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STUDYING OF THE MAGNETIC FIELD DISTRIBUTIONIN THE SUBMERGED ENTRY NOZZLE FOR CONTINUOUS CASTING

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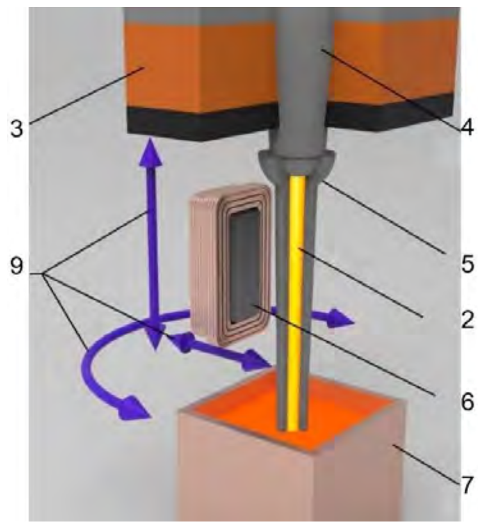
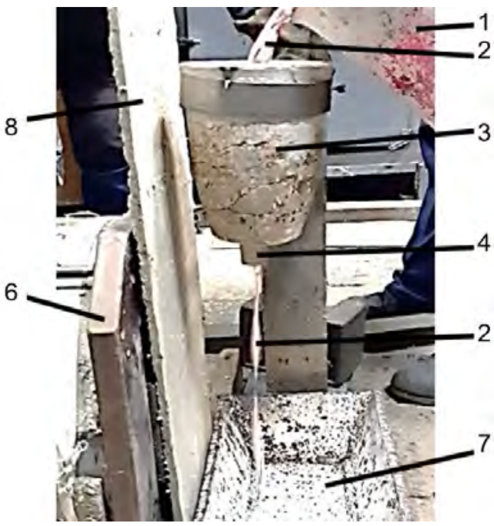
The steel casting process in continuous casting machines (CCM) is accompanied by some mandatory process transfers, with a few critical physical and chemical processes performed. They largely determine the efficiency and stability of the steel casting process in general, as well as billet quality. Meanwhile, the steel jet moving from the ladle through the tundish to a mold is the main factor of dynamic and stable monitoring of the quasi-continuous steel casting process under the conditions of discrete replacement of ladle and tundish, as well as submerged entry nozzles (SEN) and metering nozzles.

In practical continuous casting, ceramic SEN is the functional part, which is highly exposed to wear and tear in the steel pouring and metering process. There are two types of wear and tear: clogging of the SEN cavity and reduction in thickness of the SEN walls, in the lower section, because of chemical interaction between the SEN wall material and aggressive slag formed immediately in the casting process. Here the configuration of the SEN cavity changes, and the jet configuration is transformed, thus causing jet fluctuations, and splashing. In practice, the worn SEN is periodically replaced (for example, each 2-6 hours on an average) with a new one, which is pre-heated to 1000-1100 °C. The procedure for replacing the SEN provides for a mandatory stoppage of steel supply through the metering nozzle to the mold for the period of SEN replacement (100-150 seconds for bloom and billet CCMs). In general, when a new SEN is put in operation, local turbulence and splashing zones are formed in the lower section, causing instability of the jet flow and slag particle adhesion in the SEN. The replacement of the SEN as a process operation is a critical element in terms of adverse clogging in the SEN cavity and metal losses in transition zones at the time of SEN replacement. As usual, such billet section is subject to rejection (about 500-800 mm). Cyclic fluctuations of the metal level can be also observed in the SEN during the continuous casting, causing the steel flow turbulence and considerable deformation of the jet geometry.

To suppress the SEN clogging phenomena, the article offers to superimpose the downward stream of the electromagnetic field directly inside the SEN (Fig. 1, a).



