

Influence of Frequency and Induction of Longitudinal Magnetic Field on The Electrode Metal Loss and its Spattering During MAG-Welding

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Abstract. It is possible to increase the MAG-welding efficiency by controlling the electrode metal mass transfer at the reduction of discharge coefficient on spattering by influence of longitudinal magnetic field on the arc. The paper identifies a range of longitudinal magnetic field frequencies and induction which provide the discharge coefficient reduction of the electrode metal; it has also been found the characteristics of their mutual influence on electrode metal mass transfer process; mathematical models correlating the frequency and induction of longitudinal magnetic field length with loss coefficient of electrode metal on spattering are presented; technological recommendations, the implementation of which will allow to improve the efficiency of MAG-welding in industrial environments, are given.

Introduction

Mechanized welding method in active shielding gas by solid cross-section wire - MAG-welding – certainly has a number of advantages over the manual arc welding process. However, along with the advantages this method has drawbacks that reduce the effectiveness of its use: the low productivity compared to the automatic welding methods; quality dependence of the welded joint on the skill of the welder; significant metal loss on spattering, which constitutes up to 10 ... 20% of welding wire weight.

Spattering is accompanied by the ejection from arc zone the sprays of molten metal of various size, which come into physical and chemical interaction with the surface layers of the weld metal [1]. The protection of metal surface from spray sticking and / or its cleaning leads to the need of additional works in a volume of 20 ... 40% of the overall complexity of the welding operations [2].

Among the main reasons of metal droplets ejection from the welding zone the following are pointed out: unstable metal transfer, when the power which separates a drop from the electrode is directed away from the bath and a drop is ejected beyond its bounds; local explosive gases expelling in the volume of metal of welded bath caused by metallurgical reactions; destruction of molten metal bridge formed during metal transfer with the short circuits as a result of a sharp increase in current density under narrowing of the tie plate (pinch effect) [3].

The metal spattering intensity depends on the metal wire composition, the protective mixture components and the surface state of the base metal edges; the size and the ratio of welding variables;



characteristics of the power supply (the relationship between the dynamic characteristics of the power supply and loss on spattering of the electrode metal), and others. [4,5].

Therefore, we have made an assumption about the possibility of a control over the process of electrode metal mass transfer by the influence of the external magnetic field on the arc. However, the accurate data about the spattering indicators under MAG-welding with the use of additional influence of an external electromagnetic field on the arc are practically absent or are controversial [4,6].

Problem setting

The research object is the process of arc welding by smelting electrode in the medium of active protective gases with an additional influence of an external electromagnetic field on the arc.

The subject of study is the influence of the frequency and the induction of a longitudinal magnetic field (*further in the paper - LgMF*) on the processes of drop-formation and mass transfer of electrode metal during MAG-welding.

The aim of this work is to study the impact of LgMF induction and frequency on the loss coefficient of the electrode metal on spattering ψ and droplet distribution of electrode metal into fractions during MAG-welding, as well as the development of technological recommendations that will improve the technological and economic efficiency of this welding process.

The main objectives of the study are:

- determination of the frequency range and inductions of LgMF, providing the reduction of ψ coefficient;
- characterization of their mutual influence on the process of mass transfer of electrode metal;
- development of mathematical models relating the LgMF frequency and induction with a discharge coefficient on electrode metal spattering.

The introduction of new technologies in a production environment will improve the efficiency of MAG-welding and will lead to material, labor and energy reduction.

Materials and methods

In the experiments we use the retrofit of UD-209-UHL4, universal rectifier VDU-506 (i.e. Multi-operated Arc Rectifier-506); analytical laboratory scales. Rollers were fused on the flat carbon steel St3sp (i.e. dead-melted steel, carbon content – 0,14-0,22 %) GOST 380 (all-Union State Standard) by welding wire of brand Sv-08G2S (i.e. welding wire, 0,8 – carbon content, manganese – 2%, silicon – less than 1 %) in the carbon dioxide medium of the highest grade (GOST 8050 (all-Union State Standard)). To create an external electromagnetic field we used a specialized nozzle of welding head with integrated solenoid, powered by a laboratory device LATR-1 and specialized mode control unit BKRN-2 [7].

The electrode metal droplet ranging into fractions and the evaluation of their diameters have been done with the use of sizing screen (grain size: 1,5; 2,0; 2,5; 3,0; 3,5; 5 mm).

