CALCULATION METHOD OF CASCADE CONTINUOUS CONTROL SYSTEM PARAMETERS IN INDUSTRY

PHƯƠNG PHÁP TÍNH TOÁN THÔNG SỐ HỆ THỐNG ĐIỀU KHIỂN LIÊN TỤC NHIỀU TẦNG TRONG CÔNG NGHIỆP

Vo Huy Hoan

Electric Power University

Ngày nhận bài: 01/6/2022, Ngày chấp nhận đăng: 15/7/2022, Phản biện: TS. Đặng Quang Hồng

Abstract:

Calculating parameters for control systems in industry is an important issue, this issue is often interested in research, because the quality of adjustment of control systems is increasingly required, in then, industrial objects are often changing with their operational age. On the other hand, the control systems of industrial objects are multi-stage systems, the way to calculate the adjustment parameters for the system is quite complicated, making it difficult to calibrate the control system, making it difficult to adjust the system. Most engineers have to calibrate the system by tracing and testing each set of parameters in turn. That way takes a lot of time, effort and adjustment quality is not high, sometimes the system is only temporarily stable with the set of test parameters, but after a period of operation, the system will return to normal condition. poor tuning quality. To gradually meet the demand of parameter calculation for multi-stage continuous control system with strict theoretical basis, ensuring stable and sustainable adjustment quality over time. This paper will present a method of calculating parameters for a multi-stage continuous adjustment system so that the system has stable and sustainable quality and a simple calculation method.

Keywords:

Delayed object, optimization, robust, inertia, overshoot, stable reserve, settling time.

Tóm tắt:

Tính toán các thông số cho hệ thống điều khiển trong công nghiệp là một vấn đề quan trọng, vấn đề này thường xuyên được quan tâm nghiên cứu, bởi chất lượng điều chỉnh của các hệ thống điều chỉnh ngày càng được yêu cầu cao, trong khi đó, đối tượng công nghiệp thường thay đổi theo tuổi vận hành của chúng. Mặt khác, các hệ thống điều khiển của các đối tượng công nghiệp là những hệ thống nhiều tầng, cách tính toán các thông số điều chỉnh cho hệ thống khá phức tạp, làm khó khăn cho việc hiệu chỉnh hệ thống điều khiển, làm hầu hết các kỹ sư phải hiệu chỉnh hệ thống theo cách lần mò và thử nghiệm lần lượt từng bộ thông số. Cách làm đó gây mất nhiều thời gian, công sức và chất lượng điều chỉnh không cao, nhiều khi, hệ thống chỉ ổn định tạm thời với bộ thông số thử nghiệm, nhưng sau một thời gian vận hành, hệ thống sẽ trở lại tình trạng chất lượng điều chỉnh kém. Để từng bước đáp ứng nhu cầu tính toán thông số cho hệ thống điều khiển liên tục nhiều tầng với cơ sở lý luận chặt chẽ, đảm bảo chất lượng điều chỉnh ổn định và bền vững theo thời gian. Bài báo trình bày một phương pháp mới tính toán thông số cho hệ thống điều chỉnh liên tục nhiều tầng sao cho hệ thống đó đạt được chất lượng ổn định bền vững và phương pháp tính toán đơn giản.

Từ khóa:

Đối tượng trễ, tối ưu, bền vững, quán tính, độ quá điều chỉnh, dự trữ ổn định, thời gian điều chỉnh.

1. SET THE PROBLEM

As we all know, industrial control systems are usually cascade control systems, such as superheated steam temperature control systems, combustion control systems, boiler water level control systems, turbine control system, steel furnace control system, generator excitation control system, etc., they are all cascade control systems. Control objects in such systems often have long delays. In order to evaluate the tuning quality or calculate the calibration of systems with delay-objects, it is often necessary to remove the delay part from the object and then adjust the parameters or use the Taylor transform or Pedé [6] to convert the delay of the object to a string and then remove the higher order element from the sequence. Sometimes people also use the IMC (Internal Model Control) method [8] to calculate for control systems with delay objects. But in general, these methods often lead to large errors and difficulties in the calculation process. That's just the calculation for the first cascade, and from the second cascade onwards, that calculation often leads to complex problems, very difficult to solve and even without a solution. On the other hand, so far, in industry, PID (Proportional Integral Derivative) controllers are often used to control [5]. But in the PID set, there are up to 3 parameters to be calculated [5], [7], which makes the calculation of control system parameters complicated, the computational volume is often very large, and even leads to to an unsolved problem for a multistage system with a delay object. In order to solve the problem of calculating parameters for a cascade continuous control system with delay objects quickly and ensure stable and stable tuning quality, the author has researched and proposed a method as follows: For example, there is a continuous control system with a structure diagram as shown in Figure 1, where

u(s)-set value; y(s)-response system output;

