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Mathematical simulation of influence of heredity on the character of contact pressure distribution between semicylindrical surface with a hole and sealing element

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Abstract. *Based on linear laws of heredity we define relaxation of contact pressure between a cylindrical surface with a hole and sealing element, and external force necessary for achieving tightness.*
The analytic formula allowing to determine the character of contact pressure distribution between the external surface of the cylinder and sealers wall depending on its physico-mechanical properties and geometrical sizes involving a hole in its body, was found. The results of numerical calculations were represented in the form of graphs of contact pressure relaxation between a cylindrical surface with a hole and a scaling, and external force necessary for achieving sightless. It is shown that, because of heredity of the material of the sealer, the values of contact pressure and external force in some cases drop about four times.

Keywords. heredity · functional · deformation variation · stress · time · elasticity modulus · relaxation

Mathematics Subject Classification (2010): 74B10 · 74B05

1 Introduction

In practice, quite often a semicylindrical surface with a has to be sealed. This time, reliability of tightness of the surface largely depends on the character of contact pressure distribution between cylindrical surface and sealing element. The last one, in its turn depends on geometrical sizes and physico-mechanical properties of the sealer and cylindrical surface. The papers [1, 4, 5, 8, 9, 12] were devoted to such problems.

But, in these papers, the cylindrical surface has no hole. But the presence of a hole in cylindrical surface and accounting of heredity strongly changes the character of contact

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pressure distribution. Therefore, investigation and study of the influence of the presence of a hole in a cylindrical surface and heredity of the sealing material on the character of distribution between it and a sealing element is both of scientific and practical interest.

2 Statement and solution of the problem

Let us consider a semicylindrical surface with a hole. The scaler is compressed to this surface by the clamp of semicylindrical form (Fig. 1). In the case under consideration, the holes diameter is many times small compared to the cylinders diameter. Therefore, we accept the contour of the hole as a plane curve.

We locate the origin of the cylindrical coordinate system at the center of the cross section of the cylinder, direct the coordinate axis r to the side of increase of radius as was shown in Fig. 1. Besides this, we define the position of the points of the area of the hole by the coordinates φ and ρ (Fig . 1).

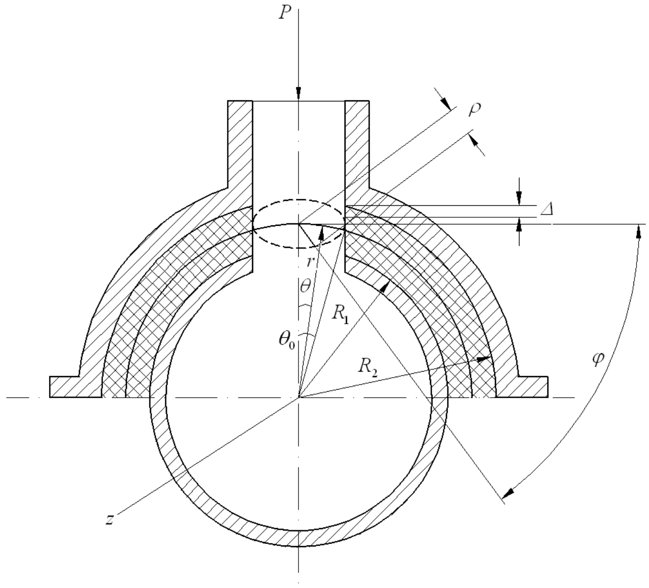

Fig 1. Calculation scheme

We accept the sealing element as an hereditarily-elastic body and assume that velocity of external force and deformation change in the boundary of the sealer happens slowly. Before loading, the sealing element has been in natural state. Then the proses deformation of the scaling element many be accepted quasistatic and for solving the problem to use elastic analogue [1-7].

