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# CONTROL OF SPEED OF TURBOEXHAUSTERS FOR AGGLOMERATION BELT

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**Abstract:** In this contribution we want to present algorithms for control of speed of turbo-exhausters for agglomeration belt. We will give relations for the computation of required and real quantities of the waste gas exhausted in individual chambers of agglomeration belt and incremental control algorithms for speed of turbo-exhausters. The mathematical models and algorithms are derived from basic models of physical and chemical processes of agglomeration belt and they are based on directly and indirectly measured quantities of agglomeration belt.

**Key words:** mathematical model, indirect measurement, control.

## 1 Introduction

For most blast furnaces sinter is a basic metallic charge, and significantly influences the blast furnace process [Brož 1988]. Mechanical and metallurgical properties of the sinter depend on its composition and on the sintering process [Majerčák et al. 1986]. As all metallurgical production, the sintering production is high in energy consumption too and has serious environmental consequences [Malindžák et al. 1997, Koštial et al. 2000, Leššo 2001]. Optimisation of the sintering process is oriented mainly toward sinter quality enhancement and fuel economy improvement. For the complex study of the sintering process mathematical model was developed [Koštial et al. 2001] which includes processes in ignition furnace and sintering strand. Optimal ignition and sintering conditions were determined by simulation. Results were used for the design of new ignition furnace and for new organisation of the suction process and for the development of adequate control strategy. The model was utilised also for the design of a new turbo-exhausters operating speed control and monitoring system.

Transformation of the sintering material into sinter takes place on the sintering strand (Fig.1). The main components of the sintering strand are the ignition furnace, sintering belt, and exhausting system. The sintering material creates a bed on the sintering belt and consists of metallic burden (concentrate, crushed ore), slag (mainly limestone), coke and water (moisture). The sintering process starts by the ignition of the upper surface of the sintering bed with the ignition furnace and the process continues up to the bottom and end of the sintering bed. The sinter is then discharged on the cooling conveyor and is transported into the blast furnace bunkers.

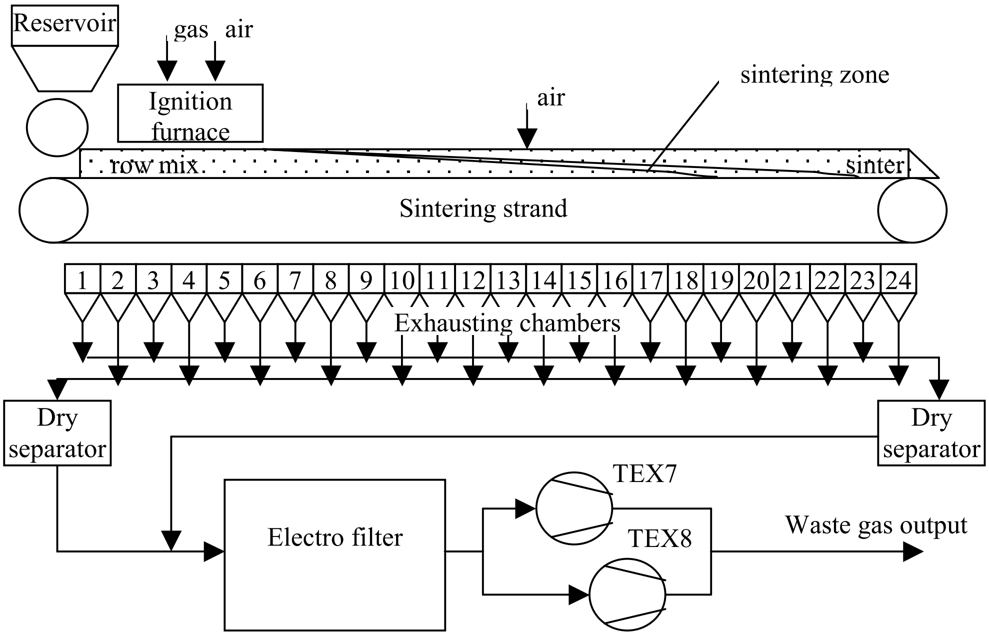

Figure 1. Sinter plant scheme

Sintering is three-stage process consisting of preheating, sintering, and cooling. The preheating process consists of moisture evaporation, carbonates dissociation ($CaCO_3$, $MgCO_3$, $FeCO_3$), and enthalpy increasing. The sintering process includes heat generation by coke combustion, melting, and chemical reactions. The cooling period includes sinter solidification, sinter cooling, and sintering air preheating.

## 2 Sintering plant control

The sintering process is essentially influenced through the sintering temperature and sintering time. The sintering temperature and sintering time depends on the coke content and moisture in the sintering charge and on the exhausting intensity throughout the length of sintering belt. The sintering plant control systems are designed with the objective to maximise sinter quality and fuel economy. The principal control functions are sintering temperature determination, coke content determination, preheating control, ignition control, sintering belt speed control, and exhaustion control.

