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[1]A. K. Ablesimov,
[2]V. A. Miroshnychenko,
[3]I. I. Chubatyuk

SUMMATION CIRCUITS OF AUTOMATIC CONTROL SYSTEMS

[1,2,3]Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation, Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine
E-mails: [1]alexander.ablesimov@gmail.com, [2]logisteree@ukr.net, [3]chubatyuk02@gmail.com

Abstract—*During the operation of the stabilization systems, the parameters of the control object and the regulator can change for various reasons within fairly wide limits. In such cases, they speak of the presence of parametric uncertainty. Note that the main indicator of the quality of the stabilization system is considered to be the accuracy of the stabilization of the control object. As theoretical studies show, the accuracy of stabilization systems directly depends on their rigidity and damping, because they directly affect the formation of the moment of stabilization and determine the effectiveness of the system's response to external disturbances. Changing stiffness and damping in order to ensure the necessary efficiency of stabilization systems is the basis of their operational adjustments. To change these parameters, there are summation circuits in the systems. Will the change in the summation circuit type affect the solution to the main task of the operational adjustment of the stabilization system? This article considers the possibilities of summation circuits to ensure the optimality of the settings of the stabilization system.*

Index Terms—Summation circuit; automatic control system; potentiometer; speed and angle sensors; stabilizing moment; amplitude; phase.

I. INTRODUCTION

Summing circuits (SC) are functionally necessary elements of automatic control systems (ACS). They are designed to sum up signals proportional to deviations and deviation rates of the control object.

In practice, SCs are performed both on resistors and on final amplifiers (Fig. 1).

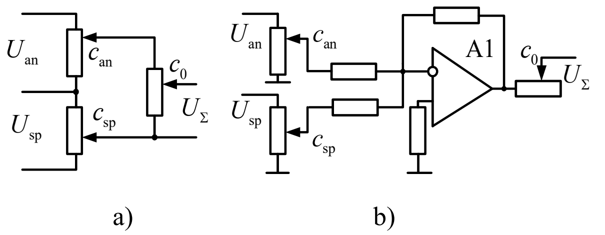


Fig. 1. Contours of summation: (a) on resistors; (b) on the summing amplifier

Here $0 < C_{an} < 1$, $0 < C_{sp} < 1$, $0 < C_0 < 1$ are transmission coefficients of potentiometers that depend on the position of their moving contacts; U_{an} is a signal proportional, for example, to the angular deviation of the control object; U_{sp} is a signal proportional to the speed of the angular deviation of the control object; U_Σ is the total signal.

The structural diagram of the circuit is presented in Fig. 2.

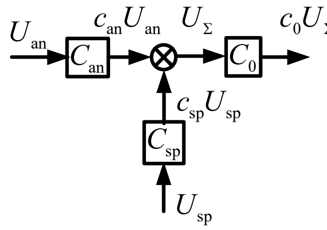


Fig. 2. Structural diagram of the summation circuit

II. PROBLEM STATEMENT

Moment M_s, stabilizing the control object under the action of external disturbances, is formed by two channels: the control object deviation sensor channel and the control object deviation speed sensor channel. The structural diagram of the ACS with separated channels for generating moments from each of the control signals is shown in Fig. 3.

Analysis of the structural diagram shows that the stabilizing moment can be represented as a vector sum of two components

$$\bar{M}_s = \bar{M}_G + \bar{M}_D ,$$

where is $M_G \equiv c_0 c_{an} U_{an}$ is a component proportional to the stiffness of the system; $M_D \equiv c_0 c_{sp} U_{sp}$ is a component proportional to the damping of the system.

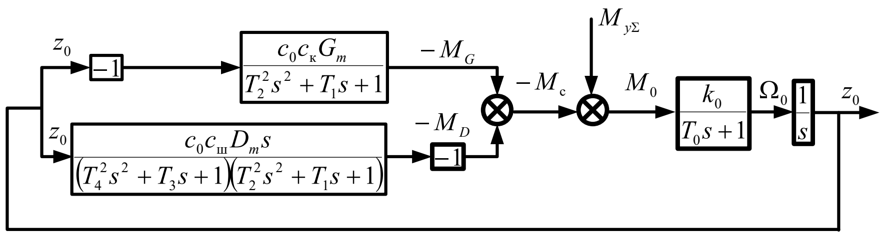


Fig. 3. Structural diagram of a typical ACS with a division of the moments acting on the control object

Thus, changing with c_0, c_{an}, c_{sp} potentiometers of the summation contour the signals of the sensors, you can change the moment of stabilization, i.e. adjust (regulate) the system.