This time, the stresses at any points of the sealing element is determined by the formula [12]

$$\tau_{ij} = \left[2\varepsilon_{ij}(x) + \delta_{ij} s(x)\right] G \left\{ e^{-\lambda^* t} + \int_0^t \left[\left(\varepsilon_{ij}(\xi)\right)_{,t} + \nu^* \varepsilon_{ij}(\xi) \right] e^{-\lambda^*(t-\xi)} d\xi \right\}, \quad (2.1)$$

where $\varepsilon(\overline{x})$, $\varepsilon(t)$ is relative deformation dependent on the coordinate x and time t, respectively, $\lambda^* = \frac{E_1+E_2}{\eta}$, $\nu^* = \frac{E_2}{\eta}$, η is viscosity coefficient of the sealing's material, E_1 is instant modulus of elasticity,E_2 is modulus of elasticity of the scaling's material, G is shear modulus of the material of the sealing element, $n = \frac{1}{\nu^*}$ is relaxation time, δ_{ij} is Kronecker's symbol.

Acceptime the elastic analogue idea, we can write [11, 12, 15]

$$\bar{G} = G\left\{e^{-\lambda^* t} + \int_0^t \left[\left(\varepsilon_{ij}\left(\xi\right)\right)_{,t} + \nu^* \varepsilon_{ij}\left(\xi\right)\right] e^{-\lambda^*(t-\xi)} d\xi\right\}. \tag{2.2}$$

Now we arrive formally to the notation that looks like the Hooke law [12]

$$\tau_{ij} = \overline{G}\left(2\varepsilon_{ij}\left(\overline{x}, t\right) + \delta_{ij} s\left(\overline{x}, t\right)\right). \tag{2.3}$$

Therefore, in the given case, after finding the solution of the problem in elastic statement, using expressions (2.2) and (2.3) we can determine stress with regard to hereditary properties of the sealer.

In the paper [10] in the elastic statement was in the form the character of contact pressure distribution on the sealers surface

$$\sigma_r = -\,2\bar{G}\Delta f'(r)\cos\theta\Big|_{r=R_1}, \tag{2.4}$$

where

$$f(r) = A_1\frac{R_1 - r}{R_1} + A_2\frac{(R_1 - r)^2}{R_1^2} + A_3\frac{(R_1 - r)^3}{R_1^3} + A_4\frac{(R_1 - r)^4}{R_1^4},$$

$$A_1 = \frac{R_1}{R_1 - R_2} - A_2\frac{R_1 - R_2}{R_1} - A_3\frac{(R_1 - R_2)^2}{R_1^2} - A_4\frac{(R_1 - R_2)^3}{R_1^3},$$

$$A_2 = -\frac{a_3^{(1)} - \frac{(R_1-R_2)^2}{R_1^2}a_1^{(1)}}{a_2^{(1)} - \frac{R_1-R_2}{R_1}a_1^{(1)}}A_3 - \frac{a_4^{(1)} - \frac{(R_1-R_2)^3}{R_1^3}a_1^{(1)}}{a_2^{(1)} - \frac{R_1-R_2}{R_1}a_1^{(1)}}A_4 - \frac{a_1^{(1)}}{a_2^{(1)} - \frac{R_1-R_2}{R_1}a_1^{(1)}}\frac{R_1}{R_1 - R_2},$$

$$A_3 = -\frac{\left(a_4^{(2)} - \nu_1 a_4^{(1)}\right) - \left(a_1^{(2)} - \nu_1 a_1^{(1)}\right)\frac{(R_1-R_2)^3}{R_1^3}}{\left(a_3^{(2)} - \nu_1 a_3^{(1)}\right) - \left(a_1^{(2)} - \nu_1 a_1^{(1)}\right)\frac{(R_1-R_2)^2}{R_1^2}}A_4 -$$

$$-\frac{a_1^{(2)} - \nu_1 a_1^{(1)}}{\left(a_3^{(2)} - \nu_1 a_3^{(1)}\right) - \left(a_1^{(2)} - \nu_1 a_1^{(1)}\right)\frac{(R_1-R_2)^2}{R_1^2}}\frac{R_1}{R_1 - R_2},$$

$$A_4 =$$

$$-\frac{\left(a_1^{(3)} - \nu_2 a_1^{(1)}\right) - \nu_3\left(a_1^{(2)} - \nu_1 a_1^{(1)}\right)}{\left(\left(a_4^{(3)} - \nu_2 a_4^{(1)}\right) - \nu_3\left(a_4^{(2)} - \nu_1 a_4^{(1)}\right)\right) - \left(\left(a_1^{(3)} - \nu_2 a_1^{(1)}\right) - \nu_3\left(a_1^{(2)} - \nu_1 a_1^{(1)}\right)\right)\frac{(R_1-R_2)^3}{R_1^3}}\times$$

