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Solving the Problem of Synthesis of an Automatic Control System for a Distillation Column

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Abstract

The oil refining and petrochemical industries are considered to be the leading sectors of the national economy. The purpose of these facilities is to ensure the production of a wide range of high-quality petroleum products from crude oil. The requirements for quality indicators of various petroleum products produced at these technological facilities require the creation of more modern and advanced control systems. It should be noted that one of the main problems of control theory is the creation and development of new control systems capable of adequately responding to more dynamically changing external and internal stimuli for complex oil refining technological complexes in accordance with the requirements of the time. Therefore, it is relevant to create new automated control systems capable of providing the required accuracy of quality control.

Keywords: distillation column, transfer function, controller, control system, dynamic characteristics.

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Distillə kalonunun avtomatik idarəetmə sisteminin sintezi məsələsinin həlli

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Xülasə

Neft emalı və neft-kimya sənayesi xalq təsərrüfatının aparıcı sahələri hesab olunur. Bu qurğuların məqsədi xam neftdən yüksək keyfiyyət göstəricilərinə malik geniş çeşiddə neft məhsullarının istehsalını təmin etməkdən ibarətdir. Bu texnoloji qurğularda istehsal olunan müxtəlif neft məhsullarının keyfiyyət göstəricilərinə qoyulan tələblər daha müasir və mükəmməl idarəetmə sistemlərinin yaradılmasını tələb edir. Qeyd etmək lazımdır ki, hal-hazırda dövrün tələblərinə uyğun olaraq mürəkkəb neft emalı texnoloji kompleksləri üçün daha dinamik dəyişən xarici və daxili həyəcanlandırıcı təsirlərə adekvat reaksiya göstərə bilən yeni idarəetmə sistemlərinin yaradılması və inkişaf etdirilməsi idarəetmə nəzəriyyəsinin qarşısında duran əsas problemlərdən biridir. Buna görə də keyfiyyət baxımından idarəetmədə tələb olunan dəqiqliyi təmin edə bilən yeni avtomatlaşdırılmış idarəetmə sistemlərinin yaradılması aktualdır.

Açar sözlər: distillə kalonu, ötürmə funksiyası, kontroller, idarəetmə sistemi, dinamik xarakteristikalar.

Решение проблемы синтеза системы автоматического управления ректификационной колонной

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Аннотация

Нефтеперерабатывающая и нефтехимическая промышленность считаются ведущими отраслями народного хозяйства. Цель этих предприятий - обеспечить производство широкого спектра высококачественных нефтепродуктов из сырой нефти. Требования к показателям качества различных нефтепродуктов, производимых на этих технологических объектах, требуют создания более современных и совершенных систем управления. Следует отметить, что одной из основных проблем теории управления является создание и развитие новых систем управления, способных адекватно реагировать на более динамично изменяющиеся внешние и внутренние факторы для сложных нефтеперерабатывающих технологических комплексов в соответствии с требованиями времени. Поэтому актуальным является создание новых автоматизированных систем управления, способных обеспечить требуемую точность контроля качества.

Ключевые слова: дистилляционная колонна, передаточная функция, контроллер, система управления, динамические характеристики.

Introduction

The experience of operation of numerous complex technological objects in various branches of oil refining industries has shown that the characteristic features of these complex technological processes are mainly the following [1]: complexity of devices as control objects; the feedstock arriving at the refining enterprise varies within rather wide limits both in terms of consumption and composition (quality indicators); the presence of a large number of controlled and uncontrolled excitatory influences, to a greater or lesser extent affecting the course of the technological process; non-stationarity of static and dynamic characteristics of processes; the complexity of building mathematical models that can adequately reflect the course of processes, due to the complex nature of dependencies between input and output parameters, as well as the lack of a complete mathematical description for many complex technological processes; high error of measurements of some technological parameters, and sometimes the lack of operational methods of measurements and control and measuring instruments, etc.

Under these conditions, it is impossible to achieve the criteria established in quality management by optimizing static modes of technological processes only at the traditional upper level. Therefore, solving the problems of synthesizing a control system capable of ensuring compliance of quality indicators of various fuel fractions obtained in the process of oil refining with the requirements of the standard at any values of flow rate and quality indicators of crude oil fed to the atmospheric unit in the technological complex of primary oil refining is relevant both from the scientific and practical points of view.

Taking all this into account, the paper proposes as a research problem to develop a control system for the atmospheric block of the technological complex of primary oil refining in such a way that this system provides an optimal mode of operation of the system as a whole, regardless of the various influences occurring in the technological complex.

Purpose of the work

The issue of optimal adjustment of controller is included in automatic control system is considered, the transfer function of control systems is determined, on the basis of which the curve of the transient process of the automatic control system is constructed and the quality indicators of transient response are determined.

