INVESTIGATION OF THE RADIUS OF BENDING FOR FLEXIBLE SCREW SECTIONAL CONVEYERS

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ДОСЛІДЖЕННЯ РАДІУСА ЗГИНУ ГНУЧКИХ ГВИНТОВИХ КОНВЕЄРІВ З СЕКЦІЙНИМИ ЕЛЕМЕНТАМИ

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ABSTRACT

Method of calculation of radius of bending for the flexible screw sectional conveyer was presented. Analytical dependencies for finding maximal turning radius in order to provide the reliable operation of the mechanism were defined. The stand construction for investigation of the angle of twist of the sectional operating members was developed. The effect of different construction parameters (section length, diameter) on their operating life characteristics as well as the comparative testing of different types screw operating elements (SOE) samples, were found. The technique of testing the working bodies of flexible screw conveyor sections for manufacturability of a construction, which provides a minimum bend radius of track transportation, was presented.

РЕЗЮМЕ

Наведено методику розрахунку радіуса згину гнучкого гвинтового конвеєра з секційними елемента. Виведено аналітичні залежності для визначення оптимального значення радіуса повороту з метою забезпечення надійної роботи механізму. Розроблена конструкція стенд для дослідження кута закручування секційних робочих органів і встановлено вплив різних конструктивних параметрів (довжина секції, діаметр) на їх ресурсні характеристики, а також порівняльні випробування різних типів дослідних взірців гвинтових робочих органів ГРО. Наведено методику відпрацювання робочих органів гнучких гвинтових секцій конвеєрів на технологічність конструкції, яка забезпечує мінімальний радіус згину траси транспортування.

INTRODUCTION

In modern agricultural mechanical engineering, elevating-transporting and other vehicles screw transporting-technological systems (STTS), the principle of operating members such as flexible screw mechanisms, are of great importance, high requirement being held for the reliability and durability of these mechanisms operation, providing high engineering-economic indices and low expenditures for operation and maintenance of the agricultural machine. From the point of view of mechanism operation reliability, determination of the acceptable and maximal radius of the operating member bending is of importance while using flexible screw conveyer sectional operating member.

The objective of the work is to develop the method for finding the radius of bending for the sectional operating member in order to provide its operational and technological parameters.

The papers by A.M. Grygoriev, S.M. Mykhailov, K.D. Vaschagin, B.M. Gevko, R.M. Rogatynsky, O.Trufanov, H. German, M.I. Pylypets etc., are devoted to the theoretical interpreting of the flexible screw transshipment mechanisms operation, methods of calculation of their basic parameters, development of advanced constructions of such means of bulk materials mechanized transporting along the curved routes. There are also other important authors works which include preoccupations in this research field *(Hevko R.B. et al., 2012; Hevko B.M., 1993; Hevko B.M., Rohatynsky R.M., 1989; Hevko I.B., 2008; Hevko B.M., et al, 2008)*.

In many works are developed the main principles of construction and modelling of screw conveyors, such as *(Fernandez J.W. et al, 2009; Hu G. et al, 2010; Owen P.J. and Cleary P.W., 2009; Zareiforoush H. et al, 2010)*.

Analysis of key principles in the design of flexible screw conveyers (FSC) testifies that the single point of view on the essence of the phenomena observed during operation of such means of mechanization is not available. Special attention in the analysis of the previous investigations is paid to those papers, in which the problem of the choose of operating members parameters and the processes of transporting grain, granular fertilizers, etc., are analysed, as the problem of the bulk materials damage has not been studied enough yet.

MATERIAL AND METHODS

Stand for investigation of the STTS sectional operating member angle of twist is presented in Fig.1. It consists of the body *1*, to which the stick *2* is mounted rigidly and on which operating member *3* is fixed, which is freely set in the U-shaped box. The box is fixed on the base *5* with supporting elements *6*. Free end of the sectional operating member is inserted into the holder hole *7*, on the right end of which the Nonius scale is made. In order to investigate different length operating members the holder is located on the guides, which make possible to change its position. On the free end of the operating member, which overhands from the holder hole, the bush with the arrow *10*, which has the ability of angle displacement while screw tightening, and calibrated level *12*, the size of which is determined by the loading capacity of the operating member, is fixed rigidly.

