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DOUBLE-CIRCUIT RESONANT ELECTRIC POWER AMPLIFIER FOR MAGNETIC-PULSE PROCESSING OF METALS

Yu.V. Batygin*, S.O Shinderuk, E.O. Chaplygin***, D.V. Fendrikov******
Kharkiv National Automobile and Highway University,
st. Yaroslava Mydrogo, 25. Kharkiv, 61002, Ukraine,
e-mail: 097931417e@gmail.com

The authors propose and substantiate the functionality of a magnetic-pulse installation consisting of two blocks, the first of which is a resonant double-circuit charger of a capacitive energy storage, and the second block is a discharge circuit with an inductor-tool for performing a given production operation. It is shown that the voltage changes in time according to an exponentially growing harmonic law. It was found that the amplitude of the voltage across the capacitor can be regulated by varying the characteristics of the coupling transformer between the circuits and the characteristics of the circuit of the reactive power conversion unit. Numerical assessments of the characteristics of the charging process showed a high efficiency of voltage formation on the capacitive storage due to resonance phenomena (the transformation ratio is equal to the Q-factor of the circuit ~ 20), which is not comparable with the well-known traditional indicators of induction methods. In terms of phase – the length in time to the maximum charge in the adopted circuit of the active electric power amplifier is set by the inequality - That is, after ~ 30 periods of charging current, the excited voltage reaches a maximum (~ 20 times higher than the source voltage), which will correspond to the end of the transient process and the establishment of a steady state of operation. An example of calculating the characteristics of an elementary resonant base illustrates the effective capabilities of a magnetic-pulse installation, consisting of a resonant charger of a capacitive energy storage and a load in the form of an inductor-tool for flat stamping of metal products. It was found that the square of the ratio of operating frequencies in the load unit and the reactive power amplification unit quantitatively determines the fundamental possibility of resonant amplification of the active electrical energy of a harmonic signal. References 12, figures 5.

Key words: magnetic pulse punching, series circuits, voltage resonance, active electrical power amplification, capacitive energy storage, discharge circuit, inductor-tool, harmonic law, stamping of metal products, harmonic signal.

Introduction. The level of technical support of any industrial production characterizes its fundamental practical capabilities. So, the achievements in the field of creating magnetic-pulse installations (MIP), as powerful energy sources, determine, in the end, the prospects for using pulsed electromagnetic fields in the implementation of modern environmentally friendly, resource-saving and high-performance technologies for the processing of metals by pressure. Without going through the numerous publications devoted to this topic, one can single out the main scientific publications that sufficiently extensively disclose and generalize information on the development of equipment for field technologies and at the present stage of technological progress [1 – 3]. So, the authors of the scientific publication describe in some detail examples of magnetic-pulse installations created at different times by world electrical manufacturers. The successes in the development of MIP by firms in Germany (Siemens), Great Britain (Wick men Machine Tools), USA (General Dynamics Corporation), etc. are highlighted. Monograph, presented by a large group of authors from various organizations in Germany, is mainly devoted to the description of the development of technical aspects in the implementation of various stamping, assembly and welding production operations.

As is known, physically, resonance effects are manifested upon excitation of exclusively harmonic oscillations. But the creation of real resonant electrical systems is possible with other methods of excitation. So, from a practical point of view, it is of interest to excite a voltage resonance using a generator of rectangular pulses with a repetition rate equal to the natural frequency of the excited resonant circuit. The publication is devoted to the calculation of current modes when feeding with bipolar and unipolar voltage pulses. It is

