Analysis of the impact of changes in system parameters on the quality of control

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Abstract: This article addresses the problem of processing hardware and software interrupts in the Siemens PCS7 distributed control system as part of industrial process control with a multitude of control objects. Problems of processing asynchronous requests for elements of control systems on the interruption of a periodic regulatory cycle will also be described. These requests increase the processing time of information, which can disturb the stability of the automatic control system. The article presents the normalized mathematical model of the regulatory system and the method for analyzing the robustness of this system.

Key-Words: mathematical modeling, stabilization of systems by feedback, synthesis problems, feedback control, discrete-time systems, digital systems, robust control.

1 Introduction

In modern automation, processing hardware and software interrupts is one of the most important tasks. The development of microprocessor technology allows us to have automation station high speed. High performance automation stations allow you to serve several control objects with the use of an interrupt system within one working cycle. It is easy to ensure the synchronization of the maintenance of objects with a constant period of information processing cycle. However, complex systems require Automation station to handle asynchronous requests for processing information related to servicing non-periodic requests to interrupt the main loop. In such situations, the controller can be programmed to one of two modes: Automation station increases the cycle time in order to process all the requests that have occurred, or the AS saves the period of the operation cycle and at the same time processes asynchronous requests first, setting aside some time for processing the periodic requests to the next cycle. In both modes, the service sample period increases

Algorithms of regulation that leads to deterioration in the quality of dynamic and static characteristics of management. The purpose of this article is to determine the ability of a control system to retain the required quality characteristics when changing settings. The above methodology was applied based on DCS PCS7.

2 Problem Formulation

Figure 1 shows a simplified block diagram of a distributed control system with central control based on the Siemens Simatic S7-400 controller. The S7-400 controller is used as a regulator for a distributed process control system based on S7-300 controllers and PROFIBUS fieldbus [7]. The central controller, use PROFINET technology, provide and receives information about the status of the controlled process.

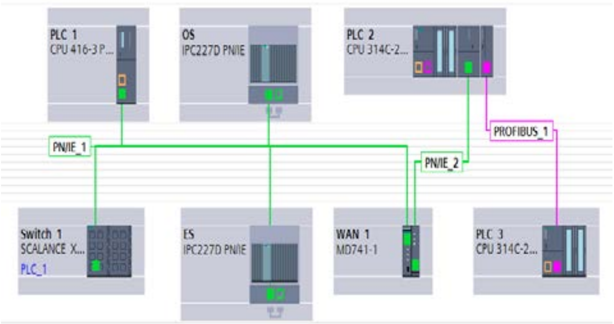

Fig 1. Typical structure of centralized control using the Siemens PCS 7 system elements.

To determine the stability of the system and the quality of management, it is necessary to consider:

1. Dynamic properties of objects

2. Dynamic properties of regulators
3. The presence of noise when the state of objects changes
4. Variability of control system parameters
5. Time delay in sending and receiving information
6. The presence of quantization noise in digital signal processing

The solution of these problems in the optimization of filtering properties by applying robust controllers. [14]

3 Problem Solution

The filtering properties of the control system are characterized by its ability not to miss the noise contained in the control action. The input of the control system receives not only useful signals, but also noise and interference. Interference is caused by random deviations of the control action, noise and errors in the measuring elements and other factors [5].

Interference and control arrive to different inputs of the system, but due to signals can be brought to the input of the control, we will assume in future that interference and control will always arrive at the input of the system.

Interference can be specified in the form of several time functions $\beta_p(t)$, but in most cases, the interference will have random characteristics, hereupon we will define their spectral density $S_p(\omega)$. Interference can cause additional changes in the output value, as a result of increasing the amount of error and reduce the quality of control.

The variance of the error of the control system caused by interference, which is a random function, is given by

$$\overrightarrow{\delta_p^2} = \frac{1}{\pi}\int_0^\infty S_p(\omega)[\Phi(j\omega)]^2\,d\omega, \qquad (1)$$

Where $\Phi(j\omega)$ is the amplitude-phase frequency characteristic of a system with a closed loop.

