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# WAYS OF IMPROVEMENT OF OPERATIONAL EFFICIENCY OF HOPPER DEVICES

**Abstract.** The operation of hopper devices, which are used in industry, civil engineering, agriculture and transport, is analyzed on the article. The external factors, which influence the process of charging, storing and discharging of loose cargo (freights) from hopper tanks, are overviewed. The subject of research of presented paper is the improvement of mechanisms of fracturing of products hangs-up (bridges) in hoppers at the stage of designing and setting up of hopper devices. In order to solve the stated problem the schemes of bridges fracturing and the structures of devices for debarment of products bridging and their uniform outflow from the hopper tank are proposed. The proposed schemes are based on the principles used in development of vibratory machinery with mechanical, cam and electromagnetic vibratory principles of structures forming. For cam spring device of bridges fracturing the technique of calculation of stiffness of elastic system and of the necessary forces for performing of technological process of bridges fracturing is presented and the recommendations for choosing of the stiffness of the system of elastic elements are suggested.

For the hoppers with spring and electromagnetic blocks of bridges fracturing and of metered (batched) feeding of products the structural diagrams of devices are presented and the recommendations for usage of various modifications of devices are suggested. The influence of parameters of flat spring elements on the efficiency of devices operation is overviewed. The structural diagrams of devices with one-cycle and two-cycle electromagnetic vibration exciters and the modifications of elastic systems are considered. the structural diagram of the production prototype of the hopper feeder is presented.

The materials of the article, the proposed structural diagrams, the operation scheme of the hopper feeder and the derived analytical formulas may be used by designers, researchers and technologists while improving of existent and developing of new devices.

**Keywords:** hopper, device, elastic system, armature, electromagnet, stiffness, stabilizer, bridge, loose material, feeder.

## Introduction

Complex mechanization and automatization of production processes, which are carried out in industry, civil engineering, agriculture and transport, provide for the usage of such machines and devices as hoppers, silos and silo tanks. This equipment is the base of loose materials storage facilities. It is widely used in production and technological processes and transporting systems as receiving, transferring, accumulating, dosing (metering), transitional or charging equipment.

The reliability and efficiency of complex operation of machines, equipment, hopper and silo devices depend on their parameters, structural properties, operation modes and exploitation conditions.

## Problem statement

The analysis of situation in transporting, storing and dosing (metering) systems shows that the problems of long-time storing of a product without quality loss, continuous and stable charging and

discharging of loose cargo (freights) are not completely solved. That's why, the research of these processes is being permanently carried out and the search of the ways of their improvement is being continued. The diversity of such investigations and designs concerning the structures of various accessory mechanisms affirms the complicity of the stated problem. Therefore, the improvement of structures of warehousing (storing) complexes and the improvement of efficiency of their operation are the urgent problems, which need the enhanced studying and have to be solved as soon as possible [1–6].

### Analysis of current information sources on the subject of the article

Hopper devices consist of hoppers, charging and discharging devices, stirrers of poor-flowing loose materials, control gates, feeders, exciting devices, apparatus of automatization and control.

The processes of charging, storing and discharging of loose material from the tanks depend on many factors, in particular, on the physical and mechanical properties of the loose cargo and on their changing in time. They largely influence the parameters of the hopper structure and shape and the process of choosing of the materials, which the hopper is made of. In order to improve the process of outflowing it is necessary to be clear about the tank chamber and about the phenomena, which take place inside the tank [3–5].

Such freights as clay, lime, powdered materials, oxides of zinc and silica, soda, snow, cement, mixed fodder, salt, sugar, flour etc. are characterized by the loss of particles mobility (fluidity) during long-time storing, becoming caked (compressed) and forming the monolithic bridges. Such phenomenon is accompanied by the hopper holes clogging that causes the obstruction of material outflowing. The same phenomenon may arise in the case of the hopper filling by small metal or plastic parts.

