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FORMING OF CONTROLLED INFLUENCES IN TH E SYSTEM WITH FUZZY REGULATOR

Andrew Lozynskyi , Ljubomyr Demkiv

National University "Lviv Polytechnic "

lozynsky@polynet.lviv.ua; demkivl@gmail.com

Abstract. A classical two-mass system of modal speed regulation containing an unstable subsystem has been considered. The dependence of the basic characteristics on the membership function parameters and a mean-geometric root has been ascertained. The system behavior under external perturbations has been also investigated.

Key words: membership function, two-mass system, fuzzy logic, adaptive control, unstable system.

1. Introduction

Today the methods of adaptive control providing the optimum performance of the system in the conditions of object's parameters change and of a q-point, under the impact of external perturbations are widely used in the technical systems. Such systems may also include the systems constructed on the basis of the piecewise-linearization method. For each system coefficients providing the stable work are calculated by means of Lyapunov's method.

Considerable success in the construction of such systems is connected with the use of the fuzzy-control theory. By means of such approach a smooth conversion from one tuning of a regulator to another or even to other structure of the regulator during the system work is possible. The papers [1] and [2] are dedicated to the investigation of the systems of the adaptive control with fuzzy logic. An important question at the analysis of such systems is a question of stability. Although there are many works devoted to the question of stability of the systems with separate subsystems, in particular [3-10], the case when one of the subsystems is unsteady has been scantily explored. At the same time, using unsteady subsystem acquires new traits of the system as a whole. Thus, during the step signal in transition from the tuning corresponding to the unstable subsystem to the tuning of the regulator corresponding to the stable subsystem the improvement of integral criteria of quality for the ITAE type occurs. And in transition from the stable system to the unstable one it is possible to obtain the oscillation mode in the area of a set value with ability to adjust the frequency and the amplitude of vibrations.

2. Problem statement

Let us consider the two-mass classical system typical for many electromechanical systems. The structure chart of such a system is represented in figure 1 (see [11]).

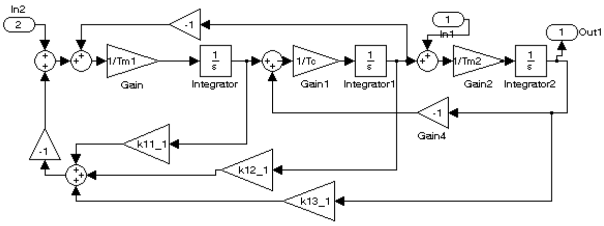


Fig. 1. Classical structure scheme of two-mass system of modal speed regulation

The transfer function of such a system is the following

$$W(p)=\frac{c_{13}/T_{M1}}{H(p)},$$
$$H(p)=p^3+p^2\frac{k_{11}}{T_{M1}}+p\left(\frac{1}{T_CT_{M2}}+\frac{k_{12}+1}{T_CT_{M1}}\right)+\left(\frac{k_{11}+k_{13}}{T_CT_{M1}T_{M2}}\right) \quad (1)$$

Here $k_{11\_1}, k_{12\_1}, k_{13\_1}$ are unknown coefficients of a feedback controller, and $c_{13}, T_{M1}, T_{M2}, T_C$ are the coefficients characterizing the system and described in [11].

Traditionally, feedback controllers are tuned either to the binomial form or the Butterwort one. The coefficients of feedback controllers are calculated by equating the coefficients at corresponding powers of characteristic polynomial and a desirable standard form. The disadvantage of the first system is the lower speed of the performance, and the disadvantage of the second one is retuning which may be inadmissible for the technical reasons.

The improvement of the system characteristics is ensured by the combination of the mentioned tunings of feedback controllers in the systems with fuzzy logic [7]. A further gain is possible using the unstable system on the primary stage [8, 9]. In this paper coefficients are determined as follows in (2), (3), (4)

$$k_{11\_1}=3w_{0\_1}T_{M1},$$
$$k_{12\_1}=\left(3w_{0\_1}^2-\frac{1}{T_CT_{M2}}\right)T_CT_{M1}-1,$$
$$k_{13\_1}=T_CT_{M1}T_{M2}w_{0\_1}^3-3T_{M1}w_{0\_1}, \quad (2)$$

$$k_{11\_2} = T_{M1} w_{0\_2},$$
$$k_{12\_2} = \left(-w_{0\_2}^2 - \frac{1}{T_C T_{M2}}\right) T_C T_{M1} - 1, \qquad (3)$$
$$k_{13\_2} = -T_C T_{M1} T_{M2} w_{0\_2}^3 - T_{M1} w_{0\_2},$$

$$k_{11\_2} = T_{M1}\left(w_{0\_2} + 2 * c\right),$$
$$k_{12\_2} = \left(\left(2a w_{0\_2} + c^2 + d^2\right) - \frac{1}{T_C T_{M2}}\right) T_C T_{M1} - 1, \qquad (4)$$
$$k_{13\_2} = T_C T_{M1} T_{M2}\left(c^2 w_{0\_2} + d^2 w_{0\_2}\right) - T_{M1}\left(w_{0\_2} + 2c\right),$$
$$c = -\sqrt{w_{0\_2}^2 - d^2},$$

and the membership function is determined as follows (fig. 2, see. [12])

$$\Gamma(u; a, b) = \begin{cases} 0, & u < a, \\ (u - a)/(b - a), & a \le u \le b, \\ 1, & u > b, \end{cases} \qquad (5)$$

Where a and b are parameters with values defining the operating range of the unstable system and the width of the transition interval correspondingly; and parameter $u = |e(t)| = |y_{set} - y_{out}(t)|$ is an error value.

