

Contact of Lubricated Surfaces

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Abstract – Mating surfaces with nanocoatings work under lubrication. At the same time the effects of surface deviations from the ideal one have not been sufficiently studied. The paper examines the contact of endface friction pairs considering their surface roughness. The problem is solved by using Reynolds equation for liquids assuming the liquid film thickness to be a random variable. In the general case the liquid film thickness is described as a random field of two variables x, y .

Keywords – load carrying capacity of surface, surface microroughness, nanocoatings.

I. INTRODUCTION

The calculation procedure of carrying ability of two flat lubricated surfaces contacting at normal loading has been carried out. Within the procedure roughness is presented as the 3D object. This approach makes it possible to solve contacting problem in conditions closer to practical. The given decision is pretty new in the field of mechanical engineering and appliance design. The received result has important value at estimation of contact rigidity on bench adaptations, in measuring devices and contact units of mechanical engineering. In the framework of the paper roughness of contacting surfaces is considered as 3D object and this aspect determines the topicality of the given theme, with reference to wear calculation of flat lubricated surfaces. The discussion concentrates on an idea of the 3D representation of rough surface. Within the idea basic concepts of casual fields are considered and the system of the initial parameters of roughness of surface is formulated. The roughness of surface in micro topographical understanding should be characterized by three coordinates in Cartesian system as the following points of surface: altitude h , abscise x , and ordinate y . As the study of irregular roughness methods of the theory of stochastic functions appeared to be effective, therefore, micro topography analogously to profile section can be presented by stochastic function as two dimensional (2D) one, i.e. casual field $h(x, y)$ of two variables x and y . As for stochastic processes in order to determine normal casual field, it is necessary to know mathematic expectation and correlation function of field $\rho(\tau_1, \tau_2)$. Relation of parameters of correlation function is defined by the parameter of anisotropy c :

$$c = \alpha_2 / \alpha_1 = Sm_1 / Sm_2 \quad (1)$$

where Sm_1, Sm_2 – step-by-step parameters of asperities of roughness on directions x and y , accordingly. It is proven that the initial parameters of the 3D rough surface are the

following: surface roughness altitude parameter Ra or σ , two step-by-step (spacing) parameters between asperities $Sm_1, Sm_2 (Sm_1 > Sm_2)$.

II. ANALYTICAL RESEARCH

A. Discussion of model analysis

A case of contacting of an ideal plane and the rough surface is considered at presence of liquid lubrication layer (Fig. 1) when normal loading operates and small lateral (non-regular)

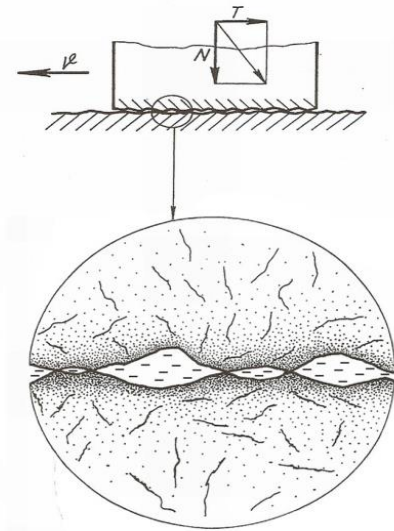


Fig.1 Contact of two surfaces

sliding is possible. Under the influence of normal loading pressing out of liquid environment and deformation of microirregularities of the rough surface take place until there is a balance. Thus, general force loading the surface of detail at balance is:

$$P_{\Sigma} = P_v + P_d, \quad (2)$$

where P_v – force of resistance to pressing out of liquid environment at approaching of surfaces,
 P_d – force of resistance to deformation of microirregularities of the rough surface.

Having divided both sides of equation (2) by the size of the nominal area A_d , it follows:

$$q_{\Sigma} = q_v + q_d, \quad (3)$$

where q_{Σ}, q_v, q_d – pressure components appropriate to forces of equation (3).

At first let's consider the first component of equation (3), i.e. pressure of resistance to pressing out liquid environment at approaching of surfaces q_v . For bring out of analytical dependences of estimation of value q_v .

