APPLICATION OF ELECTROMAGNETIC FORCE AMPLITUDE MODULATION IN THE MAGNETODYNAMIC UNIT FOR THE ALUMINIUM CASTING TECHNOLOGIES IMPROVEMENT

V. Dubodelov, V. Fixsen, N. Slazhnev, A. Gorshkov

Physico-technological Institute of Metals and Alloys
National Academy of Sciences of Ukraine,
34/1 Vernadsky ave., Kyiv-142, 03680 (mgd@i.kiev.ua)

Introduction. Heat mass transfer and interphase interaction play an important role on all stages of a technological cycle from the preparation of alloys up to the formation of half-finished products (melt, out-of-furnace treatment, pouring of metal and its solidification in the mold). It is stipulated that at the preparation of alloys it is necessary to execute dissolution of alloying and modifying additives, to homogenize the chemical composition and temperature. At metal pouring, the designate hydrodynamical mode of melt movement in a metalduct and in a cavity of the mold should be realised. Favourable thermal conditions of its solidification and filtrational feed must be ensured at the formation of half-finished product. In this paper the practical effectiveness of amplitude modulation of electromagnetic force (e.m.f.) in a foundry magnetodynamic unit (MDU) for different aluminium casting technology implementation is discussed. The selection of MDU was stipulated since it provides the regulated induction heat of metal, its electromagnetic stiring, pouring and vibrating. It is especially important that creation of the e.m.f. in MDU is always accompanied by generation of elastic vibrations in its working area (w.a.) in the direction of e.m.f. operation [1].

The use of other known methods and devices for creation of elastic vibrations and their transfer iton designated zones of the melt is insufficient since such engineering solutions do not allow to combine vibrating processes of liquid and crystallized metal with other relevant methods of the casting technology.

At present, it is shown that the effectiveness of MDU increases at generation of modulated oscillations of the electromagnetic force there [2]]. This factor was used to intensify the mass transfer at input in alloy difficultly soluble alloying and modifying elements. An amplitude modulated e.m.f. was created for modulating the frequency in the range of 0.5-30 Hz at a value of a carrier frequency of 80–100 Hz. It was found that the frequency band of modulation in 3–25 Hz at the mentioned carrier frequencies is technologically justified.

1. Experiments, results and discussion. Comparative experiments for unmodulated and modulated e.m.f. have been carried out to estimate the influence of metal forced oscillation on the dissolution process in the melt in a magnetodynamic unit. An aluminium alloy of 7 type was used as a metal-solvent and samples of electrotechnical copper, iron and zirconium in the form of cylindrical bars of 10 mm in diameter and 700 mm long as dissolved materials. The samples were dissolved in the aluminium alloy at the temperature of 730°C in the metalduct, which was connected to working area of MDU (Fig. 1). The earlier estimated relation of the oscillation amplitude of pressure in the molten metal with the e.m.f modulating frequency [3] was used to select the modulating frequency of the electromagnetic force.

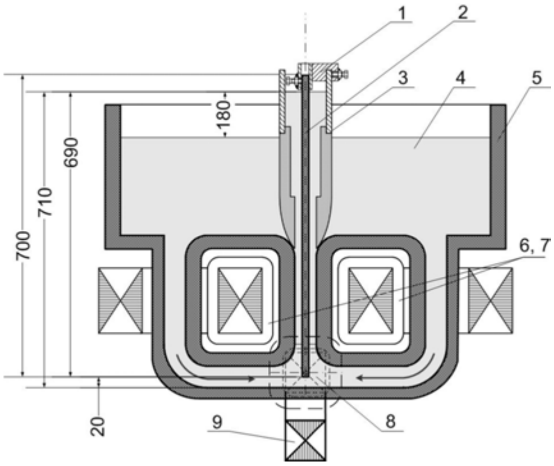

Fig. 1. Scheme of the experimental research dissolution: 1 – fixture; 2 – additive; 3 – metalduct; 4 – aluminum melt; 5 – crucible; 6, 7 – inductors; 8 – working area; 9 – electromagnet.

It was found that the use of the amplitude modulated electromagnetic force intensified the process of dissolution of the indicated metal additives in 3–3.5 times (Table 1).