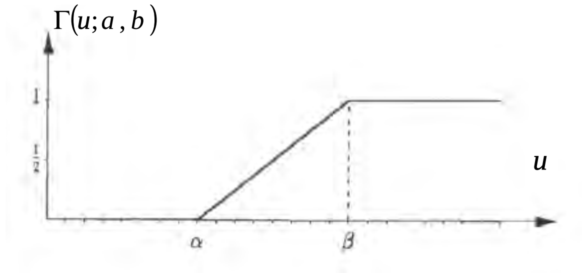


Fig. 2. Membership function $\Gamma(u; a, b)$

The case of the system with coefficients (2), (3)

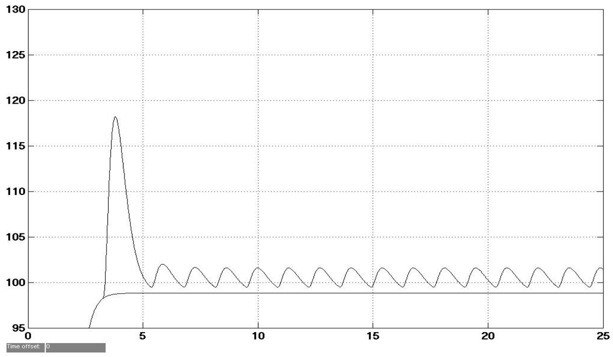
At first let us consider the case of the system with one root in the right half plane, that is, one root with a positive real part. The signal equal to 100 at time equal to 1 second is given to the input of the system.

It is obvious that the behavior of the system will depend on the value of a mean-geometric root w_0 and membership function parameters a and b. For the convenience of the calculations instead of these parameters we introduce derivative ones: Δa is the width of the interval and a^* is the middle of the interval

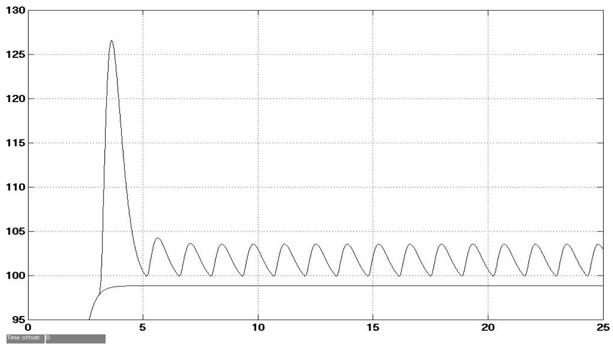
$$\Delta a = b - a,$$
$$a^* = 0.5 \cdot (a + b).$$

It should also be noted that, depending on the value of the mean-geometric root, the system (1) may behave either as the one- or the two-mass system (see [11]). In this case, the system behaves as the one-mass when $w_0 < 15.64$ and as the two-mass when $w_0 > 19.56$.

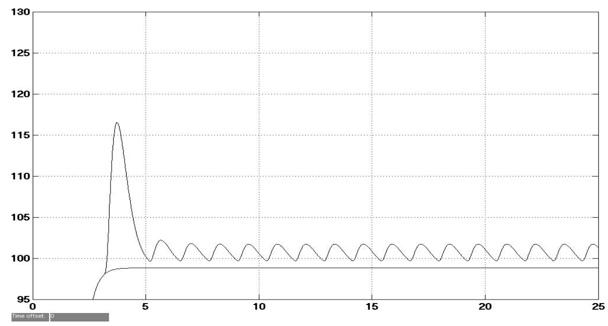
Here are some graphs illustrating the system behavior at the different values of w_0, Δa, a^* fig.3-4.