Let's take advantage of equation of movement of liquid flow (equation Navue -Stocks). Considering the movement of liquid flow between closely located solids some assumptions leading to essential simplification of these equations without any loss of common value are made.

The following ones regard the number of such assumptions:

1. Thickness of lubricant film between solids (on axis Z) is much less than the sizes of the film in two other directions (x, y).

2. Lateral sliding of details can not cause sliding on the border of flow and firm surface.

3. Liquid is considered newtonian to be incompressible.

Using these assumptions the equation of movement of the liquid flow can be written down as Reinolds common equation.

$$\frac{\partial}{\partial x} \left(h^3 \frac{\rho \partial q}{\mu \partial x} \right) + \frac{\partial}{\partial y} \left(h^3 \frac{\rho \partial q}{\mu \partial y} \right) = 12\rho V + 6 \frac{\partial(\rho U h)}{\partial x} + \frac{\partial(\rho W h)}{\partial y} + 12 \frac{\partial q}{\partial t} \quad (4)$$

where h – thickness of film,
 ρ – density of liquid,
 μ – dynamic viscosity of liquid,
 q – pressure of liquid,
 t – time of contacting process,
 U, W, V – speeds of liquid flows in direction of axes x, y, z, accordingly (Fig.1).

According to conditions of the task (at approaching of solid details in direction of axis Z) $U=W=0$ the Reinolds equation becomes as

$$\frac{\partial}{\partial x} \left(h^3 \frac{\rho \partial q}{\mu \partial x} \right) + \frac{\partial}{\partial y} \left(h^3 \frac{\rho \partial q}{\mu \partial y} \right) = -12V \quad (5)$$

Solving the obtained equation it should be taken into account that thickness of liquid film h is casual field of two variables x and y consisting of two sizes :

$$h = h_0(x, y) + h_g(x, y) \quad (6)$$

where h_0 – constant of thickness of liquid film (clearance)
 h_g – stochastic function of thickness of film due to roughness.

This equation cannot be solved by simple analytical approach due to the parameter of viscosity μ , which also is the function of two variables x, y . Alteration of viscosity μ on the surface of contact is small enough to assume it to be constant. Getting focused on expression for estimation of value q_v a model of contact assuming the above mentioned proximity is considered. The value of parameter q_v can be described as the sum of two components:

$$q_v = q_0 + q_g \quad (7)$$

where q_0 – constant pressure of resistance to pressing out lubricant layer due to nominal area of contact surfaces,
 q_g – stochastic component of lubricant pressure due to roughness of surface.

B. Form of contacting surfaces

Let's consider the first component q_0 of equation (7). As the value of q_0 characterizes constant component of pressure q_v it can be found from equation (5) taking into account independence of parameters μ and h of coordinates x, y .

$$\frac{\partial^2 q}{\partial x^2} + \frac{\partial^2 q}{\partial y^2} = -12V \frac{\mu}{h^3} \quad (8)$$

For convenience of calculation lets solve equation (8) by assumption that contacting surfaces through normal plane have the form of ellipse whose canonical equation is the following:

$$\frac{x^2}{a_0^2} + \frac{y^2}{b_0^2} = 1 \quad (9)$$

where a_0, b_0 – halfaxis of ellipse.

Thus, by reference to the above mentioned the following equation of constant pressure of resistance to pressing out lubricant layer due to nominal area of contact can be obtained:

$$q_0 = \frac{3\mu a_0^2 b_0^2}{2t(a_0^2 + b_0^2)} \left(\frac{1}{\bar{h}_2^2} - \frac{1}{h_0^2} \right) \quad (10)$$

where \bar{h}_2 - average value of altitude of heights of regularities of surface,
 h_0 - constant value of thickness of film between
 The average plane of the rough surface and the ideal plane of contact (Fig.2).

