APPLICATION OF PHYSICAL MODELLING FOR OPTIMISATION OF FLOWING AT ASSYMETRIC TUNDISH OF CCM

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POUŽITÍ FYZIKÁLNÍHO MODELOVÁNÍ PŘI OPTIMALIZACI PROUDĚNÍ V ASYMETRICKÉ MEZIPÁNVI PLYNULÉHO ODLÉVÁNÍ OCELI

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Abstrakt

V tomto článku jsou uvedeny výsledky dosažené během optimalizace proudění roztavené oceli v mezipánvi čtyřproudého sochorového kontilití v závodě TŘINECKÉ ŽELEZÁRNY, a.s. Experimentální výzkum byl proveden metodou fyzikálního modelování na modelu mezipánve vyrobené v měřítku 1:3. Celkem bylo modelováno 27 variant vnitřního uspořádání mezipánve. Tento článek také předkládá výsledky výzkumu vzniku výtokového víru v oblasti nad výtokovým otvorem osazeným kalibrovanými výlevkami.

Abstract

This article presents the results achieved during optimisation of molten steel flow in the tundish of four-strand billet caster in TŽ, a.s. Experimental research was made by method of physical modelling on the model of tundish produced on the scale 1:3. We have tested altogether 27 versions of tundish inner configuration. This article presents also the results of investigation into origination of the outflow vortices in the field of the flowing-out sector of tundish at application of the s.-c. calibrated teeming nozzles.

One of the basic tundish functions is distribution of steel among individual strands, which should be ensured in such a way, that the physical properties of steel in all strands would be the same. Steel in the individual strands should have the same temperature, chemical composition and purity from the point of view of nonmetallic inclusions and the same dynamic behaviour. The approach to this state is greatly dependent on the characteristics of molten steel flow in tundish.

1. Requirements for molten steel flow in tundish

We need to know how long certain elements of molten steel stay in the tundish so that we could assess the character of steel flow. This time is usually called residence time. The average theoretical residence time of steel in the tundish is defined as a ratio of the steel volume in tundish and the steel flow rate from the tundish. The steel flow in the tundish is usually connected with dissipation of residence times, because some elements of molten steel stay in tundish longer or shorter than average residence time.

The hypothetical model [1,2] is often used for more detailed analysis of steel flow in the tundish and this model divides the total volume into so-called mixed volume, volume with plug flow and dead volume.

The mixed volume of tundish is closely connected with its inflow part, in which the kinetic energy of pouring flow from the ladle ensures intensive mixing of steel. This mixed volume is connected to the area of steel flowing by so-called plug flow. The characteristic feature of plug flow [3] is uniform flow of liquid steel during which no element foreruns the other elements. In the area of plug flow the steel flow has already the laminar character and so there are better conditions for the rise of inclusions here.

There are also areas in the tundish with the very slow flow of steel. These areas represent so-called dead volume of tundish. Dead volume is defined [3] as the area where the liquid steel stays in tundish longer than the double of the average residence time. Existence of dead volume can substantially decrease the active volume of tundish and so reduce the residence times of steel in the tundish. In the area of dead volumes also exists the greatest danger of local solidification of steel. This is the reason for minimising the dead volume in tundish.

Very adverse character of the flow in tundish is so-called short-circuit flow, when the coming steel practically immediately gets into the outlet of tundish, which is undesirable with regard to steel purity and thermal homogeneity of cast steel in individual strands.

From the above-mentioned we can see, that it is generally needed to optimize the character of the steel flow in the tundish. With the given outer shape of tundish it is possible to optimise by adjustments of the inner arrangement e.g. by installation of different elements (dams, weirs, baffles). Relatively simple are cases of symmetric tundishes in which steel moving from the ladle shroud to the nozzles must travel approximately the same distance on both sides. The more complicated cases are asymmetric tundishes with asymmetric location of inflow place in regard to individual nozzles. Among asymmetric tundishes belong also our five-strand tundish of CCM No. 1 and four-strand end-filling tundish used in double in CCM No.2 in Třinecké železárny, a.s.

The question of steel flow optimisation in five-strand tundish was solved earlier and the results were successfully implemented to practice [4,8].

2. Operational state before optimisation and the aim of our work

The necessity of steel flow optimisation in tundish of CCM No.2 was caused by increased occurrence of breakouts in individual strands, especially in strands No.6 and No.5. There was also increased number of breakouts in casting strand No.8 in some periods. We have assumed that one of the possible causes of this unfavourable state is unsteady steel flow in tundish, the possible occurrence of short-circuit flow and dead areas.

