift period, the jump displacement should be mainly irreversible since irreversible structural transformations occur at this time which are related to the passage of individual particles into a more equilibrium position. Hence, only a negligible part of the displacement whose magnitude depends on the elastic properties of the loose material particles and the loose material structure again formed in the near-wall zone is selected in taking off the shifting force.

As the shifting force grows, the process is repeated; first occurs a smooth displacement whose major portion is elastic in nature, then collapse and a jump in displacement during which a further rearrangement occurs in the near-wall regions towards increasing the packing density of the material. This cyclic process is repeated again and again. And newer and newer layers of material are entrained during the rearrangement of the structure. This occurs until the structure of the near-wall layers acquires the properties for which further rearrangement will not be possible.

As the shifting force increases further, collapse of the surface sets in as does the passage of the process into the second phase, the phase of continuous motion under a constant shifting force. At this time the force of the loose material resisting shift along the surface acquires the maximum value (for given conditions of the shift process and a given pair of loose material and surface).

Three kinds of relative motion between the surface and the loose material are possible in the second phase of the shift process:

1. Motion without any (at least visual) changes in the structure of the near-wall layers formed during the first phase of the shift. This kind of motion originates for low surface roughness and a large normal pressure of the loose material on the surface. There is no possibility of performing rocking friction on separate particles, and the motion occurs only with the particles sliding over the surface. A high friction coefficient between the separate particles, ensuring the high structural strength of the loose material layers adjoining the surface with respect to the shifting forces being developed on the contacts between the particles and the surface, will contribute to the origination of this kind of motion.

2. Motion with the formation of a near-wall layer of loose material at some gradient of the relative velocity over the depth. The most prevalent kind of motion originates for normal pressures and roughnesses fluctuating within significant limits. For this kind of motion the relative velocity of particles adjoining the surface is less than the particle velocity in deeper layers of the material. The particle velocity relative to the surface gradually increases to some constant value with removal from the surface, and the velocity gradient between the separate particle layers diminishes from some maximum value (originating at the boundary between the loose material and the surface) to zero. Particles adjacent to the surface may perform both sliding and rocking friction.

3. Motion with the formation of a material layer with zero relative velocity at the surface. The shift of the remaining layers of material occurs along this fixed layer; hence, the properties of the surface (its roughness, material) exert no influence on the drag coefficient. The relative velocity

gradient increases from zero to some value, then again drops to zero. The particles are displaced with sliding and rocking in the zone with variable velocity gradient. Local rearrangements of the material structure and its mixing hence occur.

The formation of any kind of loose material motion relative to the surface depends on a whole series of factors: the normal pressure, the frictional properties of the material particles and the surface, the initial packing density of the loose material, the times of fixed contact, etc. The criteria for the passage from one kind of relative motion to another have unfortunately not been clarified.

Experimental investigations of the shift process of loose materials over a surface which have been conducted in the loose materials laboratory of the M. V. Lomonosov Odessa Technological Institute on a number of loose materials and surfaces confirmed the hypothesis mentioned about the mechanism of the shift process of loose materials over surfaces.

LITERATURE CITED

1. I. V. Kragel'skii and V. S. Shchedrov, Development of the Science of Friction [in Russian], Izd. AN SSSR, Moscow (1956).
2. A. D. Dubinin, Energetics of the Friction and Wear of Machine Components [in Russian], Mashgiz, Moscow–Kiev (1963).
3. I. V. Kragel'skii, Friction and Wear [in Russian], Mashinostroenie, Moscow (1968).
4. G. I. Glushkov, Trans. Scientific Research Aerodrom. Inst. [in Russian], Vol. 9 (1959).
5. G. P. Chebotarev, Mechanics of Soils, Foundations, and Earthen Structures [in Russian], Izd. Literatury po Stroitel'stvy, Moscow (1968).
6. L. V. Gyachev, Motion of Loose Materials in Pipes and Hoppers [in Russian], Mashinostroenie, Moscow (1968).
7. M. E. Aerov and O. M. Todes, Hydraulic and Thermal Operating Principles of Apparatus with a Stationary and Boiling Layer [in Russian], Khimiya, Leningrad (1968).