a



b

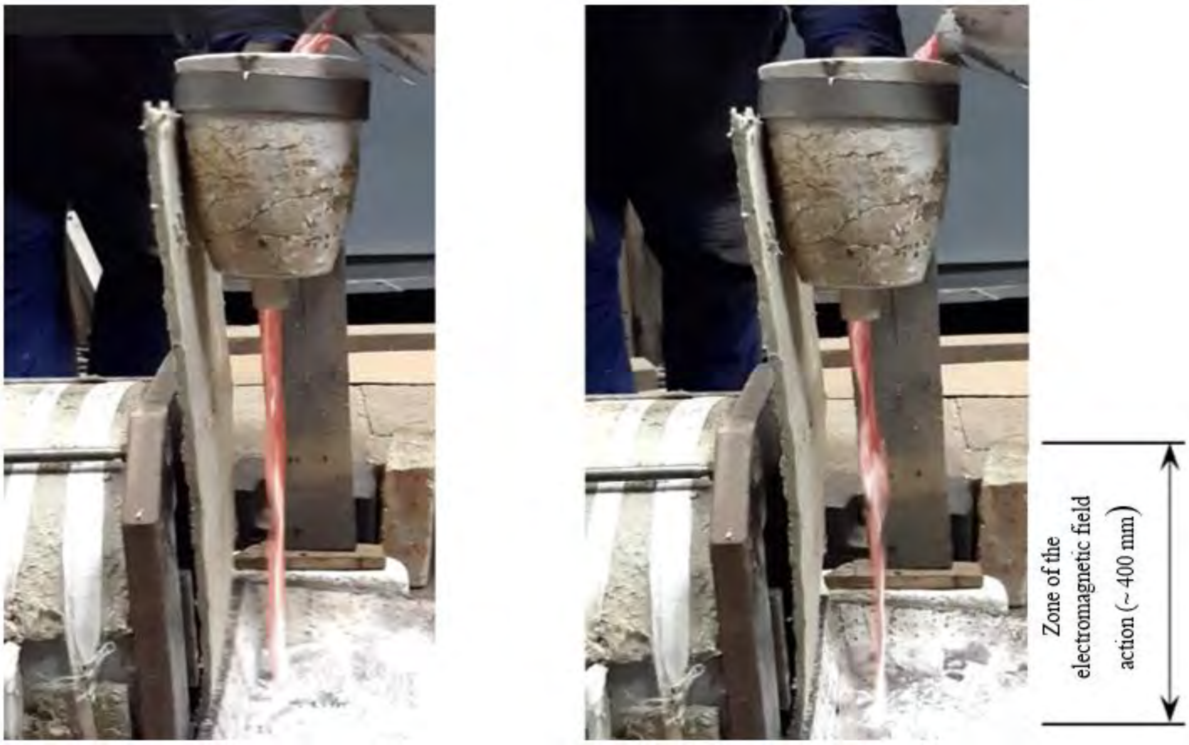
Fig. 1. Layout of the electromagnet (a) and experimental equipment (b) to influence the molten metal jet: 1 – ladle; 2 – molten steel; 3 – tundish; 4 – metering nozzle; 5 – SEN;6 – electromagnet; 7 – mold; 8 – protective shield of fire-proof cardboard;9 – possible directions of electromagnet movement

It is proposed to locate the magnet on the outside of the SEN, in the area between the tundish and the mold. In addition, a cyclic rotational and reciprocating (in and out) motion can be transmitted to the electromagnet. If parameters are selected reasonably, the effect of jet bounce from the inner surface of the SEN can be achieved and a gap between them can be formed. This allows preventing the slag particle and metal droplet deposition on the inner surface of the SEN. The electromagnet position correction is a crucial element of the designed construction, and it ensures the rational casting conditions and jet compactness. The effectiveness of the electromagnetic field impact on the jet has been evaluated using a laboratory-scale unit (Fig. 1, b), where the melt aluminum cast as an open jet was used to visualize the effect.

The free jet flow (Fig. 2, a) was initially deployed during the experiment and then, when the hydrodynamic casting conditions became steady, an electromagnet was added. This resulted in jet deformation (flattening) in the field coverage area (Fig. 2, b). Qualitative assessments were performed for the purpose of effective use of the electromagnetic effect within allowable limits. A total of 28 experiments with variable main influence parameters were conducted. It was established that the jet flowing out of the tundish can change its configuration under the influence of the created electromagnetic field and become oval, with the axis size ratio of 1:2 to 1:5. When the field intensity increases, this ratio will also grow.