Problem statement

The quality indicators of the automatic control system in dynamic modes depend on the characteristics of the control object. For this reason, in order to develop control systems with sufficient stability, reliability and high quality indicators, it is necessary first of all to study the dynamic characteristics of the automatic control object. Static and dynamic characteristics are studied both experimentally and analytically, depending on the characteristics of the object under study. However, to assess the dynamic characteristics of control objects, active experiments are carried out with open states of control circuits. Otherwise, it is necessary to use experimental methods for studying the characteristics of regulated objects. Taking into account all this, in the paper a methodology is given for solving the above issues without interfering the normal operating modes of control systems.

To solve the synthesis problem, first of all, the transfer function is determined based on the step response. The transfer function defines the relation between the output and the input of a dynamic system [2]. The step response is shown in (Fig. 1).

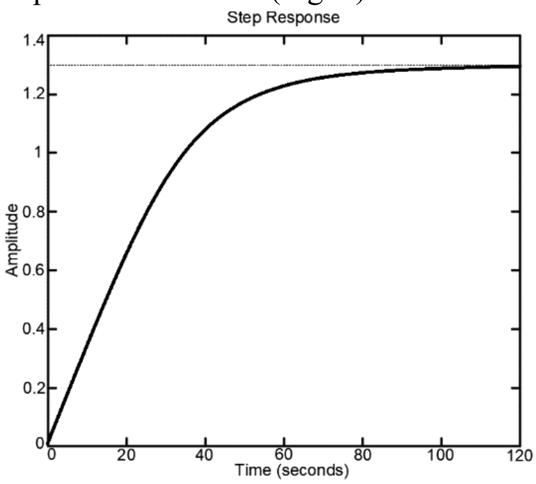

Figure 1 – Step response

Here, in order to adjust the temperature, it is necessary to change the fuel consumption, that is, to change the movement of the actuator. On the commissioning curve, the distance of the actuator is Δx=5%, and the temperature change corresponding to this distance is 110-120 □ (7.5%). There are various methods for calculating the transfer function. To calculate the transfer function in this paper the Simoyu Method was used. The input and output variables of the object were observed by performing an active experiment. A stepped control action was applied and a recording was made of the resulting output data, which was in the form of a transient response. In this method, the calculation is performed in the following sequence [3-5].

1. The time characteristic is divided into intervals with Δt=1min;

2. Let us write down the ratio of the values Δy(t) and Δymax corresponding to the intervals Δt;

3. The fields are determined by performing appropriate calculations.

Field F1 is defined as follows:

$$F_1 \cong \Delta t\{\textstyle\sum_{i=1}^{n}(1-y)_i - 0{,}5[1-y(0)]\} \quad (1)$$

Then [1-y(t)] is established in a different timeline. Therefore, the variable θ implies.

$$\textstyle\sum_{i=1}^{n}[1-y(i\Delta\theta)][1-i\Delta\theta] \quad (2)$$

$$\textstyle\sum_{i=1}^{n}[1-y(i\Delta\theta)]\left[1-2\cdot i\Delta\theta+\frac{(i\Delta\theta)^2}{2}\right] \quad (3)$$

Then the F2 and F3 fields are calculated:

$$F_2 \cong F_1^2\Delta\theta\{\textstyle\sum_{i=1}^{n}(1-y)(1-\theta)_i - 0{,}5[1-y(0)]\} \quad (4)$$

$$F_3 \cong F_1^3\Delta\theta\left\{\textstyle\sum_{i=1}^{n}(1-y)(1-2\theta+\frac{\theta^2}{2})_i - 0{,}5[1-y(0)]\right\}$$

The results are shown in Table 1.

If any of the fields is negative then the transfer function will be in the form:

$$W(p)=\frac{b_1p+1}{a_2p^2+a_1p+1} \quad (5)$$

If all fields are positive, then the transfer function will be as follows:

$$W(p)=\frac{1}{a_3p^3+a_2p^2+a_1p+1} \quad (6)$$

After applying input to the control system, output takes certain time to reach steady state. So, the output will be in transient state till it goes to a steady state. Therefore, the response of the control system during the transient state is known as transient respons. The transient state response of control system gives a clear description of how the system functions during transient state [6, 7].

Solving of the problem

Based on the method of "field" we can write a transfer function, given the calculated values a1=F1, a2=F2, a3=F3:

F1= 2,4242, F2= 1,70098, F3= 18,866

W(p)=k/(2.42p3+1.701p2+18.87p+1) (7)

The next step is to convert the transfer function from a dimensionless form to a dimension form;

$$W_o(P) = K_{ob}W(P) \quad (8)$$

In this formula

$$K_{ob} = \frac{\Delta y_{max}}{\Delta x} = \frac{7.5}{5} = 1.5$$

then Wob(P) takes the following form:

W(p)=1.3/(2.42p3+1.701p2+18.87p+1) (9)

The results are shown in Table.

