Pulse system with electromagnetic linear engine for vaults downfall in bunkers

A V Volgin, V A Kargin, E A Chetverikov, A P Moiseev, E V Volgina, L A Lagina

1 Saratov State Agricultural University n. a. N.I. Vavilov, 1, Theatralnaya Square, Saratov, 410012, Russia
2 Saratov State Law Academy, 1, Volskaya street, Saratov, 410056, Russia
E-mail: saratov-79@list.ru

Abstract. In the technological processes of processing, storage, transport and dosing of loose materials bunker devices are commonly used. The formation of stable vaults in the outlet zone of the bunkers, which worsen or completely stop the outflow of the product, is a characteristic feature of the functioning of these devices. To eliminate or prevent the formation of vault structures, it becomes promising to use linear electromagnetic engines (LEME) characterized by constructive simplicity, direct conversion of electric power into mechanical work of an armature with a linear trajectory of motion, relatively low cost. In this paper we propose the construction of a vault down-faller with pulsed linear electromagnetic engine LEME. The increase in the specific energy indicators of the vault down-faller is closely related to the conditions for effective energy conversion in pulsed linear electromagnetic engines. The use of condenser sources in power systems of linear electromagnetic engines is in many cases effective. For the vault down-faller, the energy W and the storage capacitance C are preliminarily determined so that all energy is released to the winding at the actuation stage and the discharge ends at the time when the pulled armature stops. When the regimes were formed, the found value of W was maintained unchanged for varying discharge times, capacitance and initial voltage of the accumulator.

1. Introduction
In the technological processes of processing, storage, transportation and dosing of various loose materials, bunker devices are widely used.

The formation of stable vaults in the outlet zone of the bunkers, which worsen or completely stop the outflow of the product, is a characteristic feature of the functioning of these devices. To eliminate or prevent the formation of vault structures, machines and devices are used (vault down-fallers) with reciprocating motion of the working body - the striker with electric engines of rotary action with motion transducers, either pneumatic or hydraulic drives, which are characterized by energy carrier preparation and multistage energy conversion [1].

For the vault down-faller, the use of linear electromagnetic engines (LEME) is promising, characterized by constructive simplicity, direct conversion of electric power into mechanical work of an armature with a linear trajectory of motion, relatively low cost [1-4, 11, 12].

In this paper, we propose a pulsed electromagnetic system for intensifying unloading of bunkers and examine some aspects of the justification of its parameters and the construction of elements.
2. The object and method of research

The proposed design of a rare-shot pulsed electromagnetic vault down-faller is shown in Figure 1.

![Figure 1. Construction of the vault down-faller with LEME: 1 – striker; 2 – anvil; 3 – bottom cover; 4 – terminal box; 5 – winding; 6 – stator frame; 7 – return spring; 8, 9 – combined armature; 10 – rubber buffer; 11 – top cover; 12 – a guide.](image)

The electromagnetic machine includes a housing-stator 6, the top 11 and the bottom cover 3, the winding 5, a cylindrical combined armature 8 with a flat disc part 9, the coil spring 7, the guide 12 with the anvil 2. The rubber buffer 10 serves to soften the impacts when the armature 8 is idling. The electromagnetic machine is attached directly to the bunker, pressed to it by the striker 1.

An electrical impulse from the capacitor power supply is supplied to the winding 5. The armature 8 is pulled into the winding under the influence of an electromagnetic force and, compressing the spring 7, impacts the anvil 2. When the armature is struck against the anvil, the striker 1 moves axially relative to the frame 6 of the machine.

The end of the feeding pulse corresponds to the moment of impact of the anvil and the armature, which then returns to its original position with the force of the compressed spring and the cycle repeats.

An important indicator of a pulsed electromagnetic vault down-faller is the impact energy $A_{ie}$, which depends on the kinetic energy of its armature-striker immediately before collision with the bunker. With the chosen type of magnetic system LEME, this value determines the geometric dimensions and mass of the machine [4, 5, 6, 11, 12].

