Modelling and simulation of processes from an iron ore sintering plants

Corina Maria Diniş
Politechnica University Timişoara
ROMANIA

1. Introduction

Restructuring of metallurgical industry is strongly influenced by the modernization of manufacturing processes from the sintering plants. Sintering, as physical-chemical process of iron ores preparation and obtaining of a controlled situation, is of maximum importance because the resulted agglomerate allows the obtaining of quality cast-irons as they are required currently on the market. The current technology of cast-iron making imposes more and more rigorous conditions to the quality of the charge that should allow the optimization of the entire process, increasing the productivity and reducing the coke consumption.

In this respect, the major cast-iron producing countries are using iron ores previously prepared as agglomerate, meant to ensure the achievement of some charges with high iron content and homogeneous from chemical and grading viewpoint. From the processes with special influence on preparation, will be analyze: dosing, sintering and cooling (fig.1).

Dosing flow includes the quantitative dosing of the charge components, their pre-homogenization into the primary mixing drum (TAP) and the conveying flow of the mixture/blend from the dosing station into the main body to the charge bunker of the sintering machine. Materials extraction from the dosing station's bunkers and their further dosing is achieved by means of dozers with extracting belt. These are mounted in the bunker's entry and they extract the material from the bunker at the flow required by the charge recipe. The mixture, which is formed in accordance with the calculated recipe, is collected by the conveyor belts and transported to the TAP primary mixing station. During the process, to the dosed mixture is added further the hot return brought by the metallic belts to the return bunker (Diniş et al., 2008)

From the TAP, which has an inclination of $2 - 3^0$, the charge mixture is overflowed on the conveyors and the transport is continued on other two conveyor belts towards the main section of the sintering plant from the charge bunker. The above description shows that the conveying process contains a multitude of working machines and is undergoing based on a complex algorithm, being suitable for organization into a hierarchical structure an a software-oriented control. The analyzed belt conveyor system in this work contains the following main elements: a main belt, a collector belt and two working belts. On the two working belts are delivered: the hot return from the return bunker (BRET) and the limestone, coke and iron ores from BKCM bunker (Aguilar et al., 2008).
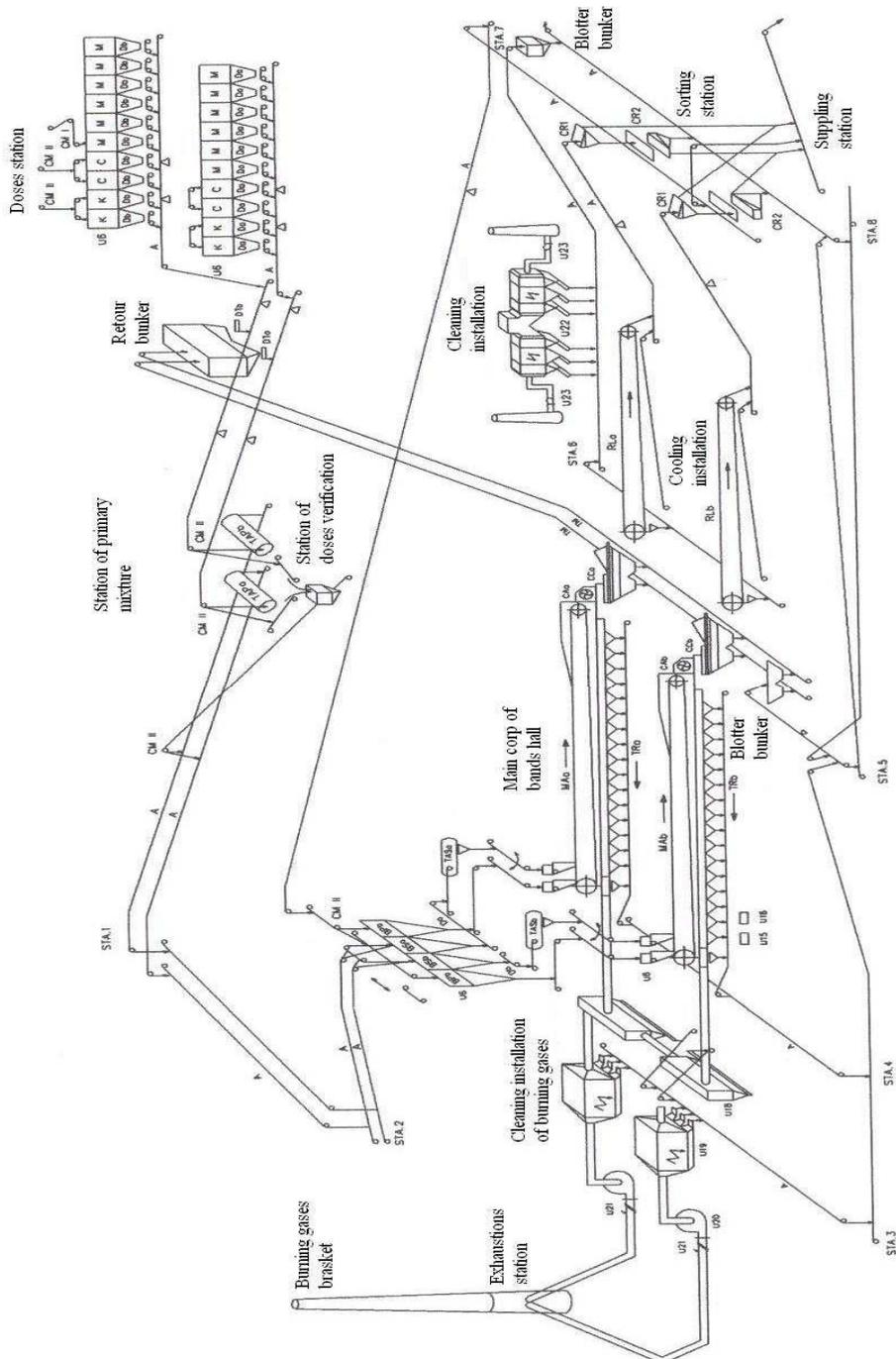
Fig. 1. Technological diagram of the sintering process

The entire charge mixture is discharged from the bus-belt into the charge bunker (BSRJ). The presence of these belts is controlled by level transducers. Each conveyor is served by three transducers: of speed, overflow and emergency and is driven by a motor, being present also a preventive signaling horn.

Sintering flow includes the following steps: mixing/blending, humectation and forming of micro-pellets in the secondary mixing drum (TAS); loading the mixture on the sintering machine's carriers; burning-up the charge; sintering of the mixture/blend; sizing of the agglomerate and recirculation of the return. The material from the charge bunker is extracted by a gravimetric dozer with extracting belt, and loaded further in the secondary mixing drum. Inside the TAS, the material is brought to the necessary humidity for the sintering process (7-10%), by adding water.

The humid material, homogenized and micro-palletized in TAS, is loaded on the sintering machine, uniformly on the entire machine's surface, by an oscillating belt. Repartition of the protection bed on the sintering machine's grills should be made in a uniform layer on the entire width of the machine.

The height of the layer on the sintering machine is adjusted by changing the position of the shield against the machine's grills and is established depending on the material's gas permeability.

Cooling flow includes the following steps: cooling of the agglomerate after the hot screening; conveying in cold condition to the screening station; conveying to the furnaces silos and to the agglomerate's shipment station.

Cooling of the agglomerate is made on two linear coolers, one for each sintering machine. The cooling air is supplied by 5 fans with an air flow of 200000 m^3/h, blow by each fan. At the entrance on the cooler, the agglomerate has a temperature of 700-800^{0}C and leaves the cooler with 80-100^{0}C, fact which allows it to be transported by some special rubber belts.

Each cooling machine is served by an auxiliary belts flow, with the role to collect and convey the material which is returning on the inferior line of the linear cooler and the one which falls under the cooling machines (Diniş et al., 2008).

Each cooling machine is served by an auxiliary belts flow, with the role to collect and convey the material which is returning on the inferior line of the linear cooler and the one which falls under the cooling machines.

The continuous transportation process using belt conveyors is one of the most used solutions in various activity fields, starting with sorting of substances from industrial shops, going further with material processing from the sintering plants and ending with flexible robotized lines or the conveyors flow from airports.

