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Modernization of casting magnetodynamic equipment

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Abstract

During last 10 years in the PTIMA NASU there is made the all-round modernization of magnetodynamic equipment for manufacturing of cast production from aluminium alloys, cast iron and steel. Such modernization had included both widening of functionality of magnetodynamic installations and development of concomitant MHD-technologies for preparation and pouring of high-quality alloys in the foundry, metallurgy and machine-building.

Introduction

Now the requirements to quality of cast production become tougher constantly. It is appeared in necessity to provide: - the high cleanness of alloys and wares from them from gases, non-metallics; - absence of casting defects; - maximal approaching of casting (ingot) to geometry of final ware; - advance of quality of alloys and castings (rise of physical, mechanical, technological, operating and special properties); - providing of automation; - rise of productivity; - improvement of ecology. Developed in the PTIMA NASU magnetodynamic devices for preparation and pouring of alloys are used widely for manufacturing of castings at foundry shops, metallurgical plants and machine-building enterprises. In the last 10 years, there is realized modernization of such equipment.

Results

As it is well known, magnetodynamic devices (installations & mixers-batchers) combines in one aggregate both induction channel furnace and electromagnetic pump [1, 2]. In comparison with similar electrotechnological equipments, it provides independent control of thermal state of melt due to regulated induction heating and guided electromagnetic stirring. At that, there are realized the processing of liquid ferrous and non-ferrous alloys, and also their controlled electromagnetic pouring into sand molds, chill molds (including die castings machines), crystallizers, pans. Electric current in melt in the magnetodynamic device is induced due to Ohm's law [1]:

$$\vec{j} = \sigma \left(\vec{E} + \vec{v} \times \vec{B} \right), \text{ A/m}^2, \quad (1)$$

where \vec{j} – electric current density, A/m²; σ – electric conduction, S; \vec{E} – electric field intensity, V/m; \vec{v} – velocity of melt, m/sec; \vec{B} – magnetic induction, T. Melt heating in the magnetodynamic equipments is provided accordingly to Joule law at carrying of electric current induced in the melt (in the channels) [1]:

$$q = \vec{j} \left(\vec{E} + \vec{v} \times \vec{B} \right) \quad (\text{or as scalar equation } Q = I^2 \cdot R \cdot \tau), \text{ J}, \quad (2)$$

where q и Q – heat generation in the melt, J; I – electric current, A; R – electrical resistance, Ohm; τ – time, sec. It is usual for any induction channel device. But, the principle feature of magnetodynamic devices is additional electromagnet [1]. It creates the internal alternating magnetic field on the part of the channel (so called working area). At superposition of this field with electric current in melt, there is generated volume electromagnetic force [1]:

$$\vec{F} = \int_V \text{Re} \left[\vec{j} \times \vec{B} \right] dV \quad (\text{or as scalar equation } F = \frac{BIL}{V} \cos \alpha), \text{ N/m}^3, \quad (3)$$

where V – volume of working area, m³; L – length of working area, m; α – phase-shift angle between electric current and magnetic field.

This force provides the melt moving. At that, modes (directions and intensities) of such moving determine by electric parameters of inductor and electromagnet. Practically, it is both circulation between crucible and channel (in fact stirring) and electromagnetic pouring of melt at set thermal and hydrodynamic terms.

Generated in the magnetodynamic devices electromagnetic pressure is determined as [1]:

$$p = \left[\begin{matrix} \vec{j} \times \vec{B} \end{matrix} \right] L \cdot \cos \alpha \quad (\text{or as scalar equation } p = \frac{BIL}{s} \cos \alpha), \text{ Pa}, \quad (4)$$

where s – square of working area, m^2 .

One of main feature of magnetodynamic aggregates is pouring of melt directly from heating zone – induction channel. It allows realizing the developed in the MHD Department of PTIMA NASU technology of differentiated heating of liquid metal [3, 4]. It consists in holding of melt in crucible of the magnetodynamic device at low temperature and overheating up to pouring temperature only poured dose of melt during its moving through induction channel. In general, average overheating of melt between channel and crucible of the magnetodynamic aggregate makes [3, 4]:

$$\Delta T_{aver.stat} = \frac{\eta_{elec} \cdot \eta_{therm} \cdot k_c \cdot P_{ind}}{c \cdot Q_{circ}}, \quad ^\circ\text{C}, \quad (5)$$

где η_{elec} , η_{therm} – accordingly electrical and thermal efficiency of magnetodynamic device; k_c – part of power released in channel in comparison with all power released in melt volume (for magnetodynamic devices $k_c = 0,7-0,8$); P_{ind} – inductor power, W; c – heating capacity of melt, $\text{J}/(\text{kg}\cdot^\circ\text{C})$; Q_{circ} – mass flow rate of liquid metal at its circulation between channel and crucible, kg/sec .