In principle, all three potentiometers can be used during adjustment. However, in order to simplify the tuning technology, the designers leave no more than two adjustable potentiometers in the summation circuits. Most often in practice there are contours $c_0 - c_{sp}$, $c_0 - c_{an}$, $c_{an} - c_{sp}$. Will a change in the summation circuit type affect the solution to the main task of operational control of the ACS – the formation of a stabilizing moment that most completely compensates for external disturbances acting on the control object?

III. Problem Solution

Let us consider in more detail the formation of the stabilizing moment depending on the change in the adjustable parameters of the system. The most obvious formation of the stabilizing moment can be shown by thinking that the total disturbing moment changes according to a harmonic law

$$M_{y\Sigma}(t) = M_{y\Sigma m} \sin \omega t .$$

In this case, it is possible for some constant frequency to construct the moment vector diagram shown in Fig. 4.

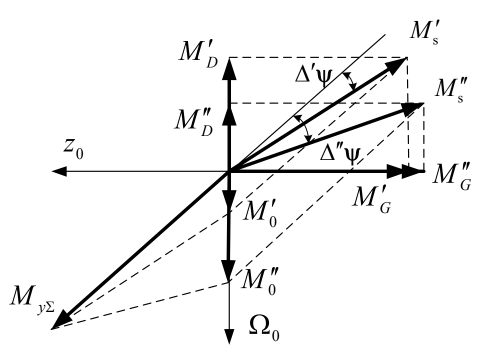


Fig. 4. Vector diagram of moments of ACS

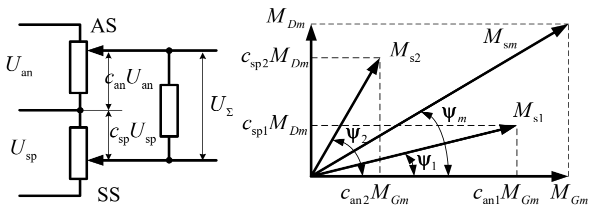
On the vector diagram, the direction of the resulting moment vector M_0 acting on the control object is taken as the beginning of the phase angle count. If the inertia of the control object is neglected, then the vector of its absolute angular velocity will coincide with the direction of the vector Ω_0. The axis of movement z_0 of the control object is shifted relative to the vector of its absolute angular velocity by an angle $-\frac{\pi}{2}$. This corresponds to the presence of an ideal integrating link in the structure of the system. The vector M_G is in phase with the displacement line, provided that the inertia of the system's actuators can be neglected. The vector M_D is in phase with the absolute angular velocity vector Ω_0. Since the moments M_G and M_D are formed in the negative feedback circuits of the ACS, in the vector diagram their phases are changed to 180º. The stabilization moment M_s is determined by the vector sum of the moments M_G and M_D.

In the above vector diagram (Fig. 4), the stabilizing moment M''_s does not completely compensate for external disturbances $M_{y\Sigma}$. This is due to the fact that the amplitudes of the moments M''_s and $M_{y\Sigma}$ are not equal, and the phase shift between them differs from 180^0. As a result of these reasons, the resulting moment M''_0 is relatively large and the corresponding deviations of the control object from the given direction will be significant.

To reduce errors, the system must be adjusted. The amplitude and phase of the stabilizing moment should be changed in such a way that more complete compensation of external disturbances is ensured. Fig. 4 shows that by changing the value of the transfer coefficients of the summation circuit potentiometers, it is possible to reduce the component of the stabilizing torque M''_G to a value M'_G, for example, and increase the component M''_D to a level M'_D. With such regulation we have $M'_0 < M''_0$, that is, the accuracy of compensation of the disturbing moment increases.

Based on the above, we will consider the possibilities of summation contours by changing the amplitude and phase of the stabilizing moment, i.e. ensuring, in the final analysis, the optimality of the ACS settings.

The contour of summation $c_{\text{an}} - c_{\text{sp}}$ is presented in Fig. 5. With its help, the signals of the angle sensor (AS) – potentiometer c_{an}, and the speed sensor (SS) – potentiometer c_{sp}, are regulated. At the same time, the coefficient $c_0 = 1$ remains constant.



a) b)

Fig. 5. Summarization contour $c_{\text{an}} - c_{\text{sp}}$:
(a) is the schematic solution; (b) is the vector diagram

By moving the movable contacts $c_{\text{an}}, c_{\text{sp}}$ of the potentiometers, the components of the stabilizing moment are adjusted

$M_G = c_{\text{an}} M_{Gm} \equiv c_{\text{an}} U_{\text{an}}$ and $M_D = c_{\text{sp}} M_{Dm} \equiv c_{\text{sp}} U_{\text{sp}}$,

where M_{Gm} and M_{Dm} are the modular values of the components due to the structural stiffness G_m and damping D_m of the system, respectively.