On the basis of carried out analysis of information sources we may conclude that the processes of storing and outflowing of loose materials may be accompanied by the bridges forming, which depends on the material characteristics being changed during the storing and on the structural properties and parameters of hoppers that may allow to reach the smallest values of pressure at the bottom of the hopper and to stabilize the density of the outflowing product [1–7]. That's why, the prevention of bridges forming and their fracturing are important and urgent problems. Designers should always try to improve such equipment in order to improve its operational efficiency. Nowadays there are no such universal hopper devices which are able to meet all the technological requirements to loose materials with any properties and storage life.

Our attention will be focused on designing and improvement of mechanisms of fracturing of bridges which are being formed in existent structures of hoppers during the metered (batched) feeding of products. This is the main subject of the research because even small improvement of efficiency of these mechanisms ensures large technical and economic effect.

In order to solve the stated problem, the diagrams of mechanisms of bridges fracturing and of improvement of products outflowing from the hoppers are proposed (Fig. 1–2) [10]. The structures of these mechanisms are simple concerning their manufacturing, setting up and servicing. They may constructed by widely spread mechanisms that is very important for modern industry.

### Main material presentation

The structure of the mechanism of bridges fracturing consists of the elastic system 1, the edges of which are attached to the hopper walls, and the stretching device 2 in a view of cam mechanism, which is driven by the geared motor (Fig. 1). On the central (axial) spring suspension there is the pressure stabilizer, which significantly influences the grade of material fluidity during the outflowing from the hopper.

The calculation of this device consists in the determination of elastic system stiffness, of forces, which arise in its elements, and of its structural parameters under the prescribed operation mode.

The theoretical precondition for calculation is the following statement: during the rotation of the cam the displacement of the particle *A* of elastic system should be changed in the range of:

$$\Delta_0 ... (\Delta_0 + R - r),  \tag{1}$$

where $\Delta_0$ is the displacement which characterises the initial spring tension; *r*, *R* are minimal and maximal radius if the cam, correspondingly.
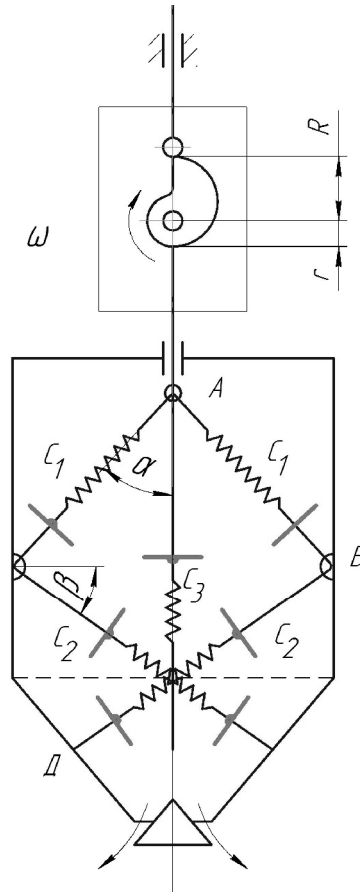
**Fig. 1.** *Diagram of spring mechanism of bridges fracturing*

Maximal force $F_3$ which arise in the spring 3:

$$F_3 = c_3(\Delta_0 + R - r),$$ (2)

where $c_3$ is the stiffness of the spring 3.

Consequently, the maximal value of the force $F_2$ which arise in springs 1 and 2 maybe calculated on the basis of equality:

$$(\Delta_0 + R - r) \cdot \cos\alpha = \frac{F_2}{c_1} + \frac{F_2}{c_2},$$ (3)

$$F_2 = \frac{c_1 \cdot c_2 \cdot (\Delta_0 + R - r) \cdot \cos\alpha}{c_1 + c_2}.$$ (4)

This force is acting upon the hopper at the point Д. In addition, at the point *B* the hopper is influenced by the force:

$$F_в = F_2 \cdot \cos\beta + F_2 \cdot \sin\alpha.$$ (5)

Therefore, the total force which acts upon the cam shaft may be determined by the formula:

$$F_к = F_3 + 2 \cdot n \cdot F_2 \cdot \cos\alpha,$$ (6)

where *n* is the number of pairs of symmetrically placed springs 1 and 2.

