Improving Processes of Mechanized Pulsed Arc Welding of Low-Frequency Range Variation of Mode Parameters

Yu N Saraev[1a], S A Solodskiy[2b], O V Ulyanova[3c]

[1a]Doctor in Engineering, professor. Institute of Strength Physics and Materials Science of the Siberian Branch of the Russian Academy of Sciences, Tomsk, Russia;
[2b]PhD in Engineering, associate professor. National Research Tomsk Polytechnic University, Yurga Institute of Technology, Tomsk, Russia;
[3c]teaching assistant. National Research Tomsk Polytechnic University, Yurga Institute of Technology, Yurga, Russia;

e-mail: [1a]litsin@ispms.tsc.ru; [2b]serdgio80@inbox.ru; [3c]olgauljanova@mail.ru

Abstract. A new technology of low-frequency modulation of the arc current in MAG and MIG welding is presented. The technology provides control of thermal and crystallization processes, stabilizes the time of formation and crystallization of the weld pool. Conducting theoretical studies allowed formulating the basic criteria for obtaining strong permanent joints for high-duty structures, providing conditions for more equilibrium structure of the deposited metal and the smaller width of the HAZ. The stabilization of time of the formation and crystallization of the weld pool improves the formation of the weld and increases productivity in welding thin sheet metal.

1. Introduction

Today conventional methods of welding and hardfacing (arc hardfacing, electroslag hardfacing, plasma-jet hardfacing) have exhausted their potential. However production of new promising steel types in industry is being constantly improved and developed. It requires research and development in new technologies increasing performance capabilities of conventional heating sources (arc, plasma, laser radiation) and their hybrid combinations used to produce permanent joints of these steels [1-4].
Pulse technologies of welding and hardfacing [5-9] as well as specialized equipment which is being intensively developed by world leading producers of welding equipment [10-16] offer opportunities for this development. The interest to pulse technologies in welding and hardfacing is aroused by their advanced performance as compared with conventional methods. Pulse technologies provide:

- control of welding, metal transfer and crystallization regardless of welding pool space position with lower values of the main process variables;
- two- or threefold increase of welding pool crystallization rate due to unsteady influence of a heating source on the welding pool reducing molten metal temperature;
- lower deformation in welded products, built-up layers;
- improvement in the quality of welded joints and the coatings applied (improved weld regardless from space position, homogenous chemical composition throughout the coating, structure atomization in the weld and in the heat-affected zone). These advantages are obtained by means of directed crystallization of the welding pool and intensified

hydrodynamic processes in the molten metal which leads to degassing of the welding pool and uniform distribution of alloying element throughout the hotmelt;
- improving mechanical properties of welded products due to considerable reduction of the heat-affected zone and atomization of its structure.

A great number of research works deal with these processes in welding but there are some understudied issues concerning development and application of low-frequency pulse control of welding mode energy parameters.
The aim of the research is finding ways to improve structural behavior and performance characteristics of permanent joints of metal structures by means of pulse technologies of welding and hardfacing low-frequency variation range of mode energy parameters.

2. Development history of low frequency pulse technologies in welding.

A method of arc welding of steel sheets with programmable low-frequency modulation of welding current was first developed by M P Zaitsev [19]. It was followed by a great variety of processes and devices for its application.
A P Petrov and G A Slavin suggested low-frequency range of pulse arc (up to 10hz) which allows periodical changes (regulations) of heat flow fed to the metal and thus control of base metal penetration and weld formation. Such a modulation of the weld current found wide application in argon tungsten arc welding [20].