The induction components of LgMF B_z , were measured near the plate surface at a distance from the flat end of the electrode to the $5 \cdot 10^{-3}$ m plate. The induction of constant magnetic field was determined by teslameter of EM-4305 type with the Hall sensor and the base of 1×1 mm, and the alternative - by teslameter of F-4356 type with a Hall sensor and the base 4×4 mm.

The level of electrode metal spattering was estimated by a coefficient, which is numerically equal to the percentage of the wire mass, spent respectively on spattering ($m_p = m_n - m_{weld}$) and on the formation of a roll of 10^{-1} m ($m_n = \gamma_n \cdot l_n \cdot \pi \cdot d_n / 4$) where: m_{weld} - weld mass, equal to the difference of sample masses before and after welding, kg; γ_n - wire material density, in kilograms; l_n - the length of wire needed for the formation of roll of 10^{-1} m, m.

$$\psi = (m_p / m_n) \cdot 100 \% \quad (1)$$

The parameter change of the metal electrode mass transfer during welding with an additional influence of external LgMF of different frequency was investigated by method based on welding on a copper disc rotating at a predetermined angular velocity. In experimental conditions the angular

velocity was $0,185\text{c}^{-1}$. Nonstick coating was periodically applied on its upper surface with a diameter of 0.5 m. To ensure the same arcing process time (15 seconds), the welding power source, the pulse generator of LgMF and the specialized drive burner were put into operation with the aid of a control device with an electronic timer. We began the experimental data processing with measuring the distances between the adjacent droplets (burns) as well as for determining the transfer frequency.

Work results

In the study the following welding conditions were taken:

$I = 220 \dots 250\text{A}$; $U = 20 \dots 22\text{V}$; $V = 0,085\text{ m/s}$; direct-current of reversed polarity (DCRP). Metal thickness 10^{-2} m , diameter of the electrode wire $2 \cdot 10^{-3}\text{ m}$.

In drawing up the experiment matrix two factors, affecting the result, were taken - LgMF induction and its frequency. The loss coefficient of the electrode metal, the number of drops of electrode metal were the consequence of this matrix. To determine the mathematical models the orthogonal central composite second-order plan was chosen. Induction B_z and pulse rate f_{imp} were changed within 0 ... 80 mT (T-Tesla) and 0 ... 50 Hz, respectively (Table. 1).

Table 1 - Matrix of the experimental plan and research data

Induction of magnetic field B_z, mT	Frequency of magnetic field f_{imp}, Hz	Loss coefficient $\psi, \%$	Drops number, n_{kn}	Induction of magnetic field B_z, mT	Frequency of magnetic field f_{imp}, Hz	Loss coefficient $\psi, \%$	Drops number, n_{kn}
+	+	15.3	212	+	0	14.9	200
-	+	12.6	172	-	0	10.9	162
+	-	14.2	189	0	+	11.2	168
-	-	14.0	78	0	-	10.6	168
0	0	10.1	181				

Experimental data processing was performed using the software StatSoft Statistica. The received dependence between the parameters was shown in the form of three-dimensional graphs (Figs 1 and 2).

A greater impact on ψ has the induction value of LgMF than its frequency according to the analysis of the dependence of electrode metal loss coefficient from LgMF induction and frequency (Fig. 1). With increasing LgMF induction from 0 to 18 mT the loss coefficient decreases in average by 25%; in absolute values (equation (1)) from 14 to 10%.

With increasing frequency of LgMF from 0 to 36 Hz with the values of its induction up to 35 mT we also observed a reduction in the loss coefficient of electrode metal. A further increase in LgMF frequency has the opposite effect - the ψ coefficient increased from a minimum of 10% to 12.5%. That is, the additional influence on the arc by outer LgMF is positive, as in welding without LgMF implementation under the same operation conditions the loss coefficient is equal to 14.2% as compared to 12.5%.

The influence on welding arc by a longitudinal magnetic field by 40 mT induction increases the loss coefficient of the electrode metal. For values of B_z 40 ... 70 mT the ψ coefficient verges towards the average data for the case of MAG-welding without LgMF implementation. Further increase of B_z causes a sharp increase in the loss coefficient from 14 to 17.5%.

Thus, the minimum ψ values are observed in conditions of influence of alternate LgMF with 16 ... 34 Hz frequency and 18 ... 38 mT induction on the arc.

