Modification of the Localization Method for Suppressing Disturbances in Automation Systems

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Abstract
The localization method is used to control non-stationary linear objects. The mathematical model of the object is given by a transfer function with varying coefficients. This method was developed and studied in an analytical form. The advantage of this method is the effective suppression of the effect of changes in the coefficients of the object model on the stability and accuracy of the system. This is confirmed by the proved theorems for the differential equations describing the response of the system to the prescription change. These advantages are not applicable when control has the goal to suppress disturbance. However, this task is the most important one in automatic control practice. In addition, the system by this method has a static error. This follows from the structure of the regulator. In all practical problems, the provision of zero static control error is necessary. This requirement is more important than requiring of a small dynamic error. There are many publications devoted to the localization method and its application, but the provision of zero static error in them is hardly discussed. The present paper is devoted to the investigation of providing a zero static error, an external loop method with an integrator is proposed. The proposed solution to guarantee the reliability of the result and for the sake of clarity is illustrated by the solution of a numerical example. The solution is implemented using the software for mathematical modeling VisSim.

Keywords
regulator, control, feedback, motion division method, localization method, error, transient process duration, dynamic error, mathematical modeling, simulation, VisSim

1. Introduction

The method of motions division is based on the method of localization [1]. “Localization method is a method of design of systems for automatic control of nonlinear and non-stationary objects, including the formation of control as a function of the velocity vector and ensuring localization and suppression of the perturbations effect” [1]. In this case, perturbations are understood as changes in the parameters of a mathematical model of an object. The disturbances, which are uncontrolled effects, which can be described in the form of an additive signal applied to the output of a control object, should be suppressed, which is most important.

The method of motion division is justified mathematically using the Laplace transform and applied sections of mathematics, according to which it is permissible to neglect small values of the values in comparison with large values of the same dimension with respect to the power s (which is argument in the Laplace transform) to the same extent.

Example 1. Let consider an example from the publication [2]. Let the given object is described by the second order differential equation:

$$\bar{y} + a_1\dot{y} + a_0 y = bu \tag{1}$$

It is equivalent to the mathematical model in the form of transient function:

$$W_0(s) = \frac{b}{a_2 s^2 + a_1 s + a_0} \tag{2}$$

For definiteness, let $a_2 = 1$. It is required to develop a control system such that the transient process in the system is described by a third-order equation of the following form:

$$(c_3 s^3 + c_2 s^2 + c_1 s + 1)y = v \tag{3}$$

In this case it is assumed that if there are rapid movements in the system, their influence on processes in the system is negligible, and they are not reflected in the prescribed equation (3). In other words, this relation describes slow motions, therefore, speaking of the desired dynamic properties, we mean only slow motions of the system.

We define the regulator as the following equation in the operator form:

$$u = k \cdot \frac{c_3 s^3 + c_2 s^2 + c_1 s + 1}{b(\mu s^3 + s^2 + \alpha s + 1)} \cdot x \qquad (4)$$

Here k/b describes the gain of the regulator, μ is a small value (a small parameter), chosen usually so that it is less than all c_i. The quality of the transient process depends on the parameter α. The structure of the system is shown in Figure 1.

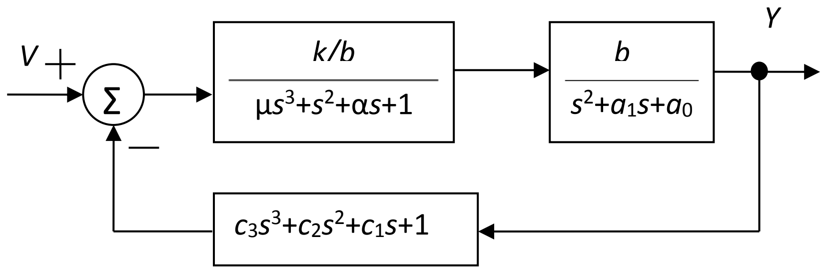

Fig. 1. Structure of the system with a regulator according to Example 1

It is seen that there is a link of derivation of the third order in the feedback channel. The realization of such a link is problematic, both for an analog regulator and for its digital implementation [3]. In this form, the system is difficult to investigate by modeling and implement in practice, which is the basis for a more detailed study of this method.

