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Study on the Angle of Stationary Crescent for Radial Compensation of Inner Mesh Gear Pumps

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Abstract: The working mechanism of the stationary crescent for radial compensation in the inner mesh gear pumps was studied in this paper. The force of the top and bottom stationary crescent in one hydraulic pressure changing cycle was analysed. The pressure distribution on the top and bottom stationary cressent in different positions and the hydraulic force at the x, y direction were determined.Under the condition of the force of the top and bottom stationary crescent is least and the two stationary crescents stay close to the tooth crest of internal gear and external gear to form radial seal, the angle of the end of the top stationary crescent in the high pressure area and the fixing angle of the seal stick was optimized. Experiment results show that the volumetric efficiency is 0.94 when the outlet pressure reach to 30Mpa, and the oil temperature is less than 55° C, there is no abrasion on the two sationary crescents and the tooth crest.

Introduction

Inner mesh gear pump is widely used in a lot of engineering machinery with the advantages of compact structure, steady operation, high pressure and low noise, low sensitivity to oil pollution, no trapped oil, excellent self-absorption and wide rotational speed range. [1]But under the high pressure load,radial leakage the inner mesh gear pump is large, the radial compensation is done usually by top and bottom stationary crescents, but if the force of the stationary crescents is high,the oil film between the stationary crescents and tooth crests can't form,which increases the friction and abrasion.Based on the analysis of foce of the top and bottom stationary crescents, the angle of the end of the top stationary crescent in the high pressure area and the fixing angle of the seal stick of the least resultant force was obtained under the condition of the radial sealing.

Working Mechanism of Inner Mesh Gear Pumps

As is shown in Fig.1, a pair of involute internal gear and external gear meshes with each other, external gear is the drive wheel, the internal gear is the driven wheel, there are top and bottom stationary crescents between the internal and external gear to form seals to reduce raial leakage and from radial compensation.There is a small stick between the top and bottom stationary crescents to avoid the leakage and separate the inlet port and outlet port.The top and bottom stationary crescents are fixed on the floating board by a pin.The hydraulic force on the front and back boards are blanced by making oil sulcuses along the gear root.The rotational direction of the two gears is same,and the teeth in the inlet port end the mesh so that the volume of inlet port increases and form vacuum,and the oil is drawn.The volume of outlet port decreases as the teeth begin to mesh,and the oil is forced out. [2]

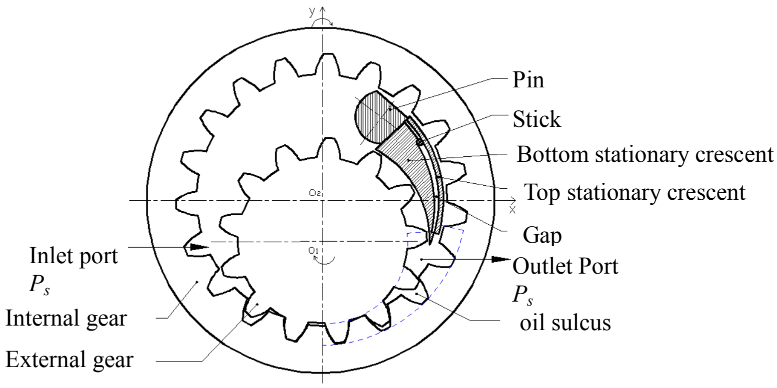


Fig.1. The working mechanism of inner mesh gear pumps

The oil pressure distribution on the top and bottom stationary crescents

As is shown in Fig.2, the boundary between inlet port and outlet port is *NI*. From O_1I to *JK* is the inlet port along clockwise,and the pressure in inlet port is $P_T=0$.From *NI* to *CL* is the top oil sulcus,from *NI* to *DM* is the bottom oil sulcus.The oil sulcus connect with the outlet port and the oil sulcus is the area of high pressure,and the oil pressure is P_S.The initial position is *C* point on the tooth crest rotate over the boundary of top oil sulcus along clockwise and *D* point on the tooth crest rotate over the boundary of bottom oil sulcus along colockwise.Then *O* chamber and *O′* chamber open to the area of high pressure,and the pressure of *O* chamber and *O′* chamber is P_S. For the transitional area of the top stationary crescent is the area between O_1P and O_1K .The pressure attenuates from the pressure of outlet port P_S to the pressure of inlet port 0 along the arc $\widehat{QJ}$ generally.For the transitional area of the bottom stationary crescent is the area between O_1P and O_1K .The pressure attenuates from the pressure of outlet port P_S to the pressure of inlet port 0 along the arc $\widehat{PK}$ generally. [3]The tooth crest gap is the area between stationary crescent and tooth crest in pressure transitional area .In fact,the gap is litter,it is magnified to be expenssed clearly.The pressure attenuates linearly,so the pressure of the any position in every tooth crest gap is[4]

