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Application of a double cross limiting method in a lime mixing and milling system

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Abstract: The article presents the adaptation of the setpoint calculation algorithm with limitation using the double cross method, known from the fuel-air regulation systems, in the system for mixing two sorts of lime, enabling the start of the process line without additional start-up procedures. The authors modified the standard double cross algorithm in order to enable the start of the system without special start-up procedures, while maintaining all the features of the algorithm. The results of the tests of the modified algorithm in the lime milling and mixing system are also presented.

Key words: control systems, double cross limiting method, programmable controllers

1. Introduction

Many technological processes require dosing several (usually two) materials (media). Often, the priority aim of control is to maintain the proportions (ratio) between different capacities of ingredients but not the absolute capacity of the ingredients. This requirement is applicable, among others, to the fuel-air mixture control in burner supply systems. In this case, the ratio between the flow capacity of the two media has to be maintained, even in the case when one of the control lines reaches its technological limits (e.g. maximum capacity) or in the case of different dynamics of the media control and adjustment units.

In order to comply with these requirements, burner supply systems often use supply methods with cross limitations, also known as double cross, described in [1–3].

The authors have successfully used this method in the belt weigh feeder control system for bulk materials, by introducing the necessary modifications. A simple implementation of the double cross method in the form used in the fuel-air mixture control system precludes the start of the lime batching line. This was a result of the function formulas in which the calculated capacity setpoints were limited by actual capacity. This has resulted in the double cross calculation algorithm that generates zero setpoints for zero actual values.

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The authors modified the formulas of limiting functions in order to enable the system to apply the setpoints grater than zero for zero actual values.

The double cross system modified in this manner was used in the process line for mixing and milling two types of lime in order to obtain a mixture with the given physical and chemical parameters. The article presents the diagram of the modified double-cross method setpoint calculation block and the developed function block for the PLC controllers software.

The tests and trials of the control system on the lime milling and mixing process line confirmed the effectiveness of the modified setpoint calculation block. The proposed and implemented control system is capable of keeping the deviations in the lime mixture composition within acceptable limits for typical disturbances occurring during the operation.

2. Basic structures of material batching systems with capacities ratio maintenance

The material batching systems used in the industry are composed of independent material (media) flow control systems for each of the ingredients and a common system for generating setpoints for the control lines of each of the ingredients. Depending on the setpoint values generation algorithm, the individual systems have various possibilities of maintaining the ratio between the ingredients in transient and emergency states.

Fig. 1 depicts the structure of the batching system for two bulk materials with belt weigh feeders.

