Journal of Modern Technology and Engineering
Vol.8, No.3, 2023, pp.258-262

SYNTHESIS AND INVESTIGATION OF THE CONTROL SYSTEMS WITH VARIABLE STRUCTURE

Gazanfar Rustamov*, Afag Mamedova

Azerbaijan Technical University, Baku, Azerbaijan

Abstract. Variable structure control systems (VSCS) refer to automatic control systems operating in "special modes". These systems do not use adaptation algorithms. However, they have robust properties against some uncertainties. At present, the robust characteristics of VSPS have not been sufficiently studied. In this paper, new control algorithms have been developed to control dynamic objects with parametric and signal uncertainty. These algorithms operate in a sliding mode, implemented in systems with a variable structure. The structure of a robust regulator consists of relays with different static characteristics: a two-position relay without hysteresis; to reduce the switching frequency, a relay-linear regulator with a linearity zone. This design allows the system to be stabilized in a small vicinity of the equilibrium position without the occurrence of self-oscillations. As a result of simulation modeling on Matlab/Simulink under conditions of parametric uncertainty, dynamic characteristics were obtained that confirm the increase in robust indicators relative to known systems.

Keywords: special modes, systems with variable structure, adaptation, robustness, relay, sliding mode, Simulink.
Corresponding author: Gazanfar Rustamov, Azerbaijan Technical University, Baku, Azerbaijan, e-mail: *gazanfar.rustamov@gmail.com*
Received: 12 July 2023; Revised: 26 September 2023; Accepted: 4 November 2023; Published: 30 December 2023.

1 Introduction

In the paper a variable structure system (VSS) is understood as a control system that has several adjustable controllers.

The methodological basis for constructing such systems is the combination of various control structures in order to use the positive properties of each of them. Depending on the current operating mode of the system, a suitable structure is connected to the object (Kondratenko et al., 2022; Prasad et al., 2022; Wang et al., 2022).

Special control modes can mainly be divided into two types:

1. Sliding modes, implemented using relays with different static characteristics (Utkin, 1992; Mamedov & Rustamov, 2012; Rustamov, 2014).

2. Oscillatory mode with output feedback (Emelyanov, 1986; Dekarlo et al., 1988; Rustamov et al., 2011; Rustamov et al., 2015).

Positive features of the VSS:

- Allows one to control objects with parametric and signal uncertainties;
- Allows one to obtain the modes inaccessible to linear systems in a simple way;
- Simplicity of the system solution and high performance.

Disadvantages:

- Applicable only when moving along the switching line has a robust property. Until it hits this line, it behaves like conventional systems.
- A slight change in structures can lead to a violation of the sliding mode;
- A disturbance with a sufficiently large amplitude can also disrupt the trajectory (Rustamov et al., 2015).

The paper discusses the features of synthesis and computer modeling of control systems with variable structure.

In the general case, the VSS control law for deterministic objects is given in the following form (Dekarlo et al., 1988; Ghazy, 2001).

$$u = \begin{cases} u_1(\varepsilon,t), if\sigma(s,\varepsilon) > 0, \\ u_2(\varepsilon,t), if\sigma(s,\varepsilon) < 0. \end{cases} \tag{1}$$

Here u_1, u_2 and σ are the controls of the first and second structures and the control switching function; $s = c^T$; ε sliding plane; $c_n = 1$; c is the vector of angular coefficients, is the vector of errors. In addition, to satisfy stabilizing at the origin of coordinates, the condition $u(0,t) = 0$ must be satisfied.

To identify features, we will use the control of VSS (1) to control the specific uncertain objects. Let us consider the case of parametric uncertainty.

Object 1. Consider a parametrically indeterminate linearized model of a DC motor (inertial-integral object):

$$\ddot{y} + a\dot{y} = bu.$$

The corresponding equation in state variables is

$$\dot{x} = \begin{pmatrix} 0 & 1 \\ 0 & -a \end{pmatrix} x + \begin{pmatrix} 0 \\ b \end{pmatrix} u,$$
$$y = x_1.$$

Let us assume that the object parameter changes over the interval $a_min \le a \le a_max$.

