Increasing dynamic control accuracy by increasing the order of integration

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This article solves the problem of increasing the dynamic accuracy of feedback control.

1. Statement of the problem

The task is decrease dynamic error. The way: high-order integration in modifier PID controller: PID + I^2 +I^3 = PI^{3}D.

2. Method for solving the problem

Solution: the use of the numerical simulation method in the *VisSim* software. Object of zero order:

$W_0(s) = \exp(-\tau s)$. (1)

The 1-st order object:

$$W_1(s) = \frac{1}{1+s}\exp(-\tau s). \quad (2)$$

The 2-nd order object:

$$W_2(s) = \frac{1}{1+2s+s^2}\exp(-\tau s). \quad (3)$$

Oscillatory one:

$$W_3(s) = \frac{1}{1+0.1s+s^2}\exp(-\tau s). \quad (4)$$

The 4-th order object:

$$W_3(s) = \frac{1}{(1+2s+s^2)(1+2s+s^2)}\exp(-\tau s). \quad (5)$$

Let $e(t) = v(t) - x(t)$. The cost function is:

$$\Psi(e) = \int_0^T \left\{|e(t)|t + w\cdot\max\{0,\ e(t)\frac{d}{dt}e(t)\}\right\} dt. \quad (6)$$

A traditional PID controller is described by the following transfer function:

$$W_{PID}(s) = k_p + k_i\frac{1}{s} + k_d s. \quad (7)$$

We offer the following type of regulator:

$$W_{I4}(s) = k_1\frac{1}{s} + k_2\frac{1}{s^2} + k_3\frac{1}{s^3} + k_4\frac{1}{s^4}. \quad (8)$$

Here, all coefficients for integrators of all degrees are determined by the numerical optimization method.

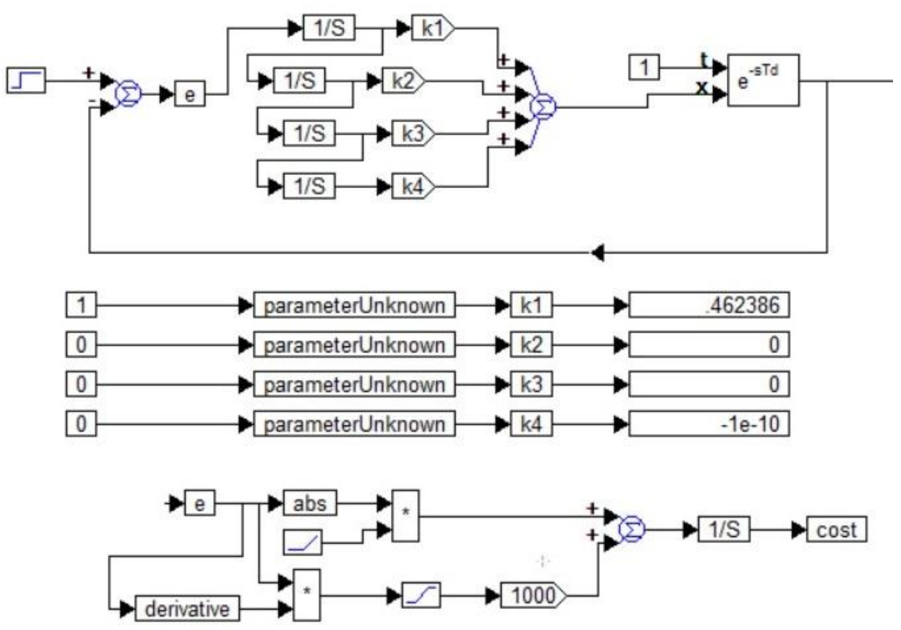

Figure 1. Structure for modeling the system in the *VisSim program* and for numerical optimization of the controller