## 3 Exhaustion control

Turbo-exhausters provide the waste gas exhausting from the exhausting chambers through the electro-filter (Fig. 1). The real quantity of the exhausting gases depends on the operating speed of the turbo-exhausters and on the parameters of the sintering process. The block scheme of the turbo-exhausters control is in Fig. 2.

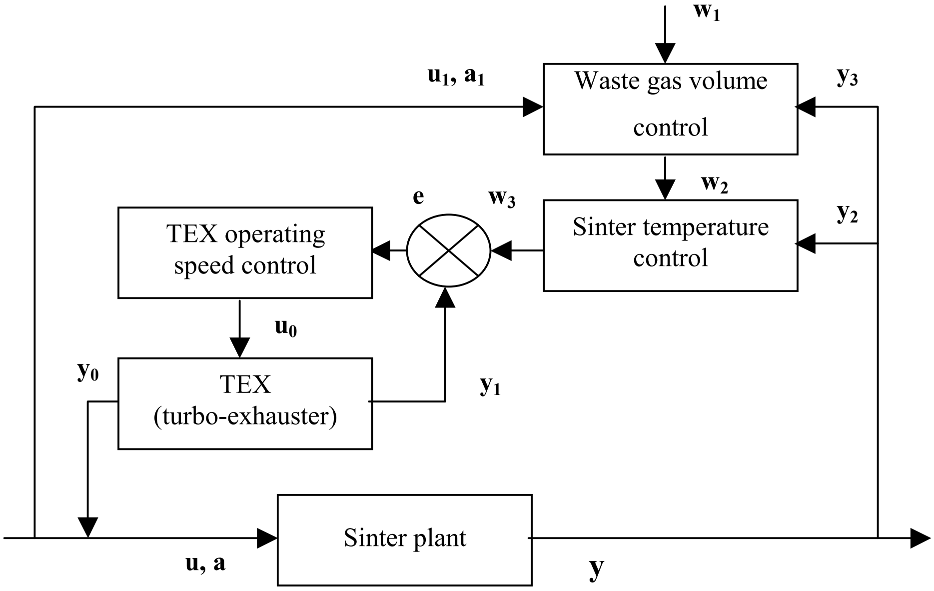

Figure 2. Control block scheme

Correct control of the turbo-exhausters operating speed is difficult without control system. The main goal of the exhausting control system is the desired quantity ($\mathbf{w}_2$) of the exhausting gas determination from the directly measured data and desired and real process parameters ($\mathbf{w}_1$, $\mathbf{u}_1$, $\mathbf{a}_1$, $\mathbf{y}_2$, $\mathbf{y}_3$) and then the determination of the desired turbo-exhausters operating speed ($\mathbf{w}_3$). The composition of these vectors is as follows : $\mathbf{w}_1=[x_w, W_{\%FeO}]$, $\mathbf{w}_2=[V_w]$, $\mathbf{w}_3=[n_w]$, $\mathbf{u}_1=[s, V_{CG}, V_{BG}, G_{sinter}]$ , $\mathbf{y}_2=[T_{22}, T_{23}, T_{24}]$ , $\mathbf{y}_3=[T_1, T_{12}, T_{15}, T_{16}, T_{17}, T_{18}, T_{19}, p_1, p_{12}, p_{15}, p_{16}, p_{17}, p_{18}, p_{19}]$, $\mathbf{a}_1$ includes percentage components of row mix (e.g. $H_2O$, FeO, $Fe_2O_3$, carbonates and coke), where

- $x_w$ is the desired position of the point of maximal waste gas temperature [m],
- $W_{\%FeO}$ is the desired percentage of the FeO in output sinter [%],
- $V_w$ is the desired quantity of the exhausting gas [$m^3$/sec],
- $n_w$ is the desired turbo-exhausters operating speed [r.p.m],
- $s$ is the real sintering belt speed [m/sec],
- $V_{CG}$ is the measured volume of the coke-oven gas [$m^3$/sec],
- $V_{BG}$ is the measured volume of the blast-furnace gas [$m^3$/sec],

- $G_{sinter}$ is the real quantity of the row sintering material [kg/sec],
- $T_{22}$, $T_{23}$, $T_{24}$ are the measured temperatures of waste gas in last three chambers [$^{o}$C],
- $T_i$ are the temperatures of waste gas in chambers 1,12,15,16,17,18,19 [$^{o}$C],
- $p_i$ are the pressures of waste gas in chambers 1,12,15,16,17,18,19 [kPa].

