MOSFET Bridge Switch Converter for Pulse Reverse Plating

Mincho Ph. Peev[1], Anastassia P. Krusteva[2], Milko G. Yordanov[3]

***Abstract*: In the present work it is presented the block-structural diagram of a bridge switch converter of pulse reverse current for electroplating, which is built on the basis of MOSFET transistors. The output pulse frequency is regulated within the range of 1 Hz to 50 kHz. The regulation range of the output voltage is within 2 V to 12 V for the maximal value of the output current equal to 15 A. A simulation model of the MOSFET switch converter in MicroSim DesignLab software environment is developed by taking into account the equivalent circuit of the electroplating bath. A maximal value of the shearing strength of a nickel coating electroplated at current frequency 500 Hz is obtained experimentally. The converter developed enables the performance of investigations with the purpose of obtaining electroplated coatings with improved properties.**

***Keywords* – Pulse Reverse Plating, Electrodeposition, MOSFET Pulse Generator.**

I. INTRODUCTION

Today’s level of development in the fields of electronics, instrument production and machine-tool industry is closely connected with the achievements in the area of electroplated coatings. Many processes of metallization through deposition of pure metals and alloys are being constantly improved with the purpose of obtaining increasingly better coating parameters (electric conductivity, magnetic properties, equalizing ability, porosity, internal voltages, hardness, wear resistance). In known literature references [1-4] the authors discuss problems related to potentials of exerting influence and improving the physico-chemical parameters of electroplated coatings by applying pulsed power supply. Its broadest application is connected with the use of rectangular pulses [1-4], where it is sought to optimize the electrodeposition regime by varying: - the pulse frequency; - the duration of forward and reverse pulses; - the pulsed value of the current.

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II. ANALYSIS OF THE TECHNOLOGICAL REQUIREMENTS

In electroplating metal coatings in a d.c. regime the process is controlled through the magnitude of the current (within close limits) as well as through the concentration of surface-active substances in the electrolyte. Applying unipolar current pulses (Fig. 1) enables the simultaneous regulation of three independent parameters [5]: pulsed current density j_p, pulse duration t_{ON}, and pause duration t_{OFF}. This conditions the following features of the process of electroplating:

- using of a high instantaneous current density, which permits to attain a high degree of cathode polarization. The high value of overpotential at the cathode is the cause for a change in the speed of electrochemical reactions with different kinetics. This is one of the reasons that the current effectiveness in pulsed metallization may be rather different from that performed with direct current. The high value of overpotential influences to a great extent the rate of forming new metal nuclei, an along with this it leads to coating structure of finer grain size.
- during the pause there occur phenomena of adsorption and desorption, as well as a re-crystallization of the metal deposited.

The average value of current density j_m in pulsed regime is equal to the current density in d.c. regime [5].

A positive effect on coating properties in pulse reverse regime of electroplating (Fig. 2) is exercised by the electrochemical processes during the anode (reverse) period t_{REV} of the current, which is expressed in prevailing dissolution of the coating microprotrusions and ionization of hydrogen atoms adsorbed in the coating.

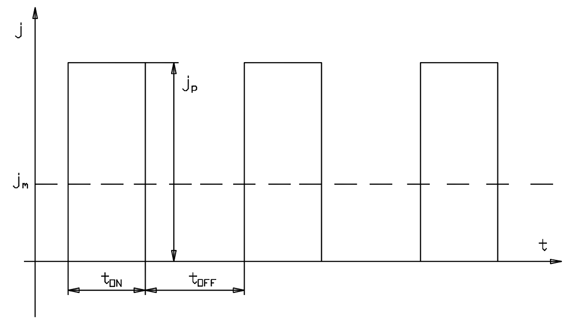

Fig. 1

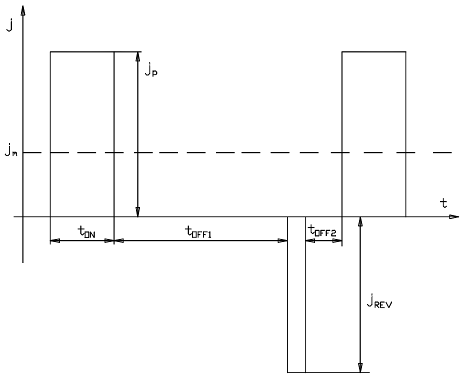

Fig. 2

The performed analysis of the technological requirements permits to synthesize the circuit of a power supply source for pulse reverse plating with the potential of regulating within broad limits the output parameters: - the pulsed value of the current; - the pulse frequency; - independent regulation for the whole frequency range of the duration of forward and reverse pulses; - the duration of the pause between forward and reverse pulses.

