Development of Principles of Technological Process Control of High Quality Metals and Alloys Melting by Method of Chamber Electroslag Remelting (ChESR)

A.D.Ryabtsev, A.A. Troyansky, V.V. Pashynskyy

Donetsk National Technical University, Department of Electrometallurgy,
Artyoma str. 58, Donetsk, 83000 Ukraine, rato@fizmet.dgtu.donetsk.ua

Abstract

Vacuum-arc remelting, vacuum-induction, electron-beam and plasma-arc cold hearth melting are the main technological processes for producing of titanium and its alloys ingots. But in some cases these processes can not to provide the necessary quality of metal. As was shown in the series of the research works, fulfilled in Donetsk National Technical University (DonNTU), the electroslag remelting of metals and alloys under slag systems with active additions in the chamber type furnaces (ChESR) permits to solve the problems, for which application of traditional methods of electrometallurgy causes the difficulties. Producing of high-quality ingots of titanium, its alloys and intermetallides may be considered as problem of this type. But providing of optimal calcium concentration in the slag close to equilibrium during the process is one of the main problems of ChESR. Using of information measuring system is the effective way of the solving of this task. One of parameters, which permit to establish the correspondence between changes of flux composition and current and voltage of process, is the harmonic spectrum of remelting current and voltage. This unique approach may be used for control and support of stable slag composition during all melting period. Analyzing and comparing of processes, which take place in technological unit, with changes in harmonic composition of signal, some dependencies can be derived. Changes of current and voltage in dependence on metallic calcium concentration in slag is one of them.

To practical realization of this approach, the information-measuring system of ChESR process was developed and created. It is based on ESR unit A-550 and personal computer with industrial modules of the digital input/output that have 32 analog-digital converters with 12-bit resolution (PCI-1202) and 16-bit resolution (PCI-1602). It permits to record sinusoids of current and voltage of remelting, temperature of the cooling water in the every cooling contour and its consumption, electrode displacement during the melting, pressure in the chamber of the furnace and other parameters. Special software for calculation of actual values of current and voltage, their shape coefficients and harmonic compositions by the mean of determination of harmonics values via Fourier transformation was developed.

Due to the proposed approach, the electrical peculiarities of ChESR under the flux of CaF2+Ca system comparing with remelting under the fluxes ANF6, ANF- 1P and chemically pure CaF2 were investigated at first time. It is established that during remelting of the steel under the commercial flux ANF6, current sinusoid has not the distortions and harmonic coefficient is in the range 2 – 3%. During the remelting under flux of CaF2+Ca system in dependence on metallic calcium additions (in investigated range from 2.5 to 10% by weight), the transformation of ESR process in the field with harmonic coefficient range from 5 to 38% is observed.

It is showed that chamber electroslag remelting under the slag systems with metallic calcium in combination with developed information-measuring system may be the basis for technology for producing of the quality ingots from titanium and its alloys.

Keywords: chamber electroslag remelting, refining, metallic calcium, indirect methods of control, harmonic analysis

Introduction

Vacuum Induction Melting, Vacuum Arc and Electroslag Remelting processes, Electron Beam and Plasma-Arc Cold Hearth Melting are the main technological processes of metals and alloys producing for critical fields of application, aviation for example. It seems that these processes are well studied and standardized. Nevertheless, at recent years the new information concerning such it would seem the standard process as Electroslag Remelting (ESR) were received by Ukrainian researchers. This information is evidence of principally new possibilities of ESR as technique for metal and alloys refining. These investigations are conducting in Donetsk National Technical University (DonNTU) too and directed to detail investigation of refining possibilities of ESR in the controlled atmosphere in chamber furnace under the calcium-containing fluxes (ChESR process) [1,2]. These works have shown the possibility of high-quality ingots production from metals with high reaction ability, titanium in that number.

Presence of chamber and controlled atmosphere creates the favorable conditions for effective refining of metals and alloys due to using of metallic calcium, rare-earth elements and other during the remelting process. At same time, the addition of metallic calcium in ESR slag causes the considerable changes of electric regime of remelting. In turn, it has the influence on velocity of melting of consumable electrode, power balance of process and forming of remelted ingot. Taking into account the necessity to achieve the main goal of project: refining and obtaining the high-quality ingots from titanium alloys, it is expediently to support the optimal concentration of calcium in slag close to certain limit (equilibrium). It may be realized by the calculation way or in result of establishing of dependence between the changes of technological parameters of the process and calcium concentration in slag (current and voltage of remelting process, first of all).

