Electric converters of electromagnetic strike machine with capacitor supply

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Abstract. The application of pulse linear electromagnetic engines in small power strike machines (energy impact is 0.01...1.0 kJ), where the characteristic mode of rare beats (pulse seismic vibrator, the arch crash device bins bulk materials), is quite effective. At the same time, the technical and economic performance of such machines is largely determined by the ability of the power source to provide a large instantaneous power of the supply pulses in the winding of the linear electromagnetic motor. The use of intermediate energy storage devices in power systems of rare-shock LEME makes it possible to obtain easily large instantaneous powers, forced energy conversion, and increase the performance of the machine. A capacitor power supply of a pulsed source of seismic waves is proposed for the exploration of shallow depths. The sections of the capacitor storage (CS) are connected to the winding of the linear electromagnetic motor by thyristor dischargers, the sequence of activation of which is determined by the control device. The charge of the capacitors to the required voltage is made directly from the battery source, or through the converter from a battery source with a smaller number of batteries.

1. Introduction
The application of pulse linear electromagnetic engines in small power strike machines (energy impact is 0.01...1.0 kJ), where the characteristic mode of rare beats (pulse seismic vibrator, the arch crash device bins bulk materials) is quite effective. At the same time, the technical and economic performance of such machines is largely determined by the ability of the power source to provide a large instantaneous power of the supply pulses in the winding of LEME [1, 2, 5].

From the LEME, the power balance equation is reduced to the form:

\[ ui = i^2 R + Li \frac{di}{dt} + i^2 \frac{dL}{d\delta} V, \]  

(1)

where \( u, i, R \) – voltage, current, active winding resistance; \( L \) – inductance; \( \delta, V \) – the displacement and speed of the armature. It follows that the rate of change of energy in the motor winding determines the efficiency of energy conversion at the stage of \( t_{st} \) starting (the second term) and at the stage of movement \( t_{mov} \) phase (second and third terms) of the armature. To increase the efficiency, it is necessary to ensure on the interval \( t_{st} \) the possible large values of current \( i(t) \), and speed \( di/dt \) of change, i.e., the forced accumulation of magnetic energy in the inductance of the machine, and at the stage of the movement – the possible constant values of \( i(t) \), ceteris paribus \((R, L)\).
To fulfill these conditions, the power supply must form a voltage pulse with a steep edge, \( \frac{dU}{dt} \to \infty \) at the stage of \( t_0 \) on the LEME winding and not significantly decrease the value of \( U(t) \) in the interval \( t_{mov} \), movement of the armature.

The rectified AC voltage pulses commonly used to power the LEME largely do not meet these requirements, especially in single-phase half-wave rectified power. This significantly degrades the achievable power and energy performance of impact machines with LEME. Their improvement by the artificial increase on the interval \( t_{mov} \) by anchoring is achieved by complicating and reducing the reliability of the design of the engine, the increased load on the power source, additional noise in the operation.

The use of intermediate energy storage devices in power systems of rare-shock LEME makes it possible to obtain easily large instantaneous powers, forced energy conversion, and increase the performance of the machine. The capacitive storage devices possess good specific parameters for stored energy \( W \leq 10^4 \) J. The energy of the capacitors, determined by capacitance \( C \) and voltage \( U \), is easy to control both at the charge stage and at the stage of power output to the LEME.

For drives of rare-shock machines (\( f_{str} \leq 0.1 \) Hz), it is possible to use electrolytic capacitors, despite their higher losses. A distinctive feature of these drives is a comparatively low charge voltage (\( U_{cs} \leq 100 \) V) and a significant battery capacity (\( C = 0.03...0.75 \) F for the LEME with strike energy of \( 0.015...1.0 \) kJ) with good weight and size parameters.

The direct conversion of the energy of the storage power source SPS to the supply pulses for the LEME with impact energy of \( A_{st} > 100 \) J and the frequency of moves \( n_{st} = 7...10 \) Hz is accompanied by an excessive load on the accumulators and degrades their performance.

In autonomous electromagnetic pulse machines, where the requirements of minimum dimensions, weight, manual carrying and starting time of the source and converter are not decisive, it is advisable to supplement the battery power source with an intermediate capacitive energy storage device.

### 2. Subject of research

Pulse dosing of a stream transmitted by the source in LEME of energy is provided by special electrical converters, due to which the energy of the source is supplied to the winding of the motor in the form of unipolar pulses of voltage and current [2, 4, 9, 13].