As overview, the control of such transportation flow is very complex, both concerning the necessary hardware equipment and the implementation of control algorithms. Nowadays, the major part of conveyors' control systems is hardware-oriented. These contain many hardware components, such as: electromechanical elements, logical and analogical devices, discrete components, power electronics, etc. The control program is reduced to minimum and is implemented, usually, on the microcontroller (Ho & Ranky, 1997)

A microcontroller is an integrated circuit that achieves many of a typical computing system's functions. This contains in a single chip a microprocessor as central processing unit, memories, counters, converters, input-output peripherals. One of the advantages of the systems with microcontroller is using the software to replace a complex logic, without modifying anything in the hard structure. Another advantage is that it uses   software

instead of some complex and expensive hardware components. Thus, by using microcontrollers are saved the costs due to some expensive hardware components, and the necessary physical space is much more reduced. In many cases, the hardware equipment reduces the reliability and flexibility of the entire system.

On the other hand, this control system, together with the power electronics, is higher in volume and price than the working machine itself.

Development of computerized technologies emphasized that very many control elements, controls, automation, etc. of mechanical, electrical and electronically nature can be achieved by program, reducing the complexity and saving materials and labor, with positive effect on cost and safety in operation.

Thus has been developed a new trend, which is currently dominant in designing of technical systems, called „software-oriented technology". This technology contains maximum of integrated software resources in product (software-embedded) and minimum of hardware resources, the software resources being in fact products of human intelligence, materialized in programs and included in the equipment, forming its artificial intelligence. In chapter is presenting a software-oriented control system, hierarchically distributed and conceived for a belt conveyors flow, with application for material dosing (Ho & Ranky, 1997).

2. Modelling and simulation of sub-processes from an iron ore sintering plant

In the dosing process from the sintering plants will be taken into account the following conditions:

- the materials supplied for sintering are wet;
- the supplied material quantities are bigger by about 0.5%, percents which represent the losses from manipulation m_a % ;
- if M is the quantity of wet material (iron ore) that should reach to dosing, the quantity M_a of supplied material is:

$$M_a = \frac{M}{(1 - m_a)} \tag{1}$$

where;
$$m_a = \frac{m_a\%}{100} \tag{2}$$

- the quality of the dosed materials is given in anhydrous condition (dry), therefore, to determine the account of iron, basic oxides and acid oxides, is taken as basis the dry material. Having $w\%$ the humidity percent, the calculation with wet materials will be made by bringing them to the dry condition. The dry iron ore will be:

$$M_{uscat} = (1 - w) \cdot M \tag{3}$$

where;
$$w = \frac{w\%}{100} \tag{4}$$

- the dosed charge is formed by the total of wet iron ores which are taken as unit or 100% and against which are reported the other additions: coke, limestone, return, as percentages against the total iron ores, or as proportion against the total iron ores, these being also in wet condition;
- a part of the iron ores, before reaching the sintering plant, are passed through the raw materials preparation sector, where are mixed and homogenized, having as result the iron ore

mixture called currently "homogenized" which has the deviations at Fe, SiO_2, CaO within the limits of $\pm 0.5\%$. This homogenized is dosed separately as a self-sustained component;

- by the sintering process, the materials are calcinated and, knowing the calcinations percent "p%", the quantity of material found in agglomerate will be:

$$A_i = (1 - w_i) \cdot M_i \cdot (1 - p_i) \tag{5}$$

where
$$p_i = \frac{p_i\%}{100} \quad i = 1, 2, \ldots, n; \tag{6}$$

- the coke C_i, after burning, participates in the agglomerate by its ash. For each coke C_i knowing the ash $Ce_i\%$, it results the account of ash in the agglomerate:

$$Ce = \sum_{i=1}^{n} (1 - w_{C_i}) \cdot C_i \cdot Ce_i \tag{7}$$

- the quantity of coke and return is reported to the total iron ore charge

$$M = \sum_{i=1}^{n} M_i \tag{8}$$

- the total coke quantity is

$$C = \sum_{i=1}^{n} C_i \tag{9}$$

$$c_0 = \frac{C}{M} = \sum_{i=1}^{n} \frac{C_i}{M} = \sum_{i=1}^{n} c_i \tag{10}$$

$$\Rightarrow$$

$$\begin{cases} C_i = c_i \cdot M \\ C = M \cdot \sum_{i=1}^{n} c_i = M \cdot c_0 \end{cases} \tag{11}$$

- the total ash quantity is:

$$Ce = M \cdot \sum_{i=1}^{n} (1 - w_{C_i}) \cdot c_i \cdot Ce_i \tag{12}$$

- the return results: from the hot screening, having $w_{r_1} = 0$ (R_1); from the cold screening, having $w_{r_2} = 0$ (R_2) and from the screening from the blast-furnace's day-shift bunkers, which is wet for not causing dust $w_{r_3} = 0 \div 1\%$ (R_3);

- for all three types of return will be considered $w_r = 0$, and the total return is:

$$R = R_1 + R_2 + R_3 \tag{13}$$

$$r_0 = \frac{R}{M} = \frac{R_1 + R_2 + R_3}{M} \tag{14}$$

where: R_1 does not pass through dosing, but is discharged on the conveyor belt from the burdening downstream and R_2 and R_3 are dosed through the dosing bunkers.

The limestone quantity is not dosed by a given average ratio, but determined by the need of basic oxides account, so that in the agglomerate's participation assembly the sum of basic oxides reported to the sum of acid oxides to be in a prescribed ratio, called basicity ratio I.

$$I = \frac{\sum\limits_{i=1}^{n}(CaO + MgO)}{\sum\limits_{i=1}^{n}(SiO_2 + Al_2O_3)} \tag{15}$$

The dosed iron ores charge is (400 ÷ 500) t/h at daily productions of (8000 ÷ 10000) tons of agglomerate/day. The ratio between the quantity of the produced agglomerate and the iron ore charge is sensitively around value 1, because at basicity I = 1.2 ÷ 1.4 as are prescribed the iron ores' calcinations losses, they are compensated by the participation of limestone into agglomerate plus the coke's ash, the return having a null effect, because it's a constant quantity that recirculates (∑outputs = ∑inputs).

The mathematic model of the dosing sub-process is described by the following equations:

$$K = M \cdot \frac{N}{(k_k - Is_k)} \tag{16}$$

$$S = M + K + C + R \tag{17}$$

$$M = S \cdot \frac{1}{1 + c_0 + r_0 + \dfrac{N}{(k_k - Is_k)}} \tag{18}$$

$$K = S \cdot \frac{\dfrac{N}{(k_k - Is_k)}}{1 + c_0 + r_0 + \dfrac{N}{(k_k - Is_k)}} \tag{19}$$

$$R = S \cdot \frac{r_0}{1 + r_0 + c_0 + \dfrac{N}{(k_k - Is_k)}} \tag{20}$$

$$C = S \cdot \frac{c_0}{1 + r_0 + c_0 + \dfrac{N}{(k_k - Is_k)}} \tag{21}$$

where: $\quad N = \sum\limits_{i=1}^{n} m_i(Is_i - k_i) + c_0 Ce(Is_{Ce} - k_{Ce}) + r_0(Is_r - k_r)$ $\tag{22}$

$$s_i = \sum (SiO_2 + Al_2O_3)_i \tag{23}$$

$$s_{Ce} = \sum (SiO_2 + Al_2O_3)_{Ce} \tag{24}$$

$$s_r = \sum (SiO_2 + Al_2O_3)_r \tag{25}$$

$$s_k = \sum (SiO_2 + Al_2O_3)_k \tag{26}$$

$$k_i = \sum (CaO + MgO)_i \tag{27}$$

$$k_{Ce} = \sum (CaO + MgO)_{Ce} \tag{28}$$

$$k_r = \sum (CaO + MgO)_r \tag{29}$$

$$k_k = \sum (CaO + MgO)_k \tag{30}$$

In the above equations: M – represents the iron ore flow; K – limestone flow; R – return flow; C – coke flow; S – charge flow; I – basicity ratio; s_i, k_i – lime and silica from the iron ores; s_k, k_k – lime and silica from the limestone ; s_{Ce}, k_{Ce} – lime and silica from the coke ashes; s_r, k_r – lime and silica from the return; r_0 – the return participation against the total iron ore ; c_0 – the coke participation against the total iron ore. In case when is taken into account the humidity of the charge components, we have the following mathematic model:

$$K = M \cdot \frac{N^{'}}{\left(k_k - Is_k\right)} \tag{31}$$

$$M = S \cdot \frac{1}{1 + c_0 + r_0 + \dfrac{N^{'}}{\left(k_k - Is_k\right)}} \tag{32}$$

$$K = S \cdot \frac{\dfrac{N^{'}}{\left(k_k - Is_k\right)}}{1 + c_0 + r_0 + \dfrac{N^{'}}{\left(k_k - Is_k\right)}} \tag{33}$$

$$R = S \cdot \frac{r_0}{1 + r_0 + c_0 + \dfrac{N^{'}}{\left(k_k - Is_k\right)}} \tag{34}$$

$$C = S \cdot \frac{c_0}{1 + r_0 + c_0 + \dfrac{N^{'}}{\left(k_k - Is_k\right)}} \tag{35}$$

$$N^{'} = \sum_{i=1}^{n}\left(1 - w_i\right) \cdot m_i \cdot \left(Is_i - k_i\right) + \\ + \left[\left(1 - w_{c0}\right) \cdot c_0 \cdot Ce\left(Is_{Ce} - k_{Ce}\right) + r_0 \cdot \left(Is_r - k_r\right)\right] \tag{36}$$

Maximization of the good-quality agglomerate production is based on the optimization of the sintering machine's speed. The mathematic model contains equations for calculating the necessary corrections for the value of the sintering machine's speed, respectively for the carbon quantity in the charge, by which is adjusted the quantity of the produced ore fines.

