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Volodymyr T. Chemerys,
Volodymyr F. Bolyukh,
Vadym V. Mashtalir

THE PROJECT ANALYSIS OF INDUCTION THRUSTER PARAMETERS FOR THE FIELD MORTARING

Introduction

The operational process of induction accelerator is investigated good enough now both theoretically and experimentally. Moreover, it stays a hobby design for the US, Russian and UK students (we can find easy the corresponding web-sites, especially the site about UK coilgun has the fundamental view). While the creation of multi-stage accelerator at high outlet velocity is connected with many technical problems (they have been described in details in the papers of scientists [1], [2]) one stage inductor system does not born the great troubles for application. The modern development of industrial electronics allows to begin the engineering analysis for induction accelerator application as the launchers of macrobody at limited energy and output velocity, for example, for the light field mortar. The needed outlet speed of mine usually about 200 up to 400 m/s with mass about 3 kg. To get kinetic energy of mine 60 up to 240 kJ that is necessary to have the electromagnetic energy store 120 ... 350 kJ per shot on the board of combat vehicle. Staying in the mid of this range, this problem is looking realistic. The mass of capacitors at such energy is quite transportable, and the power of the board electrical generator is quite enough for the charging of capacitor battery. So the electric scheme of charge/discharge contour will not have the technical troubles, and main attention in the process of design must be applied to the making of needed lifetime for the inductor coil. Specifics of electromagnetic acceleration process when the radial pressure on the walls of barrel is absent gives a possibility to reduce the barrel mass and to provide its casualty control. The project analysis of the mortar set on the base of light combat vehicle has been performed by authors and obtained results are presented in the paper. For the estimation of awaiting parameters of shot the simulation software has been used for the accelerator jointly with equations of charge/discharge contour.

I.Preliminary Consideration of Parameters Required

1.1. Goal Parameters Choice

Most usable light mortar has the next design characteristics: arrel caliber 81—82 mm; barrel length 1220 mm; mass of barrel 19 kg; total mass of mortar 68 kg; mass of mine 3.1 kg up to 3.6 kg; length of mine 250...300 mm; explosive charge in mine 0.4 kg; main drive powder charge: 8 grams (for initial velocity of mine 70 m/s); additional drive powder charge: 7...42 grams (for initial velocity of mine 105...210 m/s); maximal gas pressure in the barrel 250 kg/cm^2 ≈ 25 MPa; number of feathers in stabilizer: 6, 10 or 12; distance of fire: from 150 m (angle 75°) up to 2500 m (angle 45°); fire repetition frequency: 15 up to 18 min^{-1} (not more than 30 min^{-1}).

This data show that exchange of powder drive for electromagnetic thruster does not give the essential advantage in the sense of possible increase of explosive charge in account of removed drive powder charge. The gain is possible, first, in the mass of barrel decrease due to absence of radial pressure on the wall during the electromagnetic launch, and second, in the increase of initial velocity of mine without added powder charges So, the next parameters have been accepted as initial data for electromagnetic drive design: total mass of mine 3.5 kg; maximal initial velocity of mine 250 m/s; kinetic energy of mine 109.375 kJ.

1.2.The Choice of Suitable Components for the Energy Store

As result of the preliminary investigation it was possible to accept the estimated efficiency of electromechanical energy conversion for the chosen outlet velocity of projectile on the level 50 %. Correspondingly the needed energy store must be near 218.75 kJ. In spite of the best efficiency at fast discharge of the high voltage 20...25 kV capacitors, the mass and volume of capacitors for the movable pulsed source are looking more acceptable at the operational voltage on the level 10 kV. The capacitors of the General Atomics Company, Series C have been taken for the analysis. Most suitable units and their parameters are presented in the Table 1.

Table 1.

Capacitors "General Atomics" for the Energy Store

Serial No.	Max. voltage, kV	Capacity of unit, μF	Mass of unit, kg	Volume of unit, m^3	Discharge current, kA (max)	Energy store, kJ
32312	11	680	117.9	0.0697	125	41
32327	11	830	145.2	0.08677	150	50
33593	20	50	65.8	0.041	50	10

The set of capacitor units needed for the provision of the mine thrust is shown in the Table 2.

