Journal of the Technical University of Gabrovo, Vol. 47’2014 (26-29)

ИЗВЕСТИЯ
на Технически университет
Габрово

SIZE OF THE ABRASIVE PARTICLES, PARTICIPATING IN PROCESS OF WEARING ELEMENTS BALL BEARING

K.K. Mirzayev*, A. Irgashev

Tashkent State Technical University, Tashkent 100095
Republic of Uzbekistan

Received 20 January 2014, Received in revised form 10 March 2014, Accepted 15 March 2014

Abstract

The article deals with the methods of the calculation of the size of the abrasive particles, participating in process of wearing element of ball bearing of the ring at dry and border friction. It is installed that maximum size of the abrasive particles, participating in process of dry friction, increases with increasing radius curvatures of the point of the contact and coefficient of friction between element of the bearing and abrasive particle. At presence of the oil layer most size depends on mechanical characteristic of the material, kinematic viscosity of the butter, pressures between abrasive particle and surface of friction, velocities of the ring internal and medicine to be taken externally race and velocities of the abrasive particle in wedge-shaped clearance, but minimum of the abrasive particles depends the surfaces of friction on thicknesses of the oil layer and total elastic deforming.

Keywords: *maximum and minimum of the abrasive particles, wearing, ball bearing, dry and border friction, radius of the curvature, coefficient of friction, abrasive particle, oil layer, mechanical characteristic, kinematic viscosity, velocity, wedge-shaped clearance, total elastic deformation.*

INTRODUCTION

The size of the abrasive particles, participating in process wearing ball bearing of the ring, was defined depending on the forms, friction relationship between element of the bearing and abrasive particle, thicknesses of the oil layer and mechanical characteristic of the bearing element material.

The factor of friction between internal, medicine to be taken externally ring, ball and abrasive particle renders the essential influence upon the most size of the abrasive particles, participating in process wearing [1].

In nature abrasive particles soil origin subdivide: with sharp verge -10%; the ovoid -70…80% and spherical 10…20% [2].

In many study in purpose of the simplification calculation accounting model of the abrasive particle receive a visit at spherical form [4, 6, 7], which gives some inaccuracy in calculation of the velocities wearing. According to studies, called on for gears, these inaccuracy form under "clean" ring 7-11 %, at degree of the slide 0,6, not more 1% [1]. In bearing of the ring importance most degree of the slippage, calculated by means of molded (7) and (8), forms 0,2-0,25, at inaccuracy of the calculation abrasive wearing forms within 0,4-2,5 %. So hereinafter for calculation of the velocities abrasive wearing reasonable shapes up abrasive particles spherical.

INTERPRETATION

We shall expect that abrasive particles portioned on the whole volume of the butter of the unit evenly then the general volume of the abrasive particles with concentration ε_c to and average size d_{as}, adhering on surface of friction internal ring, is:

$$V = 0{,}0548 \cdot d_{as} \cdot \varepsilon_c \cdot \beta_i^{in} \cdot d_b \cdot \left[d_{1k} + d_b \cdot \left(1 - \cos\beta_i^{in}\right)\right]. \quad (1)$$

where ε_c - a concentration of the abrasive particles, residing in butter oil unit; β_i^{in} - slanting internal ring; d_b - diameter of the ball; d_{1k} - diameter internal ring on chute.

Gross amount of the abrasive particles, residing on surfaces of friction internal ring:

$$n_{gr} = \frac{0{,}1047 \cdot \varepsilon_c}{d_{as}^2} \cdot \beta_i^{in} \cdot d_b \cdot \left[d_{1k} + d_b \cdot \left(1 - \cos\beta_i^{in}\right)\right]. \quad (2)$$

According to condition of the even sharing the abrasive particles on volume of the butter in carter of the unit is defined amount of the abrasive particles, residing on length of the circumferences ring (n_{lei}) and arc of the contact on chute ring (n_{ari}) of the bearing:

$$\begin{cases} n_{lei} \cdot n_{ari} = n_{gr}, \\ \dfrac{n_{lei}}{n_{lei}} = \dfrac{l_{ini}}{l_{\text{ar.ini}}}, \end{cases} \quad (3)$$

where $l_{ar.ini}$ - length of the arc of the contact of the ball on surfaces of friction internal ring; l_{ini} - length to circumferences ring. Then, solved system of the equations (3) comparatively n_{lei} and n_{ari}, get:

$$n_{lei} = \frac{4{,}34 \cdot \varepsilon_c^{1/2}}{d_{\text{as}}} \cdot \left[d_{ini} + d_b \cdot \left(1 - \cos\beta_i^{in}\right)\right], \quad (4)$$

*Тел.99890-947-14-58, e-mail:mirzayev.qahramon@mail.ru

$$n_{ari} = \frac{0{,}24\varepsilon_c^{1/2}}{d_{as}} \beta_i^{in} d_b, \qquad (5)$$

where d_{ini} - current diameter internal ring.