The aim of the performed experimental study was in the first phase to assess and evaluate the character of steel flow in tundish corresponding to the usual operational conditions of CCM No. 2 in TŽ, a.s. On the basis of these results we have then suggested new inner arrangement of tundish, which would lead to more steady character of steel flow, which in the operational conditions would decrease the number of breakouts in the above mentioned strands.

We have used the method of cold isothermal modelling for the steel flow simulation in tundish. This method has substantially lower costs than operational tests and also enables us to try several variants of tundish arrangement without influencing the technological process.

The model of tundish is made from Plexiglas with the maximal precision of dimensions on the scale 1:3 in relation to the operational tundish "B" (casting strands No.5 - No.8). We have used Froude criterion as in previous works [4 - 8] together with information from literal sources for the preservation of the dynamic similarity in the relation model - original and so we have calculated the total flow from the ladle into tundish - 14,9 $l.min^{-1}$. The flow of the liquid was regulated by spherical valves and measured by precise induction flow meter.

The steel flow visualisation in model was made by injection of tracers (solution of permanganate and potassium chloride) to ladle shroud. The dispersion of contrast tracer was scanned by camcorder. On the basis of acquired video recording was made the evaluation of flow character, orientation of lines of flow, speed of flow and dead volumes and also areas with short-circuit flow. For the objective evaluation of residence times we have used the method of measuring changes of conductivity of liquid in critical points of tundish (ladle shroud, nozzles) after injecting KCl solution. The conductivity is measured by the conductivity probes and the acquired data are then interpreted by specialised software for PC.

3. Results of flow study in tundish model

During the experimental study of steel flow optimisation in tundish we have tested 27 variants of its inner arrangement. We have used different shapes of dams put intentionally in different places of tundish. We have also tested different transition states as e.g. flow with the ladle shroud elevated above steel level in tundish or only partially submerged. In regard to relatively extensive scope of experiments we will mention only the most important versions which were later tested in real conditions of CCM No.2.

<u>The basic case (ZP)</u> which uses the most often used operational arrangement of tundish, which was originally used for CCM No. 2. There is an inclined impact pad under the ladle shroud in the tundish and between the ladle shroud and nozzle No.5 low stepping dam is placed, which should prevent the short-circuit flow to this nozzle - see Fig.1.

Fig.1 Flow field in tundish under original version (ZP)

During modelling we have find out, that the flow of contrast liquid divided itself into two separate flows after the fall on the impact pad and headed in the horizontal direction. One of these two flows follows the back wall of tundish and the other flows by short-circuit flow directly to the nozzle No.6. We have also found out, that the stepping dam between the nozzle No.5 and ladle shroud is too low, the liquid flows above it and so the residence time of nozzle No.5 is shortened.

With regard to considerable unsteadiness of residence times this version is absolutely unacceptable for operational application. The existence of short-circuit flow and dead volumes in the real operational conditions can lead to the unsteady temperatures of steel cast in individual casting strands and so lead to the increase of the breakout danger.

On the basis of tests for the whole range of versions we have suggested the version B11 - see Fig.2. Broken dam was located in front of nozzle No.6 and stepping dam between ladle shroud (impact pad) and nozzle No.5 was supplanted by stepping dam with larger dimensions. The substantial effect of this suggested baffle is redirection and at the same time acceleration of the fluid flow along the tundish back wall towards the nozzles No.7 and No.8. However, we could observe interesting phenomenon under operational condition in the time when the ladle shroud is lifted above steel level (e.g. before the ladle exchange). In this period the outflow from the nozzle No. 5 was quite unsettled and in some cases it even started to spray and splash, which sometimes lead to breakouts in this casting strand.

Fig.2 Flow field in tundish under B11 version

The final solution of this problem we have found in version B17 - see Fig.3. The large compact dam that is reaching up to the steel level in tundish is placed between ladle shroud and nozzle No.5.

The used compact dam fully inhibits the direct flow to the nozzle No.5 and so the outflow from the nozzle is already settled. The flow of contrast tracer moves along the tundish back wall and between nozzles No. 6 and No. 7 it turns to the tundish front wall. The flow divides itself into two flows with the same intensity before this wall and the contrast tracer disperses in the same way as in the symmetric tundish, i.e. from the area between nozzles No.6 and No.7 it moves steadily to the nozzles No.5 and No.8 (Fig.3). The flow of liquid in this version is very favourable and it is not disturbed even when the ladle shroud is above the fluid level.