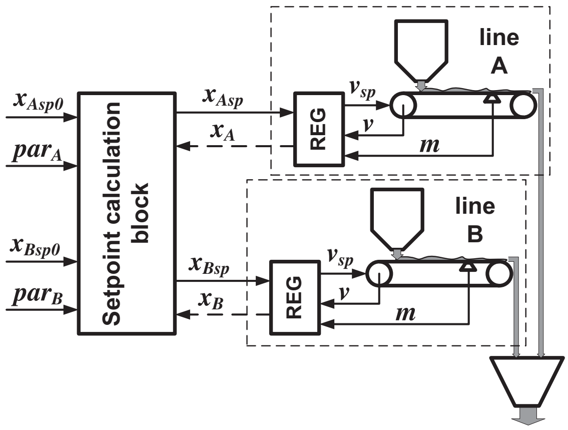

Fig. 1. Bulk material batching system

The batching system is composed of two batching lines – A and B, feeding the material into a common mixer. Each of the lines is equipped with a separate belt weigh feeder. The setpoint values x_{Asp} and x_{Bsp} for individual lines are calculated in the common setpoint calculation block based on the setpoint values from the supervisory system or operator x_{Asp0} and x_{Bsp0} as well as the actual efficiencies of individual lines x_A and x_B. The par_A and par_B values are sets of parameters of the setpoint calculation block depending on its structure. The weigh feeders are usually autonomous units, equipped with their own control and adjustment systems. They are composed of a belt conveyor with regulated speed and a scale measuring the pressure of the transported material on the belt. The actual capacity is proportional to the pressure on the belt and its speed. The weigh feeder control system sets the speed of the belt conveyor based on the setpoint and actual capacity. The implementation of the control system in the weigh feeder controller often has limited possibilities of changing and correcting the capacity regulator parameters by the user. This makes it difficult to correctly adjust the operation parameters of the weigh feeders in such a way that the reference ratio between their capacities are kept. This is especially visible when the weigh feeders have different dynamics (e.g. different belt accelerations). In these cases, the only method to keep the capacity ratio is the correct application of a block, which calculates capacity setpoints for each of the weigh feeders.

The following strategies are used to calculate the setpoint values x_{Asp} and x_{Bsp} for each weigh feeder (Fig. 1):

– setpoints calculation independent of the actual capacity,
– one capacity setpoint of the ingredients follows the actual capacity of the second component,
– two setpoints of the ingredients follow the actual values with cross limitations (double-cross method).

For the setpoints calculation independent of the actual capacity, the capacity setpoints for each weigh feeders (x_{Asp}, x_{Bsp}) are calculated based on the input data entered by the operator or provided from the supervisory system without taking into account the actual capacities. The input data may be:

– A and B line capacities, independently (1).

$$x_{Asp} = x_{Asp0}\,, \qquad x_{Bsp} = x_{Bsp0}\,, \tag{1}$$

where: x_{Asp0}, x_{Bsp0} are the capacity setpoints provided by the operator, x_{Asp}, x_{Bsp} are the capacity setpoints for the weigh feeders.

– The total capacity of lines A and B and the relative contribution of one ingredient (2).

$$x_{Asp} = (1 - k_{Bsp0}) \cdot x_{ABsp0}\,, \qquad x_{Bsp} = k_{Bsp0} \cdot x_{ABsp0}\,, \tag{2}$$

where: x_{ABsp0} is the total capacity given by the operator, k_{Bsp0} is the setpoint of relative contribution capacity of line B set by the operator.

– The capacity setpoint of one line (e.g. A) and the ratio of the capacity of the second line to the first line (e.g. B to A) (3).

$$x_{Asp} = x_{Asp0}\,, \qquad x_{Bsp} = k_{BAsp0} \cdot x_{Asp0}\,, \tag{3}$$

where: x_{Asp0} is the capacity setpoint of line A set by the operator, k_{BAsp0} is the reference ratio of the capacity of line B to line A set by the operator.

The setpoints calculation independent of the actual capacity does not maintain the proportions between the ingredients in the case of different dynamic properties of weigh feeders and in disorder situations, when the capacity regulator of one of the weigh feeders becomes saturated (e.g. because of the lack of possibility of reaching the capacity setpoint by one of the ingredients, due to the blocking of the material in the hopper).

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The other method is to follow one ingredient capacity setpoint (x_{Bsp}) on the basis of the actual capacity of the second ingredient and the capacity ratio between the two ingredients. The capacity setpoint of the second ingredient (x_{Asp}) is calculated directly based on the input data. The input data entered by the operator or provided by the supervisory system may be:

– A and B line capacity setpoints, independently (4).

$$x_{Asp} = x_{Asp0}\,, \qquad x_{Bsp} = \left(x_{Bsp0}/x_{Asp0}\right) \cdot x_A\,, \tag{4}$$

where: x_{Asp0}, x_{Bsp0} are the capacity setpoints provided by the operator, x_A is the actual capacity of line A.

– The total capacity of lines A and B and the relative contribution of one ingredient (5).

$$x_{Asp} = (1 - k_{Bsp0}) \cdot x_{ABsp0}\,, \qquad x_{Bsp} = k_{Bsp0}/(1 - k_{Bsp0}) \cdot x_A\,, \tag{5}$$

where: x_{ABsp0} is the total capacity setpoint given by the operator, k_{Bsp0} is the relative contribution of the capacity of line B set by the operator, x_A is the actual capacity of line A.