III. BRIDGE CONVERTER FOR PULSE REVERSE PLATING

The block-structural diagram of the produced power supply source of pulse reverse current for the deposition of electroplated coatings, realized with MOSFET transistors of BUZ10 type, is shown in Fig. 3. The output voltage of the

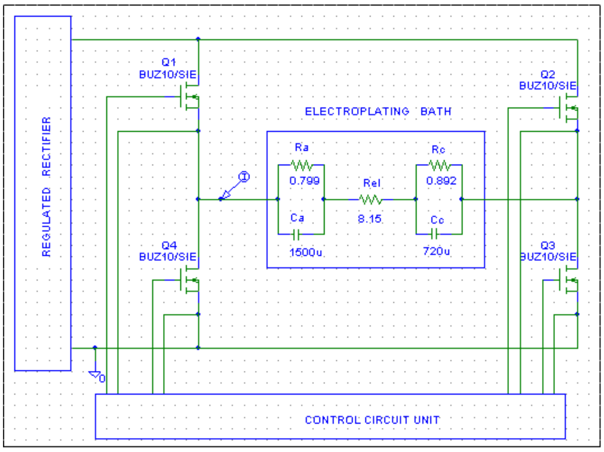

Fig. 3

power supply source is regulated from 2 V to 12 V. This is specified in the requirements for the realization of electrochemical processes in the electroplated deposition of metal coatings [6]. The output current is determined by the current density during the process and by the working area of the cathode:

$$i = j_F \cdot S_c \text{ , A} \qquad (1)$$

where: j_F is the density of Faraday current, $A.dm^{-2}$;
S_c – the cathode area, dm^2.

A maximal value of 15 A for the output current is assumed for the purposes of laboratory investigations.

The circuit includes regulated stabilized rectifier. By using it the supply voltage can be reduced to the necessary value, transformed into direct voltage, and stabilized with the possibility of regulation from 2 V to 12 V.

The stabilized voltage obtained in this manner is transformed into pulsed voltage by means of the bridge switch converter built-up with MOSFET transistors Q1 – Q4 (Fig. 3), and fed to the electroplating bath. Turning-on transistors Q1 and Q3 leads to obtaining the positive current pulse. Transistors Q2 and Q4 provide the reverse current pulse.

Controlling the MOSFET bridge switch converter is carried out by the *control circuit* unit. This unit is used for setting the parameters of output current pulses:

- frequency f – it can be regulated from 1 Hz to 20 kHz;
- duration of the forward pulse t_{ON} – it can be regulated from 0.01 to 0.9 of the duration of the pulse period τ ($\tau = \frac{1}{f}$);
- duration of the reverse pulse t_{REV} – it can be regulated from 0.01 to 0.5 of the period τ;
- duration of pauses t_{OFF1} and t_{OFF2} – they can be regulated within the range from 0.01 to 0.99 of the value of τ.

In such a way it is possible to regulate within broad limits the technological parameters in the deposition of electroplated coatings. It should be kept in mind that in metal deposition the duration of the forward pulse must be greater than that of the reverse one.

In Fig. 3 the electroplating bath is represented by its equivalent RC-circuit [7, 8]. Resistors R_a and R_c correspond to the resistances of the electrode surfaces (anode and cathode, respectively) in the transfer of electric charges between the respective electrode and the electrolyte. C_a and C_c are capacitors determined by the capacitance of the double electric layer at the "electrode–electrolyte" boundary for the anode and cathode. R_{el} is the ohmic resistance of the electrolyte.

The analysis, presented in [7], concerning the charging and discharging of the double electric layer in pulsed electrolysis is used for determining R_a, R_c, C_a, and C_c. The resistance of the electrode surface during transfer of electric charges, determined per unit area, is assumed not to depend on the value of the current flowing through it. It is obtained in accordance with the expression [7]:

$$R = \frac{d\eta}{dj_F} \text{ , } \Omega.dm^2 \qquad (2)$$

where: η is the overpotential of the electrode, V;

Determining the electrode overpotential may be performed according to the expression [9]:

$$\eta = a + b \cdot \ln j \qquad (3)$$

where: a and b are constants depending on the character of the reactions, the material of the electrode, and the electrolyte;
j - density of the current flowing through the electrode, $A.dm^{-2}$.