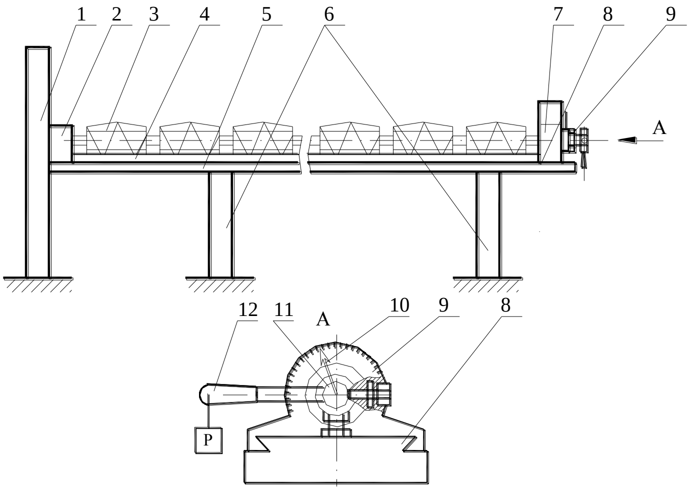
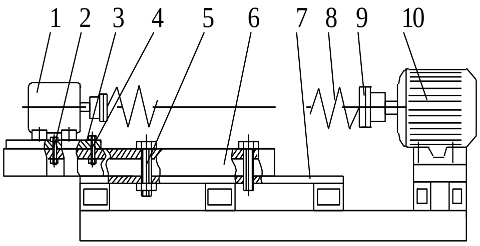


Fig.1 – Stand for investigation of the sectional operating member angle of twist

Rigidity of the screw operating member as well as the SOE sectional elements wear are found according to the angle of twist value. To find the screw spirals torsion rigidity, the curvature radius effect on the spirals operation reliability, to determine the most dangerous areas in the SOE constructions elements under overloading, experimental stand presented in Fig.2 was used. It is designed for static, dynamic and operating life testing and comparative estimation of different construction parameters operating member's structures. The stand consists of the frame *7*, on which the generator *1* (namely, engine 4PF112LVB04) is mounted on the turning plate *3*, which is bolted by the screw joints *2* and *4* to the guiding channel *6*. The guiding channel is fixed to the frame *7* and its fitting in the given position is provided by the bolt joint *5*. Besides, the stand is provided with the three-phase induction asynchronous motor *10* (AIP90L4Y3), which is mounted on the displaceable plate. Investigated SOE 8 is fixed on the motor output shafts *1* and *10* by means of either the flanged joints or the flanged joints and the safety clutch *9*.



a) **b)**

Fig.2 - Stand for investigations of the screw spirals tortion rigidity: a) scheme; b) general view

Investigations of the screw spirals torsion rigidity, taking advantage of this stand, are carried out as follows. The investigated object *8* is placed on the generator *1* and motor *10* shafts and the necessary spiral curvature radius is set with the help of the displaceable plate. As the motor can be displaced in the longitudinal and transversal directions, different length and configuration spirals can be tested on this stand. Then, is run following PC connection to the power supply source (Fig.2) and software PowerSuit for tuning of Altivar 7.1 series transformers frequency. Frequency of the motor rotation was controlled automatically from 0 till 1460 rev/min. Besides, smooth and sharp starting and reversing were performed, if needed. The generator (d.c. motor 4PF112LVB04) worked as brake, which was operating with the separate excitation to make the required loading on the investigated object possible. That is why the current comes from the stabilizer to the (laboratory automatic transformer), where its regulation (U-const) to the required value (I=0…4A) is carried out and then through the rectifier (diode bridge) it is transferred to the generator stator excitation winding. Accordingly, the excitation winding current changes the generator loading current (resultant generator magnetic field) and, thus, the generator consumption power is changed. Exact data on the rotation frequency on the motor shaft (error within ± 1.5 %) is recorded, taking advantage of the motor shaft rotation frequency meter (E40S6-10Z4-6L-5), which is connected to the motor rotor.