Optimization of the sintering machine's speed v_m is based on the coincidence principle of the longitudinal sintering front's length L_a with the machine's working length L_u.

The mathematic model of the sintering sub-process is described by the following equations. In the above equations intervene the following quantities : v_m – sintering machine's prescribed speed; H_s – layer's height; k – proportionality factor; B – sintering machine's width; T_n, T_{n-1}, T_{n-2} – temperatures in the last three suction chambers; r = R/M - proportion of the return against the total iron ore; r_0 = R_{mp}/M - proportion of the fine-grained produced against the total iron ore; a, b – constants which are determined statistically for each installation in part; w – speed agglomeration in layer; t_a – agglomeration time; Q_{at} – total agglomeration flow; ρ_v – sinter density; η_a – agglomeration yield (Meré et al., 2005).

$$v_{m\ opt} = v_m \cdot \cfrac{L_u}{L_{n-1} + 0{,}5 \cdot p_c \cdot \cfrac{T_{n-2} - T_n}{T_{n-2} - 2T_{n-1} + T_n}} \qquad (37)$$

$$\Delta v_m = v_m \cdot \left(\cfrac{L_u}{L_{n-1} + 0{,}5 \cdot p_c \cdot \cfrac{T_{n-2} - T_n}{T_{n-2} - 2T_{n-1} + T_n}} - 1 \right) \qquad (38)$$

$$\Delta C = 1.25 \cdot \Delta c \cdot M \qquad (39)$$

$$\Delta c = (a - b \cdot r_0) - (a - b \cdot r) \qquad (40)$$

$$S = k \cdot v_{m\ opt} \cdot H_s \cdot B \qquad (41)$$

$$v_{m\ min} = \frac{L_u}{H_s} \cdot w_{min} \cdot 10^{-3} \ [m/min] \qquad (42)$$

$$v_{m\ max} = \frac{L_u}{H_s} \cdot w_{max} \cdot 10^{-3} \ [m/min] \qquad (43)$$

$$t_a = \frac{L_u}{v_{med}} = \frac{H_s}{w_{med}} = 10 \ ... 20 \ [min] \qquad (44)$$

$$Q_{at} = B \cdot H_s \cdot (1 - c) \cdot \eta_a \cdot \rho_v \cdot v_{med} \cdot 60 \ [t/h] \qquad (45)$$

$$\rho_v = 1.6 \ [t/m^3]; \eta_a = 0.93 ... 0.96 \ ; \ c = 0.06 ... 0.13 \qquad (46)$$

Based on the mathematic model and using the Simulink program from Matlab environment, were executed the diagrams that achieve the simulation of the dosing sub-process of the sintering ores, as well as the simulation of the iron ores' sintering sub-process. The subsystem from fig. 2 makes the calculation of the material flow that compose the sintering charge, e.g.: the iron ore flow, limestone flow, coke flow and the return flow considering that in the agglomerate's manufacturing recipe enter four types of iron ore : Romanian iron ore (iron ore 1), Krivoi-Rog iron ore (iron ore 2), Brazilian iron ore (iron ore 3) and scale (iron ore 4), each with its own chemical composition, i.e. with different lime and silica. Based on the laboratory analysis, are established the values of the following input measures: silica and lime of iron ores, silica and lime of the limestone, as well as the silica and lime from the coke ashes.

Other input measures are prescribed measures, i.e.: basicity ratio (I), coke ashes' proportion (Ce%), c_0 – ratio between coke and iron ore, r_0 – ratio between the return and iron ore, m_1 – proportion of iron ore 1 against the total iron ore, m_2 – proportion of iron ore 2 against the total iron ore, m_3 – proportion of iron ore 3 against the total iron ore and m_4 – proportion of iron ore 4 against the total iron ore. Because in the sintering charge the total iron ore is considered 100%, it should be fulfilled the condition $m_1 + m_2 + m_3 + m_4 = 1$, where :

$$m_1 = \frac{M_1}{M} \ ; m_2 = \frac{M_2}{M} \ ; m_3 = \frac{M_3}{M} \ ; m_4 = \frac{M_4}{M} \qquad (47)$$

M_1 – Romanian iron ore flow; M_2 – Krivoi-Rog iron ore flow; M_3 – Brazilian iron ore flow; M_4 – scale flow; M – total iron ore flow.

The input measures s_r (silica in return) and k_r (lime in return) is calculated with a separate subsystem presented in fig. 3.

Because the return is in fact fine-grained agglomerate which is recycled in the process, the silica and lime from the return is equal with the silica and lime of the agglomerate.

The subsystem from fig. 3 makes the calculation of the silica and lime from the return based on the following formulas:

$$S \cdot s_r = M \cdot \sum m_i \cdot s_i + M \cdot c_0 \cdot Ce \cdot s_{Ce} + K \cdot s_k + M \cdot r_0 \cdot s_r \qquad (48)$$

$$s_r = \frac{M \cdot \sum m_i \cdot s_i + M \cdot c_0 \cdot Ce \cdot s_{Ce} + K \cdot s_k}{S - r_0 \cdot M}; \quad k_r = s_r \cdot I \qquad (49)$$
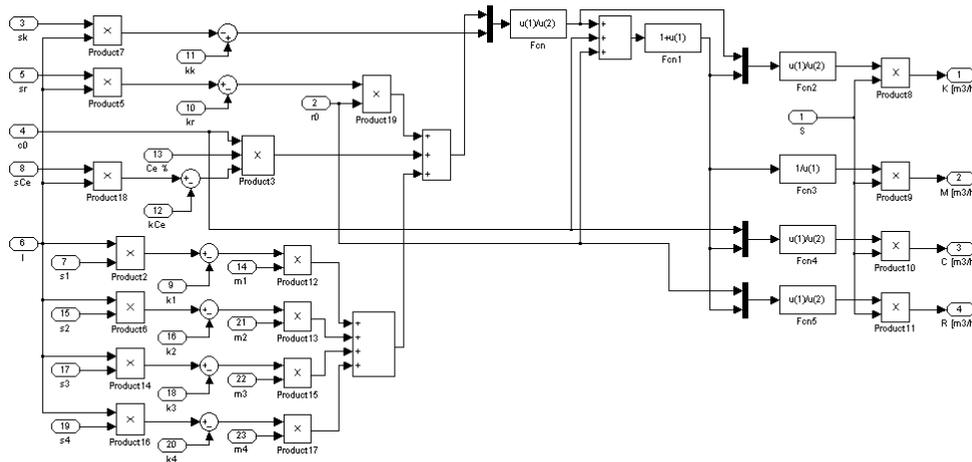
Fig. 2. Block diagram for calculation of the material flows from the charge [m³/h]

Using the Simulink program from Matlab environment it was determined the sintering machine's optimal speed variation.

The simulation allowed also to computing the carbon correction from the charge, as well as the charge flow (Diniş et al., 2009). The calculation subsystem of the sintering machine's optimal speed from fig. 4 has as input measures the following: temperatures in the last three suction chambers (T_n, T_{n-1}, T_{n-2}), the sintering machine's useful length (L_u), the length up to the penultimate suction chamber (L_{n-1}) and the suction chambers' distance (p_C).

The sintering machine's useful length, the length up to the penultimate suction chamber and the suction chambers' distance are considered constant measures (L_u=42 m, L_{n-1}=40 m, p_C=2 m), and the temperatures in the last three suction chambers are considered measures that take different values at certain moments of time.

The sub-system from fig. 5 calculates the carbons correction (coke) that should be made at dosing, in order that the fine-grained return produced in the sintering process (which is scaled) to be equal with the return which is introduced in the sintering charge at dosing. This sub-system is achieved based on the equations (39) and (40).