Analysis of the metal oscillation characteristics in a location zone of a sample has shown (Fig. 2*a*, *b*) when apply an unmodulated electromagnetic force (base mode) uncontrolable oscillations with frequencies from 0.3 up to 3 Hz and amplitude from 1 up to 1.5 mm take place, and this process is characterized by instability (Fig. 2*a*). A stable oscillation process was registered when impose the e.m.f. modulation of 7 Hz and the oscillation amplitude changes from 4 up to 6 mm (Fig. 2*b*).

Thus in the base mode the dissolution took place at a value of the Reynolds number up to 2400. At modulation it was 6400-9600 depending on the value of a designated modulation coefficient. The amplitude and speed of melt oscillations at the interface with the solid additive increased as a result of modulation of the electromagnetic force. As a result, the thickness of boundary diffusive layers has decreased in 2.3–2.8 times and the effect of the melt by the borders of crystallites has increased, having intensified the mode of erosive dissolution.

The obtained results rather good agree with the data of [4] on dissolution of the solid addition agent in a liquid alloy. That permits to establish the following relation of the flow of substance from the modulating frequency of electromagnetic force:

$$j = kD\mathrm{Sc}^{0.374}\nu^{-\frac{1}{2}}f^{-\frac{1}{4}}L^{-\frac{2}{3}}\left(C_l^0 - C^0\right)\,, \tag{1}$$

where j is the flow of substance, kg/(s·m^2); $k = 27 \div 30$ is the aspect ratio; D is the diffusion constant, m^2/s; Sc is the Schmidt number (describing ratio of convective dissolution and diffusive $\mathrm{Sc} = \nu/D$); ν is the kinematics viscosity of a aluminium alloy, m^2/s; f is the modulating frequency of e.m.f., Hz; L is the specific size of an additive, m; C_l^0 denotes a concentration of saturation, %; C^0 is a substance concentration of in a solute, %.

Table 1. Velocity of dissolution.

Metal	Time, hour	Velocity of dissolution, kg/(s · m^2)	
		Base mode	Modulated mode (7 Hz)
Copper	0.06	0.1450	0.402
Steel	0.17	0.0030	0.009
Zirconium	0.17	0.0047	0.022

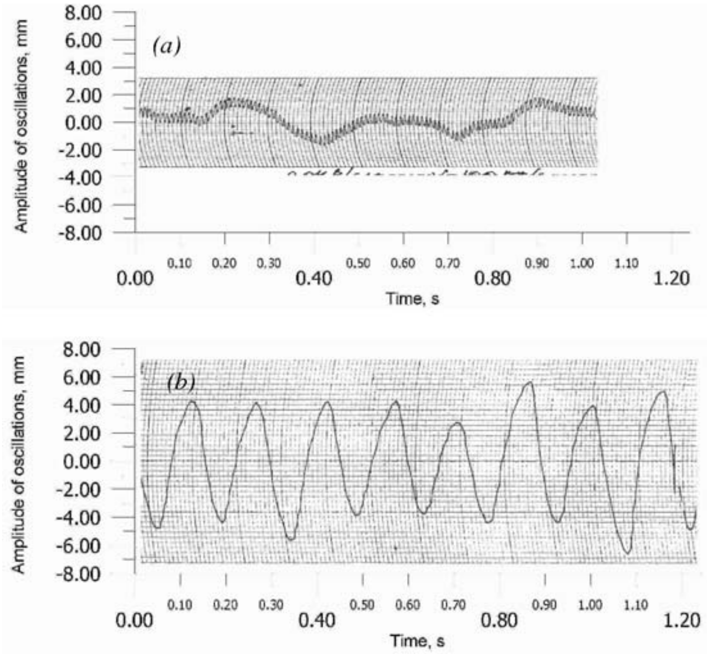

Fig. 2. Diagrams of metal oscillations: (a) base mode; (b) modulated mode (7 Hz).

