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### **The development of baking technology for bulk materials based on the use of alternative electric furnace**

The article based on the experimental data and it describes the development of a rational design of an oscillatory system for controlled vibrational feeding of bulk materials during their heat treatment in furnaces with a vibratory base plate, which, together with the moving trolley on elastic connections, is the basis to transfer bulk material in the thermal field of an electric heating system with set processing time. To create non-symmetric oscillations and to obtain unidirectional material motion at the horizontal furnace position, the conical springs are used. They should provide a gently inclined resonant peak, which can significantly reduce the sensitivity of the oscillating system to fluctuations of the natural frequency and excitation frequency, stiffness, friction and other factors under high temperatures and instability of the electrical network. However, the total elastic characteristic of the oscillatory system which is obtained as a result of the experiments consists of conical and cylindrical springs and shows a weakly expressed nonlinearity. Therefore, to achieve a transport effect it will require the installation of the entire furnace unit at an angle to the horizon. According to the available experimental data, a linear model of the oscillatory system was utilized.

*Keywords:* an electric furnace for bulk materials burning, vibrating base plate, oscillating system, nonlinear elastic characteristic, amplitude-frequency characteristic, sensitivity of the oscillating system to external factors.

#### *Introduction*

Vermiculite and materials based on it are widely used, so its processing technology is given wide attention [1–4].

The concept of electric furnaces with a vibrating base plate [5–10] appeared as an alternative to modular-trigger furnaces for puffing-up vermiculite concentrates [11]. In a number of works, for example, in [12] there are studies of the heat transfer processes of radiant energy to the processed bulk medium and other energy aspects. These studies showed that the energy efficiency of new furnaces is much greater than the modular-trigger electrical units: the energy density of vermiculite baking has decreased from 170...175 to 75...82 mJ/m<sup>3</sup>. Besides the heating system, which transfers heat of radiant energy to the treated medium, the new furnace contains an oscillating system — the oscillating system is a vibrating base plate, which is designed to control the time of transportation of bulk materials in the hot compartment of baking furnace due to the vibration transport effect.

The purpose of the research is to create a rational design of an oscillatory system and to work out the modes of vibro-displacement of bulk materials as well as figure out the required time for their heat treatment on the base of experiments with a vibrating base plate of a prototype of an electric furnace of a new design.

*Experimental*

The research was carried out on a full-scale physical model (single-phase prototype) (Figure 1).

For a better understanding the design of a furnace with a vibrating base plate shown in Fig. 2 let us consider its construction diagram. Dosing chamber for bulk material 2 is fixed on the frame 1. From the dosing chamber the bulk material is transferred through the tray 3 to the base plate surface 4, which thermally insulated underneath by heat-resistant felt 5.



Figure 1. Furnace prototype with a vibrating base plate: 1 is the drum doser; 2 is the doser drive; 3 is the trigger tray; 4 is the thermal lid; 5 is the heating system; 6 is the frame

There are fasteners 7 on the thermal lid 6 to hold the heating elements 8 which located above the base plate with a gap providing free movement of the bulk medium along its surface. The base plate is fixed on the moving trolley 9 equipped with bearings 10 which are mounted in the guides. The track is spring-loaded on the left by cylindrical springs 11, on the right — by conical springs 12.

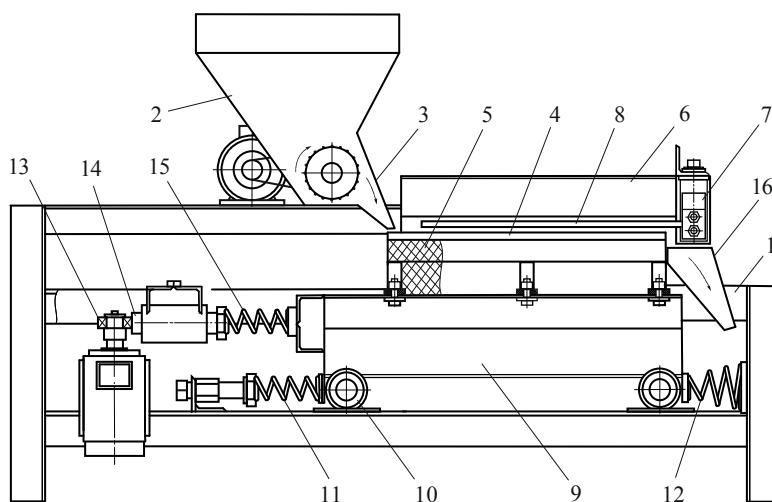


Figure 2. Constructive diagram of furnace prototype (shown in the horizontal position): 1 is the frame; 2 is the dosing chamber for bulk material; 3 is the tray; 4 is the base plate surface; 5 is the heat-resistant felt; 6 is the thermal lid; 7 is the fastener; 8 is the heating element; 9 is the moving trolley; 10 is the bearing; 11 is the cylindrical spring; 12 is the conical spring

The drive engine is equipped with the eccentric bearing fit 13, and therefore impacts on the plunger 14 by its shaft and through the spring 15 excites the vibrations of the moving trolley 9 with the base plate 4, due to which a vibrating-transport effect arises and the heat-treated material is poured through the tray 16.

