Solution algorithms of an automated control system for a technological process of thermal vortex enrichment

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Abstract. As a part of the development of a comprehensive resource-saving technology and the organization of high-tech production of nanostructures based on carbon and silicon dioxide to improve the properties of building and structural materials, the algorithms for the software package Automated Control System for the Technological Process for Obtaining Concentrates of MD1 and MD2 Nanostructures are described in part providing thermal vortex enrichment. Algorithms have been developed for controlling an analog value according to the PID control law, stopping the production line in emergency mode, and regenerating bag filters as they become clogged. The purpose and characteristics of the processes, the information used, the results of the solution, the decision algorithms and the requirements for the test example are described.

1. Introduction

To create the ecological technologies [1-5] and software package "Automated control system for the technological process of obtaining concentrates of nanostructures MD1 and MD2" in terms of providing thermal vortex enrichment [6-10], a survey was carried out that revealed processes subject to control by an analogue value according to the PID control law such as control of frequency drives, thyristor converters , positioners, and other equipment controlled by an analogous unified signal, with the possibility of manual control and automatic regulation of various process parameters. For such processes, as well as processes in energetics [11-15], shutdown of the production line in emergency mode, regeneration of bag filters as they become clogged, algorithms of automated processes have been developed. The purpose and characteristics of the processes, the information used, the results of the solution, the decision algorithms, and the requirements for the test example are described.

2. PID controller

This algorithm is designed to control the analog value according to the PID control law.

It is used to control frequency drives, thyristor converters, positioners, and other equipment, which are controlled by a unified analog signal, with the possibility of manual control and automatic regulation of various process parameters.

The output is presented in table 1, the intermediate and temporary in table 2, the output in table 3.

Table 1. Input data for the PID controller.

No	Name of the input information array	Description	Data type	Value range	Notes
1	COM_RST	Resetting the controller (restart)	Bool		
2	MAN_ON	Manual control	Bool		
3	P_SEL	Inclusion of the P-component of the law	Bool		
4	I_SEL	Inclusion of the I-component of the law	Bool		
5	D_SEL	Inclusion of the D-component of the law	Bool		
6	NEG	Inverting the operation of the controller	Bool		
7	CYCLE	Block call time	Time	T#1ms .. T#9999s	
8	SP_INT	Regulation task	Real		
9	PV_IN	Adjustable value	Real		
10	MAN	Manual output value	Real	0 .. 99999	
11	GAIN	Gain	Real		
12	TI	Integration time	Time	> = CYCLE	
13	TD	Differentiation time	Time	> = CYCLE	
14	DEADB_W	Dead zone	Real	> = 0.0	
15	LMN_HLM	The upper limit of the output quantity	Real	LMN_LLM ...100.0	
16	LMN_LLM	Lower output limit	Real	-100.0 ... LMN_HLM	

Table 2. Temporary and intermediate data for the PID controller.

No	Name of the input information array	Description	Data type	Value range	Notes
1	LMN	Control quantity	Real	LMN_LLM .. LMN_HLM	
2	STD_PID	PID Continuous Controller Block	CONT_C		
3	RETURN_VAL	Return value	Word		
4	NGAIN	Inverted Gain	Real		

Table 3. Output data for the PID controller.

No	Name of the input information array	Description	Data type	Value range	Notes
1	PV	Adjustable value	Real		
2	ER	The amount of mismatch (error)	ER		
3	LMN_VAL	DAC control value	Int	0 .. 27648	

Figure 1 shows the solution algorithm.