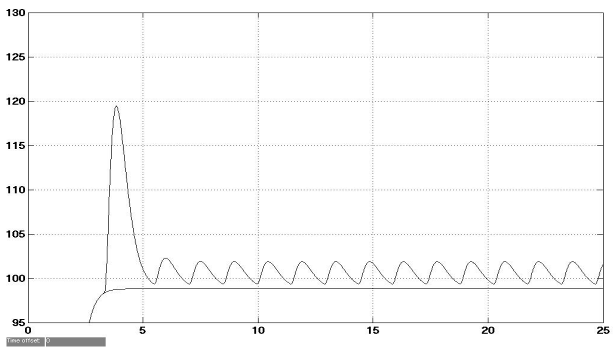
a) $a^* = 0.5$, $\Delta a = 0.5$



b) $a^* = 1$, $\Delta a = 0.5$

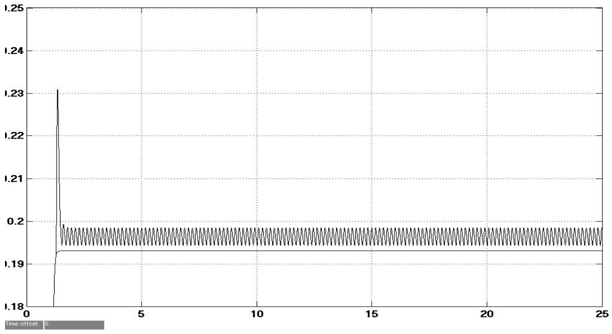


c) $a^* = 0.5$, $\Delta a = 1$

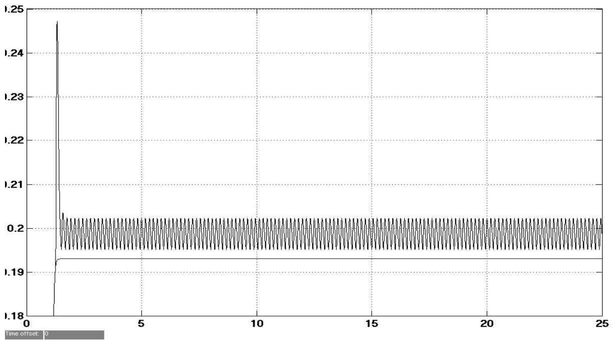


d) $a^* = 0.5$, $\Delta a = 0.2$

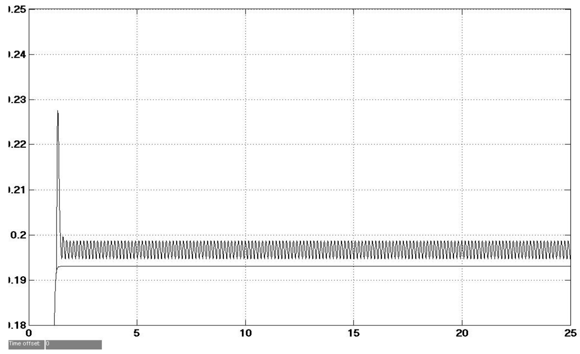
Fig. 3. The simulation result for the system at $w_0 = 4$ *and different values of parameters* a^*, Δa.



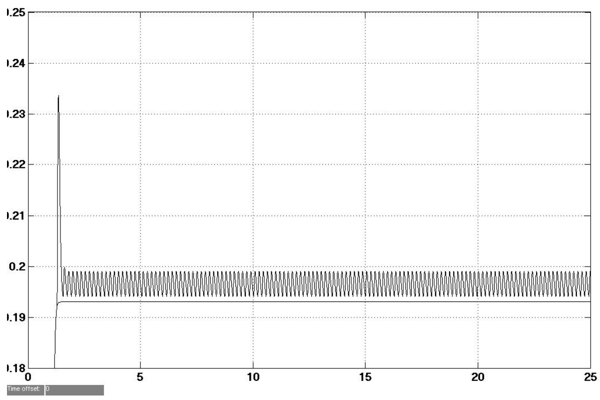
a) $a^* = 0.5, \quad \Delta a = 0.5$



b) $a^* = 1, \quad \Delta a = 0.5$



c) $a^* = 0.5, \quad \Delta a = 1$



d) $a^* = 0.5, \quad \Delta a = 0.2$

Fig. 4. Simulation results for the system at $w_0 = 32$ *and different values of the parameters* a^*, Δa.

Thus in a system with one root in the right half plane the change of the value of the mean-geometric root provides the oscillation frequency change. The average output value depends on the value of parameter b.

More detailed study of value characteristics are given in the following tables, namely: the amplitude of oscillations (table 1-2), the average output value (table 3-4), the dispersion (table 5-6). Here the amplitude is understood as the difference between the highest and the lowest value of the output signal after the transition to the mode of steady state oscillations. Here and further the first columns of the tables define the a^* values, and their first rows introduce Δa values.

Table 1

Dependence of the amplitude on a^* and Δa at $w_0 = 4$

	0.1	0.5	1	5	10
0.1	0.41	1.56	3.11	9.31	13.66
0.2	0.41	1.27	2.41	9.25	13.64
0.5		1.06	1.81	8.82	13.56
1		1.03	1.58	6.84	13.24
2			1.50	5.17	11.17
5				3.92	7.42
10				3.49	5.84
20					5.00

Table 2

Dependence of the amplitude on a^* and Δa at $w_0 = 32$

	0.1	0.5	1	5	10
0.1	0.0008	0.0030	0.0061	0.0182	0.0267
0.2	0.0008	0.0025	0.0047	0.0181	0.0267
0.5		0.0021	0.0035	0.0172	0.0265
1		0.0020	0.0031	0.0133	0.0259
2			0.0029	0.0101	0.0218
5				0.0076	0.0145
10				0.0068	0.0114
20					0.0097

Let us put investigation results (tabl. 3–4) to estimate real influence of mean-geometric root alteration on the average output value.