The suggested version is presently used in both tundishes of billet caster. The present results show, that the introduction of this version increased the stability of these casting strands during casting and at the same time the number of breakouts in individual strands was decreased.

Fig.3 Flow field in tundish under final version B17

4. Results of vortex formation study in tundish model

In the frame of the experimental work attention has been paid to the modelling research into the design of the flowing-out sector of tundish (i.e. the proper transition to the calibrated teeming nozzles on origination of an outflow vortex above the teeming nozzles and so even the possible way of entraining particles both from the bath surface at the tundish (e.g. the covering slags) into the teeming nozzles and from the proper volume of steel at the tundish. The critical height of bath at the tundish has been evaluated for various arrangements of the flowing-out sector.

For the modelling research into origination and stability of the outflow vortex a new method was proposed and applied consisting in visual evaluation of the feature of flowing in the zone of the flowing-out sector of tundish (above the teeming nozzles). The procedure taken consisted in injection of a contrast substance into zone above the teeming nozzle and visual examination of spreading the substance taken by a video record. There has been found that in case of origination of a vortex the contrast substance is relatively quickly entrained to the discharging hole with simultaneous rotation round an imaginary axis passing through the centre of the teeming nozzle. The powder-like perlit was batched to the bath surface in order to simulate the drawing in of phenomenon of particles from the bath surface at the tundish.

More than 50 experiments have been carried out in the just-cited route, whereby we got out from the variant of internal arrangement of tundish as-proposed earlier and marked B17. Any change in that internal arrangement would affect more or less the behaviour of bath above the flowing-out sectors and origination and/or the stability of the vortices. Thus, the conclusions should refer to the internal arrangement only corresponding with the B17-variant.

The model experiments showed the origination of a vortex outflow to pass through certain analogous stages. To get an objective description and further evaluation the following classification steps were attributed to the individual stages:

The illustrative appearance of unstable and stable vortex with a hollow core is shown in Fig.4.

Fig.4 Photos characterizing an unstable vortex and a stable vortex with visible hollow core

The model experiments have been carried out with four modifications of the flowing-out sector of the tundish that were mutually different due to their interior angle of the conical part above the teeming nozzle. The basic workmanship (commonly used under full-scale conditions) has the characteristic interior angle of 45°. The narro-wer workmanship and the narrow arrangement of the flowing-out sector are characterised by the angles of 35° and 25°. The fourth (and the last) broken workmanship is characterised by two angles - the bottom angle of 20° and the top angle of 75°.

In case of common teeming nozzle the flowing feature has been examined with a drop in bath level, namely from a value corresponding to the weight in actual tundish (16t) down practically to complete emptying of tundish. As the outflow vortex did not occur in the range of recommended working weights (6tons at least), our attention was focussed at even lower bath levels at which teeming can be carried out exceptionally. The experiments were run with bath levels of 94, 60, 50, 40, 30 and 20 mm referring to steel weights in actual tundish of 6 t, 3,8 t, 3,2 t, 2,5 t, 1,9 t and 1,26 t, respectively.

The modelling research was aimed especially at a condition with continuous refilling the bath in tundish by steel inflow from the teeming ladle. This condition encounters under full-scale teeming at replacement of the teeming ladle and/or at the beginning of feeding from the teeming ladle into tundish with a reduced liquid-steel level. This period is most deleterious from the viewpoint of origination of the outflow vortex.

Under such modelling conditions the presumption was confir-med about the effect of position of the flowing-out sector in tundish on origination of a vortex [9]. The vortex was found to occur, with bath level drop in tundish, above the No.5 teeming nozzle (LP5) at first and then, above the No.8 nozzle (LP8) due most probably to intensive tangential flowing in this zone. On the other hand no occurrence of vortex was evidenced in the zone above the No.6 and No.7 teeming nozzles (LP6 and LP7). The most probable reason for missing the vortex here would be relatively strong radial flowing in the zone above these nozzles that eliminates the tendency to origination of vortex even at relatively low bath levels in tundish. On the basis of such results our attention was focussed on the behaviour of steel bath above the nos.5 and 8 teeming nozzles that are potentially more liable to origination of vortex.

In case of modelling the basic arrangement of the flowing-out sector (45°) the stable vortex above No.5 teeming nozzle was found with bath level in model of tundish lower than 40 mm (2,5 tons). With a higher bath level a slight up to intensive rotation above the teeming nozzle was followed, while, with a level of 20 mm (1,26 t), no stable outflow vortex with a hollow core penetrating even to the proper teeming nozzle has encountered.