At the calculation of data for Table 2 it was accepted that electromechanical efficiency of induction accelerator everywhere is equal to 0.5. This value was confirmed during the simulation of acceleration process with special software implemented in the standard package MATLAB. For the Table 2 the energy store in the capacitor battery is 218.75 kJ for the units of serial No. 32312 and 240 kJ for units of serial No. 32327 and 33593. That is twice more than kinetic energy of projectile. The charge voltage is taken less than maximal one to provide the improved reliability of capacitor units.

Table 2.

Needed Capacitive Store for the Mine Thruster

Serial No.	Mass of mine, kg	Initial velocity m/s	Charge voltage for capacitor kV	Charge voltage per max. voltage	Number of units in the energy store	Total capacitance of the energy store, μF	Total mass of battery, kg	Total volume of battery, m^3
32312	3.5	250	8	0.727	10	6800	1179	0.697
32327	3.8	250	8	0.727	9	7470	1306	0.78
33593	3.8	250	15.5	0.775	40	2000	2632	1.64

The main criteria for the choice of the capacitor units are the total mass and total volume. Due to these parameters the variant on the base of capacitor units of serial No. 32312 was accepted as the main for the next study. At the fire repetition frequency $f = 15\ min^{-1} = 0.25\ sec^{-1}$ the power of the charging source must be $218.75 kJ \cdot 0.25\ sec^{-1} = 54.7$ kW. This power corresponds to the possibility of the board drive system at the light combat vehicle.

To be suitable for application in the mortar with induction thruster the standard mines must be modified as it is shown in the Fig. 1. The electro-conducting ring of copper *3* must be inserted in the leading surface of mine. It will serve as the secondary contour of induction accelerator. In this connection the wall of the mine case may need some increase under the copper ring for the saving of explosive effectiveness of mine.

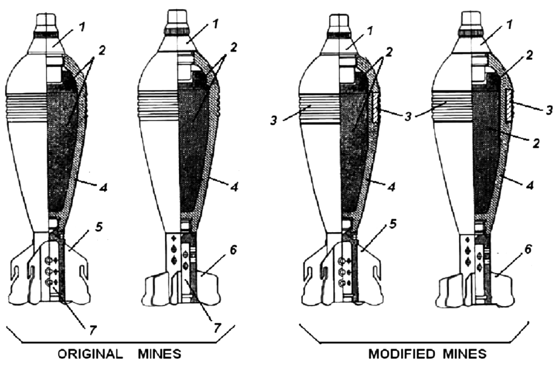

Fig. 1. Needed modification of standard 81—82 mm mines for using in the electromagnetic mortar.
Designations: 1 — blaster; 2 — explosive charge; 3 — leading ring (copper insert); 4 — case; 5 — stabilizer (6 feathers); 6 — stabilizer (10 feathers); 7 — driving powder charge (deleted in modified mines).

II. Main Characteristics of the Software Used at the Thruster Simulation

2.1. General Peculiarities of Simulation Program

For the project analysis of the induction thruster the original software program has been developed and implemented in the package MATLAB v. 6.5. Created on the base of the usual theoretical correlations, the program has some peculiarities which make it suitable for the multiple calculations. The special approximation has been introduced about relative distribution of current density along the length of the secondary electric contour (armature) mounted at the mine body taking into account the exit of forward edge of armature out of magnetic interaction. In result it was possible to consider magnetic interaction between two distributed contours (primary inductor and secondary armature) as between two big coils of given external dimensions. The change of resistance for each contour is calculated at the variable in time radial depth of current penetration. The change of the radial skin layer depth has the weak influence on the magnetic coupling of electric contours, so the main factor which defines the energy conversion is the axial displacement of armature with respect to inductor coil. For the account of thermal effects the known analytical approximations have been introduced into the program giving a dependence of electrical conductivity and specific heat capacity on the temperature of conductors. In comparison with popular programs of induction accelerator simulation where each contour is exchange by the totality of discrete elementary contour, our program is much more rapid and provide more correspondence between meanings of the own and mutual inductances of contours. In many works the own inductance and mutual inductance between two contours with a magnetic coupling have been calculated at using of formulae developed by different authors, what sometimes does not provide a correct transition of the mutual inductance into the own inductance at the full coinciding of contours. To provide such correct transition we calculate the own and mutual inductance using only formula for mutual inductance. The own inductance of primary or secondary contour is calculating by putting both contours in dimensions of one or another. Then, as coefficient of coupling in this case is equal to1, mutual inductance here is equal to own inductance. That is a good way to except the possible disagreement in formulae.