Table 3

Dependence of average output value on a^* and Δa at $w_0 = 4$

	0.1	0.5	1	5	10
0.1	99.37	100.88	102.89	112.71	121.41
0.2	99.41	100.62	102.21	112.65	121.40
0.5		100.53	101.73	112.24	121.32
1		100.70	101.68	110.35	121.03
2			101.98	108.96	119.09
5				108.67	116.10
10				109.92	116.03
20					118.39

Table 4

Dependence of the average output value on a^* and Δa at w_0 = 32

	0.1	0.5	1	5	10
0.1	0.1941	0.1970	0.2009	0.2201	0.2371
0.2	0.1942	0.1965	0.1996	0.2200	0.2371
0.5		0.1963	0.1987	0.2192	0.2370
1		0.1967	0.1986	0.2155	0.2364
2			0.1992	0.2128	0.2326
5				0.2122	0.2267
10				0.2147	0.2266
20					0.2312

Further increase of the values of membership function (5) parameters leads to the increase of the oscillation amplitude. It is not expedient from the practical point of view, that is why this case has not been considered in this work.

The results of the investigating the dependence of the dispersion on the membership function (5) parameters are given in the tables 5–6.

Table 5

Dependence of the dispersion on a^* and Δa at w_0 = 4

	0.1	0.5	1	5	10
0.1	0.08	1.15	4.64	40.03	88.81
0.2	0.08	0.73	2.69	39.64	88.71
0.5		0.53	1.57	36.79	87.92
1		0.49	1.15	21.61	84.25
2			1.06	12.78	58.27
5				7.39	26.38
10				5.97	16.73
20					12.32

Table 6

Dependence of dispersion (´10^{-7}) on a^* and Δa at w_0 = 32

	0.1	0.5	1	5	10
0.1	2.949	42.706	170.645	1528.318	3310.778
0.2	2.946	28.131	101.898	1505.733	3307.000
0.5		19.748	57.918	1373.666	3268.207
1		18.706	43.945	826.407	3117.550
2			40.269	475.724	2228.928
5				279.291	998.489
10				227.273	634.843
20					468.737

We can see that in the case of two-mass system dispersion is practically negligible.

Thus it is evident that the behavior of the studied system can be completely controlled by changing three parameters $w_0, a^*, \Delta a$.

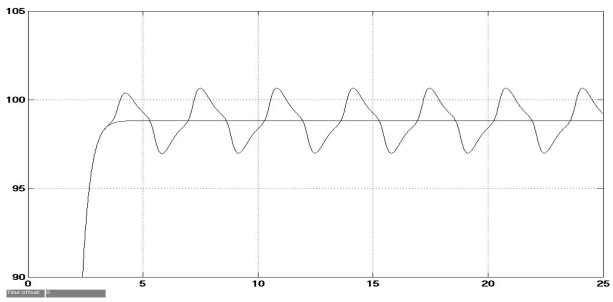
Taking into account the form of characteristic polynomial from (1), we can state that the vibration nature of the system is natural since oscillations occur only as the control of the system passes from the stable subsystem to the unstable one, because all roots of characteristic polynomial are real and the unstable behavior of the subsystem is provided only by the component $e^{w_0 x}$, which is the monotonously increasing function. That is why the average output value is raised up in comparison with the stable system which output signal approaches to the q-point (see fig. 3–4).

The research shows that there is no fundamental difference in the behavior between one– and two-mass systems.

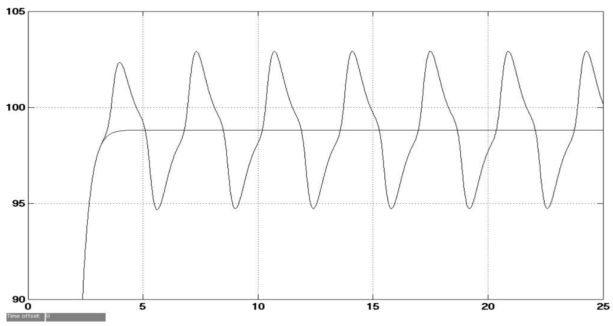
The case of the system with coefficients (2), (4)

In the case of the system with two roots in the right half plane, the behavior of the system is slightly different (see fig. 5–6).

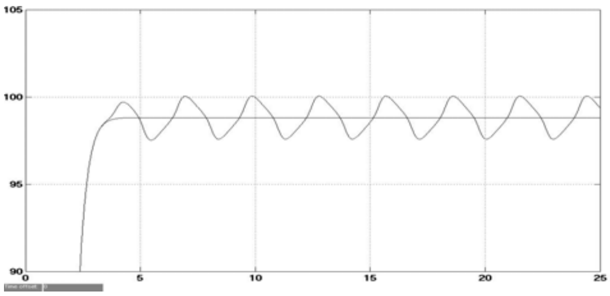
The dependence of the behavior of the system on the control parameters $w_0, a^*, \Delta a$ in the same way that in the case of the unstable subsystem with one root in the positive real part. Here are the results of investigating the amplitude dependence on these parameters (tabl. 7–8).



