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THEORY OF VERTICAL AUGER

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ABSTRACT
Vertical auger transportation of loose and pulverulent materials is an integral part of many technological processes in various industries and agriculture. The vertical screw conveyors are used in a wide range of various industries and along with such advantages as simple structure, continuity of transportation, integrity, the ability to transport dusty and pungent goods, have a significant drawback - material other than the translational motion in the direction of the axis of the pipeline performs rotational movement in the circumferential direction of the screw speed, which reduces productivity and increases the energy consumption of the conveyor. An adequate mathematical description of this process should allow designers to improve the efficiency of the vertical screw conveyors greatly by calculation and selection of the optimal values of the geometric, kinematic and dynamic parameters of working parts.

Keywords: screw conveyor, bulk materials, auger, pitch, particle, screw blade, tube.

INTRODUCTION
Generally, conveying is accomplished by a combination of mechanical, inertial, pneumatic, and gravity forces. Conveyors utilizing primarily mechanical forces are screw, belt, and mass conveyors [1]. Screw conveyors are widely used for transporting and/or elevating particulates at controlled and steady rates. They are used in many bulk materials applications in industries ranging from industrial minerals, agriculture (grains), pharmaceuticals, chemicals, pigments, plastics, cement, sand, salt and food processing. They are also used for metering (measuring the flow rate) from storage bins and adding small controlled amounts of trace materials (dosing) such as pigments to granular materials or powders. If not designed properly for the transported material, problems experienced include: surging and unsteady flow rates, inaccurate metering and dosing, inhomogeneity of the product, product degradation, excessive power draw, high start-up torques, high equipment wear and variable residence time and segregation [2]. In various industries different types of screw conveyors are used: horizontal; vertical; in the form of combinations of the horizontal and vertical; sloping and a combination of inclined and other pipelines [3].

RESULTS AND DISCUSSIONS

Application of screw conveyors in various industries
Screw conveyors are used for the uniform and continuous supply of various materials in manufacturing machinery and transport devices in many industries [3].

In machine building screw conveyors are used in automatic lines of production of bolts for transporting workpieces on subsequent machines and lines for conveying shavings from metalworking machines [3]. At the same time automatic lathes are placed on lines with a general workshop transport highway with screws mounted in the trench under the floor. The fill factor of screw cavity of the feeders is low and transported good performs translational motion along the axis of the screw. The screw conveyers are effective for crushed shavings and for shavings with a shape of spirals if at the outlet end is no support. The outlet clogging, random ingress of foreign bodies, damage to the screw and the failure of the auger drive is possible if there is any support.

In the building materials industry screws are used for transporting and mixing the components in a plant for the manufacture of dry plaster sheets [3]. Solid and broken screws are used in the camp for the manufacture of concrete products by rolling [4]. In vibro-mixing plants there are screws for feeding and dosing career and fine ground sand. Pneumatic mechanical unloader, applied in the universal scheme of unloading cement from wagons, comprises a horizontal auger. In cement plants for the production of cement clinker screw conveyors are widespread [4] that are used for supplying the raw flour on the scales for supplying material to pelleting and conveying pulverized coal to the ignitor. The screw is used for transportation and pressing the asbestos mixture into an extruder - the main machine in the manufacture of asbestos products [3]. Submission wet and powder materials screw difficult to make due to their adhesion to the auger. Under the influence of the torque transmitted of the screw, the material performs rotational movement around the axis of the screw, which reduces the productivity of the machines with screw working bodies and increases energy expenditure.

Screws are used in technological complexes for the preparation of concrete and mortar on the concrete mortar plants as transmission and distribution mechanisms. The screw is part of the machine for the continuous preparation of lime milk and also provides transportation and mixing of the material. In concrete pavers that are used in the production of concrete pipes, augers are used to supply the concrete mixture into the mold [4].

The main machine in production line clay brick is a screw belt press, the main working part is a screw shaft [5]. Press consists of a receiving box, which is used to feed the press with clay mass and feed roller that provides a secure grip on the mass by turns of screw shaft. The press body is mounted to the receiving box with bolts, where the shaft with auger blade is. Clay mass, gripped with the blade of the screw, as it rotates, moves toward the press element shape: conical head and mouthpiece. Excess pressure at the outlet of the screw (1 - 1.5 MPa) necessary for forming clay timber leads to the fact that the clay mass being transported to the pressing body moves along a spiral with a significant deviation from the axis of the screw. The angle between the axis of the conveyor and the direction of movement of the material is 75 - 80 ° C [3].

