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Electrical Exploding Wires as the Source of Nanoparticles

Volodymyr Chumakov, Oleksandr Stolarchuk, Mikhailo Ostrizhnoi

Independent Scholar, Kharkiv, Ukraine

Email address:
v.i.ch@mail.ru (V. Chumakov)

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Abstract: The results of experimental investigations of metal nanoparticles produce on the basis of the electrical exploding conductors effect for medical using are presented. Experimental equipment is designed. Analysis of copper nanoparticles biological activity was was carried out. Simplified model for calculating the current integral is shown.

Keywords: Nanoparticles, Electrical Exploding Wires, Current Integral

1. Introduction

Traditionally, the effect of electrical exploding wires (EEW) has been used to increase the slope rate of the current pulses in the high-current electronics and accelerator technology: inductive drives, power intensifiers, etc. [1, 2]. Using electrical explosive switches the overfalls of current with a slope in excess of 10^{12} A/s are realized, which is sufficient for the excitation of UWB HPM generators [2-4]. Results of the use of EEW in the water in the studies of the cavitation mechanism and the formation of shock waves in the metal processing methods are known as well [5, 6]. EEW is a process of rapid transition of metal wire from a conductive state in a non-conductive by passing through the wire a high-density current pulse. In this case the transition of the conductor material from the solid state into a dense plasma occurs to form a fine metal particles which, flying apart, and are, in fact, the nanoparticles. The particle size depends on the energy and temporal characteristics of the current pulse flowing through the conductor.

Recently the effect of EEW is used for obtaining of metal nanoparticles in different application [7-9].

This paper presents research results of the generator of metal nanoparticles for applications in medicine.

2. Experimental Results

Most of the unique properties of nanoparticles are determined by two important characteristics: large specific surface area and high value of free energy. The first stipulates their higher adsorption capacity, chemical reactivity and catalytic properties, which can lead to damage of biological structures. Small size allows nanoparticles to penetrate through cell membranes and interact with biomolecules on individually level [10]. The second is the presence of a large number of atoms at the surface of the nanomaterial, which leads to an increase of the free surface energy compared to macro - and micro-sized materials and, consequently, the intensification of the processes of adsorption, ion and nuclear exchanges, etc. [11]. Feature of EEW technology is that the excess energy that acquire the nanoparticles exceeds several times the magnitude of the heat of fusion of the same amount of the substance in the solid state [12]. We can say that of the nanoparticle at room temperature is in the molten state, whereby like "burns" a molecule of a substance microbiology object that are with it in direct contact.

Biological activity of metal nanoparticles has been considered in [12, 13] and other numerous publications. In particular, nanoparticles of copper have is shown high germicidal and bacteriostatic efficiency, given the relatively low cost of copper compared with noble metals used in pharmacology, makes the prospects of its use.

To obtain metal nanoparticles the experimental equipment which uses the effect of EEW have been designed (fig. 1). The known results show that effect EEW is defined, first of all, the geometrical dimensions of the conductor and does not depend on properties of the medium in which the explosion take place [14]. In the experiments, a container where EEW was realized filled with distilled water or air (fig. 2). The wires of copper grade M1 with diameters of 0.08, 0.12, 0.2, 0.35 mm were applied. In principle, it is possible to be pumped out of the container, providing the required pressure. Using of the water as the environment reduces the risk of breakdown on the surface of a wire conductor at a high charge voltage.