From the point of view of the total springs elasticity, the oscillatory system is not symmetrical.

The conical springs 12 (Figure 2) were used with the purpose to obtain a nonlinear static characteristic of the oscillatory system and mounted on the side which the bulk material should move [13–17]. In addition, in a non-symmetrical system, the resonance peak on the amplitude-frequency characteristic (AFC) slightly declines to the left, which makes it possible to reduce the sensitivity of the oscillating system to frequency fluctuations, rigidity, friction, etc. in high-temperature conditions and non-stability of the electric network.

Another factor that determines the process of vibrational transportation of bulk product is the dynamic surface tilt which in this case is provided by the tilt of the furnace frame [17–20].

### Results and Discussion

Figure 3 shows a diagram of the oscillating system, which contains four cylindrical springs of stiffness  $c_1$ , one coil spring of stiffness  $c_2$  and four conical springs with variable stiffness  $c_k$ .

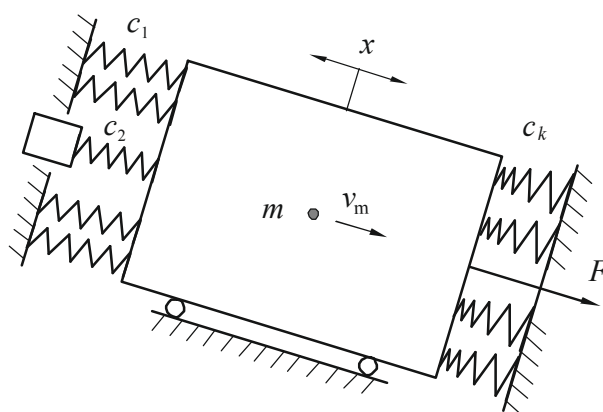


Figure 3. The diagram of oscillatory system

To evaluate the degree of nonlinearity of the oscillatory system as a whole (moving trolley 9, Figure 2), the following experiment was carried out. Using the lever tensioner and a dynamometer F2–13780, the track shifted toward the slope (Figure 3).

The ratio of the lever arms (meter) was:

- in the first case —  $1.825/0.18=10.14$ ;
- at the opposite movement —  $1.665/0.305=5.46$ ;

so in the first case the dynamometer was multiplied by 10.14, in the second — by 5.46.

The results of measurements are given in Table 1.

Table 1

#### The results of static loading system

| Shift toward the slope      |                             | Shift away from the slope   |                             |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Compressive force $F$ , [N] | Moving $x$ , [ $10^{-3}$ m] | Compressive force $F$ , [N] | Moving $x$ , [ $10^{-3}$ m] |
| 0                           | 0                           | 0                           | 0                           |
| 507.3                       | 2.0                         | 211.1                       | 0.5                         |
| 1054.7                      | 4.0                         | 481.2                       | 2.0                         |
| 1521.4                      | 6.0                         | 7785.6                      | 3.1                         |
| 2028.4                      | 7.9                         | 982.0                       | 4.1                         |
| 2535.9                      | 9.4                         | –                           | –                           |

In Figure 4, the experimental points are plotted according to the data of Table 1. The thicker graph reflects the degree of nonlinearity of the oscillatory system, the thin one — linear interpretation of the static elastic characteristic [21–23].

It is obvious that the oscillatory system is characterized by a very weak nonlinearity: firstly because of influence of the cylindrical springs with constant rigidity; secondly, the displacement  $x$  must be too large, to effect the variable rigidity of the conical springs. Therefore, we can consider the total rigidity of the system as a linear interpretation of the elastic characteristic (Figure 4), especially taking into account the result

which were obtained during the dynamic tests — the amplitude of the oscillations in the resonance does not exceed 10 mm.