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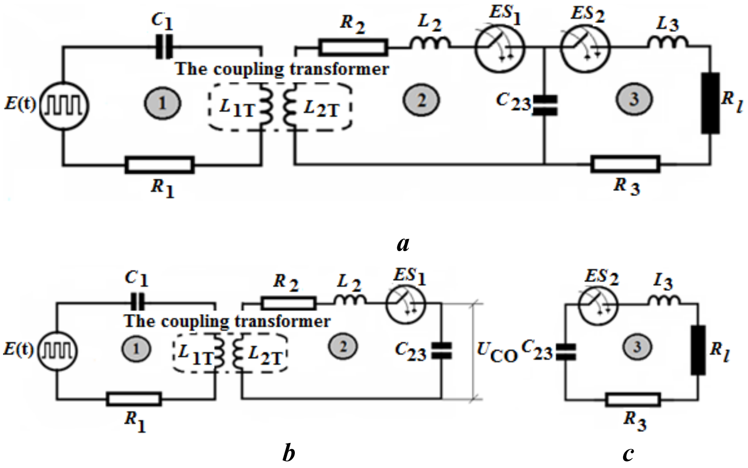
ORCID ID: * https://orcid.org/0000-0002-1278-5621; ** https://orcid.org/0000-0002-6354-4174; *** https://orcid.org/0000-0003-1448-6091; **** https://orcid.org/0000-0002-9702-6412 shown that, in the latter excitation method, the contribution of higher harmonics to the formation of a resonant harmonic current is significantly lower than in the case of bipolar excitation.

Theoretical and experimental attempts to amplify reactive electrical power at voltage resonance are highlighted in. Its conclusions make it possible to formulate the direction of further scientific research, one of the final goals of which can be called the proposal and substantiation of the efficiency of a high-voltage charger of a capacitive storage, as a power source in magnetic-pulse processing of metals, which allows to obtain at the output a given level of stored energy of electromagnetic energy at a certain value of the charging voltage. An undoubted and significantly significant advantage of the proposal to use the resonant effect in series active-reactive circuits instead of the bulky power equipment of traditional charger circuits is the possibility of increasing the voltage due to the variation of the characteristics of the charging circuit (quality factor). Moreover, the gain in the resonant circuit will be incomparably higher than in the traditional charger circuit.

In conclusion of this analysis of modern publications, we can add a phenomenological consideration about the possible next step in the development of the conclusions of publication and this work. Their generalization can result in the solution of vital problems of the modern electric power industry, and not only of electromagnetic technologies. We are talking about the creation of amplifiers of already active electrical power of currents and voltages. By the way, from a physical point of view, a resonant magnetic-pulse installation, combining the amplification of reactive power and its transformation into active electrical power, ultimately already represents a resonant generator of active electrical energy.

The purpose of this work is to propose and substantiate the functionality of a magnetic-pulse installation, consisting of two units, the first of which is a resonant double-circuit charger of a capacitive energy storage, and the second unit is a discharge circuit with an inductor-tool for performing a given production operation.

1. Scheme, principle of operation. Formulation of the problem. In Fig. 1 shows a schematic diagram of a resonant magnetic pulse installation, which, from a physical point of view, is a pulsed resonant amplifier of active electrical energy: *a* – shows the equivalent circuit of the amplifier; *b* – shows a reactive power conversion unit; *c* – load block – series circuit with active load – R_l .



a

b *c*

Fig. 1

Note. In view of the equivalence, the object of this study in the further presentation of the material can be called either a resonant amplifier of active electrical energy, or a resonant magnetic pulse installation.

In general, the amplifier circuit consists of two blocks (Fig. 1, *a*). The first of them is a reactive electrical power conversion unit, which, in turn, consists of two consecutive active-reactive circuits – *1* and *2*. The second is a load unit, consisting of one series circuit – *3* and containing a load – R_l , where in the general case, the active electrical power of the excited signal is allocated.

The components of the reactive power conversion unit (in fact, this unit is an MIU charger) Are formed by circuits *1* and *2* (Fig. 1, *b*). They are interconnected by means of a coupling transformer, the inductance of the windings of which – L_{1T}, L_{2T} is, respectively. Circuits *2* and *3* are connected by a common capacitive energy storage – C_{23}.

Reactive electricity conversion unit (Fig. 1, *b*). Circuit *1* – is a series $R_1L_{1T}C_1$ – circuit where, in the voltage resonance mode, the excited signal is transformed into circuit *2*. Here R_1 – the active resistance of the connecting conductors, including the primary winding of the communication transformer and the internal resistance of the power supply – E(t), $L_{1T,}$ L_{1T} – inductance, C_1 – capacitance.