Mathematically, the above-mentioned dependence can be expressed by the following equation:

$$\psi = 13,414 - 0,1377 \cdot B_z - 0,1043 \cdot f_i + 0,0019 \cdot B_z^2 + 0,0006 \cdot B_z \cdot f_i + 0,0016 \cdot f_i^2 \quad (4)$$

It was experimentally proved that a significant impact on the number of electrode metal droplets has LgMF induction value and as well as its frequency (see Figure 2).

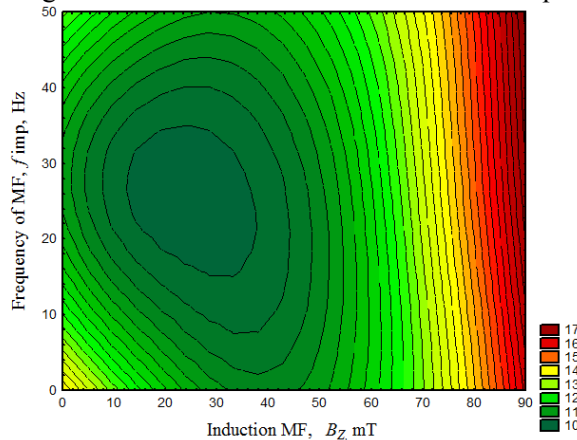


Figure 1 – Dependency graph of the loss coefficient of the electrode metal ψ from the induction B_z and frequency f_i of LgMF

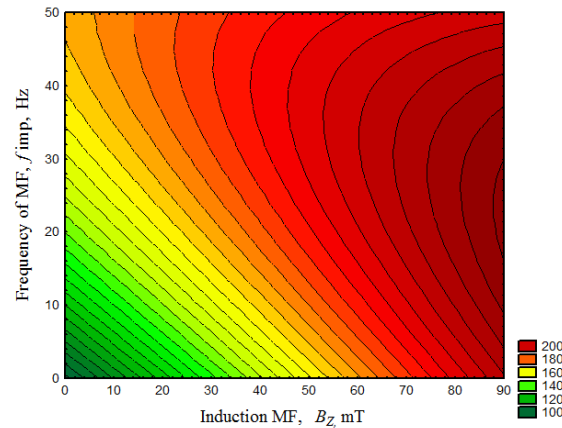


Figure 2 – Dependency graph of drops number n of electrode metal from the B_z and frequency f_i of LgMF

With induction increase of LgMF drops number of electrode metal almost doubles (from 100 to 200). With frequency increase of LgMF the increase in the drops number of electrode metal is also observed. However, the influence of LgMF frequency on the value n is less significant than the effect of induction of this field. For example, at LgMF induction index up to 20 mT the n increase was 60%, at $B_z = 30 \dots 50$ mT n increase was 80%.

The maximum droplets number is formed under the following conditions: LgMF induction $B_z = 75 \dots 90$ mT, LgMF frequency $f_i = 12 \dots 36$ Hz. At this mass transfer of electrode metal acquires jet nature.

Mathematically, the dependence data can be expressed by the equation:

$$n = 94,5833 + 1,4063 \cdot B_z + 2,81 \cdot f_i + 0,0022 \cdot B_z^2 - 0,0178 \cdot B_z \cdot f_i - 0,0264 \cdot f_i^2 \quad (5)$$

From the viewpoint of mass transfer of the metal electrode the number and the size of formed droplets have the importance in the process of MAG-welding. It is known that with decrease in droplet size the stability of arc welding process increases and the metal electrode loss on spattering reduces. In order to establish an optimum mode range of LgMF (frequency and induction) under which a minimum number of large ($> 2 d_0$) drops with the increase of the total number, a series of experiments were conducted, their results are shown in the Table 2 and 3.

Table 2 – The dependence of the electrode metal drops in number and fractions from the frequency of LgMF

Frequency, Hz	The fraction size, mm						
	1,5	2,0	2,5	3,0	3,5	5	Σ
0	7	4	5	24	31	7	78
10	37	26	19	18	21	5	126
20	56	37	26	17	19	3	158
30	61	42	29	17	17	0	166
40	63	45	31	14	16	0	169
50	67	54	28	13	10	0	172

Table 3 – The dependence of electrode metal drops distribution in number and fractions from induction of LgMF

Induction, mT	The fraction size, mm						
	1,5	2,0	2,5	3,0	3,5	5	Σ
0	7	4	5	24	31	7	78
20	30	26	24	18	28	6	132
40	44	39	37	17	26	5	168
60	64	51	46	12	4	2	179
80	71	55	52	8	3	0	189

Histograms of the distribution of the electrode metal droplets at MAG-welding with additional LgMF influence (Fig. 3).