– The capacity setpoint of one line (e.g. A) and the ratio of the capacity of the second line to the first line (e.g. B to A) (6).

$$x_{Asp} = x_{Asp0}\,, \qquad x_{Bsp} = k_{BAsp0} \cdot x_A\,, \tag{6}$$

where: x_{Asp0} is the capacity setpoint of line A set by the operator, k_{BAsp0} is the ratio of the capacity of line B to line A set by the operator.

The method when two ingredients setpoints follow the actual values helps to maintain the proportions between ingredients, regardless of the capacity of the leading ingredient. This method of setting does not maintain the proportions in the case of batching problems with the subordinate ingredient. This type of setting works very well in cases when the technological conditions enable the distinction of the ingredient with higher batching precision and better dynamics of the batching system. The batching line for this ingredient should be used as the subordinate.

The difficulties in maintaining the correct capacities ratio of feeders in the batched ingredients present in the setting methods described above can be avoided by applying the method of mutual cross limitations of set values, also called the double-cross method.

3. Double cross limitation method

The double-cross method is based on maintaining the capacity setpoint for one ingredient within the range which width depends on the actual capacity of the other ingredient. This works in both directions as described in [1, 2] and [3].

Fig. 2 presents the simplified block diagram of the system for calculating the setpoint values with the double cross method. Let us assume that the capacity setpoints of each weigh feeders – x_{Asp0} and x_{Bsp0}, are entered by the process operator or provided by the supervisory system. The diagram does not include the blocks changing the setting system structure in case the value of one of the setpoint signals is zero. In this case, you cannot talk about double-cross setpoint calculation.

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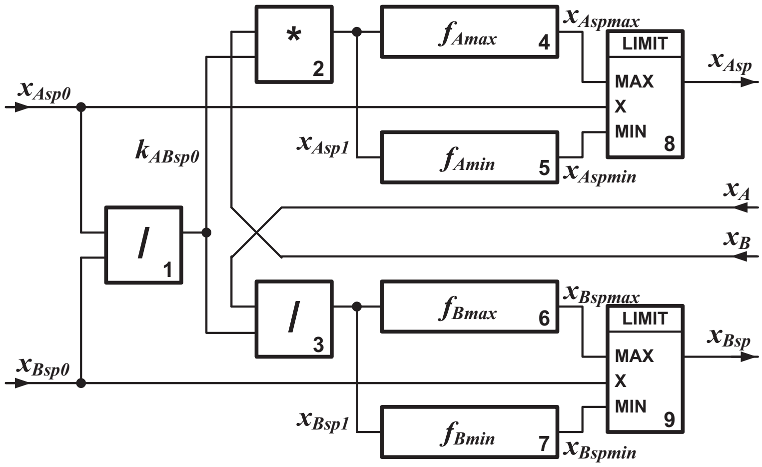

Fig. 2. System for calculating the setpoints with the double cross method

Capacity setpoint signals x_{Asp0} and x_{Bsp0} are sent to the inputs of block 1 determining the capacity ratio reference for both lines (7).

$$k_{ABsp0} = x_{Asp0} \big/ x_{Bsp0}\,, \tag{7}$$

where: x_{Asp0}, x_{Bsp0} are the capacity setpoints for lines A and B given by the operator, k_{BAsp0} is the B to A line capacity ratio reference.

Then, based on the actual efficiencies of the weigh feeders x_A and x_B and the reference ratio k_{ABsp0}, the auxiliary capacity setpoints x_{Asp1} and x_{Bsp1} for line A and B, resulting from the actual capacities of the other line are set in blocks 2 and 3 (8)

$$x_{Asp1} = x_B \cdot k_{ABsp0}\,, \qquad x_{Bsp1} = x_A \big/ k_{ABsp0}\,, \tag{8}$$

where: x_{Asp1}, x_{Bsp1} are the auxiliary setpoints for lines A and B.