The amplitude M_{s} and phase ψ of the stabilizing moment are found as

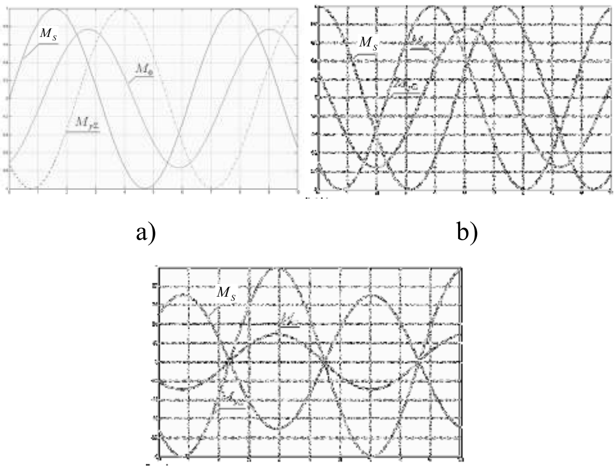
$$M_{\text{s}} = \sqrt{c_{\text{an}}^2 M_{Gm}^2 + c_{\text{sp}}^2 M_{Dm}^2},$$

$$\psi = \text{arctg}\frac{c_{\text{sp}} M_{Dm}}{c_{\text{an}} M_{Gm}}.$$

On the basis of the received data, a vector diagram of the contour is built, which is shown in Fig. 5b. Analysis of the diagram shows that the vector $\bar{M}_{\text{s}}$ of the stabilizing moment, depending on the values of the adjustment coefficients, can occupy any position in the parallelogram $OM_{Dm}M_{sm}M_{Dm}$. Its amplitude can be changed from zero (at $c_{\text{an}} = 0, c_{\text{sp}} = 0$) to the maximum value M_{sm} (at $c_{\text{an}} = 1, c_{\text{sp}} = 1$), and the phase angle ψ – from zero (at $c_{\text{an}} \neq 0, c_{\text{sp}} = 0$) to 90° (at $c_{\text{an}} = 0, c_{\text{sp}} \neq 0$).

The timing diagrams of the considered circuit are shown in Fig. 6.

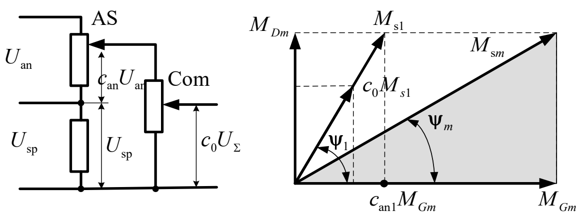
Analysis of diagrams confirms the conclusions made.



a) b) c)

Fig. 6. Time diagrams of the circuit $c_{\text{an}} - c_{\text{sp}}$:
(a) is the $c_{\text{an}} = 1, c_{\text{sp}} = 0$; (b) is the $c_{\text{an}} = 0, c_{\text{sp}} = 1$;
(c) is the $c_{\text{an}} = 0.5, c_{\text{sp}} = 0.5$

The summation circuit $c_{\text{an}} - c_0$ (Fig. 7) provides adjustment of the signal of the angle sensor (AS) due to the change in the transmission ratio c_{an} and the total signal (Com) of the angle and speed sensors due to the change in the transmission ratio c_0.



a) b)

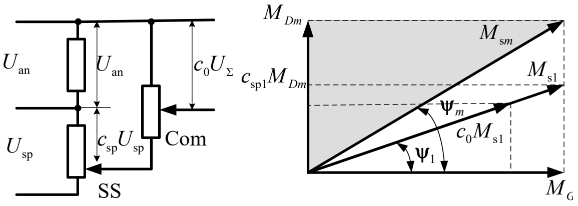
Fig. 7. Summation circuit:
(a) is the circuit design; (b) is the vector diagram

Analysis of the vector diagram shows that this circuit allows changing the amplitude of the stabilizing moment $M_{\text{s}} = c_0\sqrt{c_{\text{an}}^2 M_{Gm}^2 + M_{Dm}^2}$ in the range from $M_s = 0$ at $c_0 = 0$ to the maximum value M_{sm} at $c_{\text{an}} = 1$, $c_0 = 1$.