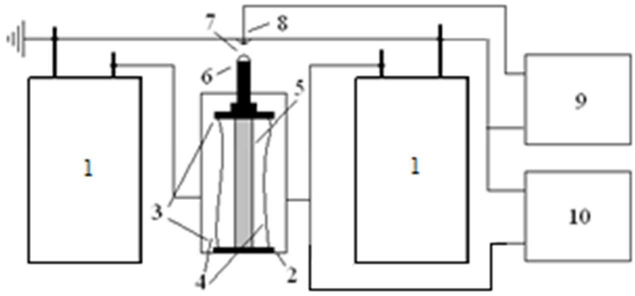


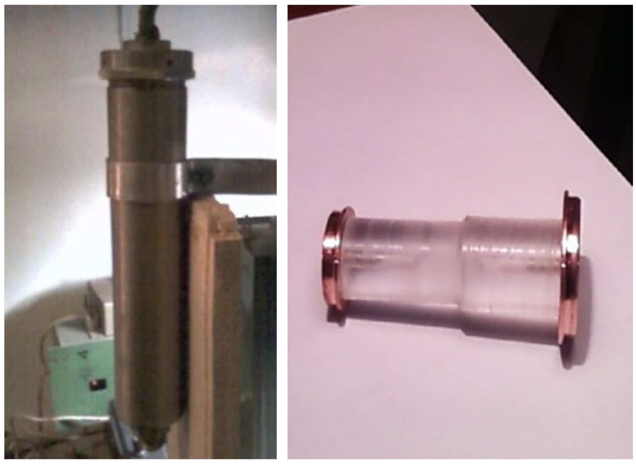
Fig. 1. *Scheme of the experimental equipment: 1 – pulse capacities, 2 – container, 3 – contact plates, 4 – electrical explosive wires, 5 – dielectric pole, 6 – electrode, 7 – discharge gap, 8 – plasma gun, 9 – starting pulse block,10 – power supply.*

Pulse capacitors (1) were charged with high voltage from a DC voltage source power supply (10). Upon reaching the desired voltage the breakdown of the discharge gap (7) is accomplished with help of the plasma gun switch (8) from the starting pulse block (9). Electrical exploding wires (4) are located into the container (2) between the contact plates (3) and locked an electrical discharge drive circuit (1). The experimental setup allows to make the exploding both a single conductor and parallel multiple conductors. It is also possible to realize the electric explosion of metal foil strips. The cross section and the number of simultaneously exploding wires or foil geometric parameters is determined by the energy possibilities of capacitive storage. As a rule, power supply stored energy is choosen from the ratio $W_c > 3W_s$, where $W_c = CU^2/2$ - is the energy stored in pulse capacitors, C - is capacity, U - is charge voltage, Ws - is sublimation energy of the EEW or the foil. If use the switch with the plasma gun [14] which is characterized by stable tripping over a wide voltage range on the discharge gap, we provide the ability to control the energy input to the discharge.

Besides control of the voltage and energy put in the discharge were realized either by changing of capacitors voltage or theirs parallel or sequential connection.

When mounting the installation, special attention should be given to ensuring a minimum parasitic circuit inductance L_p, since the amplitude of the discharge current I_m in the oscillating discharge mode depends on the inductance in accordance with the expression $I_m = U/\rho$, where $\rho = \sqrt{(L/C)}$ – is the characteristic impedance of the discharge circuit, $L = L_p + L_c$ – is the total inductance circuit consisting of the parasitic inductance L_p and EEW inductance L_c. The same requirements should be guided in choosing capacitors of energy storage, giving preference to low-inductance pulse capacitors of high energy intensity.

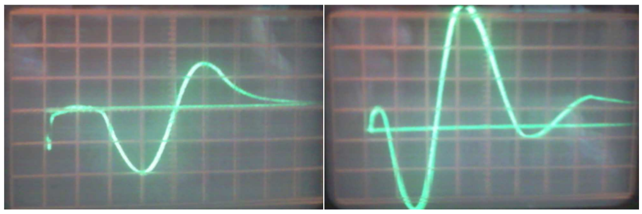
The absence on the current waveform of the phase current interruption that is a characteristic of the effect of EEW using for the slope rate of the current pulses increasing, shows that the energy put in the discharge does not exceed substantially the sublimation energy of the wire.