The values x_{Asp1} and x_{Bsp1} are input variables for 4 functions: $f_{A\min}(x_{Asp1})$, $f_{A\max}(x_{Asp1})$, $f_{B\min}(x_{Bsp1})$ and $f_{B\max}(x_{Bsp1})$, which determine the minimum and maximum setpoint values $x_{Asp\min}$, $x_{Asp\max}$, $x_{Bsp\min}$, $x_{Bsp\max}$.

In the classic systems for fuel-air mixture control using the double cross method $f_{A\min}$, $f_{A\max}$, $f_{B\min}$ and $f_{B\max}$ functions (blocks 4–7) have the form (9)–(12) as proposed in [3]:

$$f_{A\min}\left(x_{Asp1}\right) = \left(1 - k_A\right) \cdot x_{Asp1}\,, \tag{9}$$

$$f_{A\max}\left(x_{Asp1}\right) = \left(1 + k_A\right) \cdot x_{Asp1}\,, \tag{10}$$

$$f_{B\min}\left(x_{Bsp1}\right) = \left(1 - k_B\right) \cdot x_{Bsp1}\,, \tag{11}$$

$$f_{B\max}\left(x_{Bsp1}\right) = \left(1 + k_B\right) \cdot x_{Bsp1}\,, \tag{12}$$

where: k_A, k_B are the parameters of the double cross setting system.

The parameters k_A and k_B selected from the range (0, 1) determine the acceptable deviation of setpoint values x_{Asp} and x_{Bsp} sent to the inputs of capacity regulators from the auxiliary setpoint values x_{Asp1} and x_{Bsp1} (Fig. 2).

Formulas (9)–(12) show that the possibility to change the setpoint value x_{Asp} or x_{Bsp} (and the possibility of control) exists when the conditions (13) and (14) are fulfilled:

$$f_{A\min}(x_{Asp1}) \neq f_{A\max}(x_{Asp1}), \tag{13}$$

$$f_{B\min}(x_{Bsp1}) \neq f_{B\max}(x_{Bsp1}). \tag{14}$$

This is the case when $k_A > 0$, $k_B > 0$, $x_{Asp1} > 0$ and $x_{Bsp1} > 0$. Having in mind (8), the actual line capacities x_A and x_B must be greater than zero. The problem emerges during the start of the regulation system, when the actual values x_A and x_B equal zero.

The problem of zero actual values does not normally exist in gas and air supply systems to the burners, because the gas and air supply systems use two valves (dampers): cut-off and control. Opening the cut-off valve results in the flow of the medium regardless of the position of the control valve.

The situation significantly differs in the case of application of the double cross method to control the capacity of weigh feeders. In this case, the problem of zero actual values during start-up is present. In order to enable the start-up, the following solutions are available:

– Apply the initial setpoint during the start-up and after a while, when the actual capacity of the system is greater than zero, switch to the regular operation mode. This method complicates the control algorithm, because it needs to include different operation conditions (technological and emergency), which would require an additional, special start-up procedure.
– Modification of functions (9)–(12) so that the values of these functions are not equal zero for the zero actual capacity value.

In the described solution, the limiting functions were modified in blocks 4–7 by the introduction of constant components (offset) which result in the compliance with conditions (13), (14) at zero actual values. After the modifications, the limiting functions have the following form (15)–(18):

$$f_{A\min}(x_{Asp1}) = (1 - k_A) \cdot x_{Asp1} + c_A, \tag{15}$$

$$f_{A\max}(x_{Asp1}) = (1 + k_A) \cdot x_{Asp1} - c_A, \tag{16}$$

$$f_{B\min}(x_{Bsp1}) = (1 - k_B) \cdot x_{Bsp1} + c_B, \tag{17}$$

$$f_{B\max}(x_{Bsp1}) = (1 + k_B) \cdot x_{Bsp1} - c_B, \tag{18}$$

where: c_A, c_B are the parameters (constant components) of the double cross setting system.