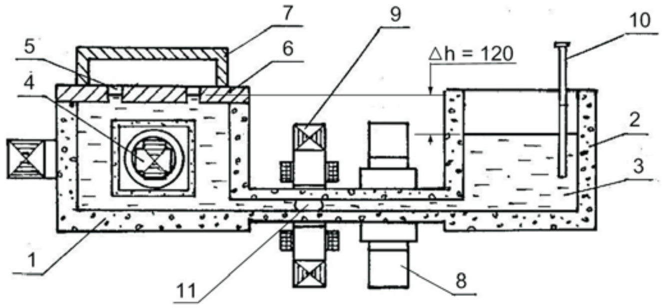

Fig. 3. Scheme of pouring of aluminium alloys under electromagnetic pressure with the use of the principle of dispersed gating system: 1 – priming chamber; 2 – metal reservoir; 3 – aluminium alloy; 4 – inductor; 5 – ladle channel; 6 – platform, down part of the chill mold; 7 – platform, upper part of the chill mold; 8 – inductor; 9 – electromagnet; 10 – thermocouple; 11 – working area.

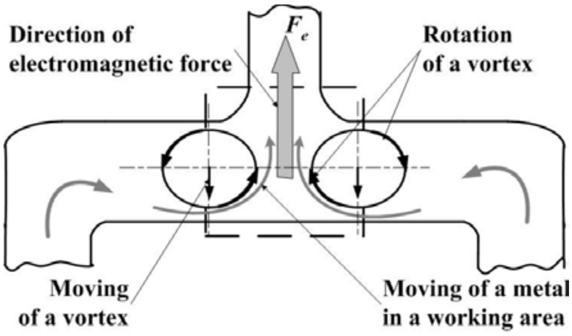

Fig. 4. Scheme of vortexes in a working area.

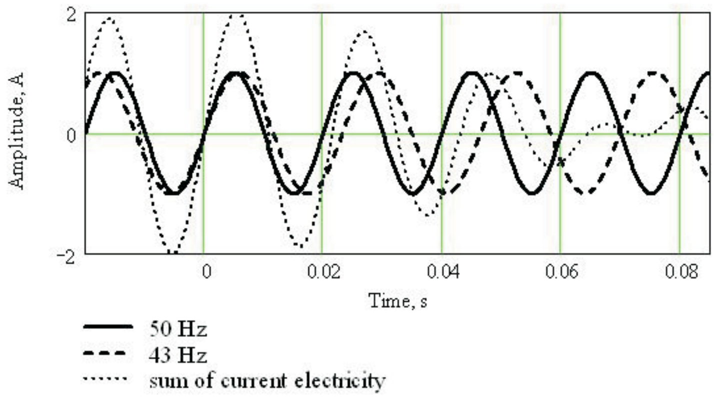

Fig. 5. Effect currents' electricity with different frequency in the working area of MDU.

The designated accuracy difference of melt levels between a priming chamber and a metal reservoir is very important at casting under low electromagnetic pressure with the use of dispersed gating feed systems ("RASLIT-LEMD" process) [5] (Fig. 3).

The uncontrollable oscillation of levels in the ladle chamber is impeded to held it. The main reason of these oscillations, which are generated in working area of MDU, is the vortical frame (Fig. 4).

Besides, a closed circuit of the whole volume of the channel and crucible takes place, which have a bound with two main vortices in the working area. Each of two vortices is gyrated in opposite directions and moves transitional. Since the space, in which they move, is confined and the value of the forces driving the vortices in motion depends on the place of their arrangement, the entire vortex pattern performs a complex and to the present time insufficiently known oscillating motion. As a result of this process, the oscillation value of hydraulic pressure, which is created by the electromagnetic force, appeared and, accordingly, the difference of levels of the melt in the chambers of a foundry unit emerged.

According to [1], a hydrodynamic picture in the w.a. hardly depends on the electrical phase angle between the currents in inductors. At frequency misalignment of the currents in inductors, there is a smooth variation of the phase angle from in-phase conditions to anti-phase and vice versa with the modulating frequency (Fig. 5).

Because of this, a possibility appears to pick up such modulating frequency, at which steady frames of vortices that appropriate the base mode of a power of unit have not time to form.

The described mechanism was experimentally affirmed by a research, when there were created unmodulated and modulated electromagnetic forces with frequencies of 3, 5, 7, 14 and 21 Hz with a difference in levels of metal in the metalduct

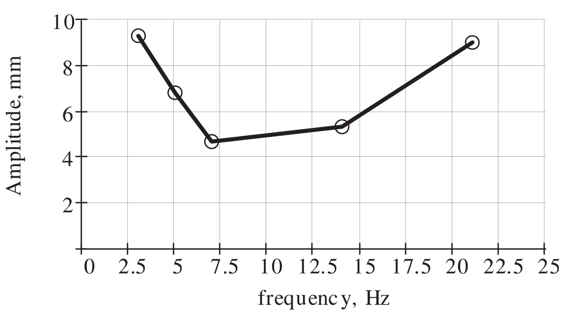

Fig. 6. Relation of the amplitude uncontrollably oscillation of metal level to the modulated frequency.