(a) (b)

Fig. 2. *(a) Experimental container, (b) dielectric pole with contact plates.*

Current monitoring was carried out using a Rogovski coil included in the discharge circuit. From these waveforms (fig. 3) it is seen that the current density reaches a value of $3.34\ 10^6$ A/cm^2, which is enough to achieve the effect of EEW.

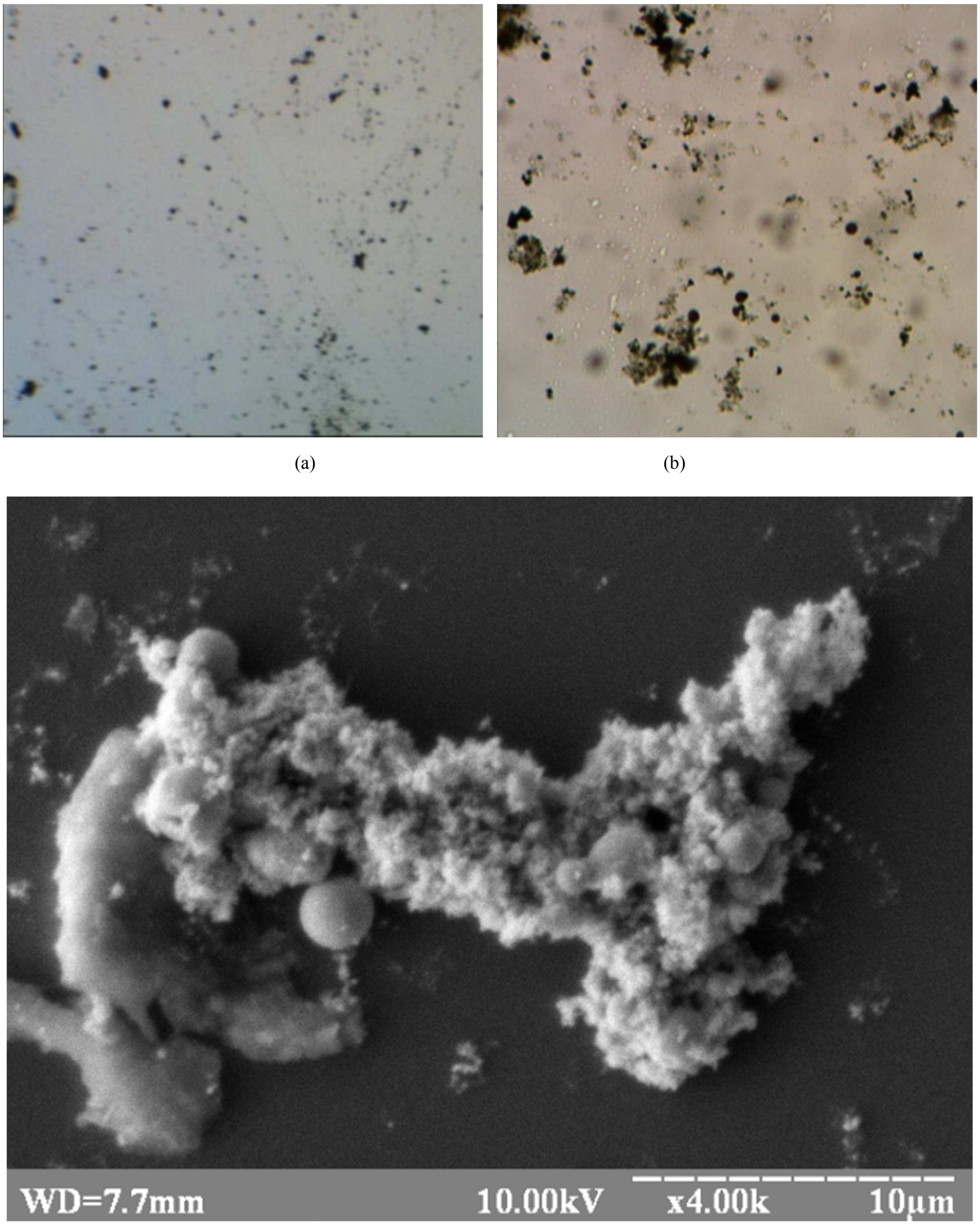


(a) (b)