Circuit *2* – is sequential $R_2(L_{2T}+L_2)C_{23}$ – circuit, where in the voltage resonance mode the capacitance is charged – C_{23}. Here R_2 – total resistance of all circuit elements, $(L_{2T}+L_2)$ – total inductance, C_{23} – capacity. Electromagnetic processes in the circuits of the reactive power conversion unit occur with a closed electronic key – ES_1 and an open key – ES_2 up to the capacity charge – C_{23} according to a given voltage level – U_{C0}. Then the electronic key – ES_1 is opened, and the key – ES_2 is closed.

Amplifier load block (Fig. 1, *b*). Circuit *3* – is sequential $(R_3+R_l)L_3C_{23}$ – circuit, where, in the voltage resonance mode, a pre-charged capacitance – C_{23} is discharged to the active load of the amplifier – R_l. Here (R_3+R_l) – total active resistance of connecting conductors, including load resistance – R_l, L_3 – inductance, C_{23} – capacity. Electromagnetic processes in the circuit of the amplifier load unit occur with a closed electronic key – ES_2 and an open key – ES_1 until the end of the capacity discharge – C_{23} After that, the electronic key – ES_2 is opened, and the key – ES_1 is closed.

The «charge-discharge» process in the blocks of the proposed amplifier circuit can be repeated cyclically with a frequency not less than the time of charging the capacitive storage in circuit *2*.

We emphasize that, from a physical point of view, the reactive power conversion unit (circuits – *1*, *2*) is an amplifier of reactive energy [7], and the load unit (circuit – *3*) is a reactive-to-active current power converter at the output of the proposed amplifier.

Formulation of the problem. According to the principle of operation of the proposed scheme of the active electric power amplifier, the theoretical description of its capacity allows consideration of transients separately in each of the selected blocks (Fig. 1, *b*) – reactive power conversion unit – circuits *1*, *2* and (Fig. *1*, *c*) – load unit –circuit *3*).

Natural resonance frequencies of circuits *1* and *2* are equal to each other:

$$\omega_{10} = 1\Big/\sqrt{L_{1T}\cdot C_1} = \omega_{20} = 1\Big/\sqrt{(L_{2T}+L_2)\cdot C_{23}} = \omega_0 \, .$$

The active resistances of the element base of the amplifier are quite small, which is due to the desire to minimize energy losses, $R_{1,2,3} << \omega_0 L_{1T,2T,2,3}$ load resistance R_l – arbitrarily.

The first amplifier circuit – *1* is excited by sequences of unipolar rectangular voltage pulses with an amplitude – E_m, repetition period – T and duration equal to – $T/2$ (Fig. 2). In Fig. 2 presents the time dependence of unipolar voltage pulses with a repetition period ~ T and duration ~ $T/2$.

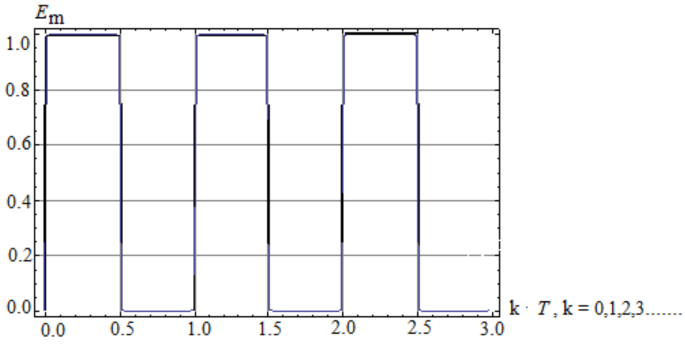


Fig. 2

The frequency of the voltage pulses is equal to the fundamental frequency of the spectral decomposition of the exciting signal and the natural resonance frequency of the amplifier circuits – ω_0.

2. Calculation results. According to the adopted formulation of the problem, we separately consider and analyze the transient processes in each of the amplifier blocks.

Reactive electric power conversion unit (charger of the proposed magnetic-pulse installation) (Fig 1, *b*).

