O‘ZBEKISTON RESPUBLIKASI OLIY VA O‘RTA MAXSUS TA‘LIM VAZIRLIGI

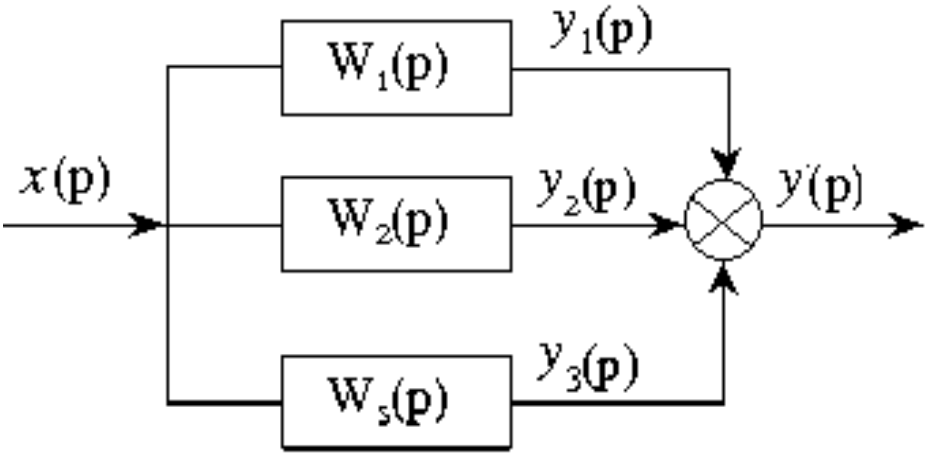
ISLOM KARIMOV NOMIDAGI TOSHKENT DAVLAT TEXNIKA UNIVERSITETI

AVTOMATIK BOSHQARISH NAZARIYASI

fanidan amaliy mashg‘ulotlar bajarish uchun

USLUBIY KO‘RSATMALAR

I qism



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Uslubiy ko‘rsatmada «Avtomatik boshqarish nazariyasi» fani bo‘yicha amaliy mashg‘ulotlar bajarishga doir ko‘rsatmalar hamda boshqarish sistemalarni tekshirishga oid misollar keltirilgan.

Ushbu uslubiy ko‘rsatma oliy o‘quv yurtlarining 5311000 - «Texnologik jarayonlar va ishlab chiqarishni avtomatlashtirish va boshqarish (kimyo, neft-kimyo va oziq-ovqat sanoati) 5330200 - «Informatika va axborot texnologiyalari (sanoat ishlab chiqarishda)», 5312600 - «Mexatronika va robototexnika» va 5312700 - «Axborotlarga ishlov berish va boshqarish tizimlari» yo‘nalishlari bakalavr talabalari hamda unga turdosh mutaxassislik talabalari uchun mo‘ljallangan.

Islom Karimov nomidagi ToshDTU ilmiy-uslubiy kengashining qaroriga muvofiq chop etildi.

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KIRISH

Respublikada chuqur bilimga hamda yuqori saviyaga ega bo‘lgan yosh kadrlarni tayyorlash va bu kadrlar yordamida ilm-fan, ishlab chiqarishdagi dolzarb masalalarni yechish, yangi natijalarga erishish ishlari jadal olib borilmoqda. Kadrlar tayyorlash milliy dasturi “Ta‘lim to‘g‘risida”gi O‘zbekiston Respublikasi qonunining qoidalariga muvofiq holda bo‘lib, milliy tajribaning tahlili va ta’lim tizimidagi jahon miqyosidagi yutuqlar asosida tayyorlangan. Albatta, kadrlarni zamon talabi darajasida tayyorlashda fanlardan yaratilgan darslik va o‘quv qo‘llanmalar muhim ahamiyat kasb etadi. Bugungi kunda talabalarga har bir fandan nazariy bilimlarni amaliyotga tatbiq etishni mukammal o‘rgata oladigan o‘quv qo‘llanmalarning mavjudligi muhim masalalardan biridir.

Boshqarish nazariyasi – fani nisbatan yaqinda vujudga kelgan bo‘lsada, inson ishtirokisiz ishlovchi alohida qurilmalar qadimdan ma’lum bo‘lgan.

Texnologik jarayonlar va ishlab chiqarishni avtomatlashtirish masalalariga avtomatik boshqarishni qo‘llash texnologik jarayonlarni avtomatik boshqarish tizimlari yordamida amalga oshiriladi. Ularda texnologik jarayon va texnologik obyekt holati zamonaviy EHMlardan foydalanilgan holda tahlil qilinadi. Shulardan ko‘rinadiki, avtomatik boshqarish insonlar tomonidan amalga oshiriladi, boshqaruv tizimining texnik vositalari, shu jumladan, EHMlar boshqaruv yechimlarini ishlab chiqish va qo‘llashning murakkab jarayonida inson imkoniyatlarini ko‘p marta oshiruvchi qudratli vosita sanaladi. EHMlar asosidagi zamonaviy avtomatik boshqaruv tizimi hozirgi davr ishlab chiqarish amaliyotida keng qo‘llanilmoqda.

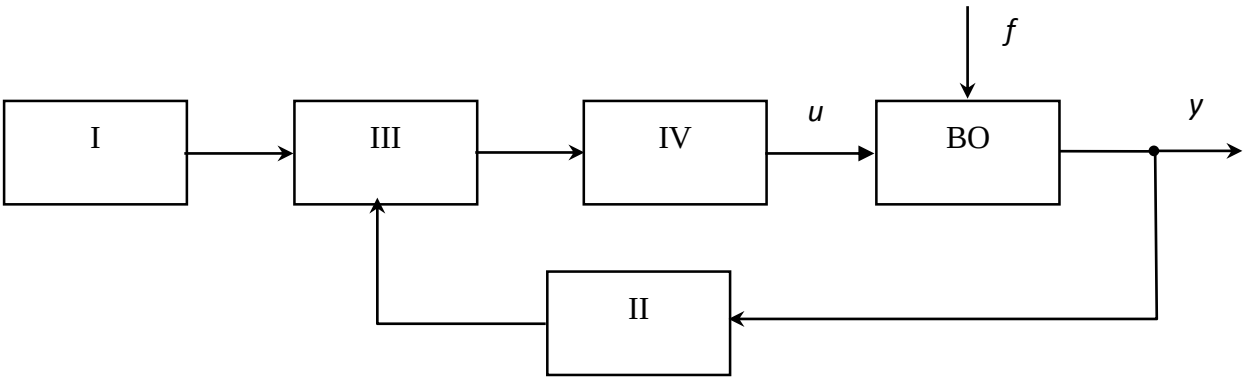
Avtomatik boshqaruv nazariyasining o‘rganish predmeti teskari bog‘lanishli avtomatik tizimlarni konstruksiyalash, ularning xossalari, hisoblash usullari hisoblanadi. Fan va texnikaning hozirgi taraqqiyotida modellarni tuzish uchun odatda, makroolam fizikasi va mexanikasining asosiy qonunlari shakllangan, ya’ni differensial tenglamalar apparatidan foydalaniladi. Shunday ekan, avtomatik boshqaruv nazariyasining predmeti avtomatik tizim modelining xossalari hisoblanadi, bu xossalar differensial tenglamalar hamda ularning turli o‘zgartirishlari va interpretatsiyalari ko‘rinishida ifodalanadi.

1-Amaliy mashg‘ulot

Avtomatik boshqarish sistemalari, ularning prinsipal va funksional sxemalari

Har qanday jarayonni oldiga qo‘yilgan maqsad sari yo‘naltirishga *boshqarish* deyiladi. Har qanday jarayonni boshqarish 4 bosqichdan iborat bo‘ladi: I – boshqarish maqsadi; II – boshqarish to‘g‘risida axborot; III – taqqoslash, solishtirish va qaror qabul qilish; IV – qabul qilingan qarorni bajarish.

Sxematik tarzda buni quyidagicha ifoda etish mumkin (1.1-rasm).

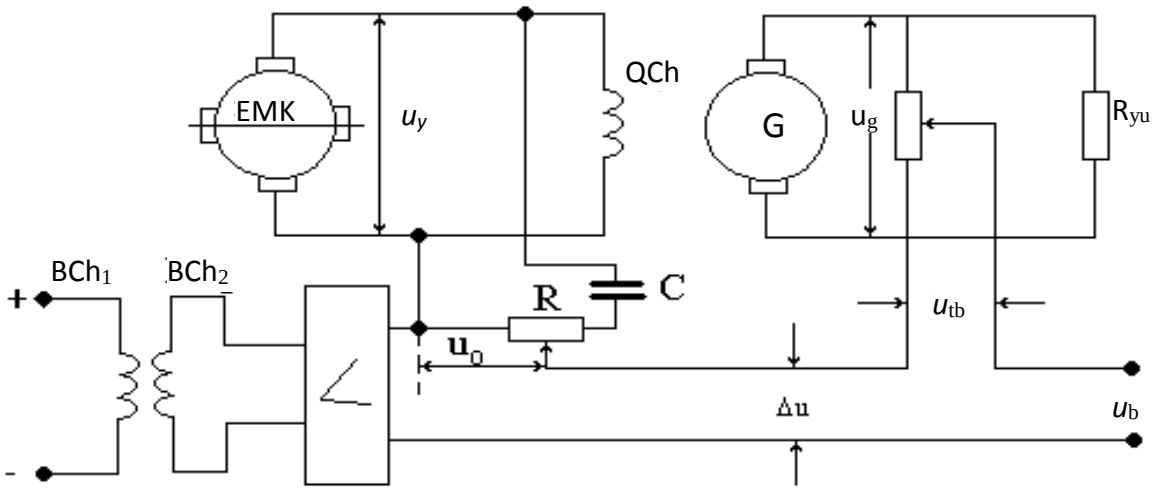


1.1-rasm. Avtomatik boshqarish bosqichlarining strukturaviy sxemasi

Funksional sxema sistema tarkibidagi elementlarni yoki bu elementlarning bajaradigan funksiyasini bildiradi. Prinsipial sxema esa funksional sxemaning kengaytirilgan ko‘rinishi hisoblanadi.

1.1- misol

O‘zgarmas tok generatorining kuchlanishini avtomatik boshqarish sistemasining prinsipial sxemasi 1.2-rasmda berilgan.



1.2 – rasm. O‘zgarmas tok generatori kuchlanishini avtomatik boshqarish sistemasining prinsipial sxemasi

Bu yerda: EMK – elektr mashina kuchaytirgich; BCH_1; BCH_2 – EMK ning boshqarish chulg‘amlari; G – o‘zgarmas tok generatori; QCH – generatorning qo‘zg‘atuvchi chulg‘ami; R_{yu} – yuklama; u_g – boshqariluvchi, rostlanuvchi kattalik; u_{tb} – teskari bog‘lanish signali; $\Delta u = u_b - u_{tb}$ – rostlanuvchi kattalikni berilgan qiymatdan og‘ishi; u_b – rostlanuvchi kattalikning berilgan qiymati; u_u – rostlovchi, boshqaruvchi signal.

Sistemaning ishlash prinsipi quyidagicha: Sistemaning maqsadi generator kuchlanishini u_g – o‘zgarmas holda tutib turish. Buning uchun

u_b kuchlanish olinadi, uning qiymati rostlanuvchi kattalik u_g kuchlanish bilan bir xil qilib olinadi, chunki generator nominal kuchlanish u_{gnom} ishlab chiqarganda $\Delta u = u_b - u_{tb} => 0$ bo‘lishi kerak. Yuklama R_{yu} o‘zgarishi bilan generator kuchlanishi u_g ham o‘zgaradi, buning natijasida teskari bog‘lanish kuchlanishi u_{tb} ham o‘zgarib $\Delta u = u_b - u_{tb}$ kuchlanish hosil bo‘ladi.

Agar $\Delta u = u_b - u_{tb}$ ishorasi musbat (+) bo‘lsa, ya’ni rostlanuvchi kattalik u_g o‘z nominal qiymati u_{gnom} kichik bo‘lsa, unda Δu signal EMKning ikkinchi boshqarish chulg‘ami BCH_1 da BCH_2 dagi magnit oqimiga mos yo‘nalgan magnit oqimi hosil qiladi. Buning natijasida BCH_1 va BCH_2 chulg‘amlardagi magnit oqimlari qo‘shilib EMKning boshqaruvchi kattaligi u_u ko‘tarilishiga olib keladi. EMK esa generatorning qo‘zg‘atuvchi chulg‘amiga QCH qo‘zg‘atuvchi rolini o‘taydi. Va oxir oqibatda generator kuchlanishi u_g nominal qiymat u_{gnom} ga teng bo‘ladi. Agar $\Delta u = u_b - u_{tb}$ manfiy ishoraga ega bo‘lsa, unda EMKning BCH_1 va BCH_2 chulg‘amlaridagi magnit oqimlari qarama-qarshi yo‘nalgan bo‘lib, EMKning ishlab chiqargan kuchlanishi u_u kamayishiga olib keladi.

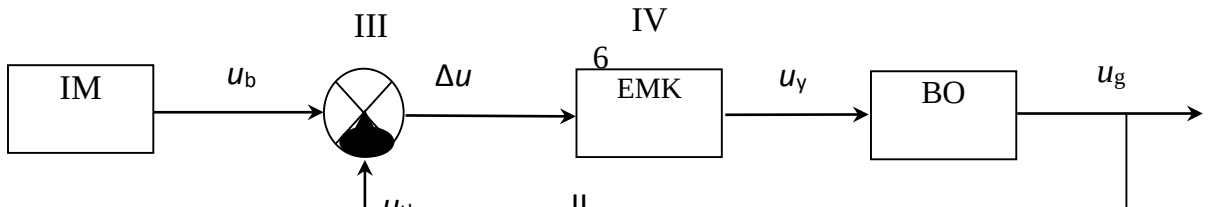
Endi bu sistema boshqarish sistemasi ekanligini isbotlaymiz. Buning uchun boshqarishga muvofiq keluvchi 4 bosqichlarni aniqlaymiz (1.3-rasm).