Fig. 3. *Current waveform: a) 1.6 kA/div., 10 µs/div., b) 4.2 kA/div., 10 µs/div.*

The result of microscopic examination is shown on fig. 4. One of the properties of metal nanoparticles is a high capacity to the aggregation. Obtained by EEW particles actively interaction point to each other, forming clusters with sizes of more than 10^3 times the original, obtained directly after EEW. The results show that aggregation of more than half of the volume of particles occurs within 2 days (fig. 4,b). To prevent aggregation the ultrasonic magnetostriction generator providing cavitation separation of particles in the water was designed.

Copper nanoparticles were placed in different substances (glycerol, propylene glycol, polyvinylpyrrolidone, PEG-400, lanolin, petrolatum, tallow, carbopol) at a concentration of 0.1 g per 1 g of the substance. The study of antibacterial activity of substances with particles was carried out by the method of serial dilutions in nutrient agar with the use of a test microorganism Staphylococcus aureus, a gram-positive spherical bacteria (and not write). After 24 hours of incubation at a temperature 32,0°C analyzed the stunted growth of the test culture of S. aureus. The substances of PEG-400 and carbopol showed the highest activity against S. aureus (table 1).



(a) (b)

(c)

Fig. 4. *Copper nanoparticles: a) just after electrical explosion, b) aggregation after 48 hours, c) electron microscopy results.*

Table 1. *Result activity and CFU (colony-forming unit).*

Substances	S.aureus activity, µg/ml	Total number of bacteria, CFU/g	Total number of fungi, CFU/g
PEG-400	50	10	<10
Carbopol	50	<10	<10
Glycerin	100	<10	<10
propyleneglycol	100	40	<10
PEG -6000	100	30	<10
polyvinylpyrrolidone	growth inhibiting missing	<10	<10

For a comparative study of antibacterial activity of substances containing copper particles, was used as a test-culture of different types of bacteria: gram-positive bacterium Bacillus subtillis, gram-negative bacteria Pseudomonas aeruginosa and Esherichia coli. The antibacterial action of copper particles in the substances the method of diffusion in agar was performed. The antibacterial activity of the substances was monitored 24 hours later by measuring the zone of growth of the test culture B. subtillis, P. aeruginosa or E. coli. Table 2 presents the results obtained.

Table 2. *Antibacterial activity in different cultures.*

Substances	**Growth inhibiting area, mm**		
	B.subtillis	**P.aeruginosa**	**E.coli**
viscous substance (lanolin, vaseline, solid fat, glycerin)	missing	missing	Missing
propyleneglycol	5 mm	12 mm	10 mm
PEG-400	6 mm	6 mm	6 mm
polyvinylpyrrolidone (PVP)	9 mm	8 mm	6 mm
carbopol	11 mm	6 mm	missing

Substance propyleneglycol, PEG-400, PVP and carbopol containing particles of copper, showed antibacterial activity against various microorganisms used as test culture.

3. Results of Modeling

The process of electrical explosion is a rapid transition from a conducting state to a non-conducting when you inject in the wire the amount of energy of the order of the sublimation energy of the conductor material. Simulations took into account that at current densities $j \geq 10^7$ A/cm^2 decisive role in the behavior of the conductor is played by thermal processes [15, 16]. According to [4] the increase of energy into conductor under current pulse passing may be represented in a form of balance energy equation

$$\partial Q / \partial t = j^2 \rho + k_T T\left(x,t\right), \quad (1)$$

where j is the current density into conductor, ρ is specific resistance, k_T is thermal conductivity, $T\left(x,t\right)$ is temperature of conductor.