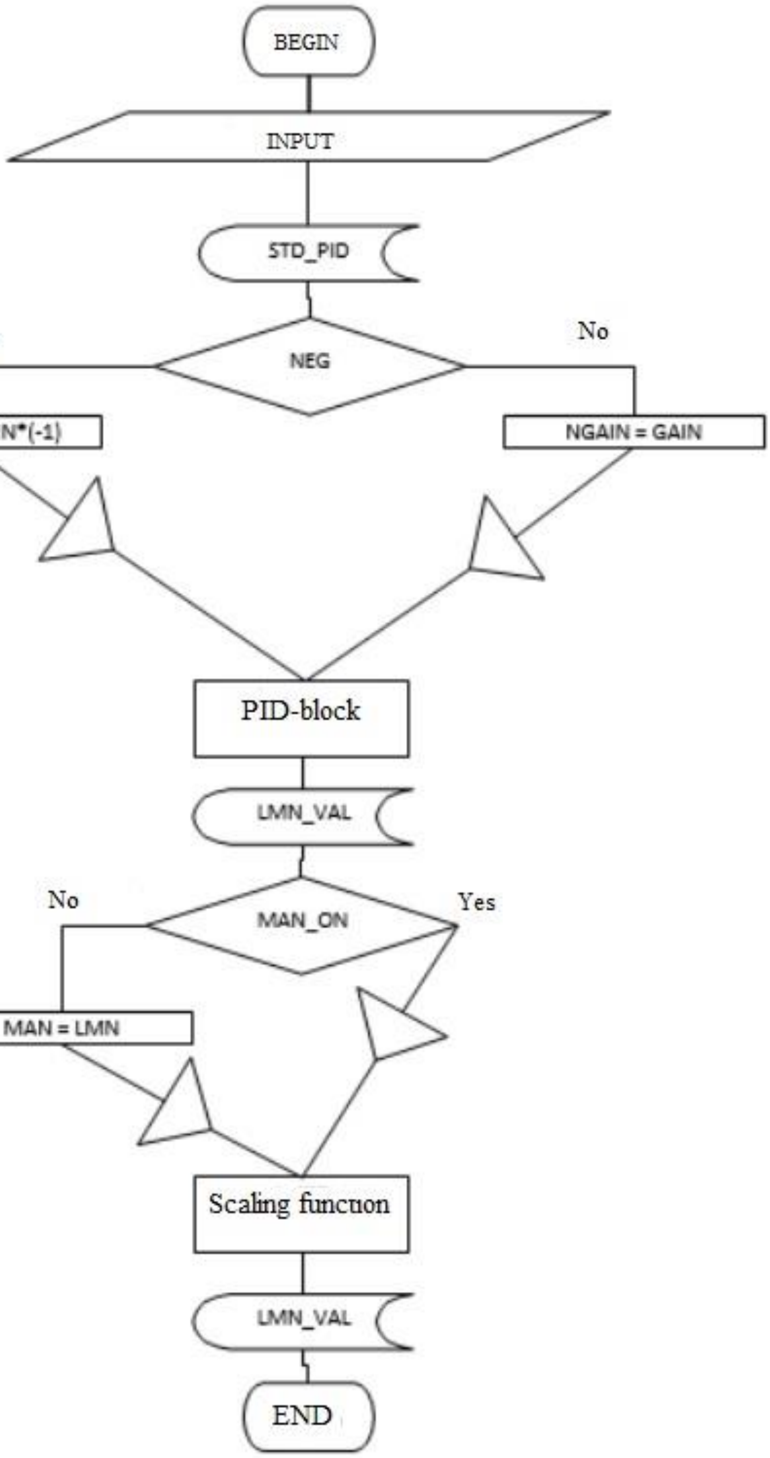

Figure 1. Solution algorithm for the PID controller.

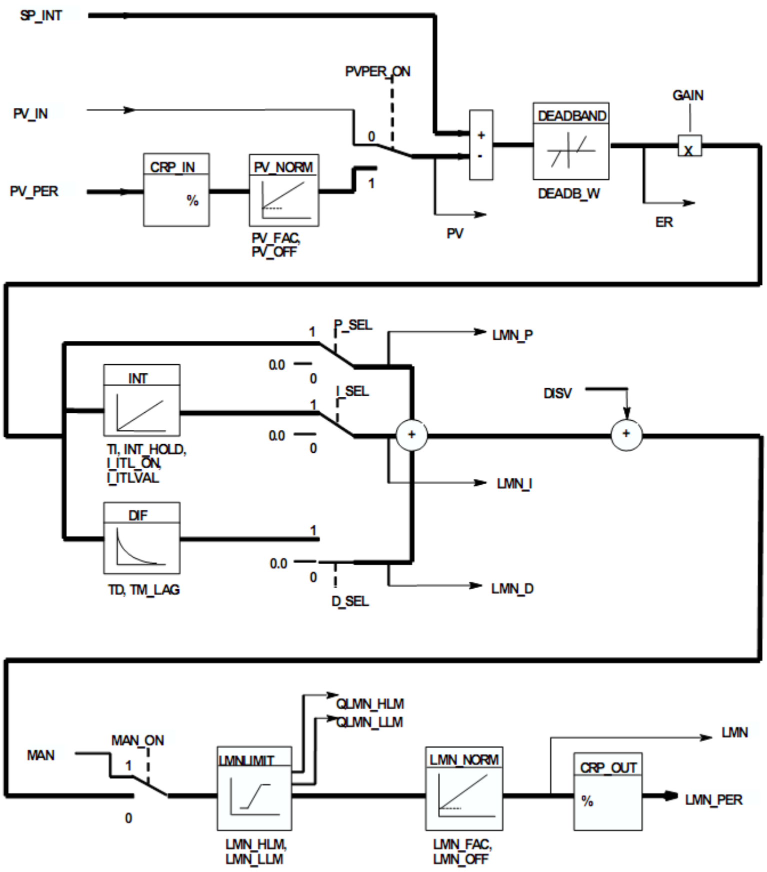

Figure 2. Solution scheme for the PID controller.

