

Current Continuous-Casting Machines: Potentials for Technological and Equipment Development

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Trends in technological and equipment development for billet continuous casting are presented.

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Introduction

Iron & steel works of Ukraine are one of the largest billet and long products suppliers on the world market, dynamics of which development is characterized by noticeable competitive growth and quality specifications. In this context, analysis of trends in technological and equipment development for billet continuous casting is of interest.

In metallurgical practice, billet is a product of metallurgical manufacture in the form of steel bar of square, rectangular or round cross-section (maximum size of smaller side is not more than 180-200 mm) produced through casting on a continuous-casting machine (**Figure 1**) or by blooming. Further, the billet is used as an incoming billet for rolling of various shapes (circle, reinforcing rod, square billet, channel bar, I-bar, etc.).

Results and Discussion

At present, 350-380 million tons of continuous cast billets are produced per year in the world. More than two tens of metallurgical plants of CIS including five Ukrainian iron & steel plants have adopted billet manufacture only for the last decade. OJSC "Yenakiyevskiy Iron & Steel Works" is the largest continuous cast billet manufacturer among CIS countries.

Steel teeming was carried out on industrial scale in the early sixties but its wide spread occurred later - in the mid-eighties [1] due to

enhanced productivity of billets. The current continuous-casting machine ensures 200-250 thousand tons of billets per year per one strand [2], which creates opportunities for combination with converters and arc furnaces.

Processing lines consisting of high-duty arc steel furnace, ladle-furnace and continuous-casting machine promoted development of continuous casting machines [3]. For example, BSE plant (Germany) equipped with 90 arc steel furnaces, 2 ladle-furnaces and 2 five-strand continuous-casting machines produces hardly more than 2 million tons of billets per year [2]. The number of miniplants in the world already exceeds 1000 and they produce approximately a third of all made steel. Annual miniplant efficiency varies from 100-150 thousand tons to 1-1.5 million tons of billets per year. Duration of smelting in the modern arc furnace is 40-45 min [4].

Quality assurance of long products has a special importance since they are subjected to multiple process stages as usually in large lots and without an individual incoming inspection, and initial product quality is indicated only by results of random tests of finished products. The technological level of production and steel teeming is of great importance under these conditions.

Manufacturers try to minimize costs and apply an open jet steel teeming when teeming commercial quality steels. Closed jet steel teeming is used when casting high-quality and special steel grades prone to secondary acidification (for example, deoxidated by aluminum) and is carried out by means of sheath tube between steel teeming

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and intermediate ladle as well as submerged nozzles between intermediate ladle and continuous casting mold (**Figure 2**). The most difficult is to position a submerged nozzle in small continuous casting mold (100 x100 or 120 x120 mm) with a regulated gap between nozzle and mold walls. Special submerged nozzles produced by isostatic pressing method are applied for this scheme implementation. Durability of nozzles is determined by wall thickness 12-15 mm.

In conjunction with growing demands to operational efficiency of continuous-casting machines, technological functions of intermediate ladle become more and more extensive including additional metallurgical processes: removal of nonmetallic inclusions, addition of components, calcium modification of steel. Today, the duration of steel teeming from one intermediate ladle of continuous-casting machine reaches 50-100 smelting operations at many plants and is limited, primarily, by two technology factors: deterioration of metering nozzles and wear of intermediate ladle lining in jet falling area.

