Development of a universal algorithm for designing linear conveyor nonmixers for producing mixes of piece tubular components

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Abstract. Paper presents algorithm calculation of automatic mixing (nonmixing) conveyor to obtain mixtures of single, piece tubular elements having similar typical overall dimensions, but differing in internal properties at effective end use. The relevance and novelty of development are shown on the example of receiving the general party of composite tubular product, at the determined forming of its uniformity, with the set qualitative and quantitative characteristics from the heterogeneous tubular components differing in functional parameters.

1. Introduction

Automatic rotor and nonmixing conveyor are the only representatives in class of the mixing equipment today, capable to implement processes of the determined forming of uniformity of mixes [1-8]. Problems, which are solved by means of this class of apparatuses, cannot be carried out on other types of the equipment [9-12].

Programs of release of tubular products of different standard sizes very strongly differ: in one case it is measured by tens of tons per shift, in another – only hundreds of kilograms.

In this regard, the enterprise needs to have as the special devices intended for release of one standard size of mass products and universal on which it is possible to prepare different nomenclatures of tubular product. At the same time, the principles of design of special and universal devices significantly differ from each other.

At the same time of both universal, and special nonmixing conveyor for preparation of mixes the general principles by which are guided at design of any technical system are inherent in designing process.

Design of technical system consists of three stages: developments of the schematic diagram of the machine; calculation and determination of the sizes, masses, etc.; choice of optimum schemes of designs.

However such approach does very long terms of creation of the new equipment.

It is more reasonable to use the modular and modular principle, which is that the system (the machine, the device, etc.) is packed from the available nodes and mechanisms and task of the designer consists in such selection of these component elements that they were functionally compatible and in total would implement process of receiving products of the set nomenclature.
The novelty of development consists in complete solution of the provided theoretical and technology tasks when algorithms and calculation results of quality indicators of mix can be tied to flow sheets of its production and technical implementation on the automated mixing modules – nonmixers. Also introduced for the first time algorithm of design of similar automatic machines for use in engineering techniques on development of technology processes and the equipment for production of high-quality mixes of heterogeneous components.

2. Problem definition
It is necessary to develop universal algorithm of calculation of linear conveyor devices of mixing of tubular products of different industrial and household purpose for the purpose of implementation of the principle of the determined forming of uniformity of the mixes received on them. The developed algorithm has to have engineering focus and application. The received mixes have to have ordered structure and exceed on quality indicators received by different ways. Results of theoretical design of this equipment have to be confirmed with practical pilot studies.

Basic data at design of nonmixer are [2-5, 7, 12-14]:
– characteristic of product (diameter, length and mass of tube, their range, tube deflection, strength data, etc.);
– requirements for quality of nonmixing (coefficient of variation or other criterion);
– productivity of nonmixer (mass or piece);
– greatest possible number of components;
– range of possible mixture ratio.

3. Problem solution
The solution of problem is step by step given below:
– modular synthesis and aggregation of the automatic machine according to technical requirements;
– choice of necessary (maximum) capacity of the projectable automatic machine;
– correction of structure nonmixing automatic machines under the specific nomenclature of small parties of tubular lengthy components according to technical capabilities of separate nodes and units;
– adjustment of effective capacity of the automatic machine under the specific nomenclature of small parties of tubular lengthy components according to technical capabilities of separate nodes and units.

The rotor and conveyor device of continuous dispensing and forming from tubes of mix includes four types of modules [2, 9, 12]:
– the loading module consisting of the cartridge and the rotor-portioning device;
– the main (technology) module which is the conveyor where flows of small parties are summed up;
– module of unloading of products;
– module of control and management of process and device, i.e. control system.

The available type of each modular group for all nomenclature of tubes allows to exclude the second stage at design and from the schematic diagram to pass directly to the third stage – the choice of optimum schemes of design of the device, i.e. to configuration of the device for nonmixing of specific products.

Conveyor nonmixer for preparation of mixes, as well as any technological machines, are projected either on set, or on maximum capacity. Special nonmixer are intended for synthesis of mix of one specific standard size of products which program of release is very big and therefore it is necessary to project nonmixer, proceeding from extremely possible values of capacity of component modules.

