MODELING AND SIMULATING OF REAL PROCESSES ON A STEEL MAKING PLANT: MOULD LEVEL CONTROL OF A CONTINUOUS CASTING MACHINE CASE[1]

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Abstract

This paper describes evidences of the importance of modeling and simulating real processes on a steel making plant and shows a real case of modeling, performed on 2007, by developing and simulating a complete model of a real mould level control system of a continuous casting plant. This work was motivated by excessive fluctuation occurrences on the casting machine Nº3 of ArcelorMittal Tubarão-Brazil. The model obtained considers the non-linearities present inside real process and the representation of some of the most important effects inherent to this process that affects the control system. The study considers: the procedures for obtaining a reliable model (by means of mathematical construction and identification), the validation of the final process model obtained and demonstrates some of the advantages of using a complete model simulation for the real process control tuning or modification in industry.

Key words: Continuous casting; Process modeling; Mold level control; Disturbances estimation.

MODELAGEM E SIMULAÇÃO DE PROCESSOS REAIS NA SIDERURGIA: MELHORIA EM SISTEMA DE CONTROLE DE NÍVEL DO MOLDE – ESTUDO DE CASO

Resumo

Este documento tem como objetivo descrever evidências da importância da modelagem e simulação de processos reais em um ambiente siderúrgico e apresenta um caso real de modelagem, realizado em 2007, consistindo no desenvolvimento e simulação de um modelo completo de um sistema real de controle de nível de molde de uma planta de Lingotamento Contínuo. Este trabalho foi motivado por diversas ocorrências de oscilações na medição do nível do molde da máquina de lingotamento Nº3 da ArcelorMittal Tubarão. O modelo obtido considera as não linearidades presentes dentro do processo real e a representação de alguns dos mais importantes efeitos inerentes ao processo, que afetam o sistema de controle. O estudo considera: os procedimentos para a obtenção de um modelo confiável (por meios de concepção matemática e identificação), a validação do modelo de processo obtido e a demonstração de algumas das vantagens do uso de um modelo completo simulado para realização de um ajuste otimizado e/ou modificações no controle de processos na indústria.

Palavras-chave: Lingotamento contínuo; Modelagem de processos; Controle de nível de molde; Estimativa de distúrbios.

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1 INTRODUTION

This paper aims to show the importance of obtaining the mathematical representation of real processes inside industry, especially for process involved inside steelmaking factories where the bad adjustment of control systems means great costs and, many times, operation/human safety reduction.

This work is concentrated inside continuous casting process, which is responsible for transforming steel in its liquid state in slabs of predetermined width, thickness, surface and mechanical properties defined by known existing standards meaning that, deviations in mechanical dimensions/surface, internal defects and non-metallic material inclusions are undesired effects on the slab that affects directly the quality of subsequent rolling processes.

Mold level control is one of the most important process control issues on a continuous casting plant and it is directly related to the final surface quality of the produced slabs, as informed above. For this importance, the mould level process and the disturbances present on it have been an object of many scientific studies,(1-3) process identification and specific control strategies proposed for reducing these disturbances(4) by many control specialists around the world, since the beginning of Continuous Casting Machines operation.

On this paper the complete modeling of the Mould Level Control System of Casting Machine #3 of ArcelorMittal Tubarão Plant, located in Serra-ES will be shown. This modeling work was motivated by several mould level fluctuations occurrences after the startup of machine on July/2007 and the final model was used to the study and modifications on the mould level control system, responsible to the quality improve obtained.

2 METHOD FOR PROCESS AND DISTURBANCES MODELING

The first step to be considered for modeling the entire system (process and control) was to identify and to represent the physical process of steel flow inside the mold. After identification of all elements and their contribution to the process, the control system and related equipments such as sensors, hydraulics and actuator must also be represented mathematically. At last, the disturbances present on the mold surface can be determined and the entire system can be evaluated in order to use the obtained model to adjust and modify the original control system, obtaining at the end the maximum disturbances reduction.

2.1. Mold Level Basic Process

At this moment we can foresee that, to achieve a model involving all elements of the control loop (and disturbances of the process to be examined), we need to develop the mathematical relationships involved in the process and apply proper techniques for identification, that means: modeling through of experiments.

Initially, as mentioned and according the Figure 1, we consider in a stable situation of process, the amount of steel that enters the mold must be the same as leaving it at the same time so that the "H" level of the mold is kept constant.