In practice, when calculating the control system, there are often cases where the noise is specified in white noise format, whose spectral density can be expressed by the formula: $S_p(\omega) = c^2$. Then

$$\overrightarrow{\delta_p^2} = \frac{1}{\pi}\,\mathrm{c}^2\int_0^\infty [\Phi(j\omega)]^2\,d\omega, \qquad (2)$$

From the preceding formula it follows that the value of the integral

$$I = \frac{1}{\pi}\int_0^\infty [\Phi(j\omega)]^2\,d\omega, \qquad (3)$$

It can serve as a measure of filtering properties of the control system, the value of I being directly proportional to the mean square error caused by interference. Accordingly, the smaller the value of the desired integral, the better the filtering properties of the system.

The value of the integral

$$\tilde{I} = \frac{1}{\pi}\int_0^\infty [\omega^2\Phi(j\omega)]^2\,d\omega, \qquad (4)$$

Can serve as an indicator of the power developed by the control system. When operating the control system, there are times when the root-mean-square error caused by interference does not exceed the permissible value, while the actuator's effective power is much higher than its nominal value. Which leads to an unacceptable load on the control system. Thus, the value of the integral I can also serve as an indicator of the quality of the control system.

The control system with respect to the control action is an astatic system of the first, second order, depending on the type of object and the type of regulator. Therefore, the low-frequency asymptote of the desired Bode diagram of the open control system has a slope of -20, -40, -60 dB/dek []. Asymptotes of the desired Bode diagram can be graphically divided into two parts: unchanged part and variable. The asymptotes of the Bode diagram of the control system elements that belong to the control object or cannot be changed belong to the unchanged part of the desired diagram. The variable part includes diagrams of Bode regulators and frequency correction elements (for example, sensor filters).

The position of the low-frequency asymptote belonging to the Bode diagram of the unchangeable part of the control system is determined by the value of the gain of the open system μ. Since the value of μ can only be found with allowance for the transfer function of the immutable part, the position of the low-frequency asymptote, which will be referred to below as the first low-frequency asymptote of the Bode diagram, will be determined separately for each case. In this case, the requirements for the component of the error caused by the perturbation applied to the control object must be taken into account.

The high-frequency part of the desired Bode diagram of the open control system is determined by the frequency response of the immovable part of the system. The high-frequency part of the Bode diagram of all considered types of control system elements can have the first asymptote with the second and third slope, the second asymptote with the fourth and fifth slope (Fig. 2)

The task of forming the desired Bode diagram of the open control system is reduced to determining the mid-frequency asymptote intersecting the frequency axis with the corresponding asymptotes of the Bode diagram of the unchanged part of the system. The point of intersection of the frequency axis by the Bode diagram is the cutoff frequency. The cutoff frequency determines the operating bandwidth (a bandwidth) of the control system and, together with the phase characteristic, makes it possible to evaluate its stability.[8]

High-frequency asymptotes of the unchanged part mainly affect the stability of the internal loop of the control system and do not have a significant effect on the stability stocks of the system. Therefore, it becomes possible to use a filter in the control system to suppress high-frequency interference. The above asymptotes should be taken into account when analyzing the stability of the internal contour.[9]

The position of the second low-frequency asymptote of the desired Bode diagram of the open control system can be determined from the predetermined accuracy of reproduction of the control system of the harmonic control component. The expression for the amplitude $\boldsymbol{\delta^a}$ of the harmonic component of the error of the control system in the case when the control action is characterized by the equality

$$(t) = \dot{\beta}_0 + \beta_a \, sin \, \omega_p t \tag{5}$$

has the form:

$$\delta_{\mathrm{a}} \approx \left|W\left(j\omega_p\right)\right|\beta_a \, . \tag{6}$$

Where: - β_a is the amplitude of the harmonic component of the control action.

The total greatest dynamic error in the absence of a perturbing moment

$$\delta = \beta_v + \beta_a = \frac{\dot{\beta}_0}{\mu} + \beta_a\left|W(j\omega_p)\right| \qquad (7$$

Where: - β_v is the speed component of the error.

As desired, we use the characteristics obtained above. The formation of these characteristics is made taking into account the minimization of integrals I and $\tilde{I}$ and the provision of required reserves of stability.