The amplitude-time dependence of the exciting voltage in Fig. 2 is represented by the spectral Fourier expansion [6 – 10]:

$$E(t) = E_m \cdot \left((1/2) + (2/\pi) \cdot \sum_{n=0}^{\infty} \frac{\sin^2(\pi\cdot(2n+1)/2)}{2n+1} \cdot \sin(\omega_n \cdot t) \right), \qquad (1)$$

where $\omega_n = (2\pi/T\cdot(2n+1)$ are the harmonic frequencies of spectral decomposition, $\omega_n=0 = \omega_0 = 2\pi/T$ is the fundamental frequency.

When deriving the necessary design ratios, we will use the individual results of [7], where a similar problem was considered for a circuit of two inductively coupled circuits in a steady-state time regime.

According to the cited work, the time dependence for the resonant current at the output of the unit under consideration with equal damping coefficients and operating frequencies in its circuits will be written in the form of a convolution of functions [10]:

$$I_2(t) = k\cdot\sqrt{L_{2T}/L_{1T}}\cdot 1/\left(L_{2T}+L_2\right)\cdot\int_0^t e^{-\delta(t-x)}\cos\left(\omega_0\left(t-x\right)\right)\cdot E(x)dx\,, \tag{2}$$

where k є [0, 1] is the coefficient of electromagnetic coupling between circuits $1-2$, relative, $\delta = R_2/2(L_{2T}+L_2)$ is the attenuation coefficient – current time, $E\left(x\right) = E\left(t\right)\Big|_{t=x}$, x is the variable of integration.

Addiction (1) should be substituted into the integrand from (2). Integrate the result. Using the found relationship for the current, you can determine the voltage across the capacitance – C_{23}

Omitting cumbersome mathematical transformations, taking into account the smallness of the quantities ~ δ and ω_0^{-1} in the end, after introducing the main characteristics of the process under study, we obtain the following dependence [10]:

$$U_{C_{23}}(t) = C_{23}^{-1}\cdot\int_0^t I_2(\tau)d\tau \approx E_m\cdot\left(k\cdot\sqrt{L_{2T}/L_{1T}}\cdot Q_0\right)\cdot\left(1-e^{-\omega_0 t\cdot(2Q_0)^{-1}}\right)\cdot\sin(\omega_0 t)\,, \tag{3}$$

where $Q_0 = 1/\omega_0\cdot C_{23}R_2 = \omega_0\ (L_{2T}+L_2)/R_2$ – series quality factor *2*.

Let's analyze the obtained result (3).

First – the charging voltage changes over time according to an exponentially increasing harmonic law. Second – the amplitude of the voltage across the capacitance can be regulated by variation characteristics of the coupling transformer between the loops – *1*, *2* and the characteristics of the loop – *2* reactive power conversion units.

Physically, this conclusion can be easily substantiated as follows.

The coefficient in (3), which determines the maximum growth of the charging voltage across the capacitor with respect to the voltage of the external source, is represented by two factors. The first is the transformation ratio of the coupling transformer between *1* и *2* contours ~ $k\cdot\sqrt{L_{2T}/L_{1T}}$ [6 – 9], and the second is the quality factor of the output circuit *2* – Q_0 such way.

The adopted double-circuit diagram of the reactive power conversion unit allows a significant increase in the charging voltage due to inductive coupling between the circuits and an increase in the quality factor of the second circuit due to a decrease in its active resistance. Note that in the first circuit, the value of its active resistance is limited from below by the value of the internal resistance of the external power source.

The third generalizing – the introduction of this unit, as a component of an active electric power amplifier, allows its very effective use as a charger for a capacitive energy storage of a resonant magnetic-pulse installation.

Next, we illustrate the charging process by using numerical values of the characteristic parameters of the investigated object [3 – 12]. Let us assume that the coupling transformer is a step – up transformer with a coefficient – k = 1.0 and, $\sqrt{L_{2T}/L_{1T}} = 2.0$, quality factor of the second circuit – Q_0 = 10.0. In this case, the voltage on the capacitive storage in comparison with the voltage of the external power source can increase ~$\left|U_{C_{23}}(t)/E_m\right| = 20$ times. In terms of the phase, the extent before maximum charge is set by the inequality – $(\omega_{0t})>>2Q_0 = 20.0$. That there is, after the incident ~ 30 periods of the charging current, the excited voltage reaches a maximum, which will correspond to the end of the transient process and the establishment of a steady state of operation.