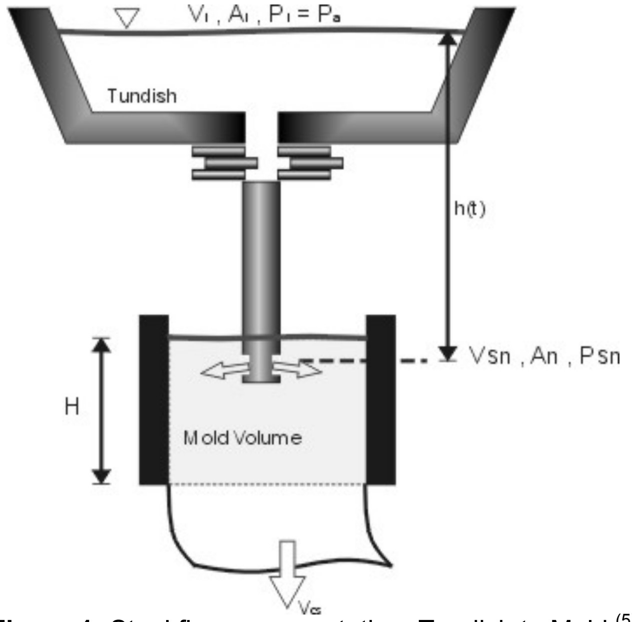


Figure 1- Steel flow representation: Tundish to Mold.(5)

On Figure 1, we can certainly consider that the area of the slide gate A_s (effective for steel passage), can replace the value of submerged nozzle area An and so therefore the speed of steel inside slide gate (V_n) should replace the value of the same of the submerged valve (Vsn). If molten steel can be considerable incompressible the mold level flow inside mold can be understood as:

$$\Delta Q = \left(dH \big/ dt \right) = \frac{1}{A_m} . \left[A_s . V_n - A_m . V_{cs} \right] \qquad (1)$$

Observing the equation (1), the opening value of the slide gate will proceed the expected compensation to replace the amount of steel inside the mold, and then we have to consider it as the manipulated variable of the control system. In order to discover the value of V_n, we must consider the steel as a viscous fluid and incompressible, allowing us to use Bernoulli's equation(5) and after few considerations, as done in Yoo(6) results on:

$$V_n = \sqrt{2.g.h} \qquad (2)$$

Possessing the Value of V_n of equation 2, it is necessary to determine the effective area of the slide gate, which will control the liquid steel flow to the mold (A_s).

2.2 Slide Gate Area Modeling

The slide gate unit is a device consisting of three overlapping plates that have a identical hole in each one of these plates, where the central one is provided with horizontal movement (Xsg). The amount of steel flow is given by the intersection area of the holes, as shown in Figure 2.

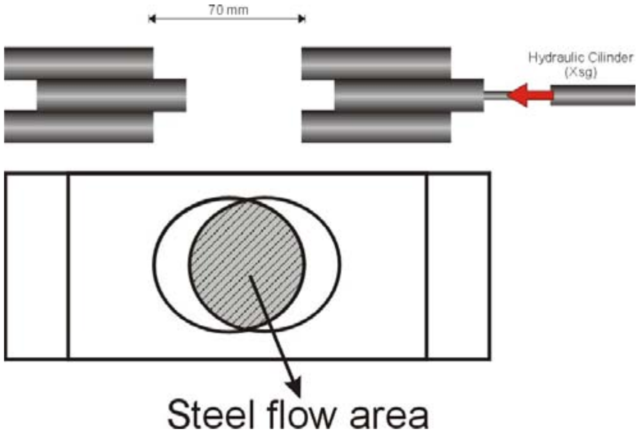


Figure 2- Slide Gate representation.

Through the movement of central the plate, controlled and monitored by the control system (by specific PLC), the steel flow area A_s can be modified. For the model construction, a relation between the central plate position (X_{SG}) and steel flow area (A_s) must be clear.

The area As of equation 1 can be described as twice the area formed by a string of points of intersection between the holes of top, bottom and center plates, as showed in different shades of gray in Figure 3. These points are function of the horizontal displacement of the slide gate (represented by X_{SG}).

