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V Dubodelov, O Smirnov, M Goryuk, V Pogorsky, V Seredenko, et al.. Features of functioning of magnetodynamic tundish at continuous casting of steel. 8th International Conference on Electromagnetic Processing of Materials, Oct 2015, Cannes, France. hal-01336369

**HAL Id: hal-01336369**

**<https://hal.science/hal-01336369v1>**

Submitted on 23 Jun 2016

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# Features of functioning of magnetodynamic tundish at continuous casting of steel

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## Abstract

Magnetodynamic tundish (MD-T) for continuous casting of steel had been developed in PTIMA NASU. Such aggregate has some features in contrast to conventional tundish and provides different-in-principle modes of work of continuous casting machines (CCM). There were carried out both physical and mathematical modeling continuous casting of steel from MD-T. In comparison with traditional technology, it was shown that reducing in 3.0-3.5 times of metal static pressure at pouring leads to decreasing in 1.7-1.8 times the depth of penetration of high-speed and high-temperature melt stream into solidifying ingot. In this case, for keeping (or rising) of mass pouring rate and ingot's withdrawal rate, it is necessary to provide increasing of melt volume which incomes into CCM mold. Results of researches had indicated that MD-T can decide this problem. Electromagnetic systems of such aggregate allow to forming the flat stream of melt in width of 0.5-0.8 m. Such features of MD-T allow changing cardinally the terms of ingot forming. So, there is increased the heat load onto mold, but at the same time the heat load is decreased in the secondary cooling zone. Also, it is possible to eliminate application of high-expensive electromagnetic systems for melt braking in the CCM mold. This fact creates preconditions for reduction of CCM length.

**Key words:** magnetodynamic tundish, mold, continuous casting, modeling, inclusions, slag, electromagnetic stirrer

## Introduction

In last 15-20 years main requirements for quality continuous casting ingot becoming more stringent. This is due to the development requirements of the global market and new technological constructions in which the combined process of casting and subsequent rolling. Many researchers are making extra efforts to enhance the technological capabilities of the tundish in protecting steel from contamination by nonmetallic inclusions, control the temperature of the metal during the casting and refining of molten steel directly into the tundish [1-4].

The functioning process of the tundish during the casting cycle can be divided into the following characteristic cycle: filling the tundish at the beginning casting when you open steel ladle be slide gate; steady state casting while maintaining the nominal level of the metal in the tundish; a period of intense decreasing of loading level steel in the tundish, which caused during the replacement of the ladle; set filling level of the metal in the tundish due to the start of the new steel ladle up to the stabilization of the entire process; fall in the level of metal in the tundish at the end of the casting process. In a liquid bath of the tundish we can be divided into three or four zones, which characterized by considerable difference velocity gradient (Fig. 1).

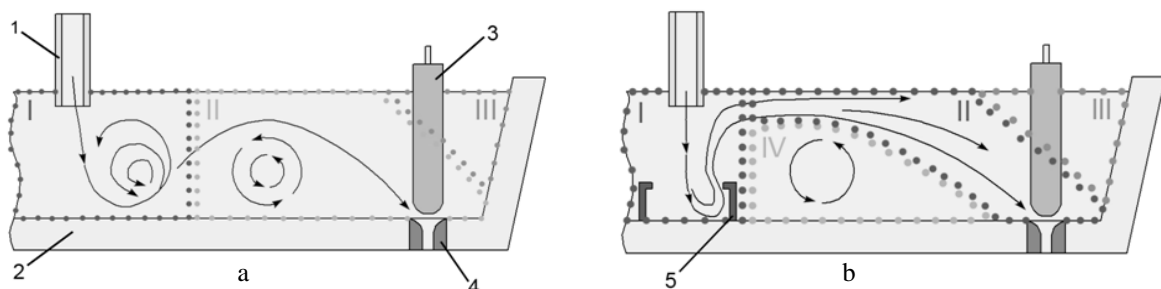


Fig.1: Key transfer zones in a liquid steel bath of the tundish: I – the zone of falling liquid steel jet and intensive suppression of its speed; II – area of active moving of melt flows in the tundish volume; III, IV – stagnant (“dead”) area, which boundaries are due to the design of the tundish and the presence of the dams and tundish-box (1 – ladle shroud; 2 – tundish; 3 – stopper; 4 – nozzle; 5 – tundish-box)

In liquid metal bath of tundish, there are formed a few areas where melt moves very slowly. Such areas are called stagnant or “dead”. In these areas the metal remains in 5-10 times longer than the average residence time of the steel in the

tundish. This phenomenon leads to the fact that non-metallic inclusions coagulate. The size of non-metallic inclusions can be increased by 10-15 times or more.

