AUTOMATION OF STANDARD TECHNOLOGICAL PROCESSES MANUFACTURING

**SCENARIO 1. INDUSTRIAL TECHNOLOGICAL PROCESS.**

**SIS\_3 Mathematical model analysis.**

**Task 1. Chose and describe the mathematical model for the control plant. The mathematical model should be in the state space and no more the 3d dimension, for creation the control system. Solve the problem of analyzing a mathematical model.**

**REPORT SHOULD CONTAIN THE FOLLOWING STEPS:**

**Part 1. Description of the mathematical model.** The mathematical model must be described in the **form of differential equations**, in the form of a **transfer function** and in the form of **a state space**. The SIS could contain brief theoretical information about the form of presentation of the mathematical model, then the mathematical model itself. Each formula must be **clearly explained in the work**, each variable described. Literature sources must be indicated in the text, before borrowing occurs.

**Form of the differential equations:**

Let a linear stationary system be described by ordinary linear differential equations of the nth order with constant coefficients:

, (1)

where  *t*– continuous time;

*t0* – initial time;

*–* control action;

*y*(*t*) – output signal.

**FORM OF THE TRANSFER FUNCTIONS:**

When representing equation (1) in input-output variables, the operators of the connection between the input and output signals **– transfer functions – are introduced into consideration**:

 (2)

Representation of systems in input-output variables has mainly technical advantages: the researcher deals with physical variables not only in the final result, but also at intermediate stages, and often has the opportunity to accompany theoretical research with an experiment. But with such a representation, mathematical descriptions of various systems and blocks, even in the linear case, are different depending on the orders of the numerators and denominators of their transfer functions.

**STATE SPACE FORM:**

A more uniform and convenient mathematical description of dynamic systems using differential equations can be obtained by introducing, instead of some (or all) output variables , other variables  called **state variables**.

The description of the system in these variables is given by a system of first-order differential equations resolved with respect to the first derivatives, i.e. equations in Cauchy form:

 , (3)

where *–* state vector of the control object;

components of the vector *х1, х2,*..., *хп* are **state variables;**

*A* – matrix, dimensions  with elements:

*,* (4)

*В –* column vector, dimensions (*n*×1) with elements:

*.*

This form has a number of advantages from the point of view of analytical research: it allows us to simplify and unify the proofs of a number of theorems, obtain uniform algorithms for research and calculations of dynamic indicators in systems of different orders, etc.

Equations (1) and (3) must be equivalent in the sense that, knowing the solution of one of them, one can unambiguously obtain the solution of the other. For this, the variables ***x(t)* and *y(t)*** must, first of all, be related by an unambiguous functional dependence:

. (5)

The conditions for the existence of solutions must also be satisfied, and for most practical problems, the conditions for their uniqueness must also be satisfied. The number of state variables *хi*(*t*)must be equal to the order n of equation (1) (in the linear case, to the order of the denominator of the transfer function (2)). The conditions for the existence and uniqueness of solutions are satisfied if *u*(*t*) are piecewise continuous functions, and the functions *f*(⋅) satisfy the Cauchy-Lipschitz conditions.

**Part 2. Specification and calculation of the general parameters of the mathematical model.** The output of the mathematical model or transition form must be specified here. Each variable must be defined. The parameters must match those specified in the black box model (SIS 2).

**Part 3. Modeling of the mathematical model in the MATLAB software.** This section should contain an analysis of the mathematical model in MATLAB for **stability, controllability and observability.**

**Definition 1. Stability** is usually understood as the property of a system to restore the state of equilibrium from which it was brought under the influence of disturbing factors after their impact ceases.

**Definition 2.** **Controllability** is one of the most important properties of a control system and a control object (a machine, a living organism, a society, etc.), describing the ability to transfer a system from one state to another. Studying a control system for controllability is one of the important steps in the synthesis of control controllers.

**Definition 3. Observability** in control theory is a property of a system that shows whether it is possible to completely reconstruct information about the states of the system from the output.