2. Study by the Method of Structural Transformations

The structure shown in Figure 1 can be transformed into an easily realizable equivalent structure by transferring the derivation link through the adder. In this case an element with an inverse transfer function, that is, a third-order low-frequency filter, arises at the input of the adder. The transferred derivation element is then combined with a low-pass filter in the forward contour regulator, because of which there is a physically realizable element in which the order of the numerator is the same as the order of the denominator. The resulting structure is shown in Figure 2. This structure clearly illustrates the lack of this method of control.

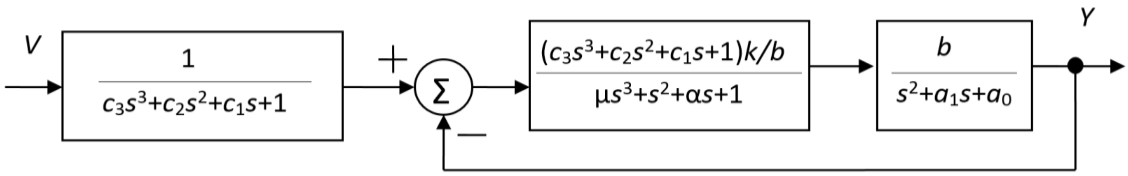

Fig. 2. The transformed equivalent structure of the system with the regulator according to Example 1

Indeed, the following can be seen from this structure.

1. The control loop consists of two elements, not counting the adder, namely, from the object and the regulator, which transfer function has polynomials of the same third order in the numerator and denominator. Since the free terms in the denominator of this regulator and in the denominator of the transfer function of the object are not zero, there is no integrator in the loop. Therefore, this control loop has a static error.

2. There is a low-pass filter at the input of the object, which is a transfer function whose denominator is the desired polynomial from equation (3), and the numerator has a unit coefficient. Such a filter converts a stepwise jump at its input into a smoothly increasing signal, and the character of the rise of this signal corresponds to equation (3).

3. Based on what has been said, it can be concluded that the control problem with the desired dynamic properties is solved in the following two steps: first, the task is transformed into a smoothly

changing signal in accordance with the desired dynamic equation; second, the control loop is made as fast as possible, although with a static error. This is achieved by a large gain factor.

4. Therefore, instead of two kinds of movement in the loop, slow and fast ones, in fact a loop with only fast movements is formed, and slow movements are formed outside the loop.

5. If the loop treated fast movements loop is described by a high quality control, i.e. a small error and a large margin of stability, then slow movements are not required, the system is sufficiently good without it. If this loop is unstable, then the presence of a filter at its input does not save the situation, and therefore in this case slow movements are also not needed. Finally, if it is described by poor quality, that is, by a large error or an insufficient margin of stability, then the presence of slow motions disguises these shortcomings if one examines the system by responses to a step input effect, but if the loop is examined from the response to the disturbance jump, then the bad quality of the control system will be revealed.

3. Study by Mathematical Modelling

Example 2. Let consider Example 1 with the following numerical values:

$$W_0(s) = \frac{1}{40s^2 + 100s + 1} \tag{5}$$

$$u = 100 \cdot \frac{s^3 + 4s^2 + 4s + 1}{0.1s^3 + s^2 + 2s + 1} \cdot x \tag{6}$$

We simulate the resulting system in the VisSim software [3–5] in accordance with the structure shown in Figure 2.

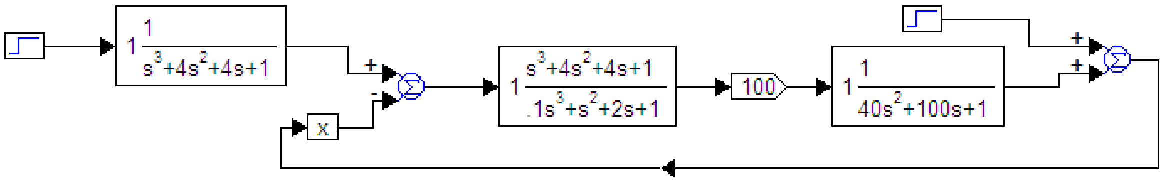

Fig. 3. The project in the software VisSim for modeling the system with a regulator for Example 2 in accordance with the structure of Figure 2