The input measure S (the sintering charge's flow) is calculated with a separate subsystem presented in fig. 6 based on the following parameters: the sintering band's speed, the sintering layer's height and the sintering band's width. The calculation subsystem of the charge flow presented in fig. 6 is achieved based on the equation (41).
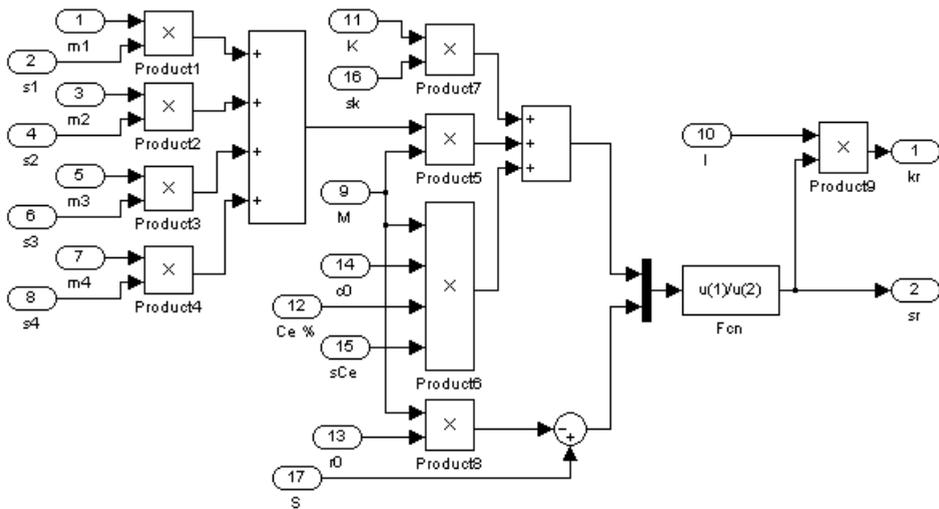
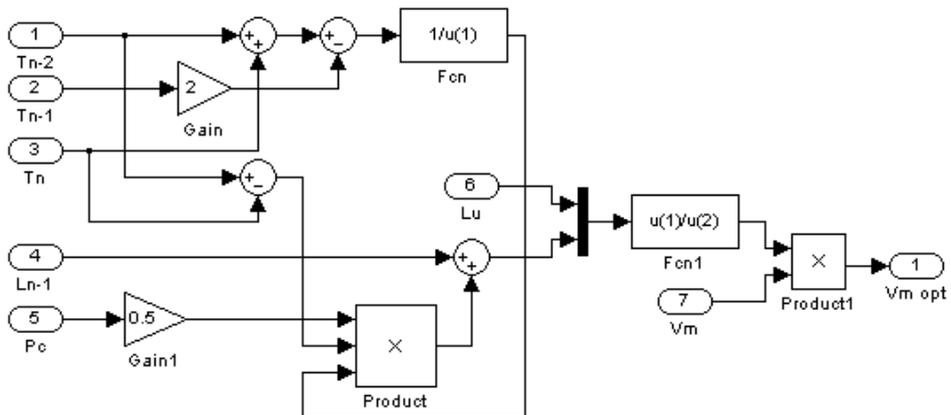Fig. 3. Block diagram for calculation of the lime and silica from the return

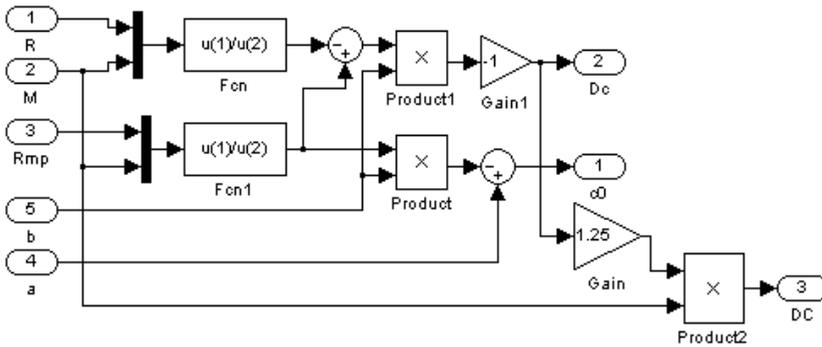Fig. 4. Block diagram for calculation of the sintering line's optimal speed

Fig. 5. Block diagram for calculation of the coke content's variation from the charge
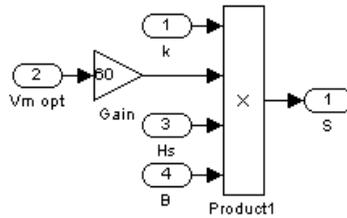

Fig. 6. Block diagram for calculation of the charge flow

For the temperature values T_{n-2}, T_{n-1} and T_n (the temperatures in the last three suction chambers of the sintering band) expressed at different moments of time, will be obtained the variation curve of the sintering machine's optimal speed. This time-variation curve of the sintering machine's optimal speed can be used successfully for the optimal control of the process from the sintering band (Diniş et al., 2009).

The temperature values T_{n-2}, T_{n-1} and T_n at different moments of time can be modified, obtaining, depending on these and the other subsystem's inputs, other time-variation curves of the sintering machine's optimal speed.
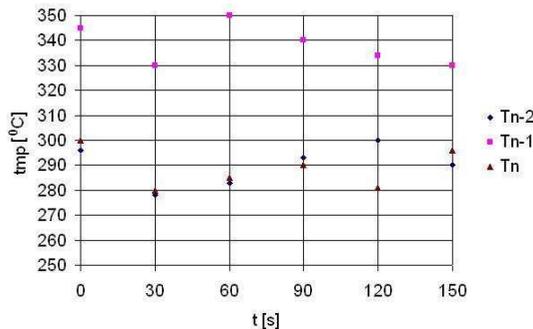
Fig. 7. The temperature values for the three suction chambers, in time, for the simulation from fig.8
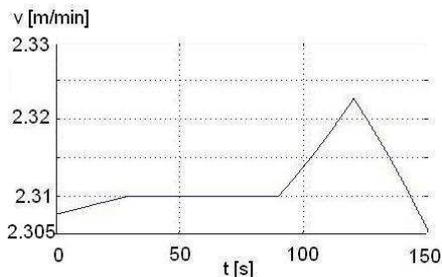
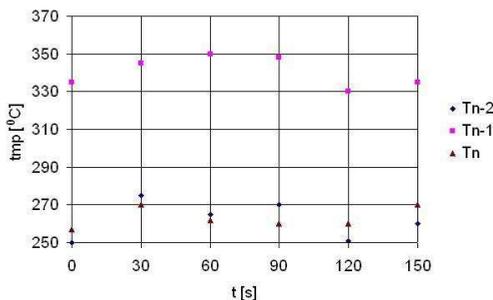Fig. 8. Variation of the sintering machine's optimal speed – case 1

Fig. 9. The temperature values for the three suction chambers, in time, for the simulation from fig.10
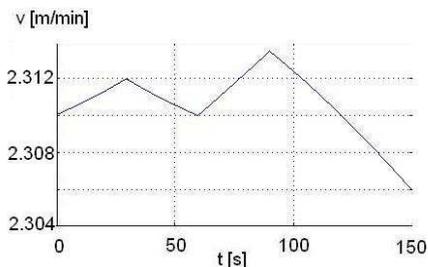

Fig. 10. Variation of the sintering machine's optimal speed – case 2
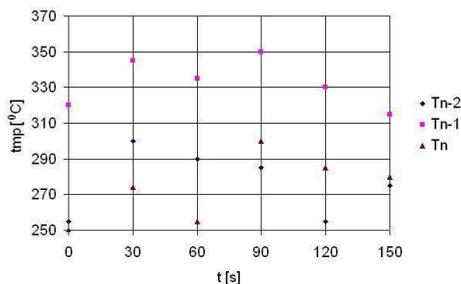

Fig. 11. The temperature values for the three suction chambers, in time, for the simulation from fig.12
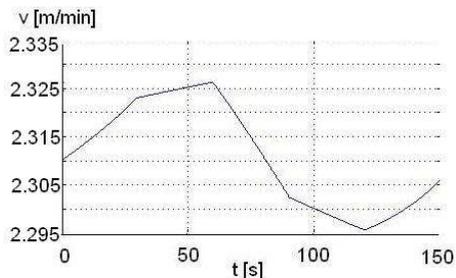
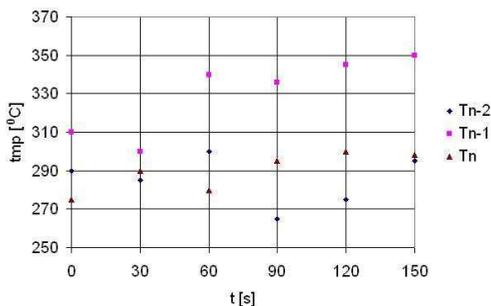Fig. 12. Variation of the sintering machine's optimal speed – case 3