Length of the way of the abrasive particle in wedge-shaped clearance in zone of the elastic contact:

$$s_{le.wi} = \left(\frac{d_{ini} \cdot h_{cr}}{2} - h_{cr}^2 \right)^{1/2}.$$

where h_{cr} - critical depth of the introducing the abrasive particles. Because of that d_{ini}>>h_{cr} in the further calculation importance h_{cr}^2 is not taken into account.

In zone elastic plastic contact critical depth introduction (h_{cr}) of the abrasive particle on surfaces of friction is [1]:

$$h_{cr} = \frac{d_{sr}}{2} \cdot \left[1 - \left[1 - 6(c \cdot \sigma_T \cdot \theta)^2 \right]^{1/2} \right].$$

Then way of the abrasive particle in wedge-shaped clearance before his crushing:

$$s_{le.wi} = \frac{d_{ini} \cdot d_{as}}{4} \left[1 - \left[1 - 6(c\sigma_T\theta)^2 \right]^{1/2} \right]^{1/2}, \qquad (6)$$

where with c – coefficient of deformation. Because of deformation result in process of friction surface of the details to appear strengthening. Herewith increases toughness of the contact surfaces. According to [4] for surfaces of friction takes steel c=3; σ_T - limit of fluidity of the material; θ - elastic constant.

The average distance between two nearby abrasive particles, residing on surfaces of friction, is:

$$l_{ar} = \frac{0{,}72 \cdot d_{as}}{\varepsilon_c^{1/2}}. \qquad (7)$$

The amount of the abrasive particles, residing on length of the way of friction of the zone of the elastic contact, is defined as:

$$n_{ai} = \frac{0{,}69}{d_{as}^{1/2}} \cdot \begin{bmatrix} \varepsilon_c \cdot \left[d_{ini} + d_b \cdot \left(1 - \cos \beta_i^{in} \right) \right] * \\ * \left[1 - (1-6) \cdot (c \cdot \sigma_T \cdot \theta)^2 \right]^{1/2} \end{bmatrix}^{1/2}. \qquad (8)$$

Gross amount of the abrasive particles, residing in zone of the elastic contact, is fixed from expressions (4) and (5),

$$n_{gra} = \frac{0{,}166 \cdot \varepsilon_c \cdot \beta_i^{in} \cdot d_b}{d_{as}^{1/2}} \cdot \begin{bmatrix} d_{ini} + d_b \cdot \left(1 - \cos \beta_i^{in} \right) * \\ * \left[1 - (1-6) \cdot (c \cdot \sigma_T \cdot \theta)^2 \right]^{1/2} \end{bmatrix}^{1/2}. \qquad (9)$$

Volume to deforming the metal all abrasive particle, residing in zone of the elastic contact:

$$V_{de} = V_{1de} \cdot n_{gra},$$

where V_{1de} - a volume to elastic deformation to surfaces of friction by one abrasive particle,

$$V_{1de} = 0{,}24 \cdot d_{as}^{5/2} \cdot d_{ini}^{1/2} \cdot \left[1 - \left[1 - 6 \cdot (c \cdot \sigma_T \cdot \theta)^2 \right]^2 \right],$$

$$\begin{aligned} V_{de} &= 0{,}039 \cdot d_{as} \cdot \varepsilon_c \cdot \beta_i^{in} \cdot d_b \cdot d_{ini}^{1/2} * \\ &* \left[d_{ini} + d_b \cdot \left(1 - \cos \beta_i^{in} \right) \right]^{1/2} \cdot \left[1 - \left[1 - 6 \cdot (c \cdot \sigma_T \cdot \theta)^2 \right]^{1/2} \right]^{5/2} \end{aligned}. \qquad (10)$$