Since operation characteristics of any elevator flexible operating member are determined by the radius of its bending, this parameter specifies the level of the production effectiveness of such transporting member. The value of the radius of bending is to be known while their designing for the loads transporting along the curvilinear routes, the designer being able to provide required technological capabilities of the device and purposefulness of its application. To find this parameter one should follow the calculation scheme presented in Fig.3.

The value of bending of the screw operating member under absolute rigidity according to the required linear sizes is equal to its general linear length. According to the calculation scheme the relation between the bending length and the screw element radius is:

$$l_{bend} = \frac{2\alpha \cdot \pi R_{bend}}{180^{\circ}} \quad (1)$$

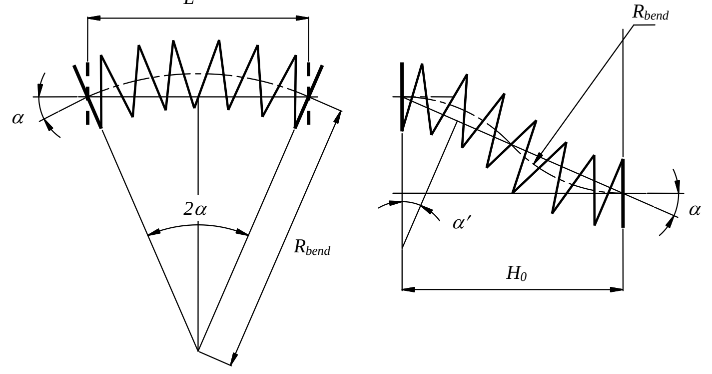
The radius of bending can be expressed by the distance between the device bended operating member ends due to L parameter. According to the calculation scheme the radius of bending equals (*Leschuk R.Y., 2003*):

$$R_{bend} = \frac{L}{2 \cdot \sin\alpha}, \quad (2)$$

where:

L – linear distance between the screw elements ends;

α – angle of bending of the screw element sections.



a) b)

Fig.3 - Calculation scheme for finding the radius of bending for the elevator flexible screw member:

a) bending rout along the radius; b) bending rout along the curve

Having substituted the values of equality (2) in the dependence (1), the value of the elevator screw operating member bending length will be obtained:

$$l_{bend} = \frac{\pi L \alpha}{180^{\circ} \sin\alpha} = \frac{\alpha \cdot L}{\sin\alpha}. \qquad (3)$$

In the case of two bending paths, the radius of bending is worthy being determined from the dependence:

$$R_{зг.р} = \frac{L \cdot \sin\alpha}{4 \cdot \cos\alpha} = 0{,}25 \cdot L \cdot \mathrm{tg}\alpha. \qquad (4)$$

The length of bending (linear length of the screw operating member) is found from the dependence:

$$l_{bend} = 0{,}5L \cdot \mathrm{tg}\alpha \cdot \pi \cdot 2\alpha. \qquad (5)$$

However, such important parameter as the angle of bending of the elevator sections α is still unknown. To find this parameter and the dependence of the angle of bending of the flexible screw operating member on the other structural parameters, one should take advantage of the calculation scheme presented in Fig.4. Thus, to find the analytical dependencies, which are used to calculate the angle of bending of one section relatively the other one, we should consider triangle Δ abc, according to which (*Hevko B.M. and other, 2008; Leschuk R.Y., 2003)*:

$$\mathrm{tg}\alpha = \frac{cb}{ac} = \frac{D_B - d_B - 2s}{B}, \qquad (6)$$

where:

D_B – outer diameter of the elevator sections bushes;

d_B – diameter of the joint rolls;

s – thickness of bushes;

B – width of bushes.