Karaganda Polytechnic Institute in cooperation with the combine "Karagandashahtostroy" designed produced and implemented a mobile machine for construction of monolithic concrete lining horizontal mine workings mixing auger conveyor-working body. [6] Cement and aggregate from dispensers come in mixing-transporting working body and mixed screw, moving up the tube to the output trays. Mixing the dry ingredients produced until mid mixing-conveying device (dry mixing zone).The screws are used in production processes of continuous process of superphosphate and, potassium chloride for transportation sylvite and mixing it with a solution.

In the chemical industry complex machines with screw working bodies is an integral part of the installation for the calcination with returnym powered of soda furnaces. In a plant for the production of heavy soda moistened soda in a mixer converted to coarsely wet monohydrate, which screw is directed into the barrel of the soda furnace.

About using screws in the food industry is illustrated by the complex mechanization of technological processes and operations on oil producing plants. Besides screw mechanisms are functional units of basic technological equipment (press, rasparochnoy machine, evaporator) are set screws in the composition of 28 devices [7]. The screws are widely used in Dough preparatory units. Flour is supplied by a screw from the bunker to the mixer. Special screw moves the leaven from the bunker to the collector, and from it screw conveyor transports raw materials to the mixer. In the production of sugar powder auger transports the sugar into the hammer microgrinder. Screw working bodies are used in machines for roasting tea leaves and machines for twisting coarse tea leaves. Feeding and dosing by screw is carried out in three revolving Packaging and packing machines for small-sized food concentrates in molding and wrapping machine for compressed yeast. Chopper is widely used in the meat processing industry, also incorporates a screw assembly serving meat from the hopper to the movable and fixed knives. The movable knife is fixe to the outlet end of a screw shaft and fixed knife (knife-mesh) attached to the body shredder.

Area of use of the screws is very extensive. The conditions of their work are varied and determined by the physical and mechanical properties of transported materials regulations and requirements processes. In the most unfavorable conditions are steeply inclined and vertical screw conveyors and screw feeders, feeding wet, plastic and powder-like materials under pressure forming, grinding and transporting devices.

The device working principle and the basic parameters of screw conveyors.

The screw conveyor consists of a shaft that carries helicoids flightings on its outer surface. These flightings are enclosed either in a trough for horizontal augers or in a tube for elevating augers. The tube or the trough is held stationary while the rotation of the flightings causes the material to move longitudinally. Figure-1 shows the essential components of a screw conveyor. At the inlet side, the auger flightings extend beyond the tube. Generally, a hopper is provided to hold the material while it is conveyed into the tube. Augers can be permanently installed in a machine, or at a site, or they can be portable. The augers are driven either at the intake side or the discharge side.

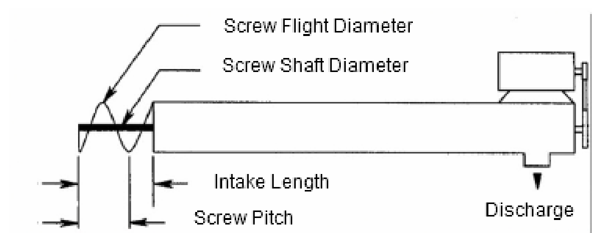

Figure-1. A schematic diagram of a screw conveyor.

The auger length is defined as the length of the tube assembly including any intake but not including the intake hopper and/or the head drive. The intake length is the visible flighting at the intake of the auger. The intake shall be guarded or otherwise designed to provide a deterrent from accidental contact with the rotating flighting. The outside diameter of the tube is referred to as the auger size. A standard pitch auger is the one whose pitch is approximately equal to the outside diameter of the helicoidal flighting. Generally, the pitch is not less than 0.9 and not more than 1.5 times the outside diameter. Standard pitch augers are used for horizontal and up to 20° inclination angles. For inclination angles greater than 20°, half - standard pitch screws are used. Double - and triple - flight, variable - pitch, and stepped - diameter screws are available for moving difficult materials and controlling feed rates [8, 9].

