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PROCEDURE FOR DETERMINATION OF INDUCTION OF CONTROLLING MAGNETIC FIELD IN POOL ZONE DURING ARC WELDING

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It is shown that there are calculation procedures at the present time, which allow determining induction in the weld pool zone, which is generated by two-rod devices for input of the transverse magnetic field during arc welding. However, these methods are quite complicated in applying. In this paper, the calculation procedure for determining the numerical values of the induction components of a transverse magnetic field in the weld pool zone were proposed. The procedure is based on the use of experimental data on the value of induction, generated by the transverse magnetic field input device in the weld pool zone at different value of rod cross-sections of theses input devices. The calculation expressions and an algorithm for their use are proposed to determine the magnetic field induction components in the indicated zone. A good correlation of the calculated data with experimental ones is shown. The procedure is recommended for applying in arc surfacing and welding of products, made of materials, which are not ferromagnetics. 8 Ref., 6 Figures.

Keywords: *transverse magnetic field, induction, ferromagnetic, weld pool*

The effect of transverse magnetic field (TMF) in automatic submerged-arc welding and surfacing allows controlling the hydrodynamics of molten metal in pool, geometry of weld (bead), increasing the coefficient of electrode melting and refining the weld metal structure [1–4].

At the present time there are no simple methods for calculation of induction components in the weld pool zone, which are generated by input devices (ID) of TMF. The known calculation methods, suitable for these purposes, [5–7], are quite complicated. In work [8] the calculation method is also suggested for similar purposes. However, it should be noted that these methods do not allow obtaining the numerical values of induction under the rods for different design parameters of ID of TMF. It is necessary to develop such calculation method for determination of induction components, generated by ID of TMF, which will allow accounting for change of such parameters as the distance between the edges of rods and windings, sizes of rod sections and number of ampere turns (IW) and will be not characterized by excessive complexity. The development of such calculation method will simplify greatly the problem of optimizing the ID of TMF, being designed.

The aim of the present work is the development of an evaluation procedure for calculation of numerical values of induction components, generated by ID of TMF, in the pool zone as-applied to the arc welding and surfacing, allowing to determine the values of the given parameters quickly and at a sufficient accuracy for practice.

To realize this aim, the following investigations were carried out. The simplest one is the design of ID of TMF in the form of two rods of a ferromagnetic steel, having windings on each rod. Figure 1 presents a scheme of ID of TMF and design of one of rods of this device. The main parameters and sizes of ID of TMF in Figure 1, *a*: a — distance between rods A and B at their lower edges; h – distance from edges to workpiece; H — distance from coil to rod lower edge. Electrode wire axis coincides with O_1Z_1 axis. Figure 1, *b* gives the sizes: b — rod width; c — rod thickness; L_r — rod length: L — winding height; H — distance from rod edge to winding. Windings on rods A and B were connected in series so, that the lower edges of rods A and B had different poles: N and S (Figure 1, *a*).

To optimize ID of TMF, it is necessary to set such its parameters (from Figure 1, *a*), which could provide the maximum level of induction component B_x between rods A and B along the axis OX at the minimum level of a longitudinal component of induction B_z.

The rods were manufactured in the form of a pack of plates of electric steel 1512 (E42) of 0.5 mm thickness and F_r = 26×16 mm section, on which the four-layer windings of copper wire of 1.0 mm diameter and L= 30 mm height with number of turns W = 100, were arranged. The rods of 26×8 mm, 26×32 mm, 32×52 mm and, respectively, with windings of L = 30 mm height were also manufactured (these windings could move along the rods to change the distance H). Direct current I_k = 16 A was passing in the windings. Induction B was measured by a