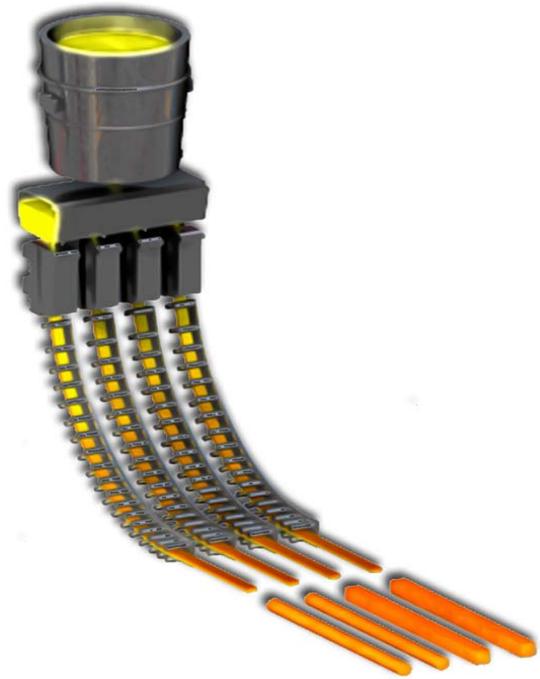


Figure 1. Continuous-casting machine

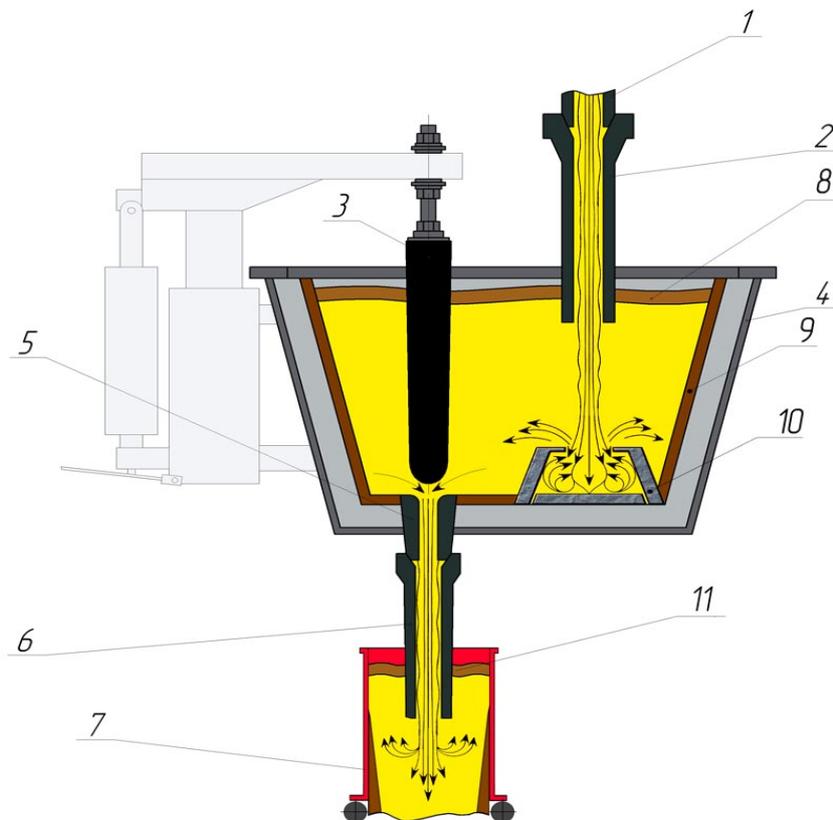


Figure 2. The general pattern of closed jet steel teeming: 1 - collecting channel of steel-teeming ladle; 2 - sheath tube; 3 - stopper; 4 - intermediate ladle; 5 - metering nozzle; 6 - submerged nozzle; 7 - continuous casting mold; 8 - heat-insulating mixture; 9 - plastic refractory covering; 10 - metal reservoir; 11 - slag-forming mixture

The first one is solved by means of optimization of steel preparation technology for teeming and application of devices for metering nozzle quick change. Application of this device ensures stable casting process due to fixed consumption of steel and also minimization of secondary tarnishing in the area intermediate ladle-mold.

Forward wear of intermediate ladle working lining is usually in the slag-line area, which is explained by flow turbulence in this part of intermediate ladle and mixing of covering slag. When teeming by ultra-long series, active contact of plastic refractory-layer of intermediate ladle with covering slag lasts for several tens hours, which requires a rational organization of steel flow motion in conjunction with following:

- washout of refractory layer in the place of jet falling;
- multiple change of metal level in the intermediate ladle;
- active mixing of covering slag including slag from steel-teeming ladles.