3. Analytical part

A number of scientific schools in the former USSR (in Kiev, Rostov, St-Petersburg, Moscow, Tomsk, Karaganda) grounded and developed this application of this method of low-frequency modulation in consumable-electrode welding. Thus I I Zaruba and co-authors [21, 22] first showed that current modulation can be an effective way of welding control reducing its cost. Further on F A Vagner, I N Vornovitskiy, F A Hromchenko, R I Dedyuh, V S Sidoruk, T G Shigaev and others [23-30] proved that in many cases current modulation can improve performance characteristics of welded joints and widen capacities of conventional welding and hardfacing.
The researchers mentioned above have determined that in manual arc metal welding under average current values changes in heat supply mode do not influence the effective efficiency of arc heating. However thermal efficiency of base metal penetration and weld dimensions in modulated current welding are higher than those in direct current welding. These values increase as the modulation depth grows (ratio of pulse current to pause current). It leads to increased arc pressure and stimulates its penetration into base metal. Conditions of transferring arc heat power to the base metal improve which provides effective melting of the metal [31, 32].
Works [33-35] prove that automatic control of the arc power by means of modulated current provides considerable stabilization of weld root pass formation which means more stable penetration as compared with continuous arc welding. This advantage of modulated current welding with forced destruction of ligament during the pause is stipulated by the more precise metering of energy supplied into the metal.
Noting a positive influence of low-frequency current on weld metal formation at different space positions it should be pointed out that majority of works in the field of development and application of pulse technologies deal with manual arc welding. However D A Dudko, V S Sidoruk, S A Zatserkovny [36-38] proved that the advantages of pulse technologies described above are valid in mechanized arc welding as well. At the same time low-frequency alternation of welding energy parameters in mechanized welding do not always eliminate the most significant drawbacks of arc welding – weld spattering and process instability especially in CO_2 [39].
To insure regular welding process under winter conditions it is important to take into account specifics of weld development at low temperatures. Low atmosphere temperature can have a negative influence not only on welding process stability but also on the structure and mechanical properties of welding joints. It is caused by quick cooling of the welding pool metal under winter conditions [40-41].

For some high-strength steels, changes in cooling rate caused by dropping temperature at low critical cooling rates makes it possible to get quenched structures in the heat-affected zone and quench cracks [42]. Due to that weld formation under extremely low temperatures requires special technologies. It becomes necessary to control the process of crystallization in weld development.

This approach becomes possible if thermal cycle control takes place at the stage of crystallization of weld metal from melt. It can be achieved by controlling two parameters: heating temperature and, what is more important, exposure time and proper transition of the weld metal from one structural condition to another according to "Iron – Carbon" diagram. Thus to obtain equilibrium, close to the base metal structure of the weld and heat affected zone it is necessary to maintain the required energy and time parameters in the power source –arc – product system so that to provide temperature ranges under which changes in structural and phase conditions go on smoothly [42].

Conventional pulse-arc technologies in the frequency range from 300 to 25hz which are now widely used in welding and assembly production are first of all aimed at controlling electrode metal transfer, increasing penetration depth and improving weld properties at all space positions. But to control structural and phase conditions in the weld metal one should control the crystallization time according to the cycles of phase condition diagram. It can be performed by means of pulse-arc welding in the range from 25 to 5hz. In Russia they are called "low frequency modulation of arc current" [5].

4. Experimental part

Controlling a crystallization temperature mode is possible only by means of arc current alternating in pulse/pause cycles with predetermined frequency and pulse/pause ratio. For example, there is a widely spread type of welding with low-frequency modulation of arc current during the pause performed by means of reducing welding current to the minimal arc current values to allow crystallization of the welding pool [18]. But this method is used in manual metal arc welding. In this case welding is carried out at flat current-voltage characteristic of the arc from power supply with falling external current-voltage characteristic which enables modulating welding current by means of the power supply values [43].

In metal active gas welding with constant electrode feed rate this method cannot be widely used because welding wire tends to dip into the welding pool [6]. It happens mainly when pauses are very long so that melting rate falls but welding wire feed rate remains the same. In this case modulation of voltage and current is possible only in a narrow range of welding energy parameters when at interpulse periods the arc length increases but not until breaking and at interpause periods it reduces but until dipping of the wire into the welding pool.

This approach provides smooth change of the pause current but does not enable reliable pulse/pause ratio control [43, 44].