By the way the “dead” area in the tundish is not constant. It moves slowly from the middle part of tundish to the zone of nozzle and then returning. It is making very difficult to quantify its borders. The existence of such “dead” volumes significantly reduces the active volume of the liquid bath, and thus reduces residence time main part of steel. For this reason, it is necessary to minimize “dead” volume of the liquid bath in the tundish. It will provide the best conditions for flotation non-metallic inclusions and give possibility to reduce the volume of the tundish and its geometrical dimensions. In present time the most actual issues that require innovative solutions in the development of the tundish, are as follows: effective methods forced flotation of non-metallic inclusions in a liquid bath of the tundish through the use of various dams and tundish box; - application MHD methods to optimize flows movement in the tundish; - refining molten steel in the tundish through the argon injection; - regulation temperature of steel in the tundish during the casting process; - optimization configuration of the inner cavity of the tundish to ensure rational motion of convective flows; - development of new methods of metal dosing from the tundish into the mold, which including the provision of the braking effect of the jet and its dispersed supply into the mold.

Thus, the most important task for the system of continuous casting technologies for the near future is the problem of optimizing the tundish as multi functional unit, which providing manufacture of high condition continuous casting ingots from pure and high purity grade steel.

### Development of tundish design

Modern tundish must perform a variety of technological features that have been listed above. It is a buffer capacity, which agrees a discrete flow of steel from the ladle into a tundish and a continuous flow of steel from the tundish into the mold. Meanwhile, the residence time of the metal in the tundish is 5-15 minutes. This ensures the averaging of incoming metal portion and to prevent ingress of slag in the mold. It is assumed that the tundish design should ensure minimal heat loss during the metal casting cycle.

From the practice of continuous casting well known that quite large areas of the liquid bath of tundish very poorly mixed by convection flows and thus reduce the efficiency of refining operations and averaging process (zone III and IV, Fig. 1). Many investigations found that this area should be stirred forced flows which are formed by injection inert gas to the molten bath [5-7]. Meanwhile, possibilities of injection process argon into steel in the tundish sufficiently strongly limited, because with increasing gas flow rate above the critical value may be a metal contamination by extra large inclusions. It should be explained by strong metal and slag wildness at the exit site argon bubbles [7].

Directional movement of forced flows in a liquid bath of the tundish can be achieved through the use of electromagnetic stirring (EMS). Determination of a stirring power, flow directions and places applying a magnetic field should be carried out in accordance with the industrial and quality tasks.

Wherein it must be take into account the configuration of the tundish and the presence of auxiliary units (design of tundish box, dams, walls, purging block). In our opinion the most effective technological solution will combine the imposition of electromagnetic stirring using electromagnetic stirring and argon bubbling of metal into a single forced system, which will be located in the bottom of the tundish around the middle part (under the “dead” zone). General view of the design tundish, which was developed with additional electromagnetic stirrer (EMS), is shown on Fig. 2. In the present version a positive effect is achieved primarily by the flow direction of the liquid bath in the tundish (eliminates “dead” zone), and more rapid transport of non-metallic inclusions to the surface of steel in tundish. Also steel refining from non-metallic inclusions occurs due to suppression of bubbling at the boarder slag-metal and reduces the wear of the refractories in zones of high turbulence.

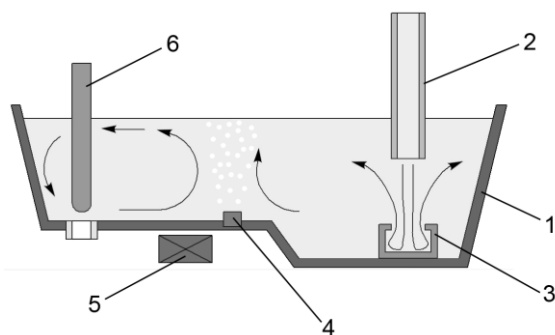


Fig.2: Design continuous casting tundish with EMS and argon injection: 1 – tundish; 2 – ladle shroud; 3 – tundish-box; 4 – purging plug; 5 – EMS; 6 – stopper

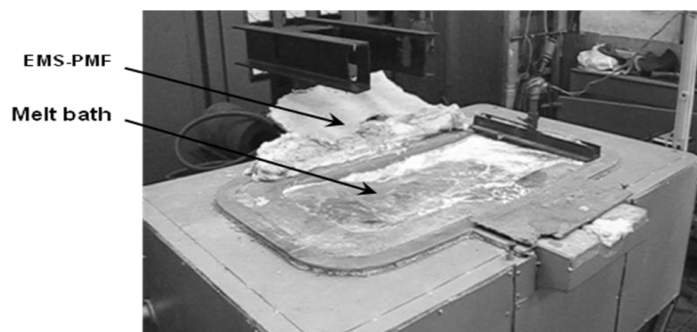


Fig.3: Laboratory tundish equipped by EMS-PMF [8]