Using of information-measuring and automated control systems of ESR technological process (ACS TP ESR) is the effective way of solving of this problem [3,4]. Computers in automated control systems increase the level of information about technological process for staff (documenting and visual presenting of parameters and other) and accuracy of recording of measured process parameters.

At ESR, the easy controlled parameters are the electric current and voltage. They may carry the information about number of physical parameters of electric circuit. Real electric circuits, as a rule, have in their structure the non-linear elements. In ESR unit, the slag pool has nonlinear resistance. It depends on chemical and phase state and temperature. Presence of metallic calcium in slag leads to abrupt changes in their physical properties, electric conductivity and melting temperature. It has the effect on electric characteristics of process and may cause the changes in parameters of melting current and voltage.

Harmonic analysis of melting current and voltage may be one of parameters that permit to establish dependence between flux composition change and current and voltage of process.

Now considerable effect in investigation of these parameters was reached for electric arc furnaces [5-8]

Thus, development of information-measuring system of ChESR process under active fluxes on the basis of the modern achievements in the sphere of computer engineering will permit to control the main parameters of remelting process (current, voltage, temperature and other) with acceptable degree of precision and establish the dependencies between changes in technological parameters (current and voltage of remelting process, first of all) and calcium concentration in the slag and develop the technology of warranted refining of titanium alloys and obtaining of high-quality ingots.

Development of Controlling system

For control and optimization of the calcium content in slag, new information-measuring system was developed based on the industrial digital input/output cards that have 32 analog-digital converters with 12 bit resolution (PCI-1202) and 16 bit resolution (PCI-1602). Potential abilities of this IMS developed on the basis of analog input/output cards are much higher than "old" one [4]. Besides sinusoids of current and voltage of remelting, with the help of the new IMS it is possible to record many another parameters of remelting: temperature of the cooling water in the every cooling contour and its consumption, electrode displacement during the melting, pressure in the chamber of the furnace and other parameters. Analysis of these parameters gives more detailed information concerning the processes that take place during the remelting. Developed IMS system has the following structure (see Fig. 1).

For providing of effective process of measurement, analog parameters were distributed between two ADC cards. Distribution was fulfilled according to principle of grouping of signals with the same parameters of enciphering. Thus, during measurement of values of current and voltage of remelting, stable frequency of sampling and high precision of measurement are necessary (PCI1602). Therefore, these signals are inputted on separate card. Parameters with relatively low frequency of sampling (up to 10 measurement per second) and digital signals are inputted on PCI1202 card.

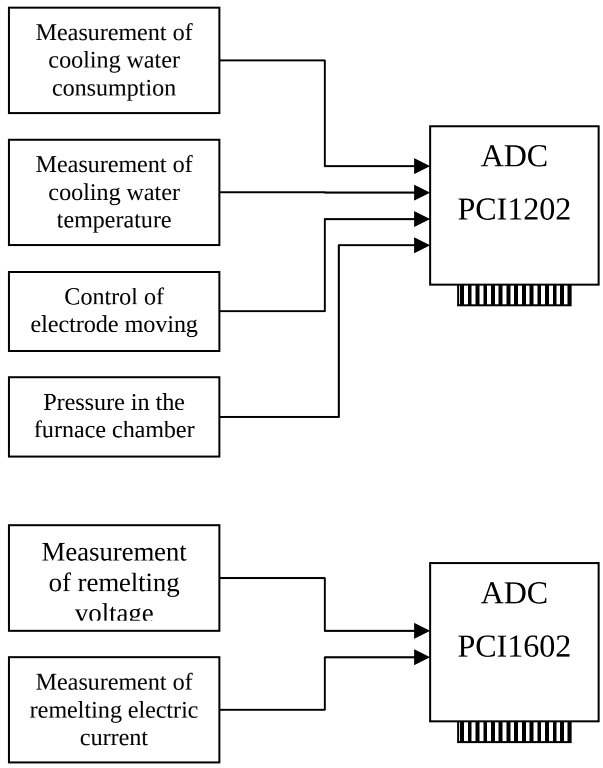

Figure 1: Scheme of distribution of input signal between ADC cards.

Signals from different analog sensors must be normalized. In order to protect from influence of industrial noises, signal is transmitted according to "current circle" scheme.

In order to test the developed information-measuring system the series of experiments has been fulfilled.

Experimental Trials

In order to establish the dependence of process parameters on content of metallic calcium in slag two experiments were carried out (CIS1 i CIS2). They consist in portion addition of metallic calcium to slag and fixation of current and voltage sinusoids and movement of electrode carriage.