To obtain a stable welding with low-frequency modulation of the welding current in metal active gas welding it is necessary to provide control of welding energy parameters when working from energy supply with external characteristic which meets the predetermined electrode feed rate at a given interval alongside with control of a corresponding automatic change of the indicated parameters when switching to another wire feed rate or even when it discontinues. Fig. 1 shows a cyclogram of the process described above.

To form a welding pool, welding is carried out with constant welding wire feed rate at rising current-voltage characteristic of the arc and flat external current-voltage characteristic of the power supply until welding pool of a predetermined volume is formed (period T1cycle "Pulse" Fig. 1 and 2). After that for the welding pool to crystallize, a pause time occurs, welding wire movement is stopped, arc burning is switched over to the flat current-voltage characteristic of the arc and external falling characteristic of the power supply (period T2 cycle "Pulse" Fig. 1 and 2).

Such technology involving simultaneous stoppage of welding wire allows controlling the pause time and increases arc current alternation range due to changing current-voltage characteristic of the power supply. The period $T=t_i + t_p$, where t_p is pause time, t_i is pulse time is of primary importance in the suggested type of welding.

The following conditions have to be satisfied:
1. pause time should be enough to enable crystallization of 75 % of the total amount;
2. pause time should provide continuous arc burning (when low-current arc is burning it must not break because of excessive electrode melting. It can be achieved through introduction of an arc current feedback channel and switch over to the falling current-voltage characteristic of the power supply.

5. Research material and methods
To assess the influence of the welding type under the study on the microstructure of welded joints we obtained macro- and microstructures by optical metallography method using optical microscope Olympus GX-71. The following parameters were involved: welding type – MAG, welding wire Sv08GSMT− 1.2 mm in diameter, power supply voltage – 22 V, pulse current – 220 A, pause current – 50 A, cycle frequency – 1.1 hz, pulse/pause ratio – 1.25, air temperature – 15 ˚C.