Fig. 13. The temperature values for the three suction chambers, in time, for the simulation from fig.14
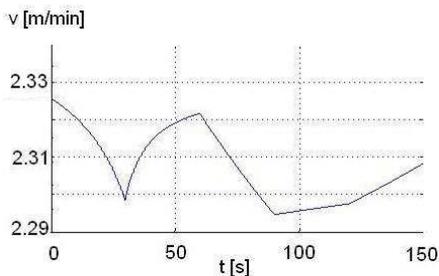

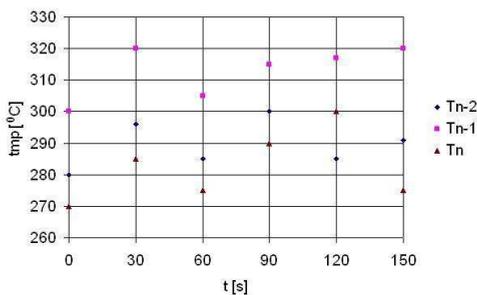Fig. 14. Variation of the sintering machine's optimal speed – case 4

Fig. 15. The temperature values for the three suction chambers, in time, for the simulation from fig.16
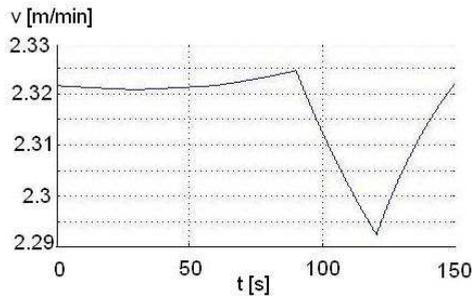
Fig. 16. Variation of the sintering machine's optimal speed – case 5

In fig. 8, 10, 12, 14, 16 are presented the variations of the sintering machine's optimal speed for different distributions of the iron ore's temperatures on the sintering band.

The temperature distributions in time, for the last three suction chambers of the sintering machine (T_{n-2}, T_{n-1}, T_n) are given under vectorial form and are presented in fig. 7, 9, 11, 13, 15. The prescribed speed (for the simulations from fig. 8, 10, 12, 14, 16) for the adjustment system is 2.2 m/s. The temperatures are considered to be measured each with a temperature transducer for each chamber. The simulation time is 150 s, and the temperature readings are made from 30 to 30 s. The measurement of the material's temperature on the sintering band is a difficult operation.

From practice, are known the temperature domains for each suction chamber: $T_{n-2} \in [250-300]$ ^0C; $T_{n-1} \in [300-350]$ ^0C; $T_n \in [250-300]$ ^0C.

Depending on the temperatures measured (fig.17) in the suction chambers, the adjustment system imposes a certain modification of the sintering band. For simulations were used the experimental data from fig.17 (graph 3, 40 cm layer).
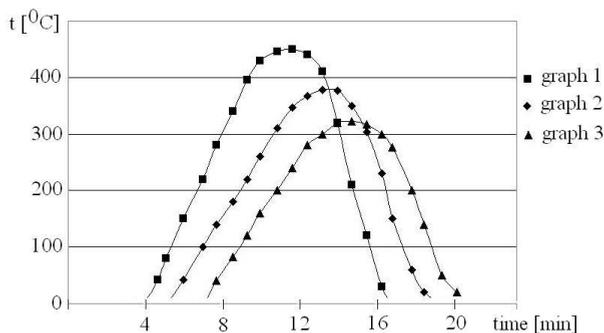

Fig. 17. Distribution temperatures, under the layer: graph 1: 20 cm layer; graph 2: 30 cm layer; graph 3: 40 cm layer

3. Control of a belt conveyors system, with MC68HC05B6 – Motorola microcontroller

Microcontroller MC68HC05B6 (Motorola) is an HCMOS integrated circuit, which has the following resources:

- 8-bit arithmetic and logical unit, which can execute adding, subtracting, multiplying, incrementing, decrementing, logical and rotating operations;

- 176 RAM 8-bit;
- 8 Kbytes EEPROM for programming;
- 256 EEPROM 8-bit;
- 16 bi-directional inputs/outputs;
- counter of 16 bits;
- 2 capture inputs;
- software reset of the main counter;
- 8 channels for 8-bit analogue-digital conversion;
- 2 conversion channels 8-bit digital-analogue;
- serial asynchronous communication interface

The conveyor belts T_2 and T_3 are supplied with material from silos S_1 and S_2. These are discharging the charge on the basic belt T_1. The transport flows on the belt system are on directions T_{a1}-T_2-T_1, respectively T_{a2}-T_3-T_1 indicated by arrows.

The power part contains five motors (M_{T1}, M_{T2}, M_{T3}, M_{Ta1}, M_{Ta2}) for driving each conveyor belt and belt feeders (fig.18). Each motor is protected by fusible fuses (F_{12}, F_{22}, F_{32}, F_{42}, F_{52} against short-circuits) and by thermo-bimetallic relays (F_1, F_2, F_3, F_{a1}, F_{a2} for overload protection). As commutation elements are used contactors (K_1, K_2, K_3, K_{a1}, K_{a2}). The contactors' coils are supplied at 380 V c.a., being controlled by the normally open contacts of the micro-relays K_{11}, K_{21}, K_{31}, K_{a11}, K_{a21} by the system with microcontroller (fig.19).
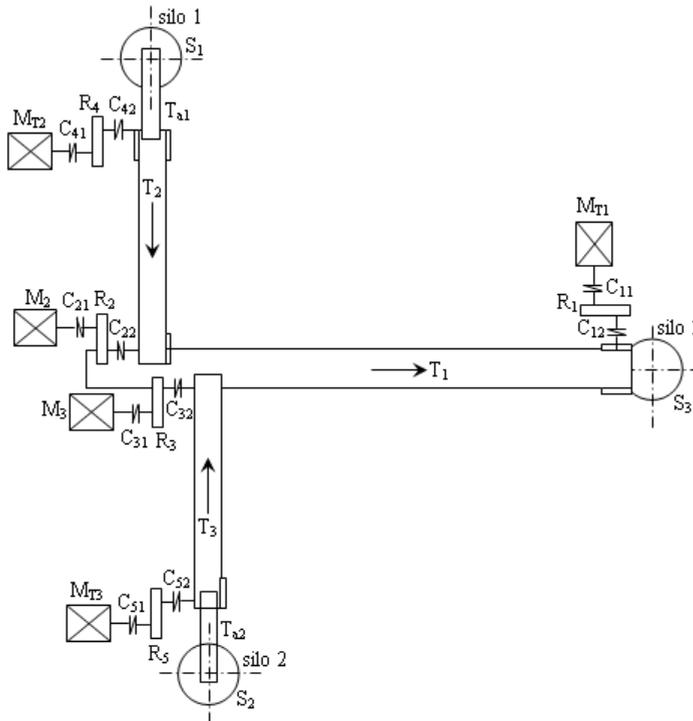

Fig. 18. Branched system of conveyor belts

Micro-relays K_{11}, K_{21}, K_{31}, K_{a11}, K_{a21} are controlled by 1 logic. The system by microcontroller is supplied at 5V. All components were connected at the first 16 digital ports (P_1,…,P_{16}). The normally closed contacts of the thermal protections (F_1, F_2, F_3, F_{a1}, F_{a2}) were connected by resistances of 10 kΩ to 5V. Thus, if the protections don't act, their normally closed contacts do not open and the microcontroller interprets this status as 0 logic. If a protection is actuating, the related contact is open and on the respective input is applied signal 1 logic.