Load block (discharge circuit of the magnetic-pulse installation, Fig.1, *b).* Let us emphasize that the discharge circuit of a magnetic-pulse installation is considered as a load unit, where all circuit elements are actually present – 3 [10].

Let the capacity discharge occur immediately after its charge. The current, as shown in well-known works, will be described by the following exponentially decaying harmonic time dependence [6 – 9]:

$$J_3\left(t\right) \approx -U_{C0}\cdot\omega_3\cdot C_{23}\cdot e^{-\delta_3\left(t-t_0\right)}\cdot\sin\left(\omega_3\cdot\left(t-t_0\right)\right),\ t\geq t_0, \tag{4}$$

where is the charging voltage across the tank, t_0 is the moment of the end of the charge of the capacity and the beginning of its discharge, t is the current time, $\omega_3 = \omega_0\cdot\sqrt{1-\left(\delta_3/\omega_0\right)^2}$ operating frequency and $\delta_3 = (R_3+R_1)/2L_3$ is the attenuation coefficient of the current excited in the circuit – *3*.

It should be noted that the temporal shape of the excited current (4) in practice is regulated by the inclusion or exclusion of an additional resistor (in this case, this is a variation of the value R_3). Thus, with the help of such an operation, it is possible to obtain both an oscillating and a periodic signal in the considered amplifier circuit [3 – 11].

In the further consideration, we restrict ourselves to the choice of the parameters of the contour *3* such, what $\omega << \omega_3 = 1 \cdot (L_3 \cdot C_{23})^{-1}$, $(R_3 + R_l) << \omega_3 \cdot L_3$ in voltage resonance; accordingly, the integral voltage across the reactive elements is zero. The voltage drop takes place only on the active resistance of the circuit element base – R_3 and load resistor – R_l. In the case when $R_l >> R_3$, the current in the load, taking into account the charging voltage on the capacitor from (3), using dependence (4), can be represented by the following expression:

$$J_H(t) \approx -E_m R_2^{-1} \cdot \left(k\sqrt{L_{2T} \cdot L_{1T}^{-1}} \right) \left(\omega_3 \cdot \omega_0^{-1} \right) \left(1 - e^{-\omega_0 t_0 \cdot (2Q_0)^{-1}} \right) \sin(\omega_0 t_0) e^{-\omega_3 (t - t_0) \cdot (2Q_3)^{-1}} \sin(\omega_3 (t - t_0)), \quad t \geq t_0, \qquad (5)$$

where $Q_3 \approx 1/\omega_0 \cdot C_{23} \cdot R_l$ is the contour quality factor *3*.

The gain, as the ratio of the instantaneous power in the amplifier load to the instantaneous power of an external source of rectangular voltage pulses, taking into account (5), can be represented by the following dependence [6 – 9]:

$$\begin{gathered} K_0(t) = P_{\text{отн}}(t) = P_{\text{н}}(t) \cdot P_{0\max}^{-1} = J_{\text{н}}^2(t) R_{\text{н}} \cdot \left(E_m^2 / R_1 \right)^{-1} = R_1 \cdot R_2^{-1} \cdot \left(k^2 \cdot L_{2T} / L_{1T} \right) \times \\ \times (\omega_3 / \omega_0)^2 \left(1 - e^{-\omega t \cdot (2Q)^{-1}} \right)^2 \cdot \sin^2(\omega_0 t_0) e^{-\omega(t - t_0) \cdot Q^{-1}} \sin^2(\omega_3 (t - t_0)), \qquad t \geq t_0. \end{gathered} \qquad (6)$$

From expression (6) follows, that:

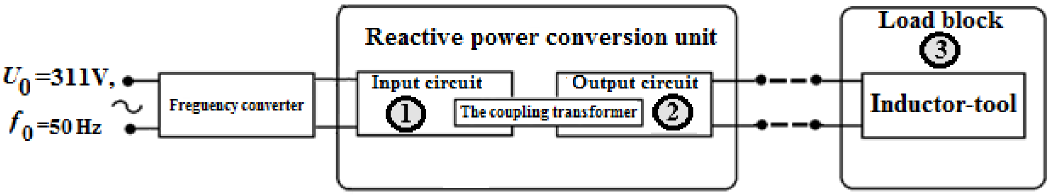
– the square of the ratio of the operating frequencies of the circuits in the selected blocks ~ $(\omega_3/\omega_0)^2$ quantitatively determines the fundamental possibility of resonant amplification of the active electrical energy of a harmonic signal;

– introduction of a double-circuit reactive power converter into the amplifier circuit and the appropriate choice of its parameters ~ $R_1/R_2 \cdot (k_2 \cdot L_{2T}/L_{1T})$ lope up additional possibilities florin creasing the efficiency of the amplifier as a whole.

An example of calculation of a resonant magnetic-pulse installation.

3. Originality. In contrast to the known traditional analogues [3 – 11], the principle of operation of the proposed resonant magnetic-pulse installation for metal boxes is based on the resonant voltages used in the studied active reactive circuits. Its charger, as defined previously, is a resonant reactive power amplifier [8] ("Reactive power conversion unit"). Its distinctive feature is the presence of two circuits with an inductively coupled circuit, where education due to a sufficient amount of active resistance can increase the quality factors and, consequently, a significant increase in the electrical signal, we emphasize, without the use of induction voltage. It should be noted that the use of one of the studied circuits does not allow to obtain a sufficiently high resonant gain due to the limited quality scheme with the help of the internal support of the external power supply.

The presentation of this issue is presented by an example of calculating the characteristics of the element base of equipment for flat magnetic-pulse stamping of metal products, consisting of a resonant charger, capacitive energy storage and a load in the form of an inductor-tool [2 – 11]. The structural diagram of the object of calculations, corresponding to the schematic diagram in Fig. 1, is shown in Fig. 3, where the main basic element – is the «Reactive power conversion unit» is introduced with the addition – «Frequency converter». The latter, when powered from an industrial network, can include a rectifier and a square-wave voltage pulse former (according to the problem statement of this work). In this case, the input circuit of the unit – 1 performs the task of resonant formation of a harmonic signal for transformation into the output circuit – 2 «Reactive power conversion unit». (Fig. 3) shows a block diagram of magnetic pulse equipment. Where *a* – is the magnetic impulse setting, the reactive power converter, *b* – is the load node of the tool inductor.



a *b*

Fig. 3

Reactive power conversion unit.

Assigned.

Working frequency: f_0 = 1500 Hz. The reference frequency – is the operating frequency of the harmonic electric signal in the second (output circuit) according to the block diagram in Fig. 3. Energy, stored by a capacitive storage: W_0 = 4000 J. Amplitude of voltage source – industrial network:

$$E_m = 220 \cdot \sqrt{2} \approx 311\,\text{V}.$$

Calculations.

1. First circuit (input)

1.1. Communication transformer (parameters can be set arbitrarily): • the level of electromagnetic coupling between the windings – k_{12} = 1.0; • inductance of the primary winding – L_{1T} = 5.0 μH; • secondary inductance – L_{2T} = 10.0 μH.

1.2. Capacitor capacity: $C_1 = 1/\left(\omega_0^2 \cdot L_{1T}\right) = 2252$ μF.

1.3. Power consumption: P_m = 2000 W (choice is arbitrary).

1.4. Current limiting resistance: $R_1 = E_m^2/P_m = 48.4\,\Omega$.

1.5. Loop current: $J_\text{1m} = E_\text{m}/R_1$ = 6.48 A.

2. Second circuit (output.)

2.1 Total loop inductance:

$$L_{2S} = 2W_0 \Big/ \left(\left(E_m/R_2\right) \cdot k_{12} \cdot \sqrt{L_{2T}/L_{1T}}\right)^2 = 10.32061\,\text{H}. \qquad (7)$$

Formula (7) is a consequence of the well-known expression for the energy of a capacitive storage [5 – 8] and formula (3) for the charging voltage in a steady state.

