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Supervision System of a FCC Plant

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Abstract

The fluid-catalytic cracking is one of the most important processes in the petrochemical industry. The catalysts performance and advanced control of the cracking catalytic plant contributes to increasing the profit and gasoline production. One component of the advanced control is represented by the supervision system. The purpose of this study is to develop a supervision system of the catalytic cracking process. The paper is structured in: presentation of the conventional control of the process, elaborating and testing the supervision system. The author is testing the possibility of implementation in real time of the supervision system, using real data from the industry.

Key words: *fluid catalytic cracking, advance control*

Introduction

The fluid catalytic cracking unit (FCCU) is the dominant conversion process in petroleum refineries, which ensure the heavy fractions oil into gasoline with high octane. This process consists of two interconnected sub processes: the sub process riser-reactor and the sub process regenerator. In the riser-reactor sub process take place almost all the endothermic cracking reactions and coke deposition on the catalyst occurs. In the regenerator sub process takes place the reactivation of the catalyst by burning the coke accumulated on the catalyst. The heat produced is carried by the catalyst from regenerator to reactor, in order to assure the endothermic cracking reactions. A typical image of the cracking catalytic process is presented in Figure 1.

The FCCU is difficult to control due to: i) the nonlinear properties of the process; ii) the strong interaction between the variables of the process; iii) the multivariable properties of the process; iv) a big difference between time constants of the process; v) the necessity to control system with changing operating conditions in the presence of unmeasured disturbances. For processes with these features, it is indicated the utilization of supervisory systems.

The control problem of the FCCU has been approached under various aspects in numerous works. Some works deal with conventional process control [1, 2] and another category of papers deal with the model predictive control [3, 4, 5, 6]. A much more reduced category of works deal with aspects of the neural network model predictive control of the FCCU [7, 8].

However, the supervisory controllers applied to FCCU are insufficient treated. In these conditions, the author has focused to bring some relevant contributions on supervisory control for the fluid catalytic cracking.

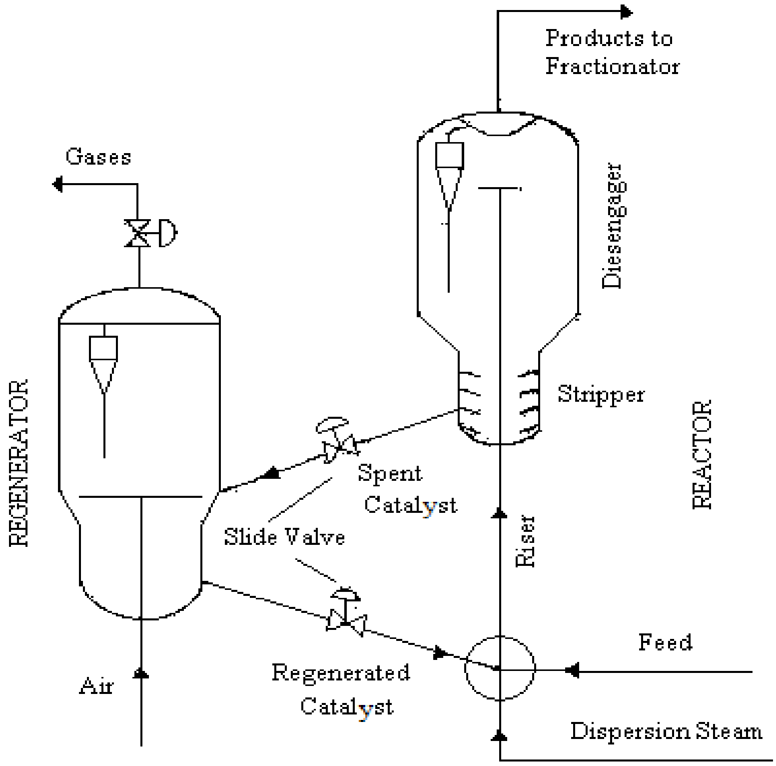


Fig. 1. Fluid catalytic cracking process [10].

Conventional Control Process

In present, in the Romanian refineries, the catalytic cracking plant is built under UOP license and contains the following elements: the riser reactor, the regenerator and the preheating oven for the feedstock. The conventional structure, presented in Figure 2, contains the following mono-variable control loops [9]:

- the catalyst level control system in stripper (SRA-1 in fig. 2);
- the control system associated to pressure drop on the valve RR1(SRA-2 in fig. 2);
- the control system of stripper temperature (presented in fig. 2 as SRA-3);
- the control system associated to the pressure drop on the valve RR2 placed on the transportation pipe of the regenerated catalyst (SRA-4 in fig. 2);
- the control system of the pressure drop $\Delta P=P_2-P_3$ between reactor and regenerator (presented in fig. 2 as SRA-5);
- the control system of the temperature difference between the upper and the bottom part of the regenerator (SRA-6 in fig. 2).