Screw conveyors are very effective conveying devices for free flowing or relatively free flowing bulk solids, giving good throughput control and providing environmentally clean solutions to process handling problems because of their simple structure, high efficiency, low cost and maintenance requirement. Screw conveyors vary in size from 75 to 400 mm in diameter and from less than 1 m to more than 30 m in length (Athanasiov *et al*., 2006). The performance of a screw conveyor, as characterized by its capacity, volumetric efficiency, and power requirements, is affected by the conveyor geometry and size, the properties of the material being conveyed, and the conveyor operating parameters such as the screw rotational speed, screw clearance and conveying angle (Srivastava *et al*., 2006) [10].

Application of engineering principles for reducing energy requirement in the form of mechanical and electrical power is necessary to reduce cost of production. Factors affecting capacity include auger dimensions (diameter, auger geometry), shear-plane flighting orientation, auger speed, angle of inclination, commodity being conveyed, and entrance-opening configuration. For economical installation and dependable performance, the capacity and power requirement of each component of a system must be accurately predicted [10].

Disadvantages of screw conveyors and work on their improvement. The variety of designs of screw conveyors, as well as their basic geometric and kinematic parameters due to a wide range of transported materials with different mechanical properties. Range of materials is so wide that the mechanics and kinematics of movement of various materials in contact with the working bodies of conveyors, can be described by different theories and laws.

The specific power requirement of the screw conveyor increased with increasing the screw clearance and screw rotational speed. The net power requirement of the conveyor increased with increasing the screw rotational speed; whilst the value decreased with increasing the screw clearance. As the rotational speed of the screw conveyor increased, the actual volumetric capacity increased up to a maximum value and further increases in speed caused a decrease in capacity. With increasing the screw clearance and screw rotational speed, the volumetric efficiency of the screw conveyor decreased [10-12].

The disadvantages of screw conveyors are associated with the process moving high specific energy consumption, significant abrasion and crushing load, increased wear of the screw. The main disadvantage is the communication of screw shaft transported material not only translational movement but also rotational, which leads to material from turning together with the screw, and thus to reduced performance of the conveyor [7]. This is largely due to the fact that currently creating vertical screw conveyors realized by designing procedures that are based on the mathematical description of the motion of the particle material, based on helical blade and pressed against the inner wall of the conveyer.

In this context there is the problem arises of increasing the efficiency of vertical screw conveyors by calculation and selection of the optimal values of the geometric, kinematic and dynamic parameters of working bodies. The solution to this problem is possible only on the basis of an adequate mathematical description of the process flow of the material, taking into account the influence of the characteristics of goods transported and the parameters of working bodies of the conveyor to the cross-sectional shape of the material flow rate and issuing material.

At the present time the most of investigations are based on the estimated scheme which substitutes the flow conveying with the conveying of a particle leaning against the screw blade and pushed to the tube. The particle's moving for an upright screw conveyer in stationary condition can be described by following differential equations:

$$\left.\begin{aligned} &N_s\cos\alpha_R - f_sN_s\sin\alpha_R - f_tN_t\cos\beta - mg = 0;\\ &f_tN_t\sin\beta - f_sN_s\cos\alpha_R - N_s\sin\alpha_R = 0;\\ &-N_s + mR\omega_0^2\left[\frac{\sin\alpha_R\sin\beta}{\cos(\beta-\alpha_R)}\right]^2 = 0;\end{aligned}\right\} \quad (1)$$

where f_s = friction coefficient of material against the screw blade;

f_t = friction coefficient against the tube;

m = mass of the material particle;

N_s = normal reaction of the screw blade;

N_t = normal reaction of the tube;

R = screw blade radius;

$\alpha_R = arctg\frac{t}{2\pi R}$ = the helix angle on outer radius;

$t = 2\pi Rtg\alpha_R$ = lead of the screw;

β = the angle contained by absolute velocity vector v of the material particle and the screw axis;

ω_0 = screw angular velocity;

$g = 9{,}81м/c^2$ = free fall acceleration.