Modules of loading can provide practically any productivity as they can be put as is wished much. The module of loading can have different constructive implementations and can provide very big capacity. The control system allows, considering availability of high-speed computer systems, to manage large number of devices in unit of time. Therefore, the limiting link in nonmixer is the process module as the single-row arrangement of tubes dictates the specific transport speed which maximum is limited to dynamics of work of nodes of the conveyor, conditions of reception of tubes on the conveyor,
conditions of safe work, etc. Therefore in the beginning it is necessary to define or appoint the greatest possible transport speed of the conveyor, and then to determine the maximum capacity of nonmixer. At design of nonmixer on the set productivity, it is necessary to define in the beginning whether exceeds set maximum capacity. In case of exceeding, the set productivity is equated to maximum, and the set volume of release is provided with creation of several samples of the device.

At the first stage, the necessary module of loading is selected. Proceeding from tube standard size, the cartridge and the rotor-portioning device get out of the corresponding type.

One of the main questions at configuration of conveyor nonmixer for preparation of mixes is definition of number of modules of loading and frequency of rotation of rotors of batchers. In case of low requirements to quality of mix there is no need to determine the feeding portioning devices and minimum necessary number of modules of loading of the device on mass productivity for specific standard size of tube decides in the following sequence [1, 2, 12, 14]:

1. Is defined \( j \)-th the automatic machine capacity share corresponding to weight \( j \)-th the small party given in unit of time

\[
C_j = P_{j\text{mm}} \cdot C,
\]

where \( P_{j\text{mm}} \) — is the mass fraction \( j \)-th small party.

2. The number of rotor portioning devices necessary for giving of tubes is defined \( j \)-th small party

\[
W_j = \frac{1000 \cdot C_j}{\omega_{0j} \cdot C_d},
\]

where \( \omega_{0j} \) — is the average mass of tube \( j \)-th small party; \( C_d \) — is the piece capacity of the rotor portioning device intended for giving of tubes of this standard size.

In case of fractional value \( W_j \) it is necessary to round to the next bigger integer.

Obviously, minimum necessary number of modules of loading for synthesis of mix from six parties as greatest possible number of parties, at any their ratio will be determined by formula

\[
W = \frac{C_p}{C_d} + 6,
\]

where \( C_p \) — is the piece capacity of the device, piece/h

\[
C_p = \sum_{j=1}^{J} \frac{C_d}{\omega_{0j}}.
\]

After that the accepted piece productivity is defined \( C_d^a_j \), the portioning device giving \( j \)-th small party

\[
C_d^a_j = \frac{1000 \cdot C_j}{\omega_{0j} \cdot W_j^a},
\]

where \( W_j^a \) — is the accepted number of the portioning devices giving \( j \)-th small party. Then the frequency of rotation of rotor of everyone is defined \( j \)-th portioning device

\[
n_{R_j} = \frac{C_d^a_j}{Z_j \cdot \eta_1 \cdot \eta_2},
\]

where \( Z_j \) — is the number of grooves (positions) of rotor \( j \)-th portioning device; \( \eta_1 \) — is the coefficient of delivery of tubes on the conveyor considering not sticking of tubes in grooves.
(positions) of rotor, slipping of rotor, etc. By experiments it is established that $\eta_1 \approx 0.8...0.85$ [1, 2, 12-14], $\eta_2$ – is the efficiency of nonmixer; for conveyor nonmixer for preparation of mixes of this type it is possible to accept $\eta_2 \approx 0.9$.

Necessary frequency of rotation is provided with kinematic chain.

In case of lifting of restriction of single-row arrangement of tubes on the conveyor the device is calculated on the set productivity, at the same time minimum necessary number of portioning devices for the limiting option of nonmixing of small parties is defined and the unloading mechanism is checked for capacity.

At increased requirements to nonmixing quality, the device has to turn on also portioning devices, which the number of which must not be less than the largest of the number of small parties. These portioning devices can work in two modes: as feeding, receiving the command for delivery of missing tubes of the relevant small parties, and as basic in case of low requirements to nonmixing quality, or in case of refusal the main portioning devices, or in case of small number of small parties.

At the following stage depending on length of tube, accuracy of its production and productivity the type of the transport orienting device (process module) and devices of unloading (the unloading module) gets out of the available type of the corresponding mechanisms.

It is known that for ensuring uniformity of product it is possible to carry out nonmixing from two to six small parties. At the same time according to specifications, the mass of each small party has to be not less than 1 t, and the difference between the mass of small parties should not exceed 6 t, i.e. the ratio between parties fluctuates from 1:1 to 1:7.