The corresponding project in this software is shown in Figure 3. In this case, an additional adder for introducing disturbance is introduced into the system. By setting unit or zero values of the input signal or disturbance, we can obtain transient processes for the corresponding situations. Figure 4 shows the transient processes in the system with different gain coefficients. An increase in the coefficient in the range from 200 to 500 does not significantly affect the form of the transient process; with a value greater than 550 in the system, high-frequency excitation appears, i.e. the system loses stability. Figure 5 shows the process at a gain of 580, and in Figure 6 shows the process at a gain of 600.

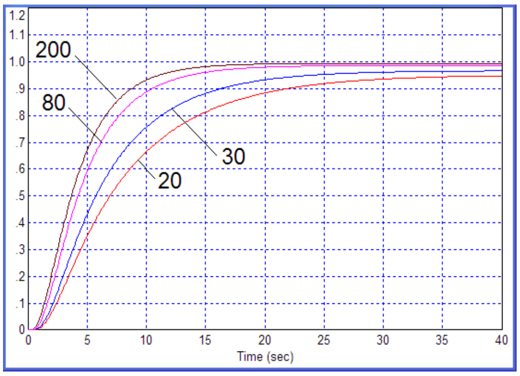

Fig. 4. Transient processes in the system for different values of the regulator gain coefficient k (the values are shown in the graph)

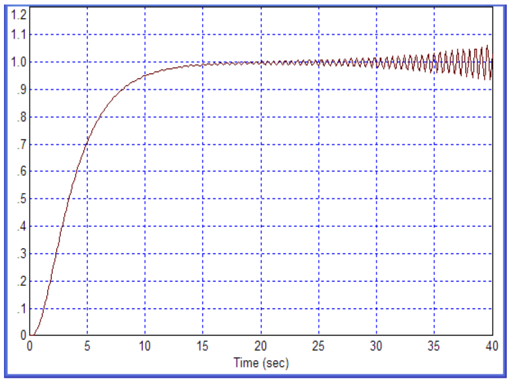

Fig. 5. Process in the system with k = 580

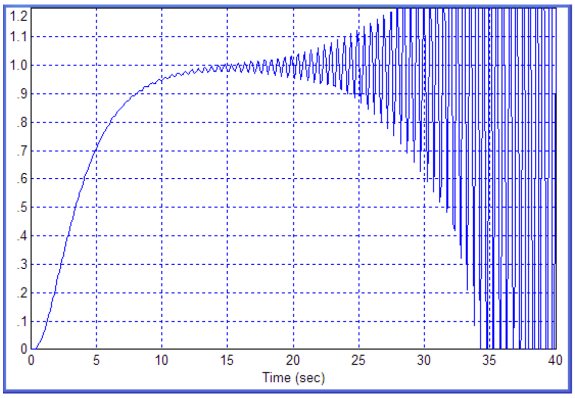

Fig. 6. Process in the system with k = 600

Figure 7 shows the transient processes in the system for different values of the coefficient a_2, while the gain of the regulator is k = 100. Figure 8 shows the transient processes in the system for different values of the coefficient a_1 for the same gain. Figure 9 shows transient processes in the system in response to a disturbance jump for different values of the coefficient a_2, Figure 10 shows the similar processes for different values of the coefficient a_1, the regulator gain is k = 100. Figure 11 illustrates the dependence of process on gain coefficient k.

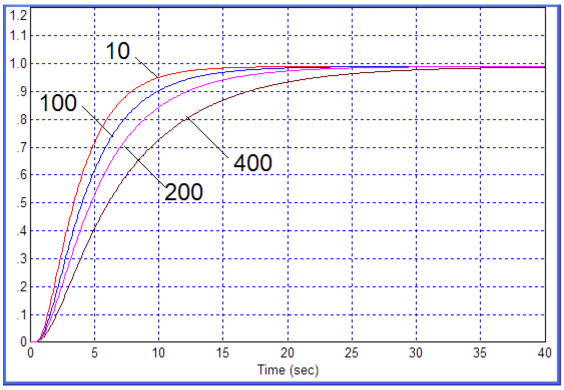

Fig. 7. Transient processes in the system for different values of the coefficient a_2, while the regulator gain is k = 100