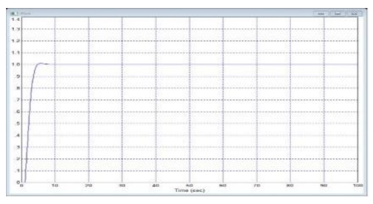

Figure 2. The resulting transient process in the system according to *Figure* 1

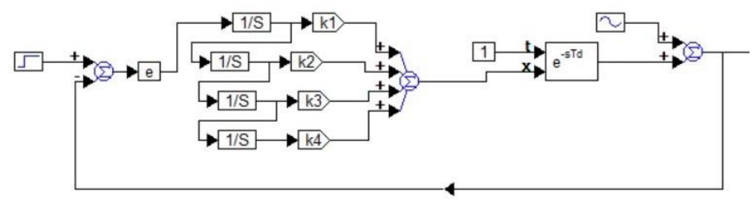

Figure 3. Modified design with harmonic interference at the plant output

3. Results of solving the assigned tasks

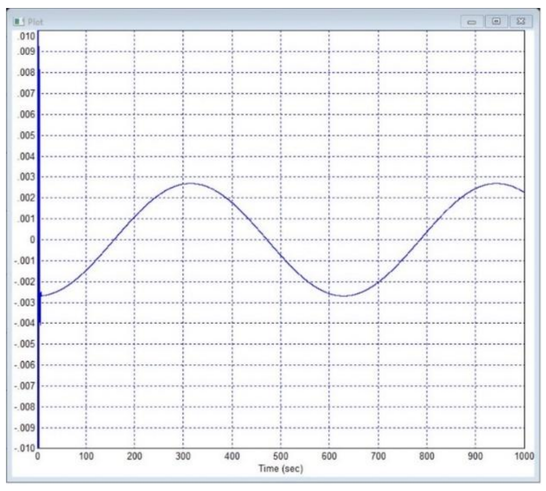

Figure 4. Error in a system with an object (1) and a PID controller, enlarged scale, residual deviation is 0.0026 units, input deviation amplitude is 0.2 units, interference is suppressed 78 times

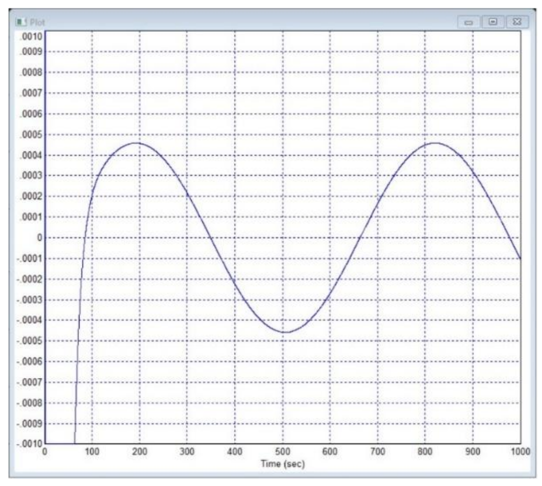

Figure 5. Error at the output of such a system with a regulator (9): overshoot is 8%, residual deviation is 0.00045 units, input deviation amplitude is 0.2 units, interference is suppressed 450 times

The controller equation in this case has the following form:

$$W_{PI2}(s) = k_p + k_1\frac{1}{s} + k_2\frac{1}{s^2}. \quad (9)$$

Also for this object the following type of regulator was used:

$$W_{PI3}(s) = k_p + k_1\frac{1}{s} + k_2\frac{1}{s^2} + k_3\frac{1}{s^3}. \quad (10)$$

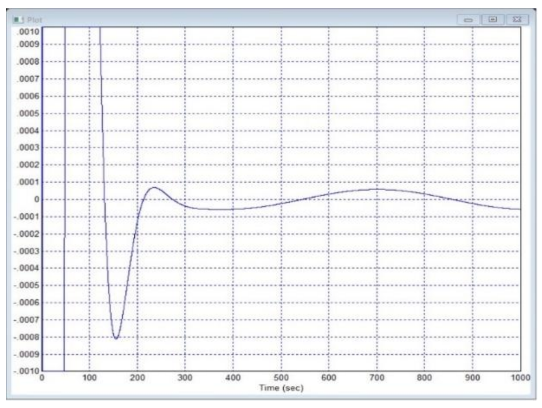

Figure 6. error at the output of a system with a regulator (10) on a larger scale: overshoot is 8%, residual deviation is 0.00005 units, input deviation amplitude is 0.2 units, interference is suppressed 40,000 times

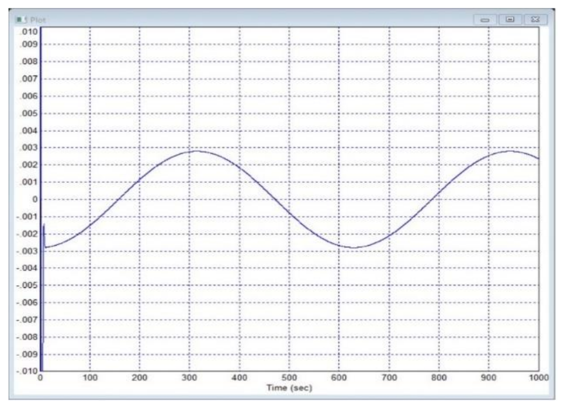

Figure 7. Error at the output of a system with a second-order object of type (2) and a controller (7): the residual deviation is 0.0028 units, the interference is suppressed 70 times