The calculation of the desired quantity of the exhausting waste gas $V_w$ is based on the calculation of the waste gas volume from the ignition furnace and from the remaining part of the sintering strand. The determination of the waste gas volume from the ignition furnace consists of the next steps:

- Minimal volume dry air for coke-oven gas calculation $V_{Air\_min\_CG} = f_1(H_{CG})$,
- Air surplus calculation $m_{CG} = V_{Air\_CG}/V_{CG}/V_{min\_CG}$,
- Air real volume for coke-oven gas calculation $V_{Air\_CG} = m_{CG}.V_{Air\_min\_CG}$,
- Waste gas real volume for coke-oven gas calculation $V_{WG\_CG} = V_{Air\_CG} + f_2(H_{CG})$,
- Minimal volume dry air for blast-furnace gas calculation $V_{Air\_min\_BG} = f_3(H_{BG})$,
- Air surplus calculation $m_{BG} = V_{Air\_BG}/V_{BG}/V_{min\_BG}$,
- Air real volume for blast-furnace gas calculation $V_{Air\_BG} = m_{BG}.V_{Air\_min\_BG}$,
- Waste gas real volume for blast-furnace gas calculation $V_{WG\_BG} = V_{Air\_BG} + f_4(H_{BG})$,
- Summary volume waste gas of ignition furnace $V_{WG\_IF} = V_{WG\_CG}.V_{BG} + V_{WG\_BG}.V_{\_BG}$

The minimal volume of dry air of coke-oven gas or of blast-furnace gas are calculated as approximate functions $f_1(H_{CG}) = 0{,}2568.10^{-3}H_{CG} - 0{,}25$, $f_3(H_{BG}) = 0{,}1911.10^{-3}H_{BG}$ and waste gas real volume $f_2(H_{CG}) = 0{,}68 + a.(H_{CG}.10^{-3} - 16{,}744)$, $f_4(H_{BG}) = 0{,}0311.10^{-3}H_{BG}$, where a = 0.0239 for caloric value $H_{CG}<16500$ [kJ.m$^{-3}$], and a = 0.0143 for caloric value $H_{CG} \geq 16500$ [kJ.m$^{-3}$].

The determination of the waste gas from sintering strand consists of the next steps :

- Quantity of carbon calculation $Q_C= W_C Q_{RM}/100$,
- Oxygen quantity calc. for carbon combustion to $CO_2$ $Q_{O2\_CO2}= Q_C K_{CO2} 2A_O/A_C$,
- Oxygen quantity calc. for carbon combustion to CO $Q_{O2\_CO}=Q_C (1-K_{CO2})*A_O/A_C$,
- Quantity of organics sulphur calculation $Q_{Sorg}= W_S Q_{RM}/100$,
- Quantity of sulphur in FeS calculation $Q_{S\_FeS}=(A_S/(A_{Fe}+A_S))W_{FeS}Q_{RM}/100$,
- Summary quantity of sulphur calculation $Q_S=\eta_S(Q_{Sorg} + Q_{S\_FeS})$,
- Oxygen for combustion sulphur to $SO_2$ calculation $Q_{O2\_SO2}=Q_S 2A_O 2/A_{S,}$
- Quantity of FeS in raw mix calculation $Q_{FeS}=W_{FeS}Q_{RM}/100$,
- Oxygen for oxidation Fe from FeS calculation $Q_{O2\_FeS}=\eta_S Q_{FeS} A_{Fe}/(A_{Fe}+A_S)3A_O/(2A_{Fe})$,
- Difference FeO in sinter and raw mix calculation $Q_{dFeO}=(FeO_w - W_{FeO}Ratio_{rawmix\_sinter})$,
- Oxygen for oxidation FeO or reduction $Fe_2O_3$ calc $Q_{O2ox\_red}=((2A_O)/(4(A_{Fe}+A_O)))\ Q_{dFeO}$
- Summary oxygen quantity calc. $Q_{SumO2}=(Q_{O2\_CO2}+Q_{O2\_CO}+Q_{O2\_SO2}+Q_{O2\_FeS}-Q_{O2ox\_red})m$,
- Summary oxygen volume calculation $V_{SumO2} = Q_{SumO2}V_{mol}/(2A_O)$,
- Summary nitrogen volume calculation $V_{SumN2} = V_{SumO2}79/21$
- Summary air volume calculation $V_{Air} = V_{SumO2} + V_{SumN2}$
- Quantity of material volatile calculation $Q_V = W_V Q_{RM}/100$
- Material volatile volume calculation $V_V = Q_V V_{mol}/A_O$
- Nitrogen volume calculation $V_{mO2} = V_{Air}0.21(m - 1)$
- Moisture volume calculation $V_{H2O}:=W_{H2O}Q_{RM}/100V_{mol}/(2A_H+A_O)$
- SO2 volume calculation $V_{SO2} = Q_S\ V_{mol}/A_S$
- SO3 volume calculation $V_{SO3} = \eta_{SO3}W_{SO3}Q_{RM}/100V_{mol}/(Ah_S+3A_O)$;