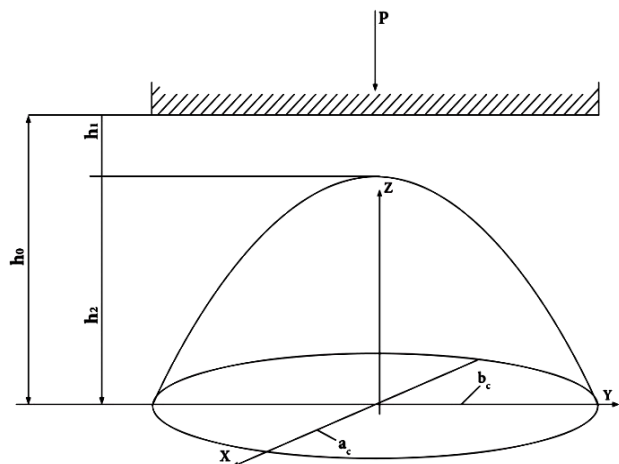


Fig.2. Contact of plane of rough surface and ideal plane

The following equation:

$$q_0 = \frac{3\mu a_0^2}{4t} \left(\frac{1}{h_2^2} - \frac{1}{h_0^2} \right) \quad (11)$$

is true for the case of approaching of round surfaces $a_0=b_0$

C. Elliptic paraboloid asperity

The second component q_g of equation of pressure (8) was determined through investigation of contact of single asperity of the surface and ideal plane. Let's assume the surface is described by normal homogeneous casual field of two variables x and y .

According to Beinerts [4] for that kind of field the form of asperity has close proximity to elliptic paraboloid at high levels ($\gamma \geq 1,5$). The form is illustrated in Fig.2. In this case thickness of lubricant film around the asperity is function of two variables :

$$h_g(x, y) = h_1 + h_2 \left(\frac{x^2}{a_c^2} + \frac{y^2}{b_c^2} \right) \quad (12)$$

where h_1 – thickness of film above height of asperity,
 h_2 – altitude of asperity,
 a_c, b_c – short and long halfaxis of base of elliptical asperity on the middle plane.

By substitution of expression (12) in equation (5) and going through transformations Reynolds equation takes the following form:

$$\frac{\partial^2 q}{\partial x^2} + \frac{\partial^2 q}{\partial y^2} + \frac{6xh_2 \partial q}{a_c^2 \left[h_1 + h_2 \left(\frac{x^2}{a_c^2} + \frac{y^2}{b_c^2} \right) \right] \partial x} + \frac{6yh_2 \partial q}{b_c^2 \left[h_1 + h_2 \left(\frac{x^2}{a_c^2} + \frac{y^2}{b_c^2} \right) \right] \partial y} = \frac{12\mu V}{\left[h_1 + h_2 \left(\frac{x^2}{a_c^2} + \frac{y^2}{b_c^2} \right) \right]} \quad (13)$$

III. CONCLUSION

Definition of carrying ability of the contact of two lubricated surfaces is interpreted in terms of the largest possible normal loading provided by elastic contact of asperities keeping layer of lubricant unbroken between the surfaces. Analysis shows that the following aspects have a substantial influence on the wear of sliding friction and particularly on the carrying ability of the contact of two flat lubricated surfaces working at normal loading:

- 1) characteristics of contacting surfaces :
 - geometry of an area ,
 - parameters of roughness R_a, S_{m1}, c, h_2 ,
- 2) parameters of process of contacting :
 - value of enclosed pressure q_Σ upon surface ,
 - size of clearance h_0 between the surfaces,
 - time t of contacting process ,
- 3) dynamic viscosity μ of liquid lubricant

Thereby, the influence of key parameters on common carrying ability of the contact of surfaces is discussed in the paper. The largest influence is caused by slopes of asperities of roughness ($\lambda=R_a/S_m$), average arithmetic deviation of roughness R_a , dynamic viscosity μ of liquid lubricant and geometry of contacting surfaces a_0, b_0 . Increase of each parameter by 10% results in alteration of the carrying ability of surfaces by 15%(λ), -8%(R_a), +7%(μ), +6%(a_0, b_0), accordingly .