$R_1(s)$ is the transfer function of the 1-stage continuous regulator $O_1(s)$ is the transfer functions of object 1;

$R_2(s)$ is the transfer function of the 2 stage continuous regulator

$O_2(s)$ is the transfer functions of object 2;.

With $O_1(s), O_2(s)$ is known. Determine the structure and parameters of the regulators $R_1(s), R_2(s)$ so that the difference between the output signal y(s) and the set signal u(s) of the system is minimal.

2. THE BASIS OF THE METHOD

A control system is said to be optimally robust with high quality [1], [2], [4] when the system has a closed system transfer function:

$$W^K(s) = \frac{1}{1+\theta s} \quad (1)$$

The corresponding high-quality optimal robust open system is:

$$W^H(s) = \frac{1}{\theta s} \quad (2)$$

The transfer function of an industrial object usually takes the form:

$O(s) = e^{-\tau s}.O_{PT}(s)$;

$$O_{PT}(s) = \frac{A(s)}{B(s)}\frac{a_0+a_1s+\ldots+a_ms^m}{1+b_1s+\ldots+b_ns^n} \quad (3)$$

τ is the time delay; $a_0, a_1,\ldots,a_m, b_1, b_2,\ldots,b_n$ are the coefficients; s- Laplace operator.

We define the concept of a soft oscillator. The Soft Oscillator is defined [3], [4]:

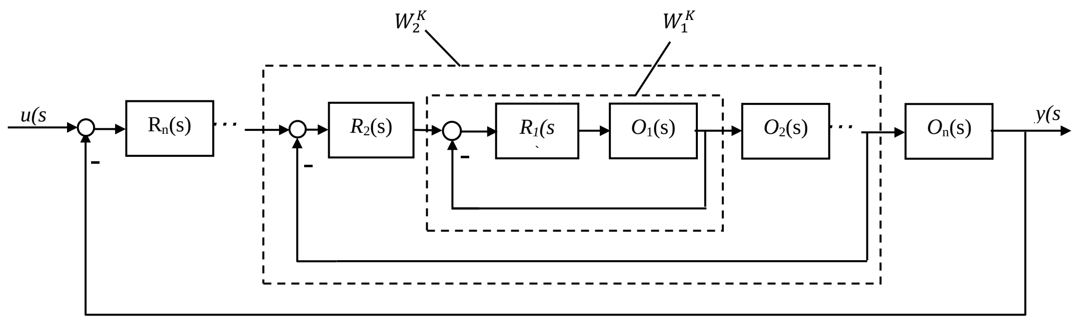

Figure 1. Structure diagram of n-cascade control system

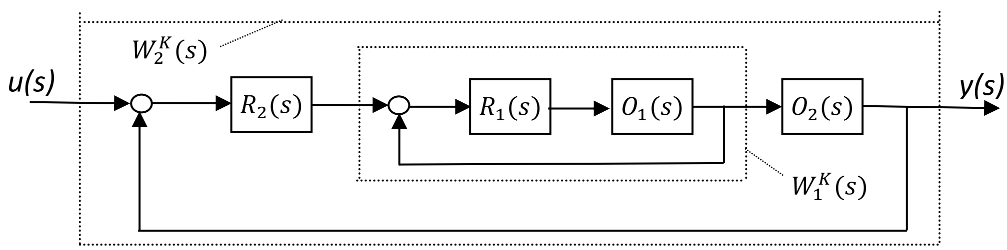

Figure 2. Structure diagram of control system for steel furnace

$$\boldsymbol{m} = \frac{\boldsymbol{m_0}\left(\boldsymbol{1}-\boldsymbol{e}^{-\boldsymbol{\alpha}|\boldsymbol{\omega}|}\right)}{(\boldsymbol{\alpha}|\boldsymbol{\omega}|)}, 0\leq\alpha\leq\tau, \quad (4)$$

where, m_0 = const – initial value, has the same meaning as the classical oscillator index [5]; α - softening coefficient, usually choose $\alpha = 0{,}2\tau$.