This conventional control structure maintains stabile working point of the process, but it cannot reject the effect of interactions of process variables, respectively the interactions between the control loops. The variable interaction is leading to an economically inefficient operating mode of the plant.

The dynamic test performed by the author proves the multivariable features of the catalytic cracking process [9]. In this case, the author proposes the opportunity for designing of a new control system in order to reject the multi-variable interactions of the plant.

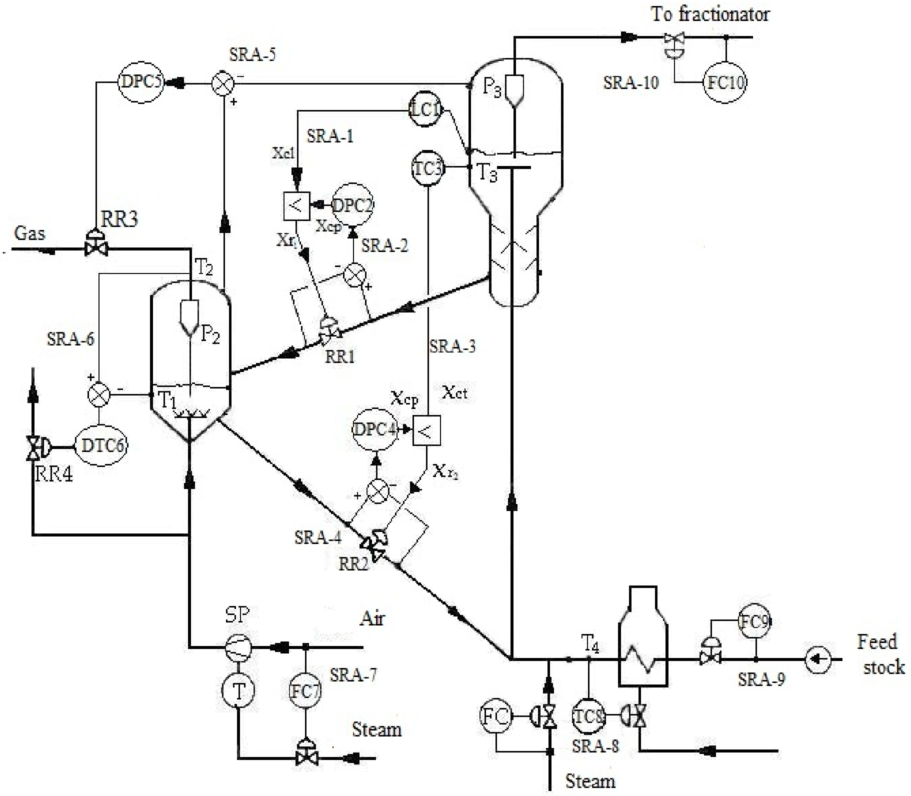


Fig. 2. Conventional control structure [9]

Proposed Supervisory System

From the automatic control point of view, the catalytic cracking process is a multivariable system, with a nonlinear behaviour and strong interactions between variables of the process and between the control loops. The requirements to control structure associated to the catalytic process are [10]:

- safety in operation, through an adequate protection system;
- ensuring an operating regime without overshoots, using a multivariable control that can reduce the effect of the interactions;
- answer to specific quality objectives of the process, which suppose ensuring a conversion efficiency in the reactor (in riser) and a good combustion in the regenerator;
- answer to specific economic objectives, represented by maximizing of the yield gasoline, having the research octane number imposed.

Taking into account these requirements, the author has elaborated the supervisory system presented in Figure 3.

The supervisory system contains two hierarchical levels: the first level is represented by conventional control of the process and the second level contains the advance control. The advanced control can be a model predictive control, a neuronal network predictive control, or a fuzzy logical control.

In this paper it is tested the model predictive control. The objectives of the predictive controller are riser outlet temperature control and temperature regenerator control.