The two flows can be controlled separately: flow 1 (T_1-T_2-T_{a1}) and flow 2 (T_1-T_3-T_{a2}). Flow 1 is started by button S_{p1}, and flow 2 by button S_{p2}. Flows' stopping is made by the stop buttons S_{o1}, respectively S_{o2}. If the buttons are not actuated, it's interpreted 1 logic, and if they are closed, is interpreted 0 logic. There are also connected two LEDs – LED1 and LED 2- that indicates the operation of flow 1 respectively flow 2. The LEDs' control is made by 1 logic.
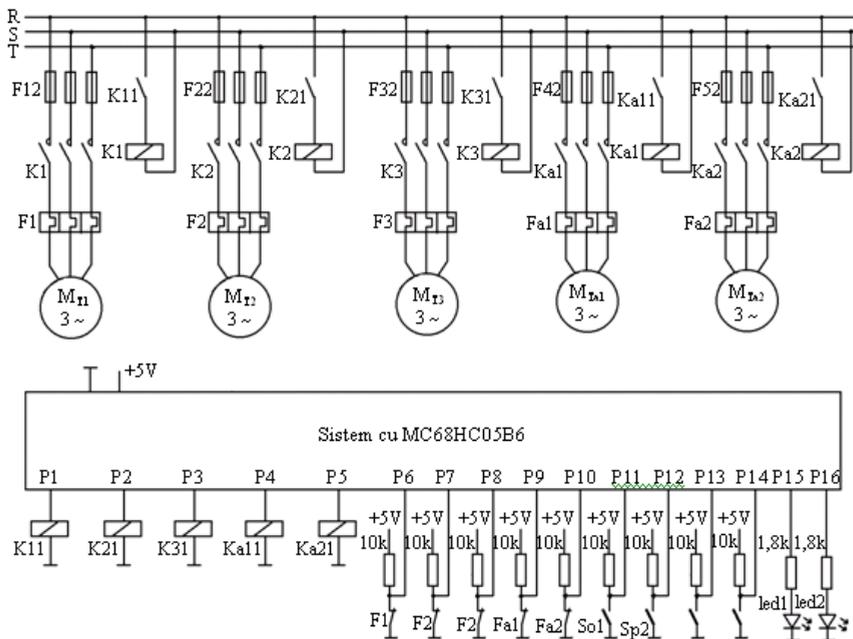

Fig. 19. The power and control diagram of the conveyor belt system

Is presented the control program's listing of the conveyor belt system achieved in CCBasic.
'Program for controlling the conveyor belts
define ports wordport [1] 'Ports 1 - 16
define t1 port [1] 'Port command contactor K1, for conveyor T1
define t2 port [2] 'Port command contactor K2, for conveyor T2
define t3 port [3] 'Port command contactor K3, for conveyor T3
define ta1 port [4] 'Port command contactor Ka1, for feeder Ta1
define ta2 port [5] 'Port command contactor Ka2, for feeder Ta2
define f1 port [6] 'Port thermal protection motor conveyor T1
define f2 port [7] 'Port thermal protection motor conveyor T2

```
define f3 port [8] 'Port thermal protection motor conveyor T3
define fa1 port [9] 'Port thermal protection motor feeder Ta1
define fa2 port [10] 'Port thermal protection motor feeder Ta2
define sp1 port [11] 'start-up button flow 1
define so1 port [12] 'shut-down button flow 1
define sp2 port [13] 'start-up button flow 2
define so2 port [14] 'shut-down button flow 2
define led1 port [15] 'LED operation flow 1
define led2 port [16] 'LED operation flow 2
'Main Program
'Initializations
ports = off
10      if sp1=off then led1=on
        if sp1=off then gosub flow1
        if so1=off then led1=off
        if so1=off then ta1=off
        pause 25
        if so1=off then t2=off
        pause 25
        if so1=off then t1=off
        if f1=on or f2=on or fa1=on then ta1=off
        if f1=on or f2=on or fa1=on then t2=off
        if f1=on or f2=on or fa1=on then t1=off
        if f1=on or f2=on or fa1=on then ta2=off
        if f1=on or f2=on or fa1=on then t3=off
        if sp2=off then led2=on
        if sp2=off then gosub flow2
        if so2=off then led2=off
        if so2=off then ta2=off
        pause 25
        if so2=off then t3=off
        pause 25
        if so2=off then t1=off
        if f1=on or f3=on or fa2=on then ta2=off
        if f1=on or f3=on or fa2=on then t3=off
        if f1=on or f3=on or fa2=on then t1=off
        if f1=on or f3=on or fa2=on then ta1=off
        if f1=on or f3=on or fa2=on then t2=off
        goto 10
        'Subroutine flow1
        #flow1
        t1=on
        pause 100
        if f1=on then t1=off
        if f1=on then led1=off
        if f1=on then goto 10
```

```
t2=on
pause 100
if f2=on then t2=off
if f2=on then t1=off
if f2=on then led1=off
if f2=on then goto 10
ta1=on
pause 100
if fa1=on then ta1=off
if fa1=on then t2=off
if fa1=on then t1=off
if fa1=on then led1=off
return
'Subroutine flow2
#flow2
t1=on
pause 100
if f1=on then t1=off
if f1=on then led2=off
if f1=on then goto 10
t3=on
pause 100
if f3=on then t3=off
if f3=on then t1=off
if f3=on then led2=off
if f3=on then goto 10
ta2=on
pause 100
if fa2=on then ta2=off
if fa2=on then t3=off
if fa2=on then t1=off
if fa2=on then led2=off
return
```

4. Hierarchical control of a belt conveyors system

To achieve the control by software orientation method, will be used a hierarchical structure on three levels, having at the superior level an industrial PC, at the middle level a number of PLCs, one for each conveyor, an date execution and feedback level the working machines and the process transducers (Da Silveira & Combacau, 2006). To achieve control software, after orientation method, is used for each belt conveyor a PLC, made with development board Keil MCB167-NET (fig.20) having the following characteristics: 5 ports I/O, 1 input port, two serial communication channels (asynchronous serial channel/synchronous ASC0 and a high-speed synchronous serial channel SSC), 1 x RS232 Interface, 2 x CAN Interfaces, 1 x Ethernet Controller. Local display of belt conveyor operation is achieved by a liquid crystal panel (LCD) (Diniş et al., 2008)
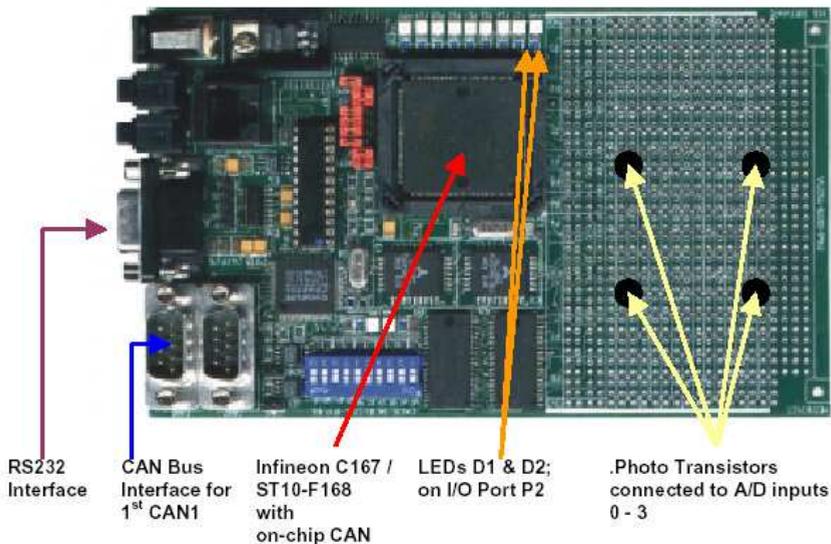
Fig. 20. Development board Keil MCB167-NET

In figure 21 is shown the block-diagram of the PLC_i afferent to the "i" conveyor and the elements which it serves. For a T_i conveyor have been made the following notes: VIT_i – speed transducer; DEV_i – overflow transducer (filling-up); AVR_i – emergency transducer (in-line); SER_i – serial communication between PLC and PC; $START_i$ – start signal for PLC_i; $STOP_i$ – stop signal for PLC_i; $START_{i+1}$ – start signal for the upstream conveyor; $STOP_{i+1}$ – stop signal for the downstream conveyor; CLX_i – control signal for the horn; MOT_i – control signal for starting the motor or motors group.
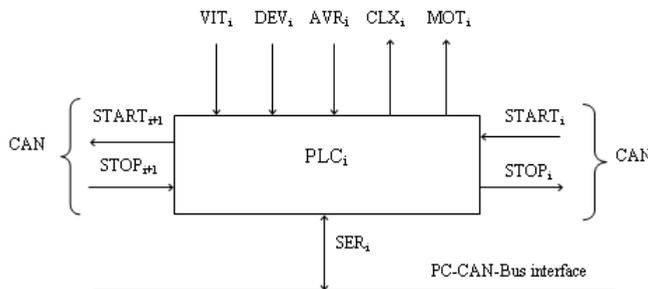

Fig. 21. Block-diagram PLC_i

The control algorithm implements the following 14 conditions: 1) Completely automatic operation with acoustic and graphic signaling in real-time; 2) At commissioning, the correctness of its integrity is tested; 3) Starting-up is made on the routes depending on the material's presence transducer; 4) Starting-up of a conveyor is made only after it was made the preventive acoustic signaling; 5) The minimum value of the material from the bunker stops the route in the direct sense of the material flow; 6) The duration of a conveyor's

starting-up is controlled by the speed transducer through the watchdog; 7) The upstream conveyor starts-up after the one from the downstream has started; 8) If a conveyor has stopped, all the others which overflow on it will stop also; 9) The upstream conveyor will be stopped if the downstream bunker has filled-up; 10) The conveyor will stop if the emergency transducer AVR_i is actuated; 11) If the watchdog has been actuated, the conveyor will stop; 12) Emergency detection produces the locking-up of starting the belt until the remedy of the defect; 13) Signaling of the system's condition is ensured at superior and local level; 14) Signaling of the transducers condition is ensured at superior and local level.