During the operation of the mechanism the forces $F_3$, $F_2$, $F_в$ are being periodically changed from the minimal to the maximal value causing the hopper "shaking". Due to the oscillating motion of elastic system, the stabilizer performs reciprocating motion in vertical plane and facilitates the separation of material at the bottom of the hopper stabilizing the pressure and the density of outflowing product. The

change of parameters of oscillating motion also influences the intensity of the process of material outflowing from the hopper.

In order to achieve the betted effect it is necessary to bring the frequency of self-oscillations of elastic system of the filled hopper closer to the frequency of excited oscillation of the cam drive, i.e., to ensure the resonance operation mode of the device.

Let us consider the elastic system of the investigated equipment as separate springs of equal stiffness. The springs are attached as shown in Fig. 1. Using the principle of equivalency [8], let us present this scheme as one-mass oscillating system, which under the influence of external force performs harmonic oscillations of the following frequency [2]:

$$\omega_o = \sqrt{\frac{c_{e\kappa}}{m}} , \qquad (7)$$

where $\omega_o$ is frequency of self-oscillations; $c_{e\kappa}$ is equivalent stiffness of the system; $m$ is oscillating mass (the mass of stabilizer).

If the rotation frequency of the drive shaft and the mass of stabilizer are known one may determine the stiffness of elastic system and the structural parameters of each spring. The amplitude and the frequency are defined by the structural parameters of the cam drive.

In order to calculate the helical (spiral) cylindrical tension (closed) spring of elastic system of the mechanism of bridges fracturing we may use the technique presented in the work [9].

The diagram shown in Fig. 2 ensures the fracturing of bridges and the metered (batched) outflowing of loose and cereal products from the hopper tank 1.
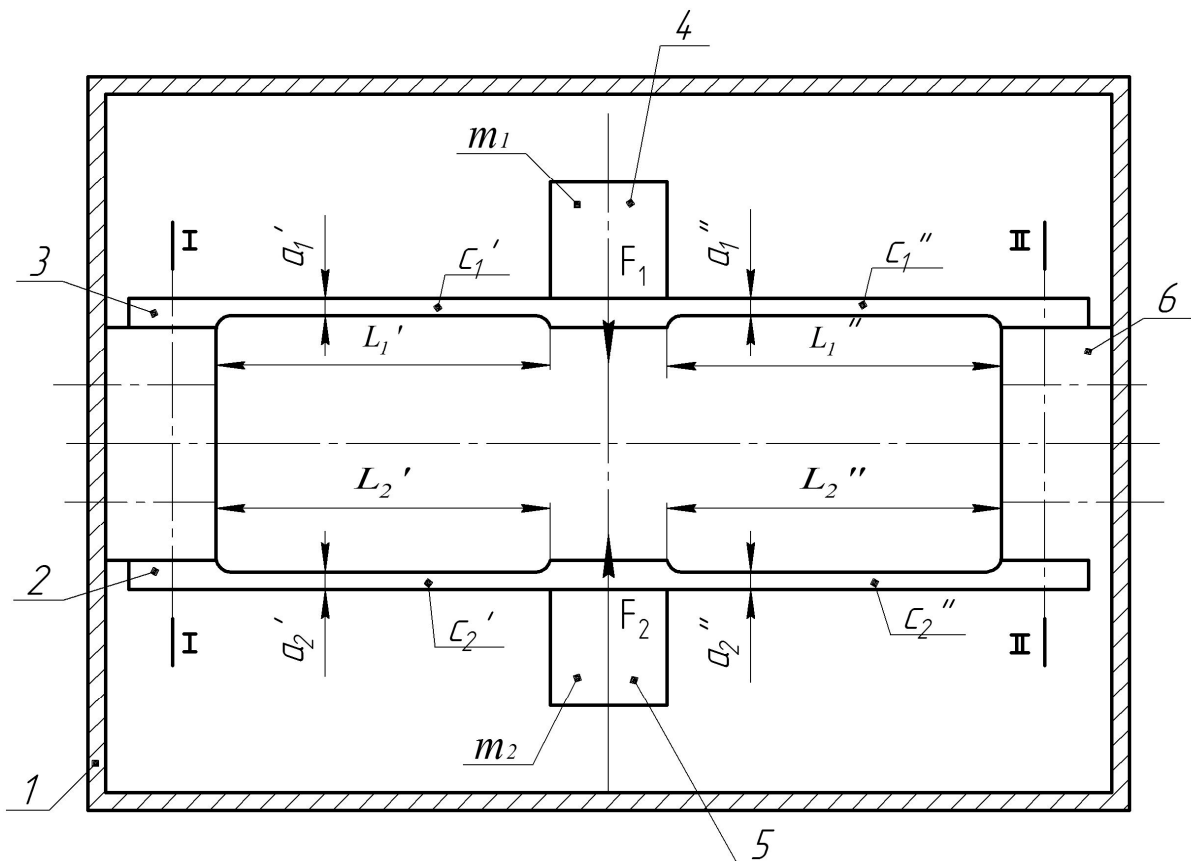