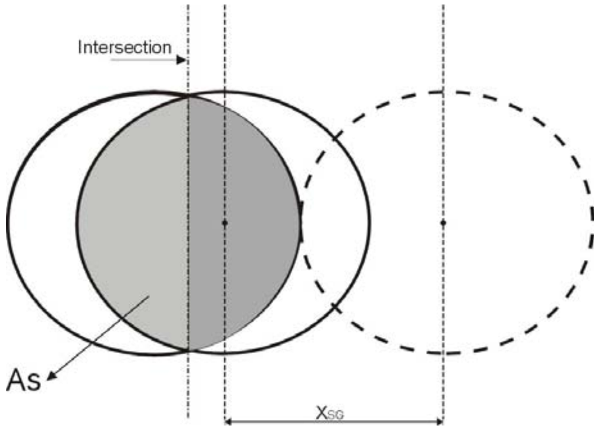


Figure 3 – Intersection area of slide gate

The Figure 4 can represent more clearly the distances to be considered for the calculation of half the area formed by the rope that crosses the common points of overlapping circles (dark grey area of Figure 3).

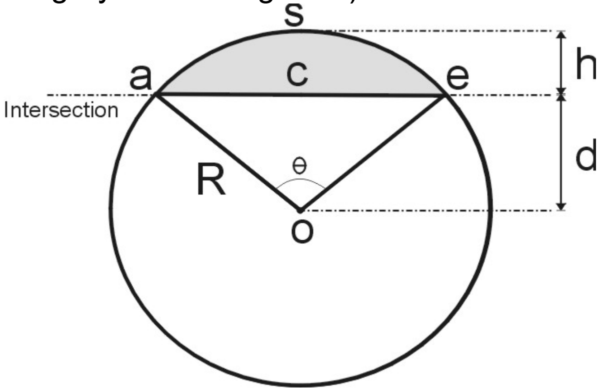


Figure 4 – ½ slide gate area intersection

By the correct geometric relations(7) and considering $h = \frac{X_{SG}}{2}$ we calculate the A_s final value as:

$$A_s = 2.\left[R^2.\cos^{-1}\left(\frac{R - \frac{Xsg}{2}}{R} \right) + \left(R - \frac{Xsg}{2} \right).2.\sqrt{R/Xsg - \left(\frac{Xsg}{2} \right)^2} \right] \qquad (3)$$

2.3 Basic Mold Level Control Loop

The equation above is indispensable to our objective of simulating the mold level real process and, calculating steel flow area according to the displacement of the plate central (X_{SG}), we can return to the equation 1 in frequency domain:

$$H = \frac{1}{A_m.S}.\left[A_s.\sqrt{2.g.h} - A_m.V_{cs} \right] \qquad (4)$$

Observing the equation 4 and the Figure 5 bellow, we can now consider a basic block diagram for the mold level control system, in closed loop. The Figure 5 exposes a typical control loop for our application and shows blocks for main controller (*controller PLC*), slide gate control, area calculation equation and mold level sensor.

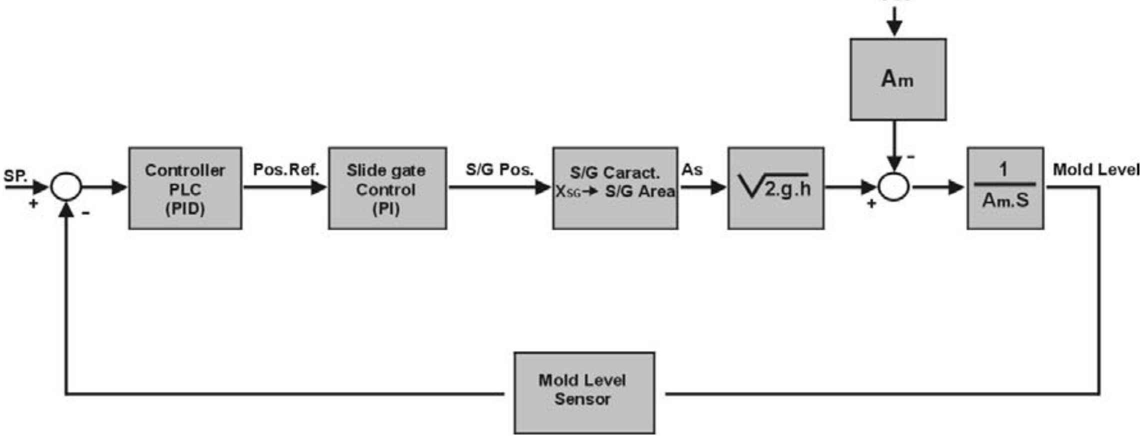


Figure 5 – Basic Block Diagram for Mold Level model.