I – BM. – u_g = const bo‘lishi kerak;

II – BTA – u_{tb} = var o‘zgarishi;

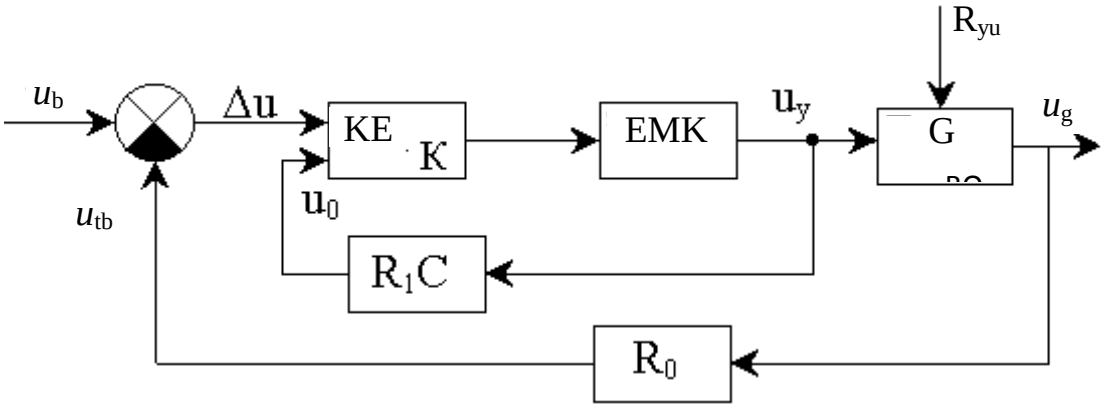
III – T.S. va QQQ - $\Delta u = u_b - u_{tb}$ hosil bo‘lishi;

IV – QQQB – kuchaytirgich va EMK yordamida amalga oshiriladi.



1.3 - rasm. Boshqarish sistemasining strukturali ko‘rinishi

Ko‘rilayotgan sistemaning ishlash prinsipiga ko‘ra, uning funksional sxemasini tuzamiz (1.4-rasm).



1.4-rasm. Boshqarish sistemasining funksional sxemasi

UZATISH FUNKSIYALARI

Bir o‘lchamli uzluksiz statsionar chiziqli sistemaning differensial tenglamasini umumiy ko‘rinishda quyidagicha ifodalash mumkin:

$$\left[a_0 \frac{d^n y}{dt^n} + a_1 \frac{d^{n-1} y}{dt^{n-1}} + ... + a_n y(t)\right] = \left[b_0 \frac{d^m x}{dt^m} + b_1 \frac{d^{m-1} x}{dt^{m-1}} + ... + b_m x(t)\right] \qquad (1.1)$$

Sistema yoki zvenoning *uzatish funkiyasi* deb – boshlang‘ich shartlari nol bo‘lganida chiqish signalining Laplas tasvirini kirish signalining Laplas tasviri signali nisbatiga aytiladi. (1.1)-tenglamani Laplas tasviri

bo‘yicha o‘zgartiramiz, buning uchun differensial tenglamada $\frac{d}{dt}$ operatorni «*p*» kompleks o‘zgaruvchi bilan almashtiramiz

$$(a_0 p^n + a_1 p^{n-1} + ... + a_n) y(p) = (b_0 p^m + b_1 p^{m-1} + ... + b_m) x(p) \qquad (1.2)$$

Uzatish funksiyasining ta’rifiga muvofiq *W*(*p*)ni quyidagi ko‘rinishda ifodalash mumkin:

$$W(p) = \frac{y(p)}{x(p)}\Big|_{t=0} = \frac{(b_0 p^m + b_1 p^{m-1} + ... + b_m)}{(a_0 p^n + a_1 p^{n-1} + ... + a_n)} \qquad (1.3)$$

yoki

$$W(p) = \frac{P(p)}{Q(p)}$$

bunda $P(p) = b_0 p^m + b_1 p^{m-1} + b_2 p^{m-2} + ... + b_m$ - *m* darajali ko‘phad;

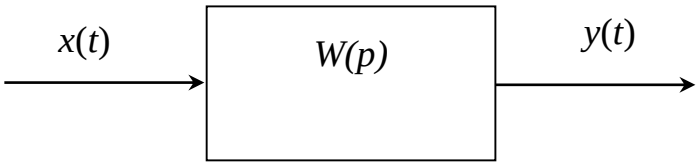
$Q(p) = a_0 p^n + a_1 p^{n-1} + a_2 p^{n-2} + ... + a_n$ - *n* darajali ko‘phad.

Sistemani amalga oshirish uchun $m < n$ shart bajarilishi kerak. Shundagini sistema ishlashi mumkin.

(2.3) tenglamaga muvofiq zveno yoki sistemaning chiqish signalining Laplas tasviri

$$y(p) = W(p) \cdot x(p). \qquad (1.4)$$

Endi zveno yoki sistemaning uzatish W(p) funksiyasi bilan o‘tkinchi funksiyasi *h*(*t*) hamda impulsli o‘tkinchi funksiyasi *ω*(*t*) orasidagi bog‘lanishni ko‘rib chiqamiz (1.5-rasm).



1.5 – rasm. Sistemaning o‘tkinchi funksiyasi h(t) hamda impulsli o‘tkinchi funksiyasi ω(t) orasidagi bog‘lanish sxemasi

a) Agar kirish signali $x(t)=1(t)$ bo‘lsa, unda uning Laplas tasviri $x(t)=\frac{1}{p}$ bo‘ladi. (2.1) formulaga muvofiq Chiqish signalining Laplas tasviri $y(p)=W(p)\cdot\frac{1}{p}$ ga teng bo‘ladi. Bundan original funksiyaga o‘tsak, $y(t)=h(t)=L^{-1}\left\{W(p)\cdot\frac{1}{p}\right\}$ bo‘ladi.

Demak, o‘tkinchi funksiya $h(t)$ bilan uzatish funksiyasi $W(p)$ bir ma’noli bog‘langan ekan.

b) Agar $x(t)=\delta(t)$ bo‘lsa, unda $x(p)=1$ bo‘ladi. (1.4) formulaga muvofiq Chiqish signalining Laplas tasviri $y(p)=W(p)$ bo‘lib, uning originali impulsli o‘tkinchi funksiya bo‘ladi, ya’ni $y(t)=\omega(t)=L^{-1}\{W(p)\}$.

Demak, impulsli o‘tkinchi funksiya $\omega(t)$ uzatish funksiyasining originali ekan.

Endi uzatish funksiyasining mohiyatini aniq misolda ko‘rib chiqamiz.

1.1. Misol. Obyektning modeli quyidagi ko‘rinishga ega: $\ddot{y}+6\dot{y}+5y=2\dot{u}+12u$. Obyekt uchun uzatish funksiyasini yozing va uning nollari va qutblarini aniqlang.

Yechish. Obyektning tenglamasini differensiallash operatori ko‘rinishida yozamiz $(p^2+6p+5)y=(2p+12)u$.

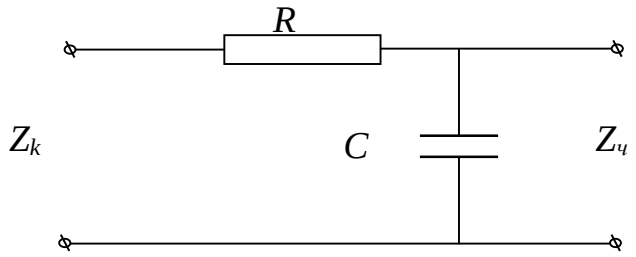
Obyektning uzatish funksiyasini aniqlash uchun $W(p) = y/u$ ifodalaymiz:

$$W(p) = \frac{y}{u} = \frac{2p + 12}{p^2 + 6p + 5}.$$

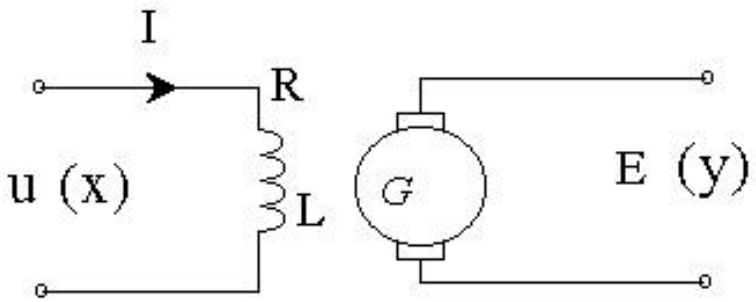
Tizimning xarakteristik tenglamasi $A(p)=p^2+6p+5=0$ ko‘rinishga ega bo‘ladi.

Uning ildizlari esa, p_1=-5 i p_2=-1 *nol* deb ataladi. Uzatish funksiyasi maxrajdagi polinom ildizi z_1=-6 *qutb* deb ataladi.

1.2-misol. O‘zgarmas tok generatorining uzatish funksiyasining aniqlang.



1.6-rasm. O‘zgarmas tok generatorining elektr zanjir sxemasi



1.7 – rasm. O‘zgarmas tok generatori

Berilgan: Qo‘zg‘atuvchi cho‘lg‘amning aktiv va induktiv qarshiligi

R_q = 65.5 Om;

Yeg – generator E.Y.K.;

L_q = 27,5 gn.

Yechish:

$m_г = \frac{E_г}{I_к} = 108 \quad v/a$ – generator salt ish xarakteristikasining chiziqli qismidagi burchak koeffitsiyenti.

Generatorning uzatish funksiyasini aniqlash uchun qo‘zg‘atuvchi zanjirlarning kuchlanishlar tenglamasidan foydalanamiz.

$$u_к(p) = I_к(p) \cdot p \cdot L_к + R_к I_к(p) \tag{1.5}$$

$$u_к(p) = I_к(p) \cdot [pL_к + R_к]$$

$$I_к = \frac{E_г(p)}{m_г} \tag{1.6}$$

$(2) \to (1)$ qo‘yamiz.

$$u_к(p) = \frac{E_г(p)}{m_г}(pL_к + R_к) \tag{1.7}$$

bundan uzatish funksiyasi:

$$W(p) = \frac{E_г(p)}{u_к(p)} = \frac{m_г}{pL_к + R_к} = \frac{\frac{m_г}{R_к}}{p\frac{L_к}{R_к} + 1} = \frac{K_г}{pT_к + 1}$$

$K_г = \frac{m_г}{R_к}$ - uzatish koeffitsiyenti; $T_к = \frac{L_к}{R_к}$ - vaqt doimiysi.

Shunday qilib, hosil bo‘lgan uzatish funksiyasi birinchi tartibli inersial zvenoni bildiradi.

$$K_г = \frac{m_г}{R_к} = \frac{108}{65{,}5} = 1{,}65; \quad T_к = \frac{L_к}{R_к} = \frac{27{,}5}{65{,}5} = 0{,}42 \ сек; \qquad W_г(p) = \frac{1{,}65}{0{,}42p + 1}.$$

Topshiriqlar

1.1. Obyektning differensial tenglamasi o‘yicha uzatish funksiyasini $W(p) = y(p)/u(p)$. toping (1.1-jadval).

1.1- jadval

№	Obyektning differensial tenglamasi
1.	$y''' + 7y'' - 5y' = u' + 5u$
2.	$y''' + 2y'' + y' = 2u'' + 3u' + u$
3.	$2y''' + y' + 3y = 2u'' + 3u' + u$
4.	$y''' + 4y'' + 2y' = u'' + 4u' + u$
5.	$4y''' + 4y'' + 2y' + y = 4u' + u$
6.	$4y''' + 4y'' + 2y' = 2u''' + u'' + 4u' + u$
7.	$5y''' + 4y'' + 2y' + 3y = 11u'' + 4u' + u$
8.	$y''' + 2y' + 3y = u'' + 2u' + u$
9.	$7y''' + 10y'' + 2y' + y = 3u' + u$
10.	$3y'' + 5y' + y = u$
11.	$13y'' + 8y' + 2y = 9u$
12.	$2y''' + 4y'' + 8y' + y = 5u' + 11u$
13.	$5y''' + 2y' + 3y = 3u'' + 14u' + u$
14.	$4y'' + 2y' + 10y = 5u$
15.	$5y''' + 4y'' + 13y = u'' + 4u' + 2u$
16.	$23y'' + 18y' + 2y = 9u$
17.	$y''' + 22y'' + 3y = 3u' + u$
18.	$y''' - 15y' = 2u' + 5u$
19.	$y''' + 2y'' + 16y = 23u' + 2u$

1.1-jadvalnning davomi

20.	$3y''' + 17y'' - y' = u'' + 5u$
21.	$3y'' + 28y' + 32y = 19u$
22.	$y''' + 2y' = 2u'' + u$
23.	$18y'' + 2y' + 12y = 9u$
24.	$y''' + 10y'' - 8y' = 2u'' + 9u$
25.	$y''' + 12y'' + y' = 5u' + u$
26.	$13y'' + 18y' + 21y = 19u$
27.	$7y''' + 7y'' - 3y = u' + 17u$
28.	$9y''' + 7y'' + y = 4u'' + u' + 2u$
29.	$y''' + 8y' - 4y = 2u'' + 15u$
30.	$11y''' + y'' - 15y' = 7u' + 6u$

1.2. Obyektning quyidagi berilgan uzatish funksiyasi bo‘yicha differensial tenglamasini yozing, holatini ifodalovchi *A*,*B*,*C*, matritsalarni va tartibini aniqlang (1.2-jadval).