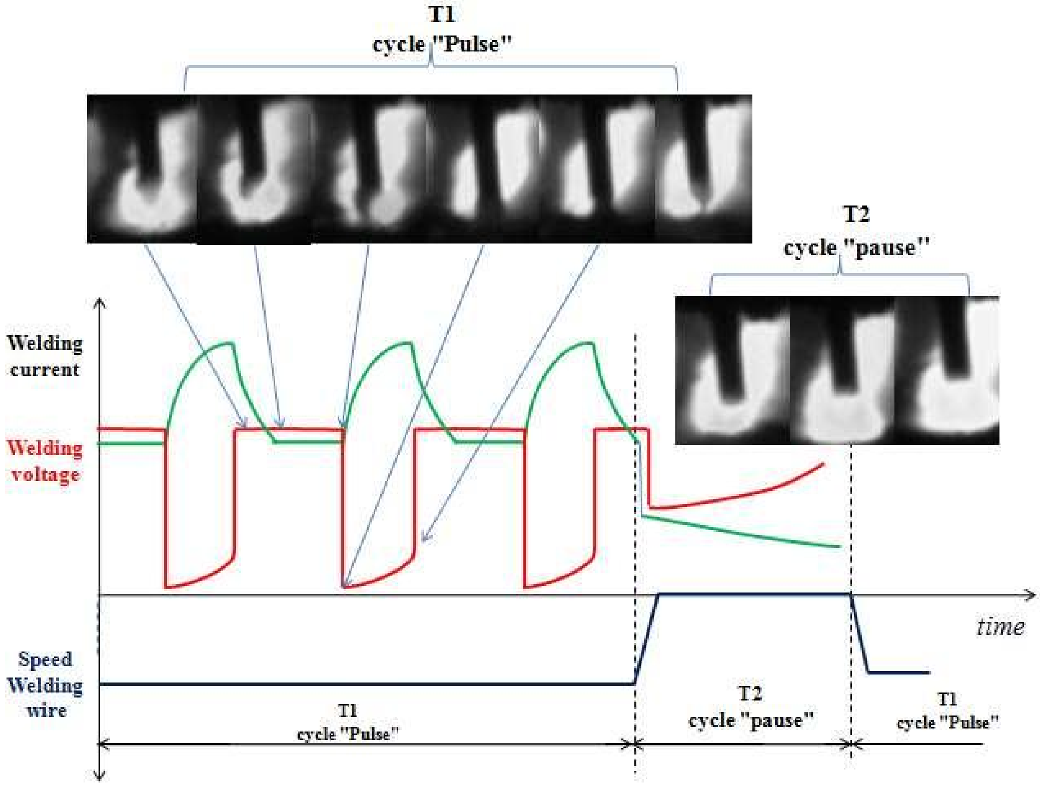


Fig.1 Welding cyclogram

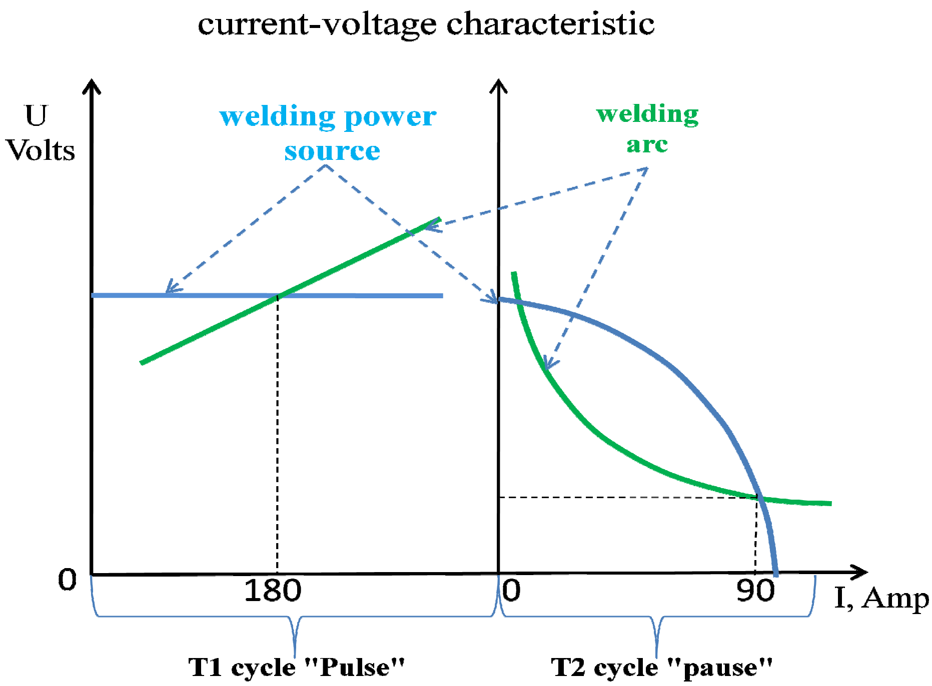
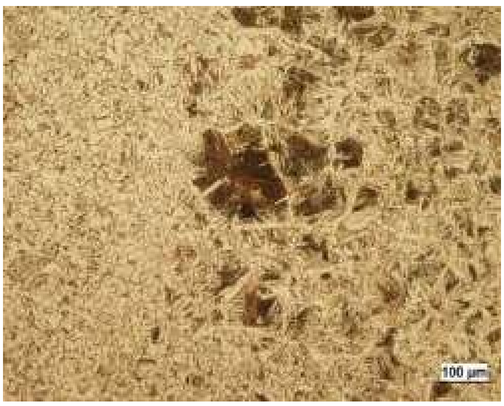


Fig 2. Interdependence of current-voltage characteristic of the arc and of the power supply at different intervals of welding process.

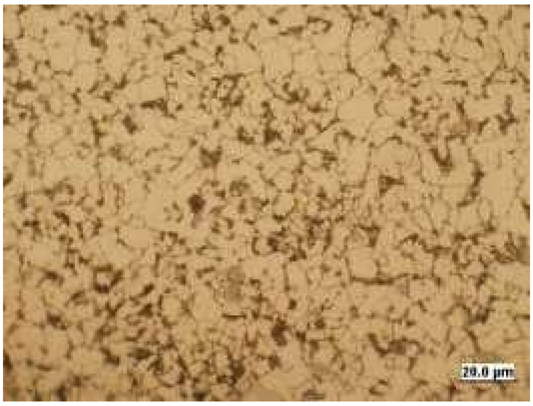
6. Research in microstructure of the weld on C17 samples of 09G2S steel (pipe 159x6).
Initially 09G2S steel has ferritic-pearlitic structure. Pearlite is distributed uniformly (Fig. 3a,b). Pearlite amount and disposition correspond to 1C category according to the National State Standard 5640-68.