2.4 Identification of Remaining Blocks

As we know, there is not a easy way to perform modeling of electronic or hydraulic devices(8) through mathematical procedures. On this paper for obtaining the *Slide Gate Control* and the *Mold Level Sensor* blocks it was used identification procedures(9) to represent it properly.

The *Slide gate control (PI)* block of Figure 5 is a basic block diagram consisted of a controller card (electronic), controlled by a proper PLC device, and the hydraulic circuit responsible for the movement of real Slide gate. The real position of Slide gate is measured by a specific sensor (magnetic type), measured by the same PLC.

In Figure 6 we see clearly the blocks components of the system's "Slide gate control"- now referred as the "slave control loop" of the mold level control. This blocks substitute the "Slide gate control" one of the Figure 5.

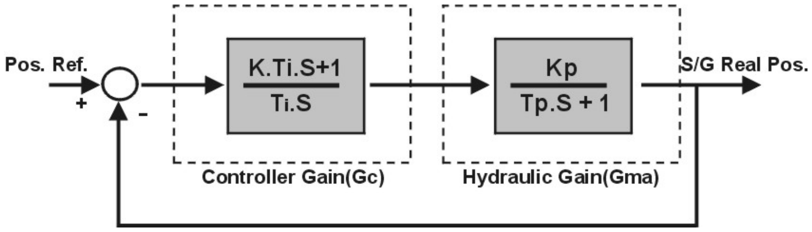


Figure 6 - block diagram of the slide gate position.

By applying a step in closed loop, and using a computational resource to obtain the model (data collected with sampling of 10 ms), we can get the values in closed loop, represented by the transfer function of the first order:

$$G_{cl} = \frac{K_{cl}.e^{-\theta S}}{\tau.S+1} \qquad (5)$$

It was made several step inputs in the position control system of the slide gate valve and it was obtained as result the τ, θ and K_{cl} values of the 1st order transfer function in closed loop of equation 5. Knowing the closed loop gain values and the controller gain values (G_c, extracted from PLC), we also know that we can extract the open loop gains showed on figure 6 by the relation:

$$G_{cl} = \frac{G_c.G_{ma}}{1+G_c.G_{ma}} \qquad (6)$$

The identification curve that compares real process of slide gate moving and model is shown in Figure 7. The simulated results differs less than 3% of the real process curve.

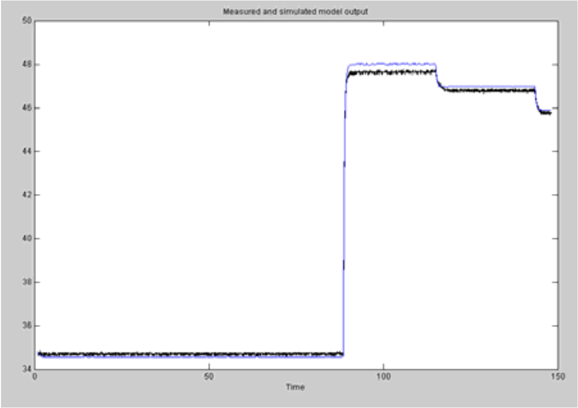


Figure 7 – Test and identification result (dark line) of the slide gate position control loop.

For the last block, a similar identification procedure was performed considering the same first order model as the equation 5. A proper defined step and trigger were performed in order to obtain the time constant (τ), delay (θ) and sensor gain (K) for the mold level sensor representation.

2.5 Basic Mold Level Model Validation

The complete model, as showed on the pictures 5 and 6, obtained up to now can show us a reliable model of a mold level control process of the real casting machine, it means, a pure process, without any disturbances inherent to this kind of process.
For validation of the model obtained, we must consider 2 real situations for a good comparison with a real casting machine:
Situation 1 - startup
During the event of starting the casting process, the slide gate valve is positioned in a fixed and pre-determined position (in this case, opening of 16.12 mm - 55.1%) and after level reaching about 48.2 mm, automatic-level began. Through these conditions, the filling time of the mold must be the same for real and simulated situation until the Slide Gate is passed on to automatic control. Thus, we got:
- Time actual filling process: 8.25 s
- Time simulated filling: 8.20 s

Figure 8 shows the comparison between the real machine and simulated on Mathematical Software, considering on both same mold dimensions and tundish level, respecting equation 4, and through this we can see the similarity of the curves behavior of mold level for this situation.