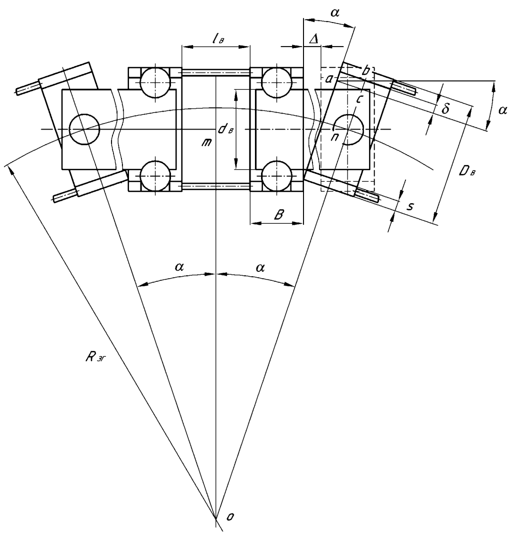


Fig.4 - Calculation scheme for finding the minimal radius of bending for the screw sectional operating members elevator

To find the angle of bending let us consider triangle Δ omn. According to the calculation scheme, presented in Fig. 4, the radius of bending Rbend will equal:

$$R_{bend} = on = \frac{mn}{\sin\alpha}. \qquad (7)$$

According to the calculation scheme the value *mn* equals:

$$mn = l_B/2 + B + \Delta + B/2, \qquad (8)$$

where:

l_B – distance between the bushes in one section,

Δ – gap between the adjacent sections

Taking into account equations (6) and (8), the dependence (7), which determines the minimal radius of bending of the sectional elements elevator operating members, will look like:

$$R_{bend} = \frac{1{,}5B + l_B + \Delta}{2\sin\left(\operatorname{arctg}\left(\frac{D_B - d_B - 2s}{B}\right)\right)}. \qquad (9)$$

RESULTS

Special stand equipment was used for the operating life testing of the strain-strength characteristics of the flexible sectional SOE (Fig.2). At the beginning of the operating life testing measuring of the angle twist of the sectional SOE with the hinged joint (Fig.9, a) and safety joint (Fig.9, b) on the stand for testing the angle of twisting of sectional SOE, were carried out. The next stage was operating life testing (under loading) on the stand for investigation of the strain-strength characteristics of the screw spirals (Fig.6). Then, equal periods of time (10 hours) repeated for measuring of the angle of twisting of the sectional SOE on the stand were carried out to investigate the angle of twisting of sectional SOE. In Fig.5 graphic dependencies of the radius of bending value change of the screw conveyer on the construction parameters of the sectional elements, are presented.

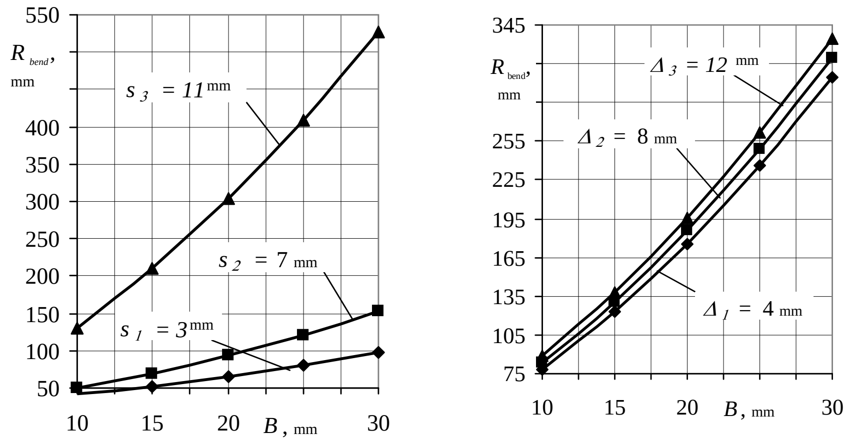


Fig.5 - Graphical dependences of the radius of bending value change of the screw conveyer on the construction parameters of the sectional elements