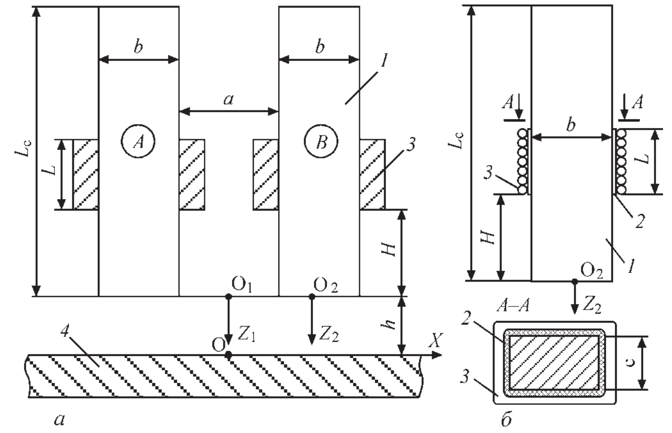

Figure 1. Input device of TMF with two rods (*a*) and design of rod with winding (*b*): *1* — rod; *2* — isolator; *3* — winding; *4* — workpiece

universal teslameter of 43205 type with Hall sensor, having a measurement base of 0.9×0.9 mm.

At first, the specifics of magnetic field (induction) structure for one rod was investigated. It was found that relative values of induction $B_z/B_{x\max}$ are distributed along the axis O_2Z_2 by one and the same dependence in change of H within H = 0–60 mm, i.e. value of $B_z/B_{x\max}$ parameter under the rod does not almost depend on parameter H. Thus, at $H = 0$ the winding has no effect by its field of scattering on the resulting field. The field generated is determined completely by the rod magnetizing.

The dependence of $B_z/B_{z\max}$ on distance from rod edge to point z, being considered, was established. It should be noted that the maximum value of induction component $B_{z\max}$ is observed at the edges of rod of ID of TMF. Rods of ID of TMF have usually a rectangular section. To simplify calculations, the rectangular section of rods was conditionally replaced by a circular section. Moreover, an equivalent radius of turn r, which was conditionally located in the rod edge plane ($z = 0$) was calculated by formula $r^2 = F_r/\pi$. Values $B_z/B_{z\max}$ were calculated at change of z (from $z = 0$) by formula:

$$B_z / B_{z\max} = \frac{r^2}{(r^2+z^2)^n}, \qquad (1)$$

where n is the degree index.

Experimental data are well correlated with design data, calculated by formula (1), if the degree index $n = 1$ is for all the applied sections of rods, i.e. 26×8 mm, 26×16 mm, 26×32 mm and 32×52 mm (I_k = 16 A, H = 35 mm, W = 100).

The relative values of inductions $B_z/B_{z\max}$ under the rods (along the axis O_2Z_2 in Figure 1, *a*), obtained by the experimental data processing, are given in Figure 2. It is shown here, that values $B_z/B_{z\max}$ do not almost depend on parameter *a* (curves *1*–*4*) and are close to values (curve *5*), when calculation is made by formula (1).

It was found by measuring the induction B_z at the rod edges to winding that with increase in H the induction B_z is decreased (at similar values I_k = 16 A, W = 100).

Induction B_z at the edges of rods is governed by relation

$$\frac{B_{z2\max}}{B_{z1\max}} = \frac{1}{\left(1+0.04H_2^2\right)}, \qquad (2)$$

where H_2 is the value of size H, m, taken in calculations.

During calculations by formula (2) it is necessary first of all to take the value $H_1 = 0$, at which value $B_z/B_{z1\max}$ is observed. If the distance H_2 is differed from taken value $H_1 = 0$ (usually in practice $H_2 > H_1$), then it is necessary to determine the value $B_{z2\max}$ by formula (2), substituting value H_2 in it. These values $B_{z2\max}$ will be observed at the given values H_2.

If to change value IW up to $I_2W_2 > I_1W_1$ (or $I_2W_2 < I_1W_1$), then it is necessary to change $B_{z\max}$ proportionally to change in IW (to increase or to decrease) to obtain the new value $B_{z\max}$, corresponding to the new taken value IW (initially taken that IW = 1600).