1.2-jadval

№	**Obyektning uzatish funksiyasi**
1.	$w_{yu}(p) = \dfrac{10}{p(p^2 + p + 1)}$
2.	$w_{yu}(p) = \dfrac{20(p+1)}{2p^3 + 4p^2 + 8p + 6)}$
3.	$w_{yu}(p) = \dfrac{20(p+1)}{p(2p^3 + 4p^2 + 8p + 6)}$;
4.	$w_{yu}(p) = \dfrac{3(p+1)}{p^3 + 3p^2 + 8p + 6}$;
5.	$w_{yu}(p) = \dfrac{p^2 + 5p + 1}{p^3 + 4p^2 + 2p + 1}$;

	1.2-jadvalnning davomi
6.	$w_{yu}(p) = \frac{2p^2 + 3p}{p^3 + 4p^2 + 3};$
7.	$w_{yu}(p) = \frac{12p^2 + 5p}{4p^3 + 5p^2 + 3p + 3};$
8.	$w_{yu}(p) = \frac{50}{p(p^2 + p + 4)};$
9.	$w_{yu}(p) = \frac{30(p + 1)}{(2p^3 + 3p^2 + 8p + 6)};$
10.	$w_{yu}(p) = \frac{20(p + 1)}{p(2p^3 + 4p^2 + 8p + 6)};$
11.	$w_{yu}(p) = \frac{(2p + 3)}{3p^3 + 2p^2 + 3p + 6};$
12.	$w_{yu}(p) = \frac{5p + 1}{3p^3 + 2p + 8};$
13.	$w_{yu}(p) = \frac{7p^2 + 5p + 5}{3p^3 + 4p^2 + 2p + 1};$
14.	$w_{yu}(p) = \frac{5}{p(p^2 + 2p + 5)}$
15.	$w_{yu}(p) = \frac{2p^2 + 3p}{p^3 + 4p^2 + p + 5}$
16.	$w_{yu}(p) = \frac{4p^3 + 3p}{5p^3 + 2p + 8};$
17.	$w_{yu}(p) = \frac{2p}{2p^2 + 5p + 3};$
18.	$w_{yu}(p) = \frac{3p}{p(p^2 + p + 1)}$
19.	$w_{yu}(p) = \frac{20(p + 1)}{2p^3 + 8p + 6};$
20.	$w_{yu}(p) = \frac{20(p + 1)}{p(2p^3 + 4p^2 + 8p + 6)}$

21.	$w_{yu}(p) = \frac{2p+3}{2p^3+3p^2+3p+5}$
22.	$w_{yu}(p) = \frac{p^3+3p)}{p^3+4p^2+3}$
	1.2-jadvalnning davomi
23.	$w_{yu}(p) = \frac{12p^2+5p}{2p^3+4p^2+5p+3};$
24.	$w_{yu}(p) = \frac{10(2p+3)}{(2p^3+3p^2+2p+5)};$
25.	$w_{yu}(p) = \frac{10(p+1)}{p(3p^3+4p^2+3p+6)}$
26.	$w_{yu}(p) = \frac{2p^2+3p+3}{p^3+4p^2+2p+6};$
27.	$w_{yu}(p) = \frac{2p^2+5p}{3p^3+5p^2+p+5};$
28.	$w_{yu}(p) = \frac{4p^2+3p}{5p^3+8p+3}$

2-Amaliy mashg‘ulot

Chiziqli sistemalarning chastotaviy xarakteristikalarini qurish

Chiziqli statsionar sistemalarni tasvirlashda chastotali xarakteristikalar juda muhim rol o‘ynaydi. Bir o‘lchamli chiziqli statsionar sistemaning umumiy ko‘rinishdagi operator tenglamasini quyidagicha ifodalash mumkin:

$$(a_0 p^n + a_1 p^{n-1} + a_2 p^{n-2} + ... + a_n) y(p) = \qquad (2.1.)$$

$$= (b_0 p^m + b_1 p^{m-1} + b_2 p^{m-2} + ... + b_m) x(p)$$

Uzatish funksiyasining ta’rifiga ko‘ra:

$$W(p)=\frac{y(p)}{x(p)}=\frac{b_0p^m+b_1p^{m-1}+b_2p^{m-2}+...+b_m}{a_0p^n+a_1p^{n-1}+a_2p^{n-2}+...+a_n}=\frac{P(p)}{Q(p)} \qquad (2.2.)$$

$W(j\omega)$ funksiyaning uzatish funksiyasi $W(p)$ dan $p=j\omega$ bilan almashtirish orqali olinadi va *chastotaviy uzatish funksiyasi* deyiladi:

$$W(j\omega)=\frac{b_0(j\omega)^m+b_1(j\omega)^{m-1}+b_2(j\omega)^{m-2}+...+b_m}{a_0(j\omega)^n+a_1(j\omega)^{n-1}+a_2(j\omega)^{n-2}+...+a_n} \qquad (2.3.)$$

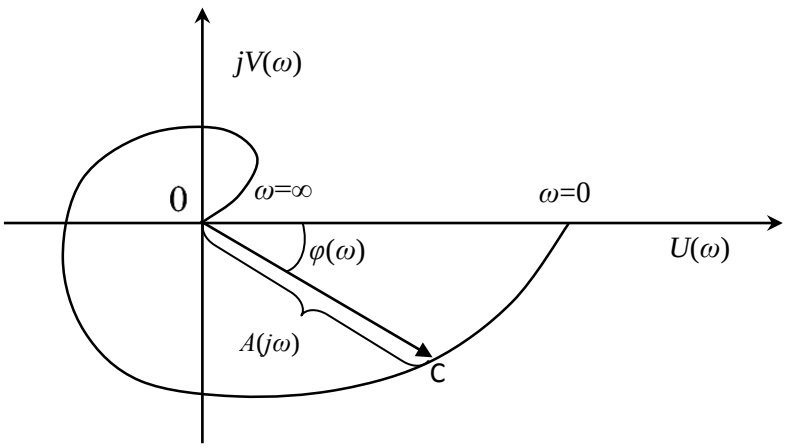
Chastotaviy uzatish funksiya $W(j\omega)$ chatota deb ataluvchi haqiqiy o‘zgaruvchi «ω» ga bog‘liq bo‘lgan kompleks funksiyadir.

$W(j\omega)=U(\omega)+jV(\omega)$ - algebraik ko‘rinishi;

$W(j\omega)=A(\omega)e^{j\varphi(\omega)}$ - darajali ko‘rinishi,

bu yerda $U(\omega)$ - haqiqiy qism; $V(\omega)$ - mavhum qism; $A(\omega)$ - amplituda; $\varphi(\omega)$ - faza.

$$A(\omega)=\sqrt{U^2(\omega)+V^2(\omega)}\ ;\ \varphi(\omega)=arctg\frac{V(\omega)}{U(\omega)} \qquad (2.4.)$$



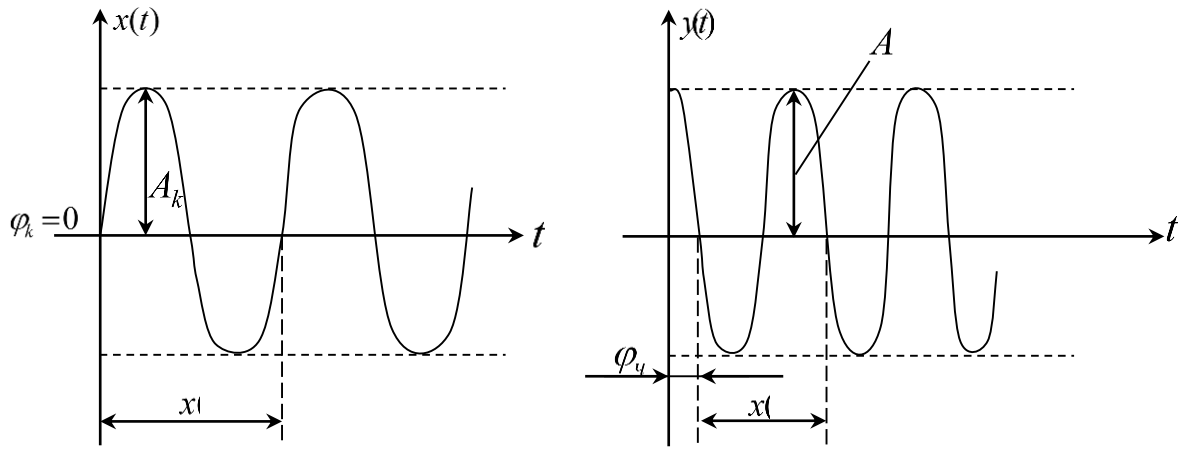
2.1 – rasm. Chiziqli sistemaning amplituda-faza chastotaviy xarakteristikasi

Kompleks tekisligida $W(j\omega)$ funksiyasini $\overrightarrow{OC}$ vektor orqali ifodalash mumkin. Bu vektorning uzunligi chastotali uzatish funksiyasining

amplitudasi «*A*»ga vektorning haqiqiy musbat o‘q bilan hosil qilgan burchagi fazasi «φ»ga teng bo‘ladi (2.1-rasm).

Chastota noldan cheksiz (0<ω<∞) oraliqda o‘zgarganda $\overrightarrow{OC}$ vektorning kompleks tekisligida chizgan egri chizig‘iga *amplituda-fazali xarakteristika* (AFX) deyiladi, yoki boshqa qilib aytganda AFX deb kompleks tekisligida chastotaning o‘zgarishiga qarab amplituda va fazaning o‘zgarishiga aytish mumkin.

Chastotali uzatish funksiyasining *amplitudasi* chiqish signalining amplitudasini kirish signalining amplitudasiga nisbatan necha marotaba kattaligini ko‘rsatadi. Chastotali uzatish funksiyasining moduli amplitudasini beradi, ya’ni $A(\omega) = \mathrm{mod}\, W(j\omega) = \frac{Ach(\omega)}{A_k(\omega)}$; chastotali uzatish funksiyasining argumenti chiqish va kirish signallari orasidagi burchak siljishini ko‘rsatadi, ya’ni $\varphi(\omega) = \arg W(j\omega)$;



2.2 – rasm. Chastotali uzatish funksiyasi amplituda va faza xarakteristikalarining chatotaga bog‘liqlik grafigi

$$W(j\omega)=\frac{y(j\omega)}{x(j\omega)}=\frac{A_{ch}(\omega)e^{j[\omega t+\varphi_ч]}}{A_к(\omega)e^{j[\omega t+\varphi_к]}}=A(\omega)e^{j\varphi(\omega)} \qquad (2.5.)$$

$A(\omega)$ - kuchaytirishning amplitudasi

$$A(\omega)=\frac{A_{ch}(\omega)}{A_к(\omega)};\ \varphi(\omega)=\varphi_{ch}-\varphi_к\,. \qquad (2.6.)$$

$W(j\omega)$ - amplituda fazaviy xaraketistika (AFX);

$U(\omega)$ - haqiqiy chastotaviy xarakteristika (HCHX);

$V(\omega)$ - mavhum chastotaviy xarakteristika (MCHX);

$A(\omega)$ - amplituda chastotaviy xarakteristika (ACHX);

$\varphi(\omega)$ - faza chastotaviy xarakteristika (FCHX).

Yuqoridagi xarakteristikalardan tashqari quyidagi ikkita logarifmik xarakteristika ham mavjuddir.

$L(\omega)=20\lg A(\omega)$ funksiya - *logarifmik amplituda chastotaviy xarakteristika* (LACHX) deyiladi. Amplitudaning $\lg\omega$ga nisbatan chizilgan grafigiga *logarifmik amplituda chastotaviy xarakteristika* (LACHX) deyiladi. $\varphi(\omega)$ning $\lg\omega$ga nisbatan chizilgan *grafigiga logarifmik fazo-chastotaviy xarakteristika* (LFCHX) deyiladi.

$\lg\omega$ning o‘lchov birligi «dekada», bir dekada chastotaning o‘n marta oshishini bildiradi.