All are an abrasive particles by size d_{ar}, residing in wedge-shaped clearance, before their smashing elastic deform the surface of friction. Herewith executed work is defined:

$$\begin{aligned} A &= \frac{0{,}0063 \cdot d_{as}}{\theta} \cdot \varepsilon_c \cdot \beta_i^{in} \cdot d_b \cdot d_{ini}^{1/2} * \\ &* \left[d_{ini} + d_b \cdot \left(1 - \cos \beta_i^{in} \right) \right]^{1/2} \cdot \left[1 - \left[1 - 6 \cdot (c \cdot \sigma_T \cdot \theta)^2 \right]^{1/2} \right]^{5/2} \end{aligned}. \qquad (11)$$

Thereby, executed work in bearing depends on power of friction between chute ring and abrasive particle, lengths of the way of the abrasive particle in wedge-shaped clearance in zone of the elastic contact and concentrations of the abrasive particles in butter oil unit:

$$\begin{aligned} A &= 0{,}0158 \cdot d_{as} \cdot \beta_i^{in} \cdot d_b \cdot f \cdot \theta \cdot (c \cdot \sigma_T)^2 \cdot d_{ini}^{1/2} \cdot \varepsilon_c * \\ &* \left[\left[d_{ini} + d_b \cdot \left(1 - \cos \beta_i^{in} \right) \right] \cdot \left[1 - \left[1 - 6 \cdot (c \cdot \sigma_T \cdot \theta)^2 \right]^{1/2} \right] \right]^{1/2} \end{aligned}. \qquad (12)$$

Leveling expressions (11) and (14), solved their for coefficient of friction (*f*), after some simplifications shall get

$$f = \frac{0{,}4 \cdot \left[1 - \left[1 - 6 \cdot (c \cdot \sigma_T \cdot \theta)^2 \right]^{1/2} \right]^{3/2}}{(c \cdot \sigma_T \cdot \theta)^2}. \qquad (13)$$

From got expressions possible to draw a conclusion about that that coefficient of friction between abrasive particle and surface of friction bear's ring depends on limit of fluidity of the material bearing element (σ_T) and elastic constant (θ) of the material to surfaces of friction.

We shall consider power, acting on abrasive particles, residing in wedge-shaped clearance between surface of the ring (the fig. 1). On abrasive particle, residing in wedge-shaped clearance when bearing element moving, act resultant power of friction and resultant power, preventing penetration of the abrasive particle in wedge-shaped clearance, formed from normal power, pressing these particles to surface of friction ring. Abrasive particle gets into wedge-shaped clearance if resultant power of friction will more be power, preventing penetration of the abrasive particle i.e. if it is executed condition:

$$N_{fin,ex} \rangle P_{in,ex}, \qquad (14)$$

where $N_{fin,ex}$ - resultant power of friction between abrasive particle and surface of friction; $P_{in,ex}$ - resultant power, preventing penetration of the abrasive particle in wedge-shaped clearance. In the event of ensuring the condition of the expression (14), abrasive particle advances toward zone of the contact in consequence of which occur deforming the surfaces of friction and further their wear-out. On measure of the moving the abrasive particle in wedge-shaped clearance toward point of the contact of the surfaces of friction normal power, acting on abrasive particle, increases. A after passing by abrasive particle of a certain distance in wedge-shaped clearance occurs, probably, their crushing. Because of small size of the crushed particles in contrast with roughness of the surfaces they hereinafter in process wearing does not participate [4].

In bearing of the ring radiuses curvatures of the zone of the contact of the abrasive particles and surfaces of friction different. According to scheme on fig. 1 from ΔABC and ΔADE ($\Delta A_1B_1C_1$ and $\Delta A_1D_1E_1$) are determined resultant power of friction N_{fin}(N_{fex}) and power, preventing penetration of the abrasive particle P_{in} (P_{ex}):

- resultant power of friction,

$$N_{fin,ex} = P_b \cdot \sqrt{\begin{matrix} f_b^{\,2} + f_{in,ex}^{\,2} - 2 \cdot f_b \cdot f_{in,ex} * \\ * \cos\left(180^\circ - (\alpha_{1,2} + \beta_{1,2}) \right) \end{matrix}}, \qquad (15)$$

where $\alpha_{1,2}$, $\beta_{1,2}$ - a corners of the action of normal power on the centre of the bearing; P_{in1}, P_{b1} and P_{ex2}, P_{b2} - power, acting on abrasive particle through internal (external) ring and ball; $f_{in,ex}$, f_b - a coefficients of friction between abrasive particle and internal (external) ring, ball.

