ANALYSIS ON MAIN STRUCTURAL AND TECHNOLOGICAL PARAMETERS OF THE SCREW MECHANISMS, UTILIZED AT WOOD CHIPS PROCESSING

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Abstract

The screw conveyors and screw processing machines for wood chips have wide application in forest and wood-processing industry. Many of the machines are assembled with screw mechanisms to perform the main operations. The utilization of these mechanisms is due to some advantages they ensure at executing the technological processes, as for example unceasing of the process, high productivity, low levels of noise, dustless work, etc. The design of screw mechanisms is in accordance with the determination of their main structural and technological parameters. Big part of the elaborated constructions is realized on the base of the practical experience. The relatively complicated transportation of products into the screw mechanisms makes difficult to express the process by mathematical means. This fact defines the problems with deducing of analytical relationships for determination of the main parameters of these mechanisms. In the present work some basic parameters of screw mechanisms used for transportation and wood chips density compression are deduced and proposed.

Key words: *wood chips, screw mechanisms, pressure, parameters, productivity*

INTRODUCTION

The screw mechanisms have wide application in construction of different machines and devices used for transporting and technological operations. There is big variety of these machines in relation to their function, as for example conveyor-screws, mixing and pressing machines, feeding devices, dewinging apparatuses, etc. This fact supposes some differences in the construction of screw mechanisms but they all have one common principle scheme including leading screw, cylinder, inlet and outlet devices.

In forest and wood-processing industry the screw mechanisms are used in machines and equipments for transporting of mineral and organic loose materials, technological chips, sawdust, etc. They are also utilized in some machines for technological processing of wood chips and materials, forest reproductive materials, etc. The main advantage of screw mechanisms is their comparatively simple construction and low prime cost, high productivity and reliability, low levels of noise and dustless work.

In fact, during the logging and wood-processing significant quantity of waste wood that can be used as source of energy, is liberated. The use of wood or other waste product of plant origin for production of briquettes is part of the world's ecological policy for better utilization of biomass as renewable energy source. In the installations for briquettes manufacturing pistons and screws presses are used for the process of wood chips pressing. The main advantage of screws presses is unceasing process, higher productivity and quality of the final product at comparatively low operational exploitation costs [2].

Presently, there is number of companies producing and trading with machines for transportation and compression of wood chips. The technical parameters of screw mechanisms build in these machines directly influence on their technical and exploitation characteristics. In the present work analytical relationships for determination of some basic parameters of screw mechanisms used in the machines are deduced and proposed.

THEORETICAL DEPENDENCES FOR DETERMINING SOME MAIN PARAMETERS OF THE SCREW MECHANISMS

Main geometric parameters of the screw are its outer diameter (*D*) and pitch (*S*). The outer diameter is considered as starting parameter at performing the calculations. When the diameter is not preliminary defined, it can be tentatively determined according to the desired productivity *W* of the machine, by the empirical dependence [6]

$$D = \sqrt[2,5]{W/0,68} \quad (1)$$

The screw pitch influences significantly productivity of the process. In the zone of filling site the pitch depends mainly on the coefficient of friction of the material against the screw's surface and cylinder's sides. For transporting of loose materials it is recommended to be in the limits of S=(1,8÷2,2)D and for screw presses S=(0,8÷1,2)D.

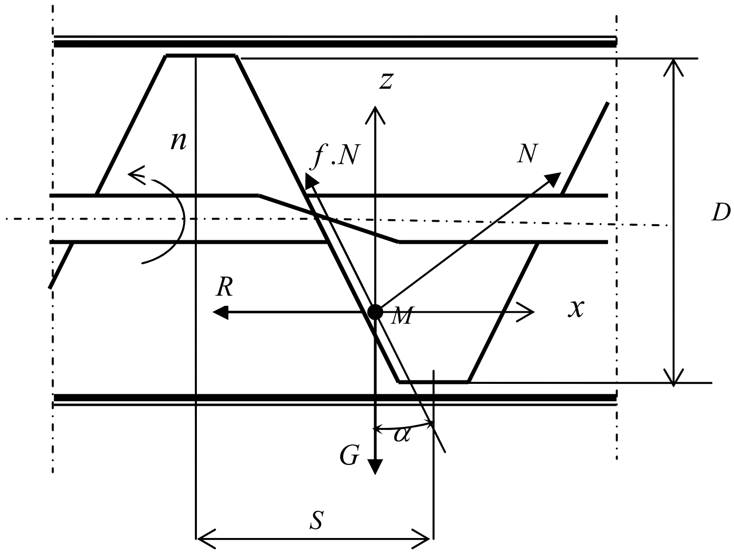

Fig. 1 Scheme of main parameters of the screw and forces, operating on particles

The description of loose materials transportation process with the help of analytical dependences is relatively complicated due to the sophisticated character of the process itself 1, 5, 7]. This investigation uses preliminary elaborated physical model for description of the movement of material particles along the helical line in the conditions of outlet caused resistance. At figure 1 some basic parameters of the screw and the forces operating on the separate particle are presented.