$L(\omega)$ning o‘lchov birligi «detsibell» quvvatni o‘n marta ko‘paytirish bir bellni beradi, ya‘ni $1дц=\frac{1}{10}белл$.

$$L(\omega)=10\lg P(\omega)=10\lg U\cdot I=10\lg A^2(\omega)=20\lg A(\omega)$$

2.1-misol. Agar obyektning uzatish funksiyasi $W(p)=10/(p+1)$. ma‘lum bo‘lsa, u holda uning AFX, HCHX, FCHX larini quring:

Yechilishi. Uzatish funksiyasiga o‘zgatirishlar kiritamiz, ya’ni:

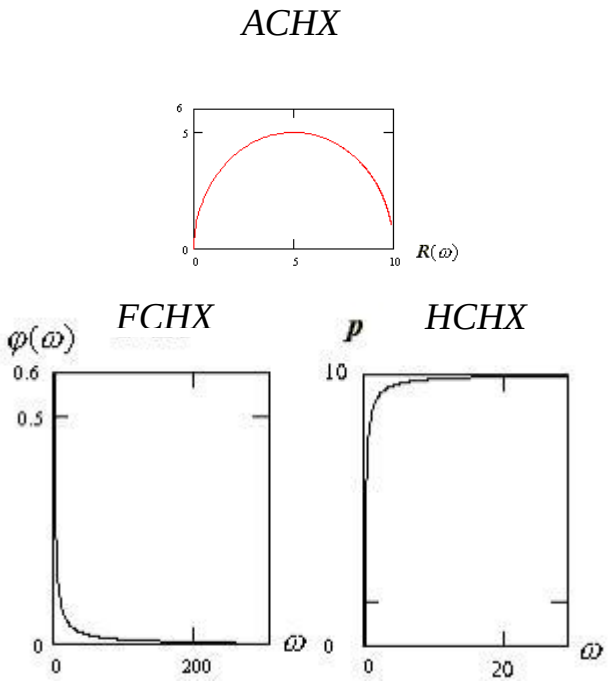
$p \to j\omega$

$$W(j\omega) = \frac{10j\omega}{j\omega+1} = \frac{10\omega^2}{\omega^2+1} + j\frac{10\omega}{\omega^2+1}.$$

HCHX va FCHX larni ifodalovchi funksiyalar quyidagi ko‘rinishga ega bo‘ladi:

$$R(\omega) = \frac{10\omega^2}{\omega^2+1}, \varphi(\omega) = arctg\frac{\mathrm{Im}}{\mathrm{Re}} = arctg\frac{1}{\omega}.$$

Chastotani 0 dan to cheksizlikkacha o‘zgartirib, HCHX va FCHX ni quramiz: (2.3- rasm)



2.3-rasm. Tizimning haqiqiy va faza chastotaviy xarakteristikalari

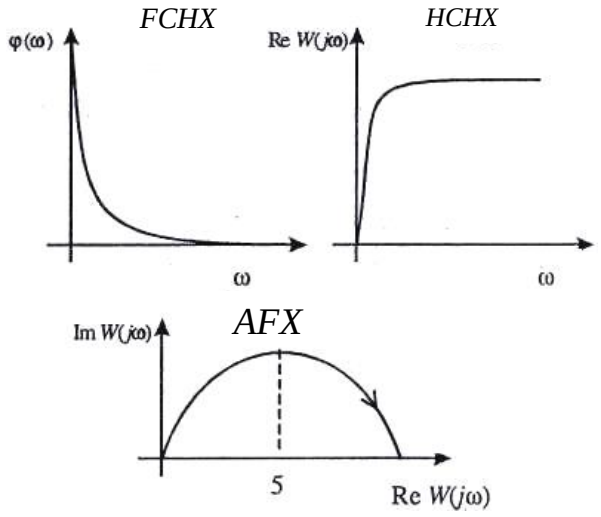
2.2 – misol. $W(p) = \frac{10p}{p+1}$ uzatish funksiyasi bilan berilgan obyekt uchun amplituda-fazaviy (AFX), moddiy chastotaviy va fazaviy chastotali xarakteristikalarini (MCHX, FCHX) quring.

Yechish: Uzatish funksiyasida $p \to j\omega$ almashtirishni amalga oshirib, umumlashgan chastotaviy xarakteristikalar uchun ifodani yozamiz:

$$W(j\omega) = \frac{10j\omega}{j\omega + 1} = \frac{10\omega^2}{\omega^2 + 1} + j\frac{10\omega}{\omega^2 + 1}.$$

MCHX va FCHX lar uchun ifodalar quyidagi ko‘rinishga ega:

$$R(\omega) = \frac{10\omega^2}{\omega^2 + 1}, \qquad \varphi(\omega) = arctg\frac{I(\omega)}{R(\omega)} = arctg\frac{1}{\omega}.$$



2.4 - rasm. Tizimning mavhum va amplituda chastotaviy xarakteristikalari

Chastota 0 dan ∞ ga o‘zgarganda qurilgan mos chastotaviy xarakteristikalar 2.4-rasmda keltirilgan.

Topshiriqlar

Uzatish funksiyasi quyidagi ko‘rinishga ega bo‘lsa, u holda obyektning AFX, ACHX, FCHX larini quring:

2.1-jadval

№	Obyektning uzatish funksiyasi
1.	$w_{yu}(p) = \frac{11}{p+1}$
2.	$w_{yu}(p) = \frac{2}{8p+6}$
3.	$w_{yu}(p) = \frac{12}{p+8}$;
	2.1-jadvalning davomi
4.	$w_{yu}(p) = \frac{15}{p+5}$;
5.	$w_{yu}(p) = \frac{9}{2p+1}$;
6.	$w_{yu}(p) = \frac{5}{4p+3}$;
7.	$w_{yu}(p) = \frac{3}{5p+3}$;
8.	$w_{\downarrow}yu\ (p) = 10/(p+4))$;
9.	$w_{yu}(p) = \frac{3}{7p+6}$;
10.	$w_{yu}(p) = \frac{10}{p+8}$;
11.	$w_{yu}(p) = \frac{4}{3p+6}$;
12.	$w_{yu}(p) = \frac{6}{2p+8}$;
13.	$w_{yu}(p) = \frac{7}{2p+1}$;
14.	$w_{yu}(p) = \frac{5}{p+9}$
15.	$w_{yu}(p) = \frac{5}{2p+5}$
16.	$w_{yu}(p) = \frac{4}{2p+8}$;
17.	$w_{yu}(p) = \frac{10}{5p+3}$;
18.	$w_{yu}(p) = \frac{3}{p+8}$
19.	$w_{yu}(p) = \frac{8}{8p+6}$;

20.	$w_{yu}(p) = \frac{12}{p+9}$
21.	$w_{yu}(p) = \frac{9}{3p+5}$
22.	$w_{yu}(p) = \frac{7}{p+3}$
23.	$w_{yu}(p) = \frac{12}{p+3}$;
	2.1-jadvalning davomi
24.	$w_{yu}(p) = \frac{10}{p+4}$;
25.	$w_{yu}(p) = \frac{5}{4p+6}$
26.	$w_{yu}(p) = \frac{2}{2p+6}$;
27.	$w_{yu}(p) = \frac{3}{6p+5}$;
28.	$w_{yu}(p) = \frac{4}{8p+3}$

3- Amaliy mashg‘ulot

Elementar zvenolar va ularning vaqt xarakteristikalari

ABTlarining zvenolari har xil fizikaviy tabiatga, ishlash prinsipiga, konstruktiv formaga hamda sxemalarga bo‘linishi mumkin. Lekin bu zvenolarning dinamik xususiyatlarini o‘rganishda, tadqiq qilishda uning chiqishidagi hamda kirishidagi kattaliklarni bog‘lovchi tenglama muhim rol o‘ynaydi.

Matematik ifodasi differensial tenglama bilan ifodalanadigan zvenolarga *dinamik zveno* deyiladi.

Tipik dinamik zveno deb, tartibi ikkidan yuqori bo‘lmagan differensial tenglama bilan ifodalanadigan zvenolarga aytiladi. Ularga asosan quyidagi zvenolar kiradi:

1. Inersiyasiz (proporsional, kuchaytiruvchi) zveno.

2. Birinchi tartibli inersial (aperiodik) zveno.
3. Ideal integrallovchi zveno.
4. Ideal differensiallovchi zveno.
5. Tebranuvchi zveno.
6. Birinchi tartibli tezlatuvchi zveno.
7. Ikkinchi tartibli tezlatuvchi zveno.

Quyida shu zvenolarning vaqt hamda chastotali xarateristikalarini ko‘rib chiqamiz.

1. Inersiyasiz (proporsional, kuchaytiruvchi) zveno. Bu zvenoning umumiy tenglamasi quyidagicha ifodalanadi:

$$y(t) = K \cdot x(t), \tag{3.1}$$

bu yerda K – uzatish koeffitsiyenti.

Bunday zvenoning chiqishidagi kattalik kirishidagi kattalikka nisbatan proporsional ravishda o‘zgaradi.

.Bu zvenoga elektron kuchaytirgich, potensiometr, taxogenerator kabi elementlar misol bo‘la oladi .

(3.1) tenglamaga Laplas almashtirishlarini kiritamiz

$$y(p) = K \cdot x(p), \tag{3.2}$$

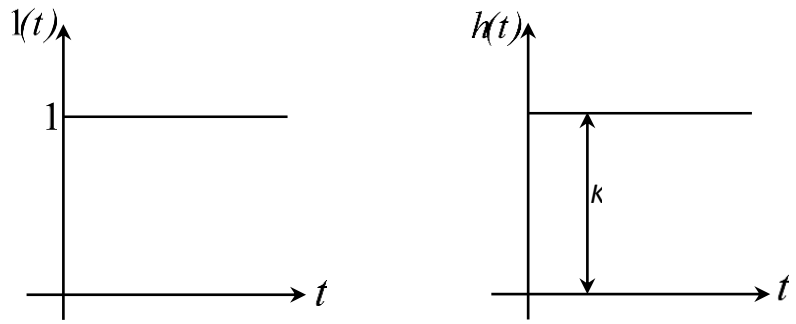
bundan

$$W(p) = \frac{y(p)}{x(p)} = K. \tag{3.3}$$

Shunday qilib, proporsional zvenoning uzatish funksiyasi kuchaytirish koeffitsiyenti «K» ga teng bo‘ladi.

Uzatish funksiyasi orqali zveno yoki sistemaning vaqt xarakteristikalarini aniqlash mumkin:

$$h(t) = L^{-1}\left\{W(p)\frac{1}{p}\right\} = L^{-1}\left\{K\frac{1}{p}\right\} = K \cdot 1(t). \tag{3.4}$$



a) *b)*

3.1-rasm. a) zvenoga berilgan birlik pog‘onali signal; b) zvenoni vaqt xarakteristikasi

2. Birinchi tartibli inersial (aperiodik) zveno. Bu zvenoning tenglamasi quyidagi ko‘rinishga ega.

$$y(t) + T\frac{dy(t)}{dt} = K \cdot x(t) \qquad (3.5)$$

bu yerda K – uzatish koeffitsiyenti; T – vaqt doimiyligi.

RC, RL – zanjirlari, o‘zgarmas tok generator iva dvigatellari bu zvenoga misol bo‘la oladi .

(3.5) tenglamaga Laplas o‘zgartirishini kiritib, bu zvenoning uzatish funksiyasini aniqlaymiz

$$y(p) + Tp \cdot y(p) = Kx(p),$$

bundan

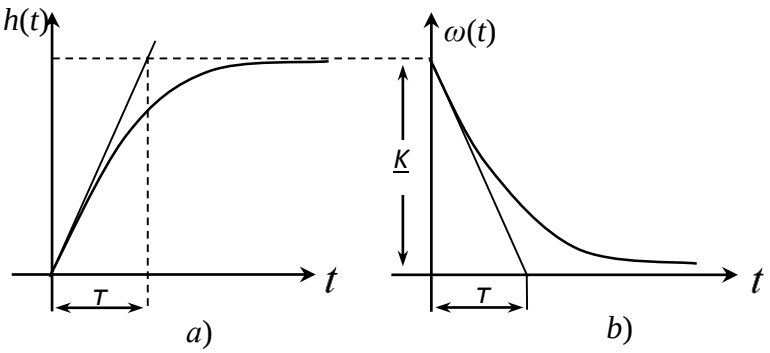
$$W(p) = \frac{y(p)}{x(p)} = \frac{K}{1+Tp}. \qquad (3.6)$$

Inersial zvenoning o‘tkinchi funksiyasi

$$h(t) = L^{-1}\left\{W(p)\frac{1}{p}\right\} = L^{-1}\left\{\frac{K}{1+Tp}\cdot\frac{1}{p}\right\} = K(1-e^{-\frac{t}{T}})1(t) \qquad (3.7)$$

eksponenta qonuni bo‘yicha o‘zgaradi. Impulsli o‘tkinchi funksiyani quyidagicha aniqlash mumkin (3.2-rasm).

$$\omega(t) = h'(t) = L^{-1}\{W(p)\} = L^{-1}\left\{\frac{K}{1+pT}\right\} = \frac{K}{p}e^{-\frac{t}{T}}1(t) \qquad (3.8)$$



3.2-rasm. a) zvenoning vaqt xarakteristikasi;

b) zvenoning impulsli xarakteristikasi

1.3. Ideal integrallovchi zveno. Bu zveno

$$y(t) = K\int_0^t x(t)dt\,, \qquad (3.9)$$

tenglama bilan ifodalanadi.

Bu yerda K – uzatish koeffitsiyenti. Unga elektr sig‘im, induktivlik, aylanma o‘q va h.k. misol bo‘la oladi.

(3.9) tenglamaning Laplas bo‘yicha tasviri quyidagi ko‘rinishga ega:

$$y(p) = \frac{K}{p}x(p)\,, \qquad (3.10)$$

zvenoning uzatish funksiyasi

$$W(p) = \frac{y(p)}{x(p)} = \frac{K}{p} \tag{3.11}$$

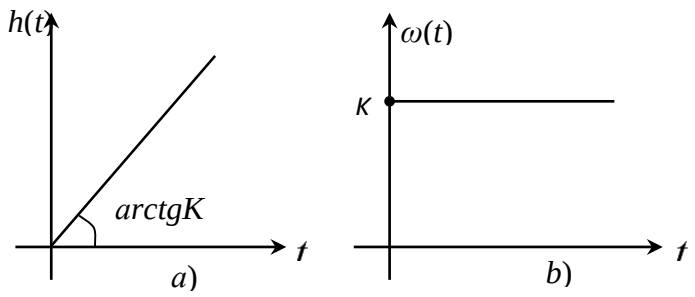
Bu zvenoni yana astatik zveno deb ham yuritiladi.