The capacitance of the double electric layer per unit area of the electrode varies from 10 to 100 $\mu F.cm^{-2}$ [7]. For rough nickel surface it is determined as 80 µF.cm^{-2} (the real area of the electrode may be 2 to 3 times greater than the geometrical one if the surface roughness is taken into consideration).

IV. EXPERIMENTAL AND SIMULATION INVESTIGATIONS

The presented MOSFET bridge switch converter is used for depositing an electroplated nickel coating with thickness of 10 µm. Specimens are produced at various pulse frequencies within the range from 100 Hz to 20 kHz. The filling factor of the forward pulse is 0.4. The duration of the reverse pulse is $t_{REV} = 0.25\ t_{ON}$.

Sulphate electrolyte of the following composition is used: nickel sulphate ($NiSO_4.7H_2O$) – 145 g/l; sodium sulphate ($Na_2SO_4.10H_2O$) – 45 g/l; boric acid (H_3BO_3); sodium chloride (NaCl) – 7 g/l. During the process the temperature of the electrolyte is maintained at 25 ^oC (298 K) and the value of pH at 5.5. The recommended range of the current density in d.c. regime is from 0.8 to 2.0 A.dm^{-2}.

The conditions for coating deposition are as follows:

- pulsed value of current density: j_p = 3.6 A.dm^{-2};
- the density of Faraday current is equal to the pulsed current density in the circuit: $j_F = j_p$;
- area of the cathode: S_c = 0.24 dm^{-2};
- area of the anode: S_a = 0.50 dm^{-2};
- distance between anode and cathode = 3 dm;
- electrolyte volume = 6 dm^3.

A. Electric parameters and time diagrams

A simulation model of the MOSFET bridge switch converter of Fig. 3 is created in MicroSim DesignLab software environment.

Realizing the model requires the calculation of elements in the equivalent circuit of the electroplating bath.

For the capacitance of the double electric layer, per unit area of the electrode, it is assumed the value [7] C_{Ni} = 3000 µF.dm^{-2} (it is operated with a cathode of smooth surface). The values of capacitors C_c and C_a from the equivalent electric circuit of the electroplating bath are determined as follows:

$$C_c = S_c \cdot C_{Ni} = 720\ \mu\text{F};$$

$$C_a = S_a \cdot C_{Ni} = 1500\ \mu\text{F}.$$

The overpotential at the cathode (η_c) and anode (η_a) is determined in accordance with equation (3), the constants a and b in electroplating deposition of nickel being [9] a = 0.63, and b = 0.11:

$$\eta_c = a + b \cdot \ln j_p = 0.771,\ \text{V};$$

$$\eta_a = a + b \cdot \ln j_a = 0.690,\ \text{V},$$

where: j_a is the anodic current density.

The current in the circuit and the anodic current density are calculated:

$$i = j_F \cdot S_c = j_p \cdot S_c = 0.864,\ \text{A};$$

$$j_a = \frac{i}{S_a} = 1.728,\ \text{A.dm}^{-2}.$$

The values of resistors R_a and R_c are obtained from the equivalent circuit of the electroplating bath in accordance with equation (2):

$$R_c = \frac{\eta_c}{j_F \cdot S_c} = 0.892\ \ \Omega;$$

$$R_a = \frac{\eta_{ac}}{j_a \cdot S_a} = 0.799\ \ \Omega.$$

The electrolyte resistance is determined from the experimental investigations as: R_{el} = 8.15 Ω.

Time diagrams of the voltage and current at the output of the bridge switch converter, plotted from the simulation model at pulse frequency of 100 Hz, are shown in Fig. 4.

Figs. 5 and 6 represent oscillograms from experimental investigations of the current and voltage at pulse frequency of 100 Hz.