Fig. 3 shows the dependence of the electrode metal amount from LgMF frequency where the columns 1-6 correspond to LgMF frequencies from 0 to 50 Hz with a step 10. As we can see with increasing LgMF frequency from 0 to 10 Hz the number of droplets almost doubled. What is more the number of small droplets fraction significantly increases: fractions from 1.5 and 2.0 mm increase in 5 times; 2.5 mm - in 4 times. A number of droplets of a larger fraction is reduced: 3.0 mm and 3.5 to 30%.

With increasing LgMF frequency from 10 to 20 Hz the number of droplets also increases and reaches 158 units, i.e., in 2.15 times. Moreover, as in the previous case, the number of small fraction droplets increases significantly: 1.5 mm fractions increase in 8 times; 2.0 mm - in 9.2 times; 2.5 mm - in 5 times respectively. A number of drops of large fraction is also reduced, on average by 30%.

With further increase in the LgMF frequency (from 30 to 50 Hz) we observed the stable high rates of droplets formation of small fraction, reducing the number of 3.5 mm fraction drops in three times and the lack of droplets with a diameter of 5 mm.

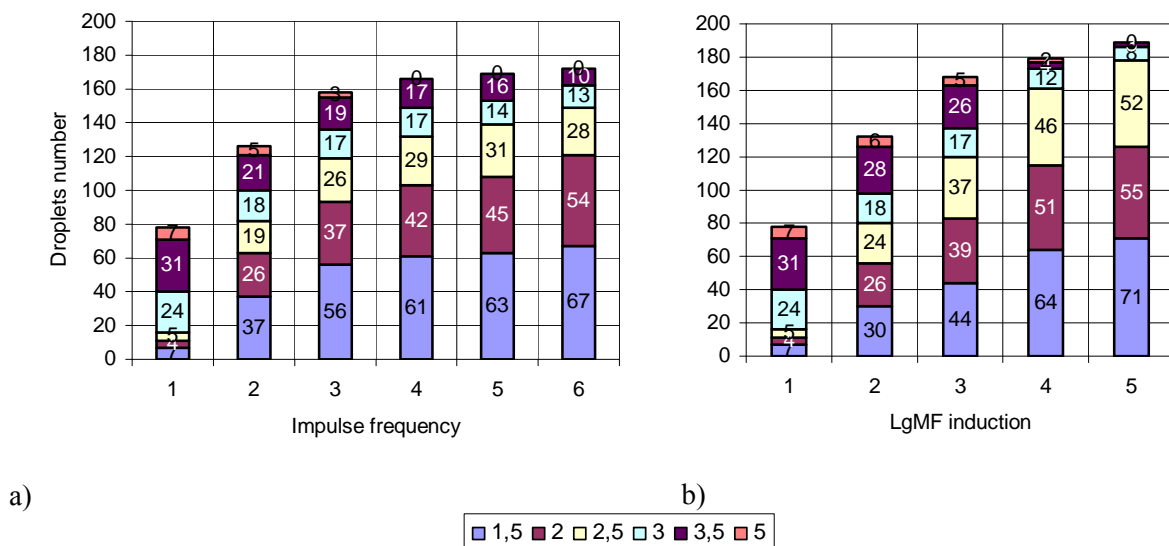


Figure 3 - Electrode metal droplets distribution during MAG-welding with the additional influence of LgMF (further explanation is in the text)

Fig. 3b shows the number of electrode metal by LgMF induction where 1-5 columns correspond to the LgMF induction values from 0 to 80 mT with the step 20. As we can see with increasing the LgMF induction from 0 to 20 mT the number of droplets is increased in 1.7 times. The number of small droplets fraction significantly increases - 1.5 in 4.3 times; 2.0 mm in 6.5 times; 2.5 mm in 5 times. And the number of fraction drops of 3.0; 3.5 and 5.0 mm reduces on average by 12 ... 16%.

For 40 mT values of LgMF induction the number of drops also increases in 2.15 times and reaches 168 units. What is more, as in the previous case, the number of small fraction droplets significantly increases - 1.5 mm in 6.3 times; 2.0 mm in 10 times; 2.5 mm in 7.4 times. A number of large fraction drops is also reduced on average by 15%.