It was found experimentally that the absolute values $B_{x\max}$ in point O_1 at axis O_1Z_1 (Figure 1, *a*) depend on parameter *a*, which is shown in Figure 2. It should be noted that data about $B_{x\max}$ (in mT), given in Figure 2, are initial for further calculations of values B_x in points at axis O_1Z_1. Values $B_{x\max}$ refer to the case

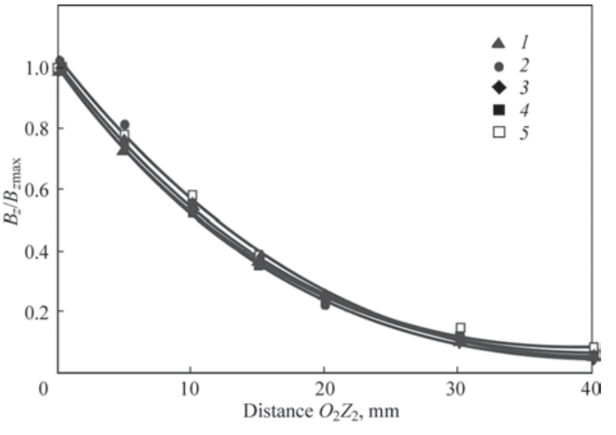

Figure 2. Distribution of values $B_z/B_{z\max}$ along the axis O_2Z_2 depending on the parameter *a*: *1* – *a* = 20; *2* — 40; *3* — 60; *4* — 13 mm; *5* — calculation of $B_z/B_{z\max}$ by formula (1)

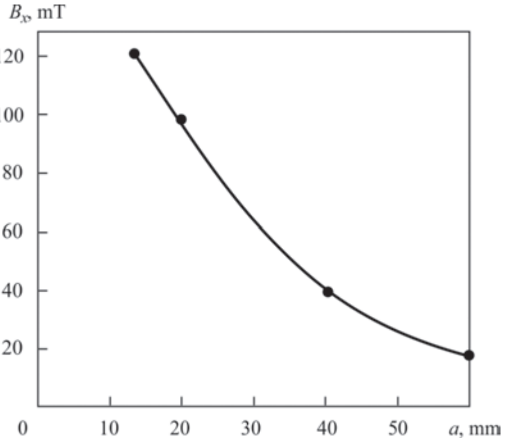

Figure 3. Dependence of component of induction B_x on parameter a

when $IW = 1600$, $H_1 = 0$, and rods have section $F_r = 26\times16$ mm ($F_r = 416$ mm$^{2)}$). When calculating other absolute values B_x in point 0_1 at axis O_1Z_1 (Figure 1, *a*) at other values F_r, H, IW which we shall denote by F_{r2}, H_2, $(IW)_2$, the calculation is made in the sequence, described above for determination of values of induction B_z in points at axis O_2Z_2 by formula (1). It was found by processing the experimental data about induction B_x that within $a \le 20$ mm the formula (1) with value $n = 1.0$ is suitable for determination of $B_x/B_{x\,\max}$.

If $a > 20$ mm, then to determine $B_x/B_{x\,\max}$ it is necessary to apply this formula with changing the values of n degree in it:

- for $a = 40$ mm: $n = 0.8$;
- for $a = 60$ mm: $n = 0.5$.

For intermediate values of parameter a within the ranges $a = 20$–40 mm it is necessary to apply the intermediate values of n degree in the denominator of formula (1): $n = 1.0$–0.8, and similarly, for $a = 40$–60 mm: $n = 0.8$–0.5. To provide their more convenient use in calculation we shall give also their numerical values in point O_1 at axis O_1Z_1 for $IW = 1600$:

- $a = 13$ mm: $B_{x\,\max} = 121$ mT;
- $a = 20$ mm: $B_{x\,\max} = 99.9$ mT;
- $a = 40$ mm: $B_{x\,\max} = 37.6$ mT;
- $a = 60$ mm: $B_{x\,\max} = 18.5$ mT.

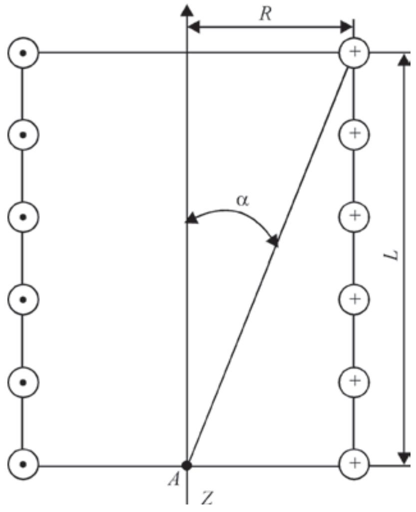

Figure 4. Scheme for calculation of induction B_z in point A at the axis Z: R — radius of solenoid windings; L — solenoid length