***Fig. 2.*** *Diagram of the hopper with flat springs*

The difference between the diagram of Fig. 2 and the diagram of Fig. 1 consists in the fact that the antiphase harmonic or nonharmonic oscillations are transmitted to flat springs 2 and 3, to central parts of

which two oscillating masses 4 and 5 of values $m_1$ and $m_2$ are attached. The edges of springs are rigidly attached to one with another with a help of inserts 6 which are fixed on the hopper walls. Such structure of elastic system is used in vibratory separators where the inserts act as supporting and hanging (suspending) elements [11; 12].

The applied forces $F_1$ and $F_2$ are equal (concerning the magnitudes) and are balanced in the cross-sections I-I and II-II due to the choosing of springs 2 and 3 stiffness $c_1$ and $c_2$, which are directly proportional to their masses:

$$\frac{c_1}{c_2} = \frac{c_1' + c_1''}{c_2' + c_2''} = \frac{m_1}{m_2}.$$ 
(8)

In vibratory conveyers the fulfilment of condition (8) ensures the effective vibration isolation of the structure because the oscillations of the areas of inserts 6 on the edges of springs are reduced almost to zero. For hoppers, which are filled by the product, it is necessary to excite the simultaneous oscillations of the hopper frame and the product. This may be ensured if the condition (8) is not fulfilled:

$$c_1 \cdot m_2 \neq c_2 \cdot m_1.$$ 
(9)

The masses $m_1$ and $m_2$ in the structures of hoppers have the concrete discrete values. The larger or the smaller value of the inequality (9) is ensured by the changing of the stiffness values $c_1$ and $c_2$ (or their components $c_1'$, $c_1''$, $c_2'$, $c_2''$) which caused the transmission of vibrations to the hopper and the product.

It is well-known [2; 11] that the stiffness of the half part of the flat spring attached according to such method is equal:

$$c_i = \frac{12 \cdot E \cdot I_i}{l_i^3},$$ 
(10)

where $E$ is the modulus of the spring material elasticity; $I_i$ is the moment of inertia of the spring cross-section (for the rectangular cross-section $I_i = \frac{a_i^3 \cdot b_i}{12}$ where $a_i$ and $b_i$ are the thickness and width of the spring, correspondingly); $l_i$ is the length of the nonfastened part of the spring.

By changing the stiffness $c_i$, we may change the values of oscillations amplitudes which are transmitted to the hopper frame. The values of oscillations amplitudes of the hopper are being increased with the increasing of inequality (9), i.e., when the unbalance between the forces $F_1$ and $F_2$ on the hopper walls increases. It is obvious that larger unbalanced amplitudes $A_i$ on the hopper walls will occur due to larger forces because the forces are directly proportional to the amplitudes of oscillating masses:

$$F_i = c_i \cdot A_i.$$ 
(11)

In order to improve the efficiency of the device the impact hammers are fixed on the oscillating masses. They facilitate the fracturing of the material bridges and of the product hands-up and ensure effective metered (batched) discharging of the hopper. In addition, the accessory elements of various configurations may be attached to the oscillating masses $m_1$ and $m_2$ in order to facilitate the effective operation.