All specified above is ensured by application of special devices. **Figure 3** presents a chamber of intermediate ladle of 6-strand continuous-casting machine at OJSC “Yenakiyevskiy Iron & Steel Works”.

High withdrawal rate (5-6 m/min) is ensured by application of parabolical (multiple-stage) tube-type moulds 1.0-1.1 m long [5], internal profile of which considers billet size change after shrinkage. And air gap between mold tube surface and billets is reduced to the minimum, and withdrawal rate increases in 2.0-2.5 times in comparison with one-conic and two-conic mold tubes.

Mold tubes of modern continuous-casting machines are made with high dimensional precision, and their working surface is coated with a special antiwear covering on the basis of Cr, Ni and other metals.

Mold tubes are cooled by high-quality (often demineralized) water and are provided with run-around system which should ensure water velocity in coolant system channels not less than 7-8 km/s. Spray cooling can be a further development of mold tubes coolant system [2]. Spray cooling requires water by 30 % less than water-jacketed crystallizers. And mold tube durability raises in 1.5-2.0 times.

Steel swirling in the upper part of continuous casting mold and non-uniform growth of sinterskin at the initial stage affect billet surface quality. Technologies related to stabilization of

sinterskin growth process are of great interest, for example, “free meniscus teeming” suggested by centre IRSID (France) [6]. The distinctive element of this technology is application of continuous casting mold of special construction with ceramic upper part (**Figure 4**). Argon is blown in through the porous ring between ceramic and copper part of the mold and ensures homogenization of melted steel.

It is possible to suppress hydrodynamic agitations of liquid metal in the upper liquid bath of continuous casting mold by imposition of high-frequency electromagnetic field (above 100 khz) on the melt [7], which requires inductors in the upper part of continuous casting mold.

Sinterskin fracture is possible due to its adhesion to the mold wall. Minimum adhesion of sinterskin can be achieved when friction force between billet surface and mold walls appears to be lower than a critical level at certain frequency and amplitude. During last decade, the most of new and redesigned continuous-casting machines have been equipped with hydraulic drive molds, which allow nonsinusoidal hunting conditions (**Figure 5**), increasing casting rate and improving quality of surface and subsurface layers of billet [8].

If internal stresses in a solid sinterskin of billet reach the limiting values, a vertical longitudinal split can appear along the billet angle due to deterioration of mold bottom, non-uniform billet cooling in the mold, elevated temperature of steel in the intermediate ladle, high concentration of detrimental impurities (S, P, Sn, Pb, Sb). It was determined that the value of metal overheating in the intermediate ladle had a considerably greater effect on the whole casting process when casting at high rates than during casting at usual rates. It was because of the fact that solid sinterskin thickness at the exit from the mold decreased and metal breakout was more probable. Cooling intensity in the secondary zone should be selected so that the temperature of billet surface would slowly drop, and heat flow through the billet sinterskin and heat-removal on the billet surface would be almost equal. Continuous-casting machines usually apply cooling by water jets splattered through specially installed sprayers (**Figure 6**).

Water-air cooling has been used recently [9]. Spray lance consists of two independent sprayers for water and air, jets of which form a torch of fine-dispersed water drops. Air ensures water spraying and gives the drops a high kinetic energy. Water spraying pattern is determined by air consumption and pressure and can be regulated in a wide range of parameters.