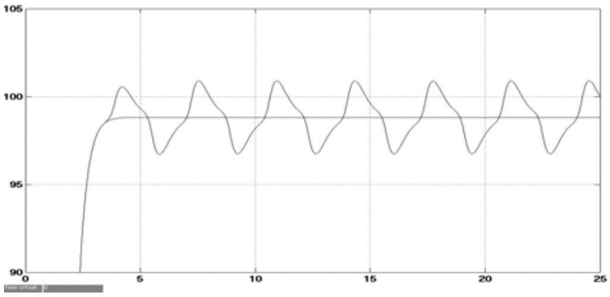
a) a^* = 0.5, Δa = 0.5



b) $a^* = 1$, Δa = 0.5

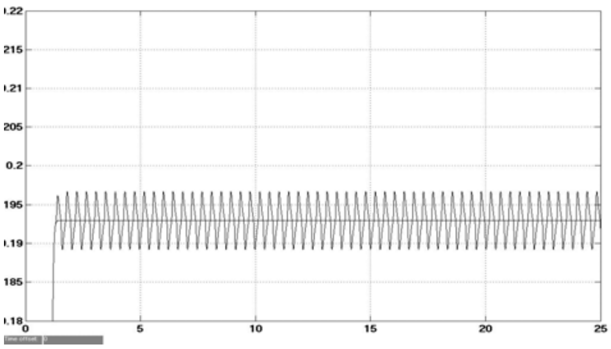


c) $a^* = 0.5, \quad \Delta a = 1$

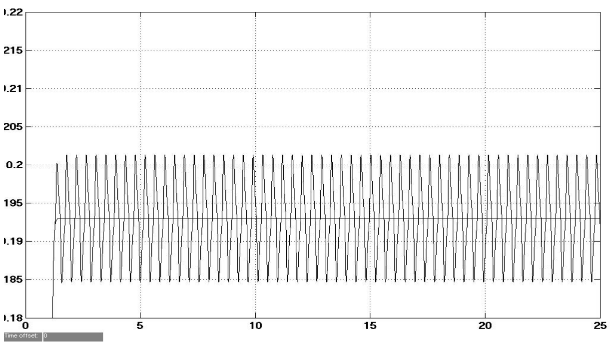


d) $a^* = 0.5, \quad \Delta a = 0.2$

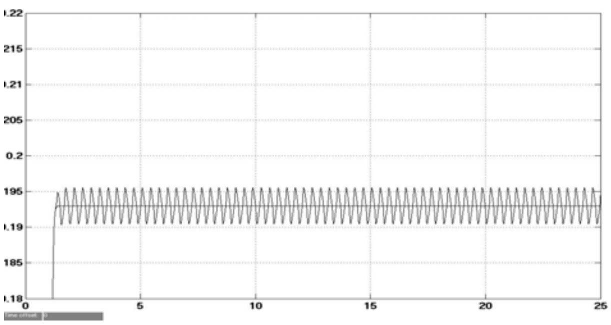
Fig. 5. Simulation results for the system at $w_0 = 4$ *and different values of parameters* $a^*, \quad \Delta a$.



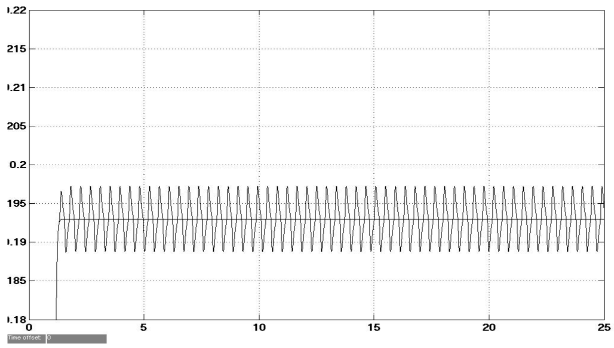
a) $a^* = 0.5, \quad \Delta a = 0.5$



b) $a^* = 1, \quad \Delta a = 0.5$



c) $a^* = 0.5, \quad \Delta a = 1$



d) $a^* = 0.5, \quad \Delta a = 0.2$

Fig. 6. Simulation results for the system at $w_0 = 32$ *and different values of parameters* $a^*, \quad \Delta a$.

Table 7

Dependence of the amplitude on a^* and Δa at $w_0 = 4$

	0.1	0.5	1	5	10
0.1	0.37	2.12	4.25	21.31	42.62
0.2	0.25	2.08	4.23	21.30	42.61
0.5		1.84	4.10	21.27	42.60
1		1.24	3.67	21.17	42.55
2			2.47	20.77	42.34
5				18.37	40.97
10				12.35	36.74
20					24.70

Table 8

Dependence of the amplitude on a^* and Δa at $w_0 = 32$

	0.1	0.5	1	5	10
0.1	0.00074	0.00430	0.00864	0.04329	0.08658
0.2	0.00050	0.00422	0.00860	0.04328	0.08658
0.5		0.00373	0.00832	0.04322	0.08655
1		0.00253	0.00747	0.04301	0.08644
2			0.00506	0.04222	0.08603
5				0.03739	0.08329
10				0.02531	0.074781
20					0.050636

Table 9

Dependence of the average output value on w_0

w_0	Average output value
4	98.82
32	0.193

For estimating the dependence of the amplitude on the mean-geometric root as in the previous case let us demonstrate the average output value (table 9). Unlike the previous case, it depends neither on a^* nor on Δa and is constant for each specific value of w_0.