According to the embodiment of the working body of the ratio between the angular velocities master and slave sections for a full rotation will be:

$$\frac{\omega_2}{\omega_1} = \frac{\cos(arctg(D_B - d_B - 2s)/B}{1 - \sin^2(D_B - d_B - 2s)/B} \qquad (10)$$

Analyzing the obtained graphical dependencies (Fig.5) of the flexible screw conveyer radius of bending change on the construction parameters of the operating members sections, one can conclude, that the thickness of the bush S together with the width of the bushes B are sufficient to influence this value. Thus, when the value S is increased within 3...11 mm and B equals 10; 15; 20; 25; 30 mm under constant value D_B=60mm; d_B=45mm; l_B=50mm; Δ=10mm, the radius of curvature increases within 41.4…125.5 mm and 95.1…531.6 mm, that is, in 3.2…5.8 times. Thus, sufficient limitation of the device technological capabilities occurs, as the radius of bending must be minimal. Under similar data of these construction parameters, but while changing the gap size between the adjacent sections Δ within 4…12 mm, the radius of bending varies within 76.3…314.1; 90.4...336.5 mm. According to the investigations the device with the less width of the bush sections will be more production effective, as under similar productivity and operating life time of operation will take less manufacturing areas.

As the result of the carried out investigations it was found that the angle of twist for the sectional SOE with the hinged and safety joints (SOE length L=2m) did not exceed 9°. Before the operating life testing the angle of twist for the investigated sectional SOE did not exceed 3,2°. At the initial stage of the operating life testing (after 10 hours of operation) the angle of twist for both sectional SOE has increased sharply, which can be caused by the wearing out of SOEe screw construction elements. Further its increase was slowed down and stabilization was observed.

In Fig.6 dependencies of the sectional SOE angle of twist on the operating time are presented (turning diameter–96 mm, section length–130 mm, SOE length–2 m, loading on SOE–12 Hm, frequency of rotation–426 rev/min under radius of bending – R_{bend} = min and under the straight SOE – R_{bend} = 0).

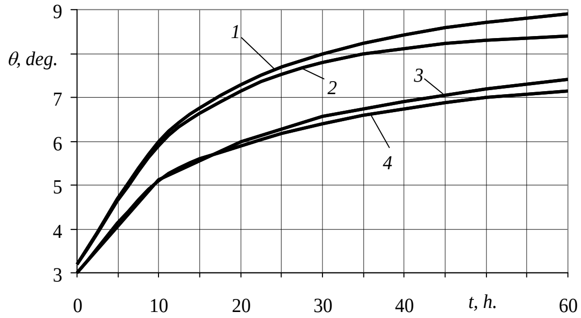


Fig.6 - Dependence of the sectional SOE angle of twist on the operating time:
1 – with the hinged joint under R_{bend} = min; 2 – with the safety joint under R_{bend} = min;
3 – with the hinged joint under R_{bend} = 0; 4 – with the safety joint under R_{bend} = 0

Angular acceleration of the master section for a uniform rotation of the slave unit is expressed by:

$$\beta_2 = \omega_1^2 \frac{\sin^2(arctg\,\frac{D_B - d_B - 2s}{B})\cos(arctg\,\frac{D_B - d_B - 2s}{B})\sin 2\alpha}{(1-\sin^2(\frac{D_B - d_B - 2s}{B})\sin^2\alpha)^2} \quad (11)$$

Accordingly, coefficient of irregularity rotation of the slave section:

$$k = tg(arctg(\frac{D_B - d_B - 2s}{B}))\sin(arctg(\frac{D_B - d_B - 2s}{B})) \quad (12)$$

Torque at an intermediate section is determined from the relationship:

$$T_{n.c.} = T\sqrt{1 + tg^2(arctg(\frac{D_B - d_B - 2s}{B}))\cos^2\alpha} \quad (13)$$

where:

T – torque that acts on slave section.