The device should be mounted on the stationary supporting construction with a help of soft supports made of coil springs or of elastic rubber elements. By modifying of the spring blocks one may obtain the changeable effects of vibrations transmission to the hopper. The spring blocks may be placed in vertical, horizontal or inclined at various angles $\gamma_i$ planes (Fig. 3)

Electromagnetic vibration exciters may be produced according to one-cycle (Fig. 4) or two-cycle (Fig. 5) schemes [11; 13; 14].

The scheme presented in Fig. 4, *a*, has the electromagnet 1 and armature 2 which are attached to the middle parts of springs of different oscillating masses. The scheme presented in Fig. 4, *b*, has two electromagnets which are fixed on two oscillating masses and are connected by one-cycle scheme exciting larger amplitudes of oscillations.

The scheme presented in Fig. 5 has two electromagnets attached to the mass $m_2$ and two armatures 2 attached to the mass $m_1$.
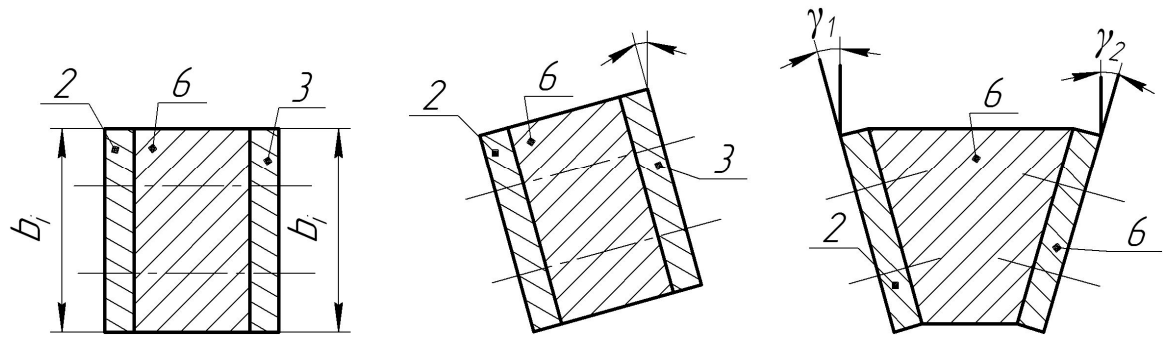
***Fig. 3.*** *Schemes of placing of spring blocks (cross-sections I-I, II-II)*
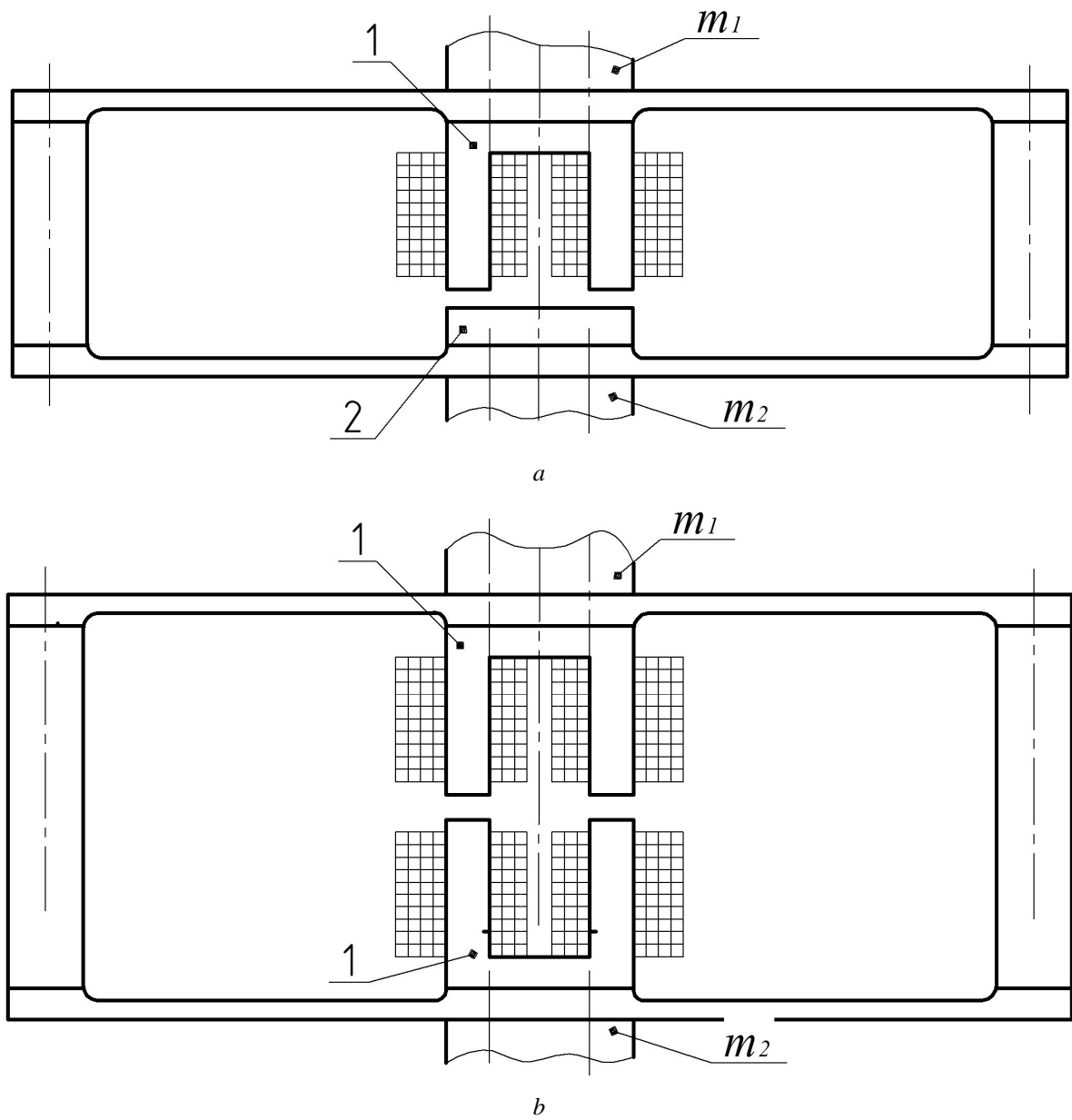