The equation for determination of angle β :

$$\frac{R\omega_0^2 f_t}{g}\left[\frac{\sin\alpha_R\sin\beta}{\cos(\beta-\alpha_R)}\right]^2 - $$

$$-\frac{f_s + tg\alpha_R}{\sin\beta(1-f_stg\alpha_R)-\cos\beta(f_s+tg\alpha_R)} = 0 \cdot \quad (2)$$

Analysis of amount results of handling process taken from solution of the relation (2) with using a

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computer shows that functioning efficiency of upright screw conveyers is considerably influenced by geometrical and kinematical parameters of the conveyer tools (the radius and the helix angle of the screw blade and rotational speed of the shaft). Indeed, material flow moving will be simulate with a particle moving, but the amount will be differ (2).

The equilibrium of material volume element engaging sector of a blade with the central angle $d\varphi$ is plotted in Figure-2. In order to proceed from particle moving it's necessary to ascertain flow cross section shape. If consider moving granular material flow as moving liquid flow, as the pressure is the free surface, the flow free surface equation is the following:

$$z = z_0 + \frac{\omega^2 x^2}{2g} \text{ or } z = ax^2 + b, \qquad (3)$$

where ω = material angular velocity.

To determinate coordinates for the intersection point of the flow free surface and the screw blade r it's necessary to study particle equilibrium at this point. Suppose, the particle is on flow free surface, leans against the screw blade at the distance r from the axis, pushed to material flow and gyrating by concentric rotational speed ω_0.

There are equations of particle moving:

$$\left.\begin{aligned} &N_s \cos\alpha_r + f_s N_s \sin\alpha_r + f_t N_t \sin\alpha_r - mg = 0; \\ &f_m N_m \cos\alpha_r + f_s N_s \cos\alpha_r - N_s \sin\alpha_r = 0; \\ &-N_m + mr\omega_0^2 = 0, \end{aligned}\right\}$$

where f_m = internal friction coefficient of the material;

N_m = normal reaction of flowing material;

$\alpha_r = arctg(\frac{R}{r} tg\alpha_R)$ - the helix angle at the distance r from the axis.

Solving this set of equations and relation (3) simultaneously yields the following relation for coordinate of the intersection point of flow free surface and the screw blade:

$$f_m \omega_0^2 r^2 - f_s (f_m R \omega_0^2 tg\alpha_R + g) r - gRtg\alpha_R = 0 \qquad (4)$$

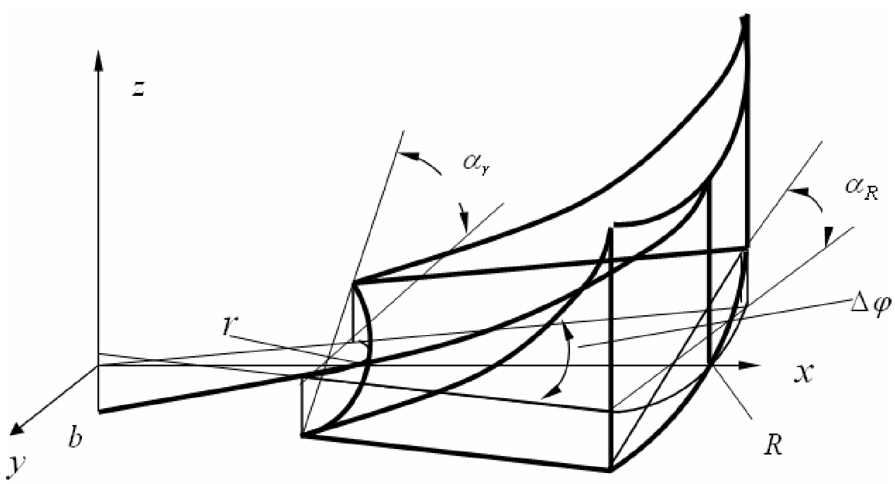

Figure-3. The equilibrium of material volume engaging sector of a blade.

As the helix angle changes from the axis to periphery, in order to describe material flow moving it's necessary to substitute in relation (1):

$$N_s \sin\alpha_\rho = P_s S_v; N_s \cos\alpha_\rho = P_s S_h. \qquad (5)$$

Taking into account (5) the set of equations (1) yields:

$$\left.\begin{aligned} &P_s S_h - f_s P_s S_v - f_t P_t S_t \cos\beta - \gamma V = 0; \\ &f_t P_t S_t \sin\beta - f_s P_s S_h - P_s S_v = 0; \\ &-P_t S_t + \frac{\gamma}{g} V \rho_c \omega_0^2 \left(\frac{\sin\alpha_R \sin\beta}{\cos(\beta - \alpha_R)} \right)^2 = 0, \end{aligned}\right\} \qquad (6)$$

where P_s - pressure of the material volume engaging sector of the blade with the central angle $d\varphi$ on the screw blade;