$$\times\frac{R_1}{R_1 - R_2},$$

$$a_1^{(1)} = \left(R_2^6 - R_1^6\right)\frac{1}{R_1}\left(-\frac{1}{12} - \frac{19}{48}\cos\theta_0 + \frac{19}{48}\cos 3\theta_0\right) + \left(R_2^5 - R_1^5\right)\times$$

$$\times\left(-\frac{19}{30} + \frac{21}{10}\cos\theta_0 - \frac{7}{6}\cos 3\theta_0 - \frac{1}{20}\frac{l}{R_1}\right) + \left(R_2^4 - R_1^4\right)\times$$

$$\times\left(R_1\left(\frac{47}{24}-\frac{111}{32}\cos\theta_0+\frac{109}{96}\cos 3\theta_0\right)+\frac{19}{16}l\right)+\left(R_2^3-R_1^3\right)\times$$

$$\times\left(-\frac{1}{3}R_1^2\left(\frac{25}{6}-\frac{23}{4}\cos\theta_0+\frac{13}{12}\cos 3\theta_0\right)-\frac{35}{12}lR_1-\frac{1}{9}\frac{l^3}{R_1}\right)+$$

$$+\left(R_2^2-R_1^2\right)\left(\frac{1}{3}l^3+\frac{17}{8}lR_1^2\right)-\left(R_2-R_1\right)\frac{l^3R_1}{3}$$

$$a_2^{(1)}=\left(R_2^7-R_1^7\right)\tfrac{1}{R_1^2}\left(\tfrac{47}{42}-\tfrac{23}{56}\cos\theta_0-\tfrac{107}{168}\cos 3\theta_0\right)+\left(R_2^6-R_1^6\right)\tfrac{1}{R_1}\times$$

$$\times\left(-\tfrac{25}{9}+\tfrac{1}{6}\cos\theta_0+\tfrac{41}{18}\cos 3\theta_0-\tfrac{47}{24}\tfrac{l}{R_1}\right)+\left(R_2^5-R_1^5\right)\times$$

$$\times\left(\tfrac{17}{15}+\tfrac{99}{40}\cos\theta_0-\tfrac{361}{120}\cos 3\theta_0+\tfrac{23}{5}\tfrac{l}{R_1}\right)+\left(R_2^4-R_1^4\right)\times$$

$$\times\left(R_1\left(\tfrac{11}{6}-\tfrac{65}{16}\cos\theta_0+\tfrac{83}{48}\cos 3\theta_0\right)-\tfrac{13}{8}l\right)+$$

$$+\left(R_2^3-R_1^3\right)\left(-\tfrac{1}{3}R_1^2\left(\tfrac{25}{6}-\tfrac{23}{4}\cos\theta_0+\tfrac{13}{12}\cos 3\theta_0\right)-3lR_1-\tfrac{2}{9}\tfrac{l^3}{R_1}\right)+$$

$$+\left(R_2^2-R_1^2\right)\left(\tfrac{2}{3}l^3+\tfrac{17}{8}lR_1^2\right)-\left(R_2-R_1\right)\tfrac{2l^3R_1}{3},$$

$$a_3^{(1)}=\left(R_2^8-R_1^8\right)\tfrac{1}{R_1^3}\left(-\tfrac{83}{48}+\tfrac{7}{8}\cos\theta_0+\tfrac{19}{24}\cos 3\theta_0\right)+\left(R_2^7-R_1^7\right)\tfrac{1}{R_1^2}\times$$

$$\times\left(\tfrac{307}{42}-\tfrac{181}{56}\cos\theta_0-\tfrac{625}{168}\cos 3\theta_0+\tfrac{127}{28}\tfrac{l}{R_1}\right)+\left(R_2^6-R_1^6\right)\tfrac{1}{R_1}\times$$

$$\times\left(-\tfrac{187}{18}+\tfrac{137}{48}\cos\theta_0+\tfrac{965}{144}\cos 3\theta_0-\tfrac{395}{24}\tfrac{l}{R_1}\right)+\left(R_2^5-R_1^5\right)\times$$