Resultant power, preventing penetration of the abrasive particle:

$$P_{in,ex} = P_{b1,2} \cdot \sqrt{2 \cdot \left(1 - \cos\left(\alpha_{1,2} + \beta_{1,2}\right)\right)}. \quad (16)$$

From Δ O_1 M_1 M_2 (ris.1) follows:

$$\cos\left(180^\circ - (\alpha_1 + \beta_1)\right) = 1 - \frac{8 \cdot R_b \cdot R_{in}}{\left(2 \cdot R_b + d_{a\max}\right) \cdot \left(2 \cdot R_{in} + d_{a\max}\right)}, \quad (17)$$

$$\cos(\alpha_1 + \beta_1) = \frac{8 \cdot R_b \cdot R_{in}}{\left(2 \cdot R_b + d_{a\max}\right) \cdot \left(2 \cdot R_{in} + d_{a\max}\right)} - 1. \quad (18)$$

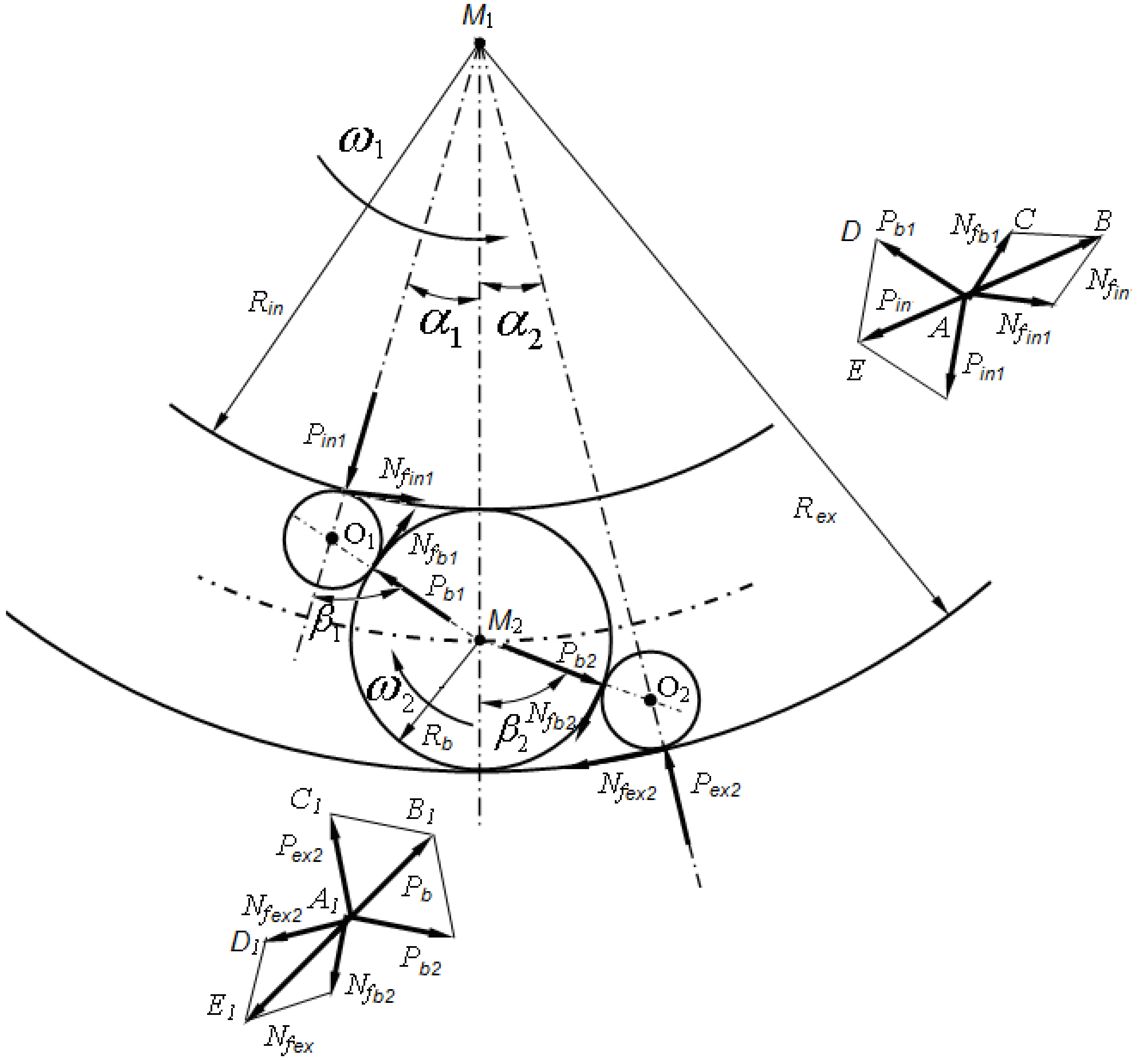

Fig. 1. *Scheme of the calculation of the most size of the abrasive particle, getting into wedge-shaped clearance between elements of the ring*