The speed of screw's revolution n is one of main technological parameters influencing on productivity of the process. By increasing the speed revolution bigger productivity is achieved. This acceleration reaches up to its maximum at so called "critical revolutions", when the particles of the product slow down and stop their movement in axial direction. This causes decrease of process productivity up to its physical ceasing. On the base of theoretical calculations [4] for determination of the critical speed revolution n_{KR} the following analytical dependence is proposed:

$$n_{KR} = \frac{30}{\sqrt{r}}\sqrt{1+\frac{1+R/G\, tg(\alpha+\varphi)}{\mu}} \quad min^{-1} \tag{2}$$

where G is the force of gravity, N;
R – resistance force of pressure, N;
α – helical line angle;
r – outer screw's radius ($r=D/2$), m;
φ – friction angle of the particle against the screw's surface;
μ –coefficient of friction of the particle against the cylinder's surface.

Critical revolutions decrease with the increase of screw's diameter and of the coefficient of friction. At determining the critical revolutions, in contrast to popular dependences described in technical literature, the force of R is introduced in the above formula (2). Increase of the resistance force in this case has positive effect and leads to acceleration of the critical values. By this force the normal pressure caused by mounting of additional loading devices at the outlet or so called "prop effect" of the outlet is taken into consideration. The prop effect on the mechanisms is characteristic especially for the screw presses. It is due to the increasing pressure on the particles as result of the material's compression in the process of screw's movement. In this case R force determines by the normal pressure p_n of the press and is calculated by the formula:

$$R = \pi . p_n \left(D^2 - d^2\right)/4 \tag{3}$$

where d is the outer diameter of the screw.

For determination of the critical screw's radius at given speed of revolution n, after performing the necessary replacements and calculations, the following equation is proposed:

$$r_{KR} = \frac{900A - C.n^2 + \sqrt{\left(C.n^2 - 900A\right)^2 + 3600\mu.B.n^2}}{2\mu.n^2} \tag{4}$$

where A, B and C are the functional parameters of the equation and are defined with the following dependences:

$$A = f\frac{R}{G} + \mu + 1, \quad B = \frac{H}{2\pi}\left(\frac{R}{G} - f + \mu.f\right), \quad C = \mu.f\,\frac{H}{2\pi}.$$

The productivity of screw machines is determined by the geometric dimensions of screw and axial speed of particles movement. This speed is function of the revolution speed, the angle parameter of movement β and the coefficient of friction. The main speed v_{oc} can be expressed with the plan of speed vectors (Figure 2). It is shifted towards the circle speed v_o under a certain angle β. This angle is function of the revolution speed, the radius at which the separate particle is positioned, the turning axis and the resistance force R.

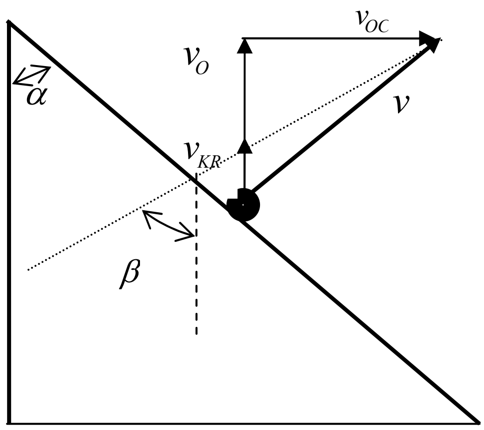

Fig. 2 Scheme of speed vectors plan

v – absolute speed
v_o – circle speed
v_{KR} – critical speed
v_{oc} – axial speed
β – angular parameter of movement

The axial speed can be presented as projection of the geometrical sum of v_o and v_{KR}, as $v_{oc} = (v_0 - v_{KR}).tg\beta$. For determination of the angular parameter of movement β, after performing the necessary calculations, the following functional dependence is drawn:

$$tg\beta = \frac{\omega\sqrt{\frac{r}{g}} - \sqrt{1 + \frac{R/G.\sin(\alpha+\varphi) + \cos(\alpha+\varphi)}{\mu.\cos(\alpha+\beta+\varphi)}}}{\sqrt{1 + \frac{R/G.\sin(\alpha+\varphi) - \cos(\alpha+\varphi)}{\mu.\cos(\alpha+\beta+\varphi)}} - \sqrt{1 + \frac{1 + R/G.tg(\alpha+\varphi)}{\mu}}}\,tg\alpha \qquad (5)$$

The solution of equation (5) is done by the method of consecutive approximations. In order this equation to give decision and parameter to be real, the angle β should be defined in the limits of

$$0 < \beta < 90^0 - (\alpha + \varphi).$$

From the deduced dependence (5) for determination of the angular parameter β the following conclusions can be made:

- parameter β increases with the acceleration of the screw's angular speed
- parameter β decreases with the increase of the resistance force R.