In accordance with the above calculations, for the desired characteristic of the first series, we have:

$$\theta = \frac{p}{\omega_p} \tag{8}$$

$$W_1(\theta) = \frac{1}{\theta(0{,}63\theta + 1)[0{,}0625\theta^2 + 0{,}15\theta + 1]} \tag{9}$$

For the desired characteristic of the second type, we have:

$$W_2(\theta) = \frac{1{,}25\theta + 1}{\theta^2(0{,}25\theta + 1)[0{,}0256\theta^2 + 0{,}096\theta + 1]} \qquad (\ 10)$$

For the desired characteristic of the third type

$$W_3(\theta) = \frac{2{,}56\theta^2 + 1{,}6\theta + 1}{\theta^3(0{,}125\theta + 1)[0{,}0064\theta^2 + 0{,}048\theta + 1]} \qquad (11)$$

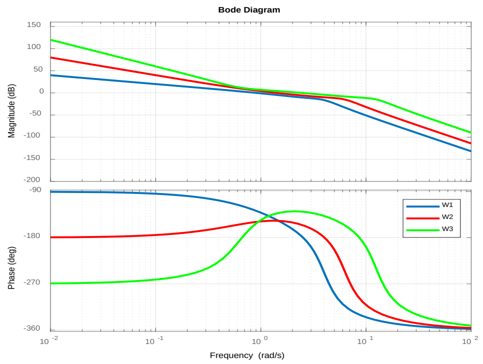

Fig. 2. The optimal form of the frequency response

Time delays are observed in industrial processes associated with transportation, mixing, burning of substances. They lead to the fact that information about the process provides to the regulator later than required, which can lead to instability of the closed-loop system. The complexity of managing objects with time delays is characterized by the ratio of the delay to the time constant of the object: the larger it is, the more difficult it is to achieve the required quality of regulation.

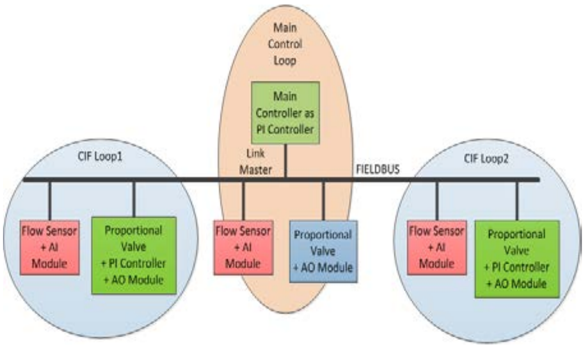

Fig 3 Multiple control loops on fieldbus and Link Master

Figure 3 shows a multiple control loop configuration on fieldbus including two CIF loops. The main controller also acts as a Link Master and is in charge of scheduling the fieldbus. The main controller is connected to a sensor device and a flow control valve actuator forming the main control loop. The two other control loops are CIF type and

uses the same fieldbus for control data transfer. CIF Loop1 contains a sensor device and an actuator device. The actuator device contains the controller of the CIF Loop1 as well. CIF Loop2 has a similar configuration. Figure 4 shows the LAS schedule for the multi-loop control system. It shows timings of sequential executing of loop components of the three loops in the scheduler [4].

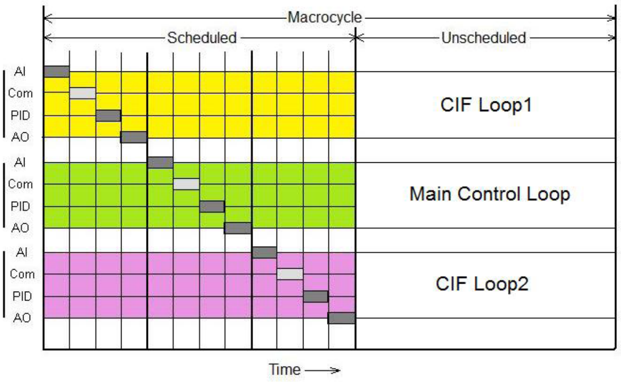

Fig.4 LAS schedule for the multi-loop control system

Time delays are observed in industrial processes associated with the transportation, mixing, burning of substances. They lead to the fact that process information provides a regulator later than is required, which can lead to instability of a closed system. The complexity of managing objects with time delays is characterized by the ratio of the delay to the object time constant: the larger, the more difficult it is to achieve the required quality of regulation. There are two ways to increase the quality control of such objects: by reducing the lag in the object by making design changes to the use of a more complex control system structure, which reduces the negative impact of the delay. [10]