At pouring, summary overheating of melt in the magnetodynamic aggregate makes:

$$\Delta T_{\Sigma} = \Delta T_{aver.stat} + \Delta T_{aver.pour}, \quad ^\circ\text{C}, \quad (6)$$

where $\Delta T_{aver.pour}$ – average overheating of poured dose directly at its pouring from the device, $^\circ\text{C}$. It is:

$$\Delta T_{aver.pour} = \frac{\eta_{elec} \cdot \eta_{therm} \cdot k_c \cdot P_{ind} \cdot M_c}{c \cdot Q_{pour} \cdot m_{dose}}, \quad ^\circ\text{C}, \quad (7)$$

where M_c – mass of melt in the induction channel of the aggregate, kg ; Q_{pour} – mass flow rate of melt at pouring, kg/sec ; m_{dose} – mass of poured dose, kg . So, equation (6) transforms to:

$$\Delta T_{\Sigma} = \frac{\eta_{elec} \cdot \eta_{therm} \cdot k_c \cdot P_{ind}}{c} \left(\frac{1}{Q_{circ}} + \frac{M_c}{Q_{pour} \cdot m_{dose}} \right), \quad ^\circ\text{C} \quad (8)$$

For optimum consumption of power resources at dosage pouring the ratio of parameters should be the next:

$$\left[(M + Q_{circ} \cdot \tau_{pause}) \cdot t - Q_{pour} \cdot \tau_{pour} \cdot t_{pour} \right] \cdot c - M_{add} \cdot c \cdot \Delta t' + \eta_{elec} \cdot \eta_{therm} \cdot P_{ind} \cdot \tau_{cycle} = 0, \quad (9)$$

where M – weight of metal in the aggregate, kg ; τ_{pause} – duration of pause between pouring of two doses of metal, sec ; t – temperature of metal in the device, $^\circ\text{C}$; Q_{pour} – mass flow of metal at pouring, kg/sec ; τ_{pour} – pouring time of one dose, sec ; t_{pour} – set pouring temperature, $^\circ\text{C}$; M_{add} – weight of metal portion, added into the aggregate, kg ; $\Delta t'$ – value of an necessary overheating of melt in the magnetodynamic aggregate (difference between the set pouring temperature of metal and temperature of metal, added into the device: $\Delta t' = t_{pour} - t_{add}$), $^\circ\text{C}$; τ_{cycle} – time cycle for one dose pouring ($\tau_{cycle} = \tau_{pour} + \tau_{pause}$), sec .

For continuous processes the ratio (9) should be changed.

So, in case of continuous adding of molten metal into the magnetodynamic aggregate without stopping of dosage pouring of melt from the device, the ratio (9) is the following:

$$\begin{cases} Q_{add} \cdot \tau_{cycle} - Q_{pour} \cdot \tau_{pour} = 0, \\ \left[(M + Q_{circ} \cdot \tau_{pause}) \cdot t - Q_{pour} \cdot \tau_{pour} \cdot t_{pour} \right] \cdot c + (\eta_{elec} \cdot \eta_{therm} \cdot P_{ind} - Q_{add} \cdot c \cdot \Delta t) \cdot \tau_{cycle} = 0 \end{cases} \quad (10)$$

Where Q_{add} – mass flow rate of melt adding continuously into the aggregate, kg/sec.

At continuous pouring of metal with periodic adding of melt into the magnetodynamic device, the ratio (9) changes to:

$$\eta_{elec} \cdot \eta_{therm} \cdot P_{ind} \cdot (\tau_{cast} + \tau_{cast+add}) + (M \cdot t - Q_{pour} \cdot \tau_{cast} \cdot t_{pour} - M_{add} \cdot \Delta t) \cdot c = 0, \quad (11)$$

where τ_{cast} – the summary time, during which there is only pouring of melt doses from the device in the receiving device, sec; $\tau_{cast+add}$ – the summary time, during which there is synchronous pouring of metal from the magnetodynamic aggregate and adding of new portion of melt into the device, sec.