Structure of the hierarchical control system is presented in figure 22 and can be extended for any configuration by cascade connections (CASC).
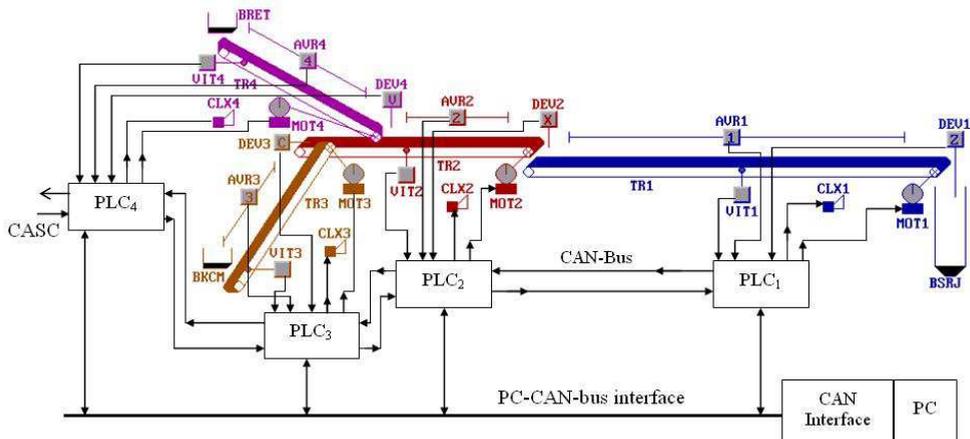

Fig. 22. Structure of the hierarchical control system

5. Modelling and implementation of the hierarchical control software

Testing of the control system's feasibility was done at the beginning by modeling and simulation of PLCi in the MatLab-Simulink. In this chapter, was developed the mathematic model which was used as basis for development of Simulink model from figure 23. In the chapter is presented the simulations results for individual PLC. Based on the model and the simulation results, it started the development and implementation of the hierarchical control software (Diniş et al., 2008).

The hierarchical control software at high level was achieved in I80X86 assembling language and contains about 8000 instruction lines. The program ensures a real-time graphic interface on PC's screen from the dispatcher, with the following elements: representing of the transportation flow in real time; real condition of the transducers; the condition of each belt; automatic or manual control; choosing a route in automatic mode, depending on the material from bunkers (Zamai et al., 1998). Further are shown few program sequences, i.e. the data segment and the main control routine.

.model small
.stack
.data

```
titleApp                db      " Control a conveyors system",0
titleKeys               db      " Keys used:",0
titleMessages           db      " Messages:",0
titleState              db      " State transducers:",0
trsp1                   db      " TR1",0
trsp2                   db      " TR2",0
trsp3                   db      "  TR3",0
trsp4                   db      "  TR4",0
damage                  db      " AVR:",0
discharge               db      " DEV:",0
speed                   db      " VIT:",0
MesDamage               db      " DAMAGE",0
MesSintering            db      " SINTERING",0
MesSpeeding             db      " SPEEDING",0
MesSpeedNormal          db      " NORMAL SPEED",0
MesSpeedAbnormal        db      " ABNORMAL SPEED",0
MesRest                 db      " REST",0
MesBNCfull              db      " FULL",0
MesBNCempty             db      " EMPTY",0
MesBNCprocessed         db      " MEDIUM",0
keys02                  db      " BKCM",0
keys03                  db      " BRET",0
keys1                   db      " Higher level (START):",0
keys2                   db      " Lower level (STOP) :",0
keys32                  db      " Q",0
keys33                  db      " W",0
keys42                  db      " A",0
keys43                  db      " S",0
keys10                  db      " ESC = exit program",0
cmdCLX                  db      00001011b          ; port control = 37ah
cmdMOT                  db      00000000b          ; port date = 378h
flagM1                  db      0        ; 0=stop & 1=start
flagM2                  db      0        ; 0=stop & 1=start
flagM3                  db      0        ; 0=stop & 1=start
flagM4                  db      0        ; 0=stop & 1=start
. code
; main program
start:    call portzero      ; initial state
call getcar
call getcar8x16
mov ax,@data
mov ds,ax
call far for whichvga
call svgamode
call doInitScreen         ;virtual instruments
call MainLoop             ; monitoring
```

```
exitDOS: call portzero       ; initial state
call txtmode
mov ax,4c00h
int 21h
end start
```
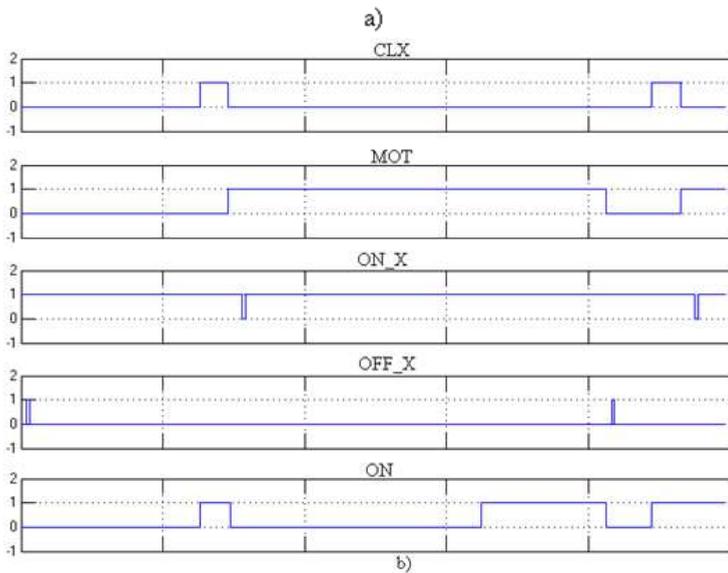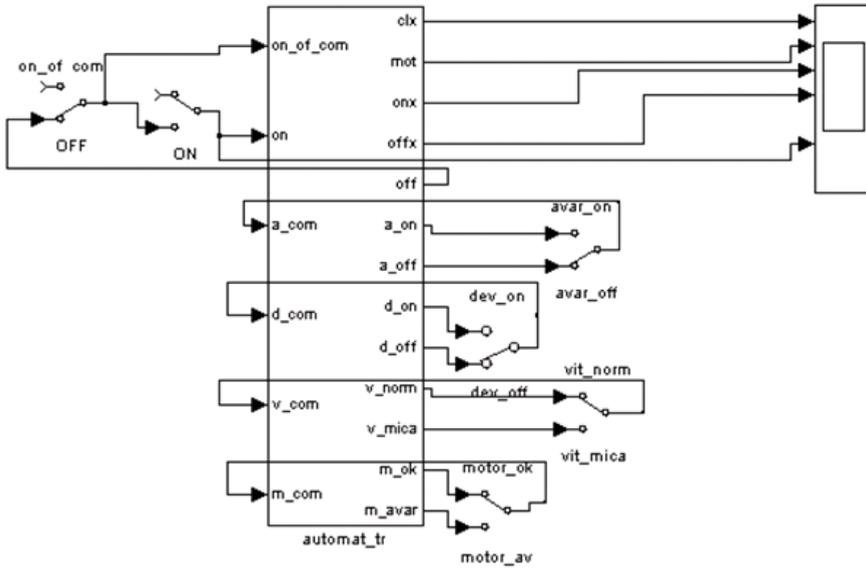

a)

b)

Fig. 23. Simulink model for PLC$_i$

Fig. 24. Simulink model for simulations

In fig. 24 are shown the results of modeling the conveying flow in MatLab-Simulink. One can see the variation in time of the control and feedback signals, in accordance with the imposed technological conditions (Lupu et al., 2008). In fig. 25 is shown the work screen of the PC from the superior level in start regime for a configuration of 4 conveyors from a sintering plant.