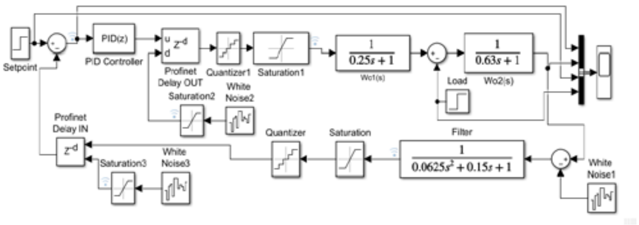

Fig. 5 Mathematical model of a distributed control system.

On the above model, we will analyze the robustness on the example of the settings of the controller parameters with the normalized characteristics of the object. Rationing of the transfer function of the automatic control system was carried out at a normalized frequency of 1rad / s.

The central processor of the distributed control system, when performing the function of the controller of a large number of objects, introduces a time delay in the calculation of control signals. With a large overload of the signal transmission channels, there is also an additional time delay. Therefore, when setting up a robust regulator, it is necessary to take into account the sensitivity of the control system. To study the effect of random additional delays on the quality of regulation and the development of a robust controller tuning method, a single DCS channel model was developed with a setting corresponding to the transfer function given in formula (9). The model is implemented using Simulink Matlab (Fig. 3) and contains elements that mimic nonlinearity, discreteness of information processing, the random nature of measurement noise and time delays.