The phase of the stabilizing moment $\psi = \text{arctg}\frac{M_{Dm}}{c_{\text{an}} M_{Gm}}$ changes from the value ψ_m at $c_{\text{an}} = 1$ to $\psi = 90°$ at $c_{\text{an}} = 0$.

Thus, the considered circuit provides a narrower range of phase change of the stabilizing moment compared to the circuit $c_{\text{an}} - c_{\text{sp}}$.

Counter summation $c_{\text{sp}} - c_0$. Adjusting the signal of the speed sensor (SS) and the common (Com) signal of the angle and speed sensors allows you to perform the circuit made according to the scheme shown in Fig. 8a.



a) b)

Fig. 8. Summation circuit $c_{\text{sp}} - c_0$:
(a) is the circuit design; (b) is the vector diagram

The application of this circuit allows you to vary the amplitude of the stabilizing moment $M_{\text{s}} = c_0\sqrt{M_{Gm}^2 + c_{\text{sp}}^2 M_{Dm}^2}$ from zero at $c_0 = 0$ to the value M_{sm} at $c_{\text{sp}} = 1$, $c_0 = 1$. The range of adjustment of the phase $\psi = \text{arctg}\dfrac{c_{\text{sp}}M_{Dm}}{M_{Gm}}$ of the stabilizing moment is equal to 0 – ψ_m at $c_{\text{sp}} = 0 - 1$ respectively. It is quite limited, especially when $M_{Dm} << M_{Gm}$.

Summation circuit c_0. Angle and speed sensors inevitably experience their own errors. Replacing one of the sensors with an integrated static circuit can improve the accuracy of the ACS as a whole. For example, a signal proportional to the speed of deflection of the control object can be obtained by differentiating the signal of the deflection sensor.

Summing up the angle sensor signal U_{an} and the signal obtained by differentiation U_{sp}, proportional to the speed, we have the classic total signal U_Σ for the formation of a stabilizing moment. The diagram of the summation circuit is shown in Fig. 9. Its use, in addition to increasing the accuracy of the system, makes it possible to adjust it using a single potentiometer c_0.

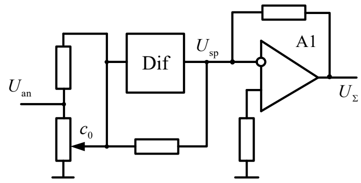


Fig. 9. Summation circuit c_0

Let's find the signal at the output of the summation circuit

$$U_\Sigma = c_0U_{\text{an}} + s\left(U_{\text{an}} + c_0U_{\text{an}}\right)$$
$$= c_0U_{\text{an}} + \left(1 + c_0\right)U_{\text{sp}} = c_0\left(U_{\text{an}} + U_{\text{sp}}\right) + U_{\text{sp}},$$

where is $U_{\text{sp}} = sU_{\text{an}}$.

Therefore, by moving the potentiometer c_0 simultaneously you can adjust the amplitude and phase of the stabilizing moment at the same time

$$M_{\text{s}} = \sqrt{c_0^2M_{Gm}^2 + \left(1 + c_0\right)^2 M_{Dm}^2}$$
$$\simeq \sqrt{c_0^2M_{Gm}^2 + c_0^2M_{Dm}^2 + M_{Dm}^2} = \sqrt{c_0^2M_{sm}^2 + M_{Dm}^2},$$

$$\psi = \text{arctg}\frac{\left(1 + c_0\right)M_{Dm}}{c_0M_{Gm}} = \begin{cases} \text{arctg}\dfrac{2M_{Dm}}{M_{Gm}}\Bigg|_{C_0=1} = \psi_m \\ \text{arctg}\dfrac{M_{Dm}}{0}\Bigg|_{C_0=0} = \dfrac{\pi}{2} \end{cases}.$$

The vector diagram of the circuit is shown in Fig. 10.

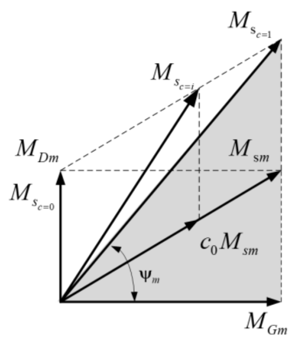


Fig. 10. The vector diagram of the circuit c_0

Analysis of the diagram shows that the circuit c_0 allows you to change the amplitude of the stabilizing moment from the value $M_{\text{s}} = M_{\text{s}_{c=1}}$ at $c_0 = 1$ to the value $M_{\text{s}} = M_{Dm}$ at $c_0 = 0$. In this case, the range of phase changes will be $\psi_m - 90°$.

