

# Optimal control of the blowing mode parameters during basic oxygen furnace steelmaking process

<https://doi.org/10.31713/MCIT.2021.30>

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**Abstract** — The oxygen converter is intended for production of steel from liquid cast iron and steel scrap at blowing by oxygen. Nowadays, Basic Oxygen Furnace process is the main method for steelmaking. The main disadvantage of the basic oxygen furnace is the limited ability to increase the part of scrap metal. The task of the proposed approach is to control of the blowing mode parameters to establish the optimal level of CO<sub>2</sub> that will ensure a minimum specific cost of steel in the presence of restrictions and boundary conditions of basic oxygen furnace steelmaking process. A model predictive control taking into account the constraints on the input signals and the quadratic functional is proposed. The design of Model Predictive Control is based on mathematical model of an object. This approach minimizes the cost function that characterizes the quality of the process. The result of the automatic control system modeling shows that the Model Predictive Control approach provides retention of carbon dioxide level when oxygen consumption is changing. The obtained quadratic functional is optimized to find the optimal control of blowing parameters.

**Keywords** — Model Predictive Control; Basic Oxygen Furnace; blowing parameters; Linear-Quadratic Functional; Optimal Control; state space model.

## I. INTRODUCTION

Basic Oxygen Furnace (BOF) is intended for production of steel from liquid cast iron and steel scrap at blowing by oxygen. Today, the production of steel by BOF is the most popular in the world and become more widespread. According to statistics, the part of the BOF in the world is 71.6% as of the end of 2019 (70.8% as of 2018) [1]. In recent years relevant methods of reducing the cost of oxygen-converter steel are the using of the design capacity of the units, increasing the stability, optimization and automation of the process.

The main disadvantage of the BOF is the limited ability to increase the part of scrap metal in melting. For steel production, the unit is loaded with scrap metal with a share of up to 30% of the metal part, the rest is liquid cast iron, which is much more expensive. Nowadays there are several ways to increase the proportion of scrap in the charge: preheating of scrap metal outside the converter and afterburning of monoxide to carbon dioxide in the cavity of the converter [2]. The gases leaving the converter mainly consist of CO, so an

effective method is to burn CO to CO<sub>2</sub>, as it does not require additional equipment, and to achieve the desired performance it is enough to control the parameters of the blowing mode, such as lance position and oxygen consumption.

## II. AIM AND OBJECTIVES OF CONTROL

Given the focus of enterprises on profit maximization, the general criterion of quality is the unit cost of steel of a specific brand. The task of the proposed approach is to control the parameters of the blowing mode (Fig. 1) to establish the optimal level of CO<sub>2</sub>, which will provide the minimum specific cost of steel in the presence of limitations and boundary conditions of the oxygen-converter smelting process.

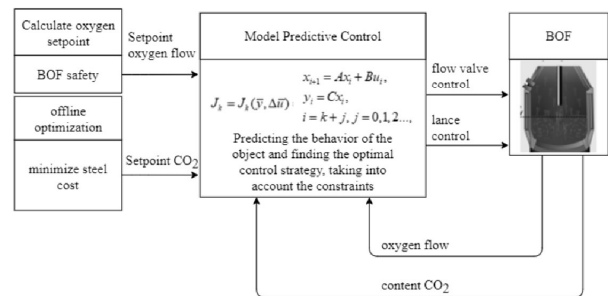


Figure 1. Block diagram of control systems with closed loop

Other embodiments (Fig. 2) of the classical systems for controlling the parameters of the purge mode during the main process of steel production in the oxygen furnace are open loop systems, i.e., do not take into account the current state of the system.

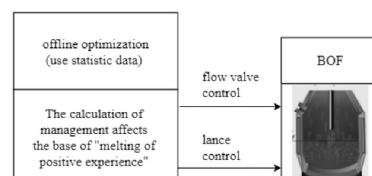


Figure 2. Block diagram of control systems with open loop

Control of CO<sub>2</sub> level in BOF gases requires the usage of modern control methods and relevant to model-predictive control. It is established that with a certain

chemical composition of cast iron the thermal mode of the process depends on the rate of decarburization, the degree of combustion of CO to CO<sub>2</sub> and the amount of iron oxides in the slag, which, in turn, depend on the distance of the lance to the quiet bath level [2].

III. CONTROLLER DESIGN AND SYSTEM MODELLING

The control problem is the non-stationary process of decarburization. The process of decarburization is described by a first order inertial model, the gain and time constant of which depends on the melting period and the duration of the purge. Control object (1) "lance position change – the level of CO<sub>2</sub>" is described by the differential equation:

$$T_{v_c} T_{\gamma_{CO_2}} \frac{d^2 \gamma_{CO_2}}{dt^2} + (T_{v_c} + T_{\gamma_{CO_2}}) \frac{d \gamma_{CO_2}}{dt} + \gamma_{CO_2} = k_{\gamma_{CO_2}}^H H, \quad (1)$$

where  $\gamma_{CO_2}$  (%) – the level of CO<sub>2</sub>;  $H(m)$  – lance position;  $T_{v_c}, T_{\gamma_{CO_2}}$  (s) – time constant;  $k_{\gamma_{CO_2}}^H$  ( $\frac{\%}{m}$ ) – gain.