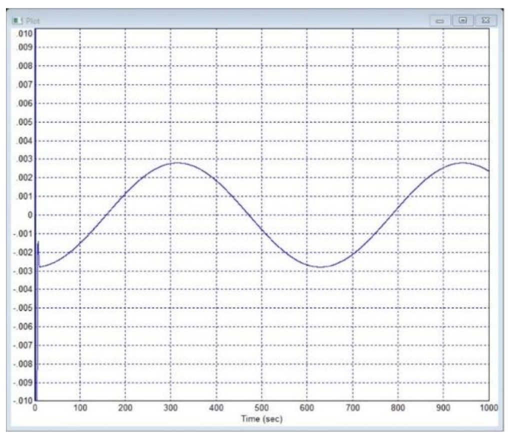

Figure 8. Error at the output of the system with object (3) and a PID controller supplemented by a double integrator: the residual amplitude of the deviation is 0.0005 units, the interference is suppressed 400 times

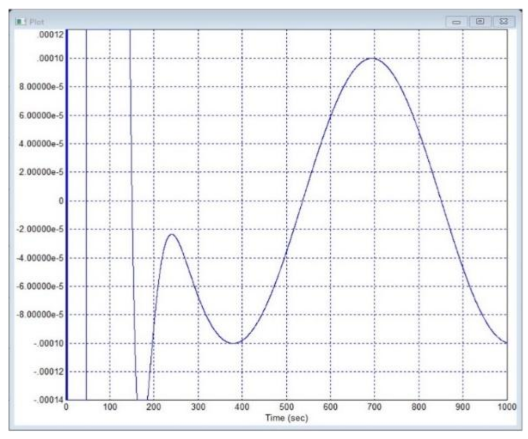

Figure 9. Error at the output of the system with object (2) and a PID controller supplemented by double and triple integrators: the residual deviation amplitude is 0.0001 units, the noise is suppressed 2000 times

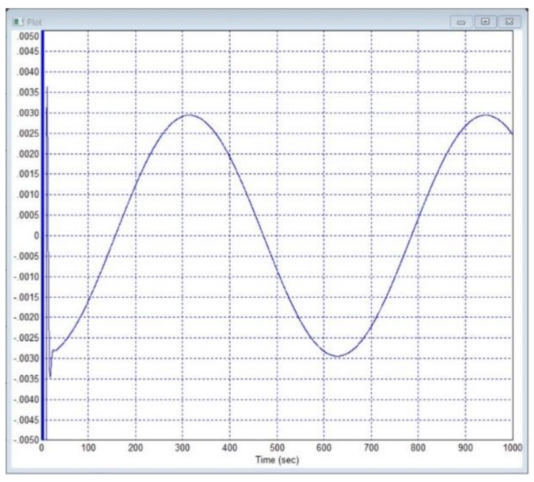

Figure 10. Error at the system output for an object (3) with a controller (7): the residual deviation is 0.002 units, the interference is suppressed 70 times

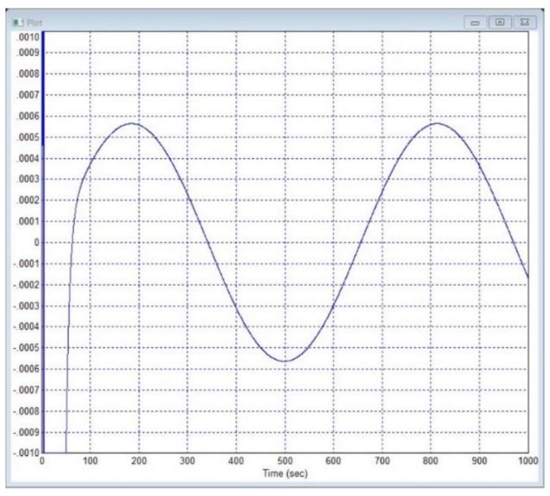

Figure 11. Error at the output of the system (3) with a PID controller (7), supplemented by a double integrator: the static deviation amplitude is 0.00055 units, the interference is suppressed 363 times