Thus, if we take into account the increased accuracy of systems when using this circuit c_0 and the ease of setting up the system, its advantages are quite obvious.

IV. Conclusions

According to their characteristics, all the circuits under consideration allow us to select such combinations of adjustable parameters in which the disturbances acting on the system are compensated by a stabilizing moment "on average," i.e. so that the average (root mean square or average amplitude) error value does not exceed the accuracy specified by the technical conditions.

The summation circuit $c_{\text{an}} - c_{\text{sp}}$ provides the widest range of adjustment of the amplitude and phase of the stabilizing moment.

Because in practice regulation with large amounts of phase shifts is of primary importance, the demand for the summation circuit $c_{\text{an}} - c_0$ is quite obvious, despite the fact that it provides a narrower range of phase change of the stabilizing moment compared to the circuit $c_{\text{an}} - c_{\text{sp}}$.

It should be noted the limitation of the range of adjustment of the phase of the stabilizing moment by the contour $c_{\text{sp}} - c_0$, especially when $\text{M}_{\text{Dm}} << \text{M}_{\text{Gm}}$. That is why it is advisable to use the circuit in automated control systems with low structural rigidity G_m and increased structural damping D_m.

If we take into account the increase in the accuracy of the ACS when using the circuit c_0 and the ease of setting up the system, the advantages of this circuit are quite obvious.

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Ablesimov Aleksandr. Candidate of Science (Engineering). Professor.
Aviation Computer Integrated Complexes Department, Faculty of Air Navigation, Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Education: Military Academy of Armored Forces, Moscow, USSR, (1971).
Research interests: Automatic control systems.
Publications: 342.
E-mail: alexander.ablesimov@gmail.com

Miroshnychenko Vladyslav. Student.
Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation, Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Research interests: Automatic control systems.
Publications: 1.
E-mail: logisteree@ukr.net

Chubatyuk Ilya. Student.
Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation, Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Research interests: Automatic control systems.
Publications: 1.
E-mail: chubatyuk02@gmail.com

О. К. Аблесімов, В. А. Мірошниченко, І. І. Чубатюк. Контури підсумовування систем автоматичного керування

Робота присвячена аналізу можливостей контурів підсумовування щодо забезпечення оптимальності налаштувань систем стабілізації. Відомо що під час роботи систем стабілізації параметри об’єкта керування і регулятора можуть змінюватися з різних причин у досить широких межах. У таких випадках говорять про наявність параметричної невизначеності. Зауважимо, що основним показником якості системи стабілізації вважається точність стабілізації об’єкта керування. Як показують теоретичні дослідження, точність систем стабілізації безпосередньо залежить від їх жорсткості та демпфування, оскільки вони безпосередньо впливають на формування моменту стабілізації та визначають ефективність реакції системи на зовнішні збурення. Зміна жорсткості та демпфування з метою забезпечення необхідної ефективності систем стабілізації є основою їх експлуатаційних налагоджень. Для зміни цих параметрів в системах є контури підсумовування. Чи вплине зміна типу схеми підсумовування на вирішення основного завдання оперативного налаштування системи стабілізації? Відповідь міститься у поданому дослідженні.

Ключові слова: схема підсумовування; система автоматичного керування; потенціометр; датчики швидкості та кута; стабілізуючий момент; амплітуда; фаза.

Аблесімов Олександр Костянтинович. Кандидат технічних наук. Професор.
Кафедра авіаційних комп'ютерно-інтегрированних комплексів, Факультет аеронавігації, електроніки та телекомунікацій, Національный авіаційний університет, Київ, Україна.
Освіта: Військова академія бронетанкових військ, Москва, СРСР, (1971).
Направлення наукової діяльності: системи автоматичного керування.
Кількість публікацій: 342.
E-mail: alexander.ablesimov@gmail.com

Мірошниченко Владислав Анатолійович. Студент.
Кафедра авіаційних комп'ютерно-інтегрированних комплексів, Факультет аеронавігації, електроніки та телекомунікацій, Національный авіаційний університет, Київ, Україна.
Напрям наукової діяльності: системи автоматичного керування.
Кількість публікацій: 1.
E-mail: logisteree@ukr.net

Чубатюк Ілля Ігорович. Студент.
Кафедра авіаційних комп'ютерно-інтегрированних комплексів, Факультет аеронавігації, електроніки та телекомунікацій, Національный авіаційний університет, Київ, Україна.
Напрям наукової діяльності: системи автоматичного керування.
Кількість публікацій: 1.
E-mail: chubatyuk02@gmail.com