The input variables associated to the predictive controllers are represented by the disturbance variable (feedstock flow and temperature – Q_{feed}, T_{feed} and T_{reg1} – the regenerated catalyst temperature), the set points that are calculated at the high level (optimal riser temperature riser – T_r^i and optimal regenerator temperature - T_{reg}^i) and reaction variable process (riser temperature – T_r and regenerator temperature - T_{reg}). The manoeuvred variables are the regenerated catalyst flow rate - Q_{cat1} and the air flow in the regenerator - Q_{air}.

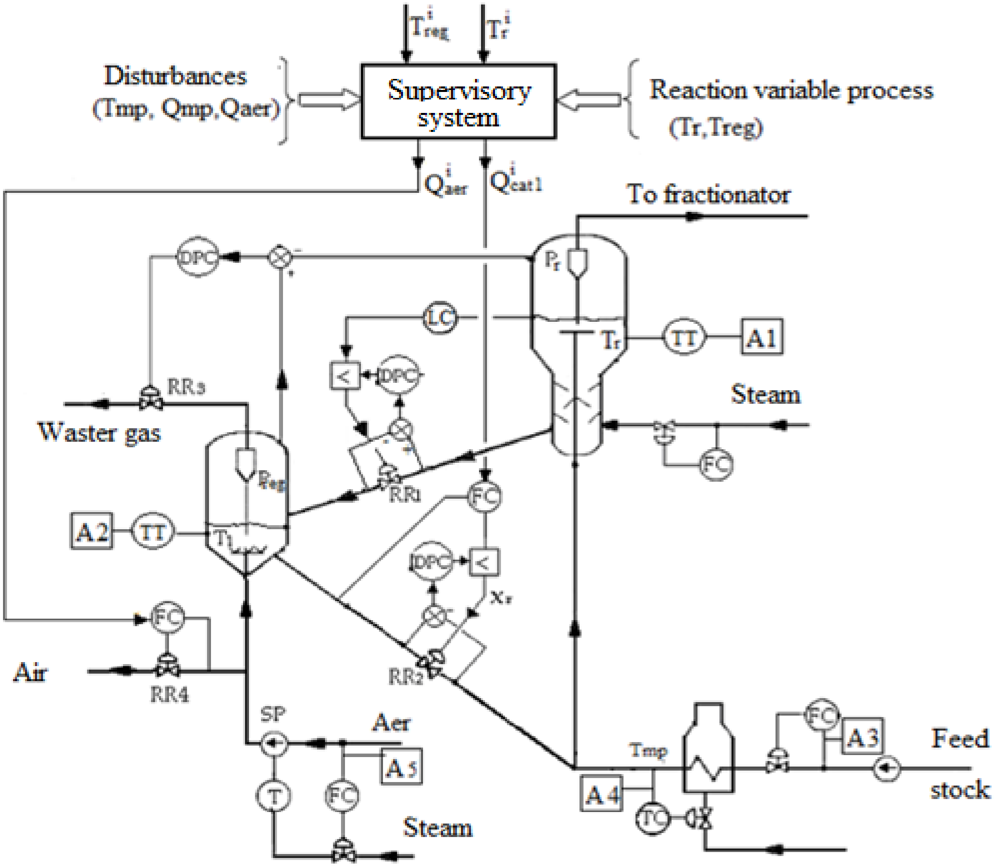


Fig. 3. Supervisory system for the FCC Plant.

Testing the Supervision System

The goal of the supervision system is to study the dynamic behaviour of the catalytic cracking process and training the operating personnel.The predictive model used is presented by the author in paper [10]. The supervision system was numerically tested around the operating point, table 1.