$$P'=P_S-\frac{\Delta\theta'}{\theta_0}P_S \tag{1}$$

Where, $\Delta\theta'$ is the central angle of from the tooth space to the boundary of high pressure O_1P or O_2Q. θ_0 is the whole central angle of all the tooth crest gap in the pressure transitional area.The central angle of the tooth crest of a internal gear is $\theta''=\frac{\pi}{z_2}+2(\alpha-\tan\alpha+\frac{\sqrt{r_{a2}^2-r_{b2}^2}}{r_{b2}}-\arccos\frac{r_{b2}}{r_{a2}})$. r_{b2} is the base radius of internal gear, r_{a2} is the tip radius of internal gear. z_2 is the number of teeth of internal gear. The central angle of the tooth crest of a external gear is $\theta''=\frac{\pi}{z_2}+2(\alpha-\tan\alpha+\frac{\sqrt{r_{a2}^2-r_{b2}^2}}{r_{b2}}-\arccos\frac{r_{b2}}{r_{a2}})$. r_{b1} is the base radius of external gear, r_{a1} is the tip radius of external gear. z_1 is the number of teeth of external gear[5].

The tooth space is the area between stationary crescent and tooth space.because the internal space is far larger then tooth crest space,so the lose of pressure can be ignored,and the pressure in every tooth space is equal.The pressure in every tooth space is

$$P=P_S-\frac{\Delta\theta}{\theta_0}P_S \tag{2}$$

Where, $\Delta\theta$ is the central angle of from the position to the boundary of high pressure O_1P or O_2Q. The central angle on crest of a tooth space of internal gear is $\theta'=\frac{2\pi}{z_2}-\theta''$.

For the top stationary crescent,the tooth crest gap and tooth space arrange alternately from the boundary O_2Q of high pressure area to boundary O_2J of inlet port .In the process of rotation of internal gear,the polar angle changes,which causes the hydraulic pressure changs on the top and bottom stationary crescent,and the cycle is the time of internal gear rotating a tooth space and a gear.Then the force on the top and bottom stationary crescent is analysed at the 2 situations of internal gear rotating a tooth space and a gear.

Force analysis of stationary crescent

Force of the top stationary crescent in the process of the internal gear rotating a tooth space

As is shown in Fig.3, known from the structure of the gear pump, ϕ_2' is the central angle from the boundary of the top oil sulcus O_2R to the end of the top stationary crescent,and ϕ_2' is the integral times of the central angle on tooth crest. The initial position is *C* point on the tooth crest rotate over the boundary of top oil sulcus *RL* along clockwise，then in the process of internal gear rotae a tooth space ,when angle of the internal gear rotating along clockwise ϕ is less than the central angle on the addendum circle of a tooth space θ',then $0<\phi<\theta'$,the top stationary crescent consisting the pressure transiting zone $\widehat{AB}$ is the central angle between the intersecting point *A*，*B*.The number of the tooth crest gaps in the transisting zone is $n_2=\frac{\phi_2'}{\theta'+\theta''}$,the number of the tooth spaces is n_2-1.

The pressure on the $i\,(1\le i\le n_2-1)$ tooth space obtained by formula (2) is

$$P_i=P_S-\frac{i}{n_2}P_S$$

The component force of *x*, *y* direction on the top stationary crescent resulted by the hydraulic force of the tooth space is

$$F_{x(\phi)1}=-\sum_{i=1}^{n_2-1}\int_{\varepsilon_1'+i(\theta'+\theta'')-\phi}^{\varepsilon_1'+\theta''+i(\theta'+\theta'')-\phi}P_i r_{a2}b\cos\beta d\beta \quad , \quad F_{y(\phi)1}=-\sum_{i=1}^{n_2-1}\int_{\varepsilon_1'+i(\theta'+\theta'')-\phi}^{\varepsilon_1'+\theta''+i(\theta'+\theta'')-\phi}P_i r_{a2}b\sin\beta d\beta$$