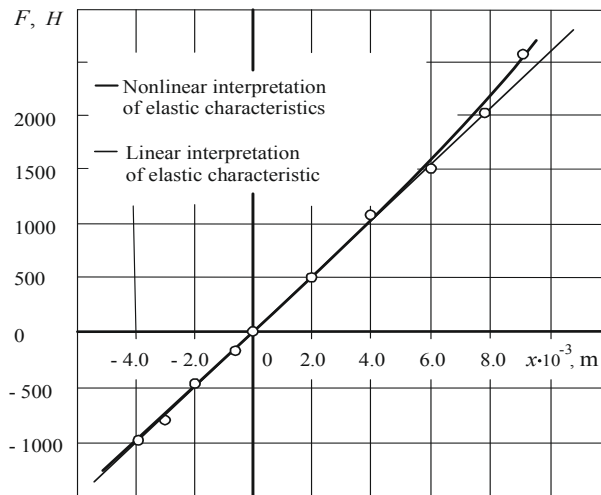


Figure 4. Static chart of the oscillating system

Table 2 shows the results of one of the conical springs loading.

Table 2

**Conical spring**

| Compressive force $F_i$ , [N] | Absolute deformation $x_i$ , [ $10^{-3}$ m] |
|-------------------------------|---|
| 0                             | 0   |
| 41.69                         | 1.45  |
| 137.34                        | 4.75  |
| 196.2                         | 6.35  |
| 290.38                        | 9.05  |
| 340.4                         | 9.85  |
| 393.38                        | 11.95                                       |
| 427.70                        | 13.45                                       |
| 691.79                        | 17.55                                       |
| 767.14                        | 19.55                                       |

Using the data of Table 2, let us determine the average rigidity value  $c_k$  (N/m):

$$c_k = \frac{1}{9} \left( \frac{F_1}{x_1} + \frac{F_2}{x_2} + \frac{F_3}{x_3} + \frac{F_4}{x_4} + \frac{F_5}{x_5} + \frac{F_6}{x_6} + \frac{F_7}{x_7} + \frac{F_8}{x_8} + \frac{F_9}{x_9} \right) = \frac{1}{9} \left( \frac{41.69}{0.00145} + \frac{137.34}{0.00475} + \frac{196.2}{0.00635} + \frac{290.38}{0.00905} + \frac{340.4}{0.00985} + \frac{393.38}{0.01195} + \frac{427.7}{0.01345} + \frac{681.79}{0.01755} + \frac{767.14}{0.01955} \right) = 32944,$$

where  $F_i$  — the compression force of the spring (H),  $x_i$  — its corresponding absolute deformation (m).

Similarly, we determine the rigidity of springs  $c_1$  and  $c_2$  (tabular data are not given):

$$c_1 = \frac{1}{9} \left( \frac{F_1}{x_1} + \frac{F_2}{x_2} + \frac{F_3}{x_3} + \frac{F_4}{x_4} + \frac{F_5}{x_5} + \frac{F_6}{x_6} + \frac{F_7}{x_7} + \frac{F_8}{x_8} + \frac{F_9}{x_9} \right) = \frac{1}{9} \left( \frac{30.41}{0.0015} + \frac{41.69}{0.0034} + \frac{61.31}{0.0046} + \frac{91.23}{0.006} + \frac{100.55}{0.0074} + \frac{136.85}{0.0093} + \frac{147.15}{0.01} + \frac{192.3}{0.0116} + \frac{195.7}{0.0134} \right) = 15030;$$

$$c_2 = \frac{1}{9} \left( \frac{F_1}{x_1} + \frac{F_2}{x_2} + \frac{F_3}{x_3} + \frac{F_4}{x_4} + \frac{F_5}{x_5} + \frac{F_6}{x_6} + \frac{F_7}{x_7} + \frac{F_8}{x_8} + \frac{F_9}{x_9} \right) =$$

$$= \frac{1}{9} \left( \frac{52.97}{0.002} + \frac{136.95}{0.0031} + \frac{195.8}{0.0042} + \frac{216.8}{0.0059} + \frac{290,38}{0.0066} + \frac{340.9}{0.0081} + \frac{392.6}{0.0097} + \frac{399.76}{0.0104} + \frac{441.94}{0.0111} \right) = 39876.$$

In accordance with the diagram of oscillatory system (Fig. 3), its total rigidity will be equal (N/m):

$$c = 4c_k + 4c_1 + c_2 = 4 \cdot 32944 + 4 \cdot 15030 + 39846 = 231742.$$

To calculate the natural frequency of the moving trolley with the base plate, it was weighed on an electronic scale PP 1001 V0 / 3A0R with an upper measurement limit of 150 kgf. As a result, the total mass (m) was equal — 76.4 kg.

For a given set of springs, the natural frequency of the oscillating system was equal, rad/s:

$$\omega_0 = \sqrt{\frac{c}{m}} = 55.1,$$

which corresponds to 8.77 Hz.