When the materials' presence transducer detects the superior level in the BRET return bunker or in the mixing bunker of limestone, coke and iron ores BKCM, the conveyors system starts as follows:

- PLC1 gives the preventive acoustic warning command to the CLX1 horn, then is given the start command for MOT1 motor, which drives the conveyor 1 (TR1);

- The speed transducer VIT1 detects the normal operation regime of the TR1 conveyor, and PLC1 will give the START command for PLC2;

- PLC2 controls the preventive acoustic warning by CLX2 horn, then is given the start command for MOT2 motor of the conveyor 2 (TR2);

- The speed transducer VIT2 detects the normal operation regime of the TR2 conveyor, and PLC2 will give the START command for PLC3 and the process continue;

- Any emergency detected by the transducers generates the initiation of STOP subroutines, by displaying the condition on the PC screen.
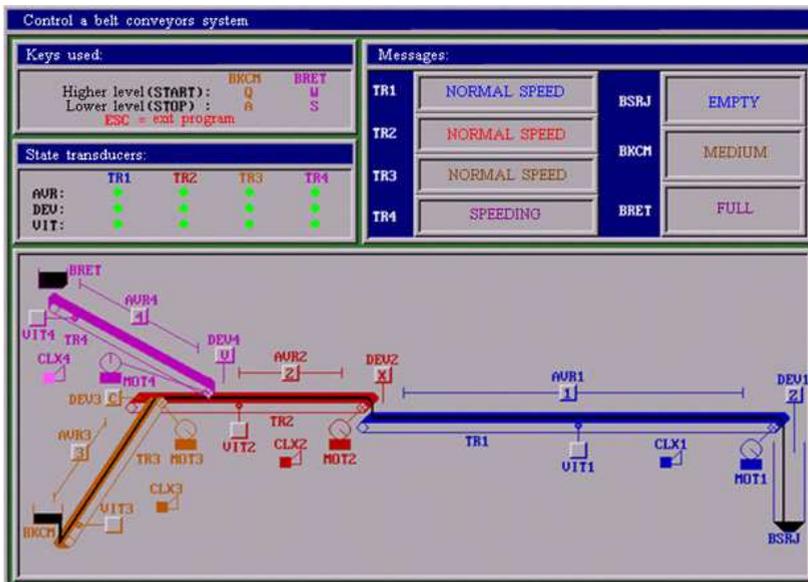

Fig. 25. Work screen when conveyors 1, 2 and 3 are started and discharged from BKCM bunker

6. Conclusion

The model achieved in Matlab/Simulink and its simulation allows the determination of the material flows in the charge, either at the variation of their chemical composition, or at variation of the reference values of the parameters S, I, r_0, c_0. The value of the charge flow S varies as result of the transitory adjusting regime of the sintering machine's speed.

The values r_0 and c_0 are established by independent criteria, e.g.: balancing the ore fines circulation, respectively ensuring the optimal compromise, between the agglomerate production on one side and the coke specific consumption on the other side, and between the agglomerate's reducibility and resistance.

Also, the achieved model allows the visualization of the optimal speed in time, which leads to the optimal charge of the sintering machine from the viewpoint of the charge's chemical and mineralogical composition. The obtained results are in accordance with the practical ones, and the model can be implemented to a real installation (Diniş et al., 2009).

The current technology of cast-iron making imposes more and more rigorous conditions to the quality of the charge that should allow the optimization of the entire process, increasing the productivity and reducing the coke consumption.

As regards the modernization of the iron ores' sintering plants, will be considered the following research directions:

- Development of an expert system for correcting the sintering belt's speed based on fuzzy logic;
- Development of computerized control systems for adjusting the water quantity in the raw materials and the agglomerate's chemical composition;
- Implementation of a surveillance system in the iron ores' sintering process.

Without the control systems by contacts and relays or by logical gates, the control by microcontroller ensures flexibility in programs' achievement and is achieved by programming without intervene upon the hard components.

It were designed and made a transport control flexible system on the basis of software orientation technology (Antipov & Malov, 2005). It was made a hierarchical control structure of the transport flux, that was modeled and simulated in Matlab/Simulink with good results. Based on the model, was conceived a hierarchical control software of the belt conveying process, adaptable to any configuration in space of the conveyors.

The obtain results may be a support for revamping the belt conveying flows used in sintering plants, lignite quarries or for the distribution conveyors from the robotic manufacturing cells, etc.

7. References

Aguilar, J.; Cerrada, M.; Hidrobo, F.; Chacal, J. & Bravo, C. (2008). Specification of a multiagent system for planning and management of the production factors for automation based on the SCDIA framework and MASINA methodology. *WSEAS Transactions on Systems and Control,* Vol. 3, Issues 2, (February 2008) page numbers (79-88), ISSN 1991-8763

Antipov, A.L. & Malov, N.A. (2005). Model of an adaptive hierarchical control system, *Proceedings of SPIE*, pp. 209-212, ISSN 0277-786X, Volume 5851 Fundamental Problems of Optoelectronics and Microelectronics II, June 2005

Da Silveira, M.R. & Combacau, M. (2006). Supervision and control of heterarchical discrete event systems. *Controle & Automação*, Vol. 17, No. 1, (Janeiro, Fevereiro e Março 2006) page numbers (1-9), ISSN 0103-1759

Diniş, C.M.; Pop, E.; Iagăr, A. & Popa, G.N. (2008). Researches upon the hierarchical control of a conveyor belt system from the sintering plants. *Metalurgia International*, Vol. XIII, No. 9, (August 2008) page numbers (54-61), ISSN 1582-2214

Diniş, C.M.; Popa, G.N. & Iagăr, A. (2008). Modeling and simulation of processes from an iron ore sintering plant. *Proceedings of the 7th WSEAS International Conference on SYSTEM SCIENCE and SIMULATION in Engineering*, pp. 119-124, ISBN 978-960-474-027-7, Italy, November 21-23 2008, Venice

Diniş. C.M.; Popa, G.N. & Iagăr, A. (2009). Mathematical modeling and simulation in Matlab/Simulink of processes from iron ore sintering plants. *WSEAS Transaction on Systems,* Volume 8, Issue 1, (January 2009) page numbers (34-43), ISSN 1109-2777

Ho, J.K.L. & Ranky, P.G. (1997). Object oriented modeling and design of reconfigurable conveyors in flexible assembly systems. *International Journal of Computer Integrated Manufacturing*, Vol. 10, Issue 5, (September 1997) page numbers (360-379), ISSN 1362-3052

Lupu, C.; Popescu, D. & Udrea, A. (2008). Real-time control application for nonlinear processes based on adaptive control and the static characteristic. *WSEAS Transaction on Systems and Control*, Vol. 3, Issues 6, (June 2008) Page Numbers (607-616), ISSN 1991-8763

Meré, J.O.; Elías, F.A.; Gonzáles, A.M.; Limas, M.C. & Ascacíbar, F.J.M.P. (2005). Data mining and simulation processes as useful tools for industrial processes, *Proceedings of the 5th WSEAS Int. Conf. on Simulation, Modeling and Optimization,* pp. 243-249, ISBN 960-8457-32-7, Greece, August 17-19 2005, Corfu

Zamai, E.; Chaillet-Subias, A. & Combacau, M. (1998). An architecture for control and monitoring of discrete events systems. *Computers in Industry*, Vol. 36, Issues 1-2, (30 April 1998) page numbers (95-100), ISSN 0166-3615
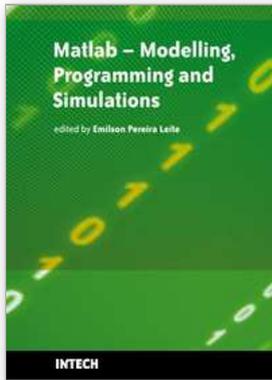
Matlab - Modelling, Programming and Simulations

Edited by Emilson Pereira Leite

This book is a collection of 19 excellent works presenting different applications of several MATLAB tools that can be used for educational, scientific and engineering purposes. Chapters include tips and tricks for programming and developing Graphical User Interfaces (GUIs), power system analysis, control systems design, system modelling and simulations, parallel processing, optimization, signal and image processing, finite different solutions, geosciences and portfolio insurance. Thus, readers from a range of professional fields will benefit from its content.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Corina Maria Dinis (2010). Modeling and Simulation of Processes from an Iron Ore Sintering Plants, Matlab - Modelling, Programming and Simulations, Emilson Pereira Leite (Ed.), ISBN: 978-953-307-125-1, InTech, Available from: http://www.intechopen.com/books/matlab-modelling-programming-and-simulations/modeling-and-simulation-of-processes-from-an-iron-ore-sintering-plants

INTECH
open science | open minds