The items on the right side (1) describe the components due to Joule heating and heat diffusion due to thermal conductivity of the conductor. Given that for most conductors, the thickness of the skin layer $\Delta_e = \sqrt{\rho / \pi\mu f}$ greatly exceeds the characteristic depth of energy penetration into the conductor due to thermal conductivity $\Delta_T = \sqrt{k_T / \pi C_p f}$ (so-called thermal skin layer [4]), the second item in (1) can be neglected, resulting in

$$\partial Q / \partial t = j^2 \rho \cdot \quad (2)$$

Integrating (2), we get

$$C_p \rho_v V \Delta T + k_m \rho_v V + k_v \rho_v V = \int j^2 \rho l / S dt, \quad (3)$$

where from we find the integral of the current, expressed by the known characteristics of the conductor material

$$J = \int j^2 dt = \rho_v / \rho \left(C_p \Delta T + k_m + k_v \right) \cdot \quad (4)$$

In (3) assumes that all the energy is spent solely on heating of the conductor in different phase states. Typically, the criterion parameter of EEW uses the value of the sublimation energy of the conductor of a given size. The sum in brackets in the right part of (4) is equal to the specific energy of sublimation W_s.

Substituting in (4) temperature of melting or evaporation and keeping the second and third item on the right side, we obtain the value of the integral current for solid, liquid or vapor state conductor (k_m and k_v are specific heat of melting and evaporation of the conductor material respectively, $V = Sl$ is the volume of a conductor of length l and cross-sectional area S). Note that the values of the current integral obtained by various authors investigated experimentally are differed (see, for example, [4, 13]). Comparison of results of calculation by the formula (4) with known results [4, 13] shows the closeness of the order of the obtained values (table 3).

Table 3. *The current integral for metals.*

Ware material	T_m,	T_v,	C_P,	k_m,	K_v,	ρ_v,	ρ,	W_ρ, **kJ/g**	$J, 10^{17}$, **A^2×s/m^4**		
	K	**K**	**J/kg×K**	**J/g**	**kJ/g**	**g/cm^3**	10^{-8} **Ohm×m**	**from (4)**	**in [4]**	**in [13]**	
Al	660	2467	920	393	9.22	2.7	2.5	11.93	1.1	0.59	0.9 – 1.09
Cu	1984	2540	385	213	4.79	8.9	1.78	5.36	2.88	1.24	1.95 – 2.1
Ag	962	2170	234	87	2.35	10.5	1.67	2.64	1.67	1.0	1.04
Fe	1539	3200	444	270	6.34	7.85	12.2	7.43	0.47	0.6	0.506
Au	1964	2947	129	67	1.65	19.32	2.3	1.85	1.65	-	0.523

4. Conclusions

1. EEW in water provides obtaining of metallic nanoparticles for various applications. Designed equipment can be used in experimental modeling of EEW and the creation of generators of the nanoparticles.

2. Simplified model for calculation of the integral of current is designed. Electrical and thermal parameters of the wire material are initial data for calculation. Estimates of the integral of current are given, close to known values that can be used in the calculation process of EEW.

References

[1] Chace W. G. Exploding wires. New York: Plenum Press, 1962.

[2] Burtsev V. A., Kalinin N. V., Luchinskii A. V. Electrical explosive of wires and its application in electrophysicat equipment. M.: Energoatomizdat, 1990–289 p.

[3] Bakulin Yu. D., Diyankov V. S., Kormilitsyn A. I. Accelerators of direct function with inductive energy storages and exploading wires [Uskoriteli priamogo deistvia s induktivnymy nakopiteliami energii I vzryvayushimisia provodnikami]. *Pribory I tehnika eksperimenta.*–1979.–№ 2.–pp. 34-37.

[4] Knoepfel H. Pulsed high magnetic fields. North-Holland Publishing Company, Amsterdam-London, 1970, 357p.