Where, β is the polar angle of any point in the solved region ; *b* is the width of the tooth; ε_1' is the polar angle of the boundary of the top oil sulcus; $\varepsilon_1'=\xi_1-\frac{\pi}{2}-\phi_2'$, ξ_1 is obtained by $\frac{r_{a1}}{\sin\xi_1}=\frac{e}{\sin(\frac{\pi}{2}-\xi_1+\varepsilon_1+\phi_1')}$, *e* is the offset O_1O_2 of the internal and external gear, ε_1 is the polar angle of the boundary of the bottom oil sulcus; ϕ_1' is the central angle between the boundary of the bottom oil sulcus O_1S and the face of the bottom stationary crescent O_1K.

Obtained by formula (1), the pressure in the $i\,(1\le i\le n_2)$ tooth crest gap is

$$P_{i(\phi)}'=P_S-\frac{\beta-(\varepsilon_1'+i\theta'-\phi)}{n_2\theta_1''}P_S$$

The component force of x, y direction on the top stationary crescent resulted by the hydraulic force of the tooth crest gap is

$$F_{x(\phi)2} = -\sum_{i=1}^{n_2}\int_{\varepsilon_1'+(i-1)(\theta'+\theta'')+\theta'-\phi}^{\varepsilon_1'+i(\theta'+\theta'')-\phi} P_{i(\phi)}'r_{a2}b\cos\beta d\beta \quad , \quad F_{y(\phi)2} = -\sum_{i=1}^{n_2}\int_{\varepsilon_1'+(i-1)(\theta'+\theta'')+\theta'-\phi}^{\varepsilon_1'+i(\theta'+\theta'')-\phi} P_{i(\phi)}'r_{a2}b\sin\beta d\beta$$

The high pressure area on the surface of the top stationary crescent is the area between the endpoint *H* of the top stationary crescent in the high pressure area and the intersecting point *A*, The component force of x, y direction on the top stationary crescent resulted by it is

$$F_{x(\phi)3} = -\int_{\phi_2}^{\varepsilon_1'+\theta'-\phi} P_s r_{a2}b\cos\beta d\beta \quad , \quad F_{y(\phi)3} = -\int_{\phi_2}^{\varepsilon_1'+\theta'-\phi} P_s r_{a2}b\sin\beta d\beta$$

Where , ϕ_2 is the polar angle of the face *H* of the top stationary crescent in the high pressure area.

As is shown in Fig.3,the high pressure area is the tooth crest gap between the 2 stationary crescents which is inported into high pressure oil. The component force of *x*, *y* direction on the top stationary crescent resulted by it is

$$F_{x4} = \int_{\phi_2}^{\phi_3} P_S(r_{a2}-\delta)b\cos\beta d\beta \quad , \quad F_{y4} = \int_{\phi_2}^{\phi_3} P_S(r_{a2}-\delta)b\sin\beta d\beta$$

The component force of x, y direction on the bottom stationary crescent resulted by it is

$$F_{x5} = -\int_{\phi_2}^{\phi_3} P_S(r_{a2}-\delta-\delta_0)b\cos\beta d\beta \quad , \quad F_{y5} = -\int_{\phi_2}^{\phi_3} P_S(r_{a2}-\delta-\delta_0)b\sin\beta d\beta$$

Where , ϕ_3 is the polar angle of the stick between the 2 stationary crescent.

The high pressure area is area between the endpoint *H* of the top stationary crescent in the high pressure area and the interacting point *G* .The component force of x, y direction on the bottom surface of the bottom stationary crescent resulted by it is

$$F_{x6} = -\int_{\phi_1}^{\phi_2} P_S(r_{a2}-\delta)b\cos\beta d\beta \quad , \quad F_{y6} = -\int_{\phi_1}^{\phi_2} P_S(r_{a2}-\delta)b\sin\beta d\beta$$

In conclusion,the force of *x*, *y* direction of the top stationary crescent in the process of internal gear rotating a tooth space

$$F_{tx} = [F_{x(\phi)1} + F_{x(\phi)2} + F_{x(\phi)3}] + F_{x4} \quad , \quad F_{ty} = [F_{y(\phi)1} + F_{y(\phi)2} + F_{y(\phi)3}] + F_{y4}$$

Similarly, the force of *x*, *y* direction of the top stationary crescent in the process of internal gear rotating a tooh can be obtained.