$$\times\left(\tfrac{67}{15}+\tfrac{91}{40}\cos\theta_0-\tfrac{689}{120}\cos 3\theta_0+\tfrac{203}{10}\tfrac{l}{R_1}\right)+\left(R_2^4-R_1^4\right)\times$$

$$\times\left(R_1\left(\tfrac{41}{24}-\tfrac{149}{32}\cos\theta_0+\tfrac{223}{96}\cos 3\theta_0\right)-\tfrac{59}{8}l\right)+\left(R_2^3-R_1^3\right)\times$$

$$\times\left(-\tfrac{1}{3}R_1^2\left(\tfrac{25}{6}-\tfrac{23}{4}\cos\theta_0+\tfrac{13}{12}\cos 3\theta_0\right)-\tfrac{37}{12}lR_1-\tfrac{1}{3}\tfrac{l^3}{R_1}\right)+$$

$$+\left(R_2^2-R_1^2\right)\left(l^3+\tfrac{17}{8}lR_1^2\right)-\left(R_2-R_1\right)R_1l^3,$$

$$a_4^{(1)}=\left(R_2^9-R_1^9\right)\frac{1}{R_1^4}\left(\frac{25}{18}-\frac{11}{18}\cos\theta_0-\frac{13}{18}\cos 3\theta_0\right)+\left(R_2^8-R_1^8\right)\frac{1}{R_1^3}$$

$$\times\left(-\frac{241}{24}+\frac{39}{8}\cos\theta_0+\frac{115}{24}\cos 3\theta_0-\frac{239}{32}\frac{l}{R_1}\right)+\left(R_2^7-R_1^7\right)\frac{1}{R_1^2}$$

$$\times\left(\frac{1021}{42}-\frac{45}{4}\cos\theta_0-\frac{1007}{84}\cos 3\theta_0+\frac{493}{14}\frac{l}{R_1}\right)+\left(R_2^6-R_1^6\right)\frac{1}{R_1}$$

$$\times\left(-\frac{227}{9}+\frac{53}{6}\cos\theta_0+\frac{265}{18}\cos 3\theta_0-\frac{1537}{24}\frac{l}{R_1}+\frac{5}{9}\frac{l^3}{R_1^3}\right)+$$

$$+\left(R_2^5-R_1^5\right)\left(\tfrac{281}{30}+\tfrac{3}{2}\cos\theta_0-\tfrac{281}{30}\cos 3\theta_0+\tfrac{267}{5}\tfrac{l}{R_1}-\tfrac{4}{3}\tfrac{l^3}{R_1^3}\right)+\left(R_2^4-R_1^4\right)\times$$

$$\times\left(R_1\left(\tfrac{19}{12}-\tfrac{21}{4}\cos\theta_0+\tfrac{35}{12}\cos 3\theta_0\right)-\tfrac{257}{16}l+\tfrac{5}{6}\tfrac{l^3}{R_1^2}\right)+$$

$$+\left(R_2^3-R_1^3\right)\left(-\tfrac{1}{3}R_1^2\left(\tfrac{25}{6}-\tfrac{23}{4}\cos\theta_0+\tfrac{13}{12}\cos 3\theta_0\right)-\tfrac{19}{6}lR_1-\tfrac{4}{9}\tfrac{l^3}{R_1}\right)+$$

$$+\left(R_2^2-R_1^2\right)\left(\tfrac{4}{3}l^3+\tfrac{17}{8}lR_1^2\right)-\left(R_2-R_1\right)\tfrac{4R_1l^3}{3},$$

$$a_1^{(2)}=\left(R_2^7-R_1^7\right)\frac{1}{R_1}\left(\frac{1}{14}+\frac{19}{56}\cos\theta_0-\frac{19}{56}\cos 3\theta_0\right)+\left(R_2^6-R_1^6\right)\times$$

$$\times\left(\frac{4}{9}-\frac{103}{48}\cos\theta_0+\frac{197}{144}\cos 3\theta_0+\frac{1}{24}\frac{l}{R_1}\right)+\left(R_2^5-R_1^5\right)\times$$

$$\times\left(R_1\left(-\frac{11}{5}+\frac{39}{8}\cos\theta_0-\frac{83}{40}\cos 3\theta_0\right)-l\right)+$$