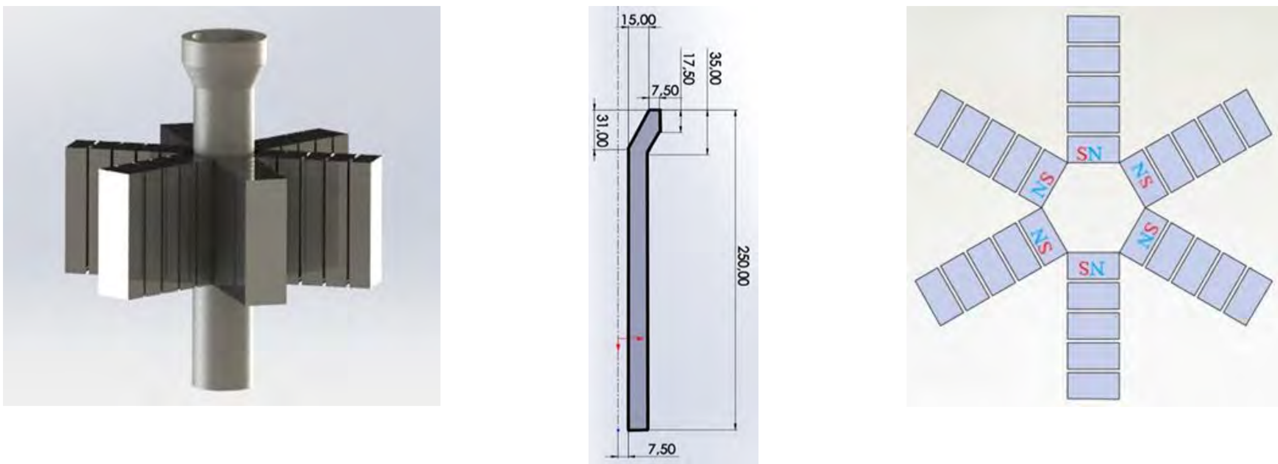
There are different options for permanent magnet effect on the molten metal flow in the engineering practice. Their use allows developing an alternative energy-saving method of influencing the metal jet in the SEN. Based on this fact, both the pairs and sets of neodymium magnets (NdFeB) simulating an electromagnetic device were used to numerical study the pattern of magnetic flux line distribution.

The characteristics of the magnetic field generated by a set of permanent magnets were evaluated with the use of the numerical model. The model geometry description used in the calculation is shown in Fig. 3. To analyze the generated set of permanent magnets, the magnetic field intensity and induction were calculated. The calculation results are given in Table 1 and Table 2. The diameter inside the set Dmag was 52 and 54 mm (D_{mag1}, D_{mag2} accordingly).



a b

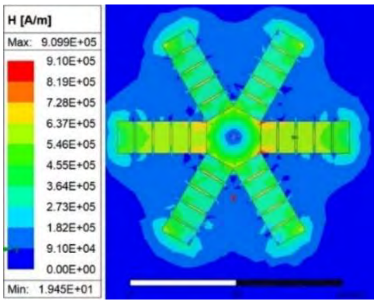
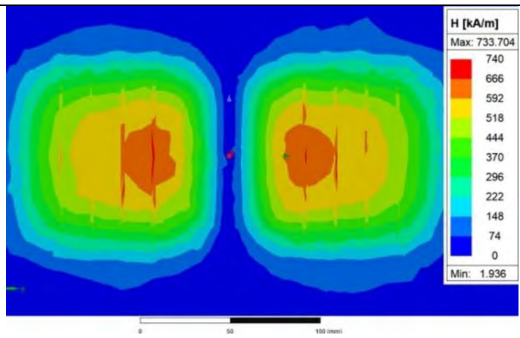
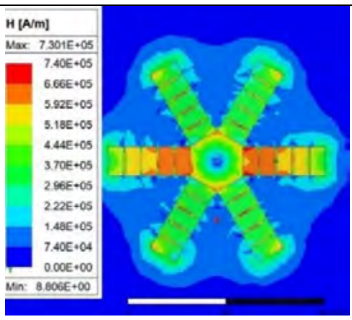
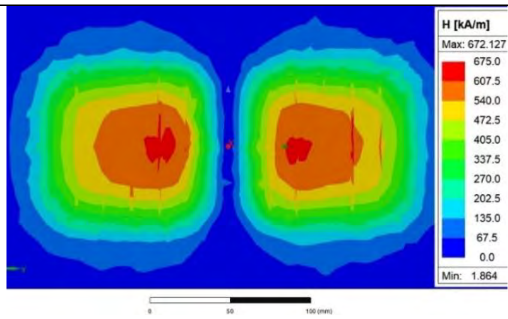
Fig. 2. Free flow of the molten metal jet (a) and its deformation under the influence of the electromagnetic field (b)



