TECHNOLOGY, CREATIVITY, IMPLEMENTATION

THEORETICAL BASIS OF THE DEVELOPMENT OF EFFECTIVE PARAMETERS OF A COMBINED CONVEYOR TRANSPORT FOR MOVING WASTE MECHANICAL PROCESSING

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Summary

The paper presents the results of technical and economic, theoretical and experimental research on the transportation of chips from the cutting zone of the machine by widely used classic types of conveyor transport and combined conveyor (hydraulic and screw). The analysis of research results showed that in domestic and foreign engineering, which uses integrated installations for the transportation of chips and sludge from the cutting area of the machine, have a number of serious shortcomings and do not allow to effectively carry out these processes. Based on the design shortcomings of the existing modifications of shop transport for moving chips and sludge, a new design of the combined (hydrowashing and screw) conveyor is proposed, which has a number of advantages, simplicity and reliability in working with the requirements for this type of transport. The description of the offered design of the combined conveyor is given. The method of calculation of these installations is stated, results of experimental researches, the analysis of the received results are resulted. According to the research results, schemes and sketches of the combined conveyor have been developed. The results of the work can be widely used in mechanical shops in the design and operation of systems for transporting chips from the cutting area of the machine to the general shop network for the movement of chips and sludge.

Keywords: screw, shavings, lubricating and cooling liquid, productivity, energy saving.

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1. Introduction

Among the many tasks in the mechanical engineering of Ukraine is the environmental problem associated with the collection, transportation and processing of chips and sludge, as a waste of mechanical processing. Taking into account the fact that processing and disposal is carried out outside the workshop areas, a new task arises related to the process of transporting chips and sludge to the next stages of processing.

Moving chips and sludge carry on their surface particles of cutting fluid (coolant) used in machining processes. Due to economic and environmental feasibility, there is a separation of the coolant from the transported material for subsequent regeneration and operation. The energy component of the problem being solved is the use of combined transport under the condition of constancy (not increase) of energy costs. The aim of the work is to increase productivity and reduce the energy intensity of the processes of transporting metal chips by combined (screw and hydraulic flush) conveyors.

Achieving this goal involves solving the following tasks:

– description of the theoretical foundations of the process of movement of chips in combined (screw and hydraulic) conveyors;

– development of recommendations for choosing the parameters of the designed equipment.

2. Existing methods of chip transportation

Transportation of shavings is an important task, which is solved by a number of design organizations and plants. However, there is very little experience in generalizing these developments *(Baranovsky and other, 2017)*. In fact, each company engaged in the design, manufacture or operation of metal-cutting equipment, solve the problem of transportation, assembly and processing of chips at its discretion.

All the variety of competitions created for the transportation of chips can be classified into separate groups, identical characteristics. For transportation of shavings from a zone of cutting of machines there are five groups of the mechanisms most widespread in mechanical engineering *(Fernandezi and other, 2009)*. Belt conveyors are used to collect small chips when processing brittle materials. They have found limited use due to structural complexity, the presence of a special drive and tension station, low durability of the tape. The use of steel tape further complicates the conveyor.

Screw conveyors are the most common, are universal, can operate horizontally, inclined and vertically. One end of the auger is connected to the drive by means of floating couplings, the other end is free – floating. However, these conveyors require careful care, cannot move the drain chips without installing an additional auger.

Vibrating conveyors are simple in structure of the device, work well for transportation with chip breaking. The disadvantage is the vibration on the process equipment, noise, especially at high amplitudes of vibration. Pulse conveyors are driven by the machine itself and work by stopping the chute instantly when moving it in the direction of chip removal.

Hydro-erosion devices have one or more nozzles on the side of the chute, angled towards the transport, to which the coolant used in the cutting zone enters. The device can work effectively at a pressure in the system of not less than 0.25 MPa, a short length of transportation and the absence of foreign objects. It is also used in industry – combined transport, such as plate conveyors and pressureless hydraulic transport. In this case, the slope of the gutter may be small, the performance is significant *(Hevko, 2015)*.

Conveyors of different types are used to move waste from mechanical material processing operations. I will introduce the technological features of the location of conveyor lines in machining shops – the most effective are screw and flush conveyors, as they have low energy consumption when able to work on short sections (Table 1).

Table 1

Technical characteristics of conveyor transport.