The parameters k_A, c_A, k_B and c_B enable to form the functions of acceptable deviations for the capacity setpoints.

In blocks 8 and 9 the setpoints given by the operator are limited to the values calculated in blocks 4–7 for each of the lines. The one of operator's setpoints (x_{Asp0} or x_{Bsp0}) is not corrected when it fits within the deadband range related to the actual capacity of the other line and the referenced ratio k_{ABsp0}. This situation occurs for the steady state operation of the batching system, if the speeds of the weight feeders belts are not at their maximums. In this case, $x_{Asp} = x_{Asp0}$ and $x_{Bsp} = x_{Bsp0}$.

If the setpoint given by the operator is outside of the acceptable range, limiting blocks 8 and 9 cause that the weigh feeder setpoint x_{Asp} (or x_{Bsp}) is set by the actual value of the other line x_B (or x_A), the reference ratio k_{ABsp0} and the acceptable capacity deviation.

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The idea of operation of the proposed, modified double cross limiting method can be explained using an example.

Assume the following limiting parameters: $k_A = k_B = 0$, $c_A = c_B = 0.4$ and the capacity setpoints of: $x_{Asp0} = 20.0$ and $x_{Bsp0} = 10.0$. The reference capacity ratio value $k_{ABsp0} = 2.0$. If the system is working normally and the weigh feeders are capable of providing the reference capacity, then in the steady state, theauxiliary setpoints are $x_{Asp1} = 20.0$ and $x_{Bsp1} = 10.0$. The applicable limitations according to (15)–(18) are: $x_{Asp\min} = 19.6$, $x_{Asp\max} = 20.4$, $x_{Bsp\min} = 9.6$ and $x_{Bsp\max} = 20.4$. Because of the inequalities: $x_{Asp\min} < x_{Asp0} < x_{Asp\max}$ and $x_{Bsp\min} < x_{Bsp0} < x_{Bsp\max}$, the capacity regulators' setpoints will be: $x_{Asp} = x_{Asp0} = 20.0$ and $x_{Bsp} = x_{Bsp0} = 10.0$.

If, in the case of a problem (e.g. material blockage), the capacity of line A drops to $x_A = 15.0$, the applicable values for line B will amount to: $x_{Bsp1} = 7.5$, $x_{Bsp\min} = 7.1$ and $x_{Bsp\max} = 7.9$. The setpoint for the control system of line B is $x_{Bsp} = 7.9$. The regulator of line B will reduce the capacity of this line to the new value $x_B = 7.9$. This value will result in changing the limitation values for line A: $x_{Asp1} = 15.8$, $x_{Asp\min} = 15.4$ and $x_{Asp\max} = 16.2$. The new setpoint for line A will be $x_{Asp} = 16.2$.

The setpoint for the line A regulator is greater than the actual capacity. After the material supply problem ends, the control and setting system will return to its initial state.

The application of the double cross limiting system results with the actual capacity ratio of k_{AB} being 1.90, not 1.50, as would be in the case if the limiting system were not applied.

4. Double cross setting method function block

Fig. 3 depicts the symbol of the developed DBLCROSS function block, applying the double cross method setting.

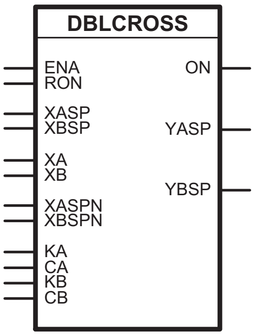

Fig. 3. DBLCROSS function block symbol

The block has the following inputs:

- XASP, XBSP are the capacity setpoints for line A and B, entered by the operator or calculated in the host system-level layer.
- XA, XB are the actual capacities of line A and B.
- XASPN, XBSPN are minimum setpoint values. If the setpoints XASP or XBSP are less than XASPN or XBSPN respectively, the output setpoints for the control system (YASP and YBSP) are proportionally recalculated so that none of them is less than the minimum, while maintaining the required ratio set by XASP and XBSP.