For the purpose of the fullest use of nonmixer, it is necessary that at any ratio and any number of small parties portioning devices whenever possible worked with the largest productivity. At design of universal or specialized conveyor nonmixer for preparation of mixes of tubular product as basic data, in addition to those, which are specified for special automatic machines it is necessary to have also the nomenclature of tubes and minimum allowed capacity of the automatic machine for each standard size of tube.

Let us stop at some design stages of the automatic machine on maximum capacity. Let us look at a specific example. Let us assume that from the nomenclature of tubes, it is necessary to select and constructively construct four sets from the type of cartridges, each of which will provide loading, transportation, unloading and storage of products with length respectively:

– the first set – from 79 to 94 mm;
– the second – from 102 to 130 mm;
– the third – from 127 to 151 mm
– the fourth – from 179 to 190 mm.

Taking into account diameter and length of tube the universal portioning device in which adjustable sidewalls provide loading of tube from 79 to 190 mm long is chosen, and four sets of removable rotors (drums) allow giving tubes with a diameter from 2.7 to 6.8 mm by the piece.

Let us pass to definition of the minimum number of portioning devices necessary for receiving maximum, proceeding from single-row arrangement of tubes on the conveyor, the capacity of the automatic machine for each standard size of tubes at any option of synthesis (synthesis from two to six parties with ratio from 1:1 to 1:7). For this purpose in the beginning, we will establish that $i$ -th tube standard size which will demand the greatest number of portioning devices. Obviously, the greatest number of portioning devices will be for the standard size of tubes having the smallest coefficient of relative productivity representing the relation of capacity of one portioning device $C_{d_i}$ to the maximum cyclic capacity of the automatic machine

$$K_{C_i} = \frac{C_{d_i} \cdot Z_i \cdot \Delta l'_i}{C_{\text{app max}}}.$$
where $\Delta l'$ is the running length of the conveyor necessary for arrangement of one tube. As the frequency of rotation of drums and transport speed of the conveyor change slightly, and height of falling of tube on the conveyor has small size, $\Delta l'$ proportional length of tube can accept.

Then the equation can be written down so

$$K_C \cong K_{const} \cdot Z_i \cdot \Delta l_i,$$

where $K_{const}$ is the constant coefficient; $\Delta l_i$ is the tube length $i$-th standard size.

Thus, the tube standard size having the smallest work of number of grooves of the rotor characterizing diameter of tube at tube length is limiting.

The order of finding of number of portioning devices for the limiting option is similar to the order described at design of conveyor nonmixer for preparation of mixes.

Further four sets of the mechanism of unloading get out of the available type.

**The basic rules of the choice of the device on the set nonmixing. Structure of conveyor nonmixer for preparation of mixes.** Conveyor nonmixer [7,9] for preparation of mixes (figure 1) consist of conveyors of giving of tubes with drying and knives 1, mechanisms of unloading 2, cartridges 3, portioning devices 4, the conveyor of unloading of the created doses 5 and capacity for mix 6.

![Figure 1. Conveyor nonmixer for preparation of mixes.](image)

Conveyor nonmixer for preparation of mixes have to be produced in the specialized readjusted option for nonmixing of tubular products of several standard sizes [7, 9].

Depending on width of cloth of working body of the conveyor of the device, have to be produced three standard sizes:

1.0.0. – with width of cloth of 200 mm;
2.0.0. – with width of cloth of 300 mm;
3.0.0. – with width of cloth of 400 mm.

Depending on cloth length, devices have to be produced three standard sizes:

0.1.0. – with length of cloth of 6000 mm;
0.2.0. – with length of cloth of 9000 mm;
0.3.0. – with length of cloth of 12000 mm.
Depending on the number of the installed batchers, devices have to be produced three types:
0.0.1. – with number of batchers 6;
0.0.2. – with number of batchers 9;
0.0.3. – with number of batchers 12.
Depending on the carried-out functions of control system automatic machines can be without the feeding portioning devices and with the feeding portioning devices in which designation at the end of numbering letter \( P \) is put.
Key indicators of technical and economic overall performance of the automatic machine under indispensable condition of quality assurance according to specifications on nonmixing of tubular products are the cyclic productivity and time of nonmixing of products of certain weight.
As cyclic productivity, size received in the set interval of time of mass of products at equal ratio of component parties is accepted. At the same time, data for two limit standard sizes of products are provided.
As more general criterion of efficiency time is accepted \( T \), during which mix is received by the weight equal to the mass of the automatic machine.
The conveyor of giving of tubes with drying and knives is presented on figure 2.