From Δ O_2 M_1 M_2 (fig.1) is seen:

$$\cos\left(180^\circ - (\alpha_1 + \beta_1)\right) = 1 - \frac{8 \cdot R_b \cdot R_{ex}}{\left(2 \cdot R_b + d_{a\max}\right) \cdot \left(2 \cdot R_{ex} + d_{a\max}\right)}, \quad (19)$$

$$\cos(\alpha_1 + \beta_1) = \frac{8 \cdot R_b \cdot R_{ex}}{\left(2 \cdot R_b + d_{a\max}\right) \cdot \left(2 \cdot R_{ex} + d_{a\max}\right)} - 1, \quad (20)$$

where R_b and $R_{in,ex}$ - a radius of the curvature of the point of the contact of the ball and internal (external) ring.

Substituting from expressions (17), (18-20) in (15) and (16) at dry friction, when $N_{fin,ex} = P_{in,ex}$, have:

$$d^2_{a\max\, in,ex} + 2 \cdot d_{a\max\, in,ex} \cdot \left(R_b + R_{in,ex}\right) - \\ - \frac{4 \cdot R_b \cdot R_{in,ex} \cdot (f_b + f_{in,ex})^2}{4 - \left(f_b + f_{in,ex}\right)^2} = 0, \quad (21)$$

where $d_{a\ max\ in,ex}$ - a most size of the abrasive particles, getting into wedge-shaped clearance between element of the bearing at dry friction.

The solved equation (21) comparatively $d_{a\ max\ in,ex}$ for dry friction shall get:

$$d_{a\max\ in,ex} = \sqrt{\left(R_b + R_{in,ex}\right)^2 + \frac{4 \cdot R_b \cdot R_{in,ex} \cdot \left(f_b + f_{in,ex}\right)^2}{4 - \left(f_b + f_{in,ex}\right)^2}} - . \quad (22)$$
$$- \left(R_b + R_{in,ex}\right)$$

In condition of border lubrificant coefficient of friction between abrasive particle and surface of the contact in contrast with dry friction decreases in consequence of which the most size of the abrasive particles, getting into zone of the contact, becomes less.

The thickness of the oil layer between element of the bearing and abrasive particle depends on viscosity of the lubrificant, geometric, kinematic and dynamic parameter of the contact of the surfaces of friction [2].

The thickness of the oil layer between internal (external) ring and abrasive particle:

$$h_{in,ex} = \frac{2{,}24 \cdot \mu_0 \cdot e^{ap} \cdot (d_{in,ex} + d_{a\max}) \cdot (v_{in,ex} + v_a) \cdot a_a}{2 \cdot P_1}, \quad (23)$$

where μ_0 - kinematic viscosity of the lubrificant; a – pyezocoefficient viscosity; p - a pressure between abrasive particle and surface of friction; $v_{in,ex}$ - a velocity of the internal (external) ring; v_a - a velocity of the abrasive particle in wedge-shaped clearance; a_a - a diameter heel contact, introduced to surface of friction of the abrasive particle; P_1 - a load, acting on one abrasive particle.

From expressions (22) and (23) define the coefficient of friction between abrasive particle and surface of friction at presence of the oil layer:

the ball of the bearing:

$$f_{ob} = \sqrt{f_{wb}^2 - \frac{\sqrt{h_{ab}^2 \cdot \left(\frac{d_a}{2} + \frac{d_b}{2}\right)^2 + 2 \cdot d_a \cdot d_b \cdot f_{wb}^2 - h_{ab}^2}}{\frac{d_a}{2} \cdot \frac{d_b}{2}}}, \quad (24)$$

internal (external) ring bearing:

$$f_{oin.ex} = \sqrt{f_{win.ex}^2 - \frac{\sqrt{h_{ain.ex}^2 \cdot \left(\frac{d_a}{2} + \frac{d_{in.ex}}{2}\right)^2 + 2 \cdot d_a \cdot d_{in.ex} \cdot f_{winex}^2 - h_{ain.ex}^2}}{\frac{d_a}{2} \cdot \frac{d_{in.ex}}{2}}}. \quad (25)$$

where f_{wb} - coefficient of friction between abrasive particle and ball without presence of lubrificant; d_a - size of the abrasive particle; h_{ab} - thickness oil layer between abrasive particle and ball; $f_{w\ in\ ex}$ - coefficient of friction between abrasive particle and internal (external) ring without presence of lubrificant; $h_{a\ in\ ex}$ - thickness oil layer between abrasive particle and internal (external) ring; $d_{in\ ex}$ - diameter of the internal (external) ring.