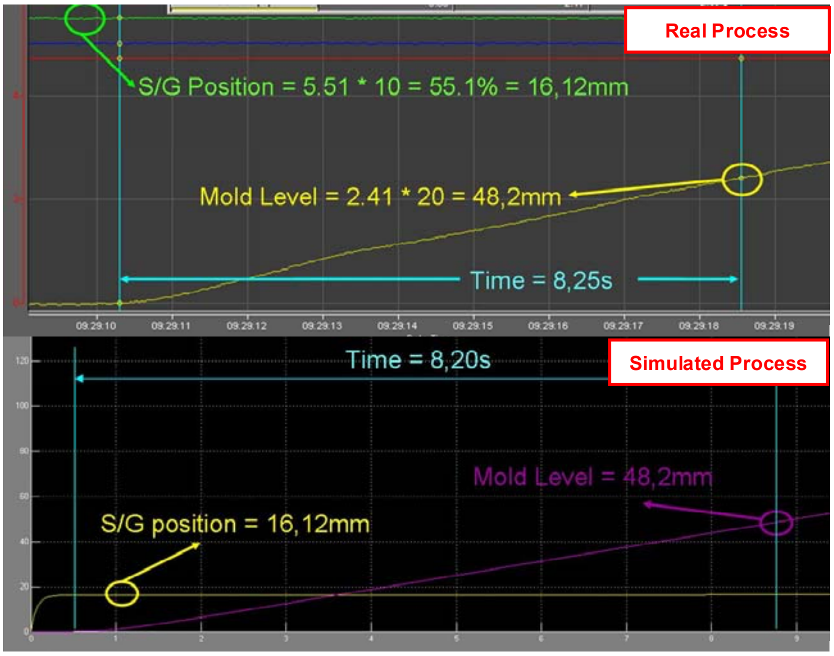
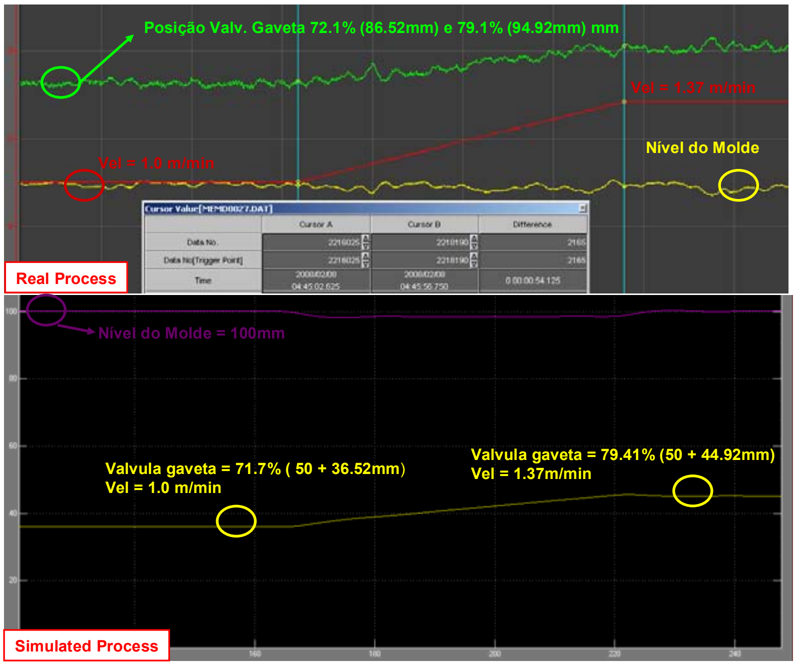


Figure 8 – Comparison of real process (up) and simulated model (down)

Situation 2 – speed change

We need now prove the effectiveness of the model for other real situation: changes in casting speed, changing the conditions of extracting the mold of steel and feeding steel to the mold, as equation 4.
As done on situation 1, same conditions of real process were established on the model, considering a casting speed change from 1.0 m/min to 1.37 m/min. The speed change times on this test were:
- Time for speed change completion on real process: 54.12s
- Time for speed change completion on simulated process: 55.0s

The Figure 9 compares the real plant under the conditions mentioned above and the simulated situation, where can be seen that the slide gate opening change on the model was similar to the real process in exacts 55 s, when speed was changed in the same proportions of real casting.