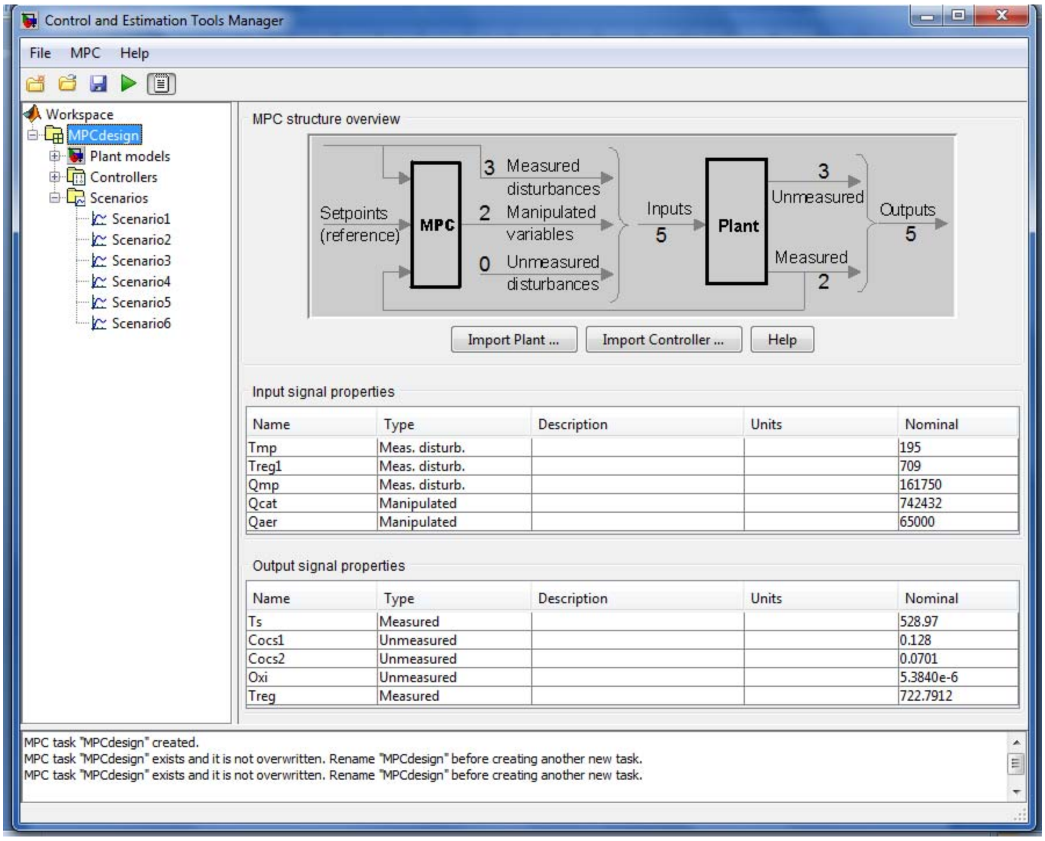
The testing of the supervisory system consists of modifying the set point (outlet riser temperature T_r, the regenerator temperature T_{reg}), and the disturbances that appear in the process (the feed stock flow T_{mp}, and the regenerated catalyst temperature T_{reg1}). The interface of the simulator associated to the supervisory system is presented in Figure 4 and it uses the Matlab Control tools in order to develop the simulator.

In Figure 5 it is presented the evolution in time of the riser outlet temperature T_r, and the regenerator temperature T_{reg1}, together with the manoeuvred variables associated (regenerated catalyst flow rate Q_{cat1} and air flow Q_{air}), when the references of the controller are modified in step variations. As seen from the above trends, the controller system successfully brings the output values to the set point values, without state steady.

In Figure 6 it is presented the evolution in time of the riser outlet temperature T_r, and the regenerator temperature T_{reg1}, together with the manoeuvred variables associated (regenerated catalyst flow rate Q_{cat1} and air flow Q_{air}), when the disturbances of the system are modified in step variations. As seen from the above trends, the controller system eliminates the effect of the distributions which appear in the process.

Table 1. Values of the variables around the operating point.

Parameters	Variable	Value	Fundamental units
Feedstock temperature	T_{mp}	195	^{0}C
Riser temperature	T_{reg1}	709	^{0}C
Feedstock flow	Q_{mp}	161750	kg/h
The rapport catalyst/ feedstock flow	a	4.59	-
Interfusion nod temperature	T_{nod}	573	^{0}C
Riser temperature	T_r	528	^{0}C
Striper temperature	T_s	528	^{0}C
Mass fraction of coke on catalyst in striper	C_{cocs2}	0.13	-
Regenerator temperature	T_{reg}	722	^{0}C
Mass fraction of coke on spent catalyst	C_{cocs3}	0.77	-



Input signal properties

Name	Type	Description	Units	Nominal
Tmp	Meas. disturb.			195
Treg1	Meas. disturb.			709
Qmp	Meas. disturb.			161750
Qcat	Manipulated			742432
Qaer	Manipulated			65000

Output signal properties

Name	Type	Description	Units	Nominal
Ts	Measured			528.97
Cocs1	Unmeasured			0.128
Cocs2	Unmeasured			0.0701
Oxi	Unmeasured			5.3840e-6
Treg	Measured			722.7912

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Fig. 4. The simulator for the supervisory system.

