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WORK VOLUME EVALUATION OF ROTARY ROLLER PNEUMATIC MOTORS

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SUMMARY
Analytical expressions applied for rotary roller pneumatic motors are presented in the paper. They refer to cameras' momentum values, the work volume of one camera, and the work volume of whole motor. These expressions can be used for theoretical work, power, rolling momentum and compressed air discharge evaluation at design and technological stage of such motors.

Main problem in dimensioning of rotary roller pneumatic motors (RRPM) is evaluation of work volume of motor and consequently its theoretical work, power and rotating momentum.

Method for RRPM work volume evaluation and more specifically its' cameras in regard of their whirling angle has not been recognized yet. Methods for dimensioning of rotational plate motors (Zeleneckii, Rjapov, Mikerov, 1976; Zinevich, Jarmolenko, Kapita, 1975; Makagon, 1971) are utilised for RRPM, imposing some errors due to neglecting the rollers volume which reduce the volume of camera.

Work volume of RRPM is defined under the following expression (also used for rotational plate motors) (Zinevich, Jarmolenko, Kapita, 1975):

$$V = V_p . z,\ m^3, \qquad (1)$$

where:
V is work volume of motor, m^3;
V_p – work volume of one camera, m^3;
z – work cameras number, equal to number of rollers.

Camera volume is the space enclosed by two neighbor rollers, rotor surface and side disks.

$$V_p = V_{max} - V_{min},\ m^3, \qquad (2)$$

where:
V_{max} is maximal work volume of camera, m^3;
V_{min} – is minimal work volume of camera, m^3.

As figure 1 shows maximal work volume V_{max} is achieved for rotor rotation angle $\varphi = \pi$, while the minimal V_{min} – when $\varphi = 0$.

Camera work volume evaluation is reduced to evaluation of camera cross section area depending on rotor rotation angle φ. This area is hatched zone named as **ampc** on figure 1.

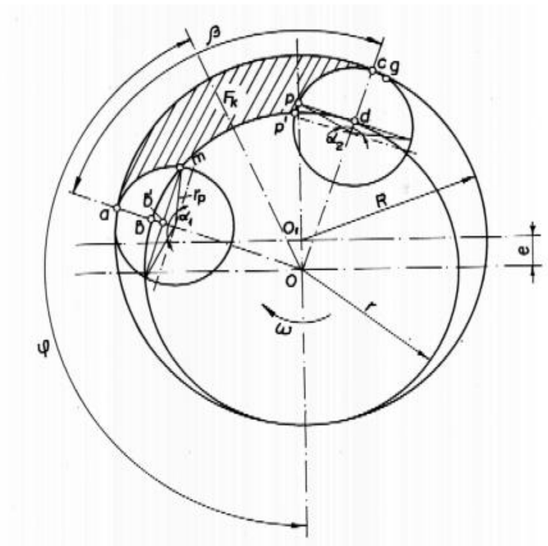

Figure 1. Cross section F_k of work camera

If we assume the following:

- Touch point of cross section of cylinders' circumference g coincides with point c at any moment of rotor rotation;
- This point is cross point of roller circumference and rotor radius extension

momentum value of camera work volume can be written as:

$$V_k = F_k . b,\ m^3, \qquad (3)$$

where:
V_k is momentum value of camera work volume, m^3;
F_k – camera area, equal to cross section of **ampc**, m^2;

b – rotor length (cylinder and roller), m.

Camera area is evaluated under formula (fig. 1)

$$F_k = F_{abdc} - F_{abm} - F_{pdc},\ m^2, \tag{4}$$

where F_{abdc} is camera cross section including rollers' area. It is evaluated under well-known formula for camera cross section of rotation plate motors, neglecting plates width (Zinevich, Jarmolenko, Kapita, 1975).

$$F_{abdc} = \frac{\beta}{2}\left(R^2 - r^2\right) - 2eR\cos\varphi.\sin\frac{\beta}{2} + \frac{e^2}{2}\cos 2\varphi.\sin\beta,\ m^2, \tag{5}$$

where:

β is angle between rollers, rad;
R – cylinder radius, m;
r – rotor radius, m;
e - eccentricity between axes O and O_1 of rotor and cylinder, m.

F_{abm} and F_{pdc} are half of areas of two neighbor rollers, located over the rotor, m^2.

Rollers areas over the rotor are set to be areas of segments of cross sections of rollers. Then camera area should be reduced with bb'm from left segment area and will increase with pp'd, which is not included into the right segment. These areas are almost equal and their influence on camera area can be neglected.

By applying well-known formula for segment area (Bronstein Semendjaev; 1986) F_{abm} and F_{pdc} can be written as:

$$F_{abm} = \frac{r_p^2}{4}\left(\alpha_1 - \sin\alpha_1\right),\ m^2; \quad F_{pdc} = \frac{r_p^2}{4}\left(\alpha_2 - \sin\alpha_2\right),\ m^2; \tag{6}$$

where:

r_p is rollers' radius, m;
α_1 and α_2 – are angles, defining correspondingly left and right segment from both sides of camera, rad.

Angles α_1 and α_2 are divided into halves by segment Oa and Oc, located compared to line crossing the camera at it half correspondingly to angles $-\frac{\beta}{2}$ and $+\frac{\beta}{2}$ (fig. 2). Half of the camera is evaluated by rotor rotation angle φ.