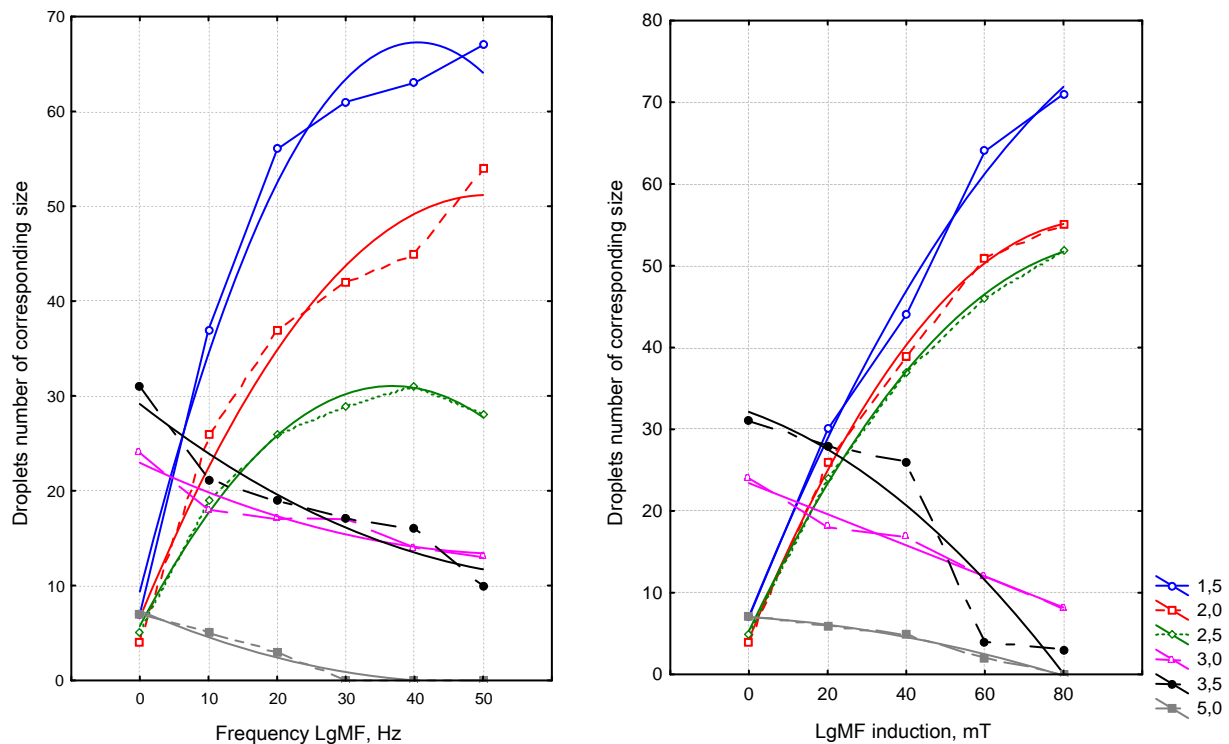


Figure 4 - Number of electrode metal drops during MAG-welding with LgMF influence

With further increase of LgMF induction (from 40 to 60 Hz) we observed consistently high indices of small droplets formation and the reduction in number of 3.0 mm drops fraction, which halved in number. Droplets with the diameter of no more than 5 mm are absent when an arc is subjected to a magnetic field induction from 60 mT.

During the analysis of LgMF frequency and induction influence it was found that a greater influence on droplet size reduction of electrode metal had a frequency of the electromagnetic impulse than its (magnetic field) amplitude values.

The dependence graphs of the drops number of the electrode metal during MAG-welding with the additional LgMF influence (Fig. 4) are plotted; we obtained the mathematical relationships (Table. 4) which afford the determination of formed droplets number (n_{fi}) at the individual fractions (index fi indicates the size of the droplets), where f_i - frequency electromagnetic pulse Hz; B_Z - LgMF induction, mT.