Cartridges (figure 3) can be executed in two options:
1. in the special (not readjusted) option for laying of tubes of one standard size or tubes of two-three closely standard sizes;
2. in the universal (readjusted) option for laying of tubes of all standard sizes.
The unloading mechanism can be manufactured in two options:
1. with three transferring plates;
2. with two transferring plates.
Figure 3. Distribution range of the 1st small batch.

Portioning devices (figure 4) can be executed in two options:
1. in the special (not readjusted) option for giving of tubes of one standard size;
2. in the specialized (readjusted) option for tubes of different diameter and different length with readjustment of the bunker and reel of piece delivery.

Figure 4. Portioning devices.
The drive provides continuous movement of the conveyor of figure 5, rotation of drums of portioning devices and oscillating motion of plates of the mechanism of unloading. The conveyor tape in all devices moves from speed of 415 mm/s.

Portioning devices are equipped with the drive with the step regulation completed with seven reversible couples of replaceable gear wheels which provide the following frequencies of rotation: 9.8; 10.5; 11.2; 12; 12.8; 13.9; 14.7; 15.7; 16.8; 18; 19.2; 20.5; 22 RPM.

Thus, the range of regulation of frequency of rotation of drums of the batcher and, respectively, batcher capacity, is equal to 2.25.

Unloading of the created doses of mix of tubes is carried out in capacity for mix, figure 6.
4. Discussion of results
Because of the development work, the general principles of choosing an automatic machine for a
given version of nonmixing of tubular products are formulated.
As basic data for selection of conveyor nonmixer for preparation of mixes there have to be following:
1. Mass of the general party \( G \), kg;
2. Quantity of mixed together components \( J \);
3. Ratio of masses \( J \)-th components - \( P_{1b}, P_{2b}, \ldots, P_{j} \);
4. Average density \( j \)-th component - \( \gamma_{avj}, \text{g/cm}^3 \);
5. Average diameter of tube \( j \)-th component – \( d_{avj}, \text{mm} \);
6. Diameter of tube (arch) \( 2\delta, \text{mm} \);
7. Average length of tube \( l_{av}, \text{mm} \);
8. Capacity \( C \), kg/h.
Sequence of the choice of standard size of design:
1. The average mass of tube of everyone is defined \( j \)-th component on formula
\[
\omega_{avj} = \frac{\pi}{4} \left( P_{avj}^2 - d_{avj}^2 \right) l_{av} \gamma_{avj} \times 1000 .
\]
2. The mass of everyone is defined \( j \)-th component \( G_j \) on formula
\[
G_j = \frac{G \cdot P_{jb}}{\sum_{j=1}^{l} P_{jb}} .
\]
3. The quantity of tubes of everyone is defined \( j \)-th component
\[
m_j = \frac{G_j}{\omega_{avj}} \times 1000 .
\]
4. Piece proportions are defined \( j \)-th component; having accepted \( P_{min} = 1 \) for that component which
has the minimum quantity of tubes \( m \), i.e. \( m_{min} \rightarrow P_{min} = 1 \)
Then
\[
P_j = \frac{m_j}{m_{min}} .
\]
5. The sum of piece proportions is defined
\[
P = P_1 + P_2 + \ldots + P_j .
\]
6. The number of the portioning devices giving tubes is defined \( j \)-th component on condition of
nonmixing on the automatic machine, having six portioning devices
\[
W_{j,est} = \frac{P}{6} .
\]
The received values are rounded in the greater or lower side to integer so that the total amount of
batchers was equal 6.
7. Piece productivity of those is defined \( j \)-th batchers which number we reduced, accepting at the
same time the maximum frequency of rotation of the drum equal 22 RPM, i.e.
\[ C_{dj} = n \cdot z = 22z \text{, piece/min,} \]

where \( z \) – is the number of grooves of drum of the batcher.