Test Case Requirements.
The input data is selected from valid ranges of values (table 4).

Table 4. Valid input data for the PID controller.

No	Name of the input information array	Choice for testing
1	COM_RST	False
2	MAN_ON	Check the operation with manual control - True, in automatic mode - False
3	P_SEL	True, False
4	I_SEL	True, False
5	D_SEL	True, False
6	NEG	True, False
7	CYCLE	T#100ms
8	SP_INT	n the range of values, PV_IN ± 5%
9	PV_IN	In the range of values
10	MAN	In the range of values
11	GAIN	In the range of values
12	TI	In the range of values
13	TD	In the range of values
14	DEADB_W	In the range of values
15	LMN_HLM	In the range of values
16	LMN_LLM	In the range of values

The output is presented in table 5.

Table 5. Test results for the PID controller.

No	Name of the input information array	Test results
1	PV	Value PV_IN
2	ER	Numeric value - difference between PV_IN - SP_INT
3	LMN_VAL	With MAN_ON = False, the numerical value of the calculated output value in the format for the DAC is according to the regulation law established by P_SEL, I_SEL, D_SEL and the parameters GAIN, TI, TD. When NEG = False, it works in reverse mode (“cooler”). With MAN_ON = True LMN_VAL = MAN

3. Emergency stop

This algorithm is designed to stop the production line in emergency mode.

It is used to stop the line depending on the state of the process equipment, as well as the values of the process parameters

The output is presented in table 6, the intermediate and temporary in table 7, the output in table 8.

Table 6. Input data for emergency stop.

No	Name of the input information array	Description	Data type	Value range	Notes
1	P_out_topk	The pressure at the beginning of the swirl tube	Real		
2	M1_1_on	Blower M1-1. Job.	Bool		
3	M1_1_alarm	Blower M1-1. Frequency Drive Failure	Bool		
4	M2_1_on	Smoke exhaust M2-1. Job.	Bool		
5	M2_1_alarm	Smoke exhaust M2-1. Frequency Drive Failure	Bool		
6	M3_1_on	Drive auger feed material M3-1. Job	Bool		
7	M3_1_alarm	Drive auger feed material M3-1. Frequency Drive Failure	Bool		
8	T_cool	Air flow temperature in the cooling duct	Real		
9	T_vozd_out	Air temperature at the outlet of the combustion chamber	Real		
10	Poloz_5_1	Gate 5-1c position	Real		
11	FREQ_M1_1	Blower M1-1. Rotation frequency	Real		
12	FREQ_M2_1	Smoke exhaust M2-1. Rotation frequency	Real		

Table 7. Temporary and intermediate data for emergency stop.

No	Name of the input information array	Description	Data type	Value range	Notes
1	P_out_topk_Low	Lower pressure value at the beginning of the vortex enrichment pipe	Real		
2	T_cool_Hi	The upper value of the air flow temperature in the cooling duct	Real		
3	T_vozd_out_Low	Lower air temperature at the outlet of the combustion chamber	Real		
4	T_vozd_out_Hi	The upper value of the air temperature at the outlet of the combustion chamber	Real		
5	T_vozd_out_cool	The value of the air temperature at the outlet of the combustion chamber to turn off the M2-1 blower	Real		

Table 8. Output for emergency stop.

No	Name of the input information array	Description	Data type	Value range	Notes
1	M1_1_toff	Blower M1-1. Switch off	Bool		
2	M2_1_toff	Smoke exhaust M2-1. Switch off	Bool		
3	M3_1_toff	Drive auger feed material M3-1. Switch off	Bool		
4	Burn_block	Burner. Lock	Bool		

Solution Algorithm:
1. Start
2. Data entry (receiving information about the parameters):
- P_out_topk
- T_cool
- T_vozd_out
- M1_1_on
- M1_1_alarm
- M2_1_on
- M2_1_alarm
- M3_1_on
- M3_1_alarm
3. Condition (emergency check)
- (P_out_topk<P_out_topk_Low and FREQ_M2_1 = 100) or
- (T_cool>T_cool_Hi and Poloz_5_1 = 100) or
- T_vozd_out<T_vozd_out_Low or
- (T_vozd_out>T_vozd_out_Hi and FREQ_M1_1) or
- M1_1_on = false or
- M1_1_alarm = true or
- M2_1_on = false or

- M2_1_alarm = true or
- M3_1_on = false or
- M3_1_alarm = true

If any of the conditions is fulfilled, then the actions from paragraph 4 are performed.
If not, the survey again occurs.