Task in MATLAB:

* create the model in MATLAB with command *SS* (state space) or *TF* (transfer function);
* create the model in MATLAB with command *SS* (state space) or *TF* (transfer function);
* сheck the state space model for **Observability.**

[Ob = obsv(A,C)](https://ww2.mathworks.cn/help/control/ref/dynamicsystem.nyquist.html#d126e173589)

[Ob = obsv(sys)](https://ww2.mathworks.cn/help/control/ref/statespacemodel.obsv.html#d126e173616)

* сheck the state space model for **Controllability.**

[Co = ctrb(A,B)](https://ww2.mathworks.cn/help/ident/ref/dynamicsystem.bode.html#d126e3346)

[Co = ctrb(sys)](https://ww2.mathworks.cn/help/control/ref/dynamicsystem.nyquist.html#d126e3373)

- сheck the state space model for **Stability.**

1. obtain the step response with command ***step.***

[[y,tOut] = step(sys)](https://ww2.mathworks.cn/help/control/ref/dynamicsystem.step.html?s_tid=srchtitle_site_search_1_step%20response%20#d126e242330)

1. obtain the impulse characteristic with command ***impulse*.**

[[y,tOut] =impulse(sys)](https://ww2.mathworks.cn/help/control/ref/statespacemodel.obsv.html?searchHighlight=impulse%20response%20&s_tid=srchtitle_support_results_2_impulse%2520response%2520#d126e98746)

1. find the **poles of the system**.

[P = pole(sys)](https://ww2.mathworks.cn/help/ident/ref/dynamicsystem.pole.html#d126e187660)

[P = pole(sys,J1,...,JN)](https://ww2.mathworks.cn/help/ident/ref/dynamicsystem.pole.html#d126e187691)

1. verify the stability of the system by usage any stability criteria **(Nyquist and Hurwitz criterion).**

**Nyquist response of dynamic system:**

[[re,im,wout] = nyquist(sys)](https://ww2.mathworks.cn/help/ident/ref/dynamicsystem.bode.html#d126e165295)

[[re,im,wout] = nyquist(sys,w)](https://ww2.mathworks.cn/help/control/ref/dynamicsystem.nyquist.html#d126e165320)

[[re,im,wout,sdre,sdim] = nyquist(sys,w)](https://ww2.mathworks.cn/help/control/ref/statespacemodel.ctrb.html#d126e165369)

1. add an additional analysis of the mathematical model on the discretion **(logarithmic amplitude-frequency and phase-frequency characteristics).**

**Bode frequency response of dynamic system:**

[[mag,phase,wout] = bode(sys)](https://ww2.mathworks.cn/help/control/ref/statespacemodel.ctrb.html#d126e16709)

[[mag,phase,wout] = bode(sys,w)](https://ww2.mathworks.cn/help/ident/ref/dynamicsystem.bode.html#d126e16740)

[[mag,phase,wout,sdmag,sdphase] = bode(sys,w)](https://ww2.mathworks.cn/help/control/ref/dynamicsystem.impulse.html#d126e16765)

*Describe in report the following form of analysis:*

1. *Time response analysis*
2. *Frequency response analysis*
3. *Rise time analysis*
4. *Percent overshoot analysis*
5. *Settling time analysis*
6. *Steady state error analysis*

The time domain specifications of a **Control System Performance** are normally defined from its transient response to different inputs. These are:

1. **Steady state error:** This is the deviation of the actual output from the desired one in the final steady state condition. For a step input, the output follows the input and hence the steady state error is the deviation of the output from the input. This is called offset Steady state error depends on gain in the case of proportional control. It is theoretically zero for integral control. For ramps and parabolic inputs velocity and acceleration errors defined.
2. **Rise time:** The time period between the instants of the change in the input or disturbance and the output attaining the value of the input for the first time; x = 0 for the first instance for under damped systems. For overdamped systems this is the time period between the output values 10-90% of the input. This characterizes the speed of response.
3. **Peak time:** The peak time is the time period between the instants of the change in the input or disturbance and the first peak overshoot of the.
4. **Settling time:** The period of time which starts when the change in the in­put occurs and ends when the output differs from the input with an acceptable This is related to the time constant of the system.
5. **Overshoot** Mp of the controlled quantity. Is the maximum deviation of the output from the desired one (input) during the control when the change in the input occurs. This is directly a measure of the relative stability of the system. It must be within 3 to 5%.

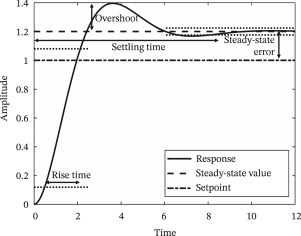


Figure 1 – Example of the control plant time domain specifications

1. Conclusion.
2. References.
3. Appendix (Add in appendix all listing of the mathematical models analysis in MATLAB).

**ATTENTION!** Before upload the report verifies the text according Checklist (table 1).

Table 1 - Checklist for students what should be in the SIS 3.