Model-predictive control is based on mathematical methods of optimization using predictive models. The approach uses a mathematical model of the object, the initial conditions for which is its current state. With a given control, the forecast of the object's motion is performed at some finite period of time (forecast horizon). Control optimization is performed, the purpose of which is to approximate the control variables of the forecasting model to the corresponding setpoint on the forecast horizon. The optimal control is realized and measurement (or restoration on the measured variables) of an actual condition of object at the end of a step is carried out. Starting from the next step, the forecast and search for optimal control are repeated for the new object conditions [3]. Model-predictive control is reduced to the usual proportional feedback on the state of the object, which is not fundamentally different from the LQ-optimal controller. But the situation changes significantly, given the limitations on the control effect and the state of the object, which significantly limits the set of regulators in the problem of LQ-optimization. Obtaining an accurate optimal solution in real time is quite problematic, which significantly increases the validity of the MPC-strategy. The main advantage of the MPC approach, which determines its successful usage in the practice of design and operation of control systems, is the relative simplicity of the basic feedback scheme combined with high adaptive properties.

The design of MPC controller with constraints was performed using the Matlab MPC Designer package [4]. The design of the MPC controller (Fig. 3.) used the mathematical model of the oxygen converter process (Fig. 4).

The figure 5 show the transients of the control system, in the simulation of the task for oxygen consumption set 300m<sup>3</sup> / min, the initial setpoint for CO<sub>2</sub> level – 10%, for 50 seconds of the blowing mode setpoint is set at 15%.

The obtained transients of the system of automatic control of the oxygen-converter process using MPC-strategy provide the requirements for the quality of the system.

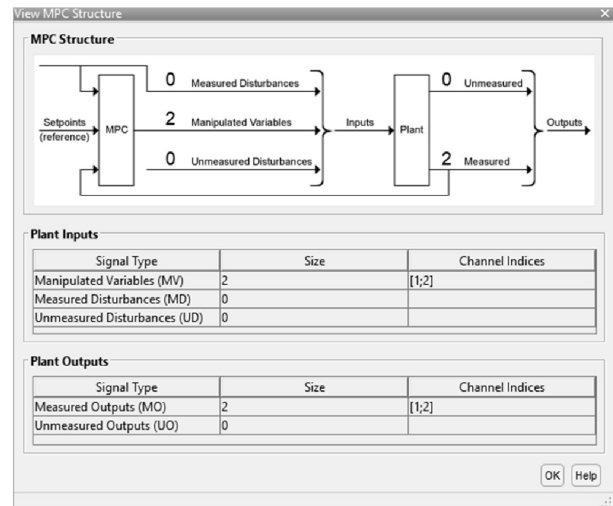


Figure 3. MPC controller structure

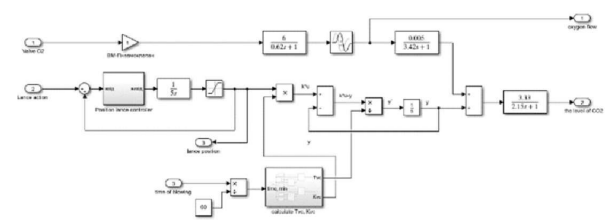


Figure 4. Model of the blowing mode parameters

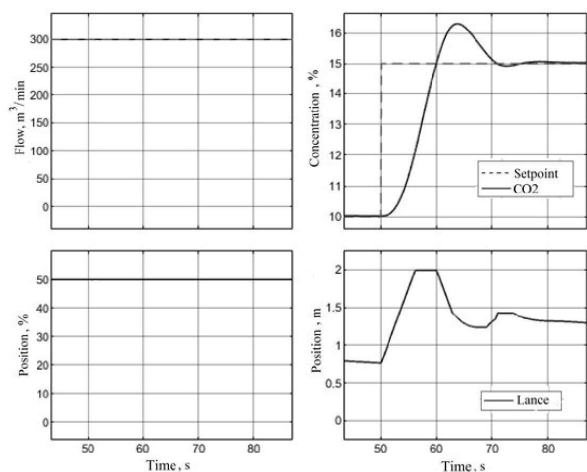


Figure 5. Transient processes of the automatic control system

IV. CONCLUSION

The problems of control CO<sub>2</sub> concentration in the convector cavity include non-stationarity, so the usage of classical control methods is difficult. The MPC approach minimizes the cost function that characterizes the quality of the process. The obtained functional is optimized to find the optimal control of the carbon oxidation level. As a result of application of the offered approach, in comparison with smelts of gross production, the following results are expected: increase in processing of scrap to 5%, resistance of lining to 3%, decrease in duration of a purge to 5%, increase in weight of the smelted suitable steel to 0.5%. In general, the proposed approach allows to reduce the specific cost of steel to 0.5%.

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