$$+\left(R_2^4-R_1^4\right)\left(R_1^2\left(3-\frac{157}{32}\cos\theta_0+\frac{45}{32}\cos 3\theta_0\right)+\frac{27}{8}lR_1+\frac{1}{12}\frac{l^3}{R_1}\right)+$$

$$+\left(R_2^3-R_1^3\right)\left(-\frac{1}{3}R_1^3\left(\frac{25}{6}-\frac{23}{4}\cos\theta_0+\frac{13}{12}\cos 3\theta_0\right)-\frac{1}{3}l^3-\frac{13}{3}lR_1^2\right)+$$

$$+\left(R_2^2-R_1^2\right)\left(\frac{1}{2}l^3R_1+\frac{17}{8}lR_1^3\right)-\left(R_2-R_1\right)^2\frac{l^3R_1}{3},$$

$$a_2^{(2)}=\left(R_2^8-R_1^8\right)\frac{1}{R_1^2}\left(-\frac{47}{48}+\frac{23}{64}\cos\theta_0+\frac{107}{192}\cos 3\theta_0\right)+\left(R_2^7-R_1^7\right)\frac{1}{R_1}\times$$

$$\times\left(\frac{7}{2}-\frac{31}{56}\cos\theta_0+\frac{145}{56}\cos 3\theta_0+\frac{47}{28}\frac{l}{R_1}\right)+\left(R_2^6-R_1^6\right)\times$$

$$\times\left(-\frac{67}{18}-\frac{91}{48}\cos\theta_0+\frac{689}{144}\cos 3\theta_0-\frac{139}{24}\frac{l}{R_1}\right)+\left(R_2^5-R_1^5\right)\times$$

$$\times\left(R_1\left(-\frac{1}{3}+\frac{229}{40}\cos\theta_0-\frac{527}{120}\cos 3\theta_0\right)+\frac{59}{10}l\right)+$$

$$+\left(R_2^4-R_1^4\right)\left(R_1^2\left(\frac{23}{8}-\frac{11}{2}\cos\theta_0+2\cos 3\theta_0\right)+\frac{5}{8}lR_1+\frac{1}{6}\frac{l^3}{R_1}\right)+\left(R_2^3-R_1^3\right)\times$$

$$\times\left(-\frac{1}{3}R_1^3\left(\frac{25}{6}-\frac{23}{4}\cos\theta_0+\frac{13}{12}\cos 3\theta_0\right)-\frac{2}{3}l^3-\frac{53}{12}lR_1^2\right)+$$

$$+\left(R_2^2-R_1^2\right)\left(l^3R_1+\frac{17}{8}lR_1^3\right)-\left(R_2-R_1\right)\frac{2l^3R_1^2}{3},$$

$$a_3^{(2)}=\left(R_2^9-R_1^9\right)\frac{1}{R_1^3}\left(\frac{83}{54}-\frac{7}{9}\cos\theta_0-\frac{19}{27}\cos 3\theta_0\right)+\left(R_2^8-R_1^8\right)\frac{1}{R_1^2}\times$$

$$\times\left(-\frac{65}{8}+\frac{237}{64}\cos\theta_0+\frac{259}{64}\cos 3\theta_0-\frac{127}{32}\frac{l}{R_1}\right)+\left(R_2^7-R_1^7\right)\frac{1}{R_1}\times$$

$$\times\left(\frac{227}{14}-\frac{159}{28}\cos\theta_0-\frac{265}{28}\cos 3\theta_0+\frac{261}{14}\frac{l}{R_1}\right)+\left(R_2^6-R_1^6\right)\times$$

$$\left(-\frac{127}{9}+\frac{23}{24}\cos\theta_0+\frac{827}{72}\cos 3\theta_0-\frac{267}{8}\frac{l}{R_1}\right)+\left(R_2^5-R_1^5\right)\times$$
$$\times\left(R_1\left(\frac{31}{10}+6\cos\theta_0-\frac{38}{5}\cos 3\theta_0\right)+\frac{131}{5}l\right)+\left(R_2^4-R_1^4\right)\times$$
$$\times\left(R_1^2\left(\frac{11}{4}-\frac{195}{32}\cos\theta_0+\frac{83}{32}\cos 3\theta_0\right)-\frac{81}{16}lR_1+\frac{1}{4}\frac{l^3}{R_1}\right)+$$
$$+\left(R_2^3-R_1^3\right)\left(-\frac{1}{3}R_1^3\left(\frac{25}{6}-\frac{23}{4}\cos\theta_0+\frac{13}{12}\cos 3\theta_0\right)-l^3-\frac{9}{2}lR_1^2\right)+$$
$$+\left(R_2^2-R_1^2\right)\left(\frac{3}{2}l^3R_1+\frac{17}{8}lR_1^3\right)-\left(R_2-R_1\right)R_1^2l^3,$$

