It should be emphasized that, in contrast to many other results on the stability of non-autonomous systems (see, e.g., [2,3,5,6]), we do not require that $\lim_{t\to\infty} \|\dot{\gamma}(t)\| \to 0$ to prove the attractivity property. In this talk, we extend the approach of [1] to a general class of non-autonomous systems and discuss applications of the obtained results to such control problems as dynamical optimization and trajectory tracking.

References

1. *Grushkovskaya V., Dürr H.-B., Ebenbauer C., Zuyev A.* Extremum seeking for time-varying functions using Lie bracket approximations // IFAC-PapersOnLine. 2017. Vol. 50. P. 5522–5528.
2. *Khalil H.K* Nonlinear Systems. Prentice-Hall, 1996.
3. *Kelemen M.* A stability property // IEEE Trans. Autom. Control. 1986. Vol. 31. No. 8. P. 766–768.
4. *Langa J.A. Robinson J.C., Suárez A.* Stability, instability, and bifurcation phenomena in non-autonomous differential equations. // Nonlinearity. 2002. Vol. 15. P. 887–903.
5. *Lawrence D.A., Rugh W.J.* On a stability theorem for nonlinear systems with slowly varying inputs // IEEE Trans. Autom. Control. 1990. Vol. 35. No. 7. P. 860–864.
6. *Malkin I.G.* Theory of Stability of Motion. U.S. Atomic Energy Commission, 1952.

INCREASING THE ROBUSTNESS OF DEADBEAT CONTROLLER

D.A. Hryniuk, N.M. Oliferovich, I.H. Suhorukova, I.O. Orobei

Belarusian State Technological University
13a Sverdlova str., 220006 Minsk, Belarus
hryniukda@gmail.com

Introduction. In modern control systems, almost all algorithms are implemented in digital form. At the same time the PID algorithm has a number of limitations. The problem of integral saturation is emerged if there is limitation of the control action; response speed problem; adapting the settings when changing the dynamic characteristics of the object.

1. Receiving formulas for calculating regulators. Calculation of many digital controllers is much more algorithmized. One such option is a deadbeat controller [1]. This controller is characterized by high response speed. However, this is achieved by forming a high value of the control action, which is difficult to implement under applied conditions.

At the same time, it is possible to achieve the regulator's correspondence to the technological norms by increasing the time of the transient process. In [1] the expressions of choosing a primary pulse were obtained. We extend it to several time steps.

$$w(k) = 1 \; \forall \; k = 0, 1, 2, ... \tag{1}$$

For the case $b_0 = 0$, the z-transformations of the main, controlled and control variables have the following equations

$$w(z) = \frac{1}{1 - z^{-1}}. \tag{2}$$

Let

$$\frac{y(z)}{w(z)} = p_1 z^{-1} + p_2 z^{-2} + \; ... \; + p_m z^{-m}; \tag{3}$$

$$\frac{u(z)}{w(z)} = q_0 + q_1 z^{-1} + q_2 z^{-2} + \; ... \; + q_m z^{-m}, \tag{4}$$

where $u(z)$ – regulator output; $y(z)$ – output parameter; m – order. The condition for constructing a deadbeat controller, regardless the number of given time steps, is not changed:

$$\frac{b_1 z^{-1} + \; ... \; + b_m z^{-m}}{1 + a_1 z^{-1} + \; ... \; + a_m z^{-m}} = \frac{p_1 z^{-1} + \; ... \; + p_m z^{-m}}{q_0 + q_1 z^{-1} + \; ... \; + q_m z^{-m}}. \tag{5}$$

2. Formulas for the regulator. For two time steps one has

$$q_m = u_{SP}(a_m - a_{m-1} a_1) + a_{m-2} D_2; \tag{6}$$

$$p_m = u_{SP}(b_m - b_{m-1} a_1) + b_{m-2} D_2, \tag{7}$$

where

$$D_2 = q_C - u_{SP} + a_1 u_{SP}; \quad q_C = \frac{1}{\sum_{k=1}^{m} b_k}. \tag{8}$$

For three time steps the version for calculating the settings is

$$q_m = u_{SP}(a_m - a_{m-1} a_1 + a_{m-2} E_1) - a_{m-3} E_0; \tag{9}$$

$$p_m = u_{SP}(b_m - b_{m-1} a_1 + b_{m-2} E_1) - b_{m-3} E_0, \tag{10}$$

where

$$E_0 = u_{SP}(1 - a_1 + a_1^2 - a_2) - q_C; \quad E_1 = a_1^2 - a_2. \tag{11}$$

We obtain an expression for the regulator from condition for a time $u_{SP} = u(0) = u(1)$, for two time $u_{SP} = u(0) = u(1) = u(2)$ and for three time steps $u_{SP} = u(0) = u(1) = u(2) = u(3)$. Then, respectively

$$u_{SP} = \frac{q_C}{1-a_1}; \quad u_{SP} = \frac{q_C}{1-a_1^2-a_2-a_1}; \tag{12}$$

$$u_{SP} = \frac{q_C}{1+a_1(a_1-a_1^2-2a_2-1)-a_2-a_3}. \tag{13}$$

3. Conclusion. The obtained expressions were checked for some variants of object transfer functions. The increasing of the steps number that are specified by the conditions makes it possible to substantially increase the robustness of the system with a deadbeat digital regulator. When using three time steps the robustness's system approaches the proportional-integral-differential controller [2].

References

1. *Isermann R.* Digital Control Systems. Springer-Verlag. 1981. 565 p.
2. *Oliferovich N., Hryniuk D., Orobei I., Suhorukova I.* Increasing the robustness of the digital controller // International Conference "Electrical, Electronic and Information Sciences", 2018. P. 1–5.

MATHEMATICAL RESEARCH OF THE EQUILIBRIUM STATE OF SYMMETRIC SYSTEMS OF HARD SPHERES IN THE BOLTZMANN-GRAD LIMIT

H.M. Hubal

Lutsk National Technical University
75 Lvivs'ka str., 43018 Lutsk, Ukraine
galinagbl@yandex.ru

The evolution of states of dynamical systems of particles (hard spheres) can be described by the BBGKY hierarchy of equations [1, 2]. However, in some cases, simpler approaches can be applied to one-dimensional system of hard spheres. The main feature of such a system is that there is no change in the speed distribution function. This function is specified by an initial distribution that is the Maxwell speed distribution:

$$\varphi(v) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{v^2}{2\sigma^2}}$$