The force of the bottom stationary crescent in the process of external gear rotating a tooh space

As is shown in Fig.3, known from the structure of the gear pump, the central angle of the bottom stationary crescent in transiting region ϕ_1' is the integral times of the central angle of tooth and tooth space on the addendum circle.The initial position is *D* point on the tooth crest of the external gear rotate over the boundary of bottom oil sulcus *SM* along clockwise，then in the process of external gear rotae a tooth space ,when angle of the external gear rotating along clockwise α is less than the central angle on the addendum circle of a tooth space θ_1',then $0<\alpha<\theta_1'$,the top stationary crescent consisting the pressure transiting zone $\widehat{EF}$ is the central angle between the intersecting point *E*, *F*.The number of the tooth crest gaps in the transisting zone is $n_1 = \frac{\phi_1'}{\theta_1'+\theta_1''}$, α_0' is the sum of central angle of a tooth space and a tooth of the external gear . $\alpha_0'=2\pi/z_1$,the number of the tooth spaces is n_1-1.

The pressure on the $j\,(1 \le j \le n_1 - 1)$ tooth space in the pressure transiting zone is

$$P_j = P_S - \frac{j}{n_1} P_S$$

The component force of *x, y* direction on the bottom stationary crescent resulted by the hydraulic force of tooth space is

$$F_{x(\alpha)7} = \sum_{j=1}^{n_1-1} \int_{\varepsilon_1 + j(\theta_1' + \theta_1'') - \alpha}^{\varepsilon_1 + j(\theta_1' + \theta_1'') + \theta_1' - \alpha} P_j r_{a1} b \cos\beta \, d\beta \quad , \quad F_{y(\alpha)7} = \sum_{j=1}^{n_1-1} \int_{\varepsilon_1 + j(\theta_1' + \theta_1'') - \alpha}^{\varepsilon_1 + j(\theta_1' + \theta_1'') + \theta_1' - \alpha} P_j r_{a1} b \sin\beta \, d\beta$$

The pressure in the $j\,(1 \le j \le n_1)$ tooth crest gap in the pressure transiting zone is

$$P_{j(\alpha)}' = P_S - \frac{\beta - (\varepsilon_1 + j\theta_1'' - \alpha)}{n_1 \theta_1''} P_S$$

The component force of x, y direction on the bottom stationary crescent resulted by the hydraulic force of the tooth crest gap is

$$F_{x(\alpha)8} = \sum_{j=1}^{n_1} \int_{\varepsilon_1 + (j-1)(\theta_1' + \theta_1'') + \theta_1' - \alpha}^{\varepsilon_1 + j(\theta_1' + \theta_1'') - \alpha} P_{j(\alpha)}' r_{a1} b \cos\beta \, d\beta \quad , \quad F_{y(\alpha)8} = \sum_{j=1}^{n_1} \int_{\varepsilon_1 + (j-1)(\theta_1' + \theta_1'') + \theta_1' - \alpha}^{\varepsilon_1 + j(\theta_1' + \theta_1'') - \alpha} P_{j(\alpha)}' r_{a1} b \sin\beta \, d\beta$$

The high pressure area on the bottom surface of the bottom stationary crescent is the area between the interacting point *G* and the intersecting point *E* of the tooth and tooth space of the external, The component force of x, y direction on the bottom stationary crescent resulted by it is

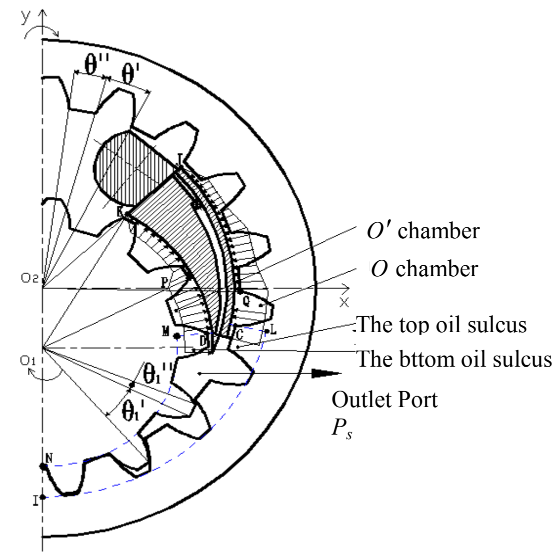
$$F_{x(\alpha)9} = \int_{\theta_1}^{\varepsilon_1 + \theta_1' - \alpha} P_s r_{a1} b \cos\beta \, d\beta \quad , \quad F_{y(\alpha)9} = \int_{\theta_1}^{\varepsilon_1 + \theta_1' - \alpha} P_s r_{a1} b \sin\beta \, d\beta$$

