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To cite this version:
A.Yu. Kizilova, M.A. Slazhniev, K.S. Bogdan, Kyung Hyun Kim, Hyun Suk Sim. Dynamic control of operational characteristics in magneto-weighting casting installation (MWI) for aluminium alloys. 8th International Conference on Electromagnetic Processing of Materials, Oct 2015, Cannes, France. EPM2015. <hal-01336360>

HAL Id: hal-01336360
https://hal.archives-ouvertes.fr/hal-01336360
Submitted on 23 Jun 2016

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Dynamic control of operational characteristics in magneto-weighting casting installation (MWI) for aluminium alloys

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Abstract
In this study by the analysis of the possibilities for direct measurement of the melt weight into magnetodynamic installations was substantiated the ways for realization of direct and indirect dynamic control of pouring processes and managing of it operational characteristics.

In the course of studying of the pouring process has been estimated the roles of inertial drain of melt on the the accuracy of dosing by open stream method.

The special algorithm for dynamical control by the "tracking" method was developed and tested, which include the 4-steps recalculation the difference poured melt mass (m_{i+1}-m_i) within corresponding time (t_{i+1}+t_i). Application the “tracking” method at indirect correction of the melt flow rate at pouring from MDI to casting mold is allowed to reduce the it oscillation to ±2% in comparisons with existing 6% before.

Especially for widely using in the industrial conditions has been developed the prototypes of simple devices and methods for dynamic control flow rate of pouring melts into molds, that based on measurement of metal flow rate by determining of “instantaneous value” of force, which is creating by the mass of the melt at it flowing via sloped tray.

Keywords: dynamic control, magneto-weighting installation, operational characteristics, electromagnetic forces.

Introduction
For providing of controlled electromagnetic pouring and discrete dosage the set portions (dose) of aluminum alloy in PTIMA NAS of Ukraine the magneto-weighting installation (MWI) [1] was developed. The MWI is a magnetodynamic installation (MDN-6A) [2] which are placed on the weight measuring system (WMS) as a scales platform. It is allow producing the continuous static and dynamic (in real time mode) high-precision measurement of the molten melt weight in crucible and channels with accuracy 0.1%. That practically was used for weight control of melt discrete dosing from MDI in a dose range 2–400 kg and accuracy from 2.0% to 0.5%.

In the simple execution the weight measuring device there is a scales platform with four strain gauges sensors (BSA Shear beam load cell 2000 kg, with accuracy 0.02%), on which the MDI was placed as shown on Fig. 1.

Each load cells to a digital microprocessor unit CAS CI-8000V is connected. The outputted from this device analog/digital signal further using for control of the electromagnetic pump of MDI at pouring of set portion of melt to casting mold by measure decreasing total mass MDI by detaching methods [2, 3]. The dosage process by achieving of set unloading value (in range from -2 up to -400 kg) on the weighting systems was produced and by generating the “stop of pumping” command to the control circuit of MDI. By its means the row dosage methods has been tested at application in MDI. There are possible to make the traditional mode of electromagnetic melt pouring from metalduct to casting mold at constant mass flow rate. For precision melt dosing, for example doses 1–400 kg with an accuracy of 1–0.5%, the two-stages pouring mode has been developed. Second stage of pouring included the refilling mode at reduce flow rate (Q) in the output dosing phase. Especially for the pouring melt to die-casting machines can be used the special mode with braking stream of melt in the finishing phase of dosing. For braking stream of melt at the finishing of pouring have used the reversing electromagnetic force action. That to allowing achieved the dosage accuracy greater than ±1.5% for doses of 0.5 kg by the decreasing of inertial process negative overfilling melt from metalduct at stopping of electromagnetic pump.

However the existing dosing weighting system not allow producing the wide dynamic controlling of flow rate melt making during pouring from MDI to casting mold. Because it is can be predetermine set up only before starting of pumping and can be changed only manually in little range ±18%.

Presentation of the problem
At exploitation MDI as a mixer-batcher, for example at the dosing aluminium alloy to casting mold on conveyer, the of melt temperature (T°C), mass flow rate at pouring (Q (t)) and electromagnetic pressure (p_{em}) must be maintaining on set position and not changing. There is a total requirement for dosing device in the industries application.
However, the electromagnetic pressure ($P_{em}$) in the electromagnetic pump of MDI is possible maintaining as constant value, that is depend from parameters (voltages) of electrical powering on inducers and electromagnet ($P_{em} \approx f(U_{ind}, U_{em})$). But hydraulic pressures ($H$) is so very depend from the difference between melt level in crucible ($h_{met}$) and output nozzle of metallduct (Fig. 1), exactly at the melt pouring by open stream methods.