a b c

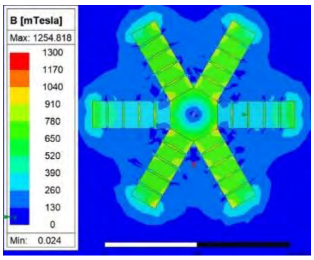
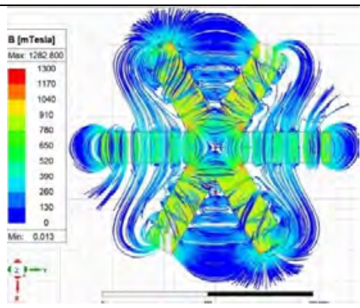
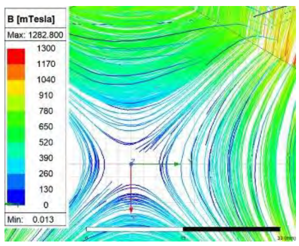
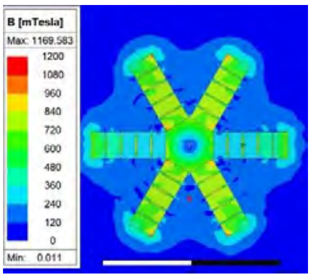
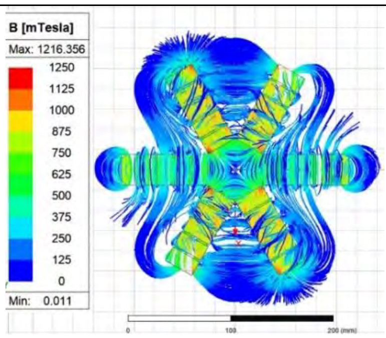
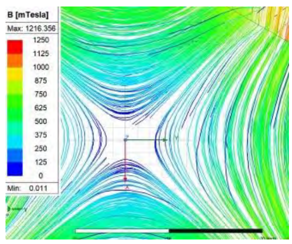
Fig. 3. Model geometry description: 3D view of the calculated area (a); magnetization direction of the rectangular diametrical magnets (b); SEN parameters (c)

Table 1 – Volume distribution of the magnetic field intensity H

D_{mag}	Global XY H_{mag*}, A/m	Global YZ H_{mag}, kA/m
D_{mag1}		
D_{mag2}		

*H_{mag} – magnetic field intensity [A/m]

Table 2 – Volume distribution of the magnetic field intensity B

D_{mag}	Global XY B_{mag*}, mTesla	Global model B_{vector}, mTesla	Global model B_{vector} in D_{mag}, mTesla
D_{mag1}			
D_{mag2}			

B_{mag*} – magnetic induction intensity [T]

The completed quantitative analysis of the data in Table 1 and Table 2 showed that the magnetic field generated by a set of permanent magnets, as well as the selected air gap of 12 mm are sufficient to influence the metal jet in the SEN. The distribution of the magnetic field induction along the vertical cross-section and of the intensity along the horizontal cross-section of the SEN is uniform.

A general assessment of the electromagnetic field effect on the metal jet was made. The jet transformation (flattening) was observed in the electromagnet coverage area. In general, the laboratory-scale unit simulating the metal flow from the tundish to the mold was used to make a qualitative assessment for efficient use of electromagnetic effect within allowable limits.

A 3D numerical model was created to verify the alternative energy-saving method under which the magnetic field is generated with the sets of permanent magnets. As part of the numerical simulation, the distribution of induction and intensity of the magnetic field across the SEN section, and the hydrodynamic pattern of steel flow inside the SEN were studied. The following conclusions were made:

When a rotating magnetic field generated by a set of permanent magnets is used, the outer layer of the metal jet which is 5% of its diameter can swirl at a rate of 4 m/s at the inlet of the SEN. It follows that such result may have a positive effect on the floating up of non-metallic inclusions in the tundish and thus have a refining effect and improve the molten steel purity.

It was established that the maximum possible bounce of the molten steel jet from the inner wall of the SEN may vary within the following range: 0.7-3.5 mm for the nozzle with an inner diameter of 28 mm (with the appropriate distance between the magnetic device poles to the outer wall of the nozzle, which is 25% (7 mm) and 5% (1.4 mm) of its inner diameter); 0.9-4.5 mm for a nozzle with an inner diameter of 34 mm (with the appropriate distance between the magnetic device poles and the outer wall of the nozzle), which is 25% (9 mm) and 5% (1.8 mm) of its inner diameter).