In case of No.8 teeming nozzle a stable vortex was not found until at lower bath level, say 30 mm with 1,9 t. This quiet behaviour, if compared with the No.5 teeming nozzle, is pro-bably to be attributed to a lesser intensity of tangential flowing round the flowing-out sector.

Quite different situation encountered with application of narrow arrangement of the flowing-out sector (25°). Origination of vortex was seen already with bath level of 50 mm (3,2 t). It was namely an unstable vortex, however, with a slight drop in bath level it changed over into quite a stable vortex with hollow core. Thus, in case of modification of the flowing-out sector there can be said as follows: The smaller angle of the flowing-out sector, the more is initiated the vortex with higher bath levels in the tundish. Origination of vortex above the broken arrangement, of the flowing-out sector did not practically differ from the basic arrangement, however, with a low bath level (say 20 mm and 1,26 t) no intensive initiation of vortex with a hollow core was found here. The relevant behaviour of the steel bath, expressed by means of classification stages, is shown in relation with the bath level in Fig.5.

For the sake of completed information on origination of vortex when tundish is no more refilled (replacement of the teeming ladle, end of sequence casting) another series of examination were carried out. It was found in such case the vortices to encounter in the last period of emptying the tundish i.e. with bath levels below 20 mm (1,26 t). It is obvious that such situation would be more favourable from the viewpoint of possible origination of the outflow vortex.

In case of origination of an outflow vortex the spiral flowing would probably entrain the particles of covering slag from the bath surface; these slag particles would be then injected down into the liquid core of a blank and so to impair the final microcleanness of steel. This problem is rather serious in case of absence of an outflow vortex when non-metallic inclusions can be entrained from the room between tundish bottom and bath surface down into tee-ming nozles by means of rotary flowing; otherwise such inclusions would have floated out to the bath level and would be further absorbed by liquid slag.

5. Conclusion

The experimental study of steel flow optimisation for the four-strand asymmetric tundish used in the Třinecké železárny, a.s. was made by method of physical modelling. The suggested version of model study is presently used in both tundishes of billet caster. The results show, that the introduction of this version increased the stability of these casting strands during casting and at the same time the number of break-outs in individual strands was decreased.

The modelling research of origination of outflow vortex at the outlets of tundish resulted among others to the fact that origination of vortex depends markedly on the position of the flowing-out sector in tundish, on the interior angle of the flowing-out sector and on the height of bath level in tundish.

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Literature

[1] Heaslip, L.J., McLean, A. : In.Continuous casting,Vol I,Warrendale, ISS of AIME, 1983, s.93-97

[2] Sahai, Y., Ahuja, R. : Fluid flow and mixing of melt in steelmaking tundishes. Ironmaking and steelmaking, 13,1986, č.5, s.241-247

[3] Levenspiel, O. : Chemical reaction engineering, 2 edn,1972, New York, Wiley

[4] Michálek, K., Plura, J., Klimek, K., Benda, M. : Proudění ocelové lázně v mezipánvi zařízení plynulého odlévání oceli. Hutnické listy, 1992, č.3, s.18-25

[5] Michálek, K., Bůžek, Z., Pindor, J. : Význam optimalizace proudění lázně v mezipánvi a zvyšování jakosti plynule odlévané oceli její filtrací. Hutnické listy, 1995, č. 7-8, s. 24-29.

[6] Michálek, K., Plura, J., Irmler, B., Klimek, K.: Možnosti zvyšování kvality plynule odlévané oceli ovlivňováním proudění lázně v krystalizátoru. Hutnické listy, 1995, č.9, s.17-21.

[7] Michálek, K., Bůžek, Z., Pindor, J., Cieslar, M., Bednarz, V. : Zvyšování kvality plynule odlévané oceli dmýcháním argonu dnem mezipánve v Třineckých železárnách. Hutnické listy, 1997, č.1, s.14-19.

[8] Pindor, J., Michálek, K., Cieslar, M., Bednarz, V : Application of tundish metallurgy for increasing continuously cast steel quality. In. 5th. International Clean Steel Conference, Balatonfüred, 1997,vol.2, s.11-17.

[9] Andrzejewski, P., Diener, A., Pluschkell, W.: Model investigation of slag flow during last stages of ladle teeming. steel research, 58, 1987, No.12, p.547-552