Theoretical equations and correlations as well as the accepted approximations have been transformed in the numerical model into non-dimensional form using the system of basic units for time, length, currents and voltage. In result the number of designing factor which have influence on the acceleration process has been shorten more than twice due to formation of the combined criterial parameters.

The system of the main criterial parameters includes:

1. Basic values: the characteristic time of process $T_{bas} = (L_1 \cdot C)^{1/2}$; characteristic length l_{bas} — it is safe to accept this length equal to the axial length of inductor coil l_1, i.e. $l_{bas} = l_1$; basic velocity $V_{bas} = l_{bas} / T_{bas}$; initial (charging) voltage of energy store U_{C0}; basic value of primary current amplitude$I_{1bas} = C \cdot U_{C0} / T_{bas}$; basic value of secondary current amplitude (total current of armature) $I_{2bas} = I_{1bas} M_{\max} / L_2$; maximal coefficient of magnetic coupling of primary and secondary contours $K_0 = M_{\max} / (L_1 \cdot L_2)$; electrical conductivity of the inductor coil conductor at 0˚C (g_{10}); electrical conductivity of the armature conductor at 0˚C (g_{20});

2. Key criteria in the simulating system of equations: normalized dependence of the mutual inductance on armature displacement $r(z) = M(z) / M_{\max}$; initial non-dimensional displacement of armature with respect to inductor along the motion direction (z_0 / l_{bas}); non-dimensional function of electrical conductivity dependence on the temperature:

for the inductor

$$g_{1\tau} = g_{10} / [1 + k_{R1}(T_1 - 273)]$$

and for the armature

$$g_{2\tau} = g_{20} / [1 + k_{R2}(T_2 - 273)];$$

non-dimensional function of heat capacity dependence on the temperature in the form: $(cc_V)_1 = c_1 \cdot c_{v1} \cdot \exp(\alpha_1(T_1 - 273))$ for the inductor

and $(cc_V)_2 = c_2 \cdot c_{v2} \cdot \exp(\alpha_2(T_2 - 273))$ for the armature;

ratio of energy $q = W_{C0} / W_K$; thermal criterion for the conductor of the inductor coil $Q_{1T} = W_{C0} / Q_{1bas}$; thermal criterion $Q_{2T} = W_{C0} / Q_{2bas}$ for the conductor of armature.

The next designations have been used above: $z = x / l_{bas}$ is the non-dimensional coordinate (location) of armature in the inductor frame, x is dimensional path; C is the capacitance of the energy store; L_1 is the own inductance of inductor coil (primary contour); L_2 is the own inductance of the armature (secondary contour); M_{max} is the maximal mutual inductance between contours (for symmetrical position of one inside another); $W_{C0} = 0.5C \cdot (U_{C0})^2$ is the initial energy store in the battery of capacitors; $W_K = 0.5m(V_{bas})^2$ is the basic (~ awaited) kinetic energy of projectile; m is the full mass of projectile (charged mine); k_{R1} and k_{R2} are the coefficients on the temperature dependence in the formulae of electrical conductivity at inductor and armature, respectively; α_1 and α_2 are the coefficients of temperature dependence of heat capacity on temperature for the inductor and armature conductors, respectively; Q_{1bas} is the initial enthalpy of the basic volume of the inductor coil conductor at the temperature T_{10} by Kelvin (before a launch), Q_{2bas} is the initial enthalpy of the basic volume of the armature conductor at the temperature T_{20} by Kelvin (before a launch):

$$Q_{1bas} = c_1 \cdot c_{v1} \cdot A_{1bas} \cdot T_{10};$$

$$Q_{2bas} = c_2 \cdot c_{v2} \cdot A_{2bas} \cdot T_{20}.$$

Here c_1 and c_2 are the meanings of density for the material of inductor and armature conductors, respectively; c_{v1} and c_{v2} are the initial meaning of the specific heat capacity for the materials of inductor and armature conductors, respectively; A_{1bas} and A_{2bas} are the basic volumes of current-carrying layers of conductor at inductor coil and armature, respectively.