### Conclusion

In addition to the electric heating system, which is used to create powerful temperature radiation and to transfer it to the processed bulk medium, a prototype of an electric furnace of a new design was added to the operation. The new furnace also contains an oscillating system in the form of a spring-loaded base plate designed to control the heat treatment process time of the material in the furnace due to the generated vibrating transport effect. The vibratory base plate on the moving trolley is a simple vibrating dispenser that provides the flow and time-controlled movement of bulk materials in the thermal field of the furnace.

We conducted the experiments where the total elastic characteristics of a set of conical and cylindrical springs were aimed to be worked out. The experiments proved that the oscillatory system exhibit a weak nonlinearity, which does not allow transporting bulk material at the horizontal position of the plate. And this requires the installation of a vibration base plate with a slope toward the material being moved in order to achieve a stationary transport process of the bulk material. Therefore, for further research, a linear model of the oscillating system was used for the process of working out the special parameters such as an analytical dependence for calculating the natural frequency of a spring-loaded base plate and the range of resonant oscillations. The parameters were worked out.

However, studies have not yet been completed, since the linear system has some drawbacks related to its high sensitivity to possible fluctuations of the natural frequency and excitation frequency, fluctuations of spring stiffness and friction forces and other factors in high temperature conditions and instability of the electrical network.

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### **Баламалы электрпешті пайдалану негізінде сусымалы материалдарды күйдіру технологиясын әзірлеу**

Мақалада эксперименталды мәліметтер негізінде дірілді тірек плитасы бар пештерде оларды термоөңдеу кезінде сусымалы материалдарға реттейтін дірілді беру үшін тербелмелі жүйенің ұтымды құрылымын әзірлеу сипатталған, ол серпімді байланыстардағы жылжымалы арбамен бірге сусымалы материалдарды берілген өңдеу уақытымен электр қыздыру жүйесінің жылу өрісінде тасымалдау үшін негіз болып табылады. Симметриялы емес тербелістерді жасау және пештің көлденең жағдайында материалдың бір бағыттағы қозғалысын алу үшін конустық серіппелер қолданылған. Олар резонанстық шыңның қиғаштауын қамтамасыз етуі тиіс, бұл тербеліс жүйесінің жоғары температура мен электр желісінің тұрақсыздығы кезінде өз жиілігінің тербелісіне және қозу жиілігіне, қаттылыққа, үйкеліске және басқа да факторларға сезімталдығын айтарлықтай төмендетуге мүмкіндік береді. Алайда, эксперименттер нәтижесінде алынған тербеліс жүйесінің жалпы серпімді сипаттамасы конустық және цилиндрлік серіппелерден тұрады және әлсіз көрінбейтін сызықтықты көрсетеді. Сондықтан көліктік әсерге жету үшін горизонтқа бұрышпен барлық пеш агрегатын орнату қажет. Тәжірибелік деректер бойынша тербеліс жүйесінің сызықтық моделі қолданылған.

*Кілт сөздер:* сусымалы материалдарды күйдіруге арналған электр пеші, дірілді тірек плитасы, тербелмелі жүйе, сызықсыз-серпімді сипаттама, амплитудалық-жиілік сипаттамасы, тербелмелі жүйенің сыртқы факторларға сезімталдығы.

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## Разработка технологии обжига сыпучих материалов на основе использования альтернативной электропечи

В статье на основе экспериментальных данных описана разработка рациональной конструкции колебательной системы для регулируемой вибрационной подачи сыпучих материалов при их термообработке в печах с вибрационной опорной плитой, которая вместе с подвижной тележкой на упругих связях является основой для переноса сыпучих материалов в тепловом поле электронагревательной системы с заданным временем обработки. Для создания несимметричных колебаний и получения однонаправленного движения материала в горизонтальном положении печи используются конические пружины. Они должны обеспечивать пологий наклон резонансного пика, что позволяет значительно снизить чувствительность колебательной системы к колебаниям собственной частоты и частоты возбуждения, жесткости, трению и другим факторам при высоких температурах и нестабильности электрической сети. Однако общая упругая характеристика колебательной системы, полученная в результате экспериментов, состоит из конических и цилиндрических пружин и демонстрирует слабо выраженную нелинейность. Поэтому для достижения транспортного эффекта потребуется установка всего печного агрегата под углом к горизонту. По имеющимся экспериментальным данным, была использована линейная модель колебательной системы.

*Ключевые слова:* электрическая печь для обжига сыпучих материалов, вибрирующая опорная плита, колебательная система, нелинейно-упругая характеристика, амплитудно-частотная характеристика, чувствительность колебательной системы к внешним факторам.

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