With provision for factor of friction between surface of friction and abrasive particle under border lubrificant most size abrasive particle, getting into wedge-shaped clearance of the bearing, is:

$$d_{a\max o,ex,b} = \frac{d_{a\max cin,ex,b} \cdot c \cdot \sigma_T}{2 \cdot c \cdot \sigma_T} + \quad (26)$$
$$+ \frac{\sqrt{d_{a\max cin,ex,b}^2 \cdot c^2 \cdot \sigma_T^2 - 9{,}34 \cdot \sigma_T \cdot \mu_0 \cdot e^{ap} \cdot d_{in,exb} \cdot \left(v_{in,ex,b} + v_a\right)}}{2 \cdot c \cdot \sigma_T}$$

For minimum of the abrasive particles, participating in process wearing, are accepted that, which have a size to equal amount of the thickness of the oil film and general elastic deforming the surfaces of friction. Then

$$d_{a\min in,ex,b} = h_{\min in,ex,b} + s_{c\,in,ex,b}, \quad (27)$$

where $h_{min\ in,ex,b}$ - a thickness of the oil layer between surface of friction:

$$h_{\min in,ex,b} = \frac{1{,}12 \cdot \mu_0 \cdot e^{ap} \cdot \left(d_{in,ex,b} + d_a\right) \cdot \left(v_{in,ex,b} + v_a\right) \cdot l_{b\,in,ex}}{P_0}.$$

Here $l_{b\ in,ex}$ - length of the arc of the girth of the ball internal and external rings; P_o - a load, attached on bearing; $s_{c\ in,ex,b}$ - a total elastic deforming the surfaces of friction [5]:

$$s_{c\,in,ex,b} = \frac{2{,}36 \cdot P_0 \cdot \left(1 - v^2\right)}{\pi \cdot l_{\partial\,in,ex,b} \cdot E},$$

where ν - a coefficient of the Poisson, E - a module to bounce.

The average size of the abrasive particles, participating in process wearing, on maximum and minimum has following logarithmic regularity [3]:

$$d_{a\,as} = \sqrt{d_{a\max} \cdot d_{a\min}}. \quad (28)$$

Conclusion

Thereby, from got accounting dependencies possible to do the following findings: maximum size of the abrasive particles in process of dry friction increases with increasing radius curvatures of the point +contact and coefficient of friction between element of the bearing and abrasive particle; at presence of the oil layer he depends on mechanical characteristic of the material, kinematic to viscosity of the butter, pressures between abrasive particle and surface of friction, velocities of the internal ring and medicine to be taken external ring and velocities of the abrasive particle in wedge-shaped clearance. The minimum of the abrasive particles, participating in process wearing, depends the surfaces of friction on thicknesses of the oil layer and total elastic deforming.

LITERATURE

[1] Иргашев А. Методологические основы повышения износостойкости шестерен тяжелонагруженных зубчатых передач агрегатов машин. Дисс. докт. техн. наук. -Ташкент. 2005. -245 с.

[2] Иргашев А. Оценка износостойкости узлов трения качения, работающих в абразивной среде. -Ташкент: ТашГТУ, 1996. -132 с.

[3] Икрамов У., Махкамов. Расчет и прогнозирование абразивного износа. – Ташкент: Фан, 1982. –148 с.

[4] Крагельский И.В., Добычин М.Н., Комбалов В.С. Основы расчетов на трение и износ. –М.: Машиностроение, 1977. –526 с.

[5] Коднир Д.С. Контактная гидродинамика смазки деталей машин. –М.: Машиностроение, 1987. -192 с.

[6] Ямпольский Г.Я., Крагельский И.В. Исследование абразивного износа элементов пар трения качения. –М.: Наука. 1973. -63 с.

[7] Shoobidov Sh.A., Irgashev A., Mirzaev Q.Q. Wear resistance of elements of antifiriction bearings. WCIS-2006. Fourth World Conference on Intelligent systems for Industrial Automation Tashkent, Uzbekistan/ November 21-22,2006.p.337-339.