Electroslag remelting of electrodes 45 mm in diameter from St. 3 steel was fulfilled in chamber electroslag furnace ESR, created on the basis of A-550 unit in copper water-cooled crucible 100 mm in diameter and length 500 mm. Water-cooled chamber was mounted directly on the top of the crucible. System is designed with correspondent seals that permit to create vacuum or excessive pressure of gases in working space. Before the melting chamber was evacuated and after that was filled by argon. During the melting, excessive pressure of argon was supported to compensate the leakage through different sealing.

As a flux creating materials calcined at the temperature 973 K during 3 hours. Powder of the fluorite calcium of “Ch” grade (TU 6-09-5335-88) was used with addition of metallic calcium. The flux melted directly in crucible using "solid" start. Metallic calcium was introduced by portions by the local disposition of it on consumable electrode. On Fig. 2, 3 scheme of disposition of metallic calcium portions on electrode is shown. They introduce in slag pool during the electrode melting. Portions of metallic calcium with mass 30 g every, are marked by the numbers.

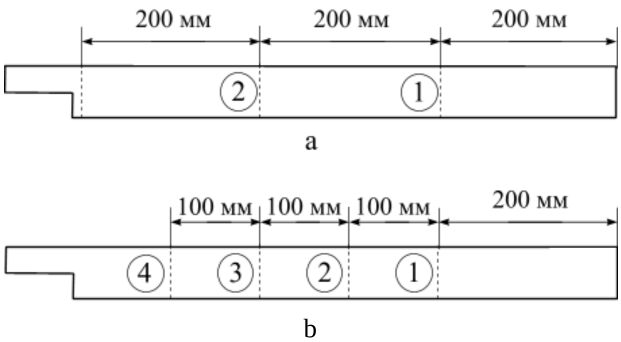

Figure 2: Scheme of disposition of metallic calcium portions on electrode:
a- experimentm №1 (CIS1); b – experiment №2 (CIS2)

Figure 3: Scheme of disposition of metallic calcium portions on electrode during fulfillment of experiment on A-550 furnace.

Fixed during the experiments current of melting and corresponding to it harmonic coefficient are shown on Fig. 4 – 13.

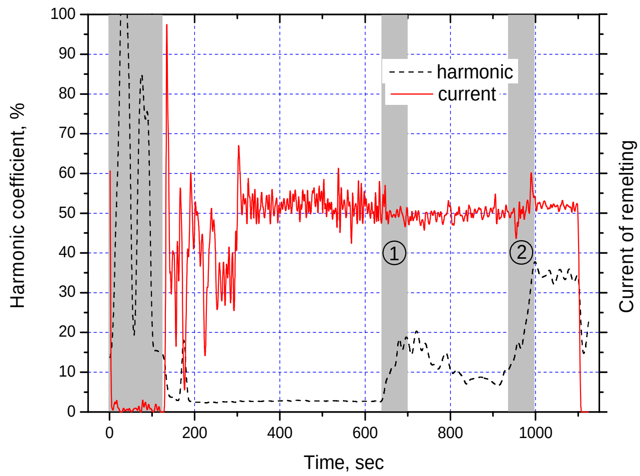

Figure 4: Current of remelting and corresponding to it harmonic coefficient fixed during the melting CIS1.

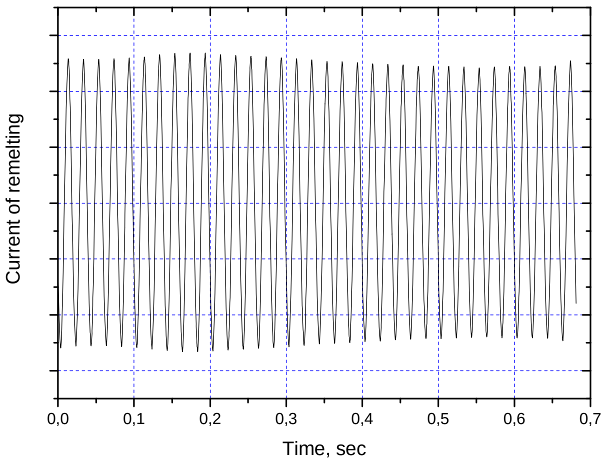

Figure 5: Oscillogram of remelting current during the consumable electrode melting in period of absence of metallic calcium (experiment CIS1).