P_t - pressure which the material volume brings to the tube;

S_c - contact area of the material volume element and the tube inside;

S_h - horizontal projection of the sector of the blade with the central angle;

S_v - vertical projection of the sector of the blade with the central angle $d\varphi$;

V - material volume engaging the sector of the blade $d\varphi$;

ρ_c - the distance from the screw axis to the material volume element centre of mass;

γ - bulk weight of the material.

Horizontal projection area of the sector of the blade $d\varphi$ between the limits r and R (Figure-3)

$$S_h = \int_r^R x\Delta\varphi dx = \frac{R^2 - r^2}{2}\Delta\varphi . \tag{7}$$

Vertical projection area of the sector of the blade $d\varphi$:

$$S_v = \int_r^R xtg\alpha_x \Delta\varphi dx .$$

As $xtg\alpha_x = t = const$, so that

$$S_v = \int_r^R t\Delta\varphi dx = t(R-r)\Delta\varphi = R(R-r)tg\alpha_R \Delta\varphi \cdot \tag{8}$$

Material volume engaging the sector of the blade $d\varphi$ (Figure-2) is equal to material volume which is a part of body of revolution formed by plane xOy, cylinder surface formed by rotation (around axis z) of vertical elements passing through points of plane xOy of plot $y^2 + x^2 = R^2$ and curve surface formed as plot $z = f(x)$ or $z = a(x^2 + y^2) + b$ rotates around axis z. The equation for the material volume can be determined by relation (3)

$$V = \iint_S f(\rho) d\rho d\theta = \int_0^{\Delta\varphi} d\theta \int_r^R f(\rho)\rho d\rho = \left[(R^2 + r^2)a + 2b\right]\frac{R^2 - r^2}{4}\Delta\varphi , \tag{9}$$

where $\rho = \sqrt{x^2 + y^2}$, $x = \rho\cos\theta$, $y = \rho\sin\theta$.

Coordinate for the centre of mass of material element, taking into account (9), can be determined by relation:

$$\rho_c = \frac{\int_V xdv}{V} = \frac{\int_0^{\Delta\varphi}\int_r^R f(\rho)\rho^2 \cos\theta d\rho d\theta}{\int_0^{\Delta\varphi}\int_r^R f(\rho)\rho d\rho d\theta} = \frac{\sin\Delta\varphi \int_r^R (a\rho^2 + b)\rho^2 d\rho}{\Delta\varphi \int_r^R (a\rho^2 + b)\rho d\rho},$$

$\Delta\varphi$ is infinitesimal so that $\frac{\sin\Delta\varphi}{\Delta\varphi} \approx 1$, so that after integrating

$$\rho_c = \frac{\frac{a}{5}\left(R^5 - r^5\right) + \frac{b}{3}\left(R^3 - r^3\right)}{\frac{R^2 - r^2}{4}\left[a\left(R^2 + r^2\right) + 2b\right]} . \tag{10}$$

Introducing relations (7-10) in set of equations (6) yields the following relation for angle beta