One can see that the downward trend of the ordinate axe of the oscillation at the mean-geometric root increase is kept here as well. This is concerned with the form of characteristic polynomial from (1). Unlike the case of the system with coefficients (2), (3), there is no dependence of the average output value neither on a^* nor on Δa here, as the oscillating character of the output signal is caused not only by the transition between stable and unstable subsystems, but also by the presence of complex-conjugated roots with positive real parts, that is the presence of the term $e^{-cx}(\cos dx + i \sin dx)$ (see. (4)) in the solution of the differential equation which models the output signal of the system. Moreover, from (4) one can see that $c < 0$.

Let us show the dependence of the investigated system dispersion on the parameters of the membership function (5) at the different values of w_0 in the tables 10–11.

Table 10

Dependence of the dispersion on a^* and Δa at w_0 = 4

	0.1	0.5	1	5	10
0.1	0.06	1.79	6.90	163.34	654.25
0.2	0.03	1.72	6.84	163.28	654.19
0.5		1.29	6.37	162.84	653.76
1		0.66	4.96	161.28	652.26
2			2.62	155.21	646.44
5				129.00	611.97
10				65.84	548.99
20					273.80

Table 11

Dependence of the dispersion ($\times 10^{-7}$) on a^* and Δa at w_0 = 32

	0.1	0.5	1	5	10
0.1	2.1504	69.4609	280.3320	7028.8012	28118.1972
0.2	1.1135	66.9583	277.7515	7026.1168	28115.2779
0.5		53.7598	260.3649	7007.5886	28096.6209
1		27.5413	215.0147	6942.0919	28030.6902
2			110.1149	6696.7074	27771.7612
5				5375.6104	26259.8987
10				2778.6422	21503.5389
20					11137.0155

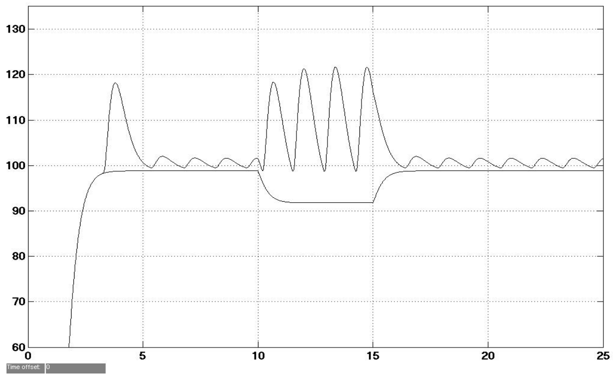
Having considered these tables, one can come to the same conclusions about the influence of w_0, a^* and Δa on the system frequency as in the previous paragraph of this article.

In general we can say that qualitative characteristics of the influence of both membership function parameters and the mean-geometric root do not differ in each considered case.

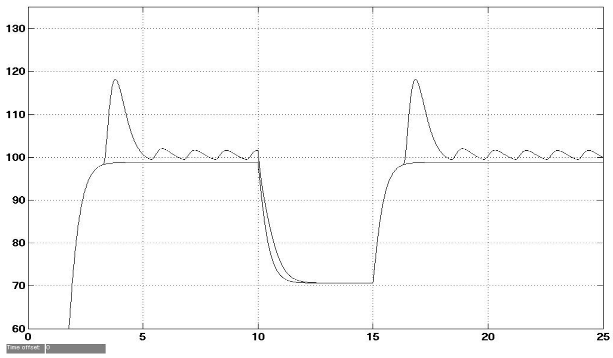
The case of the system under external perturbation

A system functioning in the real-life environment undergoes external impacts. Let us investigate the behavior of the systems (1), (2), (3) and (1), (2), (4) under the external perturbation.

The results of the research at the load exposure are given in fig. 7-11

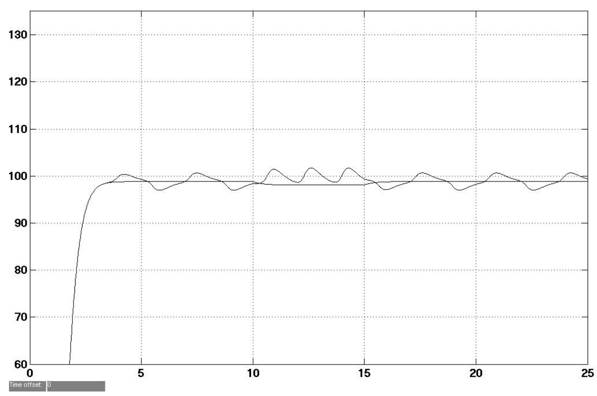


a) 10%M_n

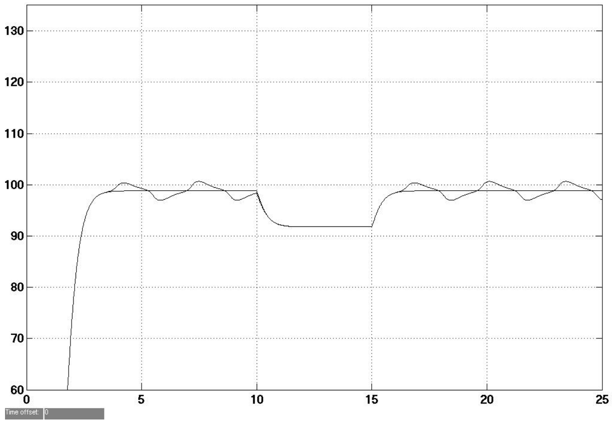


b) 40%M_n

Fig. 7. Simulation results for the system with coefficients (2), (3) at a^* = 0.5, Δa = 0.5, w_0 = 4 *and different loads*