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– KA, CA, KB, CB are the parameters of functions determining the minimum and maximum output setpoints of YASP and YBSP, according to the formulas (15)–(18).
– ENA and RON are logical inputs to enable and to turn on the limitation block. The ENA input is intended for a technological permission, the RON input – for remote turning on/off the block by the operator. IF ENA = 1 and RON = 1, the block limits the output setpoints YASP and YBSP using the double cross method; in the opposite case, YASP and YBSP outputs are equal to the XASP and XBSP inputs.

The outputs of the unit are:
– ON is the signal informing about the current on/off state of the block operation mode,
– YASP, YBSP are the outputs of setpoints for the control systems of individual lines.

The ENA and RON inputs and the ON output are of the BOOL type, the remaining inputs and outputs are REAL type.

The DBLCROSS function block was implemented in the FBD and ST languages in the ISaGRAF environment mentioned in [4] in accordance with the EN 61131-3 standard [5] described also in [6] and [7].

5. Tests of the ball mill batching system with double cross calculation of setpoint capacities

The tests of the ball mill batching system with double cross setpoint calculation were carried out on the process line for the production of the mixture of two types of quicklime. One of the elements of this installation is the batching system with two belt weigh feeders – WA and WB, batching the material into the ball mill partially described in [8] and [9].

The capacity setpoints for the weigh feeders may be set by the operator in two modes:
– remote, when the capacity setpoints of the WA and WB weigh feeders are set independently,
– proportional, when the total capacity of the two weigh feeders is set together with the percentage contribution of the WB feeder to the total capacity.

The maximum capacity of each of the weigh feeders is 20 Mg/h. Due to the performance of the mill, the maximum total capacity of two feeders is limited to 30 Mg/h.

The tests included trials for:
– rapid (step) change of the capacity setpoint with a constant capacity ratio – a typical situation during the operation,
– disturbing the actual capacity of one of the lines – a typical situation during a fault.

The measurements were made for different values of the setting system parameters, assuming the equal values of corresponding parameters in the setting system ($k_A = k_B = k$ and $c_A = c_B = c$) in Formulas (15)–(18).

5.1. Rapid (step) change of capacity setpoint

Capacity setpoints were entered in the proportional mode. The contribution of the WB weigh feeder to the total capacity was set at 25%. The total capacity was set at 20.0 Mg/h, reduced to 5.0 Mg/h after the operation reaches steady state and then increased again to 20 Mg/h.

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The results of the measurements are presented in Table 1. The analysis of these data shows the small impact of the limiting block parameters on the mean variation of the capacity contribution of the WB feeder to the total capacity. This is a result of the fact that in transient conditions, the capacity regulators did not reach the saturation.

Table 1. Measurement results for rapid change of capacity setpoint

Event	**Value**	**Double cross limiting block**				
		off	**on $k = 0$, $c = 0.5$**	**on $k = 0$, $c = 0.1$**	**on $k = 0.1$, $c = 0.1$**	**on $k = 0.05$, $c = 0.1$**
Setpoint change from 20 Mg/h to 5 Mg/h	Mean contribution [%]	24.3	24.1	24.8	24.6	24.7
	Mean contribution deviation [%]	−0.7	−0.9	−0.2	−0.4	−0.3
	Max. contribution deviation [%]	−2.4	−2.5	−0.9	−0.8	−0.9
	Time for reaching the set state [s]	8.0	17.0	59.5	16.5	21.0
Setpoint change from 5 Mg/h to 20 Mg/h	Mean contribution [%]	25.4	25.7	25.2	25.3	25.3
	Mean contribution deviation [%]	0.4	0.7	0.2	0.3	0.3
	Max. contribution deviation [%]	2.7	2.3	0.9	0.8	1.0
	Time for reaching the set state [s]	8.0	16.5	60.0	17.0	23.0