As a result was built graphical dependence (Fig.7, Fig.8) in analysis of which we can conclude that they are close to the straight line of law distribution.

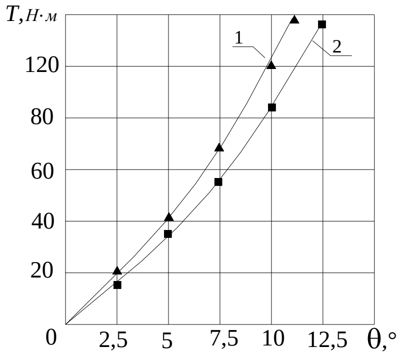


Fig.7 - The dependence of the torque T from the angle of twisting θ working unit for one section:
1 - l = 100 mm, 2 - l = 130 mm

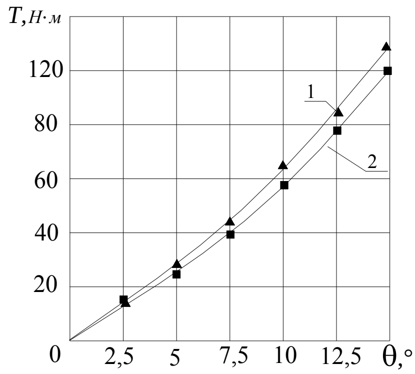
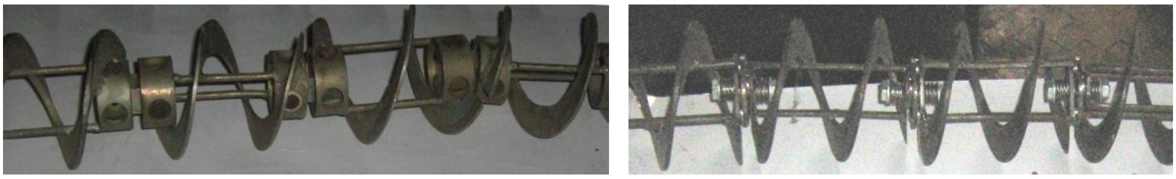


Fig.8 - The dependence of the torque T from the angle of twisting θ working unit for two section:
1 - l = 100 mm, 2 - l = 130 mm

As seen from (Fig.7 and Fig.8.) the increase of the length of the section naturally leads to a proportional increase in the maximum angle of twist and hinge joint almost has no effect on the amount of strain, as its stiffness is much higher than the stiffness of the section. It has been found that maximum torque T_{max} that results in a breakdown of the section of working unit is much larger than the torque required for handling bulk cargo by designed working unit at maximum working height of handling and minimal radius of curvature of pipeline.