Integral zvenoning o‘tkinchi funksiyasi

$$h(t) = L^{-1}\left\{W(p)\frac{1}{p}\right\} = L^{-1}\left\{\frac{K}{p}\cdot\frac{1}{p}\right\} = K\cdot t\cdot 1(t) \tag{3.12}$$

va impulsli o‘tkinchi funksiyasi (vazn funksiyasi) 3.3-rasmda keltirilgan.

$$\omega(t) = h'(t) = K \tag{3.13}$$



3.3-rasm. a) zvenoning vaqt xarakteristikasi;

b) zvenoning impulsli xarakteristikasi

3.1-Misol. Dinamik zvenoning uzatish funksiyasi quyidagicha berilgan bo‘lsin:

$$W(p) = \frac{2}{p^2 + 5\cdot p + 4} \tag{3.14}$$

o‘tish xarakteristikasi quyidagicha ifodalanadi:

$$h(t) = L^{-1} \cdot \left[\frac{1}{p} \cdot W(p) \right] = L^{-1} \cdot \left[\frac{2}{p \cdot (p^2 + 5 \cdot p + 4)} \right] \tag{3.15}$$

o‘tish xarakteristikasini aniqlashda uzatish funksiyasini uch qismga ajratib olamiz:

$$W(p) = \frac{K1}{p - p1} + \frac{K2}{p - p2} + \frac{K3}{p} \tag{3.16}$$

Bundan tenglamaning ildizlari va koeffisientlari aniqlanadi K1, K2, K3:

$$p \cdot (p^2 + 5 \cdot p + 4) = 0 : p1 = -1, p2 = -4, p3 = 0$$

$$K1 = \left[(p+1) \cdot \frac{2}{p \cdot (p+1) \cdot (p+4)} \right]_{p=-1} = \frac{2}{(-1) \cdot (-1+4)} = -\frac{2}{3}$$

$$K2 = \left[(p+4) \cdot \frac{2}{p \cdot (p+1) \cdot (p+4)} \right]_{p=-4} = \frac{2}{(-4) \cdot (-4+1)} = -\frac{1}{6}$$

$$K3 = \left[p \cdot \frac{2}{p \cdot (p+1) \cdot (p+4)} \right]_{p=0} = \frac{1}{2}$$

topilgan koeffisientlar (3.14) tenglamaga qo‘yiladi:

$$W(p) = -\frac{2}{3} \cdot \frac{1}{p+1} + \frac{1}{6} \cdot \frac{1}{p+4} + \frac{1}{2} \cdot \frac{1}{p} \tag{3.17}$$

Laplas almashtirish quyidagicha aniqlanadi:

$$L^{-1} \cdot \left[b \cdot \frac{1}{p+a} \right] = b \cdot e^{-at} \tag{3.18}$$

a va b - konstantalar.

(3.17) va (3.18) ifodalardan foydalanib o‘tish jarayoni aniqlanadi:

$$h(t) = -\frac{2}{3} \cdot e^{-t} + \frac{1}{6} \cdot e^{-4t} + \frac{1}{2}$$

Impulsli xarakteristika o‘tish xarakteristikasidan vaqt bo‘yicha olingan hosilaga teng:

$$\omega(t)=2/3e^{-t}+2/3e^{-4t}$$

Topshiriqlar.

Quyida berilgan elementar zvenolarning uzatish funksiyalaridan foydalanib, *h(t)* o‘tish funksiyasi va *w(t)* vazn funksiyalarini aniqlang.

3.1-jadval

№	Obyektning uzatish funksiyasi
1.	$W(p)=\frac{3}{2p^2+10p+9}$
2.	$W(p)=\frac{5}{p^2+26p+25}$
3.	$W(p)=\frac{9}{p^2+82p+81}$
4.	$W(p)=\frac{5}{p^2+p+25}$
5.	$W(p)=\frac{8}{2p^2+65p+64}$
6.	$W(p)=\frac{5}{5p^2+p+25}$
7.	$W(p)=\frac{4}{2p^2+17p+16}$
8.	$W(p)=\frac{3}{3p^2+10p+9}$
9.	$W(p)=\frac{6}{2p^2+37p+36}$
10.	$W(p)=\frac{2}{4p^2+8p+4}$

4-Amaliy mashg‘ulot

Struktura sxemalarini o‘zgartirish qoidalari

ABTlarni tekshirganda va hisoblaganda ularda sodir bo‘layotgan fizik jarayonlarni ifodalovchi matematik ifodalardan foydaniladi. Odatda bunday ifoda o‘zgaruvchi kattaliklar va ularning xosilalarini ko‘rsatuvchi differensial tenglamalar sistemasi ko‘rinishida bo‘ladi. Shuning bilan birga chiziqli ABSlar uchun boshqa operator metodidan foydalaniladi. Bu usulda tekshirilayotgan sistema bir necha qismlarga bo‘linadi, ya’ni signallarni bir tomonlama kirishdan chiqishga yo‘nalgan zvenolarga ajratiladi.

Dinamik zvenolarning grafik ko‘rinishiga struktur sxema deyiladi. Funksional va struktur sxemalarda bir xillik mavjuddir, chunki ular boshqarish sistemasining berk konturidagi axborotlarni uzatish va o‘zgartirish jarayonlarini aks ettiradilar. Shuning bilan birga ular orasida farq bor, funksional sxema sistema tarkibidagi, elementlarni, ularning bajaradigan funksiyasini ko‘rsatadi.

Bir tomonlama yo‘naltirilgan zvenolardan tashkil topgan struktur sxema sistemaning dinamik xususiyatlarining matematik ifodasini bildiradi. Struktur sxemalarning afzalligi shundan iboratki, u sistemadagi jarayonlarini sistemadan o‘tayotgan signallarning uzatilishini, o‘zgartirilishini yaqqol tasvirlaydi.

Bir tomonlama harakatlanish xususiyatiga ega bo‘lgan ochiq sistemani ko‘rib chiqamiz. Bu bitta zveno yoki ularning turli bog‘lanishi bo‘lishi mumkin.

Uzatish funksiyasining ta’rifiga ko‘ra

$$W(p) = \frac{y(p)}{x(p)}; \qquad (4.1)$$

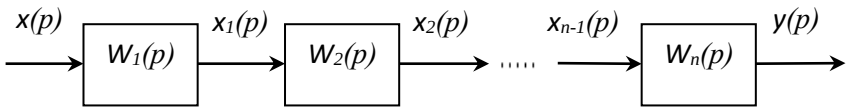
Bundan bir tomonlama yo‘nalgan sistemaning asosiy xususiyati kelib chiqadi.

$$y(p) = W(p) \cdot x(p) \tag{4.2}$$

Ya’ni chiqish signalining tasviri uzatish funksiyasini kirish signalining tasviri ko‘paytmasiga tengdir.

Bir tomonlama yo‘naltirilgan zvenolarning asosiy bog‘lanish hollarini ko‘rib chiqamiz.

a) **<u>Ketma-ket bog‘lanish</u>.** Bunda oldingi zvenoning chiqish signali keyingi zvenoning kirish signali hisoblanadi.



4.1 – rasm. Zvenolarning ketma-ket bog‘lanish sxemasi

(4.2) formulaga ko‘ra

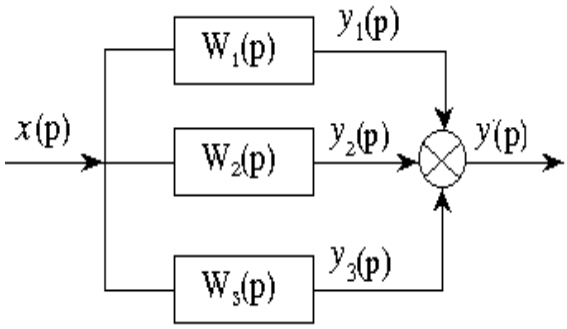
$$\left.\begin{array}{l} y(p) = W_n(p)\ x_{n-1}(p) \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ x_2(p) = W_2(p)\ x_1(p) \\ x_1(p) = W_1(p)\ x(p) \end{array}\right\} \tag{4.3}$$

(4.3) tenglamada oraliqdagi kattaliklarni yo‘qotib, $y(p) = W_1(p) \cdot W_2(p) \dots W_n(p) \cdot x(p)$ hosil qilish mumkin.

Bundan uzatish funksiyasi $W(p)=\frac{y(p)}{x(p)}=\prod_{i=1}^{n}W_i(p)$ kelib chiqadi. Demak, zvenolar ketma-ket ulanganda ularning uzatish funksiyalari ko‘paytiriladi.

b) **<u>Parallel bog‘lanish.</u>** Bunda hamma zvenolar kirishiga bir xil signal beriladi, chiqish signallari esa qo‘shiladi.

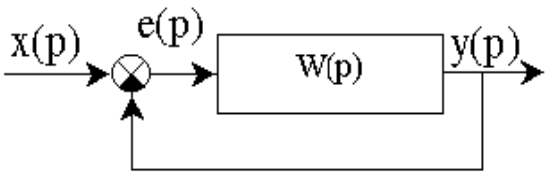
$$y(p)=y_1(p)+y_2(p)+y_3(p)$$
$$y_1(p)=W_1(p)\cdot x(p)$$
$$y_2(p)=W_2(p)\cdot x(p)$$
$$y_3(p)=W_3(p)\cdot x(p)$$
$$y(p)=[W_1(p)+W_2(p)+W_3(p)]x(p)$$
$$W(p)=\frac{y(p)}{x(p)}=\sum_{i=1}^{n}W_i(p)$$



4.2 – rasm. Zvenolarning parallel bog‘lanish sxemasi

Shunday qilib, zvenolar parallel ulanganda ularning uzatish funksiyalari qo‘shiladi.

v) **<u>Qarshi parallel bog‘lanish (teskari bog‘lanish)</u>.** Teskari bog‘lanish deb, chiqish signalini kirishga ulanishiga aytiladi. Agar teskari bog‘lanish signali kirish signalidan ayrilsa manfiy, qo‘shilsa musbat teskari bog‘lanish bo‘ladi.



4.3 – rasm. Zvenolarning teskari bog‘lanish sxemasi

$y(p) = W_T(p) \cdot e(p)$

$e(p) = x(p) \pm y_{ТБ}(p)$ (+) musbat TB, (-) manfiy TB.

$y_{ТБ}(p) = W_{ТБ}(p) \cdot y(p)$

$y(p) = W_T(p)[x(p) \pm W_{ТБ}(p) \cdot y(p)]$

$y(p) = [1 \pm W_T(p) W_{ТБ}(p)] = W_T(p) x(p)$ (-) musbat TB, (+) manfiy TB

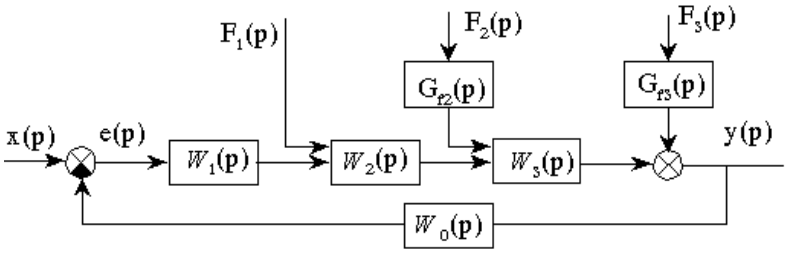
$$W(p) = \frac{y(p)}{x(p)} = \frac{W_T(p)}{1 \pm W_T(p) W_{ТБ}(p)} = \frac{W_T(p)}{1 \pm W(p)} \qquad (4.4)$$

$W(p) = W_T(p) \cdot W_{ТБ}(p)$ – ochiq sistema uzatish funksiyasi.

Endi ochiq sistemani manfiy birlik TB bilan bog‘laymiz. Yuqoridagi (4.4) ifodaga ko‘ra berk sistema uzatish funksiyasi $\Phi(p) = \frac{y(p)}{x(p)} = \frac{W(p)}{1 + W(p)}$ teng.

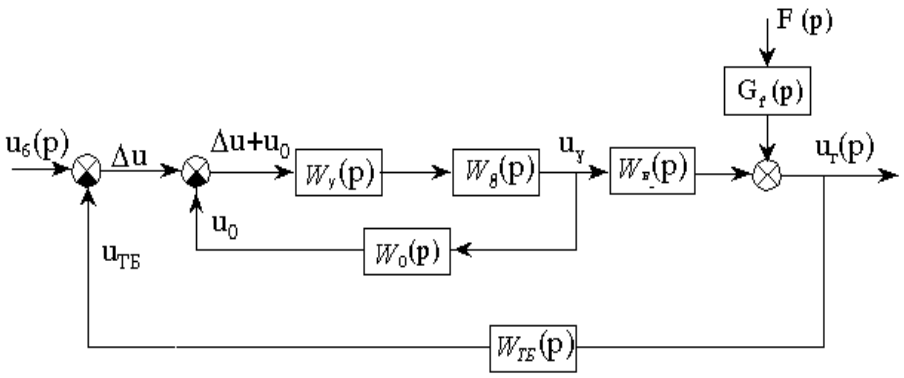
F(r) – berk sistemaning kirish signali bo‘yicha uzatish funksiyasi.