Cursor Value[MEMD0027.DAT]

	Cursor A	Cursor B	Difference
Data No.	2216025	2218190	2165
Data No[Trigger Point]	2216025	2218190	2165
Time	2008/02/08 04:45:02.625	2008/02/08 04:45:56.750	0:00:00:54.125

Figure 9 - Comparison of real process (up) and simulated model (down)

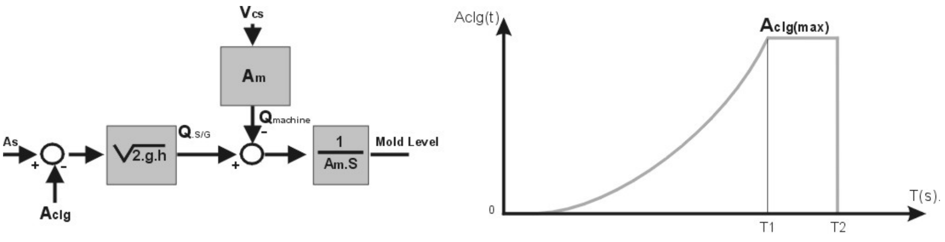
We confirm so far the mathematical representation obtained by modeling the system in a real situation fully controlled, without the consideration of disturbances outside the control system and special features in the actual plant of continuous casting.

2.6 Simulation of Disturbances

In a mold level control loop of a real continuous casting machine, there are known a series of undesirable effects (10), inherent to the process of slabs production, that affect directly and indirectly the stable regime of steel level on the mold surface and have to be interpreted as disturbances to be controlled / reduced by our control system. Some of these effects were responsible for the fluctuations mentioned on this paper and were mathematically represented on the model obtained to allow the complete study and real machine control System adjustment for fluctuations reduction.

Argon Influence: The amplitude of the Argon interference on mold level signal detected by sensor measuring is proportional to the gas flow inserted inside the submerged valve and this influence has a stochastic behavior. In terms of frequency this phenomena is detected inside window of 0.4 through 0.8Hz. For simulation and adjustment of the controller, a original signal from argon was filtered and inserted on the obtained mold level control model.

Clogging effect: For the simulation of the clogging effect identified in our process, it must be considered reducing the effective passage of steel inside the submerged valve(11) by a determined quadratic function, considering at the end the same effect of the real process. Figure 10a indicates the point of inclusion of simulated effect of clogging in the block diagram of our system. The figure 10b shows the behavior expected of the function to simulate the effect clogging. Figure 11 shows the simulated effect on the model obtained.



a) b)

Figure 10 – Simulation proposal for clogging effect function.

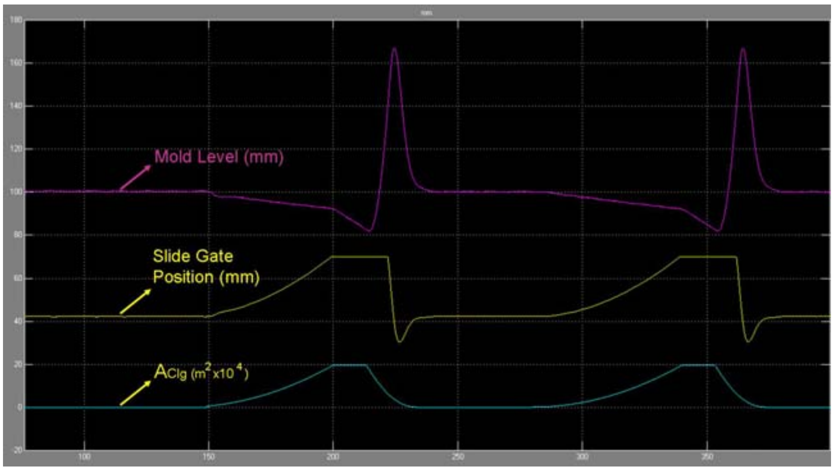


Figure 11- Clogging effect simulation

Bulging effect: This phenomenon is one of the most challenges on mold level control system designers up today and the periodical disturbance caused by it was the most responsible for mold level fluctuation experienced on the real casting machine analyzed. As mentioned by Furtmueller and del Re,(12) "The strand solidifies from outside to inside downward the strand. due to increasing pressure inside the strand bulging occurs between rolls".