### **Hot modeling**

Evaluate the effectiveness of applying a magnetic field to the molten bath of the tundish were performed in the laboratory equipment. The capacity of the container, which simulates the tundish, has 600 kg of aluminum (Fig. 3). Measuring the speed of the forced flows was performed using Pitot tubes. It was found that the most effective impact on the melt is pulsing magnetic field (EMS-PMF) [8]. Thus, nearly the wall of the tundish, which inductor EMF-PMF with capacity of approximately 20 kW had placed, a result of his actions had formed submerged flow, which ensures mixing of the melt to form a toroidal vortex along both the longitudinal and transverse sides of the container. Moreover, the speed of the melt flow in the core achieves 1 m/sec.

This speed is maintained at a distance of not less than 1.2 m from the wall of the tundish. It was research the effect of influence distance from the pole of the inductor to the liquid metal boarder on the velocity of the liquid aluminum in the core flow. It was shown that the critical value of this quantity for the unipolar EMS-PMF is the distance nearly 200 mm, but since this date the speed of the melt had decreased in 3 times. As the comparison, for application running magnetic field inductor in the furnace wall its placed on the distance a 60-100 mm from the liquid metal boarder.

### **Physical modeling**

Due to the fact that the industrial test aimed at the investigation of processes taking place in the tundish, is associated with a number of practical complexities (high test costs, impossibility to visualize specific stages of the process, difficulty to measure physical values), the present paper applies physical modelling method for experimental research [9-11]. For the present study, the tundish physical model and its basic functional units were fabricated from transparent material. The model's scale is 1:4. This scale appeared to be sufficient for visual monitoring of all hydrodynamic processes taking place in the tundish, almost in online mode.

The behaviour and up floating pattern of non-metallic inclusions was investigated by means of introduction of dedicated mechanical mixture (suspended solids) of hydrophobic particles into the shroud placed between the steel-teeming ladle and the tundish, the mixture density being lower than the water's density. For this purpose, a dedicated multi-component mixture to include several types of oils and emulsions and very fine solid particles, was developed. Therewith, in the course of tests, the motion trajectory of "slag" particles in the tundish liquid bath was assessed, as well as the approximate portion of particles up floated to the surface and out flown from the tundish together with the water. The motion of liquid convective flows in the tundish originated at the jet location incoming from the steel-teeming ladle, until liquid outflow from nozzles, was recorded by a digital camera. Concurrently, volumes of liquid outflowing from the ladle were painted with coloured dyes.

### **Results and discussion**

The physical model was applied to compare efficiency of various methods of liquid steel refining in the tundish. For this purpose, a certain volume of substance imitating non-metallic inclusions (oil and fine solid particles mixture), was fed into the shroud. Following that, the liquid out flowing from the tundish, was collected in the dedicated vessel and settled down for several hours. Concurrently, the substance imitating non-metallic inclusions floated up to the surface. This part of simulating substance was collected in the dedicated tank and weighted. The highest efficiency of non-metallic inclusions removal was observed at gas injection and flow forced to the molten bath. This is accounted for a transportation phenomenon, which accompanies flotation of the purging gas bubbles.

The cumulative effect of the ring-shaped purging block application can be considered as a reasonably efficient practice to enable flotation of non-metallic inclusions. To enhance performance of the ring-shaped purging lance, it is necessary to control behaviour of bubbles ingress to the liquid surface in the tundish, since this ingress can lead to steel and slag mixing. This process causes entrapment of non-metallic inclusions by steel convective flows. The significant influence on the turbulence of steel and slag mixing is exerted by the injected gas flow-rate. It should be also considered that the minimum mixing of steel and slag was observed under liquid bath purging in the bubbling mode.

### **Practical**

There were carried out both physical and mathematical modeling continuous casting of steel for magnetodynamic tundish (MD-T). In comparison with traditional technology, it is shown that reducing in 3.0-3.5 times of metal static pressure at pouring leads to decreasing in 1.7-1.8 times the depth of penetration of high-speed & high-temperature melt stream into solidifying ingot. At that, either maintenance or rising both mass pouring rate and ingot's withdrawal rate needs corresponding increase of melt volume melt incoming into CCM's mold. Results of modeling and experimental measures indicate that MD-T can decide this problem due to forming (under action of electromagnetic forces) the flat melt stream in width of 0.5-0.8 m.