2.2. Additional inductance: $L_2 = L_\text{2S}\text{-}L_\text{2T} \approx 10.3206$ μH.

2.3 Active loop resistance (experimental experience): R_2 = 0.5 Ω.

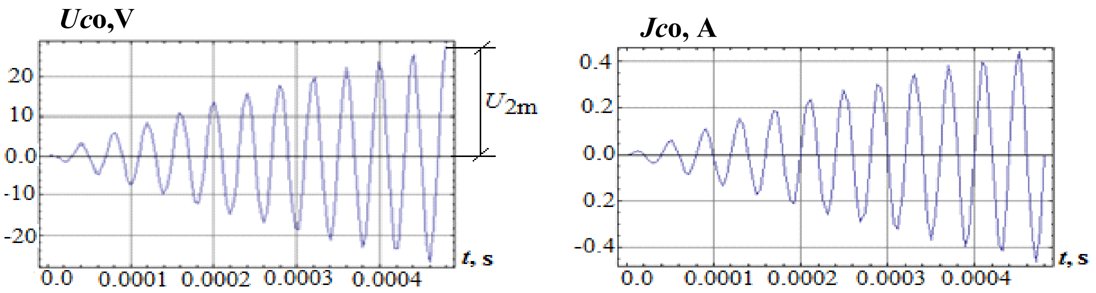
2.4. Storage capacity: $C_2 = 1/\left(\omega_0^2 \cdot L_{2S}\right) = 1.0877$ μF.

2.5. Quality factor of the contour: $Q_2 = 1/\omega_0 C_0 R_2$ = 194.727.

2.6. Charging voltage: $U_\text{2m} = E_\text{m} Q_2$ = 60584 V.

2.7. Charging voltage: $J_\text{2m} = U_\text{2m}\ \omega_0 C_2 \approx 622$ A.

Figure 4 shows typical graphical illustrations of the electromagnetic process in the second (output) circuit of the calculated charger.



a *b*

Fig. 4

4. Summary.

Output data of the reactive power conversion unit

(magnetic impulse charger): stored energy ~ 4.0 kJ; charging voltage ~ 60.6 kV.

Load block

Assigned. The characteristic value of the current in the inductor-tool, the excitation of which allows realize flat stamping of thin-walled metal products: $J_{3m} \approx 60000.0$ A [3 – 11].

Area of the deformable area: $S = 0.06 \times 0.06$ m^2. Voltage on the capacitive energy storage: $U_{2m} = 60584$ V.

Storage capacity: $C_2 = 1/\left(\omega_0^2 \cdot L_{2S}\right) = 1.0877$ µH.

Calculations.

Working frequency: $f_3 = 1/2\pi \cdot J_{3m}/U_{2m}\ C_2 \approx 144635$ Hz. Required inductance of the discharge circuit: $L_3 = 1/(2\pi \cdot f_3)^2 C_2 \approx 1.11$ µF. Maximum developed magnetic pressure force: $P_m = 628$ MPa.

Summary:

– load blocks output (discharge circuit of the magnetic-pulse installation);

– the discharge frequency is ~ 144635 Hz, which provides an almost absolute skin-effect for most metals and a maximum magnetic pressure;

– maximum magnetic pressure ~ 628 MPa;

– oscillograms in Fig. 5 illustrate the possible forms of currents in the inductor-tool, depending on the value of the active resistances of the discharge circuit [3 – 12]. Fig. 5 shows typical samples of oscillograms of currents at various values of active resistances in the discharge circuits: *1* – exponentially decaying signal, $\left(R_3 + R_{\text{н}}\right) < \sqrt{L_3/C_{23}}$; *2* is the aperiodic signal, $\left(R_3 + R_{\text{н}}\right) > \sqrt{L_3/C_{23}} \cdot \left(R_3 + R_{\text{н}}\right)$.