This effect and the extent of this phenomenon is mainly related to the cooling capacity, machine project and steel grade casted. To represent this effect on simulation it was included specific wave generation signal, with frequency dependent of roll spacing D and amplitude A, similar to found on real process:

$$F_{bu\lg}(m^3) = A.\cos(2.\pi.f_{Osc}.t) \qquad (7)$$

On Figure 12 is showed the inclusion of the generated bulging signal on the achieved process model and on Figure 13 the result of simulated bulging effect, with 2 bulging frequencies combined, compared to the real process on the effect presence.

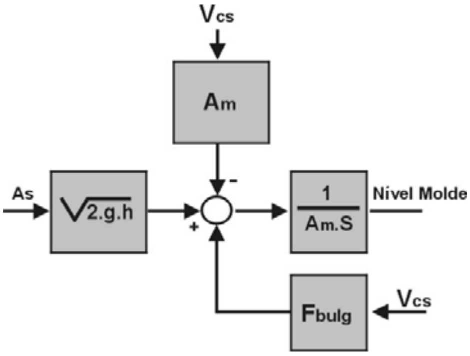


Figure 12 – Inclusion point for equation 7 on the simulated model.

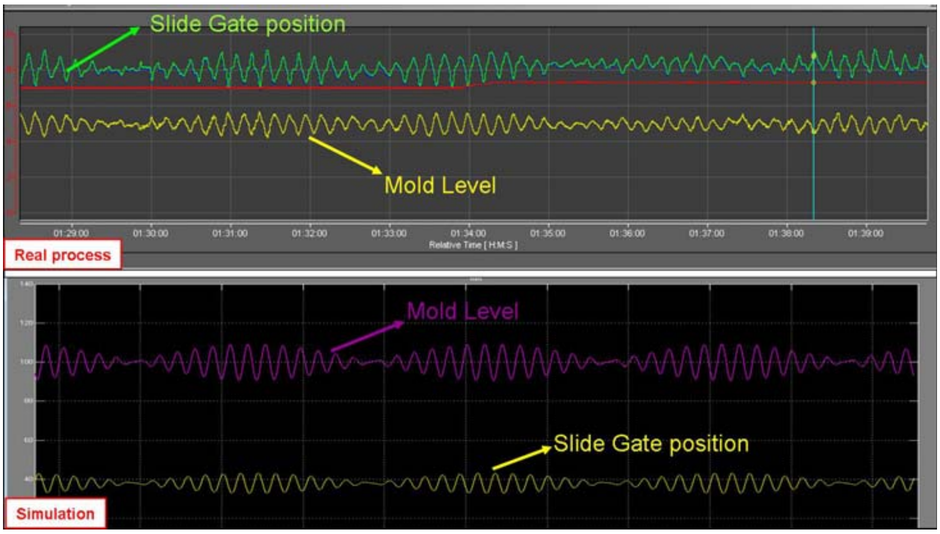


Figure 13 – Simulation of bulging effect

3 RESULTS

The final process (including disturbances) model obtained, as showed on this paper, was used to perform a severe adjustment on the mold level control system of the real Casting Machine analyzed, including actions as: controller adjustments according amplitude and frequency response signals, development of new solution to bulging effect reduction, design of new filter for specific oscillations and other proper actions on the system and process.

The modifications mentioned above were performed from Dec/2007 through Oct/2008 and resulted in a substantial increase of general performance for this system. One of the performance indexes monitored by the production team is the percentage of the sequence casting time that the mould level deviation value remains between +-3mm. On figure 14 a box plot graphic shows the performance evolution of this index on the worst casting production case (low carbon steel grade, 200mm thickness).

On Figure 15 there is a comparison between similar castings on the mold level control view, before and after the modifications performed on control system. This figure evidences that by reducing the fluctuations, casting operation can be better controlled, increasing production team confidence and maintaining faster and regular casting speeds.

Other important performance index is the rate of slabs produced witch had mold level fluctuations above +- 10mm of the setpoint deviation. The evolution of this performance index from 2007 castings up to the end of 2008 is shown in Figure 16.