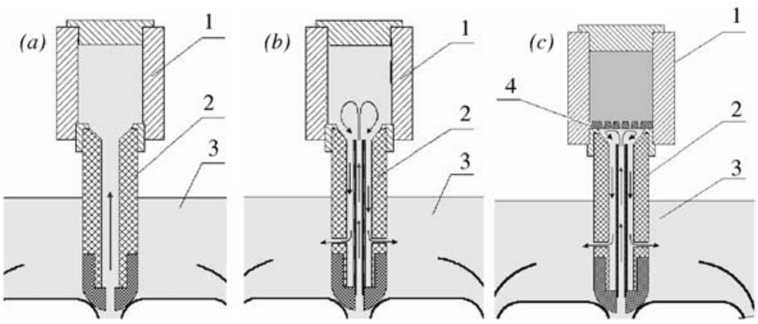

Fig. 7. Scheme of pouring of aluminium alloys under low electromagnetic pressure: (*a*) LEMD; (*b*) LEMD with creation of melt movement at the solidified front; (*c*) RASLIT-LEMD (1 – chill mold; 2 – metalduct; 3 – aluminium alloy; 4 – gating plate).

and in the crucible being 120 mm [6]. As a result, the relation of the oscillation frequency of melt level in the metalduct to the modulating frequency is obtained. In comparison with the base mode, when its amplitude was equal 20 mm, it did not exceed 5 mm at modulation with a frequency of 7–14 Hz.

Thus, the 4-4.5 times decrease of the amplitude of uncontrollably oscillation was reached (Fig. 6).

One of main applications of MDU is the time-dosage of the melt in the mold. The accuracy of dosage essentially depends on the accuracy of holding of desired law changing of the melt flow mass during pouring. The experience of technical application of a MDU-batcher with a standard electricity supply has shown that the designed mode of pouring is essentially distorted because of the influence of the described uncontrollably oscillation of the hydraulic pressure head. Thus, the influence is greater, if the mass flow is less. In this case it is possible to receive in MDU a minimum mass flow of 0.3 kg/s without discontinuing of the stream.

Researches on the influence of modulation on the dosage accuracy were performed at pouring of 0.5 kg and 1.5 kg doses of aluminium alloy and the modulating frequency of 7 Hz. Statistical processing of the results has shown that the error in dosing has decreased in 2–3.5 times in comparison with the base mode and did not exceed 1.2%. Thus the minimum stable mass flow of 0.085 kg/s was achieved. The decrease of the lower boundary of the stable mass flow is also necessary to analyze the melt flow effect on the solidified front for the half-finished product [7].

Three known technologies of casting under low electromagnetic pressure: LEMD [8] (Fig. 7*a*), LEMD with creation of melt motion at the solidified front [9] (Fig. 7*b*), RASLIT-LEMD [6, 8] (Fig. 7*c*), were realised to estimate the effect of modulated oscillations on the process of crystallization (Fig. 6).

As a result of performance experiments, the prototype casts from the alu-

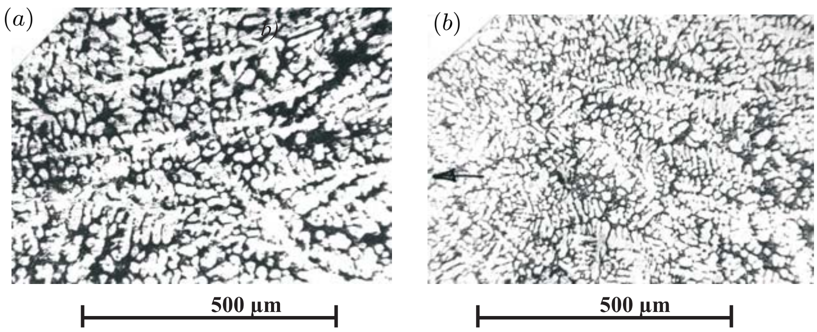

Fig. 8. The microstructure of middle part of cast (×100, etching): (*a*) base mode; (*b*) modulated mode (7 Hz).

minium alloy (AK7p) were obtained with application of the modulation e.m.f. in the indicated technologies of casting. Metallographic analysis has shown that the sizes of equiaxial dendrites in the middle of the cast has twice decreased if compared to the base mode (Fig. 8*a*) at creation of the melt flow along the solidified front and the oscillation of metal flow with a designed modulating frequency (Fig. 8*b*).