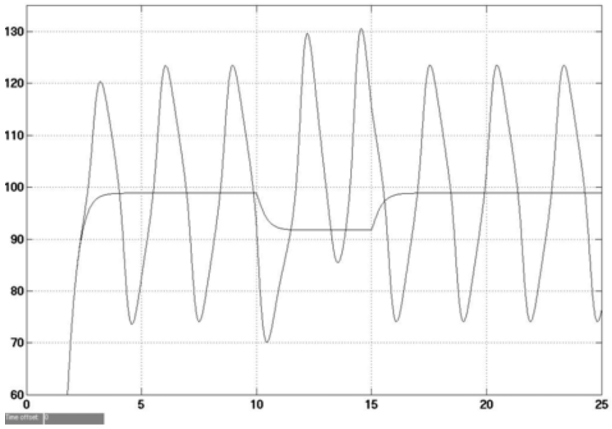


a) 1%M_n

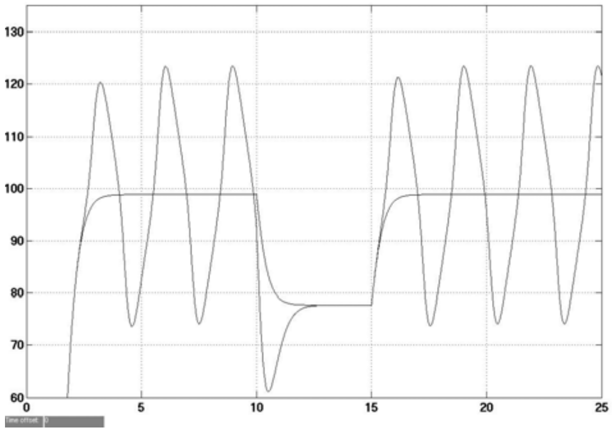


b) $10\%M_n$

Fig. 8. Simulation results for the system with coefficients (2), (4) at $a^* = 0.5$, $\Delta a = 0.5$, $w_0 = 4$ *and different loads*



a) $10\%M_n$



b) $30\%M_n$

Fig. 9. Simulation results for the system with coefficients (2), (4) at $a^* = 10$, $\Delta a = 20$, $w_0 = 4$ *and different loads*

The effect of the perturbation begins at the time equal to 10 seconds and stops in 5 seconds. It is interesting that despite the disturbance action, in some cases the output value increases unlike the stable system. It happens because the transfer function for a perturbation of the system has the following form (see [11]):

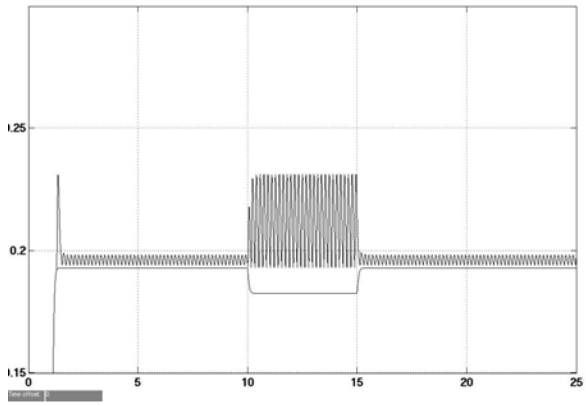
$$W_c(p) = -\frac{p\left(p + \frac{k_1^*}{Tm1}\right) + \frac{k_2^*+1}{Tm1 \cdot Tc}}{p^3 + p^2\frac{k_1^*}{T_{M1}} + p\left(\frac{1}{T_C T_{M2}} + \frac{k_2^*+1}{T_C T_{M1}}\right) + \left(\frac{k_1^*+k_3^*}{T_C T_{M1} T_{M2}}\right)}$$

and at the change of $k_i^*, i = \overline{1,3}$ correspondingly to

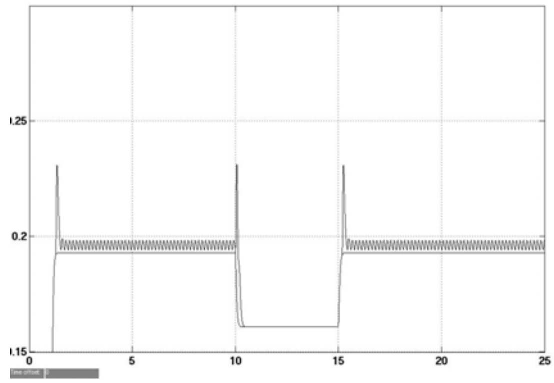
$$k_i^* = m \cdot k_{1i\_1} + (1-m) \cdot k_{1i\_2}, \qquad i = \overline{1,3}$$

Its sign changes.