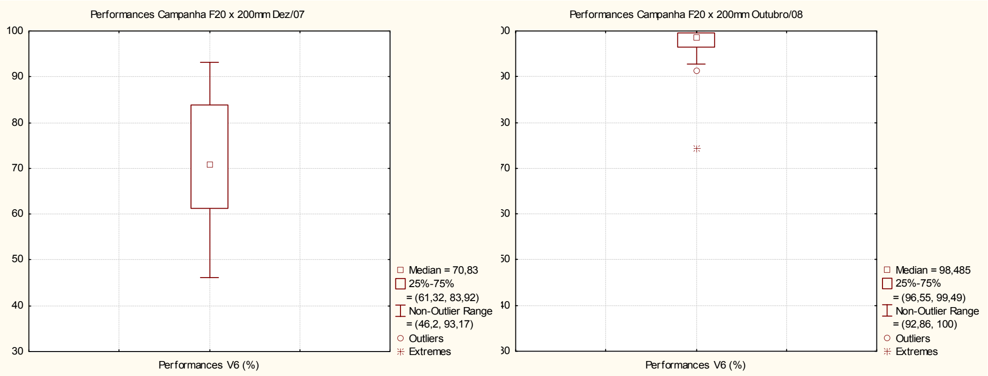


Figure 14 – Performance índex of deviation: before the system adjustment (left) and after (right)

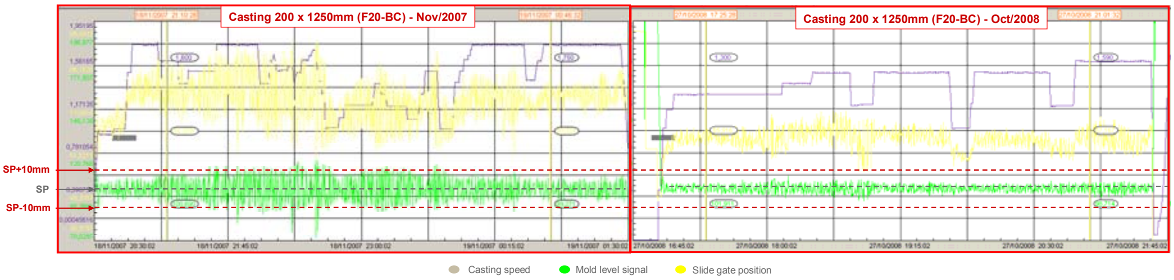


Figure 15 – Mold level control behavior: before the system adjustment (left) and after (right)

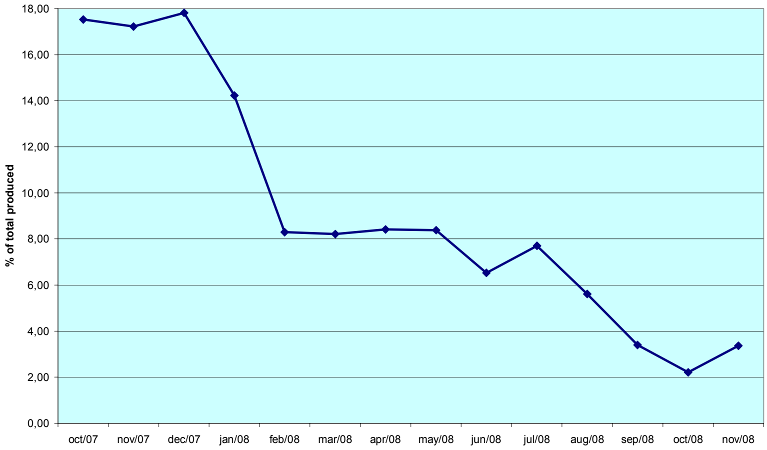


Figure 16 – Quality events occurrence (% of total slabs produced) on casting production

4 CONCLUSION

This paper showed a specific case of modeling and simulating a real industrial process and make it clear the benefits of this kind of work for process adjustments, production increases, costs reduction, equipment diagnosis and human/process safety.

The importance of developing real solutions for controlling the mold level providing maximum mold level fluctuation reduction in presence of the common disturbances of this kind of process is nowadays one of the most persuaded objective of steelmaking

and control specialists around the world, responsible for a increasing number of technical papers regarding this subject.
On the steel industry, normally a high competitive sector, the process identification and simulation can mean a real competitive differential.

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