*a*



*b*

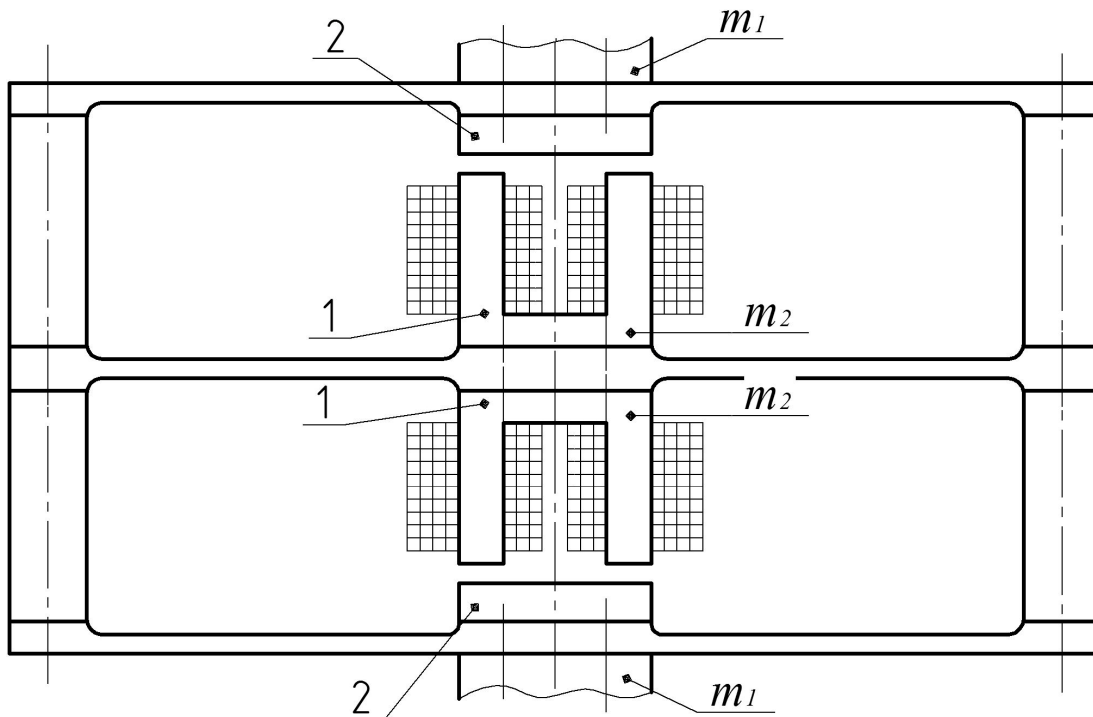***Fig. 4.*** *Scheme of one-cycle vibration exciter*