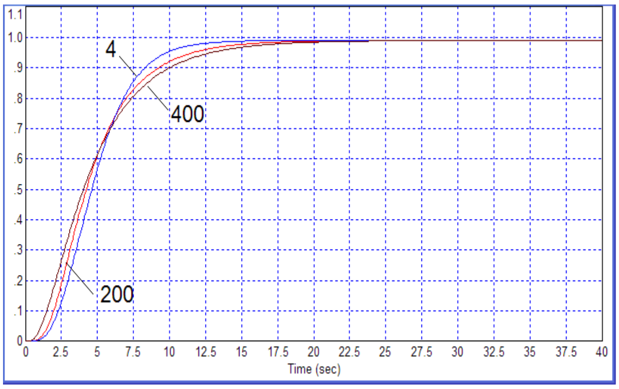

Fig. 8. Transient processes in the system for different values of the coefficient a_1, while the regulator gain is k = 100

On this basis, we can conclude that the system, at first glance, remains stable with a relatively large margin of stability with changes in the parameters of the object over a wide range.

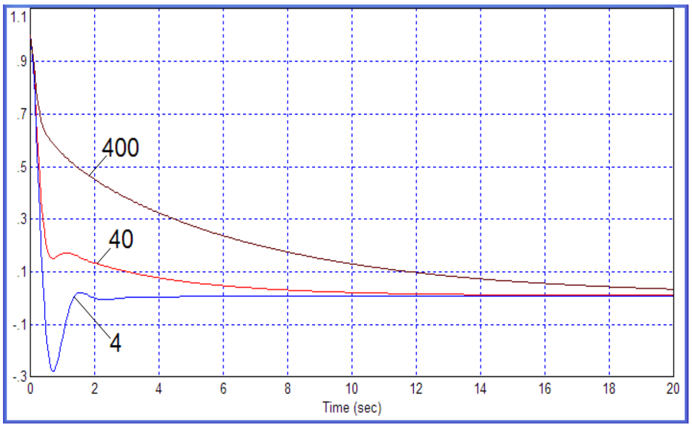

Fig. 9. Transient processes in the system in response to a disturbance jump for different values of the coefficient a_2, while the regulator gain is k = 100

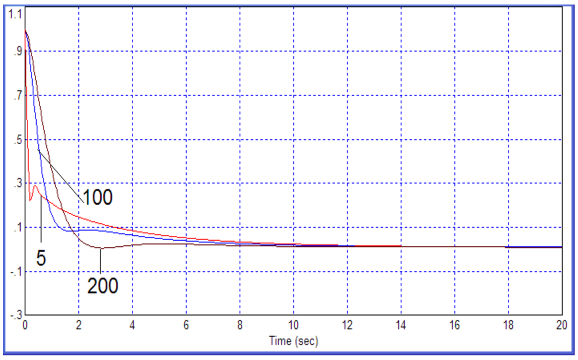

Fig. 10. Transient processes in the system in response to a disturbance jump for different values of the coefficient a_2, while the regulator gain is k = 100

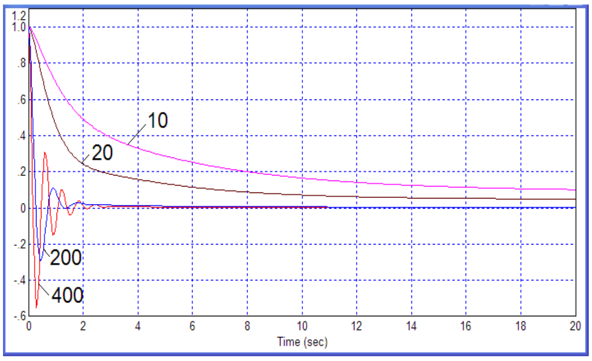

Fig. 11. Transient processes in the system in response to a disturbance jump for different values of the regulator gain k (values are shown in the graph)

For comparison, the response to the jump of the prescription $v = -1$ was simulated when the filter was removed from the system. The result is shown in Figure 11. It can be seen that the processes are completely identical, they differ only in a constant level.