Under the load the system can leave the zone of the oscillation modes. After elimination the load, the oscillations will reappear in the system.

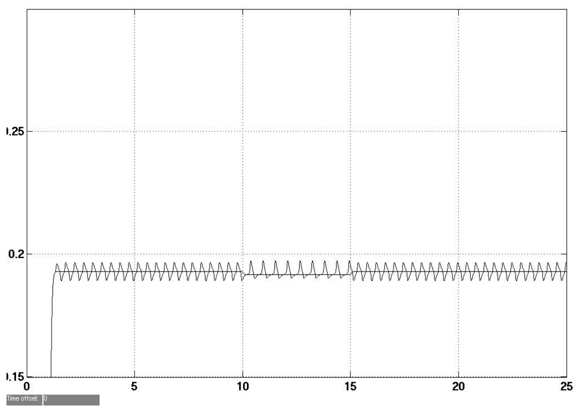


a) $40\%M_n$

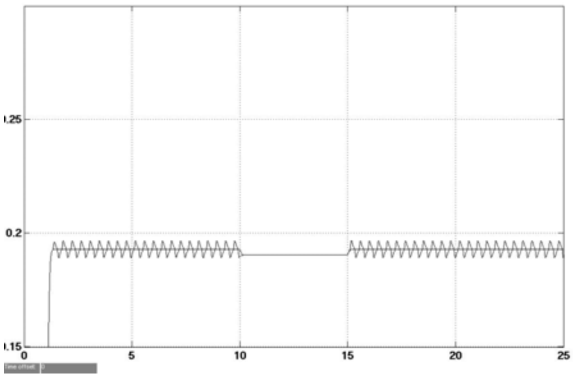


b) $125\%M_n$

Fig. 10. Simulation results for the system with coefficients (2), (3) at $a^* = \Delta a = 0.5$, $w_0 = 32$ *and different loads*



a) $5\%M_n$ *5%*



b) $10\% M_n$

Fig. 11. Simulation results for the system with coefficients (2), (4) at $\boldsymbol{\alpha}^* = \Delta\boldsymbol{\alpha} = 0.5$, $\boldsymbol{\omega}_0 = 32$ *and different loads*

Conclusions

The application of this approach (the case of fuzzy control) can provide new properties to the system.

The amplitude of oscillations in the system depends on its switching function. By changing the range of overlapping of switch functions one can adjust the amplitude. The oscillation frequency is determined by the value of the mean-geometric root of the system. Unlike classical systems, the value of initial coordinates does not decrease with the load increase. It increases due to the change in sign of the polynomial in the numerator of the transfer function for perturbation during the transition from one subsystem to another.

In a system with one root in the right half-plane the average value of the output coordinate depends on the parameter β of the switching function.

In a system with the pair of complex conjugates roots in the right half-plane, the average output value corresponds to output signal of stable system.

Andrew Lozynskyi , DSc. (2004), professor (2006). Graduating student (1993) of electromechanics faculty of the Lviv polytechnic institute, specialized in "Drive and automation of industrial options and technological complexes".

After completion of post-graduate and PhD thesis (1996) worked at the department of electrical machinery and apparatus at the University, where he rose from assistant to professor. Since May 2004 - Deputy Rector for Research at Lviv Polytechnic National University. Expert of the Phare / Tacis CBC project, implemented in 2000 at Lviv Polytechnic National University. The Ukrainian Cabinet of Ministers Grant Holder in 2001-2002. Leaded the accomplishment of President of Ukraine Grant for support of scientific researches of young scientists in 2006. Took part in execution of the series of the researches state budgets works of MOS of Ukraine in 1997 - 2009

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ФОРМУВАННЯ КЕРОВАНИХ ВПЛИВІВ В СИСТЕМІ З НЕЧІТКИМ РЕГУЛЯТОРОМ

А. Лозинський Л. Демків

Розглянуто класичну двомасову систему модального керування швидкістю, що містить нестійку підсистему. Встановлено залежність основних характеристик системи від параметрів функції належності та середньогеометричного кореня. Також досліджено поведінку системи під дією зовнішніх збурень.

Basic direction of scientific researches is development of the intellectual control systems by the electrical engineering devices. Author and coauthor of 1 monograph, over 100 scientific articles, 5 tutorials, 4 patents of Ukraine and 2 patents of a Russian Federation.

Lyubomyr Demkiv , PhD (2006). Graduating student (2003) of applied mathematics and fundamental sciences institute, specialized in "Applied mathematics". Since November 2006 – lecturer at the Department of applied mathematics at Lviv Polytechnic National University.

Obtained the Diploma (2001) of presidium of National Science Academy of Ukraine on competition of young scientists and students of higher educational establishments.

The main direction of his scientific research is development of the intellectual control systems with help of electrical engineering devices.