***Fig. 5.*** *Scheme of two-cycle vibration exciter*

The connection of electromagnets according to the two-cycle scheme of power supply allows to improve the efficiency of usage of the alternating current (AC) network and to obtain larger amplitudes of oscillations using the electromagnets of smaller power. The armatures 2 may be attached to the only mass $m_1$ or the mass $m_1$ may be divided into two parts. This allows to get tree-mass system with improved possibilities by using the phase shift of three-phase AC network [11]. The operation frequencies of oscillations of vibration exciters, which schemes are presented in Figs. 4 and 5, depend on the schemes of power supply. When using the one-cycle schemes of power supply with one phase the doubled frequency of the network (for Ukraine – 100 Hz) is to be divided on any integer of the following series of numbers: 1, 2, 3, 4 … This allows the device to vibrate with exciting frequencies 100, 50, 33.3, 25, 20, 16.7 Hz. When using the two-cycle system of power supply it is necessary to divide on the even number getting the operation frequencies of 50, 25, 16.6 Hz. The analysis of frequencies when using two or three phases of the network is not presented in this paper because it needs more thorough investigation to be carried out.

One of the proposed schemes was used in hopper feeder (Fig. 6) for metered (batched) uniform one-layer feeding of various types of grain products on vibratory conveyer with the simultaneous rupturing of grains by means of infrared heating and obtaining of product of "popcorn" type. In the hopper 1 the unit of elastic system which consists of armature and spring 3 and electromagnet and spring 4 attached by the inserts 9. The unit is rigidly joined to the hopper by bolts 26. Above the spring and electromagnetic unit there is a cone 13 that supports the filled product. The shields 15 and 16 are fixed to two oscillating masses. Between the shields and the cone there are elastic rubbers 14. The structure is mounted on the supports 7 with a help of brackets 