The basic volumes of conductors are calculated as

$$A_{1bas} = 2\pi r_1 l_1 k_1 \Delta_1, \quad A_{2bas} = 2\pi r_2 l_2 k_2 \Delta_2$$

where r_1 is the internal radius of the inductor coil (taken without insulation layer), r_2 is the external radius of the armature conductor, $k_1 < 1$ is the linear coefficient of the inductor coil length filling by conductor, Δ_1 and Δ_2 are the radial thicknesses of conductor in the inductor coil and armature, respectively. For the more accuracy each of them can be taken equal to the awaiting thickness of skin-layer for corresponding conductor at the end of acceleration process.

2.2. System of Equations for the Solution in the MATLAB

Equations of the electrical contours prepared for the solution in the MATLAB take a view:

$$\frac{\partial i_1}{\partial \tau} = [(K_0^2 \cdot \gamma(z) \cdot i_1 \cdot \frac{\partial z}{\partial \tau} \cdot \frac{\partial \gamma(z)}{\partial z} + K_0^2 \cdot \gamma(z) \cdot a_2 \cdot i_2 - K_0^2 \cdot i_2 \cdot \frac{\partial z}{\partial \tau} \cdot \frac{\partial \gamma(z)}{\partial z} - a_1 \cdot i_1 + \nu(\tau))]\frac{1}{(1 - K_0^2 \cdot \gamma^2(z))};$$

$$\frac{\partial \nu(\tau)}{\partial \tau} = -i_1;$$

$$\frac{\partial i_2}{\partial \tau} = [(K_0^2 \cdot \gamma(z) \cdot i_2 \cdot \frac{\partial z}{\partial \tau} \cdot \frac{\partial \gamma(z)}{\partial z} + \gamma(z) \cdot a_1 \cdot i_1 - i_1 \cdot \frac{\partial z}{\partial \tau} \cdot \frac{\partial \gamma(z)}{\partial z} - a_2 \cdot i_2)]\frac{1}{(1 - K_0^2 \cdot \gamma^2(z))};$$

Here i_1, i_2, are the normalized currents of primary and secondary contour, respectively, $\nu(\tau)$ is the normalized voltage of energy store.

Equation of the armature motion takes a view

$$\frac{\partial z}{\partial \tau} = u; \quad \frac{\partial u}{\partial \tau} = q \cdot K_0^2 \cdot i_1 \cdot i_2 \cdot \frac{\partial \gamma(z)}{\partial z}$$

here z is the non-dimensional armature displacement in time at the frame of inductor; u is a normalized velocity of projectile.

With a using of basic volumes and basic enthalpy a non-dimensional temperature of each current-carrying layer can be calculated in millisecond range of process duration neglecting the heat propagation out of the current-carrying layer (skin depth) [4]. The next equation is written for the inductor heating: $\frac{d\theta_1(\tau)}{d\tau} = \frac{i_{1eff}^2(\tau) \cdot a_1(\tau)}{\tilde{\delta}_1(\tau)} \cdot Q_{1T}$, where $\theta_1(\tau) = T_1(\tau) / T_{10}$ is a non-dimensional temperature of inductor conductor; $a_1(\tau) = R_1(\tau) \cdot (C / L_1)^{1/2}$ is a non-dimensional resistance of inductor coil as the function of non-dimensional time τ; $i_{1eff} = 0.707\, i_1$ is the primary "heating" current; $\tilde{\delta}_1(\tau) = \delta_1(\tau) / \Delta_1 = \frac{1}{\Delta_1}[b_0 + \left(\frac{\tau \cdot T_{bas} \cdot g_{10}}{\mu_0 \cdot g_{1\tau}}\right)^{1/2}]$ is the time-varying non-dimensional depth of the current penetration in the radial direction of inductor coil; $\mu_0 = 1.26 \cdot 10^{-6}$ H/m, $b_0 \approx 10^{-6}\, m$ is the skin depth taken for $\tau = 0$.