$$a_3^{(3)}=\left(R_2^{10}-R_1^{10}\right)\frac{1}{R_1^3}\left(-\frac{83}{60}+\frac{7}{10}\cos\theta_0+\frac{19}{30}\cos 3\theta_0\right)+\left(R_2^9-R_1^9\right)\frac{1}{R_1^2}\times$$
$$\times\left(\frac{473}{54}-\frac{293}{72}\cos\theta_0-\frac{929}{216}\cos 3\theta_0+\frac{127}{32}\frac{l}{R_1}\right)+\left(R_2^8-R_1^8\right)\frac{1}{R_1}\times$$
$$\times\left(-\frac{357}{16}+\frac{555}{64}\cos\theta_0+\frac{789}{64}\cos 3\theta_0-\frac{649}{32}\frac{l}{R_1}\right)+\left(R_2^7-R_1^7\right)\times$$
$$\times\left(\frac{1189}{42}-\frac{13}{2}\cos\theta_0-\frac{811}{42}\cos 3\theta_0+\frac{189}{4}\frac{l}{R_1}\right)+\left(R_2^6-R_1^6\right)\times$$
$$\times\left(R_1\left(-\frac{601}{36}-\frac{97}{24}\cos\theta_0+\frac{1283}{72}\cos 3\theta_0\right)-\frac{1325}{24}l\right)+\left(R_2^5-R_1^5\right)\times$$
$$\times\left(R_1^2\left(\frac{9}{10}+\frac{87}{8}\cos\theta_0-\frac{387}{40}\cos 3\theta_0\right)+\frac{121}{4}lR_1-\frac{1}{5}\frac{l^3}{R_1}\right)+$$
$$+\left(R_2^4-R_1^4\right)\left(R_1^3\left(\frac{91}{24}-\frac{241}{32}\cos\theta_0+\frac{275}{96}\cos 3\theta_0\right)+l^3-\frac{27}{16}lR_1^2\right)+\left(R_2^3-R_1^3\right)\times$$
$$\times\left(-\frac{1}{3}R_1^4\left(\frac{25}{6}-\frac{23}{4}\cos\theta_0+\frac{13}{12}\cos 3\theta_0\right)-2l^3R_1-\frac{71}{12}lR_1^3\right)+$$
$$+\left(R_2^2-R_1^2\right)\left(2l^3R_1^2+\frac{17}{8}lR_1^4\right)-\left(R_2-R_1\right)^3R_1l^3,$$

$$a_4^{(3)}=\left(R_2^{11}-R_1^{11}\right)\frac{1}{R_1^4}\left(\frac{25}{22}-\frac{1}{2}\cos\theta_0-\frac{13}{22}\cos 3\theta_0\right)+\left(R_2^{10}-R_1^{10}\right)\frac{1}{R_1^3}\times$$
$$\times\left(-\frac{158}{15}+5\cos\theta_0+\frac{77}{15}\cos 3\theta_0-\frac{239}{40}\frac{l}{R_1}\right)+\left(R_2^9-R_1^9\right)\frac{1}{R_1^2}\times$$
$$\times\left(\frac{1030}{27}-\frac{649}{36}\cos\theta_0-\frac{2005}{108}\cos 3\theta_0+\frac{122}{3}\frac{l}{R_1}\right)+\left(R_2^8-R_1^8\right)\frac{1}{R_1}\times$$
$$\times\left(-\frac{143}{2}+\frac{499}{16}\cos\theta_0+\frac{589}{16}\cos 3\theta_0-\frac{937}{8}\frac{l}{R_1}+\frac{5}{12}\frac{l^3}{R_1^3}\right)+$$
$$+\left(R_2^7-R_1^7\right)\left(\frac{1559}{21}-\frac{709}{28}\cos\theta_0-\frac{527}{12}\cos 3\theta_0+\frac{1282}{7}\frac{l}{R_1}-\frac{40}{21}\frac{l^3}{R_1^3}\right)+\left(R_2^6-R_1^6\right)\times$$