The general concept of the multifunctional magnetodynamic tundish (MD-T), which provides forced mixing, preheating and controlled casting of metal, and its refining, had been developed in Physico-Technological Institute of Metals and Alloys of National Academy of Sciences of Ukraine (PTIMA NASU). Such type a tundish is most interesting in the case of continuous casting special steels with high requirements for quality. Typically, these grades of steel have been

producing at relatively a small quantity, which making them a very difficult for process ladle treatment. Accordingly, in this case some part of technological operations has been transferred into tundish. Schematic diagram of the MD-T is shown on Fig. 4.

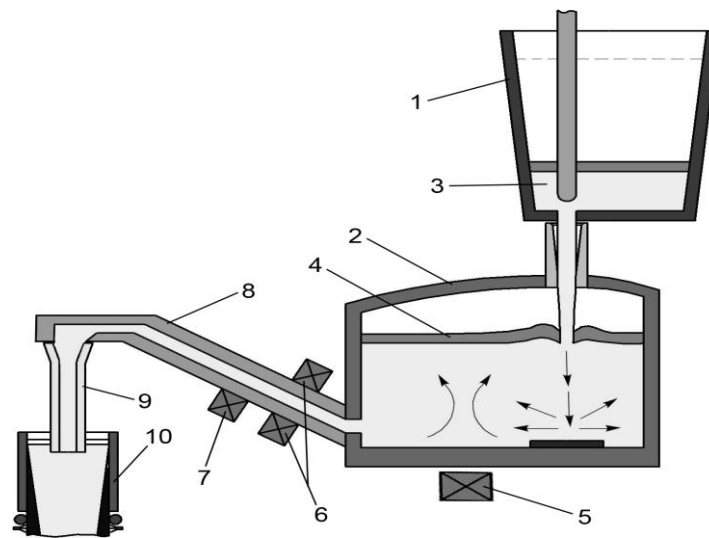


Fig.4: General design of tundish with MHD pouring and preheating steel: 1 – steel ladle; 2 – MD-T; 3 – liquid steel; 4 – covering slag; 5 – EMS; 6 – inductor for preheating; 7 – unit for EM dosing; 8 – refractory pipe for transport steel; 9 – submerged nozzle; 10 – mold of CCM

There is a possibility for effective control of the liquid steel temperature at its moving from crucible through channel for subsequent pouring into CCM mold; regulation of out flow of liquid steel from MD-T is made without application nozzle-stopper equipment and sliding shutters. Besides there is possibility for control of pouring pressure and pouring mass flow rate of metal.

### Conclusion

Trends in the development of the global steel market will demand from steel manufacturers to improve the technology and equipment for the production of cleaner steel for requests of non-metallic inclusions. A key element of improving the purity of steel, apparently, can be multi-functional tundish with MHD units.

Thus such tundish will have some improving design of configuration in combination with a number of improvements in the technology of treatment and casting steel. The effectiveness of the MD-T is substantially extended by the MHD effects. In particular MD-T can be use for controlling the temperature of the steel, control and suppression of turbulent flow and dispensing of the metal during its flow to the mold.

Application of MD-T may be of special interest for technologies of manufacturing of small lot (to 10-20 thousand tons steel per year) of high-quality ingots for machine-building and casting enterprises. It will allow organizing the metallurgical micromill by the semicontinuous casting process with using of MD-T. There is developed the technical project of semicontinuous casting machine (SCCM).

### References

- [1] A. McLean (1988), Proc. Steelmaking Conf., Iron and Steel Society, 71, 3-23
- [2] Y. Sahai, T. Emi (2008), Technology for Clean Steel Production, New Jersey: World Scientific
- [3] K. Marukawa, S. Hara, M. Sano (2001), ISIJ International, Supplement, 36-41
- [4] D. Satish Kumar, T. Rajendra, R. Prasad e. a. (2009), Ironmaking and Steelmaking, 36, 470-475
- [5] L. C. Zhong, L. Y. Li, B. Wang e. a. (2008), Ironmaking and Steelmaking, 35, 436-440
- [6] J. Zhu, J. Li, L. Sun e. a. (2011), Advanced Materials Research, V.291-294, 255-258
- [7] A. Smirnov, V. Efimova, A. Kravchenko (2014), Refractories and Industrial Ceramics, 55, 173-178
- [8] V. Dubodelov, V. Fikssen, M. Slazhniev e. a. (2009) 6<sup>th</sup> International Conference on Electromagnetic Processing of Materials, Dresden (Germany), 599-602
- [9] K. Chattopadhyay, M. Isac, R. Guthrie (2010), ISIJ International, 50, 331-348
- [10] D. Mazumdar, R. Guthrie (1999), ISIJ International, 39, 524-547
- [11] S. Koria, S. Singh (1994), ISIJ International, 34, 784-793