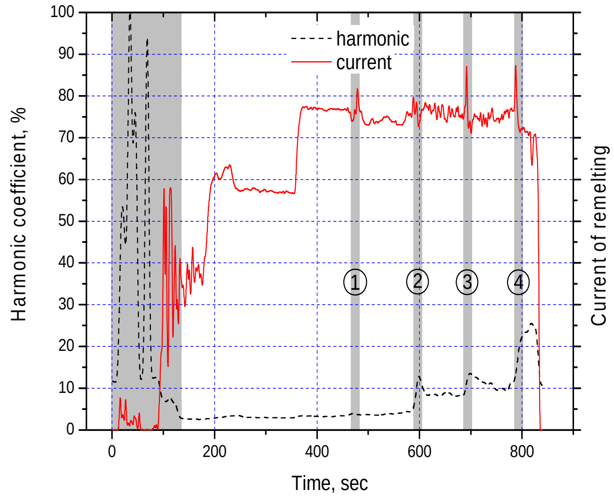

Figure 8: Current of remelting and harmonic coefficient corresponding to it, fixed during the melting CIS2.

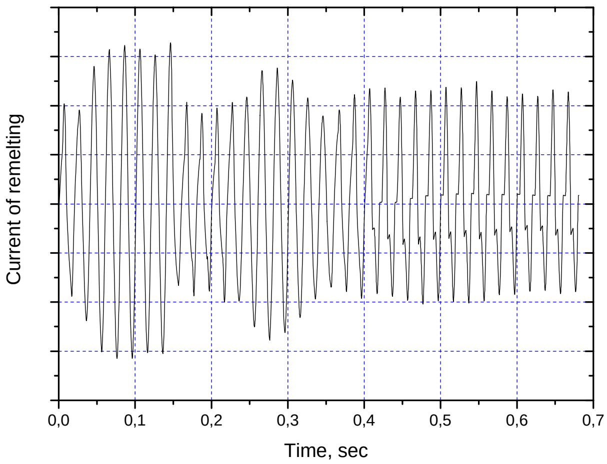

Figure 6: Oscillogram of remelting current during the consumable electrode melting after addition of 1st portion of metallic calcium (experiment CIS1).

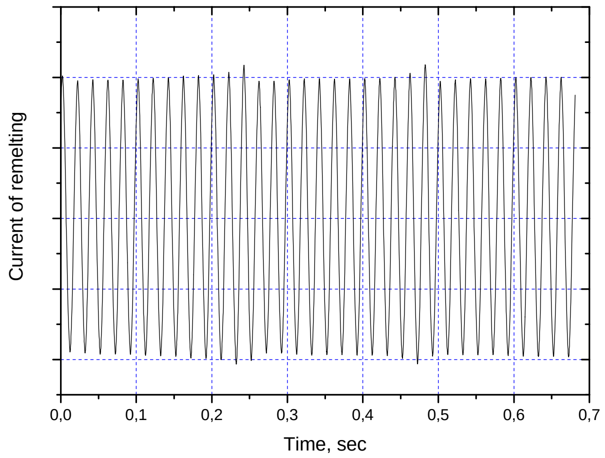

Figure 9: Oscillogram of remelting current during the consumable electrode melting in period of absence of metallic calcium (experiment CIS2).

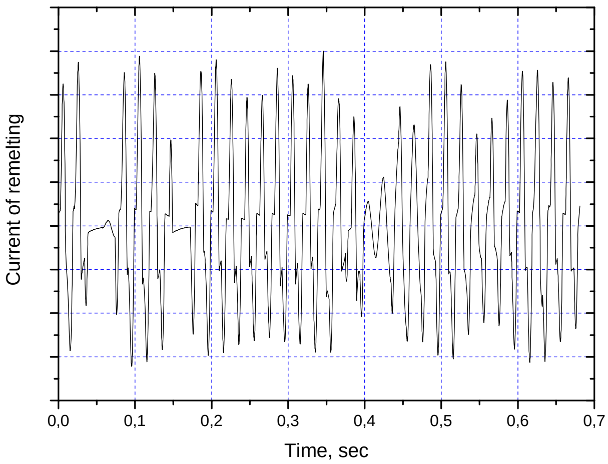

Figure 7: Oscillogram of remelting current during the consumable electrode melting after addition of 2nd portion of metallic calcium (experiment CIS1).