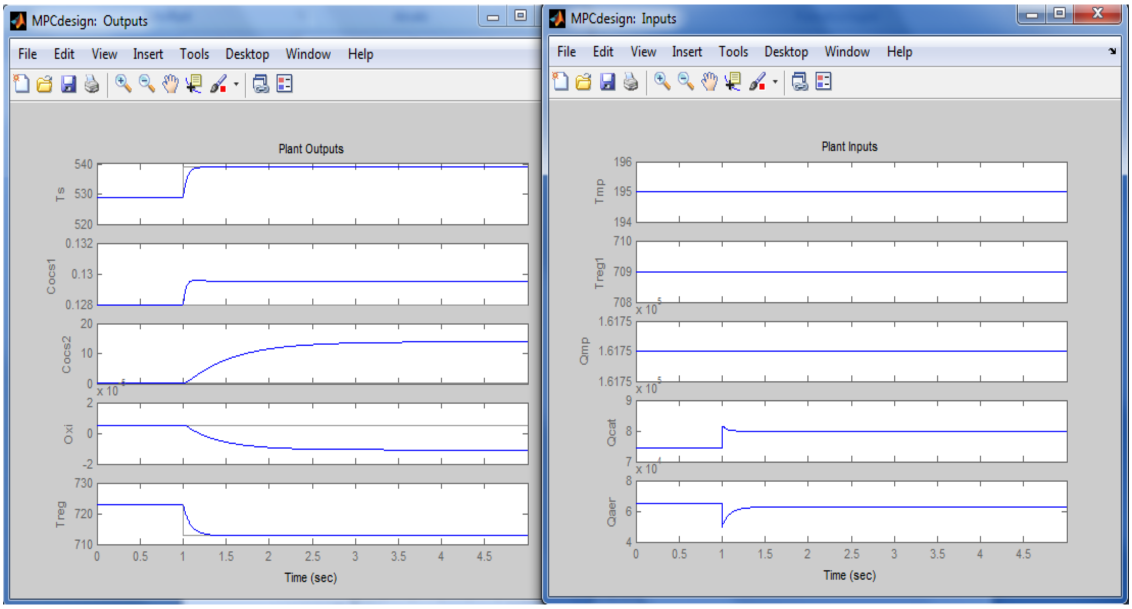


Fig. 5. The dynamic evolution of the riser outlet temperature and regenerated catalyst flow when the controller setpoints – *Tr* increases from 529 °C to 539 °C and *Treg* increase from 722 °C to 712 °C.