Similarly, the equation for armature has a view $\frac{d\theta_2}{d\tau} = K_0^2 i_{2eff}^2(\tau) \frac{a_2(\tau)}{\tilde{\delta}_2(\tau)} Q_{2T}$, where $\theta_2(\tau) = T_2(\tau / T_{20})$ is a non-dimensional temperature of inductor conductor; $a_2(\tau) = R_2(\tau) T_{bas} / L_2$ is a non-dimensional resistance of secondary contour calculated with account of change of current-carrying cross section in a time; $i_{2eff} = 0.707\, i_2$ is the secondary "heating" current; $\delta_2(\tau) = (1 / \Delta_2)[b_0 + (\tau \cdot T_{bas} g_{20} / (\mu_0 g_{2\tau}))^{1/2}]$ is the time-varying non-dimensional depth of the current penetration in the radial direction of the armature conductor, K_0 is the initial value of magnetic coupling coefficient. At the process of solution the temperature of conductors can be obtained directly in Celsium degrees if the initial values are given.

The solution of described system of non-dimensional differential equation was obtained in the package MATLAB using the internal subroutine "ode15s" FOR the time interval [0, 1.5] with a step 10^{-4} at the initial conditions: $\nu(0) = 1$; $i_1(0) = i_2(0) = 0$; $z(0) = z_0$ (varying as 0.05...0.3); $u(0) = 0$; $\theta_1(0) = 1$; $\theta_2(0) = 1$.

MATLAB provides the output of unlimited number of graphs in debug mode. Time of solution in the ready program is very small and depends mainly on the number of extracted graphs of functions.

2.3. Short Resume about Main Properties of Simulation Program

Resuming it is possible to give a brief list of characteristics for the simulation program developed in this work.

1. Program realizes the acceleration process simulation taking into account the non-linear properties of electrical conductivity and specific heat capacity as the function of the conductors temperature.

2. Thermal state of active conductors is estimated in the program with the average temperature on the thickness of current skin layer.

3. Program uses the generalized non-dimensional characteristics of magnetic coupling between inductor and projectile which is built on the base of fundamental investigations of other authors [3].

4. The program takes into account the change of the current-carrying zone dimension at the armature in the result of its displacement with respect to inductor coil.

5. Implementation of differential equation in the non-dimensional form led to the shortening of design parameters under consideration, it is enough practically to use 7 generalized criteria instead 18, only 5 of 7 are the signs of acceleration mode, and remains 2 of them form the group of functions which are the characteristics of the applied conducting materials.

6. The program fulfills the calculation of the skin depth at the inductor and armature as the continuous functions of time.

7. The program uses the improved procedure of the own and mutual inductances calculations by application the same formula to both of them.

8. Program was added by the account of nonlinear thermal effects in the active conductors in comparison with published first version [5].

III. Dynamics of the Projectile Acceleration by Results of Simulation

The principal scheme of mortar with electromagnetic (inductive) thruster is shown in the Fig. 2. Barrel of mortar made of titanium which is non-ferromagnetic metal and its electrical conductivity is not so big in comparison with copper or aluminum. Nevertheless in the zone of inductor position the wall of barrel can be made thin with axial slots for reduction of the secondary contour screening. Main part of barrel also can be made thin-wall but with longitudinal edges for durability increase. Ends of the inductor coil are mounted with connector (Fig. 2, pos. 5). This connector serves for the cable switching of inductor on the charge/discharge commutators block which is mounted

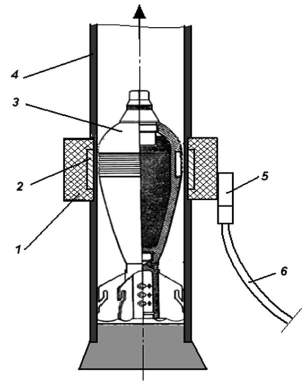

Fig. 2. The principal scheme of electromagnetic mortar. Designations: 1 — reinforced case of inductor; 2 — inductor coil; 3 — mine (modified); 4 — light titanium barrel; 5 — connector; 6 — high voltage (10kV) cable.

at the energy supply facility. In the transport position this cable is disconnected.