A type	**Transportation distance, m**	**Productivity, t/h**	**Power consumption, kW/h**	**Overall dimensions, diameter, width, m**	**Type of transported chips**	**Elevation angle**	**Energy intensity of transported material, kW/t**
Band-plate	2–80	5–125	30–110	400–1400	chipping, fracture	55°	7–1
Vibrating	0,5–18	2–25	2,2–20	500–800	chipping, fracture	50°	4,1–1,55
Pulse	0,8–10	1–5	3,5–16	200–800	chipping, fracture	25°	2,1–1,85
Screw	0,5–25	2–45	1,5–20	100–1000	fracture	25°	0,85–0,45
Water flush	0,5–15	0,5–60	1,1–40	30–300	sludge, fracture	15°	2,5–0,5

Based on the above data, the combination of a screw conveyor with a hydraulic flush conveyor is the most effective due to their low energy consumption and relatively high productivity *(Hevko and other, 2014)*.

After analyzing the designs of screw conveyors and devices aimed at upgrading and correcting prototypes, the main upgrades were identified, which are as follows:

- changing the geometry of the loading and unloading openings;
- combined use of additional hydraulic and pneumatic transport;
- change of screw diameter (stepless);
- use of additional chambers (aeration);
- impact on technical and design parameters by using additional intermediate supports *(Hevko and other, 2014)*.

The screw conveyors and attachments described above are designed to adjust performance due to design changes, technology upgrades and the use of additional attachments, etc.

However, none of the designs consider or address the issue of increasing productivity by combining types of conveyors in order not to increase energy costs.

3. Combined conveyors for transporting chips from the cutting zone

Effective transportation of chips from the cutting area is one of the most difficult tasks in the design of metal-cutting machines. Creating new designs of metal-cutting machines, the designer must provide for the rational removal of chips: windows in the frame; absence of protruding parts; for which the shavings would cling; sufficient chip space, etc.

The chips should fall down to a special cavity under the action of their own weight, the windows in the machine, and from there to be taken out by the conveyor. However, this only happens in the presence of elemental chips. High adhesion of drain shavings, ability to get into chains, winding around the protruding parts of mechanisms and tools, etc., forces to apply transporting devices with big traction forces, forced capture of shavings *(Hevko and other, 2016)*.

Analysis of existing methods of collecting chips from the cutting area, shows that all devices have certain shortcomings and cannot fully solve this problem *(Ince and other, 2019)*. This task is especially complicated when oil is used as a coolant, the processing process is intensive, a large amount of chips is formed *(Pankiv and other, 2017)*.

The authors proposed, developed and implemented a new design of a combined conveyor for collecting chips from the cutting area of the machine. These conveyors create a series of intersecting jets of fluid parallel to the bottom of the gutter. To do this, pressure pipelines of different cross-sectional length are installed in the side walls of the gutter and connected to nozzles symmetrically mounted on the inside of the side walls of the gutter, reinforced at the bottom with low-fraction material.

Pressure pipes can be made of box section, as a low-fraction material can be used tempered glass. This design of the conveyor allows to obtain a jet of liquid, to have a low coefficient of friction of the chips against the bottom of the chute, ie in general to increase the efficiency of transportation. The compact arrangement of pressure pipes and nozzles allows to reduce considerably the overall dimensions of the device.

The combined conveyor (Fig. 1) has a gutter of semicircular cross-section, at the side walls of which are installed pressure pipelines 1 also shaped corresponding to the cross section of the auger, but moved along the length of the cross section. Nozzles 2 with oval outlets 3 are welded to the pipelines.