$$\times\left(R_1\left(-\frac{358}{9}+\frac{17}{6}\cos\theta_0+\frac{581}{18}\cos 3\theta_0\right)-\frac{655}{4}l+\frac{10}{3}\frac{l^3}{R_1^2}\right)+$$

$$+\left(R_2^5-R_1^5\right)\left(R_1^2\left(6+\frac{221}{20}\cos\theta_0-\frac{57}{4}\cos 3\theta_0\right)+\frac{386}{5}lR_1-\frac{44}{15}\frac{l^3}{R_1}\right)+\left(R_2^4-R_1^4\right)\times$$

$$\times\left(R_1^3\left(\frac{11}{3}-\frac{65}{8}\cos\theta_0+\frac{83}{24}\cos 3\theta_0\right)+\frac{13}{6}l^3-\frac{41}{4}lR_1^2\right)+$$

$$+\left(R_2^3-R_1^3\right)\left(-\frac{1}{3}R_1^4\left(\frac{25}{6}-\frac{23}{4}\cos\theta_0+\frac{13}{12}\cos 3\theta_0\right)-\frac{8}{3}l^3R_1-6lR_1^3\right)+\left(R_2^2-R_1^2\right)\times$$

$$\times\left(\frac{8}{3}l^3R_1^2+\frac{17}{8}lR_1^4\right)-\left(R_2-R_1\right)^3\frac{4R_1l^3}{3},$$

$$\nu_1=\frac{a_2^{(2)}-\frac{R_1-R_2}{R_1}a_1^{(2)}}{a_2^{(1)}-\frac{R_1-R_2}{R_1}a_1^{(1)}},\quad \nu_2=\frac{a_2^{(3)}-\frac{R_1-R_2}{R_1}a_1^{(3)}}{a_2^{(1)}-\frac{R_1-R_2}{R_1}a_1^{(1)}},$$

$$\nu_3=\frac{\left(a_3^{(3)}-\nu_2a_3^{(1)}\right)-\left(a_1^{(3)}-\nu_2a_1^{(1)}\right)\frac{(R_1-R_2)^2}{R_1^2}}{\left(a_3^{(2)}-\nu_1a_3^{(1)}\right)-\left(a_1^{(2)}-\nu_1a_1^{(1)}\right)\frac{(R_1-R_2)^2}{R_1^2}},$$

R_1 and R_2 are inner and outer radii of the wall of the sealing element, θ_0 is an angle between the radius passing through the center and the point on the holes contour, l is the half of the length of the sealing element.

Based on the elastic analogue [3, 4, 6] accepting the axial deformation of lateral sections

$$\begin{aligned}&\varepsilon_1(z,t)=\varepsilon_1(\bar{z})\cdot\varepsilon_1(t)\\&\varepsilon_1(t)=w_1(t)=1.\end{aligned}\tag{2.5}$$

From formula (2.5) we get

$$\bar{G}=G\left[e^{-\lambda^*t}+\nu^*\int\limits_0^t e^{-\lambda^*(t-\xi)}d\xi\right].\tag{2.6}$$

Integrating formula (2.6), we get

$$\bar{G}=G\left[\left(1-\frac{\nu^*}{\lambda^*}\right)e^{-\lambda^*t}+\frac{\nu^*}{\lambda^*}\right].\tag{2.7}$$

Then allowing for formula (2.7) from the expression (2.4) we get

$$\sigma_r=-\,2G\left[\left(1-\frac{\nu^*}{\lambda^*}\right)e^{-\lambda^*t}+\frac{\nu^*}{\lambda^*}\right]\Delta f'(r)\cos\theta\Big|_{r=R_1}.\tag{2.8}$$

Formula (2.8) determines the contact pressure change between the outer surface of the cylinders wall and inner surface of the sealer with regard to hereditary property of the scaler depending on time.