For fully continuous processes (continuous adding of melt into the aggregate and continuous pouring of melt from the device), the ratio (9) transforms into the following:

$$\eta_{elec} \cdot \eta_{therm} \cdot P_{ind} - (Q_{pour} \cdot t_{pour} + Q_{add} \cdot \Delta t) \cdot c = 0 \quad (12)$$

Using ratios (9)–(12), it is possible to optimize material & power consumptions and to provide high quality of production at casting processes with application of magnetodynamic equipment for preparation and pouring of alloys.

There is developed multifunction casting MHD-complex for manufacturing of high-quality aluminium castings. The complex is able to work effectively in different being casting technologies. The main device of the complex is the magnetodynamic mixer-batcher (Fig. 1) that provides advanced technical parameters (induction heating, electromagnetic pressure, and mass flow rate at electromagnetic stirring & pouring of aluminium melt).



Fig. 1: Magnetodynamic mixer-batcher for preparation and pouring of aluminium alloys

Mixer-batcher operates at supply of three-phase AC by frequency 50-60 Hz and voltage 220/380 V. The complex provides the substantial improvement of structure and increasing of properties of aluminium alloys and castings due to:

- high-speed dissolution of alloying additions and modifiers in melt, homogenizations of chemical composition and temperatures of liquid aluminium alloys at controlled electromagnetic stirring;
- thermal & forced processing of melt [5], including possible combination of electromagnetic influence and MHD-effects with other high-energy actions, modulation of electromagnetic force [6] and creation of controlled pinch-effect in the induction channel and working area of magnetodynamic mixer-batcher [7];
- realization of high efficiency refining of alloys (by argon blowing – reduction of hydrogen content to 0,10-0,05 cm³/100 g of metal at the simultaneous economy to 50% argon and reducing on 30% time of treatment in comparison with existing technologies, by filtration with passing of electric current in melt – removal to 80% non-metallics) [8];
- decreasing dosage error at electromagnetic pouring of metal no more than 1-2% from mass of dose [9];
- reduction of minimum mass flow rate of melt at pouring to 0.3 kg/sec and increasing of maximum mass flow rate up to 10 kg/sec;
- realization of casting technological processes under low controlled electromagnetic pressure, including using of lost foam models and dispersed non-solidifying gating system [10, 11].

Application of developed casting complex and magnetodynamic mixer-batcher provides manufacturing of high-quality aluminium alloys (hypoeutectic & hypereutectic silumins, high-strength Al – Cu alloys) and castings with improved structure and increased mechanical properties. In particular, thermal & forced processing of liquid alloys A356 & A390 in the MHD-mixer-batcher creates the conditions for break-up of microinhomogeneities (caused by negative metallurgical heredity) in the melt. It provides increasing to 2-4 times of elongation of indicated alloys [5].

Further progress of magnetodynamic equipment for aluminium alloys consists in providing of higher electromagnetic pressure for new casting technologies [12].

There is realized modernization of magnetodynamic devices for overheating and pouring of cast iron and steel (Fig. 2).



Fig. 2: Magnetodynamic mixer-batcher for overheating and pouring of cast iron and steel

So, it is developed the analog system based on using thyristor regulator of electric current for operation control of magnetodynamic mixer-batcher for cast iron. Comparing to similar well-known control systems for induction channel furnace, using such system for magnetodynamic devices has some features. Usually thyristor distorts the sinusoidal current which is important for generating of substantial electromagnetic pressure for different modes of stirring and pouring of melt by magnetodynamic mixer-batcher. This task was solved successfully, and such aggregate with new control system was applied in industry at manufacturing of castings from cast iron. It provides the economy to 20% of energy in comparison to using of control system on the base of autotransformers.

In comparison of conventional ladle pouring, using of electromagnetic pouring of cast iron and steel by MHD-mixer-batcher at production of castings and ingots allowed to stabilize the thermal and hydrodynamic terms of mould filling and further forming of casting, to decrease the spoilage, to provide the improvement of cast structure of and increase of basic mechanical properties of alloys and castings on 10-15% [13]. Guided electromagnetic stirring of melt in the magnetodynamic mixer-batcher provides melt homogenization on temperature and chemical composition, necessary thermal and hydrodynamic terms for dissolution and distributing in melt volume of alloying and modifying additions [14].

Lately there is successful application of such aggregate as magnetodynamic tundish at continuous casting of steel [14].

Conclusion

Modernization of magnetodynamic devices for foundry and metallurgy has provided to improve the quality of manufactured cast production, to increase the technical and economic indices of process, to create the necessary prerequisites for further fundamental and applied researches and technological progress.

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