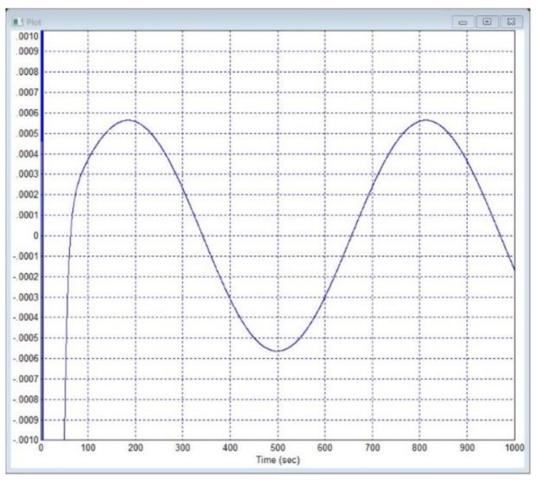

Figure 11. Error at the output of the system (3) with a PID controller (7), supplemented by a second integrator: the static deviation amplitude is 0.00055 units, the interference is suppressed 363 times

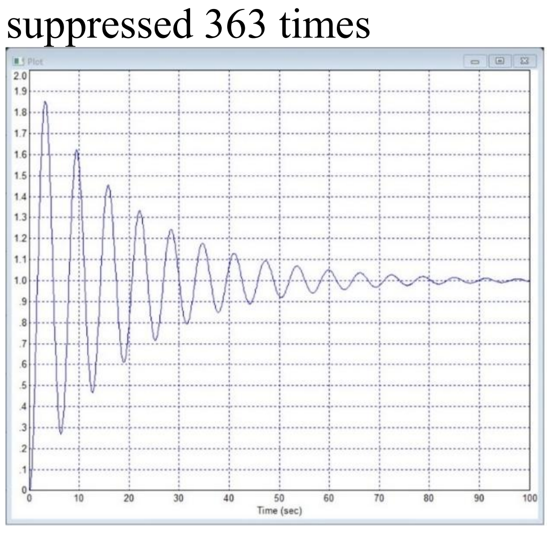

Figure 12. Response of an object with model (4) to a stepwise jump

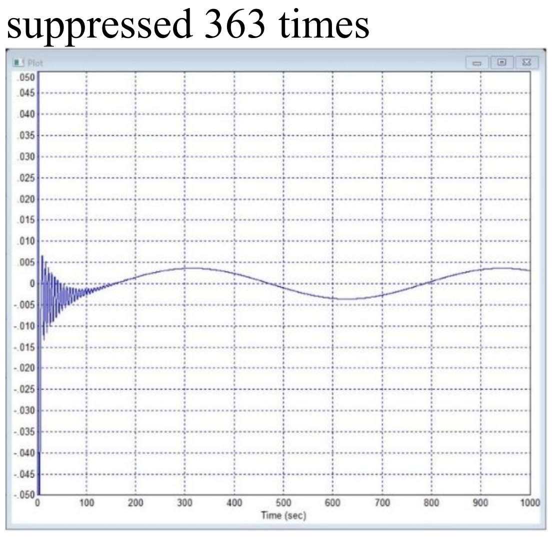

Figure 10. Error at the system output for an object (4) with a PID controller (7) : the residual deviation is 0.005 units, the interference is suppressed 40 times

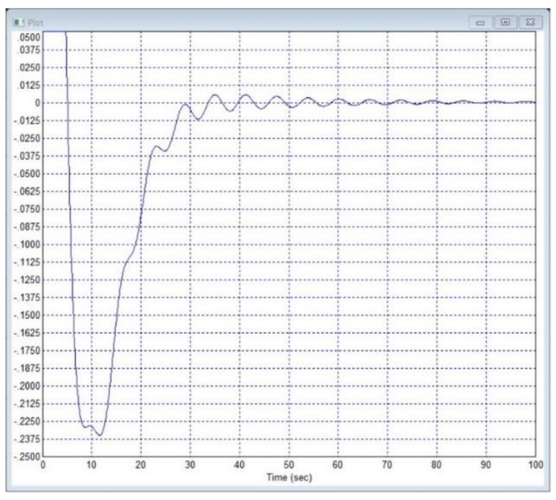

Figure 11. Error at the system output for a system for an object (4) with a PID controller (7), supplemented by a double integrator : the residual amplitude of deviation due to interference is much less than resonant oscillations, their amplitude is initially equal to 0.006 units, and then quickly decays