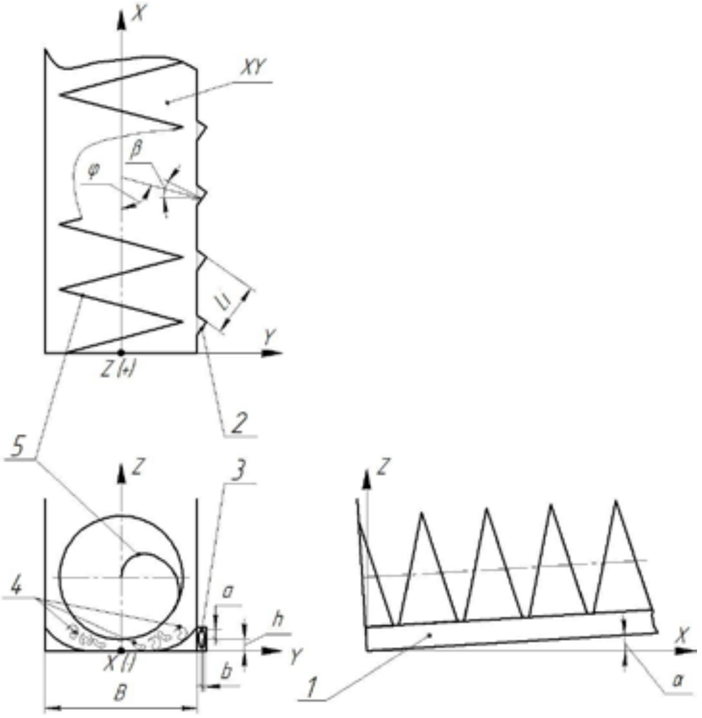

Fig. 1 Combined conveyor

Under pressure, the coolant is fed through pipes into pressure pipelines, from where it is injected into the chute through nozzles in the form of jets parallel to the bottom. To prevent chips from entering the nozzles, protective screens are mounted above them. Jets of liquid flying out of the holes pick up the chips 4 and move it from one jet to another, thereby ensuring the movement and mixing of the transported particles that did not fall into the area of action of the screw spiral. The installed auger 5 can be made of both tape and blade construction.

Under even more limited conditions, it is advisable to use several modified nozzle designs in the form of slits formed by wall elements to transport chips from the cutting area of the machine. In this case, the energy of the resulting jets is fully used and larger chips can be moved. In this case, the chips in some areas float "on the stream" and slide along the bottom of the gutter.

4. Theoretical foundations of the chip movement process in combined conveyors

Denote by Li (Fig. 1) – the distance between the nozzles along the length of the chute, which is also a value equal to the pitch of the auger spiral, h – height from the middle of the nozzles to the bottom, α – angle of the chute, B – width of the chute, 1.05-1.1 external diameter of the auger, a and b – half the length and width of the nozzle hole, φ – the angle of the axis of the jets with the longitudinal axis of the chute, Qr – fluid flow from one nozzle, d – average particle size.

Let the X axis coincide with the gutter axis, the XУ plane coincide with the bottom plane, and the Z axis coincide with it. Since a solid substance (Qт) – chips or sludge – enters the chute every second, and at the same time liquid (Qr) from each nozzle (n) is fed to each turn of the auger spiral in the corresponding section of the chute, it can be assumed that the whole mass of solid substance evenly distributed over the mass of the liquid and the mass of solid per unit mass of liquid can be taken as the mass (m_t) of the conditional proportion of solid, so:

$$m_t = \frac{Q_T}{Q_r \cdot n} H, \tag{1}$$

where H is the coefficient that takes into account the maintenance of the dimension of the mass distribution of solids in the area of the gutter. Conditional material spherical particle of medium diameter falls on the plane of the gutter (X0, У0) and under the action of flow forces begins to move along the gutter. In each section, in addition to the main stream, which was formed earlier, there is a local flood, obtained as a result of jet flow in this area. The following assumptions apply to the description of jets:

- the expansion of the jets 2β in the plane XУ for all nozzles is the same;
- the liquid is perfect, uncompressed;
- the process of jet flow – isothermal and stationary;
- in each section of jets the velocity field is homogeneous.

Then the continuity equation applies the form:

$$S_0 V_0 = SV \tag{2}$$

where S_0, S - the area of the initial and arbitrary cross section of the fluid jet;
V_0, V – the velocity of the initial and arbitrary fluid flow.

The velocity of the liquid in an arbitrary cross section is determined:

$$V = \frac{S_0}{S} V_0 \text{ or } V = \frac{a_0}{a} V_0 \tag{3}$$

where a – the acceleration of the jet being determined

$$a = a_0 + kx \tag{4}$$

where $k = \tan\beta$, $x = L_0 + (i - l)L_i + x\cos\phi$

From here

$$a = a_0 + \frac{\tan\beta}{\cos\phi}\left(x - L_i - (i-1)L_i\right) \quad (5)$$

where L_0 – the distance from the beginning of the gutter to the first section.