Algorithm of obtaining a transition response is as follows:

```
>> Wt=tf([1.3],[2.42 1.701 18.87 1]);

>> Wt=tf([0.54 0.23],[1 0]);

>> Wo= tf([1.3],[2.42 1.701 18.87 1]);

>> W1=series(Wt,Wo);

>> Fi=feedback(W1,1);

>> step(Fi);grid
```

The transition response is shown in (Fig.2).

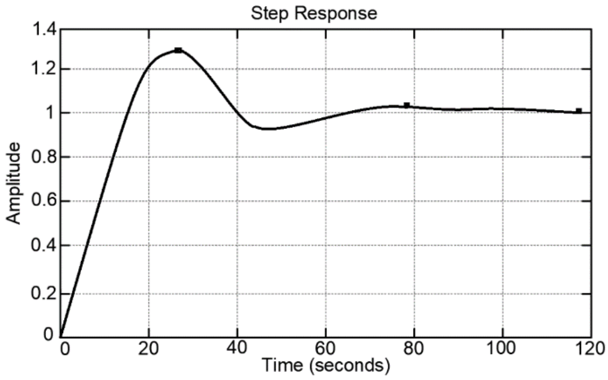

Figure 2 – The transient response

The transient state response of control system gives a clear description of how the system functions during transient state. Based on the transition response, we determine the following quality indicators:

Overshoot - 37%

Control time – 24.4

The first maximum – 1.32

The second maximum - 1.03

Static error – 0

The quality indicators obtained based on trancient response meet the requirements for a sustainable control system.

Conclusion

In the presented paper, the distillation column which is the main technological device of the primary oil refining unit, has been studied as a control object. Due to the non-stationarity of the dynamic characteristics of this control object, the necessity of periodic and operational assessment and adjustment of control systems is substantiated. The evaluation of dynamic model of automatic control system of the distillation column of a technological facility is solved. İt involves calculation of transfer function of the controller , building of transient response and determination quality indicators of the transient response.

Table – The calculation results of transfer function

t	y(t)	1-y(t)	θ	1-θ	C*E	1-2θ +(θ ^2) /2	G*H
A	B	C	D	E	F	G	H
0	0	1	0	1	1	1	1
0,3	0,045	0,955	0,124	0,876248	0,8368167	0,7959717	0,760153
0,6	0,1	0,9	0,248	0,752496	0,6772461	0,5951339	0,495621
0,9	0,158333	0,841667	0,371	0,628744	0,5291924	0,387805	0,306403
1,2	0,225	0,775	0,495	0,504991	0,3913683	0,170967	0,132499
1,5	0,283333	0,716667	0,619	0,381239	0,2732214	-0,06431	-0,17609
1,8	0,4	0,6	0,743	0,257487	0,1544922	-0,348939	-0,20936
2,1	0,475	0,525	0,866	0,133735	0,0702108	-0,680615	-0,39732
2,4	0,566667	0,433333	0,99	0,009983	0,0043258	-1,130695	-0,48997
2,7	0,691667	0,308333	1,114	-0,11377	-0,035079	-1,969616	-0,6973
3	0,733333	0,266667	1,238	-0,23752	-0,063339	-2,659922	-0,75931
3,3	0,775	0,225	1,361	-0,36127	-0,081287	-3,537842	-0,79601
3,6	0,808333	0,191667	1,485	-0,48503	-0,092963	-4,525562	-0,8874
3,9	0,85	0,15	1,609	-0,60878	-0,091317	-6,156485	-0,97357
4,2	0,866667	0,133333	1,733	-0,73253	-0,097671	-7,231743	-0,96423
4,5	0,875	0,125	1,856	-0,85628	-0,107035	-7,917381	-0,98967
4,8	0,8875	0,1125	1,98	-0,98003	-0,110254	-8,887117	-0,9998
5,1	0,895	0,105	2,104	-1,10379	-0,115898	-9,472516	-0,99461
5,4	0,925	0,075	2,228	-1,22754	-0,092065	-12,98817	-0,97411
5,7	0,95	0,05	2,351	-1,35129	-0,067565	-18,76595	-0,9383
6	0,958333	0,041667	2,475	-1,47504	-0,06146	-21,29184	-0,90717
6,3	0,966667	0,033333	2,599	-1,5988	-0,053293	-24,62191	-0,88072
6,6	0,983333	0,016667	2,723	-1,72255	-0,028709	-44,33686	-0,85896
6,9	1	0	2,846	-1,8463	0	0	0
		8,580833			2,8389391		-11,201

Conflict of Interests

The author declares there is no conflict of interests related to the publication of this article.

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