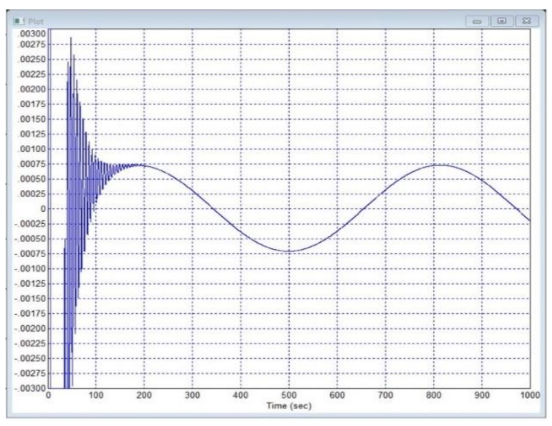

Figure 12. Error at the system output for an object (4) with a PID controller (7), supplemented by two integrators: second and third orders: overshoot is 20%, the static deviation amplitude is 0.00075 units, interference is suppressed 267 times

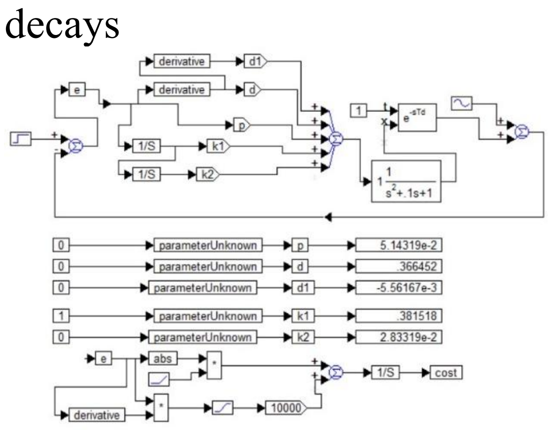

Figure 13. Structure for modeling and optimizing this system for object (4) using a PID controller supplemented with an additional double integration channel and an additional double differentiation channel

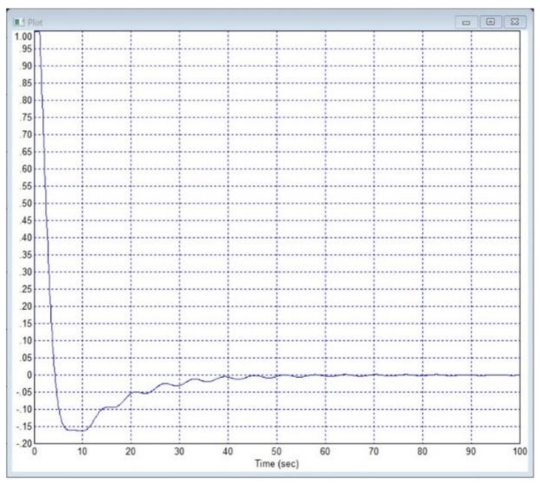

Figure 14. Error at the system output according to *Figure* 13

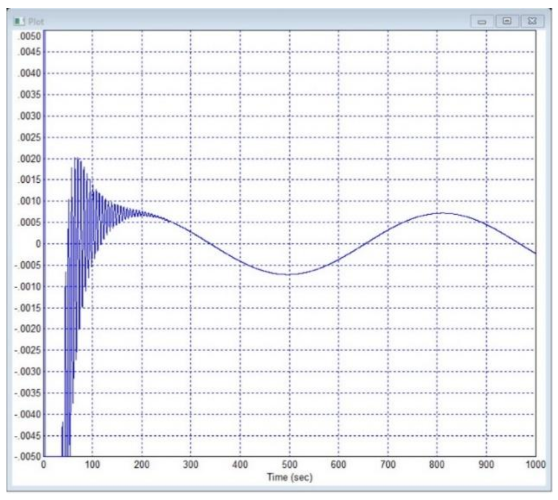

Figure 15. Error at the system output according to Figure 13 on an enlarged scale

To control an object of type (5), all types of listed regulators were also used. The results are approximately the same. Namely: when using a conventional PID controller, the overshoot is 15%, the residual deviation has an amplitude of 0.0045 units, and the interference is suppressed by 44.4 times. When adding a double integrator to the regulator, the overshoot is 22%, the amplitude of the residual deviation is less than 0.0015, and the noise suppression is 133 times. When adding a triple integrator, the overshoot is 20%, the residual amplitude is 0.0018, the noise suppression is 111 times, that is, in this particular case, the third integrator turned out to be ineffective.

In all the cases considered, the introduction of a fourth-order integrator did not produce better results than in the case of adding only second- and third-order integrators.

4. Discussion

Thus, using the method of numerical modeling and optimization it is shown that the dynamic error of a closed dynamic automatic control and stabilization system can be effectively increased by using additional integrators in the serial channel, namely, in addition to the proportional, differentiating and integrating paths, effectively adding a path with double and triple integrator. It can also be effective to add a double differentiation path, which helps provide better stability, but only when controlling second- and higher-order objects.

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