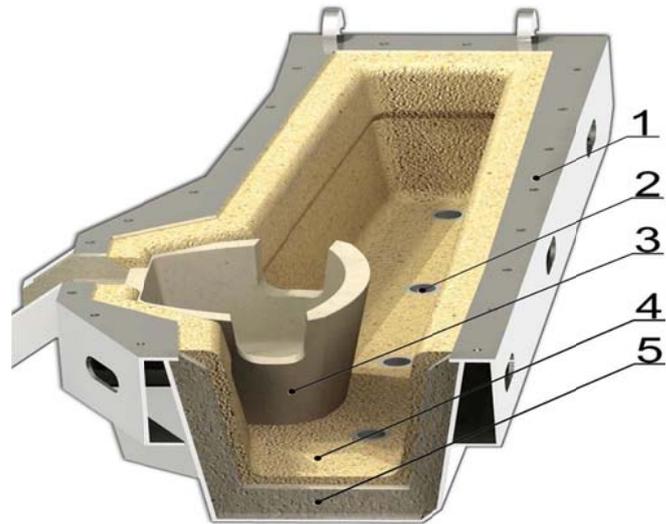


Figure 3. Intermediate ladle of continuous-casting machine: 1 – steel jacket; 2 – metering nozzle; 3 – metal reservoir; 4 – gunned layer; 5 – concrete

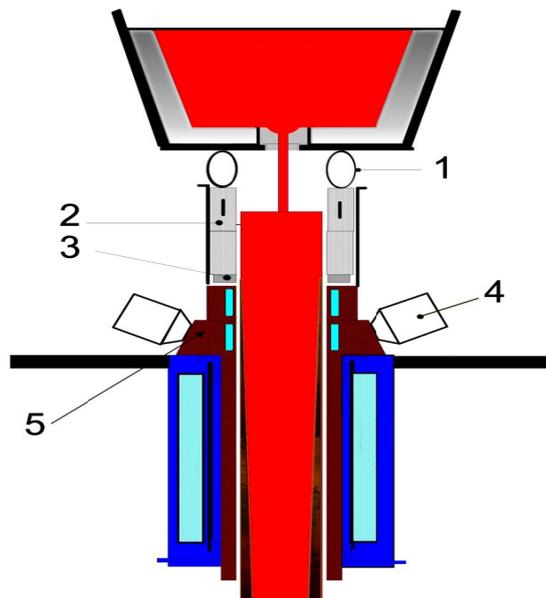


Figure 4. Continuous casting mold with ceramic insert: 1 – secondary oxidation protector; 2 – ceramic insert; 3 – porous ring; 4 – ultrasonic transducer; 5 – copper part of the mold

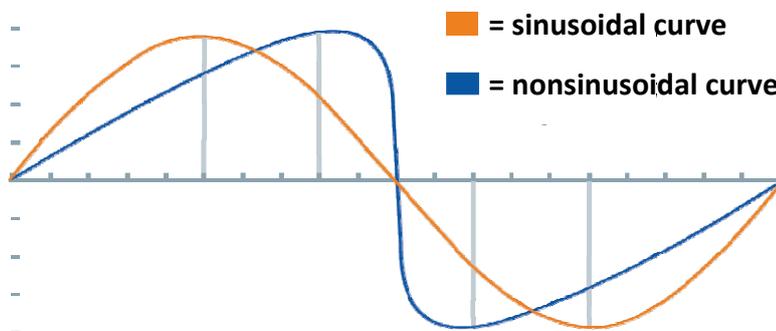


Figure 5. Change of mold motion speed for sinusoidal and nonsinusoidal hunting conditions

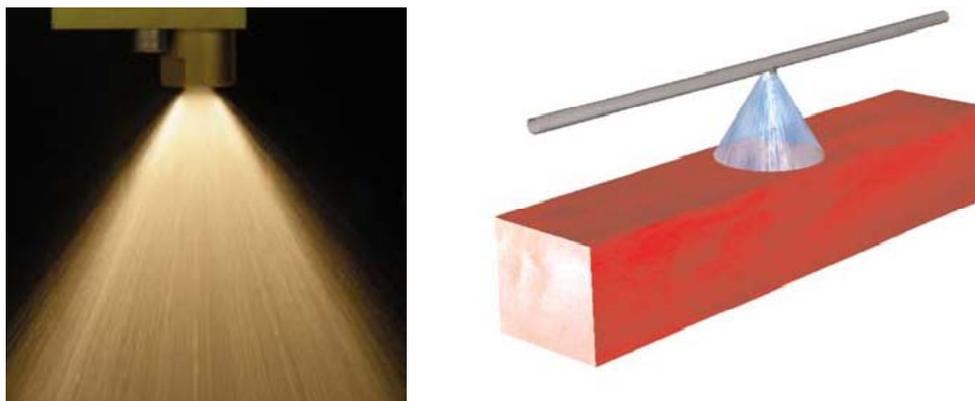


Figure 6. Photo of spray water (left) and lay-out of sprayer in relation to billet surface