By this means, the process of pouring alloy from metallduct is equal to overpressure ($\Delta P_{em}$) above the nozzle of metallduct (Fig. 1.). In result at the decreasing of melt level in crucible MDI the useful overpressure also decreasing up to appearing of full stopping outflowing melt from metallduct.

For analysis of the hydrodynamics processes at discrete dosing the experimental dependence of the 2 kg aluminum was provided [1]. Essence of dynamic mass flow control is consisted in the continuously determine the actual difference between the surface of the metal in the crucible and the level in spout of metallduct ($L_{metallduct}$) for calculation existed overpressure value $\Delta P_{em} \approx \Delta H = H_{em} - h_{met}$ (1). Defined by this way $\Delta P_{em}$ is compared with initial conditions at start of pouring, and at the it reducing or increasing was produced the correction of voltage supplying to the electromagnetic pump of MDI.

$$Q(H) = \rho \cdot \varepsilon \cdot \varepsilon \cdot \phi \cdot b \cdot \sqrt{2g \cdot (H - L_{metallduct} - h_{met})^{3/2}} \text{, kg/sec}$$

(1)

wherein $Q(H)$ - flow rate as a function of the pressure, kg/sec; $\varepsilon$ - coefficient of vertical stream compression; $b$ - width of the nozzle of metallduct, m; $\varepsilon$ - side compression ratio of stream ($\varepsilon = 0.85-0.9$); $\phi$ - flow rate ratio (0.97), $H$ - hydraulic pressure, m; $h_{met}$ - level of melt in crucible, m; $L_{metallduct}$ - lenght of metallduct, m.

Take into account that measurement of actual height of aluminium alloy level in the crucible by contacting or optical methods is difficult and required of expensive equipment, in study was implemented methods of the in real time calculation the mass of alloy into MDI to it volume and next to height it level into crucible. For this purpose the experimental pragmatic model as a dependence from metal mass ($m_{met}$) was developed - $h_{met.lev}(m_{met}) = 0.569 \cdot m_{met} + 5.385$. As an incoming the analog signal $U_{WMS}$ from weight measuring devise has been used ($m_{met} = f(U_{WMS}) = [(863 \times U_{WMS})/550]-1$). For practical application of this methods the special algorithm was developed and programmed into the microcontroller Mitsubishi ALFA AL2-14 MRD (used now as automatic control system ACS), which was installed into the control circuit of magnetodynamic installations with weighting system. Experimental approbation of the developed correction methods to allowed maintained the initial flow rate in the range of from 6.0 to 3.81% (for pouring velocities 2-6 kg/sec), and achieved it independence from melt level in the crucible ($h_{met.lev} = 50-350$ mm). Accuracy of the discrete dosage melt portions 10.5 kg is makes 0.7%, and without using - 2.75%.

**Development the methods for indirect dynamic control of flow rate pouring aluminium alloys.**

For analysis of the hydrodynamics processes at discrete dosing the experimental dependence of the 2 kg aluminum pouring within time 2.5sec was registered by the means of weight measuring device (Fig. 2, curve 1). Its studying is showed of the oscillations of the mass flow rate of the melt during it pouring from MDI, that at values of flow rate $Q=0.8$ kg/sec makes 5~15%.

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**Fig. 1.** Structural diagram of MWI for aluminium alloy and SAC for discrete/continues dosing and photo of prototype
These oscillations is a result of the appearing the vortex structures in T-shape working area (WA) of MDI and its interaction [1] at the creation of electromagnetic force. In additional the fluctuation of hydrodynamic characteristics (pen) have a 5 to 15% from nominal electromagnetic pressure and appearing at achieving of linear velocity of the melt moving via working area MDI more than 1-3 m/sec. Frequency analyses of pressure fluctuations shown of 3 main harmonics in range 0.4–0.8 Hz, 2.5–3 Hz, and 4.0–4.4 Hz.

Such fluctuations of pressure and flow rate characteristics is seriously are reducing the accuracy of discrete dosing, and there are impacting to the inertial drain of melt from metallduct after stopping of electromagnetic pump. There is shown on Fig. 2 (line 1) that the uncontrollable drain process have a time 0.5sec and 20% of total pouring time. Impact the inertial drain melt dependent from the influence of the force "momentum" $J_m$ (2), and characterize the any quantity of aluminum melt, drained under the action of inertia forces in the end of pouring:

$$J_m = (m_{\text{met}} \times Q)/(S_{\text{met.duct}} \times \rho_{\text{Al}}), \text{ kg}$$ (2)

where $m_{\text{met}}$ - weight of melt in channel/metalduct, kg; $Q_i$ - instant value of flow rate $(Q = \bar{x}_{\text{met}} \times S_{\text{met.duct}} \times \rho_{\text{Al}})$, kg/s; $\bar{x}_{\text{met}}$ - linear velocity of melt in metalduct, m/s; $S_{\text{met.duct}}$ - cross section of metalduct, m$^2$; $\rho_{\text{Al}}$ - density of Al alloy, kg/m$^3$.