4. Actions (actions to be taken in the presence of an emergency)

- Burn_block = true
- M1_1_toff = true
- M2_1_toff = true

After the action is completed, the condition from paragraph 5 is checked.

5. Condition (check whether the air from the combustion chamber has cooled down)

- T_vozd_out<T_vozd_out_cool

If the condition is met, then the action from paragraph 6 is performed, otherwise 7.

6. Action (completion of the emergency stop process)

- M3_1_toff = true

7. The end

Test Case Requirements
The input data is selected from the valid ranges of values (table 9).

Table 9. Valid input values for emergency stop.

No	Name of the input information array	Choice for testing
1	P_out_topk	In the range of values
2	M1_1_on	False
3	M1_1_alarm	True
4	M2_1_on	True
5	M2_1_alarm	True, False
6	M3_1_on	True
7	M3_1_alarm	True
8	T_cool	In the range of values
9	T_vozd_out	In the range of values
10	Poloz_5_1	In the range of values
11	FREQ_M1_1	In the range of values
12	FREQ_M2_1	In the range of values
13	P_out_topk	In the range of values

The output is presented in table 10.

Table 10. Test results for emergency stop.

No	Name of the input information array	Test results
1	M1_1_toff	True
2	M2_1_toff	True
3	M3_1_toff	True
4	Burn_block	True

4. Bag filter regeneration

This algorithm is designed to regenerate bag filters as they become clogged.

Input data is represented in type REAL (table 11), INT; output data in REAL type (table 12).

Table 11. Input data for the regeneration of bag filters.

No	Name of the input information array	Description	Data type	Value range	Notes
1	P_filtr_razn	Pressure difference in clean and dirty bag filter chambers	Real		
2	N_open	Number of openings of the filter bag regeneration valves	Real		
3	T_open	Regeneration valve open time	Real		
4	T_close	Regeneration Valve Closed Time	Real		
5	P_filtr_max	The pressure difference in the filter chambers at which regeneration starts	Real		
6	FREQ_M2_1_reg	The value of the rotation speed of the exhaust fan M2_1 during the regeneration of filters	Real		

Table 12. Output data for the regeneration of bag filters.

No	Name of the input information array	Description	Data type	Value range	Notes
1	Air_filtr_reg	Bag Filter Regeneration Signal	Bool		
2	M3_1_toff	Drive auger feed material M3-1. Switch off	Bool		
3	C_FREQ_M2_1	Smoke exhaust M2-1. Speed control	Real		

Solution Algorithm:
1. Start
2. Data entry (receiving information about the parameters):
- P_in_filtr
- P_in_filtr
3. The calculation
- P_filtr_razn = P_in_filtr- P_in_filtr
4. Condition (comparison of pressure difference with the maximum allowable)
- P_filtr_razn>P_filtr_max
When the condition is met, the action in paragraph 5 is performed.
5. Action (regeneration starts)
- the output parameter Air_filtr_reg is set to true
- M3_1_toff = true
- C_FREQ_M2_1 = FREQ_M2_1_reg
- Air_filtr_reg takes true for the time set by the T_open parameter, then there is a pause equal to the time set in the T_close parameter. The closing opening cycle is repeated the number of times set in the N_open parameter
6. Action (upon completion of regeneration)
- M3_1_ton = true
7. The end

Test Case Requirements
Input data are selected from the valid ranges of values (table 13).

Table 13. Input Values for Bag Filter Regeneration.

No	Name of the input information array	Choice for testing
1	P_in_filtr	0.6
2	P_out_filtr	0.0
3	P_filtr_razn	0.6
4	P_filtr_max	0.5
5	N_open	9
6	T_open	2.0
7	T_close	2.0
8	FREQ_M2_1_reg	50

The output is presented in table 14.

Table 14. Test results for emergency stop.

No	Name of the input information array	Test results
1	Air_filtr_reg	True
2	M3_1_toff	True
3	C_FREQ_M2_1	50
4	Burn_block	True

5. Conclusion

The use of algorithms for controlling the analog value according to the PID law of regulation, stopping the production line in emergency mode, regeneration of bag filters as they become clogged up as part of the Automated Process Control System for the Preparation of MD1 and MD2 Nanostructure Concentrates program in terms of providing thermal vortex enrichment will provide:

- continuous technological control of equipment operation and parameters of the technological process of thermal vortex enrichment;
- process safety in the production of MD1;
- collection of data on technological processes and equipment operation, their processing, display and documentation;
- optimization of the technological process through the use of developed visualization tools, modern control algorithms and analysis of accumulated technological information;
- minimizing the influence of the human factor on the processes of collecting and processing information about the technological process;
- automatic prevention of emergency situations.

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