- CO2 volume from combustion carbon calculation $V_{CO2} = Q_C K_{CO2} V_{mol}/A_C$
- CO volume from combustion carbon calculation $V_{CO} = Q_C (1 - K_{CO2}) V_{mol}/A_C$
- CO2 quantity from carbonate calculation

$$Q_{CO2\_MeCO3}=Q_{RM}(Ah_C+2Ah_O)/100$$
$$(W_{CaCO3}/(A_{Ca}+A_C+3A_O)+W_{MgCO3}/(A_{Ca}+A_C+3A_O)),$$

- CO2 volume from carbonate calculation

$$V_{CO2\_MeCO3}=Q_{CO2\_MeCO3}.V_{mol}/(A_C+2A_O),$$

- Summary waste gas volume calculation $V_{WG\_RM} = V_{SumN2} + V_V + V_{mO2} + V_{H2O} + V_{SO2} + V_{SO3} + V_{CO2} + V_{CO} + V_{CO2\_MeCO3}$.

Summary waste gas volume from ignition furnace and from raw mix. calculation

$$V^w_{Sum} = V_{WG\_IF} + V_{WG\_RM} \qquad [m^3/sec]$$

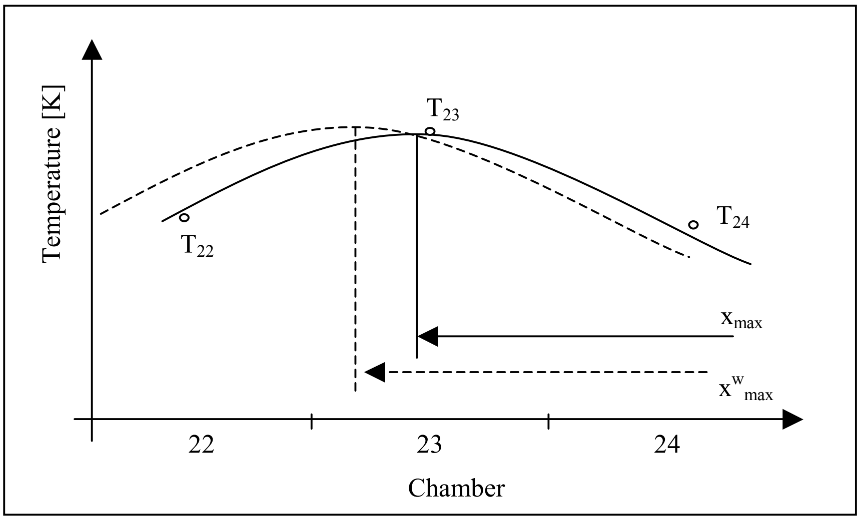

Figure 3. Fire-through temperature control

The calculated desired waste gas exhausting volume for turboexhausters is corrected according to difference of the positions of real and desired point of maximal waste gas temperature. The standard position of this point is in the centre of the 23th chamber, in some cases in the 22 th or 24th chamber. The real position of this point (Fig. 3) we can identify from the parabolic approximation of the measured temperatures in last three chambers :

$$T(x) = a_2 \mathrm{x}^2 + a_1 \mathrm{x} + a_0 \tag{1}$$

From this parabolic approximation we can also compute the difference betwen real and desired position the point of maximal waste gas temperature

$$e_x = x_{\max} - \mathrm{x}^w_{\max} \tag{2}$$

and then we determine the correction of desired waste gas exhausting volume

$$V_{Sum}^{w} = V_{Sum}^{w}(1 + e_x /(x_{belt} - \mathrm{x}_{\max}^{w})) \tag{3}$$

There are several methods for the turbo-exhausters operating speed determination from the desired waste gas exhausting volume. If the dependency of the waste gas exhausting volume on the turbo-exhausters operating speed is known as a function V = f(n,p), then we can compute the desired turbo-exhausters operating speed simply from the inverse function. In the case of unknown dependency computation go out from the direct proportion between real and desired exhausting volume and real and desired turbo-exhausters operating speed ($n_w / V_w = n / V$), thus the desired operating speed

$$n_w = n(1 + e_V / V) = n(1 + (V_{Sum}^{w} - V) / V) \tag{4}$$

executes the TEX operating speed control.

## 4 Conclusion

Presented control system of the turbo-exhausters operating speed is feedforward - feedback type. This structure enables dynamic reaction on some input disturbances. The control system has adequate behaviour on changes in sintering belt speed, coke content, position of the point of maximal waste gas temperature and so on. After successful implementation the control system is now under acceptance run.

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