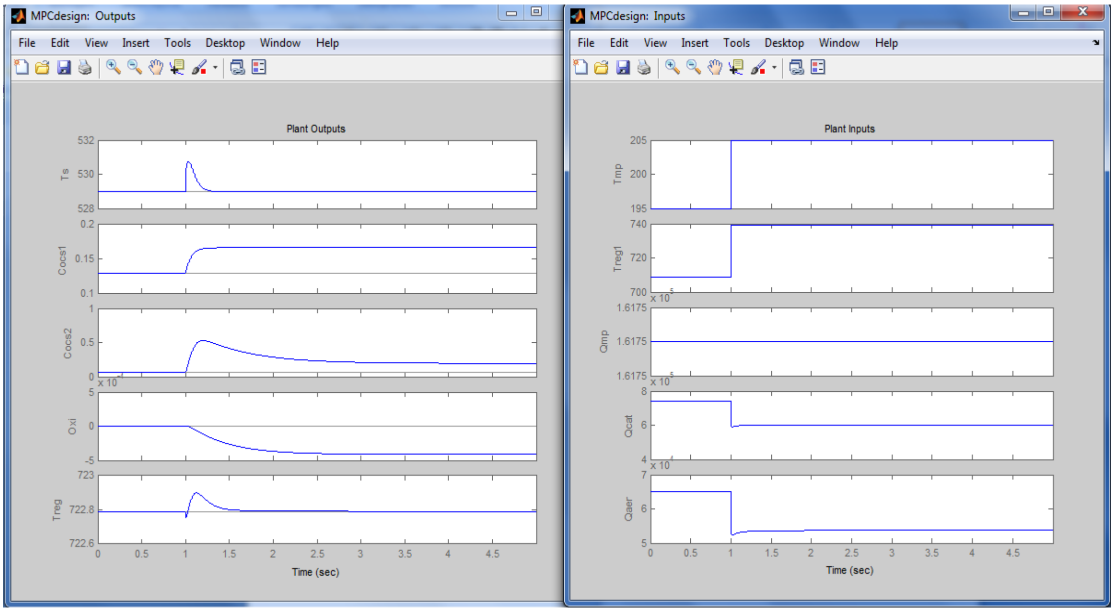
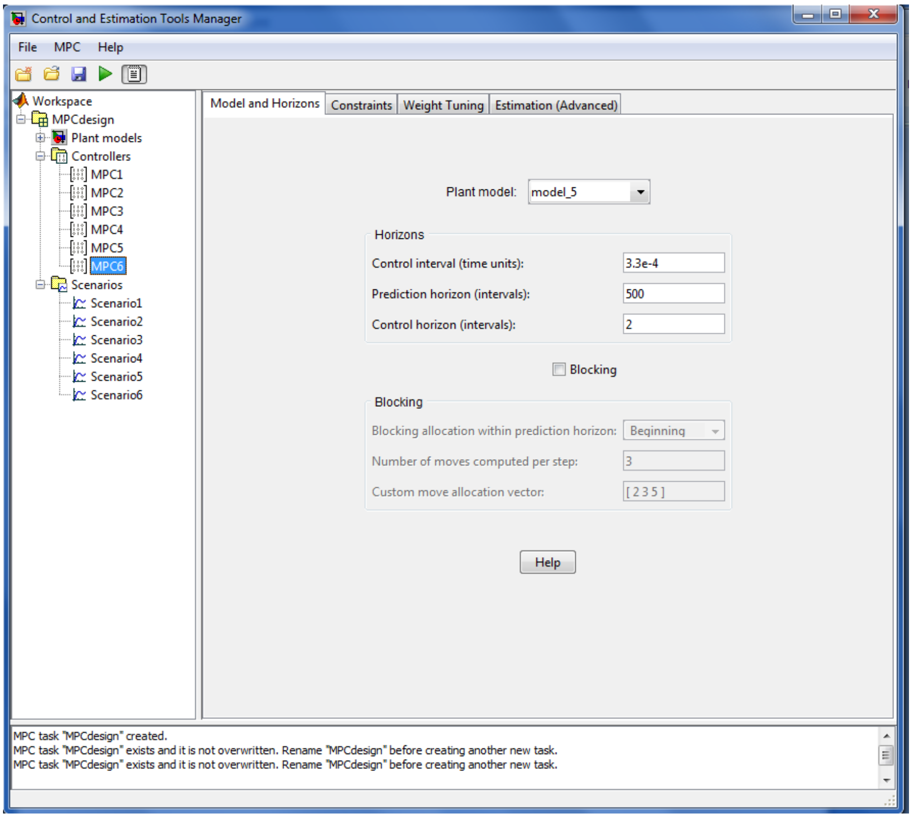


Fig. 6. The dynamic evolution of the riser outlet temperature and regenerated catalyst flow when the disturbance – T_{mp}increases from 195 °C to 205 °C and T_{reg1}increase from 790 °C to 820 °C.

For the model predictive controller, there are considered the following default simulation parameters: prediction horizon $p = 500$ intervals; control interval $T = 3.3\text{e-}4\text{h}$; control horizon $M = 2$ control intervals, Figure 7. The values of the tuning parameters are experimentally obtained, in order to achieve the best dynamic performance of the controller.



Plant model: model_5

Control interval (time units): 3.3e-4

Prediction horizon (intervals): 500

Control horizon (intervals): 2

☐ Blocking

Blocking allocation within prediction horizon: Beginning

Number of moves computed per step: 3

Custom move allocation vector: [2 3 5]

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Fig. 7. The controller parameters.

Conclusion

The aim of this paper was to build the supervisory system for the catalytic cracking process. The structure of the supervisory system contains two levels: conventional control of the process and advanced control level. The principal objective of this paper is to test the model predictive controller associated to the second level. As seen from the above trends, the behaviour of the control system was studied for different values of the set point. One can also observe that the process output values follow the set point value within the best dynamic performance.

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Sistem de supervizare pentru procesul de cracare catalitică

Rezumat

Procesul de cracare catalitică este unul dintre cele mai importante procese din industria petrochimică. Performantele noilor catalizatori şi reglarea avansată aplicată procesului de cracare catalitică pot contribui la creşterea profitului şi a producţiei de benzină. O componentă a reglării avansate este reprezentată de un sistem supervizor. Obiectivul acestei lucrări este de a dezvolta un sistem de supervizare pentru procesul de cracare catalitică. Lucrarea este structurată în: prezentarea structurii convenţionale a procesului, elaborarea şi testarea sistemului de supervizare. Autorul a testat posibilitatea de implementare in timp real a sistemului de supervizare, utilizând date din industrie.