Suppose, $s_i = \beta_i + j\omega_i$ ($\omega_i \geq 0$) is the root of the characteristic polynomial of the optimal robust control system [1], [2], [3] then the root of the characteristic equation always has $\beta_i < 0$.

Set $\beta_i = m\omega$; substituting β_i into the solution of the characteristic equation of a high-quality optimal robust control system, we get:

$$s_i = -m\omega_i + j\omega_i \ (\omega_i \geq 0) \quad (5)$$

Substitute (5) into the corresponding open system, then the open system is a function of m and ω. If we draw the function of the open system on the complex coordinate axis, we will get a curve describing the open system, we call that curve the soft characteristic of the open system.

3. SYNTHESIS OF HIGH-QUALITY CONTINUOUS CONTROLLER STRUCTURE FOR N-STAGE SYSTEM IN A CONTINUUM

The condition for the control system to become a high quality optimal robust control system [1], [2], [4] is the open system must be satisfied (2). For a system with n- stage, we have, the condition for a multi-stage control system to become a high-quality optimal sustainable control system is that each layer in the system must satisfy (2).

With a multi-stage control system, the inertia of the outer layer is usually much longer than that of the inner stage, The transition of the inner layer turns off very quickly compared to the outer layer.

Therefore, we can separate them and calculate for each floor. Then we have:

The innermost open system: $W_1^H(s) = R_1(s).\,O_1(s) = \frac{1}{\theta_1 s}$

The corresponding closed system: $W_1^K(s) = \frac{W_1^H(s)}{1+W_1^H(s)} = \frac{1}{1+\theta_1 s}$

Infer

$$R_1(s) = \frac{1}{\theta_1 s}[O_1(s)]^{-1} \quad (6)$$

$$W_2^H(s) = R_2(s)W_1^K(s)O_2(s) = \frac{1}{\theta_2 s}$$

$$W_2^K(s) = \frac{W_2^H(s)}{1+W_2^H(s)} = \frac{1}{1+\theta_2 s}$$

$$R_2(s) = \frac{1}{\theta_2 s}[W_1^K(s)O_2(s)]^{-1}$$

$$R_2(s) = \frac{1}{\theta_2 s}\left[\frac{1}{1+\theta_1 s}O_2(s)\right]^{-1} = \frac{1}{\theta_2 s}[(1+\theta_1 s)O_2(s)]^{-1}$$

$$W_3^H(s) = R_3(s)W_2^K(s)O_3(s) = \frac{1}{\theta_3 s}$$

$$R_3(s) = \frac{1}{\theta_3 s}\left[\frac{1}{1+\theta_2 s}O_3(s)\right]^{-1} = \frac{1}{\theta_3 s}[1+\theta_2 s)O_3(s)]^{-1}$$

In general, we have:

$$R_{i+1}(s) = \frac{1}{\theta_{i+1} s}[(1+\theta_i s)O_{i+1}(s)]^{-1} \quad (7)$$

với i ≥ 1 và i nguyên dương.

Here $O_i(s)$ are any industrial objects of the i-th cascade; θ_i is the controller parameter of the i-th cascade.

4. SYNTHESIS OF CASCADE CONTROL SYSTEM PARAMETERS

We see that, if we separate each cascade of the system to consider or consider the structural diagram transformation, the structure of each cascade must satisfy the condition that the transfer function of the open system has a high-quality robust structure [1], [2], [4] and satisfy the extended Nyquist criteria [1], [2]. The necessary and sufficient condition for the closed system to preserve the stability reserve is the soft property of the open system passing through and not including the critical point (-1, j0) on the complex coordinate system. So the condition for ⎝ to reach the minimum is:

$$W_i^H(-m + j) = -1 \quad (8)$$

The condition for n stages of the continuous control system to become the optimal sustainable control system is that each layer in the system needs to satisfy (2) and (8). Then the optimal parameter of the layers of the control system is calculated as follows:

$s = -\beta + j\omega$ với $\beta = m\omega$

$$W_i^H(s) = \frac{1}{\theta_i s} = \frac{1}{\theta_i(-\beta + j\omega)}$$

$$= \frac{j\omega+\beta}{\theta_i(-\omega^2-\beta^2)} = -\frac{\beta}{\theta_i(\omega^2+\beta^2)} - j\frac{\omega}{\theta_i(\omega^2+\beta^2)}, \Rightarrow -\frac{\beta}{\theta_i(\omega^2+\beta^2)} = -1;$$

$$\frac{\omega}{\theta_i(\omega^2+\beta^2)} = 0 \Rightarrow \theta_i = \frac{1}{m\omega} = \frac{0,2\tau_i}{m_0(1-e^{-0,2\tau_i\omega})}. \quad (9)$$

We see that, when ω →∝ the expression (9) degenerates to:

$$\theta_i = \frac{0,2\tau_i}{m_0} = 0,545\tau_i \quad (10)$$

Thus, the problem of synthesizing a cascade continuous control system with the control quality criterion of the system being robust and optimal is abbreviated as follows:

Step 1: Find the first cascade structure of the system according to the formula (6).

Step 2: Find the i-th cascade structure (with $i_{min} = 1$) of the system according to formula (7).

Step 3: Calculate the parameter θ_i of the floors according to equation (10).

5. TEST METHOD

We test the proposed method through the following example:

Assume that the control system of the steel furnace has a structural diagram as shown in Figure 2, in which: $O_1(s) = e^{-\tau_1 s}\frac{k_1}{s+a}$; $O_2(s) = e^{-\tau_2 s}\frac{k_2}{s+b}$. Let's determine the structure and parameters of the controllers so that the system is stable and robust? knowing $k_1 = 3$; $k_2 = 7$; a= 7; b = 9; $\tau_1 = 0,5$ minutes t; $\tau_2 = 0,9$ minutes.

Applying formula (6), we can calculate the structure of the 1st cascade controller as:

$$R_1(s) = \frac{1}{\theta_1 s}[O_1(s)]^{-1} = \frac{1}{\theta_1 s}\left[e^{-\tau_1 s}\frac{k_1}{s+a}\right]^{-1} = \frac{1}{\theta_1 s}e^{\tau_1 s}\frac{s+a}{k_1}$$

Applying formula (7) for the case i = 1, we can calculate the structure of the 2nd cascade controller as:

$$R_2(s) = \frac{1}{\theta_2 s}[(1+\theta_1 s)O_2(s)]^{-1} = \frac{1}{\theta_2 s}\frac{1}{1+\theta_1 s}e^{\tau_2 s}\frac{s+b}{k_2}$$

Calculate the optimal parameters of the controller:

Applying equation (10) we have the optimal parameters of the 1st cascade as:

$$\theta_1 = 0,545\tau_1 = 0,545\ x\ 0,5 = 0,272;$$

the optimal parameters of the second cascade is:

$\theta_2 = 0{,}545\,\tau_2 = 0{,}545\ x\ 0{,}9 = 0{,}490.$

We find the controller is:

$$R_1(s) = \frac{s+7}{0{,}272s} e^{0{,}5s} \quad (11)$$

$$R_2(s) = \frac{s+9}{0{,}49s(1+0{,}27s)} e^{0{,}9s} \quad (12)$$

Proof of the correctness and effectiveness of the proposed method:

In order to prove the correctness and adjustment quality of the method, we calculate the transfer function of the open system and the closed system of the system, then we have:

$$W_1^H(s) = R_1(s)O_1(s) = \frac{1}{\theta_1 s}\frac{s+a}{k_1} e^{\tau_1 s} e^{-\tau_1 s} \frac{k_1}{s+a} = \frac{1}{\theta_1 s}$$

$$W_1^K(s) = \frac{W_1^H(s)}{1+W_1^H(s)} = \frac{1}{1+\theta_1 s}$$

$$W_2^H(s) = R_2(s)W_1^K(s)O_2(s) = \frac{1}{\theta_2 s(1+\theta_1 s)^2} \quad (13)$$

$$W_2^K(s) = \frac{W_2^H(z)}{1+W_2^H(z)} = \frac{1}{\theta_2 s(1+\theta_1 s)^2+1} \quad (14)$$

Investigating the open system (13) and closed system (14) on Malab software, and at the same time, changing the optimal coefficient of the controller in an increasing trend, we obtain the transient characteristic curves of Figure 3. We can also check the stability reserve of the calculated control system through the open system soft characteristic or the Bode characteristic as shown in Figure 4. We see that, with the theta coefficients found of the cascades, the system gives the overshoot, the settling time and the stability reserve to ensure the stable and robust operation of the system (see Figures 3 and 4). As we gradually increase the theta coefficient of each regulator in each control layer, the tuning quality tends to decrease, that is, the overshoot increases and the tuning time becomes longer. that proves that the proposed method is completely correct and effective.