Real sharoitda sistema boshqaruvchi (kirish) signalidan tashqari yana ko‘p qo‘zg‘atuvchi ta’sirlarga (yuklamaning o‘zgarishi, halaqitlar, element xarakteristikalarining nostabilligi va boshqa) duch kelishi mumkin. Bunday qo‘zg‘atuvchi ta‘sirlarning ta’sirini bilish uchun struktur sxema bo‘yicha boshqariluvchi kattalik bilan qo‘zg‘atuvchi ta‘sirlar orasidagi bog‘lanishni aniqlashni o‘rganish kerak, quyidagi struktur sxemani ko‘rib chiqamiz:



4.4 – rasm. Sistemaga ta‘sir ko‘rsatuvchi tashqi ta’sirlar sxemasi

Sistemaning to‘g‘ri zanjiri $W_1(p)$; $W_2(p)$; $W_3(p)$ uzatish funksiyasiga ega bo‘lgan bir tomonlama yo‘naltirilgan zvenolardan tashkil topgan. Keyingi ikki zveno kirishga qo‘zg‘atuvchi ta’sirlar $F_1(r)$; $F_2(r)$ kelib tushib, oldingi zvenoning chiqish kattaligi bilan qo‘shilmoqda. Bundan tashqari $F_3(r)$ qo‘zg‘atuvchi ta’sir bevosita chiqish kattaligiga ta’sir ko‘rsatmoqda. $F_3(r)$ signalning qo‘yilgan joyi TB bilan qamrab olingan bo‘lib, bu juda katta ahamiyatga ega, chunki $F_3(r)$ signalning ta‘siri $W_0(p)$ zvenoga ham kelib tushadi, aksincha bo‘lgan holda $F_3(r)$ signalning rostlash jarayoniga ta’siri bo‘lmay, bu katta xatoliklarga olib kelgan bo‘lar edi.



4.5– rasm. Sistemaning superpozitsiyali prinsipi bo‘yicha ko‘rinishi

Ko‘rilayotgan sistema chiziqli bo‘lganligi uchun unga superpozitsiya (ustlash) prinsipini qo‘llash mumkin, ya‘ni sistemaning umumiy reaksiyasini, har bir ayrim ta‘sirlardan hosil bo‘lgan reaksiyalar summasi ko‘rinishida aniqlash mumkin.

x(r)=0; *F₂(r)=0*; *F₃(r)=0* deb faraz qilamiz va sistemani $F_1(r)$ signaldan olgan reaksiyasi *u(r)* ni aniqlaymiz. $W_2(p)$ zveno kirishiga $[F_1(p)+W_1(p)\cdot e(p)]$ signal ta‘sir etadi.

$e(p)=x(p)-W_0(p)y(p)$ e’tiborga olsak, unda bu signal $W_2(p)$, $W_3(p)$ zvenolardan o‘tib quyidagi reaksiyani hosil qiladi.

$$y(p)=W_2(p)\cdot W_3(p)[F_1(p)-W_1(p)\cdot W_0(p)\cdot y(p)]$$
$$y(p)[1+W_1(p)W_2(p)W_3(p)\cdot W_0(p)]=W_2(p)W_3(p)F_1(p)$$
$$y(p)=\frac{W_2(p)W_3(p)}{1+W_1(p)W_2(p)\cdot W_3(p)W_0(p)}\cdot F_1(p)$$

$W(p)=W_1(p)W_2(p)W_3(p)W_0(p)$ – ochiq sistemaning uzatish funksiyasi.

Shunday qilib, sistemaning $F_1(r)$ signaldan olgan reaksiyasi $y(p)=\frac{W_2(p)W_3(p)}{1+W(p)}\cdot F_1(p)$.

Xuddi shunday tarzda qolgan ta‘sirlardan hosil bo‘lgan reaksiyalarni aniqlash mumkin.

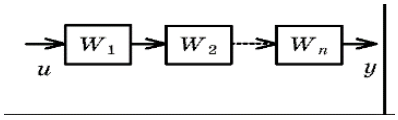
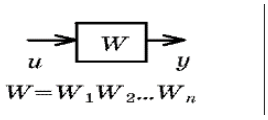
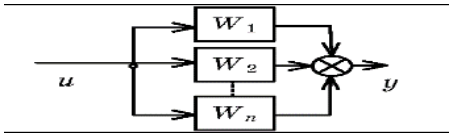
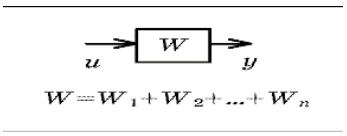
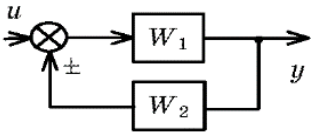
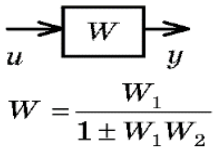
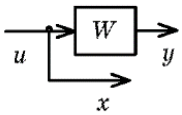
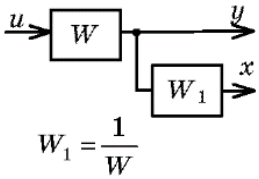
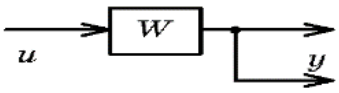
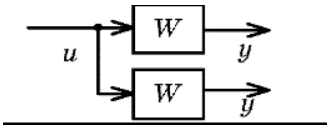
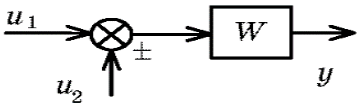
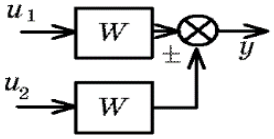
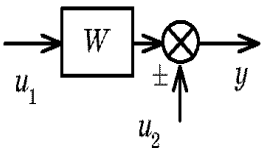
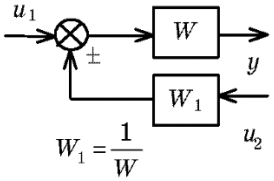
$$y(p)=\frac{W_1(p)\cdot W_2(p)\cdot W_3(p)}{1+W(p)}x(p)$$

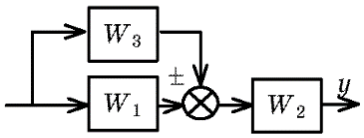
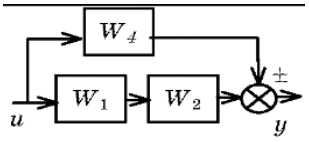
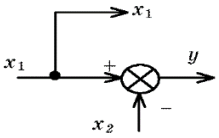
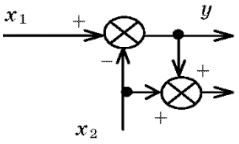
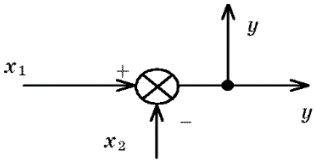
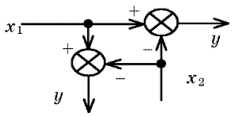
$$y(p)=\frac{G_{f2}(p)W_3(p)}{1+W(p)}F_2(p) \quad \Rightarrow \quad y(p)=\frac{G_{f2}(p)}{1+W(p)}F_2(p)$$

Hamma qo‘zg‘atuvchi ta’sirlarning bir vaqtda ta‘siridan hosil bo‘lgan reaksiyani quyidagicha ifodalash mumkin.

$$y(p)=\frac{W_1W_2W_3x(p)+W_2W_3F_1(p)+G_{f2}W_3F_2(p)+G_{f3}F_3(p)}{1+W(p)};$$

		4.1-jadval
Struktura sxemalarini o’zgartirish qoidalari		
O‘zgartirish	**Struktura sxemasi**	
	Berilgani	**Ekvivalenti**

Ketma-ket bog‘lanishni yoyish		
		4.1-jadvalning davomi
Parallel bog‘lanishni yoyish		
Teskari bog‘lanishni yoyish		
Uzelni zvenodan keyinga o‘tkazish		
Uzelni zvenodan oldinga o‘tkazish		
Yig‘ish elementini zvenodan keyinga o‘tkazish		
Yig‘ish elementini zvenodan oldinga o‘tkazish		

To‘g‘ri bog‘lanishni zveno orqali o‘tkazish		
		4.1-jadvalnning davomi
Bog‘lanish uzelini yig‘ish elementi orqali keyinga o‘tkazish		
Bog‘lanish uzelini yig‘ish elementi orqali oldinga o‘tkazish		

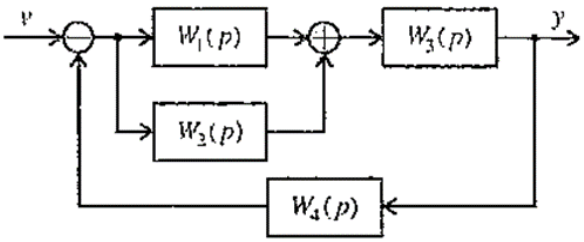
4.1-masala

4.6-rasmdagi strukturali sxemadan sistemaning umumiy uzatish funksiyasini aniqlash. Dastlab tipik ulangan zvenolarning uzatish funksiyalarini aniqlaymiz: parallel ulangan zvenolarning uzatish funksiyasi:

$$\overline{W}_1(p) = W_1(p) + W_2(p),$$

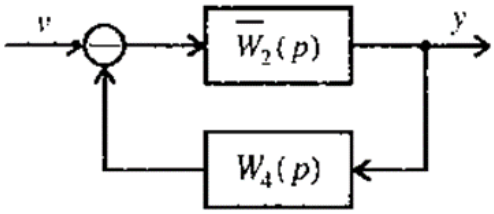
ketma-ket ulangan zvenolarning uzatish funksiyasi

$$\overline{W}_2(p) = \overline{W}_1(p) W_3(p).$$



4.6-rasm. Sistemaning strukturali sxemasi

Kiritilgan belgilashlarni hisobga olib sistemaning tuzilishini 3.10-rasmda ko‘rsatilgan ko‘rinishga keltirish mumkin:



4.7- rasm. Ekvivalent sistemaning strukturali sxemasi

Strukturali o‘zgartirishlarida foydalanib, sistemaning umumiy uzatish funksiyasini yozamiz:

$$W(p)=\frac{\overline{W}_2(p)}{1+\overline{W}_2(p)\,W_4(p)}.$$

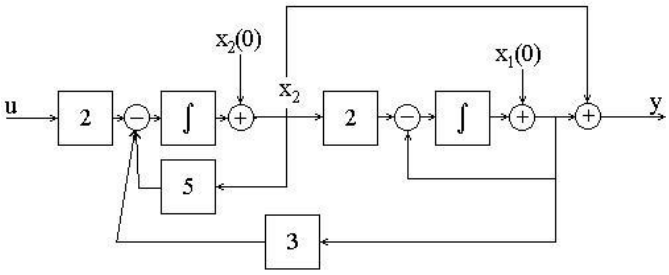
$\overline{W}_1(p)$va $\overline{W}_2(p)$ larning o‘rniga qiymatlarini qo‘yib, quyidagiga ega bo‘lamiz:

$$W(p)=\frac{[W_1(p)+W_2(p)]\,W_3(p)}{1+[W_1(p)+W_2(p)]\,W_3(p)W_4(p)}.$$

4.2-masala. Quyida obyektning differensial tenglamalar tizimi orqali berilgan modeli asosida obyektning strukturaviy sxemasini tasvirlang:

$$\begin{cases} x_1' = -x_1 + 2x_2, \\ x_2' = -3x_1 - 5x_2 + 2u, \\ y = x_1 + x_2. \end{cases}$$

Yechilishi. Obyektning strukturaviy sxemasi quyidagi ko‘rinishga ega bo‘ladi:

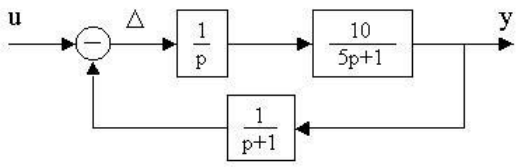
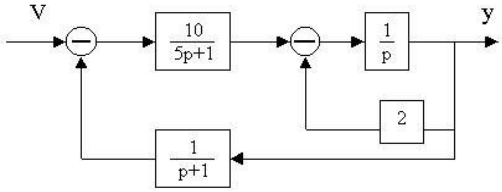
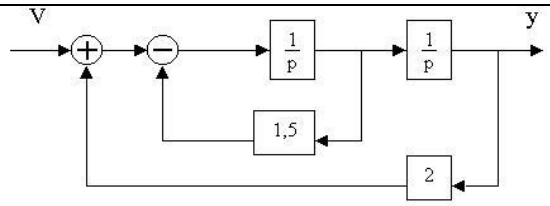
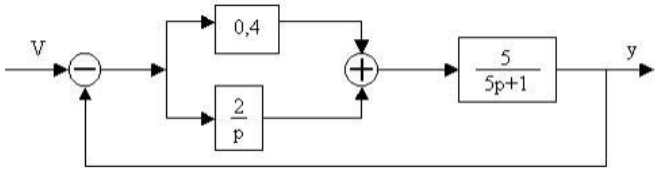


4.8-rasm. Obyektning strukturali sxemasi

Topshiriqlar

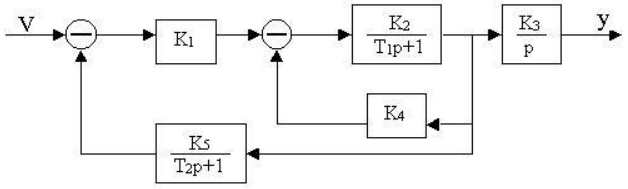
1.1. Quyida tizimning strukturaviy sxemasi keltirilgan. Strukturaviy sxemadan foydalanib tizimning uzatish funksiyasini aniqlang.

4.2-jadval

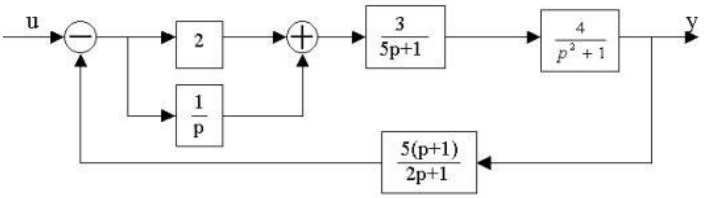
№	Tizimning strukturaviy sxemasi
1.	
2.	
3.	
4.	