In the paper [10] the value of the external force P necessary for archiving tightness depending on the radius of the sealers inner wall, is defined based on the variation of calculus method. Accepting the sealer as an elastic body, the following formula was obtained

$$P=\pi\bar{G}\Delta lR_1f'(R_1).\tag{2.9}$$

Allowing for expression, (7) from expression (9) we get

$$P = \pi G \left[\left(1 - \frac{\nu^*}{\lambda^*} \right) e^{-\lambda^* t} + \frac{\nu^*}{\lambda^*} \right] \Delta l R_1 f'(R_1). \tag{2.10}$$

Numerical calculation was carried out by formula (2.8) and (2.10) for the following values of parameters: $R_1 = 0.084m$; $R_2 = R_1 + \delta$; $\delta = 2 \cdot 10^{-2}m$; $\Delta = 0.005m$; $l = 0.3m$; $\theta_0 = \frac{2\pi}{35}$; $G = 1.3 \cdot 10^7 Pa$; $\nu^* = 0.01$; $\lambda^* = 0.1$.

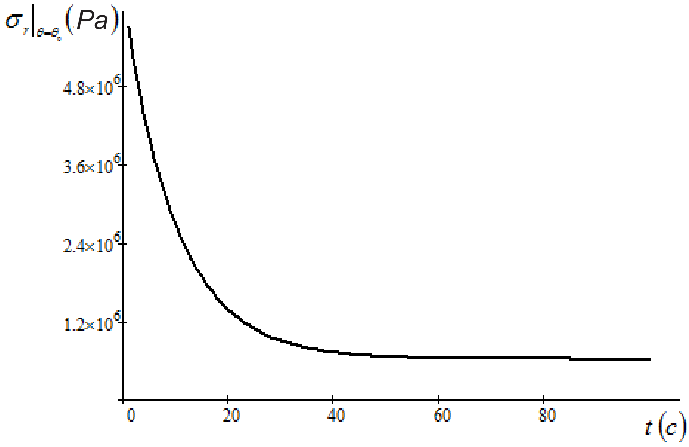

Fig 2.

The results of numerical calculations by formulas (2.8) and (2.10) were represented in Fig. 2. and Fig. 3. As seen from Fig. 2 and 3 the contact pressure between the outer surface of the cylinders well and inner surface of the sealing element σ_r and the external force P necessary for achieving tightness drop in the course of some time and are stabilized after some time.

The character of contact pressure distribution between the other surface of the cylinders wall and inner surface of the sealing element involving a hole is given in Fig. 2.

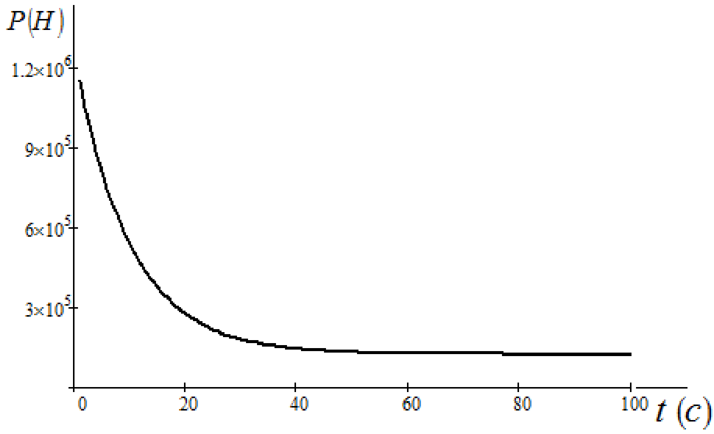

Fig 3.

As is seen from Fig. 2, the contact pressure between the outer surface of the cylinders wall and inner surface of the sealing element σ_r with regard to heredity drops about four times.

Graph of dependence of the character of contact pressure distribution between the outer surface of the cylinders wall and inner surface of the sealing element depending on time (relaxation graph)

Graph of dependence of the external force P for achieving tightness depending on time (relaxation graph).

3 Conclusion.

Thus, the obtained formula enables to determine the character of contact pressure distribution between the inner surface of the sealer and the cylinders wall depending on its physical-mechanical properties and geometrical sizes involving a hole in its body with regard to heredity of the sealings material. The carried out investigation show that disregard of the heredity properties of the sealing elements in some cases may lead to incorrect results and conclusions.

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