The time for reaching the steady state was increased after the change of the total capacity setpoint. The double cross setting system caused the limitation of the speed of changing the setpoints for the capacity regulators, which led to a longer-lasting transient state. The duration was the longest for the most narrow ranges of possible setpoint variations ($k = 0$, $c = 0.1$). Applying the non-zero k coefficient reduces the transient state duration, because the ranges of possible setpoint changes grow with the increase of the actual capacity.

5.2. Capacity disturbances in one line

The results of measurements are presented in Table 2 (DC means double cross).

The capacity setpoints of the weigh feeders were set in the remote mode: WA – 15.0 Mg/h and WB – 5.0 Mg/h, which results in the contribution of the WB feeder capacity of 25%. After the stabilization of the operation, a disturbance was simulated by closing the sliding damper in the hopper over the belt. It caused the reduction of the actual capacity of the WB weigh feeder to approx. 2 Mg/h. Fig. 4 present the capacity waveforms and contribution of the WB feeder to total capacity.

The disturbance of the capacity was large enough to cause the saturation of the WB weigh feeder capacity regulator and the feeder actual capacity could not achieve setpoint, despite reaching the maximum speed of the belt. When the double cross block was on, the setpoint of the other weigh feeder was reduced, maintaining the proportion of the ingredients with the tolerance resulting from the parameters of the double cross limiting block.

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Table 2. Measurement results for capacity disturbances at lines A and B

Event	Value	Disturbance of the WA weigh feeder			Disturbance of the WB WB weigh feeder		
		DC system off	DC system on $k = 0$ $c = 0.5$	DC system on $k = 0.05$ $c = 0.1$	DC system off	DC system on $k = 0$ $c = 0.5$	DC system on $k = 0.05$ $c = 0.1$
Transient state at the start of the disturbance	Mean contribution [%]	31.2	27.9	27.3	8.8	21.1	23.1
	Mean contribution deviation [%]	6.2	2.9	2.3	−16.2	−3.9	−1.9
	Max. contribution deviation [%]	10.7	9.0	9.4	−21.1	−21.7	−21.9
	Time for reaching the steady state [s]	1.5	2.3	2.8	3.3	12.8	29.7
Steady state of the disturbance	Mean contribution [%]	29.4	27.3	26.4	11.8	23.6	23.8
	Mean contribution deviation [%]	4.4	2.3	1.4	−13.3	−1.4	−1.2
	Max. contribution deviation [%]	4.5	2.4	1.5	−13.4	−1.6	−1.4
Transient state after the disturbance ends	Mean contribution [%]	24.0	23.9	24.0	35.7	30.6	31.7
	Mean contribution deviation [%]	−1.0	−1.1	−1.1	10.7	5.6	6.7
	Max. contribution deviation [%]	−4.6	−6.7	−6.2	29.6	48.6	50.3
	Time for reaching the steady state [s]	5.0	5.0	5.0	3.0	6.0	6.0

The analysis of the data for the disturbance of the WB weigh feeder presented in Table 2 shows that the WB contribution in total capacity in the steady state improved from 11.8% in the case of the double cross limiting block was turned off to 23.8% with the system switched on. Improvement is also visible in the transient state. Larger deviations in the transient state after the disturbance is resolved are acceptable due to the short duration of the transient state and additional averaging of the mixture composition in the mill.

Similarly to the first test including the rapid change of the capacity setpoints, the duration of the transient state depends on the width of ranges of possible setpoint variations. Narrowing the variation ranges for setpoints increases the accuracy of maintaining the ingredients capacity ratio. However, the time required to reach the steady state increases significantly. Advantageous operational properties – required accuracy of the capacity ratio and acceptable durations of transient states – may be achieved by choosing k_A, c_A, k_B, c_B parameter values greater than zero. Such values of k_A and k_B ensure the increase of the range of setpoint variations with increased capacity – this reduces the time required to reach the steady state while maintaining the constant deviation of the capacity ratio between both lines. The non-zero value of the c_A and c_B constants enables the start of the line.