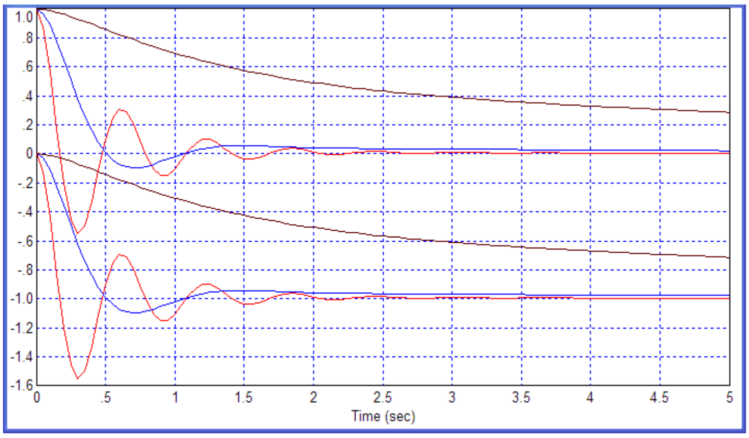

Fig. 12. Comparison of transient processes in the system according to Figure 11 in comparison with the processes in response to a jump in the prescription to a value of $v = -1$ in the absence of a filter: the identity of the graphs are visible (except for a constant shift)

Thus, the simulation confirms the conclusions made in the previous section based on reducing the system to a realizable form with simple loops through equivalent transformations. The conclusion is confirmed that the most important are the so-called fast movements in the loop, and slow movements are formed outside the loop by filtering the reference signal.

4. Provision of Astatism and High Quality of Control by the Creation of External Control Loop

The resulting system can be treated as a new object, and in connection with this object, a traditional PI regulator can be designed, as it was done in [6], where an integral regulator was used for these purposes. The corresponding structure is shown in Figure 13.

Figure 14 shows the changes when the transient process changes of the parameter a_1 of the object in the range of from 4 to 200. The system remains stable, the overshoot of less than 10%, the duration of the transient process is not more than 10 s. Figure 15 shows the process changes when the parameter a_2 varies from 4 to 80. With further increase, overshoot increases, and then the system is unstable. Within these limits, the system still remains stable, the transient process lasts no more than 10 s, the overshoot at worst is 15%.

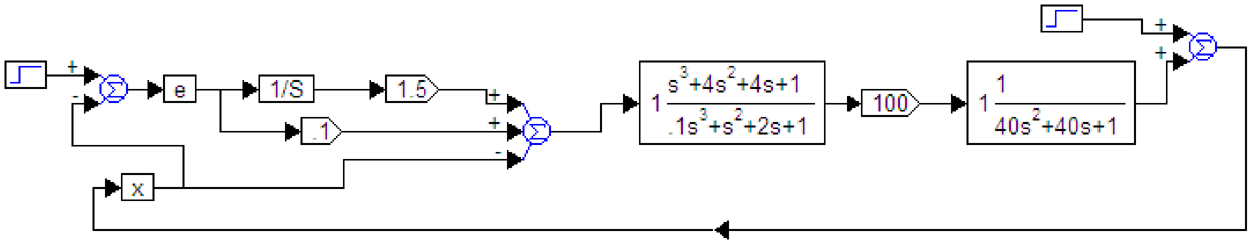

Fig. 13. Structure with external control loop with PI controller (iterative tuning)

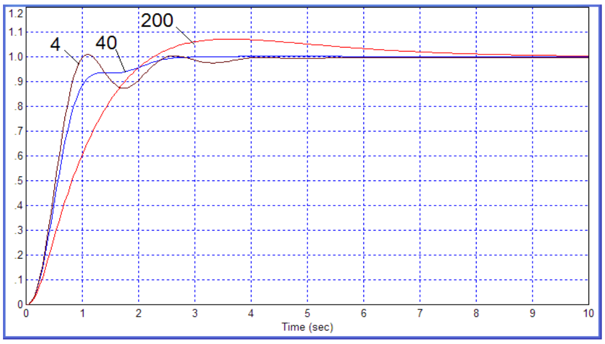

Fig. 14. Changes in the transient process in the system according to Figure 14 when the parameter of the object a_1 varies from 4 to 200