Taking into account (5) and the angle of inclination of the chute (α) equation (3) will take the form:

$$V = \frac{a_0 V_0}{a_0 + \frac{\tan\beta}{\cos\phi}\left(x - L_i - (i-1)L_i\right)} \cdot \cos\alpha \quad (6)$$

At each section, the flow of jets is summed and the flow velocity in an arbitrary cross section is determined from a system of equations:

$$V_{xi} = \frac{2Q_r \cos\phi}{\pi b\left[a_r + \frac{\tan\beta}{\cos\phi}\left(x - L_i - (i-1)L_i\right)\right]} \cdot \cos\alpha \tag{7}$$

$$V_{yi} = 0;\ V_{zi} = \pi$$

After a series of transformations and accepting L_0=0, we obtain the equation for determining the total fluid flow rate in an arbitrary cross section:

$$V xi = \left(\frac{Q_r \cos\phi}{\pi b} - \frac{2a_0 + \frac{\tan\beta}{\cos\phi}\left[a_0 + \frac{\tan\beta}{\cos\phi}\left(x - L_i - (i_0 - 1)L_i\right)\right]}{\left(a_0 + \frac{\tan\beta}{\cos\phi}L_i\right)\left[a_0 + \frac{\tan\beta}{\cos\phi}\left(x - L_i - (i-1)L_i\right)\right]}\right)\cos\alpha\ , \tag{8}$$

(i=2,3…….)

The following forces act on the solid particle in the fluid flow: frontal pressure force, lifting force, friction force.

Frontal pressure force:

$$S^r_{lob.x} = K_1\left(V^r_{xi} - U^r_x\right) \tag{9}$$

where Ux – the speed of movement of solid particles in the axial direction X (Uy = 0; Uz = 0).

K_1 – coefficient, and in accordance with Stokes' law – $K_1 = \frac{18M}{d^2}$ K,

M – coefficient of dynamic viscosity.

Then

$$S_{lob.x} = \frac{18M}{d^2}\left(V_{xi} - U_x\right) \tag{10}$$

The lifting force acting on the particle is determined

$$S_{lob} = PV_\infty x\tau r \tag{11}$$

where V_∞ – the speed of the oncoming flow;

τ – from the direction of the vortex;

r – circular speed $rot_L, rot_\varepsilon, rot_0 V$ to the polar coordinate system.

Determining values $rot_L, rot_\varepsilon, rot_0 V$ we obtain the following expressions of the lifting force in the projections on the axis:

$$S_{n\bar{o}z} = S_{n\bar{o}zR}\cos\theta - S_{n\bar{o}z\theta}\sin\theta = \frac{9p}{4\sqrt{2\pi}}\left(\frac{Q_T}{\gamma_T Q_r}\right)^{\frac{3}{2}}\frac{\sin^2\theta\cos\theta}{R^2} \tag{12}$$

$$S_{n\bar{o}z} = S_{n\bar{o}zR}\sin\theta\cos\varepsilon +$$

$$+S_{n\bar{o}z\theta}\cos\theta\cos\varepsilon\frac{3p}{4\sqrt{2\pi}}\left(\frac{Q_T}{\gamma_T Q_r}\right)^{\frac{3}{2}}\frac{\sin\theta\cos\varepsilon}{R^2}(V_{xi}-U_x)^2(\sin^2\theta - 2\cos^2\theta) \tag{13}$$

where θ – the angle of inclination of the vector R to the horizon;

ε – the current spatial coordinate at this point of the chute;

R – fluid vortex radius;

p – fluid density;

γ_T – solid density.

The sliding friction force is equal to:

$$F_{mp.x} = -f_{mt}g\cos\alpha \tag{14}$$

where f_{mt} – sliding friction coefficient,

g – acceleration of gravity.

Taking into account all the forces considered above, the differential equation of motion of a conditional spherical particle along the X axis has the following form:

$$m_T x = m_T g\sin\alpha + \frac{g\mu\pi\gamma Q_r}{Q_T}\left(V_{xi} - U_x\right) - f_{mt}g\cos\alpha \ , \tag{15}$$

where μ – integrating multiplier.