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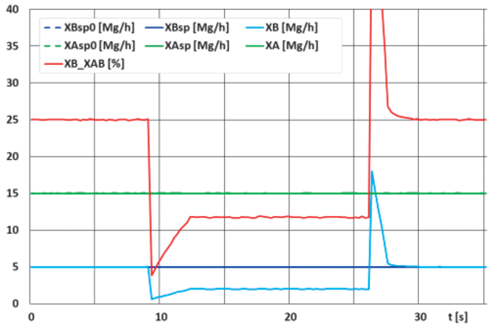
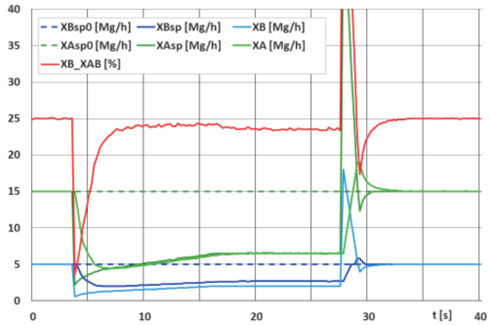


(a)



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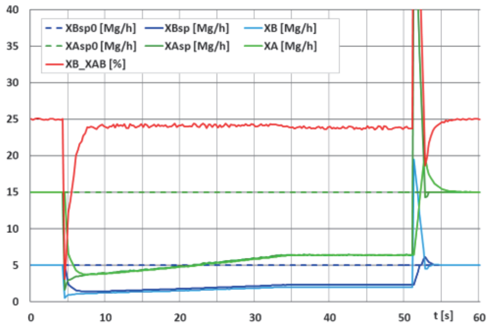

(c)

Fig. 4. Disturbance of the WB weigh feeder capacity with the double cross function block: turn off (a); turn on and $k = 0$, $c = 0.5$ (b); turn on and $k = 0.05$, $c = 0.1$ (c)

Similar tests were also carried out for the WA weigh feeder with its capacity damped to 12 Mg/h at full belt speed. The character of the waveforms is similar to those presented in Fig. 4. The deviations of the contribution of the WB weigh feeder in the total capacity were on a similar level.

6. Conclusions

The article presents the application of the setpoint calculation method with mutual cross limitations, known as the double cross method, in the system controlling the efficiencies of two weigh feeders in the process line for milling and mixing two sorts of lime. The application of this method enabled the maintenance of the proportions between the ingredients in the case of problems with batching one of the ingredients, due to – for example – blocking of the material in the hoppers suppling the material on the weigh feeders.

The standard double cross setting algorithm, typically used for setting the composition of the fuel and air mixture supplying the burners of furnaces cannot be directly applied to calculate capacity setpoints of weigh feeders, due to the inability to start the system. This is a result of the zero value of actual capacities during line stop, where the typical double cross algorithm forces zero setpoint values for the weigh feeders.

The authors proposed a modification of the functions calculating the limitations in the setpoint calculation system by introducing a constant component while calculating the setpoint variation ranges in addition to the component proportional to the actual capacity. This modification enables the start of the process line without any additional start-up procedures, such as initial capacity setpoints with the double cross system switched off, starting the weigh conveyors and switching on the double cross limiting system. The elimination of the start-up procedures simplifies the control software for the process line.

The developed function block was coded in languages compliant with the EN61131-3 standard, which enables its use on various programmable controller platforms.

The tests and trials of the control system on the lime milling and mixing process line confirmed the assumptions and the effectiveness of the modified setting system. The proposed and implemented control system is capable of keeping the deviations in the lime mixture composition within acceptable limits for typical disturbances occurring during the operation.

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