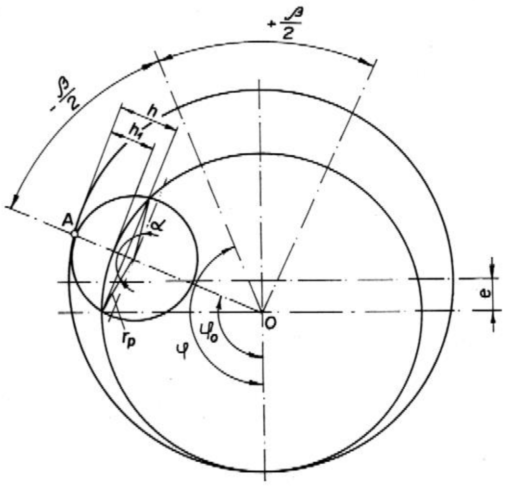

Figure 2. Work camera location in accordance with rotor rotation angle φ

Expressions (5) and (6) are substituted into (4) and camera area is:

$$F_k = \frac{\beta}{2}\left(R^2 - r^2\right) - 2eR\cos\varphi.\sin\frac{\beta}{2} + \frac{e^2}{2}\cos 2\varphi.\sin\beta - \frac{r_p^2}{4}\left[\left(\alpha_1 - \sin\alpha_1\right) + \left(\alpha_2 - \sin\alpha_2\right)\right],\ m^2. \tag{7}$$

In order to estimate changes in area F_k depending on rotation angle φ, angles α_1 and α_2 should be written with this angle.

Evaluation of α in accordance with rotation angle φ (fig. 2), we assumed that difference between height of segment h and height of sticking up part of roller over the rotor h_1 is very little and can be neglected ($h=h_1$).

Changes in height h in accordance with rotation angle together with rotor height is evaluated under the formula (Zinevich, Jarmolenko, Kapita, 1975) (fig. 2)

$$h = e\left(1 - \cos\varphi_0\right),\ m, \tag{8}$$

Where φ_0 is roller rotation angle together with rotor, rad.

Height h, set to be also the segment height, can be evaluated also under the following expression (Bronstein Semendjaev; 1986) (fig. 2)

$$h = r_p\left(1 - \cos\frac{\alpha}{2}\right),\ m. \tag{9}$$

Equalizing right parts of (8) and (9) for α we received:

$$\alpha = 2\arccos\left[1 - \frac{e\left(1 - \cos\varphi_0\right)}{r_p}\right],\ rad. \tag{10}$$

Bearing in mind that segments rollers angles α_1 and α_2 are shifted towards camera half at angel $\frac{\beta}{2}$ and putting that information into expression for φ_0, we can obtain

$$\alpha_1 = 2\arccos\left\{1 - \frac{e\left[1-\cos\left(\varphi+\frac{\beta}{2}\right)\right]}{r_p}\right\}, \text{ rad};$$
$$\alpha_2 = 2\arccos\left\{1 - \frac{e\left[1-\cos\left(\varphi-\frac{\beta}{2}\right)\right]}{r_p}\right\}, \text{ rad}. \quad (11)$$

Camera momentum area is evaluated when angles α_1 and α_2 from (11) are substituted into (7) under taking into account camera (rotor) rotation angle φ.

Areas F_{max} and F_{min} of the camera are obtained under rotation angles correspondingly: $\varphi = \pi$ и $\varphi = 0$. For that figures camera is symmetrically located towards vertical axes of motor and areas F_{abm} and F_{pdc} are equal. For this two cases in formula (7) is assumed that $\alpha_1 = \alpha_2 = \alpha$.

Maximal and minimal camera area is obtained correspondingly:

$$F_{max} = \frac{\beta}{2}\left(R^2 - r^2\right) + 2eR\sin\frac{\beta}{2} + \frac{e^2}{2}\sin\beta - \frac{r_p^2}{4}\left\{2\arccos\left[1 - \frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1 - \frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\}, m^2; \quad (12)$$

$$F_{min} = \frac{\beta}{2}\left(R^2 - r^2\right) - 2eR\sin\frac{\beta}{2} + \frac{e^2}{2}\sin\beta - \frac{r_p^2}{4}\left\{2\arccos\left[1 - \frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1 - \frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\}, m^2. \quad (13)$$

We put the expressions

$$\frac{r_p^2}{4}\left\{2\arccos\left[1 - \frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1 - \frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\} = A;$$

$$\frac{r_p^2}{4}\left\{2\arccos\left[1 - \frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1 - \frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\} = B$$

After setting up the above written expressions into (12) and (13) and their substitution into (2), taking into account camera length b, expression for one camera work volume for RRPM is developed

$$V_p = b.\left[\frac{\beta}{2}\left(R^2 - r^2\right) + 2eR\sin\frac{\beta}{2} + \frac{e^2}{2}\sin\beta - A\right] - b.\left[\frac{\beta}{2}\left(R^2 - r^2\right) - 2eR\sin\frac{\beta}{2} + \frac{e^2}{2}\sin\beta - Б\right], m^3;$$

or

$$V_p = b.\left(4eR\sin\frac{\beta}{2} - A + Б\right), m^3 \quad (14)$$

Motor work volume is evaluated under formula (1) which is substituted into (14)

$$V_{дв} = V_p.z = zb.\left(4eR\sin\frac{\beta}{2} - A + Б\right), m^3. \quad (15)$$

CONCLUSIONS

1. Analytical expression (7) for moment values evaluation of rotational rollers motors camera areas in accordance with rotor rotation angle is worked out.
2. Also formulas for one camera work volume (14) and work volume of whole motor (15) are worked out. Their application in design process can help in evaluation theoretical work, compressed air discharge, power and rotating moment of rotation rollers pneumatic motors.

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