The average axial speed of a stream of material particles can be determined through the established dependence [1] from the following equation:

$$v_{cp} = \frac{\int_0^{2\pi}\int_{r_1}^{r_2} v_{oc}.rdr.d\theta}{\int_0^{2\pi}\int_{r_1}^{r_2} rdr.d\theta}$$

where r is the radius, at which the particle is positioned towards the turning axis, *m*;
r_1 and r_2 are respectively the inner and the outer radiuses of the screw, *m*;
θ is the angle of screw's turning, varying from *0* to 2π;
v_{oc} is the sped of particle in direction of screw's axis, *m/s*.

After performing the necessary mathematical transformations, for determination of the average speed v_{av} the following equation is drawn:

$$v_{av} = \frac{\int_0^{2\pi}\int_{r_1}^{r_2}\left[\omega.r - \sqrt{\frac{g.r}{\mu}.\frac{R/G.\sin(\alpha+\varphi)+\cos(\alpha+\varphi)}{\cos(\alpha+\beta+\varphi)}}\right]tg\alpha.rdr.d\theta}{\int_0^{2\pi}\int_{r_1}^{r_2} rdr.d\theta} \qquad (6)$$

Due to a certain extent of complexity of the obtained equation (6) special program for its calculation is required. To determine the average axial speed of movement v_{av} with practically appropriate accuracy, the following simplified dependence is suggested:

$$v_{av} = \frac{S}{2\pi}\left[\frac{\pi.n}{30} - \sqrt{\frac{g}{\mu.r_{av}}.\frac{R/G.\sin(\alpha_{av}+\varphi)+\cos(\alpha_{av}+\varphi)}{\cos(\alpha_{av}+\beta_{av}-\varphi)}}\right] \quad m/s \qquad (7)$$

where $r_{av} = \frac{D+d}{2}$ is the average conventional radius of screw, *m*;

$\alpha_{av} = arctg\frac{S}{2\pi.r_{av}}$ – average angle of screw's helical line;

β_{av} – angular parameter of movement, determined by the average angle of the helical line a_{av};

n – speed of revolution of the screw, s^{-1}.

The average axial speed at wood chips stream movement along the helical area is used for determination of the productivity. To calculate productivity of one-thread screw machines working with wood chips, the following analytical dependence is proposed:

$$W_h = 3600.\pi\left(\frac{D^2-d^2}{4}\right).S.\rho\left[n - \frac{1}{2\pi}\sqrt{\frac{g}{\mu.r_{av}}.\frac{R/G.\sin(\alpha_{av}+\varphi)+\cos(\alpha_{av}+\varphi)}{\cos(\alpha_{av}+\beta_{av}+\varphi)}}\right] \quad kg/h \qquad (8)$$

where ρ is the wood chips density, kg/m^3;

The work speed revolutions of the screws vary in the boundaries of $n_N = (0,3 \div 0,8) n_{KR}$. The lower values are applied for screws with smaller diameter and the higher ones – for screws with bigger diameter.

In contrast to the existing dependences for determination of productivity of screw machines for transporting of wood particles, in the proposed here formula (7) the influence of prop effect at the side of outlet is also reflected. By increasing the value of this influence, the normal pressure increases and consequently the R force increases too. This leads to decrease of productivity.

CONCLUSIONS

1. Theoretical dependences for determination of some basic parameters at wood particles movement along the helical area of screw mechanisms are proposed. These relationships are used in determination of the dynamic and exploitation indexes of transportation and briquetting machines.
2. On the base of performed theoretical investigation on screw mechanisms used for transportation and processing of wood particles analytical dependences are deduced and proposed for determination of:
   - axial speed of wood particles movement;
   - angular parameter of movement;
   - average transport speed of the total wood particles stream;
   - productivity of conveyor-screws and screw presses for briquettes and technological processing of wood particles.
3. The obtained results can be applied to other similar machines that use screw mechanisms and work in conditions of axial pressure for transportation of disperse materials as conveyor-screw, mixing and press machines, etc.

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