8. The expense is defined \( j \text{-th component} \)

\[ C_j = C_{dj} W_j \omega_{avj} \frac{60}{1000} \text{, kg/h.} \]

9. The expense of other components from ratio is defined

\[ \frac{C_j}{C_{j+1}} = \frac{P_j}{P_{j+1}}. \]

From here

\[ C_{j+1} = C_j \frac{P_{j+1}}{P_j}. \]

10. Frequency of rotation of drums of the batchers giving other components is defined

\[ n_{j+1} = \frac{C_{j+1}}{W_j \omega_{avj} z}. \]

In view of step regulation of frequency of rotation of drums of batchers calculated value \( n_{j+1} \) can differ from hardware. Therefore for providing more exact set ratio of small parties drums of the batchers giving \( j+1 \) component, can rotate with different frequencies of rotation, however, provided that the general expense \( j+1 \) component it has to be equal \( C_{j+1} \).

11. Cyclic capacity of the unit is defined

\[ C_{app}^{cycl} = \sum_{j=1}^{J} C_j^{cycl} \].

12. The predicted device capacity is defined

\[ C_{app, pre}^{cycl} = C_{app}^{cycl} \eta_{app}. \]

where \( \eta_{app} \) – is the coefficient of technical use of the device (usually \( \eta_{app} = 0.85 \)).

If the predicted productivity of nonmixer is less required, then accept the automatic machine with nine batchers. If and in this case the predicted productivity is less required, then accept nonmixer with 12 batchers.

13. The efficiency of nonmixer – operating time is defined

\[ \tau_{non} = \frac{1000G}{C_{app}^{cycl}}, \text{h.} \]

14. At failure to provide the set productivity, it is necessary installing two automatic machines with the identical or different number of batchers so that the predicted productivity was not less than the specified one.

5. Conclusions

The universal algorithm of design of linear conveyor nonmixer is developed for receiving mixes of piece tubular components of the different nomenclature and physic mechanical properties, at the determined forming of their uniformity. The scientific and practical novelty of the development lies in
the fact that for the first time, in relation to the design of mixing equipment, the algorithm for its design allows you to take into account and link the incoming technological parameters of the dosing and mixing equipment with the final quality characteristics of the finished heterogeneous mixtures. It allows receiving more quality mixes with possibility of the automated forming and management of their quality indicators. Results of practical pilot studies will be provided in the following works of the author.

References
[1] Evseev A V 2014 Classification of nonmixing composite products and devices News of Tula State University. Technical science 3 pp 82–88
[2] Lukash A N, Evseev A V and Chuvpilo A V 2000 Development of technologies and equipment for preparation of mixes of bulks News of Tula State University. Mechanical engineering 5 pp 218–224
[3] Evseev A V, Paramonova M S and Preis V V 2018 A Quantitative Criterion for Quality Mixing Assessment for the Effective Unit of Mixed Products J. of Phys.: Conf. Series 1050 012025
[4] Podgornyj Y I, Martynova T G, Skeeba V Y, Kosilov A S, Chernysheva A A and Skeeba P Y 2017 Experimental determination of useful resistance value during pasta dough kneading J. of Phys., Conf. Series.: Earth and Environmental Science 87 082039
[5] Stepchuk L Ya and Mikulsky V V 2015 Scientific premises to creation of high-precision volumetric batchers of continuous action Transactions of the international scientific and technical conference: Scientific and Technical Progress in Agricultural Production (Minsk) pp 105–116
[6] Weinekotter R and Gericke H 2000 Mixing of Solids (Powder Technology Series, No. 12. Norwell, MA:. Kluwer Academic Publishers) p 156
[7] GOST 8032-84. Preferred numbers and series of preferred numbers
[8] Khan Z S, Van Bussel F, Schaber M, Seemann R, Scheel M and Di Michiel M 2011 High-speed measurement of axial grain transport in a rotating drum New Journal of Physics 13 105005
[9] Lukash A N, Evseev A V and Ovchinikova T A RU Patent No. 2271243 (10 March 2006)
[10] Lukash A N, Klusov I A and Evseev A V RU Patent No. 2129911 (10 May 1999)
[11] Evseev A V RU Patent No. 2707998 (03 December 2019)
[12] Evseev A V Nonmixing 2019 News of Tula State University. Technical science 9 pp 27–36
[13] Aleksandrovsky A A and Akhmadiev F G 1986 Current state and problems of mathematical modelling of loose materials mixing Abstracts to the all-union conference. Part 2 (Belgorod) pp 83–84
[14] Evseev A V, Preis V V and Kasatkin G V 2019 Algorithm to optimize the accuracy of the metering devices for obtaining loose material mixture of a given quality J. of Phys.: Conf. Series 1260 032016