Microstructure analysis of sample 1 (low frequency modulation current welding) shows that the heat- affected has ferritic-pearlitic structure. Ferrite grains are in sub-microcrystalline state, ferrite is becoming sorbitic (Fig. 3c). Pearlite amount and disposition correspond to 1B category according to the National State Standard 5640-68. Deposited weld metal structure is ferritic-pearlitic.



a

b



c

d

Fig. 3 – Weld microstructure: a,b – microstructure of 09G2S steel, c – microstructure of welded joint heat affected zone (low frequency modulation current welding); d – microstructure of welded joint heat affected zone (conventional feed of welding wire)

Sample №2. In the fusion zone of the weld and the base metal there is a small area with Widmanstatten pattern − 3B category according to the National State Standard 5640-68 Fig. 3d). The weld structure is identical to that of Sample 1.

As compared with the upper row, in the bottom row Widmanstatten pattern disappear from the weld and the base metal attached to the weld due to auto thermal treatment.

Differences resulting from the research can be explained by different characteristics of changing cooling temperature in the range of critical temperatures of phase transformations during secondary crystallization (in solid phase) [45].

7. Conclusion

1. Using falling current-voltage characteristic of the power supply during welding pool crystallization increases crystallization time which is advantageous for the welding process. Reduction of current to minimal values during crystallization provides conditions for thermal treatment of the weld.
2. Stabilization of welding pool formation and crystallization time improves the weld and increases labor productivity in welding of thin sheet metals.
3. The suggested technology of MAG welding takes into account time of welding pool formation and crystallization under different temperature conditions of structural-phase transformations which allows a wide-range control of crystallization processes both in liquid and solid phases.

The work was done as a part of Fundamental Scientific Research Program of State Academies of Science of the Russian Federation for 2013-2020.

References

[1] Saraev Yu N, Lebedev V A and Solodsky S A. The development and practical application of adaptive pulse-arc welding in the manufacturing and repair of metal structures responsible function // Applied Mechanics and Materials. Vol. 682 (2014). Pp. 332-338. Submitted: 07.07.2014. Online available since 2014/Oct/27 at www.scientific.net Accepted: 31.07.2014 © (2014) Trans Tech Publications, Switzerland, doi:10.4028/www.scientific.net/AMM.682.332.

[2] Lebedev V A, Maksimov S Yu, Zhernosekov A M and Saraev Yu N Controlling weld geometry by means of welding equipment in mechanized and automatic consumable electrode arc welding. Welding International, 2015. Vol. 29, No. 5, 379–385, http://dx.doi.org/10.1080/09507116.2014.934537.

[3] Paton B E Critical analysis of the current notions of arc self-regulation in consumable electrode welding / B E Paton, V S Sidoruk, S Y Maksimov and Yu Saraev // Engineering: network electronic scientific journal. - 2015 - Vol.3, №4. – P. 38-47.