A generalized block diagram of a system with a capacitive storage device is shown in Fig. 1.

![Figure 1. A block diagram of the converter with a capacitive storage device](image)

The sections of capacitive storage \( CS \) are connected to the LEME winding by thyristor discharger \( VS \), the switching sequence of which is determined by control device \( CD \). The charge of capacitors \( CS \) to the required voltage is produced either directly from battery source \( SPS \), when \( U_{sps} = U_{cs} \), or through the converter from \( SPS \) with fewer batteries when \( U_{cs} = (2 \div 3) U_{sps} \).

Since the frequency of charge-discharge cycles is small, and the time for the output of energy from the \( CS \), determined by the armature travel interval, is significant (20 ... 150 ms) for the LEMEs under consideration, a large capacity tank (up to 1 F or more) with a relatively low charge voltage (100 V) is
considered as expedient. Since the voltage of the battery source voltage is less than the voltage of the charged CS, and the intensive charging of the drive is not necessary, the system applies a relatively low-power transistor converter with high switching frequency of the power elements. Since the power supply pulses are formed when the accumulator is discharged to the LEME winding, there is no need for artificial commutation gaps in the scheme, or it is greatly simplified.

A capacitor power source of a pulsed source of seismic waves SSW for the exploration of shallow depths is proposed [1, 3, 5, 14].

In the diagram (fig. 2), LEME M winding via thyristor discharger VS is connected to the contacts of the storage, which is charged from the GB batteries through the DC-DC converter.

Its capacity is determined by the energy of the charged accumulator and the charging time of capacitors CS to the maximum voltage. Limitation of the output current of the converter at the beginning of charging and prevention of the effect of a charged CS on the output circuit of the converter is provided by inductor L and diode VD5. To reduce the intrinsic inductance of the capacitor coupling source to the battery the discharger circuit VS and the output terminals are made with short, stiff tires of large cross-section.

The control algorithm of the condenser source determined by the exploration technology and the necessary interlocks are set by the control unit of the control device. The use of relay elements in schema CD greatly simplifies the task of testing or commissioning in the field, reduces the requirement for training of personnel and appears to be reasonable.

The duty cycle is as follows. Before starting the source, toggle switch S is moved to the "Operation" position. Pressing with a short delay (0.3 ... 0.5 s), the SB1 button "Charging storage device" switches the device on. At the holding interval of the SB1 button, an impulse tripping releasing of the KM contactor, briefly shunting the VS discharger, and the subsequent operation of the KL3 relay, which connects the input terminals of the converter to the batteries GB and activates it, are provided.

Undesirable in the transient start-up process, the idle mode of the converter is prevented at this stage by load resistor R5 connected to the output terminals of relay contact KL1. The release of the SB1 button provides the output voltage of the converter to the terminals of the CS drive through the VD-L elements and the disconnection of load resistor R5 to reduce losses.

As the charge increases, the voltage at the terminals of the storage increases. When it reaches a voltage stabilizing Zener diode VD7, VD8, their breakdown occurs, which ensures the emission of the
LED of thyristor optocoupler $VU1$ and unlocking the photothyristor including the $KL2$ relay. The converter is disconnected from the SPS and the charge storage is terminated. Signaling the termination of charging $CS$ and its readiness for action is provided by light-emitting diodes $VD4$, $VD6$.

Control of thyristor discharger $VS$ that connects the drive to winding $SSW$ LEME is made either with the $SB2$ button "Fire" with a remote control board, or "Sync" contact, controlled from the keyboard of the seismic station. After the discharge of the storage on the LEME winding, the circuit returns to its original state and the cycles are repeated by pressing the $SB1$ button "Storage charge". The device is provided with the necessary interlocks that increase safety and convenience in operation, and provide different levels of the charge voltage of the $CS$ and the output energy of the LEME $SSW$. The main technical parameters of capacitor source $SSW$ are the capacity of storage $C_{st}=0.7...0.9$ F; charging voltage $U_{st} \leq 100$ V; energy storage $W_{st} \leq 4.5$ kJ; charge time to maximum voltage $t_{ch}=6$ s; the duration of the discharge pulse in the winding of the SSW $t_p \approx 100$ ms; the amplitude of discharge power $P_d \approx 70$ kW; battery voltage 36...48 V.

3. Conclusion
The capacitor power supply of a pulsed source of seismic waves is proposed for the exploration of shallow depths. The electric converter is stable in operation, realizes the necessary range of output parameters regulation determined by the process conditions.

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