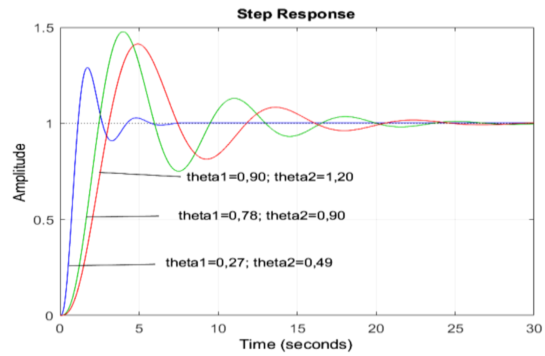

Figure 3. Transient characteristics of the furnace regulating system

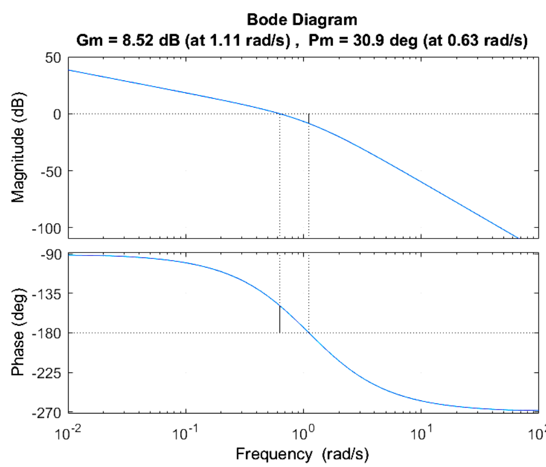

Figure 4. Bode characteristics of the furnace regulating system

6. CONCLUSION

- The method to find the structure and

parameters of the high-quality optimal robust controller in the continuum for the cascade control system presented in this paper is a general method, suitable for industrial objects;

- The author's method can be applied to calculate and calibrate industrial continuous control systems conveniently. The calculation method proposed by the author will give fast results, the adjustment quality ensures a stable reserve for a given, fast settling time and guarantee overshoot;

- The synthetic controller according to the method proposed by the author has only one parameter ζ, so the calculation volume is significantly reduced compared to the traditional method using PID controller.

REFERENCES

[1] Nguyen Van Manh, Vo Huy Hoan. Optimum robust method of synthesizing numerical control system with certain object, *Journal of thermal science and technology,* No. 70, pp. 15-19, 2006*. (in Vietnamese).*

[2] Vo Huy Hoan, Nguyen Van Manh. The new method for synthesizing industrial robust control system, *The 1st South East Asian Technical University Consortium (SEATUC) Symposium, 2006*.

[3] Nguyen Van Manh, Vo Huy Hoan. On the effectiveness and adjustment quality of some methods of synthesis and design of automatic control systems, *Journal of thermal science and technology,* No. 67, pp. 18-22, 2006. (in Vietnamese).

[4] Vo Huy Hoan. Design method of digital control system in power plant, *Journal of Energy Science and Technology*, No. 1, pp. 15-20, 2010. (in Vietnamese).

[5] Nguyen Doan Phuoc, Linear automatic control theory, *Science and Engineering Publishing House, 2002.*

[6] Nguyen Phung Quang, Matlab & Simulink for automatic control engineers, *Science and Engineering publisher, 2003.*

[7] Benjamin C. Kuo, Automation control systems. *Prentice-Hall Intrernational*, Inc.

[8] Morari M., Zafiriou E. Robust process control, *NewYork: Prentice Hall*, *1989*.

Biography:

Vo Huy Hoan, received a Bachelor's and Master's degree from the Faculty of Energy, received a PhD in 2006 majoring in automation, all from Hanoi University of Science and Technology, Vietnam. He is a lecturer at Control and Automation faculty, Electric Power University, Ha Noi, Viet Nam.

His current researchs focus on electrical engineering and automatic control.