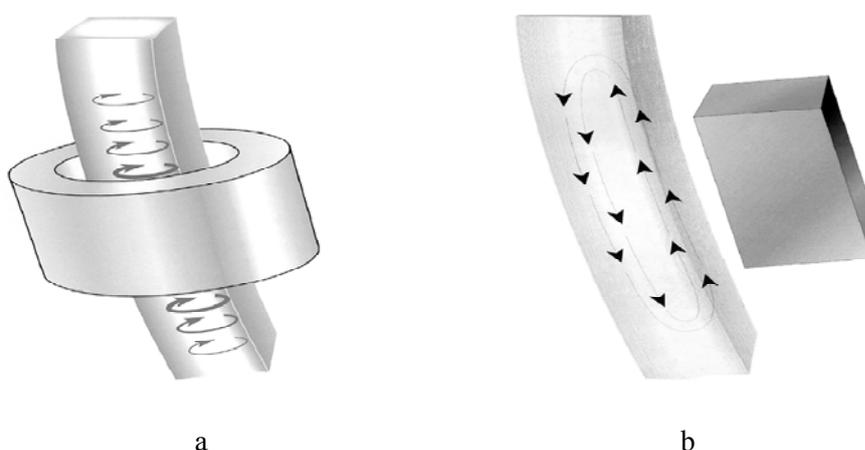


Figure 7. Patterns of superposition of electromagnetic agitation with rotating (a) and linear field (b) for a billet

“Soft reduction” method of continuous cast billet in the presence of 30-50 % liquid phase has been widely used for elimination of axial porosity and liquation for last 10-15 years [10].

Possibilities of soft reduction for liquation decrease in the axial zone of billet are limited by sinterskin ability to elongate solid-liquid interphase boundary. As heavy loading on the sinterskin in the zone of solidification front leads to formation of internal defects, value of separate stages of strain should not exceed the maximum value. It is possible to enhance effect of "soft" reduction by means of optimization of geometrical shape of mold chamber [11].

One of effective methods to improve quality of continuous cast billet is electromagnetic circulation of melted steel [12]. As a result, quality of subsurface and axial zone of continuous cast billets improves thanks to effect on crystal

structure formation, migration of nonmetallic inclusions, chemical segregation and distribution of gases. Stators with rotary and linear fields are used in practice (**Figure 7**). The basic electric parameters of electromagnetic circulation units vary in the wide range depending on their construction and billet cross-section.

Electromagnetic circulation provides treatment of surface and subsurface layers of continuous cast billet. Electromagnetic circulation in continuous casting mold ensures formation of upward currents along the solidification front or steel rotation in a horizontal plane. When open jet casting, rotating magnetic field in the mold creates a deep metal meniscus with nonmetallic inclusions concentrated in the bottom. These inclusions rotate at the smaller rate than molten steel. As a result, density of nonmetallic inclusions in the ingot decreases significantly.

Conclusions

1. The world billet market is developing in the line of severization of billet quality requirements on macro and micro level.

2. The majority of billet manufacturers prefer direct production of light gauge billets on high-speed continuous-casting machines.

3. Conditions for billet manufacture in high unit size aggregates are created.

4. Further improvement of continuous cast billet quality will be achieved due to application of methods protecting steel from secondary oxidizing.

In the nearest 10-15 years it should be expected that advance in billet continuous casting will be achieved on the basis of traditional solutions and constructions of continuous-casting machines due to technological modifications and increase of machine operation automation level.

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Современные сортовые МНЛЗ: перспективы развития технологии и оборудования

Смирнов А.Н., Подкорытов А.Л.

Представлен анализ тенденций развития технологии и оборудования для непрерывного литья сортовой заготовки.