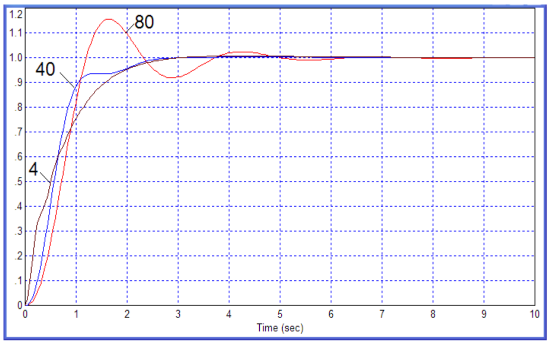

Fig. 15. Changes in the transient process in the system according to Figure 13 when the parameter a_1 of the object varies from 4 to 80

Figure 16 shows changes in the transient process in the system with a change in the gain k in the range from 40 to 400. Overshooting about 13 % for k = 40 exists, with the increase of k overshooting disappear. Figure 17 shows comparison of transient processes in the system according to Figure 13 when the gain a_1 is varied in the range from 20 to 80: the top graphs are the response to the task jump, the lower graphs are the response to the disturbance jump. More value of a_1 is better in this case.

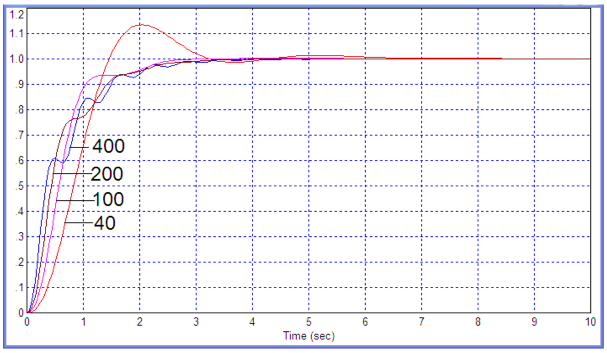

Fig. 16. Changes in the transient process in the system according to Figure 13 with a change in the gain k in the range from 40 to 400

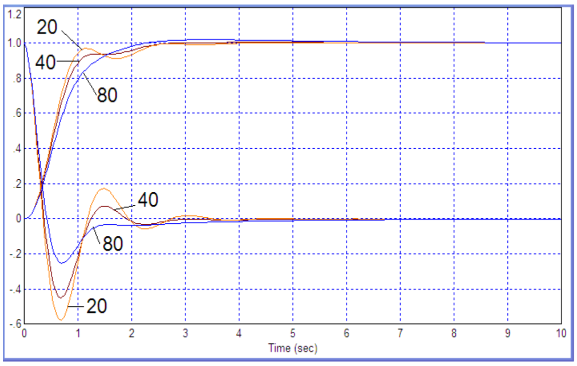

Fig. 17. Comparison of transient processes in the system according to Figure 13 when the gain a_1 is varied in the range from 20 to 80

5. Conclusion

As a result of the research, it has been shown that the method of the motions division from paper [3] and some other publications of the same authors of this period is operable within limited limits. Based on the theoretical analysis of the transformed structure and proceeding from the results of numerical modeling, the following can be asserted.

1. There is no actual division of movements in the loops: there is an input filter that affects only the jump in the prescription signal, but does not affect the jump of disturbance, and also there is the stabilization loop itself, which was previously treated as a loop of fast movements. The properties of this particular loop are most important from the standpoint of qualitative suppression of disturbance.

2. The regulators proposed in [3] are mostly static, to provide astaticism, an additional external astatic regulator is required.

3. The system received with an additional external contour satisfactorily retains its properties when the parameters of the object change with respect to working out the prescription; however, this property does not fully characterize the quality of the system of automatic control.

4. Analysis of the disturbance suppressing in the received versions of the system with an additional external regulator is analyzed. The systems are rated as satisfactory, but the degree of suppression of the non-stationary properties of the object is not too high.

5. The analyzed design method is extremely complicated in comparison with the numerical optimization methods developed in the cycle of works [3–5].

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