The composition of the pulsed power supply facility on the base of Russian car UAZ-469 is shown in the Fig. 3. The internal space of cabin is enough for the setting of capacitor battery, charging system and needed commutators for the loading of inductor each 4 sec.

Capacitor battery consists of 10 units capacitor "General Atomics" Company, Series C, serial No. 32312. The primary generator of electrical energy for the charge of battery has the mechanical connection with a driving motor of car. At the fire repetition frequency 15 min^{-1} the primary generator must be in operation during all time the fight. The sketch of mortar at the fighting position is given in the Fig. 4.

To avoid the change of the voltage polarity at the capacitors of energy store the mode of acceleration is calculated with provision of deep enough but not full discharge of battery at each pulse. Commutation system with electronic control realizes the stop of discharge current in the circuit of battery simultaneously with crowbar of inductor on itself. At the time instant when the armature mounted at the mine leaves the zone of electromagnetic interaction the voltage of battery does not exceed 10...15% of initial value.

The results of mathematical simulation for the basic mode of thruster operation are presented in the Fig. 5. Data presented corresponds to inductor with number of turns 15, internal diameter of inductor coil 90 mm, the length of coil 150 mm, thickness of the winding 10 mm.

The copper insert at the mine has a thickness 6 mm. Initial values for simulation: voltage of energy store U_{C0} = 8 kV, capacity of store C = 6800 μF, basic time T_{bas} = 0.8 ms, basic velocity V_{bas} = 187.9 m/s, magnetic coupling coefficient K_0 = 0.974, projectile mass m = 3.5 kg, q = 3.55, $Q_{1\text{T}}$ = 3.06, $Q_{2\text{T}}$= 3.157, T_{10} = 393 K, T_{20} = 313 K.

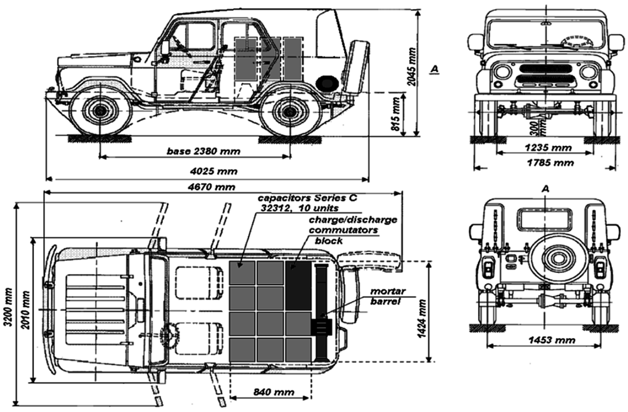

Fig. 3. The Mortar Composed on the Base of Russian car UAZ-469 (transport position)

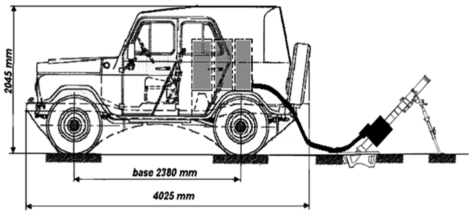

Fig. 4. Fighting Position of Mortar

Calculation has been done for the initially heated conductors (120°C in inductor, 40°C in armature) as for repeating fire. Indeed the heat energy per one pulse is not so much at this level of energy and grow of temperature is not so threatened.

As it is seen in the Fig. 5 the armature mounted on the projectile leaves the zone of main electromagnetic interaction ($x \leq 0$) at normalized time $\tau \approx 1.25$. Output velocity of projectile is equal to V_{out}=1.34V_{bas}= 251.8 m/s. Electromechanical efficiency of thruster can be estimated as $\eta = m(V_{out})^2 \,/\, C(U_{C0})^2 = u^2 \,/\, q$, and $\eta > 1/q$ when $u > 1$. At the considered situation the initially accepted value was $q = 3.55$, resulting $\eta = 0.5$ at $u = V_{out} \,/\, V_{bas} = 1.34$.