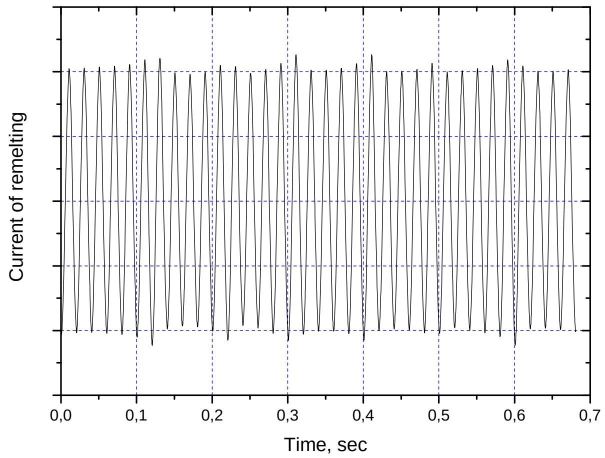

Figure 10: Oscillogram of remelting current during the consumable electrode melting after addition of 1nd portion of metallic calcium (experiment CIS2).

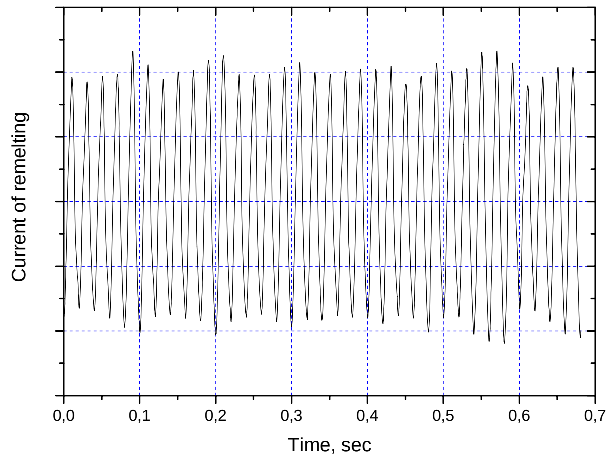

Figure 11: Oscillogram of remelting current during the consumable electrode melting after addition of 2nd portion of metallic calcium (experiment CIS2).

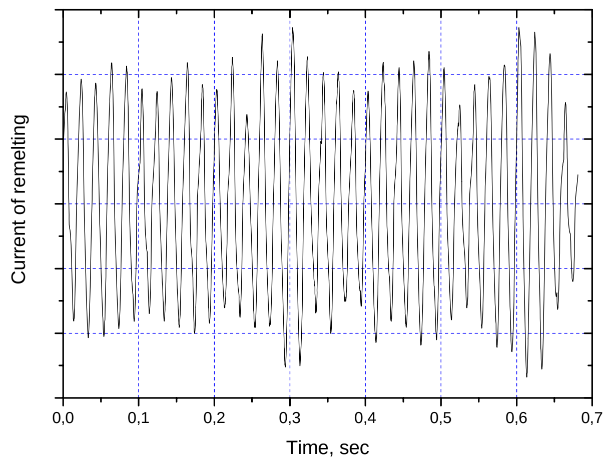

Figure 12: Oscillogram of remelting current during the consumable electrode melting after addition of 3rd portion of metallic calcium (experiment CIS2).

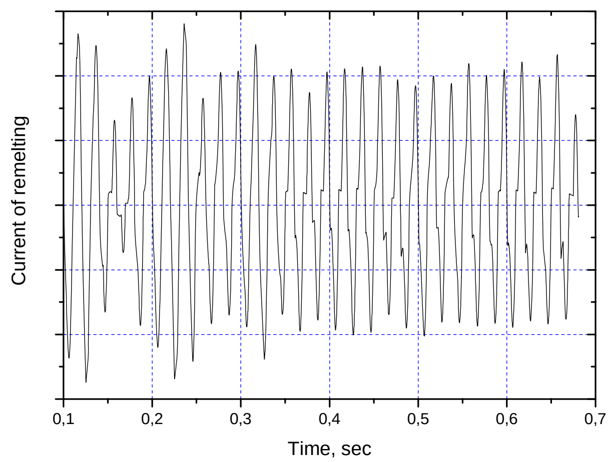

Figure 13: Oscillogram of remelting current during the consumable electrode melting after addition of 4th portion of metallic calcium (experiment CIS2)/

Analysis of obtained results has shown the following.: From above figures, we can see that harmonic coefficient for remelting under CaF_2 flux is small, order of 2.5%. After introduction of metallic calcium, harmonic coefficient abruptly increases and after reaching of certain maximum, decreases gradually. Such behavior connects obviously with consumption of metallic calcium for refining of furnace space, slag and metal.