REFERENCES

1. **Rudzitis J.**, *Surface Roughness Topography Investigations*, 8.Internationales Oberflächen Kolloquium 1992, Chemnitz, Bd.2.S. 123-128
2. **Husu A.**, *Finite journal bearings with arbitrary position of source* . J.Mech.Eng.Sci., 1(1959) 6-15
3. **Nayax P.R.** *Random process model of rough surfaces*. J.Lubr. Technol., 93 (1971) 398-407.
4. **Beinerts Z.K.** *Analiticheskoe isledovanie vliania gidkovo sloia na harakteristiki kontaknowo vzaimodeistvia ploskih poverhnosti*. Riga: Zinatne , 1985.-216 p.
5. **Rudzit J.A., Kamols A.J.** "Engenerni rashchot facticheskoj ploschadi contacta i sbligenia neregularnoj sherohovatosti. Book „Microgeometria i ekspluzionnie svoistva mashin” Riga, 1979, pages 66-67.
6. **Kragelsky I., Alisin V.** *Tribology – Lubrication, Friction and Wear*, Mir publishers, Moscow, 2001
7. **Kragelsky I., Dobichin M.,Kombalov V.**, *Fundamentals of friction and Wear Calculation*, Mashinostroenie, Moscow, 1977 (in Russian)

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Oskars Liniņš, Armands Leitāns, Guntis Sprinģis, Jevgenijs Semjonovs. Eļļotu virsmu kontakts

Šīs aprēķina metodikas mērķis ir izpētīt divu plakānu virsmu nestspēju, kuru kontaktā ir eļļojošais materiāls un abas detaļas atrodas kontaktā normālas slodzes apstākļos. Šīs metodes ietvaros virsmas raupjums tiek uzskatīts, kā 3D objekts. Šāda tipa pieeja dod iespēju atrisināt kontaktā esošo detaļu problēmu, pietuvinot to praktiski sastopamai divu plakānu virsmu kontaktā. Šāds risinājums uzskatāms par diezgan jaunu mašīnbūves jomā AHD projektēšanā. Gadījuma lauka pamatjēdzieni tiek apskatīti kā virsmas raupjuma raksturotāji un formulējami virsmas mikropogrāfiskā izpratnē, ko raksturo ar trim koordinātām dekarā koordinātu sistēmā. Divu kontaktā esošu eļļotu virsmu nestspējas noteikšana interpretējama no viedokļa, ka pie maksimāli iespējamā normālā spiediena virsmu kontaktā virsmas izcilņu elastība nodrošina eļļas slāņa noturīgumu uz virsmām. Iegūtais rezultāts sniedz svarīgu lielumu, novērtējot kontakta virsmas cietību piestrādes procesā, dažādu mašīnbūves iekārtu kontakta virsmās. Analīze parāda, ka dažādi virsmu raksturojošie lielumi būtiski ietekmē nodilumu un slīdes berzi, īpaši eļļotas kontakta virsmas nestspēju normālas slodzes gadījumos.

Оскарс Лининш, Арманс Лейтанс, Гунтис Спрингис, Евгений Семёнов. Контакт смазанных поверхностей

Определена методика расчета несущей способности двух плоских поверхностей, контактирующих в смазочном материале при нормальной нагрузке, которая представлена как 3D объект. Такой подход дает возможность решить проблемы деталей в условиях контактирования, ближе к практическим. Данное решение является довольно новым в области машиностроения для проектирования в области АНД. Полученный результат имеет важное значение при оценке жесткости контакта на приработке процесса, в измерительных приборах и контактных единицах машиностроения.

Обсуждение открывает представление о 3D шероховатой поверхности. Основные понятия случайного поля рассматриваются и системой исходных параметров шероховатости поверхности, формулируются в микропографических понятиях, и должны характеризоваться тремя координатами в декартовой системе. Определение несущей способности контакта двух смазанных поверхностей интерпретируется с точки зрения максимально возможной нормальной нагрузки. Предоставлен упругий контакт, неровности при непрерывном поддержании слоя смазки, между поверхностями. Анализ показывает, что следующие аспекты оказывают существенное влияние на износ и трение скольжения, особенно на несущую способность контакта: когда две плоских поверхности при смазке работают с нормальной нагрузкой.