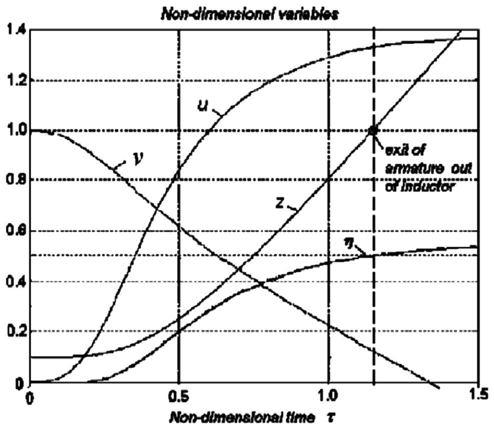

Fig. 5. Dynamic Characteristics of the Acceleration Process. Designation of non-dimensional variables: z is the armature displacement (location) in the frame of inductor; u is the velocity of projectile; ν is non-dimensional voltage of energy store; η is electromechanical efficiency.

V. Conclusion

Project analysis of thruster which is done in the generalized variables gives a possibility easy make a transition to the dimensional values. As the previous estimation shows the induction accelerator is able to be effective thruster for the field mortar mounted on the mobile car. Cabin space of light combat car is most probably not enough for the store of ammunition and for setting the means of mechanical development of fight position. Nevertheless using of electromagnetic launcher as a thruster for the mortal enables to increase efficiency of fire due to increase of outlet velocity without need to mount additional charges at the mine. Beside of this, it is provides the ability to change the position for a short time, jointly with some improvement of the work condition for the service team. The hazard of double charging with casual explosion is excluded completely in the electromagnetic thruster. The full mechanizing of the opening and closing position is possible only at the most powerful mortar, for example as Russian 2C4 Tulpan (“Tulipe”) which is mounted on the tracklaying vehicle. It’s great caliber 240 mm, big mass of mine (130.7 kg or 228 kg — including nuclear ones), high initial velocity of mine (158...362 m/s), small time of fight position preparing (5 min), in spite of low rate of fire (near 1 min^{-1}) needs a very powerful electrical energy system for the using of electromagnetic principle of mortaring. At the electromechanical efficiency estimated as 0.7, the high kinetic energy of shot for 2C4 (3...8 MJ) means that the electromagnetic energy store must have 4...12 MJ per shot with electric power of charging system 75...225 kW. Main problem here consists in the great volume of energy store. So, the light mobile mortar at caliber 82 mm can be considered as the more prospective goal for the application of induction thruster in mortar.

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Авторами статті виконаний проектний аналіз електромагнітного індукційного прискорювача, як метальної системи для легкого міномета калібру 82 мм з кінетичної енергії міни близько 120 кДж. Для визначення основних характеристик прискорювача використано власне програмне забезпечення, створене у стандартному пакеті MATLAB. Критеріальна форма рівнянь комп'ютерної моделі придатна для швидкої оцінки багатьох варіантів конструктивних параметрів. Ефективність електромагнітного прискорювача оцінена на рівні 50%. В роботі представлена компоновочна схема міномета на основі легкої бойової машини Передбачається, що накопичувач енергії для прискорювача створений з використанням конденсаторів компанії General Atomics (11 кВ, 680 мкФ в кожній одиниці).

Ключові слова: проектний аналіз електромагнітного індукційного прискорювача, легкий міномет калібру 82 мм, пакет MATLAB, компоновочна схема міномета на основі легкої бойової машини, конденсатори компанії General Atomics.

Авторами статьи выполнен проектный анализ электромагнитного индукционного ускорителя, как метательного устройства для легкого миномета калибра 82 мм при кинетической энергии мины около 120 кДж. Для определения основных характеристик миномета использовано собственное программное обеспечение, разработанное в стандартном пакете MATLAB. Критериальная форма уравнений в компьютерной модели пригодна для быстрой оценки многих вариантов конструктивных параметров. Эффективность электромагнитного ускорителя оценена на уровне 50%. В работе представлена компоновочная схема миномета на основе легкой боевой машины. Предполагается, что накопитель энергии для ускорителя создан с использованием конденсаторов компании General Atomics (11 кВ, 680 мкФ в каждой единице).

Ключевые слова: проектный анализ электромагнитного индукционного ускорителя, как метательного устройства для легкого миномета калибра 82 мм, пакет MATLAB, компоновочная схема миномета на основе легкой боевой машины, конденсаторы компании General Atomics.