Let us take the control of VSS (1) in the following form

$$u = K \cdot \begin{cases} -\alpha\varepsilon if\sigma > 0, \\ +\alpha\varepsilon if\sigma < 0. \end{cases}$$

Here $\sigma = s\varepsilon$ is the switching function; $s = c\varepsilon + \dot{\varepsilon} = 0$ is the sliding line; $K$is enough large coefficient of regulator gain. The controller has three setting paremeters $a, c, K > 0$.

At $\sigma > 0$ the control of the first structure is $\dot{x}_1 = x_2, \dot{x}_2 = -b\alpha x_1$. This equation describes the family of the stable spirals (Fig. 1a). For the stability of sliding motion to the origin of coordinates, the relation $a > c^2/b_{\min}$ must be satisfied

At $\sigma < 0$ the control of the second structure defines the family of "saddles" (Fig. 1b). Angular coefficient of the stable asymptotic is $c = \sqrt{ba}$.

To execute the sliding mode, the condition $c > \sqrt{ba}$ must be satisfied.

Let $a = 2, b = 1$. Then $c > \sqrt{1 \cdot 2} = 1.41$. Let us take $c = 2$. Figure 2 shows the block diagram of control of VSS on Simulink.

From Fig. 3a is clear that, unlike a system with a relay, here the feedback causes a decrease in the oscillations of the transient response. In addition, as follows from Fig. 3c as it approaches the origin, the amplitude of the control signal also decreases, which does not allow the occurrence of self-oscillations in a small vicinity of the equilibrium position.

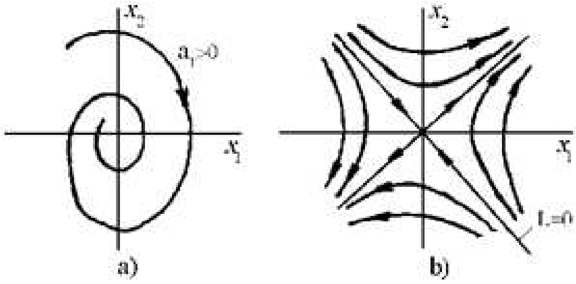

Figure 1: Phase portraits of various structures

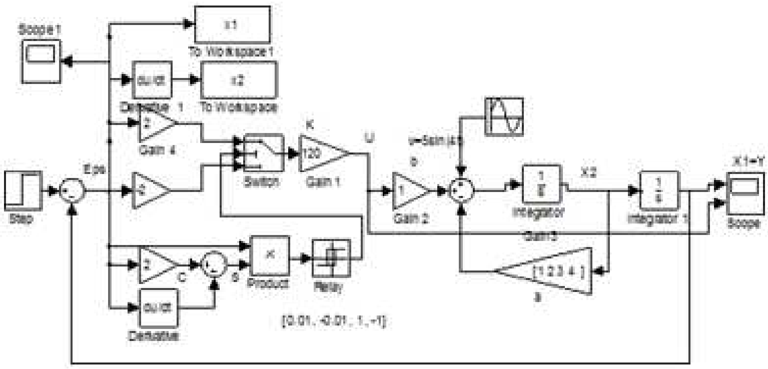

Figure 2: Variable structure control system

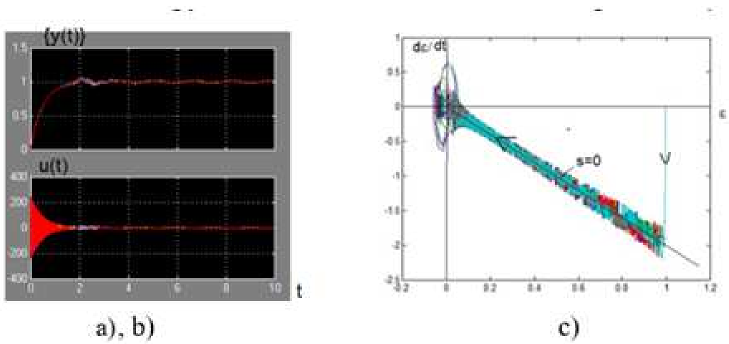

Figure 3: The dynamic characteristics of the VSS at $K = 120S$.