6 and elastic damper 18. The gate 4 regulates the area of the discharging window with a help of pneumatic cylinder 39 [15]. The oscillations of the elastic system excited by the electromagnetic vibration exciter ensure the uniform feeding of the product. The developed designs of hopper feeders with the volumes of 10, 15, 30 and 50 liters are reduced to practice for feeding of loose and grain food and nonfood products. The devices allowed to mechanize the discharging with uniform feeding and with fracturing of product bridges and hangs-up. The usage of such devices in combination with vibratory conveyers, which ensure uniform discharging of hoppers, is especially effective [15; 16].
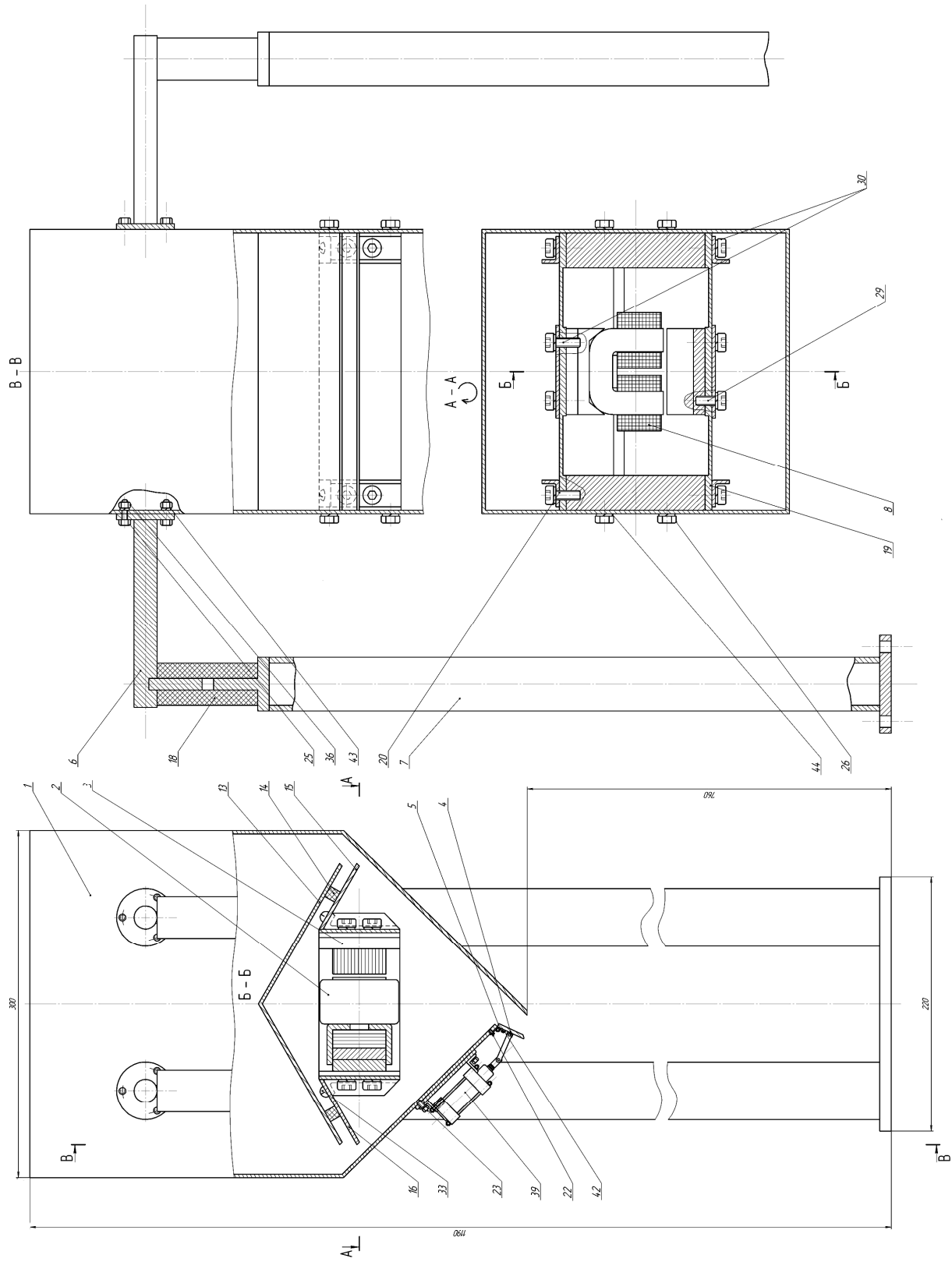
***Fig. 6.*** *Structural diagram of the hopper feeder*

**Conclusions**

The proposed structures expand the operational possibilities of hopper devices. They allow the fracturing of bridges in hopper due to the vibratory motion of its elastic system; the stabilization of density of the outflowing product; ensuring the opportunity of influencing on the outflowing process intensity by changing the parameters of vibratory motion of stabilizer; the improvement of operational efficiency of equipment.

The proposed schemes with one-cycle and two-cycle vibration exciters and various modifications of elastic systems significantly expand the technological possibilities of devices. They are the basis for further improvement and development of new structural designs.

In order to expand the technological possibilities of hopper devices with electromagnetic drive it is expedient to use the three-phase AC network and multicomponent elastic system of block or other type.

the further development of devices designed on the basis of proposed schemes (Figs. 2-6) consists in optimization of structural parameters in order to define the optimal setting up of elastic system with the aim to ensure resonance operation mode in conditions of completely filled hopper tank.

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