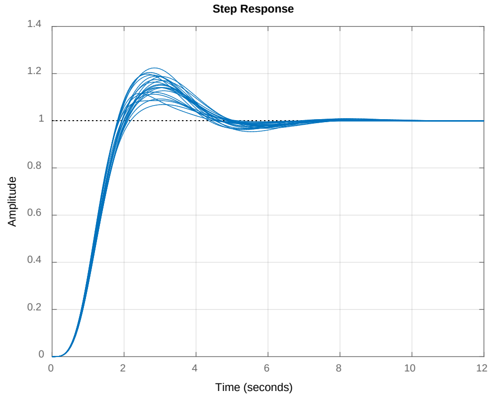

Fig.6. Robustness analysis of control system

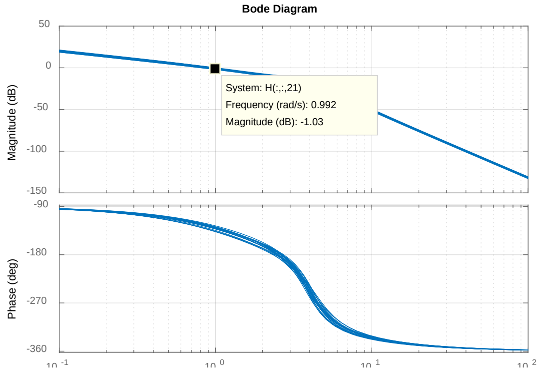

Fig. 7 Bode diagram for open-loop system

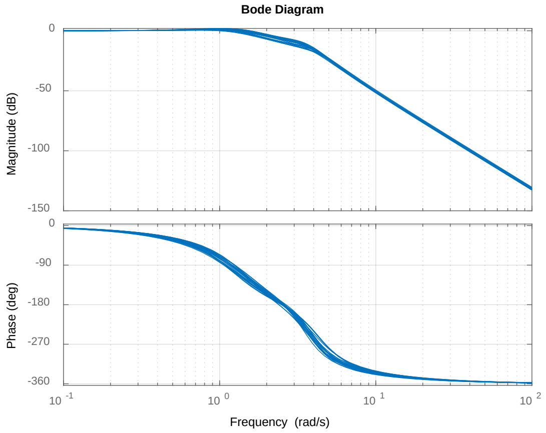

Fig. 8 Bode diagram for a closed-loop system

Below is a pragment of the development code for the robust controller from the matlab environment.

```
>> bw1 = ureal('bw1',
25.4,'Percentage',10)

>> Tw1 = ureal('Tw1', 1,'Percentage',10)

>> Tw2 = ureal('Tw2',
3.988,'Percentage',10)

>> Tw3 = ureal('Tw3', 19.76
,'Percentage',10)

>> Tw4 = ureal('Tw4',
25.4,'Percentage',10)

>> H = tf(bw1,[Tw1 Tw2 Tw3 Tw4 bw1])
```

```
>> H = tf(bw1,[Tw1 Tw2 Tw3 Tw4 bw1])



  Uncertain continuous-time state-space
model with 1 outputs, 1 inputs, 4
states.

  The model uncertainty consists of the
following blocks:

    Tw1: Uncertain real, nominal = 1,
variability = [-10,10]%, 1 occurrences

    Tw2: Uncertain real, nominal = 3.99,
variability = [-10,10]%, 1 occurrences

    Tw3: Uncertain real, nominal = 19.8,
variability = [-10,10]%, 1 occurrences

    Tw4: Uncertain real, nominal = 25.4,
variability = [-10,10]%, 1 occurrences

    bw1: Uncertain real, nominal = 25.4,
variability = [-10,10]%, 1 occurrences
```

4 Conclusion

The paper studies the possibility of using a robust controller on the stability of the PCS7 system, taking into account the transport delay, and the effects of noise, alarms and other processes affecting the stability of the system. Using the considered indicators of sustainability and quality allows you to synthesize minimum order regulators that provide stability and specified dynamic properties of the control system for any valid values of the object parameters. The reference model of objects in the form of inertial links of the first, second and third order with delay and the corresponding model of the inertial link of the first order with delay for adjusting the regulators were determined; the limits of parameter uncertainty were set for the study of robustness from 90% to 110% of nominal values; the optimal method of synthesis of robust and classical PID regulators was chosen. According change of controls options system saves optimal quality parameters.

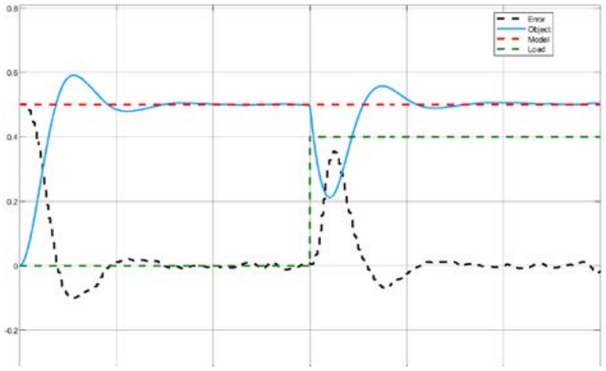

Fig. 9 Transient response graph with exact parameters of controller

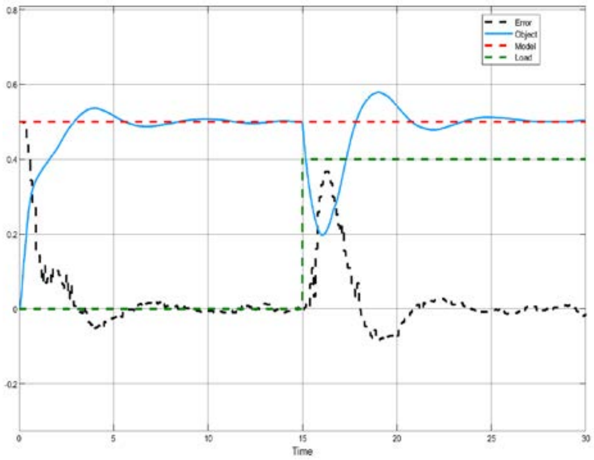

Fig. 10 Transient response graph with ideal parameters of controller

5 Acknowledgments

This publication is the result of implementation of the project "UNIVERSITY SCIENTIFIC PARK: CAMPUS MTF STU - CAMBO" (ITMS: 26220220179) supported by the Research & Development. Operational Program funded by the EFRR and of the project: MTF STU №1323 “Design and implementation of adaptive controllers with indeterminate logic for controlling distributed processes in PC7 environment”

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