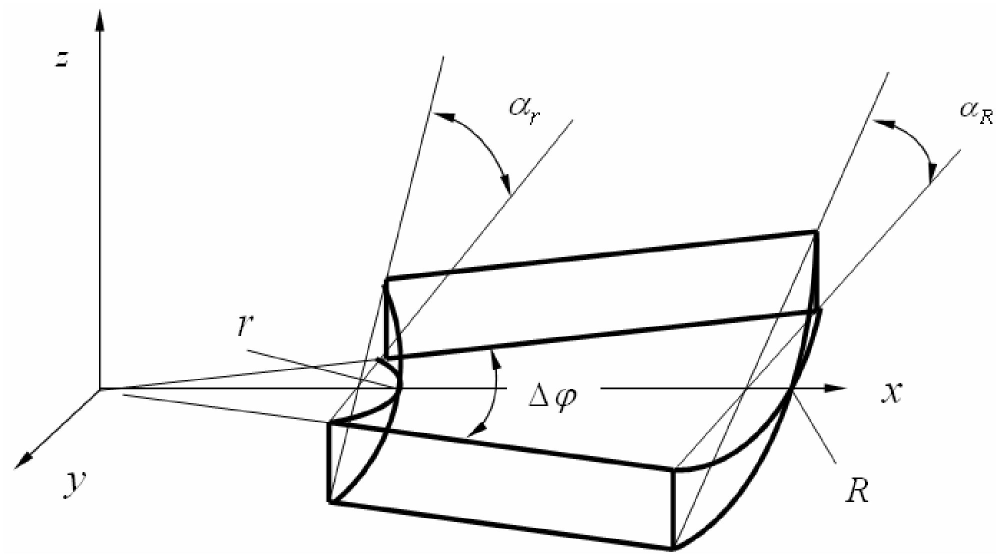

Figure-4. The sector of the blade and its horizontal and vertical projections.

$$\frac{f_t \rho_c \omega_0^2}{g}\left[\frac{\sin\alpha_R \sin\beta}{\cos(\beta-\alpha_R)}\right]^2 - \frac{f_s S_h + S_v}{(S_h - f_s S_v)\sin\beta - (S_v + f_s S_h)\cos\beta} = 0 . \quad (11)$$

Figure-3 plots the variation of angle beta for α_R particle and for material flow in an upright screw conveyer vs. helix angle for different angle velocities of the screw, taken from the relation (2) and (11). Material friction coefficients against the screw and cylinder are $f_t = f_s = 0{,}5$. The radius of the blade $R = 0{,}5m$.

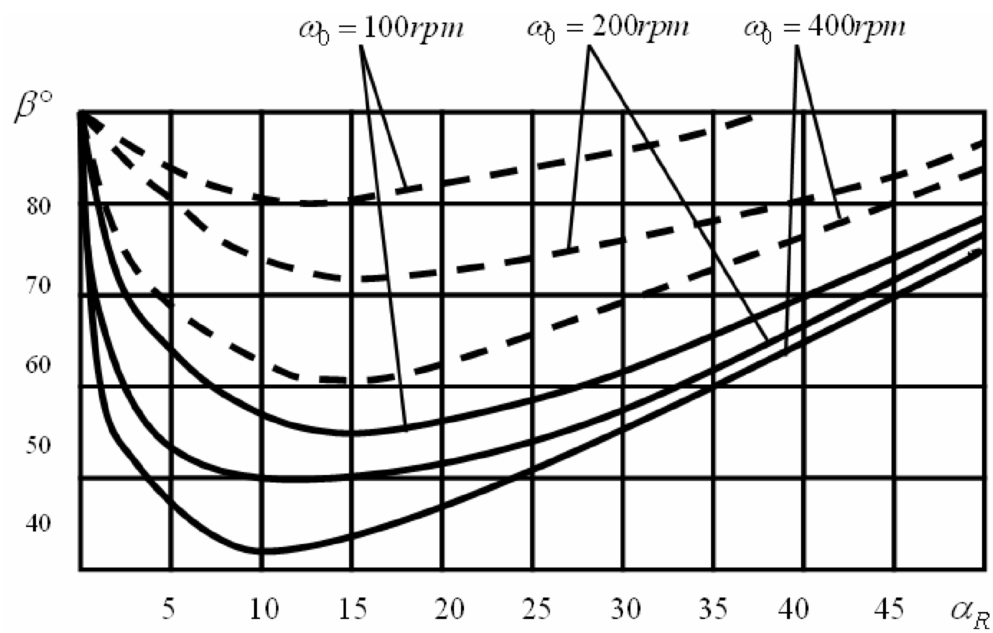

Figure-5. The variation of angle beta for a particle and for material flow in an upright screw conveyer vs. helix angle for different angle velocities. of the screw: __________ - a particle, ------------- - material flow

As the graph shows every curve has its own extremum. It means that there is some rational value for helix angle in some rational value for helix angle in every case when absolute velocity vector V deviation from the axis will be the least.

Therefore, the value of angle beta for a particle and for material flow are considerably different.

CONCLUSIONS

Establishment of laws transported material flow in a vertical screw conveyor is of practical importance, since it allows for the design of screw conveyors more reasonably choose their design and operating parameters, creating preconditions for the production of high performance conveying machines.

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