The assessment of the value $A_{ie}$ necessary for a stable downfall of the vault is done through the balance of the $m_{1}$ in pretonic time $t$ of the force (Figure 2), represented as:

$$F_{e} = m_{1} \left( \frac{d^{2}x}{dt^{2}} \right) + F_{sp} + m_{1}g \cos \alpha + F_{fr}$$

where $F_{e}$ – electromagnetic force; $F_{sp}$ - the force of the return spring; $F_{fr}$ - the force of the friction; $m_{1}$ – mass of interacting element; $\alpha$ – the angle of inclination to the wall of the bunker.
Figure 2. A calculation scheme of the forces of the elements "bunker – armature"

The same forces act on the armature at the moment \( \tau \) of the impact of the anvil 2 with the striker 1, but since they are unstressed forces, their action on the collision interval \( \tau \to 0 \) can be neglected. The impact force \( F_{ii} \), which occurs when the elements collide, is large and varies considerably. Therefore, the shock pulse is taken as a measure of their interaction during the time \( \tau \):

\[
\bar{S}_{sp} = \int_{0}^{\tau} F_{ii} \, dt = \bar{F}_{ii} \tau.
\]  

(2)

Having chosen the numerical values of \( S_{sp} \) by the recommendations of [2], it is easy to determine the energy of the impact of \( A_{ii} \). Assuming the direct impact of the armature \( m_1 \) on the wall \( m_2 \) is inelastic, and assuming that the elements \( m_1 \) and \( m_2 \) are fixed at a small impact interval \( \tau \to 0 \), by changing the amount of motion of the armature we find the energy necessary for vault downfall:

\[
2A_{ii} = m_1 v_1^2 = F_{ii} \tau v_1 = \bar{S}_{sp} v_1.
\]  

(3)

where \( v_1 \) is the velocity of the armature of the LEME.

The preferred zone of application of the shock impulse, which ensures effective reduction of the disturbance and determines the location of the electromagnetic vault down-faller on the bunker, is selected taking into account the recommendations of [1].

In the practical designs of LEME, the speed range of the armature is \( V = 5...10 \) m/s. Then, for bunkers with specified parameters (wall thickness) with a known force impulse ensuring stable vault downfall [1], with allowance for the expression (3), it is easy to determine the corresponding energy range of the vault down-faller: \( A_{ii} = 25...50 \) J.

Functional links and interactions in a sparingly pulsed electromagnetic system are represented by a block diagram (Figure 3), the main elements of which are the power supply (PS), the pulse electric converter (PEC), and the vault down-faller with the LEME.

The pulse electric converter PEC with the control device \( CD \) generates the required algorithm for the functioning of the vault down-faller 4 and matches the electrical mode of the power supply source PS and the load (of the engine). The efficiency of transmission of output mechanical energy in the interaction of the LEME and the load (of the vault down-faller 1) is achieved by means of a matching device.

The increase in specific energy indicators of the vault down-faller is closely related to the conditions for effective energy conversion in pulsed linear electromagnetic engines [1, 7, 8, 9, 10]. The use of condenser sources in power systems of linear electromagnetic engines, in some cases is effective [1, 11, 12].

Figure 4 shows a schematic diagram of a pulsed source that contains a cumulative \( C_c \) and the switching \( C_s \) capacitance, charged from the mains rectifier. With the simultaneous opening of the
Figure 3. A structural diagram of a pulsed system with LEME for intensification of unloading of bunkers: 1 – bunker; 2 – screw drive; 3 – screw; 4 – vault down-faller; PS – power supply source; PEC – pulse electric converter; CLSE – contactless switching elements; CD – the control device.

VS1 and VS2 thyristors, $C_s$ capacitance is connected to the linear motor winding $LM$. The thyristor VS3, including the commuting capacitance $C_s$, is unlocked by the armature position sensor [3].

For the vault down-faller, the energy $W_c$ and the capacity of the cumulative $C_s$ are preliminarily determined so that all energy is released to the winding at the actuation stage and the discharge ends at the time when the pulled armature stops. When the regimes were formed, the found value of $W_c$ was maintained unchanged for varying discharge times $t_d$, capacitance $C_s$ and initial voltage $U_i$ of the accumulator.

Figure 4. Impulse source scheme.
Figure 5. The energy diagrams of LEME with capacitor single-pulse power. Cumulative $C_c = 2 \cdot 10^{-3}$ F; $W_c = 100$ J.

Figure 6. The energy diagrams of LEME with capacitor single-pulse power. Cumulative $C_c = 22 \cdot 10^{-3}$ F; $W_c = 100$ J.

3. Conclusion
Comparison of the characteristics shows that the process of converting the energy transferred to the LEME from the storage device depends significantly on its performance.

Cumulatives that realize the forced discharge (Figure 5), when all or most of the energy enters the engine with the fixed armature, form cycles $\psi = \text{const}$ or close to them with significant losses in copper and steel. Smooth discharge of a source of considerable capacity with a reduced voltage (Figure 6) minimizes losses and increases the output of LEME impact 1.4 ... 1.6 times.
The processing of the diagrams shows that the capacitive source makes it easy to realize in electromagnet the cycles with different intensities of converting magnetic energy into mechanical energy and recovering magnetic energy from electrical energy and is an effective means of improving the energy parameters of the vault down-faller with pulsed LEME.

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