The checking showed that by using the developed procedure it is possible to determine the numerical values of components of inductions B_z and B_x, respectively, along the axes O_2Z_2 and O_1Z_1 (see Figure 1) at different values of parameters F_r; a; IW; H. As initial parameters (as was noted above) the following parameters were taken: $F_r = 26\times16$ mm ($F_r = 416$ mm^2); $IW = 1600$; $H = 0$. It should be noted that at the plate surface (weld pool) it is necessary to take the value $z = h$ during calculation of induction B_x component by formula (1) (see Figure 1, *a*).

To realize the suggested procedure it is rational to know the values of induction B_z at the edges of rods ID of TMF (and when coils are located near the rod edges, i.e. when $H = 0$) depending on section of rods and number of ampere-turns of windings arranged on them. For these purposes it is possible to apply the following calculation method.

Induction on longitudinal axis of solenoid of length L (without ferrocore inside it) in point A, which is located at its edge (Figure 4) [6] is:

$$B_z = \mu_0 \frac{IW}{2L} \cos\alpha, \tag{3}$$

where μ_0 is the magnetic constant; $\mu_0 = 4\pi\cdot10^{-7}$ H/m; IW is the number of ampere-turns in solenoid;

$$\cos\alpha = \frac{L}{\sqrt{R^2 + L^2}}. \tag{4}$$

Here R is the equivalent radius of «window» of coil (solenoid):

$$R = \sqrt{\frac{F_r}{\pi}}, \tag{5}$$

where F_r is the rod section.

Figure 5 gives the calculation values (curve *2*) of induction B_z at the coils edges, free of rods of different sections (F_r). Calculated and experimental (curve *1*) values B_z are close and do not depend on value of «window» section of coils and can be used for calculations. Experimental values B_z at the edges of rods (with coils, when $H = 0$) are much higher, than those in coils (solenoids) without rods (curve *3* in Figure 5) and with increase in F_r they are linearly decreased by relation (for $IW = 1600$):

$$B_z = 90–3.37(F_r - 2.08). \tag{6}$$

For calculations it is possible to use the coefficient n, which accounts for the presence of ferromagnetic rod in (solenoid) coil:

$$n = \frac{B_{z\,\max}}{B_z}, \tag{7}$$

where $B_{z\,\max}$ is the induction at the rod edge, mT.

The coefficient n is decreased linearly with increase in rod section F_r. This dependence corresponds to formula (Figure 6):

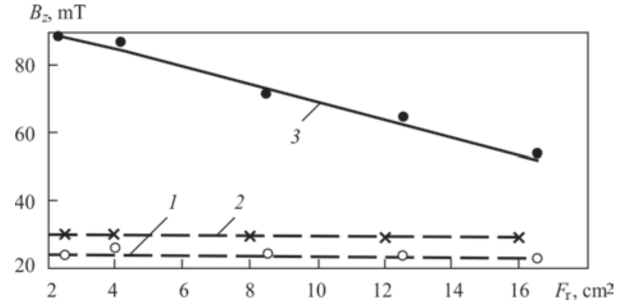

Figure 5. Dependence of induction B_z on section of rods F_r (IW = = 1600): *1*, *2* — solenoid without a ferrocore; *1* — experimental data; *2* — calculation data; *3* — solenoid with a ferrocore, experimental data

$$n = 3.75–0.0912(F_r – 2.08). \quad (8)$$

The values of coefficient *n* did not change for rods of a pack of sheets of electric steel 1521 (E42) and for those of a solid section of steel VMSt.3 (killed) and 09G2S (at equal magnetizing force of windings *IW*). The values of coefficient *n* did not also change in passing of direct or alternating current of 50 Hz frequency and in change of these parameters in coils within the ranges: ampere-turns 800–3200; size H = = 0–70 mm, size h = 15–50 mm.