Object 2. Now let's consider the features of the VSS when controlling an inertia-free object of the "double integrator" type. The equation of this system is as follows

$$d^2y/dt^2 = bu + f(t),$$

$$u = \begin{cases} k_1\varepsilon, se \geq 0, \\ -k_2\varepsilon, se < 0. \end{cases}$$

Here $s = c\varepsilon + \dot{\varepsilon} = 0$ is a sliding line; k_1 and k_2 are the gain coefficients; $\varepsilon = g - y$ is the error of control; c, k_1, k_2 are the controller setting parameters. In contrast to the previous cases, here the gain factors k_1 and k_2 are different.

Assume that the object has parametric uncertainty over a wide range of changes $1 \leq b \leq 6$. In addition, an unmeasurable harmonic external disturbance $f(t) = sin2t + rond(.)$ acts on the input of the object. The simulation was performed for 6 values $b = [123456]$.

Figure 4 shows a simulation diagram of the system on Matlab/Simulink with $c = 1, k_1 = 30, k_2 = 20(a)$, transient bundle $y(t)(b)$, control bundle $u(t)(c)$, phase port (c), disturbance $f(t)(d)$ and adjustable output $y(t) = 1(e)$.

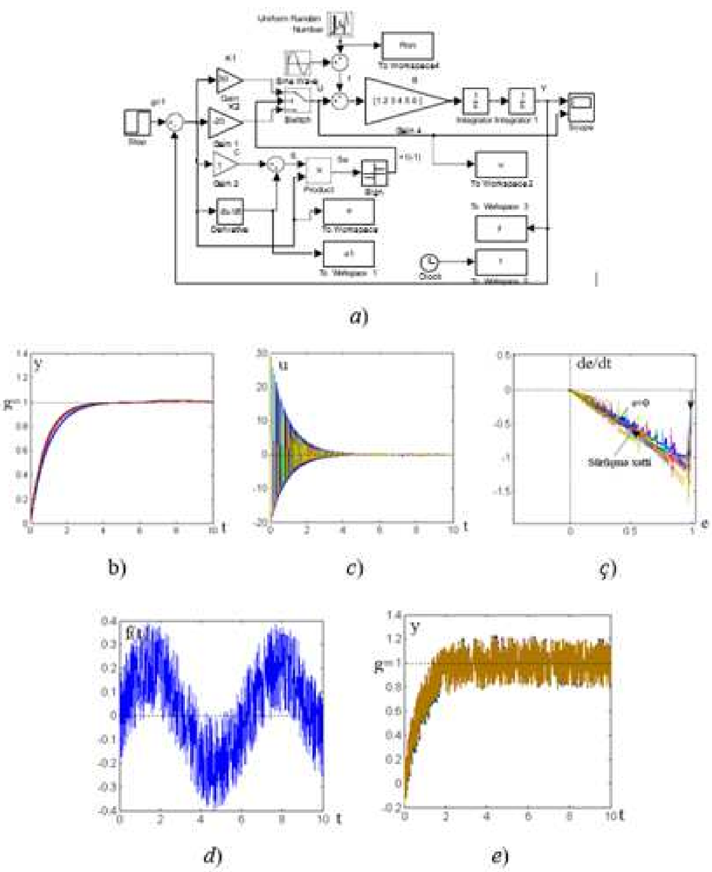

Figure 4: Features of sliding mode, implemented in the ATP.

From the transient characteristic a) and the phase portrait c) it follows that, despite the fact that the parameter of the object changes over a wide range and the object is affected by an unmeasured disturbance f(t) d), in the sliding mode the transient characteristic in the transient and steady-state modes performs slight scatter (dispersion). This feature confirms the robustness of the sliding mode.

Figure 4e shows the transient response y when the disturbance $f(t)$ acts on the output of the object. As can be seen in this case, the high-frequency component $f(t)$ (Random Number) passing through the regulator influenced the controlled coordinate y and caused its greater dispersion.

2 Conclusion

In the paper new control algorithms have been developed in order to control dynamic objects with parametric and signal uncertainty. These algorithms operate in a sliding mode, implemented in systems with a variable structure. The structure of a robust regulator consists of relays with different static characteristics:

1. Two-position relay without hysteresis.
2. In the second case, to reduce the switching frequency, use a relay-linear regulator with a linearity zone.

The second design allows the system to be stabilized in a small vicinity of the equilibrium position without the occurrence of self-oscillations. As a result of simulation modeling on Matlab/Simulink under conditions of parametric uncertainty, dynamic characteristics were obtained that confirm an increase in the robust performance of known systems.

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