Table 4

Dependence of droplets number of electrode metal by fractions on LgMF frequency	Dependence of droplets number of electrode metal by fractions on LgMF induction
$n_{1,5} = -22,8 + 35,7 \cdot f_i - 3,54 \cdot f_i^2$	$n_{1,5} = -18,4 + 1,37 \cdot B_Z - 0,0045 \cdot B_Z^2$
$n_{2,0} = -12,7 + 2,1 \cdot f_i - 0,017 \cdot f_i^2$	$n_{2,0} = -21,6 + 1,43 \cdot B_Z - 0,006 \cdot B_Z^2$
$n_{2,5} = -9,9 + 1,75 \cdot f_i - 0,02 \cdot f_i^2$	$n_{2,5} = -17 + 1,23 \cdot B_Z - 0,005 \cdot B_Z^2$
$n_{3,0} = 26,7 - 0,4 \cdot f_i + 0,003 \cdot f_i^2$	$n_{3,0} = 27,2 - 0,19 \cdot B_Z$
$n_{3,5} = 35,2 - 0,65 \cdot f_i + 0,004 \cdot f_i^2$	$n_{3,5} = 34,4 - 0,06 \cdot B_Z - 0,003 \cdot B_Z^2$
$n_{5,0} = 10,8 - 0,37 \cdot f_i + 0,003 \cdot f_i^2$	$n_{5,0} = 7,4 - 0,004 \cdot B_Z - 0,0007 \cdot B_Z^2$

Thus, it was found that:

- the loss coefficient of electrode metal is minimal on condition that the influence on the arc by alternate LgMF is 16 ... 34 Hz frequency and induction is 18 ... 38 mT;
- the maximum number of droplets formed while influence on the arc of alternate LgMF with 12 ... 36 Hz frequency and 70 ... 90 mT induction, in this case a transition to the jet electrode metal transfer is observed, and the total number of drops is doubled compared to the welding process without the LgMF use;
- a greater influence on the reduction of droplet size of electrode metal has a frequency of the electromagnetic impulse than its (magnetic field) amplitude values.

However, it should be noted that the additional impact on the arc of external/outer LgMF with values of $B_z = 70 \dots 90$ mT is negative, as the loss coefficient of the electrode metal is greatly increased. The LgMF modes optimization in terms of the lowest values of the loss coefficient and the maximum number of drops of electrode metal were performed graphically. Optimization results are shown in Fig. 5.

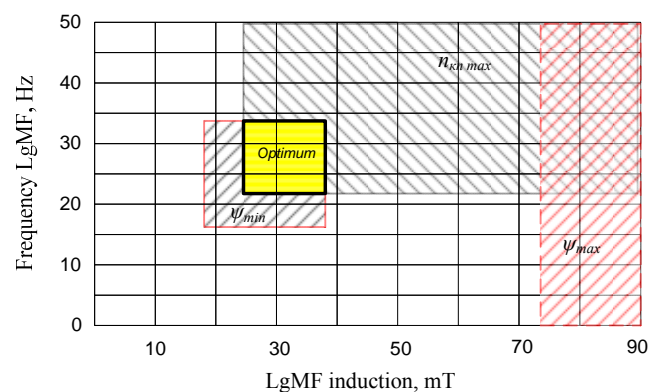


Figure 5 – Optimizing graph of LgMF frequency and induction as for the loss coefficient - ψ and the number of electrode metal drops - n

As we can see in Figure 3 the achievement of the jet electrode metal transfer during MAG-welding with minimum losses is possible by influence of longitudinal magnetic field induction of 26 ... 38 ... 22 mT and frequency of 34 Hz on the arc. Appliense of LgMF induction of more than 75 mT is not recommended due to the significant loss of electrode metal.

Thus, the proposed model can be used to determine the LgMF conditions for the arc MAG-welding by steel solid wire with a diameter up to $2 \cdot 10^{-3}$ m to minimize losses of welding materials.

Conclusions

It was determined that the efficiency of MAG-welding process can be achieved by jet electrode metal transfer while minimizing its losses spray with an additional influence of longitudinal magnetic field on the arc. The mathematical dependences for determining the number of droplets formed in separate factions, and a map of LgMF modes optimization are obtained. The recommendations are presented which allow to achieve the best results saving of welding materials with MAG-welding by low-carbon and low-alloy steels using external LgMF, namely:

- the core wire diameter of 1.2 ... 2.0 mm;
- current intensity $I = 240 \dots 280$ A;
- arc voltage $U = 20 \dots 24$ V;
- wire feed speed $V = 0.065 \dots 0.085$ m/s;
- direct-current reversed polarity;
- LgMF induction of B_z , 26 ... 38 mT;
- impulse frequency f_i 22 ... 34 Hz.

The affect of longitudinal magnetic field induction of more than 75 mT on the arc is not recommended due to the significant loss of electrode metal during spttering.

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