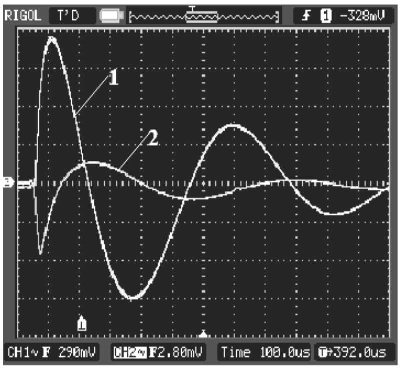


Fig. 5

Conclusions.

Proposed and substantiated the functionality of a magnetic-pulse installation, consisting of two blocks, the first of which is a resonant double – circuit charger of a capacitive energy storage, and the second block is a discharge circuit with an inductor-tool for performing a given production operation.

1. Numerical assessments of the characteristics of the charging process showed a high efficiency of voltage formation on the capacitive storage due to resonance phenomena (the transformation ratio is equal to the *Q*-factor of the circuit), which is not comparable with the well-known traditional indicators of induction methods.

2. It has been shown that the presence of two resonant circuits makes it possible to increase the transformation ratio in comparison with the single-circuit version of the charger.

3. An example of calculating the characteristics of the element base illustrates the effective capabilities of a magnetic-pulse installation, consisting of a resonant charger, capacitive energy storage and a load in the form of an inductor-tool for flat stamping of metal products.

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ДВОКОНТУРНИЙ РЕЗОНАНСНИЙ ПІДСИЛЮВАЧ ПОТУЖНОСТІ ДЛЯ МАГНІТНО-ІМПУЛЬСНОЇ ОБРОБКИ МЕТАЛІВ

Ю.В. Батигін, докт. техн. наук, **С.О. Шиндерук,** канд. техн. наук, **Є.О. Чаплигін**, канд. техн. наук,
Д.В. Фендріков
Харківський національний автомобільно-дорожній університет,
вул. Ярослава Мудрого, 25, Харків, 61002, Україна,
e-mail: 097931417e@gmail.com

Запропоновано та обґрунтовано функціональність магнітно-імпульсної установки, що складається з двох блоків, перший з яких є резонансним двоконтурним зарядним пристроєм ємнісного накопичувача енергії, а другий – розрядним контуром з індуктором-інструментом для виконання тієї чи іншої виробничої операції. Показано, що напруга змінюється в часі за експоненціально зростаючим гармонічним законом. Встановлено, що амплітуду напруги на конденсаторі можна регулювати, змінюючи характеристики трансформатора зв'язку між ланцюгами та характеристики схеми блоку перетворення реактивної потужності. Чисельні оцінки характеристик процесу зарядки показали високу ефективність формування напруги на ємнісному накопичувачі за рахунок резонансних явищ (коефіцієнт трансформації дорівнює добротності ланцюга ~ 20), що не порівняти з відомими традиційними показниками індукційних методів. По фазі – довжина в часі до максимального заряду в прийнятому ланцюзі активного підсилювача електричної потужності задається нерівністю – тобто через ~ 30 періодів зарядного струму збуджена напруга досягає максимуму (~ у 20 разів вище напруги джерела), що буде відповідати завершенню перехідного процесу та встановленню стійкого режиму роботи. Приклад розрахунку характеристик елементарної резонансної бази ілюструє ефективні можливості магнітно-імпульсної установки, що складається з резонансного зарядного пристрою ємнісного накопичувача енергії та навантаження у вигляді індуктора-інструменту для плоскої штампування металевих виробів. Встановлено, що квадрат відношення робочих частот в блоці навантаження та блоці підсилення реактивної потужності кількісно визначає принципову можливість резонансного посилення активної електричної енергії гармонічного сигналу. Бібл.12, рис. 5.

Ключові слова: магнітно-імпульсне штампування, послідовні схеми, резонанс напруги, активне посилення електричної потужності, ємнісний накопичувач енергії, розрядний контур, індуктор-інструмент, гармонічний закон, штампування металевих виробів, гармонічний сигнал.

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