[4] Chinahov D A Study of thermal cycle and cooling rate of steel 30ХГСА single-pass weld joints // Applied Mechanics and Materials. – Vols. 52-54. – 2011. – p. 442-447. - Mode of access: http://www.scientific.net/AMM.52-54.442.
[5] Saraev Yu N Pulse welding procedures and welding. Novosibirsk, Nauka, 1994, 108 p.
[6] Zhernosekov A M Trends in the development and management of processes of metal transfer in protective gases (Review) // Automatic welding. - 2012. - № 1. - p.33-38.
[7] Saraev Yu N Features of the development of electro-technological processes of welding and hardfacing on the basis of algorithms of adaptive pulse control mode energy parameters // Engineering: network electronic scientific journal. - 2015 - Vol.3, №3. - P. 3-11.
[8] Wagner R A Equipment and pulsed arc welding methods. M: Energy, 1980. 120 p.
[9] Lebedev V A and Saraev Yu N Pulsed impact of mechanized and automatic welding equipment on welding processes and welding systems // Welding production. - 2015. - № 5. - P. 34-44.
[10] Loos A V, Lukutin A V and Saraev Yu N Power supplies for pulsed electro-technological processes. - Publishing and printing company of TPU. - Tomsk, 1998 - 159 p.
[11] Paton B E, Lebedev V A, Pichak B G and Poloskov S I Evolution of pulse welding wire feed for welding and surhardfacing. Welding and diagnostics. 2009. № 3. P. 46-50.
[12] Lebedev V A Tendencies in mechanized welding with a controlled transfer of electrode metal (Review) // Automatic welding. - 2010. - № 10. - P.45- 53.
[13] Lankin Yu N Automatic control of the mechanized welding process with controlled electrode metal transfer (Review) // Automatic welding. - 2007. - № 1. - P. 3-10.
[14] Bondarenko V L Arc welding with pulsed wire feed - SMT process proposed by "Fronius" company // Automatic welding. - 2004. - № 12. - P. 55 - 58.
[15] Saraev Yu N Evaluation of the productivity and quality of repair and reconditioning operations in equipment made of 12CR18N10T1 type steel // Saraev Y, Selivanov Y. – Welding International, 2012, T.26, p.p. 466-470.
[16] Paton B E, Maksimov S Yu, Sidoruk V S and Saraev Yu N On the issue of arc self-regulation in consumable electrode welding // Welding production. - 2014. - № 12. - P.3 -11.
[17] Saraev Yu N Experience from the development and practical application of adaptive pulse-arc welding equipment for construction and repair of main pipelines // Problems of Materials Science. - 2015. - № 1. - P. 210-218.
[18] Saraev Yu N The development and application of adaptive pulse-arc welding methods for construction and repair of pipelines. Group Author of books: IEEE Conference: International Conference on Mechanical Engineering, Automation and Control Systems (MEACS). Locality: Tomsk, RUSSIA, published: OCT. 16-18, 2014 Sponsors: Inst Elect Engineers; Russian Fdn. Basic Res; Tomsk Polytechnic University Tomsk IEEE Chapter; Tomsk Polytechnic university, Institute of Physics high-Tech 2014, Pp. 1-5. Print ISBN: 978-1-4799-6220-4. DOI: 10.1109 / MEACS.2014.6986956. Published: 2015.
[19] Zaitsev M P and Kuleshov O M Means of automation in equipment for arc welding // L: Energy, 1975. – 144 p.
[20] Petrov A V and Slavin G A Research of technological capabilities of pulsed arc // Welding Production. 1966. № 2. P. 1 - 4.
[21] Zaruba I I, Lebedev V K, Sheyko P P et al. Arc welding with modulated current // Automatic welding, 1968. - № 5. P. 70.
[22] Zaruba I I, Lebedev V K, Sheyko P P et al. Welding modulated current // Automatic welding, 1968. - № 11. P. 35 - 40.
[23] Wagner F A Manual arc welding with pulsed arc // Welding production // 1970. - № 3. - P. 21 - 22.
[24] Wagner F A Cyclic changes in the parameters of welding process and their impact on the gas saturation of welds // Power plant construction, 1981. - № 4. - P. 70 - 72
[25] Vornovitskiy I N and Trusov A G Optimization of modes in manual pulsed arc welding by the level of gases in welds // Power plant construction, 1978. - № 4. - P. 51 - 52.