The developed calculation procedure for determination of induction components can be recommended not only for optimizing the design of ID of TMF, consisting of rods of the rectangular section, but also for rods of a cylindrical section. It should also be noted, that the developed procedure for determination of values of components of induction B_x, B_z accelerates greatly the determination of optimum sizes of ID of TMF design elements (sizes of rods in sections, distance between rods). The procedure refers to the variant when the base metal (plate) is not a ferromagnetic. The suggested method allows determining the numerical values of induction B_x in points at the axis O_1Z_1 and induction B_z in points at the axis O_2Z_2.

It is rational to make calculations of inductions in the following sequence. At first, to apply the formulae (3)–(5) and Figure 4, and then to apply the formulae (7), (8). After this, the real values H and h are taken into consideration and calculations are made of numerical values of inductions B_x in points at the axis O_1Z_1 and induction B_z in points at the axis O_2Z_2 by using formulae (1) and (2), and those at the surface of product-plate $z = h$.

Nature of changing the relative values of components of inductions $B_x/B_{x\,\max}$ and $B_z/B_{z\,\max}$ along the axis *OX* (Figure 1, *a*) corresponds to that which was set earlier in work [8]. Using the data of this work about the nature of change of these relative values of induction components along the axis *OX* according to this procedure it is possible to determine the numerical values of induction components in any point of the weld pool surface and in the zone of an electrode drop in arc welding and surfacing. If the rods in design of ID of TMF are connected by a crosspiece at the top (made of the same material and the same cross-section as the rods), then the values of components of inductions B_x and B_z, obtained during calculations, should be increased by 20–25 %.

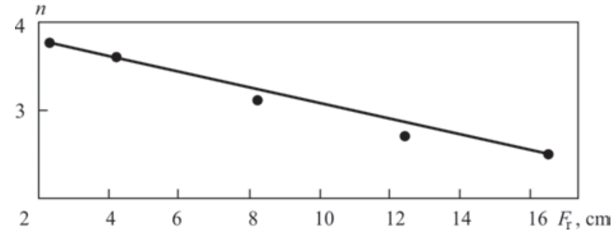

Figure 6. Dependence of coefficient *n* on rod section F_r

Conclusions

1. The calculation expressions, developed on the basis of experimental data processing, for determination of induction, generated by ID of TMF, in the weld pool zone, provide a fair correlation of calculated data with experimental ones.

2. The calculation procedure allows determining the absolute values of induction in the zone under edges of rods of ID of TMF, if the sizes of their sections are known, or determining their optimum sizes to achieve maximum values of a transverse component of induction at minimum values of a longitudinal component of induction in the weld pool zone.

1. Skipersky, N.A., Rybachuk, A.M. (2000) Weld formation by transverse magnetic field in welding of nonmagnetic materials. *Svarochn. Proizvodstvo*, **7**, 53–55 [in Russian].
2. Iofinov, P.A., Ibragimov, V.S., Dmitrienko, A.K. et al. (1991) Effect of external electromagnetic field on speed of electrode wire melting in automatic submerged-arc welding. *Ibid.*, **1**, 34–35 [in Russian].
3. Razmyshlyaev, A.D., Mironova, M.V., Kuzmenko, K.G. et al. (2011) Efficiency of melting of electrode wire in submerged arc surfacing with influence of transverse magnetic field. *The Paton Welding J.*, **5**, 39–42.
4. Ryzhov, R.N., Kuznetsov, V.D. (2006) External electromagnetic effects in the processes of arc welding and surfacing (Review). *Ibid*., 29–35.
5. Andreeva, E.G., Shamets, S.P., Kolmogorov, D.V. (2005) Calculation of stationary magnetic fields and characteristics of electrical devices using program package ANSYS. *Electron. Sci. J. Oil and Gas Business*, **1.** http//ogbus.ru/authors/Andreeva/Andreeva_1.pdf
6. Bessonov, L.A. (2003) *Theoretical fundamentals of electrical engineering. Electromagnetic field*. Moscow, Gardariki [in Russian].
7. Tozoni, O.V. (1975) *Method of secondary sources in electrical engineering*. Moscow, Energiya [in Russian].
8. Razmyshlyaev, A.D., Mironova, M.V., Yarmonov, S.V., Vydmysh, P.A. (2013) Structure of transverse magnetic field generated by input devices for arc welding processes. *Visnyk Pryazov. DTU: Transact. Mariupol*, **26**, 135–141 [in Russian].

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