After presenting x as $\frac{U_x dU_x}{dx}$ integration of equation (15) in the range from 0 to Li and substitution of the found values, we obtain:

$$u\frac{Q_{T\max}}{Q_r}gL_i\left(\sin\alpha - f\cos\alpha\right) -$$

$$-\frac{4.5Q_r^2\gamma_T M\cos\phi^2}{Q_T\max B}\cdot\frac{1}{a_0\cos\phi + \tan\beta L_i}\int_0^4\frac{\left\{\left[x - L_i(i-2)\right]\frac{\tan\beta}{\cos\phi} + 2a_0\right\}dx}{a_0 + \frac{\tan\beta}{\cos\phi}\left[x - (i-1)L_i\right]}$$

After the second integration we get:

$$u\frac{Q_{T\max}}{Q_r}gL_i\left(\sin L - f\cos\alpha\right) - \frac{4.5Q_r^2\gamma_T M\cos\phi^2}{Q_{T\max}B}\times$$

$$\times\frac{1}{a_0\cos\phi + \tan\beta L_i}\left[L + L_i\ln\left|1 + \frac{Ltg\beta}{a_0\cos\phi - tg\beta L_i(i-1)}\right|\right] = 0 \tag{16}$$

Solving equation (16) with respect to $Q_{T\max}$ it is possible to determine the maximum transport capacity of the flow at a given fluid flow rate and the accepted parameters of the conveyor.

5. Conclusions

The solution of equation (16) allows to establish the transport capacity of the flow and to design the effective parameters of the combined conveyors:

- length;
- width;
- the angle of the gutter to the horizon;
- width of the nozzle inlet;
- the length of the inlet of the nozzle;
- the distance of the plane of the nozzle holes from the bottom of the conveyor chute;
- the distance between the nozzles along the axis of the conveyor;
- supply pressure;
- the angle of entry of the axis of the jet to the axis of the conveyor;
- fluid consumption for each nozzle;
- conveying capacity of the conveyor.

All the above parameters contribute to the solution of the scientific environmental problem aimed at increasing productivity without increasing energy consumption.

References

1. *Baranovsky V.M., Potapenko M.V. (2017). Theoretical analysis of the technological feed of lifter root crops. INMATEH–Agricultural Engineering. National Institute of research development for machines and installations designed to Agriculture and food industry. Inma Bucharest. Vol. 51. No. 1/2017. P. 29–38.*
2. *Fernandezi J. Cleary P., Mc. Bride W. (2009). Effect of screw design on hopper draw down by a horizontal screw feeder : seventh International Conference on CFD in the Minerals and Process Industries CSIRO (Melbourne, Australia, 9–11 December 2009).*
3. *Hevko R.B. (2015). Development and investiga-tion of reciprocating screw with flexible helical surface. INMATEH–Agricultural engineering. National Institute of research development for machines and installations designed to Agriculture and food industry. Inma Bucharest. Vol. 46. No. 2/2015. P. 133–138.*
4. *Gevko R.B., Klendiy O.M. (2014). The investigation of the process of the actuation of the safety device of a screw conveyer, INMATEH: Agricultural engineering, vol. 42, no. 1/2014, p. 55–60, Bucharest, Romania*
5. *Hevko R.B., Dzyura V.O., Romanovsky R.M. (2014). Mathematical model of the pneumatic-screw conveyor screw mechanism operation. INMATEH–Agricultural engineering. National Institute of research development for machines and installations designed to Agriculture and food industry. Inma Bucharest. Vol. 44. No. 3/2014. P. 103–110.*
6. *Hevko R.B., Klendiy M.B., Klendiy O.M. (2016). Investigation of a transfer branch of a flexible screw conveyer. INMATEH–Agricultural Engineering. National Institute of research development for machines and installations designed to Agriculture and food industry. Inma Bucharest. Vol. 48. No. 1/2016. P. 29–34.*

7. Ince E., Güler MA, (2019). Design and analysis of a novel power-split infinitely variable power transmission system. Journal of Mechanical Design. https://doi.org/10.1115/1.4041783
8. Pankiv V.R., Tokarchuk O.A. (2017). Investigation of constructive geometrical and filling coefficients of combined grinding screw conveyor. INMATEH–Agricultural engineering. National Institute of research development for machines and installations designed to Agriculture and food industry. Inma Bucharest. Vol. 51. No. 1/2017. P. 59–68.