In order to this for reducing negative influencing of inertial drain processes and achieving of high accuracy of dosing it is a pouring time should be increase at increasing value of flow rate Fig. 3.

However, for improving possibilities of pouring control in this study was developed the original methods online calculation of presence flow rate flowing melt, as the first derivative of the value of the mass changes by time $m' = f(t)$.

The special algorithm for dynamical control by the "tracking" method was developed and tested, that include the 4-steps recalculation the difference of poured melt mass $(m_{i+1} - m_i)$ within corresponding time $(t_{i+1} - t_i)$, where is flow rate can be presented as - $Q_i = m'_{i+1} = (m_{i+1} - m_i)/(t_{i+1} - t_i)$. On Fig. 2 by lines 2~5 is shown the results of 4-stages recalculation of $(m_{i+1} - m_i)$ during time $(t_{i+1} - t_i)$, for points of $i = 1, 2, 3, 4$ by expressions $Q_i = \sum_{n=1}^{4} Q_{i+n}/n$. The each values of $m_i$ and $t_i$ in this case was defined as i-point, which inputted to microcontroller of automatic control system with frequency 50Hz, at renewing of each 0.02sec. The most useful for practical application there are the 4-th constituent of the "tracking" algorithm (Line 5 on Fig. 2), that have been a by time delayed no more than 0.08s, and error in range 5%. Additionally, for dynamic monitoring and control on the pouring process it can be realized by the back-calculation of the expression (1) $Q(H)$, by calculating the pressure caused by electromagnetic pressure ($p_{\text{em}}$). For the next deeply studying of possibilities dynamic control of operating characteristics in magnetodynamic installation rationally is use the complementary system (3), that also can be programmed as algorithms in the microprocessor unit:

$$Q(m) = m_{i+1} - m_i, (t_{i+1} - t_i)$$

$$Q(H) = \rho \cdot e \cdot e \cdot \varphi \cdot b \cdot \sqrt{2g} \cdot (H - L_{\text{met.duct}} + h_{\text{met}})^{1/2}$$

where - $Q(v_{\text{met}}) = \sqrt{\varphi}$ a component of the equation, which can be measured with the use of assistive devices that can be included with the MWI with integrated IWMS.
Experimental tests of "tracking" algorithm at discrete dosing of 1, 3 and 5 kg/s aluminum with automatic correction voltage on electromagnet by deviation real value of flow rate from set has been showed reducing of it oscillation to ±2% in comparisons with existing 6% before.

Development the prototypes of the methods and devices for direct dynamic control pouring melts
Especially for widely using in the industrial conditions the prototypes of simple devices and methods for dynamic control flow rate of pouring melts into molds has been developed (Fig. 4).

Fig. 4: The prototypes of measurement devices for dynamic control of the flow rate on sloped tray (a) and scheme for ponderomotive contactless melt flow rate measuring (b).

According to the proposed methods the measurement of metal flow rate was realized by determining of the “instantaneous value” of force, which is creating by the mass of the melt at it flowing via sloped tray (Fig. 4), during given period of time. Such methods can be realized by two ways, at direct measurement of melt mass flowing on sloped tray melt mass by means of strain gauges or by continuously measurements of the ponderomotive force (Fp) of the interaction of the AC magnetic field (B) from electromagnet that located under of sloped tray (Fig. 4 b) [4].

\[
Q(F_p) = k_{ph} \cdot F_p^{3/2} + c_g \cdot F_p,
\]

where \(Q(F_p)\) - melt flow rate at the trough, kg / s; \(F_p\) - ponderomotive force N, \((kg \cdot m / s^2)\); \(k_{ph}\) - factor for the physical properties of melt and geometric parameters of the trough \((k_{ph} \geq 1), s^2/(m / kg)^{1/2}\); \(c_g\) - constant that takes into account the geometrical parameters of the trough, its position relative to the drain spout of metalduct and physical properties of melt \((c_g \geq 0), s/m\).

Conclusion
The original methods of the maintaining of the set point of flow rate characteristics independence from the level of metal in the crucible MDI was developed and described, that allowed obtaining the stable dosing high accuracy not less than 1%. By deeply studying of the pouring process has been estimated the roles of inertial drain of melt to the accuracy of dosing by open stream method.

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