[26] Hromchenko F A, Anokhov A E and Alekhova I A Structure and properties of welded joints made by stationary and pulsed arc // Welding production, 1980. - № 6. - P. 21 - 23.
[27] Mazel A G, Dedyuh R I and Knyazkov A F The arc stability in manual arc welding with modulated current // Impact of welding parameters of modulated current on the process of electrode melting and the depth of penetration in manual arc welding // Welding Production, 1976. - № 4. - P. 9 - 10.
[28] Dudko D A, Sidoruk V S, Zatserkovny S A, Taraborkin L A and Makhlin N M Dependence of the chemical composition of the weld parameters from the manual arc welding the modulated current. - Automatic welding. - 1989. - № 2. - p.27 - 29.
[29] Shigaev T G On terminology in modulated current welding // Welding Production.- 1980.- №7.- P.40.
[30] Mazel A G and Dedyuh R I On the stability of manual arc welding with modulated current // Welding Production, 1978. - № 12. - P. 11 - 13.
[31] Wagner F A Equipment and methods for pulsed arc welding M.: Energia, 1980. - 120 p.
[32] A method for adaptive pulse arc welding. - Invention patent number 2410216 (Russia) / Saraev Yu N - Priority on June 16, 2008
[33] Saraev Yu N, Bezborodov V P, Grigorieva A A, Golikov N I, Dmitriev V V and Sannikov I I Distribution of residual stresses in welded joints in 09G2S steel produced by adaptive pulsed-arc welding. Welding International, 2015. Vol. 29, No. 2, 131–134, http://dx.doi.org/10.1080/09507116.2014.897804.
[34] Saraev Yu N, Gladkovsky S V, Golikov N I and Veselova V E Increase of operational properties of steel structures by methods of adaptive pulse-arc welding for use in low temperature climatic // Welding Production. - 2015. - №11. - P 33-41.
[35] Dudko D A, Lebedev V V, Moshkin V F and Pichak V G Stability of arc welding processes and surfacing with pulse feed of welding wire // Welding Production - 2000. - № 1. - P. 12 - 15.
[36] Sidoruk V C, Dudko D A, Zatserkovny S A and Taraborkin L A Influence of the manual arc welding with modulated current on the primary structure of the weld metal. - Welding Production. - 1988. - № 5. - P.1-3.
[37] Zatserkovny S A Improving the process of manual arc and mechanized welding in carbon dioxide, based on the low-frequency modulation current. - Abstract of the thesis for the degree of candidate of technical sciences. - Kyiv, 1989. - 16 p.
[38] Potapyevsky A G, Saraev Yu N and Chinakhov D A Welding of steel with consumable electrode in shielding gases. Technique and technology of the future: monograph / Potapyevsky A G, Saraev Yu N and Chinakhov D A; Yurga Institute of Technology. - Tomsk: Publishing House of Tomsk Polytechnic University, 2012. - 208 P. ISBN 978-5-98298-620-7.
[39] Larionov V P, Sleptsov O E, Saraev Yu N and Bezborodov V P New approaches to the development of modern technologies of welding and coating to ensure the operational reliability of steel structures and products, operating in conditions of Siberia and the Far North // Bulletin of the Academy of Military Sciences. 2008. № 3. - P. 67-69.
[40] Saraev Yu N Experience in the development and practical application of adaptive pulse-arc welding equipment for construction and repair of main pipelines // Problems of Materials Science. - 2015. - № 1. - P. 210-219.
[41] Chinakhov D A and Agrenich E P Computer simulation of thermo-mechanical processes at fusion welding of alloyed steels // Materials Science Forum. – Vols. 575-578 (2008). – Pp. 833-836.
[42] Patent for invention number 2.293.630 (RF). The method of mechanized welding in CO_2 with low-frequency modulation of the weld pool. Fedko V T, Brunov O G, Solodsky S A, Kryukov A V and Sednev V V The priority of invention July 14, 2005 V23K 9/33. Published on 10.04.2007. Bul.№10
[43] Solodskii S A, Brunov O G, Zelenkovskii A A Automated system for controlling the process of CO_2 welding with pulsed wire feed and welding current modulation. Welding International. 2012. T. 26. № 4. p. 314 − 317.

[44] Brunov O G, Fedko V T and Solodskii S A Transfer of electrode metal in welding with the pulsed feed of welding wire. Welding International. 2007. T. 21. № 1. C. 50−54.