4.2-jadvalning davomi

5.



6.



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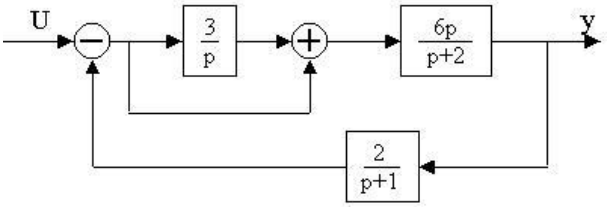

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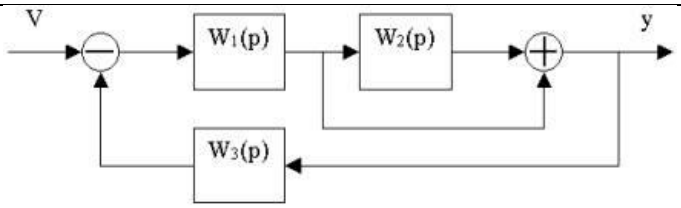

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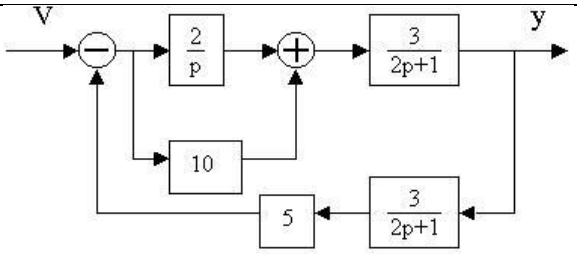

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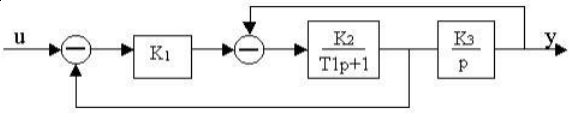

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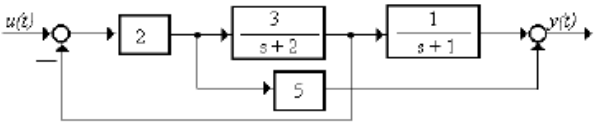

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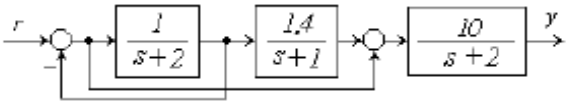

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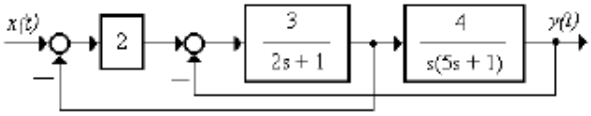

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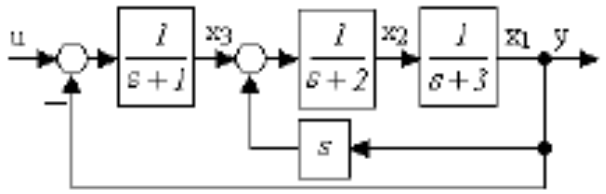
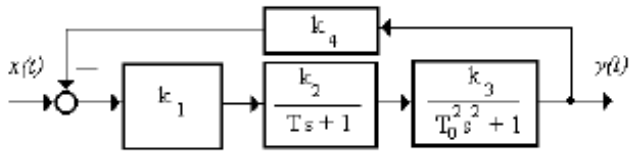
14.	
15.	

5-Amaliy mashg‘ulot

Chiziqli avtomatik boshqarish sistemalarining turg‘unligini tahlil qilish

Avtomatik boshqarish tizimlarining ishlash qobiliyatiga qo‘yilgan talab, ularning turli xil tashqi qo‘zg‘atuvchi ta‘siriga nosezgir bo‘lishiga mo‘ljallangan bo‘lishidir.

Agarda sistema turg‘un bo‘lsa, unda u tashqi qo‘zg‘atuvchi ta’sirlarga bardosh bera oladi va o‘zining muvozanat holatidan chiqarilganda yana ma‘lum aniqlikda shu holatiga qaytib keladi. Agarda sistema noturg‘un bo‘lsa, unda u tashqi qo‘zg‘atuvchi ta’sir natijasida muvozanat holati atrofida cheksiz katta amplitudaga ega bo‘lgan tebranishlar hosil qiladi yoki muvozanat holatidan cheksiz uzoqlashadi.

Agarda har qanday cheklangan kirish kattaligining absolyut qiymatida chiqish kattaligi ham cheklangan qiymatga ega bo‘lsa, bunday sistema *turg‘un* deb yuritiladi.

Rauss – Gurvits algebraik mezoni. Bu mezon 1877 yilda ingliz olimi Rauss va 1893 yilda nemis matematigi Gurvits tomonidan ta‘riflangan:

n-tartibli chiziqli tizimning turg‘un bo‘lishi uchun berilgan tizimning xarakteristik tenglamasida koeffitsiyentlardan tashkil topgan p ta aniqlovchilar musbat bo‘lishi zarur va yetarli:

$$a_0 p^n + a_1 p^{n-1} + a_2 p^{n-2} + ... + a_{n-1} p + a_n = 0 \qquad (5.1)$$

Bunda quyidagi qoidalarga asosan koeffitsiyent $a_0 > 0$ bo‘lishi kerak:

1) asosiy diagonal bo‘yicha o‘sish tartibida a_1 dan a_n gacha barcha koordinatalar ko‘chirib yoziladi;

2) aniqlovchining barcha ustunlari diagonaldan yuqoriga indekslari o‘sayotgan koeffitsiyentlar, diagonal elementlaridan pastga esa indekslari kamayuvchi koeffitsiyentlar bilan to‘ldiriladi;

3) eng katta tartibli Gurvits aniqlovchisi tizimning xarakteristik tenglamasi darajasiga to‘g‘ri keladi;

4) n dan katta indeksli koeffitsiyentlar nolga teng;

5) indekslari noldan kichik bo‘lgan koeffitsiyentlar nolga tenglashtiriladi;

6) oxirgi Δ_n aniqlovchi $a_n\Delta_{n-1}$ ga teng. Shunga muvofiq Gurvits aniqlovchilari quyidagicha bo‘ladi:

$$\Delta_1 = a_1; \quad \Delta_2 = \begin{vmatrix} a_1 & a_3 \\ a_0 & a_2 \end{vmatrix}; \quad \Delta_3 = \begin{vmatrix} a_1 & a_3 & a_5 \\ a_0 & a_2 & a_1 \\ 0 & a_1 & a_3 \end{vmatrix}$$

va hokazo.

Gurvits aniqlovchisining umumiy ko‘rinishi esa:

$$\Delta_n = \begin{vmatrix} a_1 & a_3 & a_5 & a_7 & \dots & 0 \\ a_0 & a_2 & a_4 & a_6 & \dots & 0 \\ 0 & a_1 & a_3 & a_5 & \dots & 0 \\ 0 & a_0 & a_2 & a_4 & \dots & 0 \\ 0 & \dots & \dots & \dots & \dots & 0 \end{vmatrix}$$

Rauss-Gurvits mezoni asosida eng sodda tizimlar turg‘unligining quyidagi shartlari kelib chiqadi: 1) agar birinchi va ikkinchi tartibli tizimlarda xarakteristik tenglamaning barcha koeffitsiyentlari musbat bo‘lsa, bu tizimlar turg‘un bo‘ladi; 2) agar uchinchi tartibli tizimda xarakteristik tenglamaning barcha koeffitsiyentlari musbat bo‘lib, $a_1 \cdot a_2 > a_0 \cdot a_3$ bo‘lsa, tizim turg‘un bo‘ladi; 3) agar xarakteristik tenglamaning barcha koeffitsiyentlari musbat bo‘lib, $a_1 \cdot a_2 \cdot a_3 > a_0 \cdot a_3^2 \cdot a_4 \cdot a_1^2$ bo‘lsa, to‘rtinchi tartibli tizim turg‘un hisoblanadi.

Rauss-Gurvits mezonidan foydalanilganda Δ_1 dan Δ_n gacha barcha aniqlovchilarni hisoblashning keragi yo‘q. Masalan, uchinchi tartibli tizimning turg‘unligini aniqlash kerak bo‘lsa, uchta aniqlovchidan birini topishning o‘zi kifoya. a_4 va a_5 koeffitsiyentlar Δ_3 aniqlovchida nolga teng:

$$\Delta_2 < \begin{vmatrix} a_1 & a_3 \\ a_0 & a_2 \end{vmatrix} = a_1 a_2 - a_0 a_3 \ .$$

Agar Δ_2 aniqlovchi musbat bo‘lsa, Δ_3 aniqlovchi ham musbat bo‘ladi. $\Delta_3 = a_3 \Delta_2 > 0$, chunki $a_3 > 0$. Δ_1 aniqlovchi esa ma’lum $(\Delta_1 = a_1)$ va musbat (chunki $a_1 > 0$). Algebraik mezon beshinchi tartibdan oshmaydi va u kechikishsiz chiziqli tizimlar uchun ancha qulay.

Mixaylov geometrik mezoni. Chiziqli avtomatik rostlash tizimining turg‘unlik mezoni A.V. Mixaylov tomonidan 1938 yilda taklif etilgan. Kompleks o‘zgaruvchining tekisligidagi rostlash tizimining xarakteristik tenglamasi orqali aniqlanuvchi vektor tizimning xarakteristik tenglamasi (5.1) dagi ω kattalik mavhum $j\omega$ argument bilan almashtirish yo‘li bilan topiladi:

$$L(j\omega) = a_n (j\omega)^n + a_{n-1} (j\omega)^{n-1} + \ldots + a_1 (j\omega) + a_0 \quad (5.2)$$

$j=\sqrt{-1}; \quad j^2=-1; \quad j^3=-j; \quad j^4=1; \ldots$ ekanligini esga olamiz. (5.2) xarakteristik funksiya tarkibiga kirgan barcha juft darajali $j(\omega)$ qo‘shiluvchilar haqiqiy, toq darajaligi esa mavhum kattalik bo‘ladi. Demak:

$$L(j\omega) = M(\omega) + jN(\omega),$$

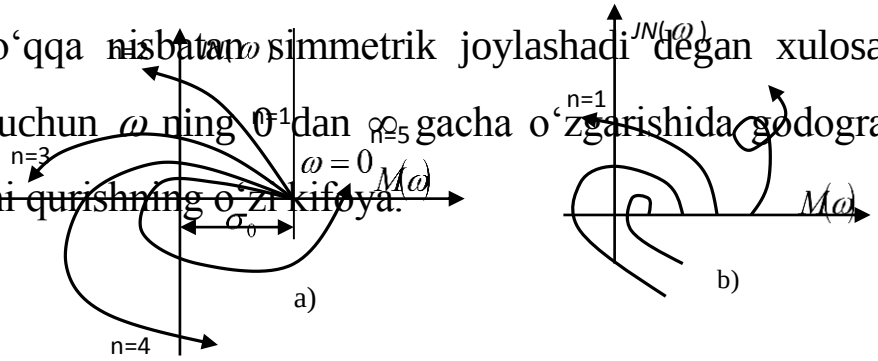
bunda

$$M(\omega) = a_0 - a_2\omega^2 + a_4\omega^4 - \ldots,$$

$$N(\omega) = a_1 - a_3\omega^3 + a_5\omega^5 - \ldots.$$

Agar ω ni 0 dan ∞ gacha ketma-ket o‘zgartirsak, vektor Mixaylov godografi nomli egri chiziqni hosil qiladi. Kompleks tekislikdagi godograf shakli bo‘yicha tadqiq qilinayotgan tizimning turg‘unligi haqida fikr yuritish mumkin. Mixaylov kriteriysi quyidagicha ifodalanadi: Agar $L(j\omega)$ xarakteristik funksiyasining godografi ω ning 0 dan ∞ gacha o‘zgarishida musbat yo‘nalishda kompleks tekislikning n kvadrantlarining birontasini ham tushirib qoldirmay aylanib chiqsa (n – ko‘rilayotgan tizim xarakteristik tenglamasining darajasi), rostlash tizimi turg‘un bo‘ladi. Bu xususiy holda soat strelkasining harakatiga teskari yo‘nalish musbat hisoblanadi.

Agar (5.1) yoki (5.2) ifodalarda $\omega=0$ deb faraz qilinsa, $L(j\omega)=a_0$ bo‘ladi. Boshqacha qilib aytganda $\omega=0$ bo‘lsa, godograf haqiqiy o‘qni koordinata boshidan a_0 masofada turgan nuqtada kesib o‘tadi. Agar $M(\omega)$ o‘zgaruvchi ω ning juft, $N(\omega)$ esa toq funksiyasi ekanligini e’tiborga olsak, godograf haqiqiy o‘qqa nisbatan simmetrik joylashadi degan xulosaga kelamiz. Shuning uchun ω ning 0 dan ∞ gacha o‘zgarishida godografning yarim tarmog‘ini qurishning o‘zi kifoya.



5.1 – rasm. Mixaylov godograflari:

a – turg‘un tizimlar uchun; b – noturg‘un tizimlar uchun

5.1-rasmda birinchi tartibdan beshinchi tartibgacha bo‘lgan turg‘un va noturg‘un tizimlar uchun Mixaylov godograflari ko‘rsatilgan. Birinchi tartibli tenglamaga – mavhum o‘qqa parallel bo‘lib, undan a_0 masofada turgan to‘g‘ri chiziq mos keladi. Yuqori tartibli tizimlarga egri chiziqlar mosdir. Mixaylov mezonidan kechikishga ega bo‘lgan turg‘un chiziqli tizimlarni o‘rganishda ham foydalanish mumkin.