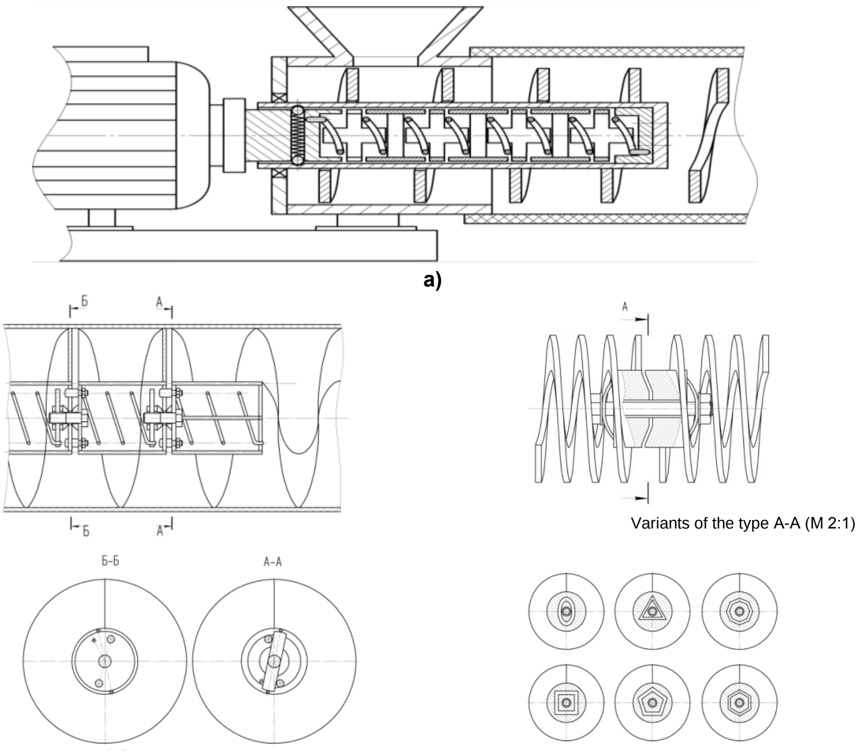
Basing on the presented calculations screw sectional elements operating members were designed and manufactured, which are presented in Fig.9. The results of the carried out investigations testify that the period of running-in in the idle regime of the sectional SOE must be carried out in order to provide the fitting of SOEe construction elements, which should be followed by the maintenance inspection. However, existing screw operating members (SOE) constructions are often exposed to dynamic loadings in starting and operating conditions during the operation. Therefore, we have developed a number of advanced constructions with elastic and safety connections, that help us to improve the reliability and durability of flexible screw conveyers (FSC) and also help to avoid their failures. They allow to ensure a smooth launching of screw operating members (SOE) during starting an engine and during operation and also they avoid failures from dynamic loadings. Flexible screw conveyers (FSC) as shown in the image 10.a, allow us to compensate for starting loadings on screw operating members (SOE) by using compensation connection. The image 10.b shows us a flexible helical spring working body which provides compensation starting loads as well as those that arise in the process of transporting the material (*Hevko I.B., Melnychuk A.L., Shust I.M., 2015 ; Hevko I.B., Komar R.B., Leschuk R.Y., Novosad I.Y., 2005)*. Fig.10.c shows a helical spiral with safety cone-shaped cam connection sections, which provides separate sections of screw operating members (SOE) during the critical loadings, that helps us to avoid faults of elements of flexible screw conveyers (FSC).

The developed models of the screw operating members (SOE) and flexible screw conveyers (FSC) with sectional elements can be widely used in the food processing branches of industry, agriculture, as well as in technological processes of mechanized loading of mineral fertilizers, seeds and grains due to the improved technological capabilities while decreasing the radius of its bending and raising reliability as the result of the improved construction.



a) **b)**

Fig.9 - Sectional screw operating members with a) hinged joints; b) safety joints



b) **c)**

Fig.10 - Flexible screw conveyers:

a) connection with compensation; b) elastic flexible screw working body;
c) flexible screw working body with conical cam precautionary connection sections

CONCLUSIONS

1. The developed models of the screw operating members (SOE) and flexible screw conveyers (FSC) with sectional elements can be widely used in the food processing branches of industry, agriculture, as well as in technological processes of mechanized loading of mineral fertilizers, seeds and grains due to the improved technological capabilities while decreasing the radius of bending and raising reliability as the result of the improved construction

2. Construction stand for investigation of the sectional operating member angle of twist has been developed. Dangerous radii of the spiral curvature and critical loadings, which cause the SOE fracture, have been found. The effect of different construction parameters (section length and diameter) on their operating life characteristics, has been determined. Comparative testing of different types SOE samples, have been carried out.

3. Basing on the carried out investigations analytical dependencies for finding the radius of bending of the sectional flexible screw conveyer, depending on the sections construction parameters, have been derived. Graphical dependencies of the change of radius of bending value of the sectional operating member on the sectional elements construction parameters have been found. The change of the minimal radius bending is affected by the turn thickness comparatively with its width, the angle of bending for the sectional SOE with hinged and safety joints (SOE length = 2m) not exceeding 90°.

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