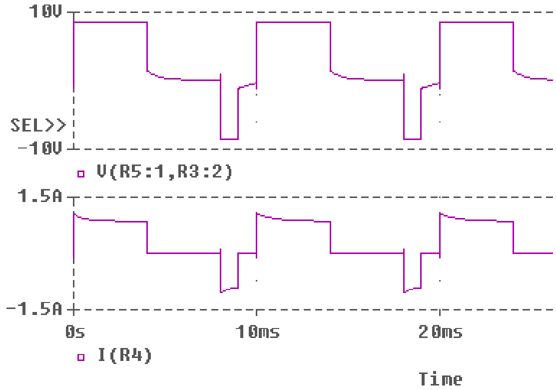

Fig.4

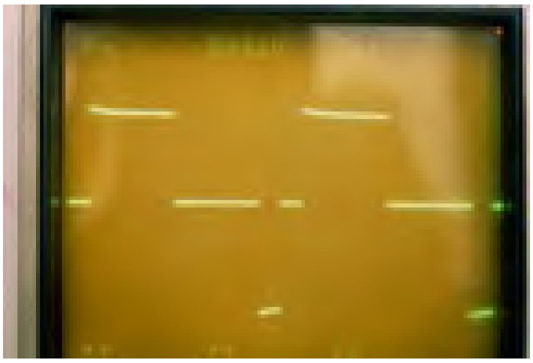

Fig. 5

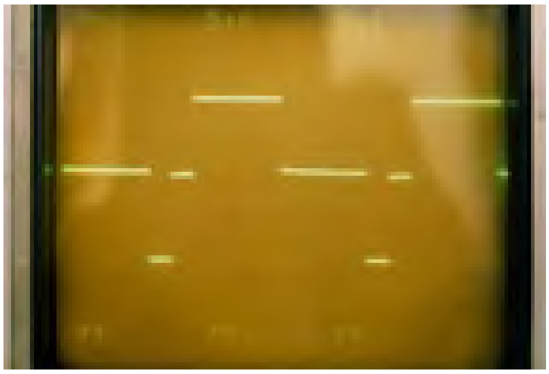

Fig. 6

B. Mechanical properties of the coating deposited depending on the frequency

The influence of pulse frequency upon the shearing strength of an electroplated nickel layer is determined.

Shearing strength σ_{sh} can be obtained from tension strength Rm in accordance with the relationship [10]:

$$\sigma_{sh} = 0.6 \times Rm \text{, MPa} \qquad (4)$$

The tension strength can be determined through the measured Rockwell hardness (HRC) in accordance with the relationship [11]:

$$Rm = 325 + 207 \times e^{0.0377 \cdot HRC} \text{, Mpa} \qquad (5)$$

The hardness is measured by means of a FISCHERSCOPE H100 nanotester (made in Germany) by the method of Vickers at a load of 100 mN.

Upon performing the measurement, Vickers hardness (HV) values obtained are re-calculated in hardness according to Rockwell's method [12]. Results are shown in Table 1.

TABLE I

f	logf	HRC	Rm	σ_{cp}
Hz	-	-	MPa	MPa
100	2,0	39,00	1225,6	735,3
200	2,3	39,25	1234,1	740,4
500	2,7	46,00	1497,5	898,5
1000	3,0	41,50	1314,6	788,7
10000	4,0	39,00	1225,6	735,3
20000	4,3	39,50	1242,7	745,6

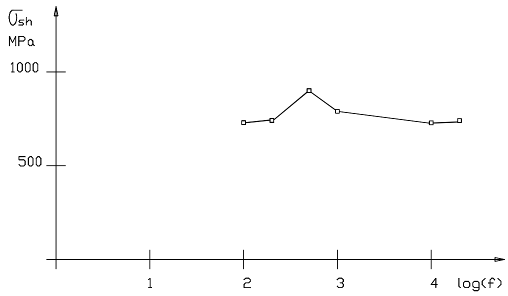

Fig. 7

The diagram of shearing strength variation for a nickel layer, deposited by electroplating, with the pulse frequency during coating deposition is shown in Fig. 7.

V. CONCLUSIONS

The experimental power source for pulse reverse deposition of electroplated coatings, developed on the basis of MOSFET transistors, provides output voltage regulation within the range from 2 V to 12 V at maximal value of the current in forward and reverse direction equal to 15 A. The pulse frequency is regulated within the range from 1 Hz to 50 kHz. Durations of the forward and reverse pulses as well as that of pauses between pulses are regulated independently all over the frequency regulation range.

A simulation model of the MOSFET switch converter in MicroSim DesignLab software environment is developed by taking into account the equivalent circuit of the electroplating bath.

The method of combined analysis presented, simultaneously taking into consideration the circuit components and load parameters, may be useful for the engineering practice.

The mechanical parameter of shearing strength of the nickel coatings deposited by electroplating is studied in the frequency variation range from 100 Hz to 20 kHz. A maximal value of the shearing strength of the nickel layer deposited at current frequency 500 Hz is found.

The power supply source developed allows the performance of experimental investigations with the purpose of obtaining electroplated coatings with improved properties

VI. REFERENCES

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