[5] Maliushevski P. P. *Osnovy razriadno-impulsnoi tehnologii* [Basis of the pulse-discharge technology]. Kiev, Naukova dumka, 1983–272 p.

[6] Krivitskii Ye, V. *Dinamika elektrovzryva v zhydkosti.* [Dynamics of the electrical explosive in liquids]. Kiev, Naukova dumka, 1986–208 p.

[7] Chumakov V. I., Taranchuk A. A., Stolarchuk A. V., Ostrizhnoi M. A. Nanoparticle generation on plasma technology. *The 5th Int. Workshop on Advanced Material Sci. and Nanotechnology, IWAMSN 2010*, Hanoi, Vietnam, Nov. 9-12, 2010, NLE-P13.

[8] Babushkina I. V. Nanochastitsy metallov v lechenii eksperimentalnyh gnoinyh ran [Metal nanoparticles in the treatment of experimental purulent wounds]. *Saratovskii nauchno-meditsynskii zhurnal,* 2011. Vol. 7, No. 2, pp. 530-533.

[9] Gulchenko S. I., Gusev A. A., Zakharova O. V. Perspektivy sozdanija antibakterialnyh preparatov na osnove nanochastits medi [Perspectives of creation of antibacterial preparations based on copper nanoparticles]. *Vestnic Tambovskogo universiteta. Seria: Estestvennie i technicheskie nauki,* 2014, No. 5, v. 19, pp. 1397-1399.

[10] Pershina A. G., Sazonov A. E., Itin V. I., Terehova O. G., Magaeva A. A. Adsorption of proteins on the nanoscale particles of the powder $CoFe_2O_4$ [Adsorbtsia belkov na chastitsah nanorazmernogo poroshka $CoFe_2O_4$]. *Nanosystems, Nanomaterials, Nanotechnologies,* 2008, Vol. 6, No 3, pp. 1019–1028.

[11] Lopat'ko K. G., Aftandiliants E. G., Zaulichnyi Ya. V., Karpets M. V. Preparation and use of nanoparticles, containing copper and silver. [Poluchenie I primenenie nanochastits, soderzhastchih med' i serebro]. - 2010.-233-243 // www.nbuv.gov.ua/portal/natural/Teke/2010/10ekgmis. Pdf

[12] Mikubaeva E. V., Kobotaeva N. S., Skorohodova T. S., Sirotkina E. E. Investigation of the reactivity of copper nanopowders in the test reactions by microcalorimetric method. [Issledovanie reaktcionnoi sposobnosti nanoporoshkov medi v testovyh reaktsiyah mikrokalorimetricheskim metodom]. *Izvestia Tomskogo politehnicheskogo universiteta.*–2008, vol. 312, No. 3, pp. 67–71.

[13] Kotov Yu. A. Electric explosion of wires as a method for preparation of nanopowders // *J. of Nanopart.*, 2003, (5), pp. 539-550.

[14] Oreshkin V. I., Barengol'ts S. A., Chaikovsky S. A. Numerical calculation of the current specific action integral at the electrical explosion of wires // *Technical Physics*, Vol. 52, No. 5, May 2007, pp. 642-650.

[15] Controlled high-current discharger / V. I. Chumakov, O. V. Stolarchuk, G. F. Koniakhin, M. A. Ostrizhnoi / Pat. of Ukraine № 49383, 2012.

[16] Kolgatin, S. N., Lev, M. L., Peregud, B. P., Stepanov A. M., Fedorova T. A., Furman A. S., Hachatur'iants A. V. Destruction of Copper Conductors due to the Current Flow in Them of the Density of above 10^7 A/cm^2. [Razrushenie mednyh provodnikov pri protekanii po nim toka plotnost'yu, bolshei 10^7 A/cm^2.] *Zh. Tekh. Fiz.* 1989, V.59, No.9,: pp. 123-133.