Where , θ_1 is the polar angle of the line of *G* and O_2, $\theta_1 = \frac{\pi}{2} - \xi_2$, $\xi_2 = \arccos \frac{e^2 + r_{a1}^2 - (r_{a2} - \delta)^2}{2 e r_{a1}}$, δ is the thickness of the top stationary crescent.

The force of *x*，*y* direction of the bottom stationary crescent in the process of external gear rotating a tooth space

$$F_{bx} = [F_{x(\phi)7} + F_{x(\phi)8} + F_{x(\phi)9}] + (F_{x5} + F_{x6}) \quad , \quad F_{by} = [F_{y(\phi)7} + F_{y(\phi)8} + F_{y(\phi)9}] + (F_{y5} + F_{y6})$$

Similarly, the force of *x*，*y* direction of the bottom stationary crescent in the process of external gear rotating a tooh can be obtained.



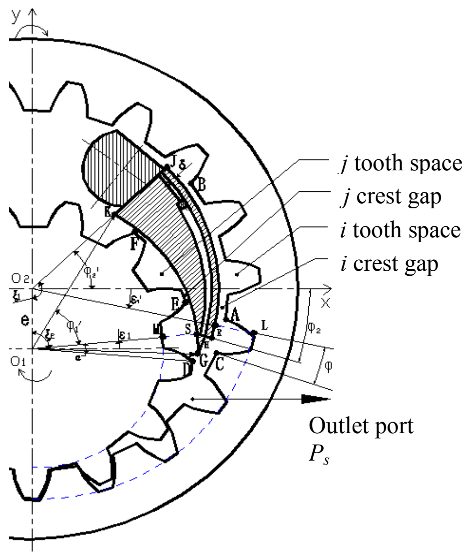


Fig.2. The pressure distribution on stationary crescent   Fig.3. The process of internal and external gear rotate a tooth space

Similarly,the force of the top stationary crescent and the bottom stationary crescent in the process of internal gear and external gear rotating a tooh can be obtained.

Experimental study

Now take the inner mesh gear pump studied by our group for example,the objective function is the least force of the 2 stationary crescents.The designing variables is ϕ_2 and ϕ_3.The constraint conditions of the two stationary crescents stay close to the crest of inner gear and external gear to form radial seal. ϕ_2 and ϕ_3 is obtained by optimization.

A prototype was made according to the computed paramters,which is shown in Fig.4. Experiment results show that the volumetric efficiency is 0.94 when the outlet pressure reach to 30Mpa, and the oil temperature is less than 55° C, there is no abrasion on the two sationary crescents and the tooth crest, as is show in Fig.5.

Fig.4. Inner mesh gear pump

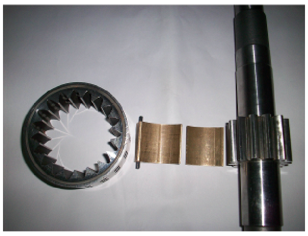


Fig.5. Abrasion of surface

Conclusions

(1) Based on the analysis the working mechanisms of stationary crescent of radial compensation ,the change of the hydraulic force in x, y direction of the top and bottom stationary crescents in a cycle is obtained.
(2) Under the condition of the force of the top and bottom stationary crescent is least and the two stationary crescents stay close to the tooth crest of internal gear and external gear to form radial seal，the angle of the end of the top stationary crescent in the high pressure area and the fixing angle of the seal stick was computered by optimization.
(3) Experiment results show that the volumetric efficiency is 0.94 when the outlet pressure reach to 30Mpa, and the oil temperature is less than 55° C, there is no abrasion on the two sationary crescents and the tooth crest.

Acknowledgements

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