|  |  |  |  |
| --- | --- | --- | --- |
| **Position** | **Description** | **Software** | **Done/not done** |
| **Part 1** | Mathematical model of control plant in form of the differential equations | use the word formula editor to represent the mathematical model, copying of drawings is not allowed according to standards |  |
| Mathematical model of control plant in form of the transfer function | use the word formula editor to represent the mathematical model, copying of drawings is not allowed according to standards |  |
| Mathematical model of control plant in form of the state space model | use the word formula editor to represent the mathematical model, copying of drawings is not allowed according to standards |  |
| **Part 2** | Description of the model parameters. | Text form. |  |
| **Part 3** | Results of the model **observability test** | MATLAB software |  |
| Results of the model **controllability test** | MATLAB software |  |
| *Time response analysis:*  - unit impulse signal;  - unit step signal;  - table with control system performance: steady state error, rise time, peak time, settling time, overshoot. | MATLAB software. Two graphs must be presented with characteristics.  **Example:**    Typical step response graph | Download Scientific Diagram |  |
| Poles of dynamic system | MATLAB software. Poles map should be presented. Example: |  |
| Results of the model **stability test.**  **-** Nyquist response of dynamic system. | MATLAB software. Nyquist plot. Show on the graph the stability margin and the point with coordinate -1,j0. Example: |  |
| Results of the model **stability test.**  -Hurwitz criterion. | Calculation in the form of formulas with conclusions about the stability of the system. |  |
| Frequency response analysis.  -logarithmic amplitude-frequency and phase-frequency characteristics. | MATLAB software. Bode frequency response of dynamic system. Show on the graph the stability margin. Example:  Bode Plots in Control System - GeeksforGeeks |  |
| **Defining design parameters:** What are desired performance parameters, e.g. rise time, overshoot, settling time, steady state error, gain margin, phase margin etc., for the given system under study. | Table form. Determining the desired dynamics of an object is necessary to solve the problem of synthesizing a control system. |  |

**DESCRIPTION OF THE THIRD SECTION**

**OF THE COURSE PROJECT**

|  |  |  |
| --- | --- | --- |
| **Name of the chapter** | **Content of the chapter** | **Software** |
| Description of the mathematical model of the control object | It is necessary to select a mathematical model for the control object. The mathematical model must be **linear** (models in which the relationship between the dependent and independent variables can be linear), **not higher than third order**, presented in the form of differential equations. Next, it is necessary to present the mathematical model in the form of a **transfer function** and in the form of a **state space**. Carry out modeling in MATLAB software to determine the dynamics of the system. Based on the type of transfer function and the graph of the transient process, determine a typical link of the automatic control system (ACS). Present conclusions to the section. | It is necessary to analyze the mathematical model in the MATLAB software product. Obtain the impulse response and response of the link to a single step action. |

**SCENARIO 2. ROBOT MANIPULATOR CONTROL SYSTEM**

**#SIS\_3**

**For this scenario, the analysis of the mathematical model is the same as in the first scenario.**

**DESCRIPTION OF THE THIRD SECTION**

**OF THE COURSE PROJECT**

|  |  |  |  |
| --- | --- | --- | --- |
| **№** | **Name of the chapter** | **Content of the chapter** | **Software** |
| 3 | Description of the mathematical model of the control object | Based on the information obtained about the dynamics of the robot manipulator, it is necessary to provide a mathematical model of the robot. Carry out modeling. Obtain a graph of the transient process of the robot manipulator. | It is necessary to analyze the mathematical model in the MATLAB software product. |

**SCENARIO 3. SMART CITY CONCEPT**

**#SIS\_3**

For this scenario, the analysis of the mathematical model is the same as in the first scenario.

**DESCRIPTION OF THE THIRD SECTION**

**OF THE COURSE PROJECT**

|  |  |  |  |
| --- | --- | --- | --- |
| **№** | **Name of the chapter** | **Content of the chapter** | **Software** |
| 3. | Description of the mathematical model of the control object | For the control object, it is necessary to select a mathematical model (for example, ventilation systems, air conditioning, heating, cooling, water supply, etc.). The mathematical model **must be linear** (models in which the relationship between the dependent and independent variables can be linear), **not higher than third order**, presented in the form of differential equations. Next, it is necessary to present the mathematical model in the form of a **transfer function** and in the form of **a state space**. Carry out modeling in MATLAB software to determine the dynamics of the system. Based on the type of transfer function and the graph of the transition process, determine a typical gain of the automatic control system (ACS). Present conclusions to the section. | It is necessary to analyze the mathematical model in the MATLAB software product. Obtain the impulse response and response of the link to a single step action. |