The combination of oscillations of electromagnetic pressure with forced convection in the zone of pouring – feeding systems provides optimization of thermal conditions and improves the filtrational feed of half-finished products during their crystallization. At implementation of technology RASLIT-LEMD [6, 8] (Fig. 3) is was possible to execute this process for the difference in metal levels up to 120 mm in a crucible and pouring slab at the expense of stabilization of designed metal level under a pouring slab in intervals between pouring.

2. Conclusions. It was shown that with 3–3.5 times intensification the metallic alloying additions dissolve with the use of modulation mode. The MDU hydrodynamic parameters are stabilized, too. So, the batching error at the portioned pouring of aluminium alloy is reduced in 2–3.5 times. The value of the minimal stable mass pouring rate is reduced to 0.085 kg/s, and the value of metal level fluctuations in the metal duct is decreased to 5 mm. Advanced development allowed to realize the casting process with the dispersed gating system (RASLIT-LEMD) that has one magnetodynamic unit instead of two, as in the case of non-modulated electromagnetic force. The advanced technological process of aluminium alloys casting with the use of the modulated electromagnetic force is developed. The processes of aluminum alloys treatment, its chemical composition finishing and portioned pouring in molds with the mass error not more than 1.2% may be realized with the help of this technology. Casting under low electromagnetic pressure improves the items structure.

REFERENCES

1. V.P. Polishchuk, M.R. Tsin, R.K. Horn, *et al. Magnetodynamic Pumps for Liquid Metals* (Naukova Dumka, Kiev, 1989).
2. V.I. Dubodelov, V.N. Fixsen, V.K. Pogorsky, A.O. Gorshkov, N.A. Slazhnev. Application of modulated oscillations of electromagnetic force for aluminium alloys processes in magnetodynamic units. In *Physical Metallurgy and Technologies of Light Alloys* (VILS, Moscow, 2001), pp. 264–270.
3. V.I. Dubodelov, V.N. Fixsen, V.K. Pogorsky, A.O. Gorshkov, N.A. Slazhnev. Research of the creation process of the modulated oscillations of electromagnetic force and their use processing aluminium alloy. In *Proceedings of the Third International Symposium on Electromagnetic Processing of Materials* (Nagoya, Japan, April 3-6, 2000), pp. 67–72.
4. V.S. Shumihin, A.K. Bilethsky *et al. Physicochemical Processes in Pig Iron Electromelting* (Naukova Dumka, Kiev, 1989), p. 168.
5. F.M. Kotlarski, B.N. Fixsen, V.I. Belik. Production of casting with dispersed gating feed system under electromagnetic pressure (RASLIT - LEMD). In *EMRS1993 FALL NEETING. 4^{th} European East-West Conference Exhidition on Materials and Process* (St.-Peterburg, Russia, 1993), p. 63.
6. V.N. Fixsen, V.I. Dubodelov, A.O. Gorshkov, N.A. Slazhnev, B.G. Musienko. Stabilization of melt level in magnetodynamic unit. *Processes of Casting* (2002), no. 1, pp. 33–38.
7. V.I. Dubodelov, V. Fixsen, D. Eskin, L. Katgerman. Application of electromagnetic pump for the examination of the effects of melt flow on the solidification front. In *Proc. Fifth International* Pamir *Conference on Fundamental and Applied MHD* (Ramatuelle, France, 2002), vol. 2, pp. II-19–II-24.
8. V.N. Fixsen, V.I. Dubodelov, F.M. Kotlarski. Reception of cast from aluminium with usage of electromagnetic pressure. *Processes of Casting* (1996), no. 4, pp. 64–72.
9. V.N. Fixsen, L.G. Smolyakova, M.F. Gavrutenko. In *Advancing of processes of Kiev* (Naukova Dumka, Kiev, 1976), pp. 50–53.