Thus, in CIS1 experiment after 1st addition of calcium harmonic coefficient growth to 20% (see fig. 4), at that pulsation of current increase and distortion caused by arc discharge (see fig. 6) appears on oscillogram of current. After 2nd addition of calcium harmonic coefficient growth to 38% and considerable distortion caused by arc discharge were observed on oscillogram of current (see fig. 4, 7).

In second experiment CIS2 1st addition of calcium practically had not influence on harmonic coefficient, only splash of current was observed (see fig.8-13). Supplying of 2nd addition causes short-time increasing of harmonic coefficient to 12% with its further stabilization on the level 8%. After 3rd addition of calcium, harmonic coefficient growth to 13-14% and decreases gradually. Before the 4th addition it was equal to 9.5%. Pulsations of current considerably increases on diagram, distortions, caused by arc discharge had not detected. 4th addition causes the increasing of harmonic level up to 26%, distortions caused by arc discharge appears and were seen visually on oscillogram of current.

Taking into account data concerning current, harmonic coefficient and electrode carriage displacement we can say that dissolution of calcium portion in slag has the influence on all of these parameters. However, information about harmonic composition of current is more informative, because changing of remelting current value and velocity of electrode supplying may be caused in time of melting by many another factors.

The experimental testing of developed information-measuring system has shown that it may be used for monitoring of metallic calcium content during all period of melting and correction of its content if it is necessary.

Taking into account the necessity of reaching of the main investigation goal – development of ecologically clean, economically acceptable and technically reproducible technology of obtaining of quality ingots from titanium and its alloys, series of experiments for obtaining of alloys of Ti-Al system was carried out. To develop of technology of producing of γ-TiAl alloy by ChESR method, experiments for remelting of electrode from titanium and electrotechnical aluminium under the slag of CaF_2-Ca system in argon atmosphere was carried out. Obtained alloy was investigated by chemical, macro- and microstructre analysis, microhardness measurement and determination of resistance to gas corrosion were carried out.

At investigation of macrostructure, presence of 3 zones in transverse cross section of ingot was determined. Structure of skin and core zones is dense. At the same time zone of columnar crystals contains elongated pores. Their longitudinal axis is oriented in direction of columnar crystals growth. Local spectral analysis of material in different point of cross-section confirms high uniformity of chemical composition that practically coincides with composition of initial consumable electrode. Analysis of microstructure has shown that it is formed by monophase matrix with isolated inclusions of excessive phases. Concentration of excessive phase in core zone (9-11 % vol.) higher than in skin zone (5-6 % vol.). X-ray structure analysis has shown that main phase of alloy is the titanium aluminide γ-TiAl, microhardness measurement of phase γ-TiAl shows that it has value 4500 – 4800 N/mm^2, main excessive phase is $TiAl_3$. This result does not fully correspond with equilibrium diagram, corresponding to those precipitations of $TiAl_2$ must be observed in structure. Obviously, conditions of ingot crystallization are different from equilibrium. Besides main phases, calcium oxides of globular shape in small quantities and separate inclusions of intermetallic compound Ti_nSi_m of variable composition have been found. Impurities in initial charge are the probable source of their formation. Therefore, preliminary results confirm that ChESR under calcium containing flux permits obtaining of ingot of TiAl with high uniformity of chemical composition with low content of oxide inclusions from combined electrode from metals with high reaction ability.

Conclusions

1. Information-measuring system of ChESR process was developed and created. It is based on ESR unit A-550 and personal computer with industrial modules of the digital input/output that have 32 analog-digital converters with 12 bit resolution (PCI-1202) and 16 bit resolution (PCI-1602). It permits to record sinusoids of current and voltage of remelting, temperature of the cooling water in the every cooling contour and its consumption/ electrode displacement during the melting, procure in the chamber of the furnace and other parameters.

2. Fulfilled experimental testing of developed information-measuring system has shown perspectivity of such characteristic as harmonic composition of melting current for monitoring of metallic calcium content during all period of melting and correction of its content if it is necessary.

3. By the example of obtaining of ingot of TiAl with high uniformity of chemical composition with low content of oxide inclusions from combined electrode, it is shown that electroslag remelting under calcium containing fluxes in chamber type furnaces is the real and perspective direction in the field of producing of ingots from titanium and its alloys.

Acknowledgment

The authors would like to acknowledge Science & Technology Center of Ukraine (STCU) for financial support (STCU Grant #3385) of investigations, presented in this paper.

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