Naykvist-Mixaylov chastota mezoni. Bu mezon 1932 yilda elektron kuchaytirgichlarning turg‘unligini tadqiq qilish uchun Naykvist tomonidan taklif etilgan. Avtomatik rostlash nazariyasida chastota mezoni 1936 yilda umumlashtirilgan holda qo‘llanilgan. Tutashmas tizimning tahlilida Naykvist-Mixaylov amplituda-faza mezonidan foydalanib, rostlash tizimining turg‘unligi haqida fikr yuritiladi. Turg‘unlikni bu metod bo‘yicha o‘rganishda tajriba usulida aniqlangan amplituda-faza tavsiflardan foydalaniladi. Nihoyat, mezon tizimning turg‘unlik darajasi haqida ma’lumot olishga imkon beradi. Agar tizim noturg‘un bo‘lsa, Naykvist-Mixaylov mezoni tizimni stabillashtirish va to‘g‘rilovchi zveno hamda konturlar yordamida tutash tizimning istalgan tavsifiga erishish yo‘llarini ko‘rsatadi.

5.2-rasm. Turli tizimlar uchun amplituda-faza tavsiflarining namunalari:

1 – turg‘un tizimlar uchun; 2 – turg‘unlikka yaqin tizimlar uchun; 3 –noturg‘un tizimlar uchun

Bu mezonning ifodasi quyidagicha: tutashmas holatda turg‘un bo‘lgan avtomatik rostlash tizimi agar tutashmas tizimning amplituda faza tavsifi ω ning 0 dan ∞ gacha o‘zgarishida (-1,10) koordinatalarga ega bo‘lgan nuqtaga yetmasa, yopiq holatda ham turg‘un bo‘ladi.

5.2-rasmda turg‘un va noturg‘un, shuningdek, turg‘unlik chegarasida turgan tizimlarning ochiq holatidagi amplituda-faza tavsiflari keltirilgan. Birinchi tartibli differensial tenglamalar orqali tavsiflanuvchi tizimlarning AFX bir kvadrantda joylashadi. Ikkinchi tartibli differensial tenglamalar orqali tavsiflanuvchi tizimlarning AFX ikki kvadrantga joylashadi. Xarakteristik tenglamalarning koeffitsiyentlari musbat bo‘lsa, bu tizimlar turg‘un bo‘ladi.

5.1-misol. Gurvits kriteriyasi yordamida tizimning turg‘unligini baholang:

$$\begin{cases} \dot{x}_1 = -2x_1 + x_2, \\ \dot{x}_2 = x_1 - x_3, \\ \dot{x}_3 = -5x_1 + 8x_2 + 2u, \\ y = x_1. \end{cases}$$

Yechilishi. Berilgan tenglamalar tizimini operator shaklida yozamiz:

$$\begin{cases} px_1 = -2x_1 + x_2, \\ px_2 = x_1 - x_3, \\ px_3 = -5x_1 + 8x_2 + 2u, \\ y = x_1. \end{cases}$$

Uzatish funksiyasini aniqlaymiz:

$$W(p) = \frac{-2}{p^3 + 3p^2 + 9p + 10}$$

Xarakteristik tenglamasi quyidagi ko‘rinishga ega bo‘ladi:

$$A(p) = p^3 + 3p^2 + 9p + 10.$$

Uning asosida Gurvits matritsasini yozamiz:

$$H = \begin{bmatrix} 3 & 10 & 0 \\ 1 & 9 & 0 \\ 0 & 3 & 10 \end{bmatrix}$$

Uning turli tartibdagi aniqlovchilarini topamiz:

$$\Delta_1 = 3 > 0, \Delta_2 = \begin{bmatrix} 3 & 10 \\ 1 & 9 \end{bmatrix} = 17 > 0, \Delta_3 = \det|H| = 170 > 0.$$

Chunonchi hamma diagonalli minorlar musbat bo‘lganligi uchun berilgan tizim turg‘undir.

5.2-misol. Mixaylov kriteriyasi yordamida $\dddot{y} + 5\ddot{y} + 2\dot{y} + 20y = 5u$ tizimning turg‘unligini tekshiring.

Yechilishi. Tizimning uzatish funksiyasi quyidagicha

$$W_{y/u}(p) = \frac{5}{p^3 + 5p^2 + 2p + 20}$$

Xarakteristik polinomini yozamiz

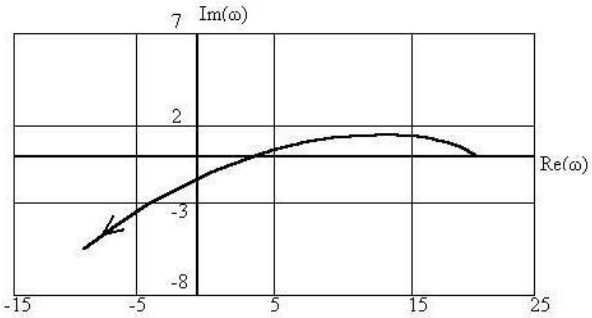
$$A(p) = p^3 + 5p^2 + 2p + 20$$

P ni $j\omega$ ga almashtirib $A(j\omega) = (j\omega)^3 + 5(j\omega)^2 + 2j\omega + 20$ ifodani olamiz.

$A(_{j\omega})$ haqiqiy va mavhum qismlarga ajratamiz

$$\begin{cases} \mathrm{Re}(\omega) = 20 - 5\omega^2 \\ \mathrm{Im}(\omega) = 2\omega - \omega^3 \end{cases}$$

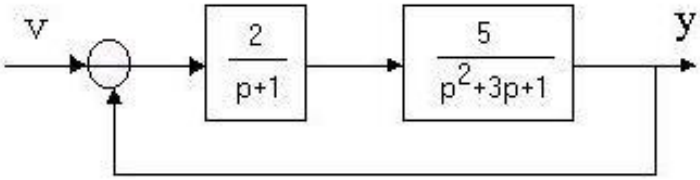
ω ni 0 dan to ∞ o‘zgartirib, Mixaylov godografini quramiz:



5.3-rasm. Mixaylov godografi

Bundan ko‘rinadiki, tizim turg‘un emas, negaki Mixaylov kriteriyasi shartlarini bajarilmayapti.

5.3 - misol. Naykvist kriteriyasi yordamida tizimning turg‘unligini tekshiring.



5.4-rasm. Yopiq bog‘lanishli tizim sxemasi

Yechilishi. Ochiq tizimning uzatish funksiyasini topamiz

$$W_p(p) = \frac{2}{p+1} \times \frac{5}{p^2+3p+1} = \frac{10}{p^3+4p^2+4p+1}$$

r ni $j\omega$ almashtirib, tizimning chastataviy xarakteristikasiga o‘tamiz:

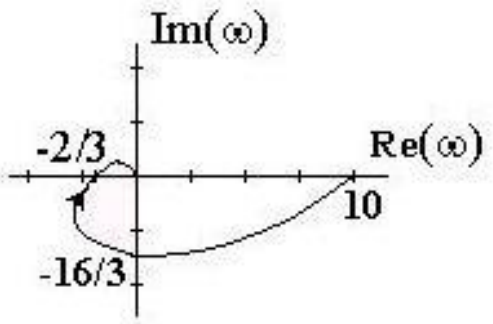
$$W_p(j\omega) = \frac{10}{(1-4\omega^2)+j(4\omega-\omega^3)}$$

Haqiqiy va mavhum qismlarga ajratamiz

$$\begin{cases} \mathrm{Re}(\omega) = \dfrac{10(1-4\omega^2)}{(1-4\omega^2)^2+(4\omega-\omega^3)^2}; \\ \mathrm{Im}(\omega) = \dfrac{10(4\omega-\omega^3)}{(1-4\omega^2)^2+(4\omega-\omega^3)^2}; \end{cases}$$

ω ni 0 dan to ∞ o‘zgartirib, ochiq tizimning AFX ni quramiz

ω	0.5	2	∞
Im(ω)	16/3	0	0
Re(ω)	10	-2/3	0



5.5-rasm. Ochiq tizimning amplituda-faza xarakteristikasi

Shunday qilib, ochiq tizimning AFX si koordinata nuqtalarga (-1; *j*0) ega bo‘lmayapti, shuning uchun ochiq tizim turg‘un emas.

Topshiriqlar

Agar tizimning differensial tenglamalari quyidagi ko‘rinishga ega bo‘lsa, u holda tizimning turg‘unligini Gurvits, Naykvist va Mixaylov kriteriyalari yordamida tekshiring:

5.1-jadval.

№	Obyektning differensial tenglamasi
1.	$y''' + 7y'' - 5y' = 5u$
2.	$y''' + 2y'' + y' = 2u$
3.	$2y''' + y' + 3y = 10u$
4.	$y''' + 4y'' + 2y' = 12u$
5.	$4y''' + 4y'' + 2y' + y = 4u$
6.	$4y''' + 4y'' + 2y' = 6u$
7.	$5y''' + 4y'' + 2y' + 3y = 11u$
8.	$y''' + 2y' + 3y = 9u$
	5.1-jadvalning davomi
9.	$7y''' + 10y'' + 2y' + y = 3u$
10.	$3y'' + 5y' + y = 15u$
11.	$13y'' + 8y' + 2y = 7u$
12.	$2y''' + 4y'' + 8y' + y = 11u$
13.	$5y''' + 2y' + 3y = 8u$

14.	$4y'' + 2y' + 10y = 5u$
15.	$5y''' + 4y'' + 13y = 2u$
16.	$23y'' + 18y' + 2y = 9u$
17.	$y''' + 22y'' + 3y = 5u$
18.	$y''' - 15y' = 8u$
19.	$y''' + 2y'' + 16y = 2u$
20.	$3y''' + 17y'' - y' = 15u$
21.	$3y'' + 28y' + 32y = 19u$
22.	$y''' + 2y' = 11u$
23.	$11y''' + y'' - 15y' = 6u$
24.	$18y'' + 2y' + 12y = 9u$
25.	$y''' + 10y'' - 8y' = 8u$
26.	$y''' + 12y'' + y' = 4u$
27.	$13y'' + 18y' + 21y = 2u$
28.	$7y''' + 7y'' - 3y = 7u$
29.	$9y''' + 7y'' + y = 12u$
30.	$y''' + 8y' - 4y = 15u$

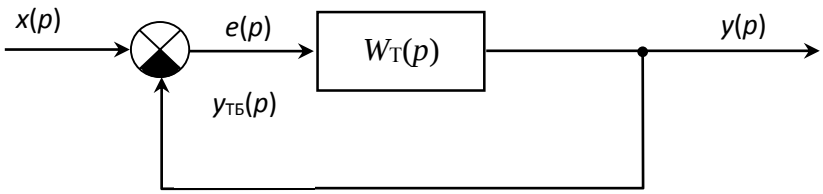
6-Amaliy mashg‘ulot

Korrektlovchi moslamalarni logarifm amplituda chastotaviy xarakteristika (LACHX) lar yordamida sintez qilish

Avtomatik sistemani tekshirganda o‘tkinchi jarayonning sifatini ta’minlashga doir masalalarni yechishga to‘g‘ri keladi. O‘tkinchi

jarayonning aniqligini va rostlash bir tekisligini xarakterlovchi sifat ko‘rsatkichlarga o‘tkinchi jarayon tezkorligi (o‘tkinchi jarayon vaqti), tebranishlar soni (o‘tkinchi jarayonning tebranishlar soni) hamda o‘tarostlash kiradi.

O‘zgarmas koeffitsiyentli chiziqli differensial tenglama bilan ifodalangan chiziqli sistema berilgan bo‘lsin:



6.1-rasm. Chiziqli differensial tenglama bilan ifodalangan chiziqli sistema sxemasi

Kirish kattaligi $x(t)$ o‘zgarganda sistemaning chiqishidagi $y(t)$ kattalikning o‘zgarishini quyidagicha ifodalash mumkin

$$y(t) = y_э(t) + y_м(t), \tag{6.1}$$

bunda $y(t)$ - sistemani ifoda etuvchi tenglamaning umumiy yechimi; $y_э(t)$ - shu yechimning erkin tashkil etuvchisi. Agar $y_э(t)$ karra ildizga ega bo‘lmasa, unda

$$y_э(t) = \sum_{i=1}^{n} C_i e^{p_i t} \tag{6.2}$$

bunda C_i - sistemaning parametrlari va boshlang‘ich shartlarga bog‘liq bo‘lgan o‘zgarmas son; p_i - berk sistemaning xarakteristik tenglamasi, $A(p) = 0$ ildizlaridir. $y_м(t)$ - kirish signali $x(t)$ning o‘zgarishiga bog‘liq bo‘lgan o‘tkinchi jarayonning qaror rejimini ifodalovchi majburiy tashkil etuvchidir.

(1) tenglamadan ko‘rinib turibdiki, o‘tkinchi jarayonning sifatini uning $y_э(t)$ va $y_м(t)$ tashkil etuvchilari yordamida aniqlash mumkin, shu nuqtai nazardan qaraganda rostlash jarayonining sifatini aniqlash yoki baholash ikki guruhga bo‘linadi.

<u>*Birinchi guruh.*</u> O‘tkinchi jarayon $y_э(t)$ning sifat ko‘rsatkichi.

<u>*Ikkinchi guruh.*</u> Sistemaning aniqligini belgilovchi o‘tkinchi jarayonning majburiy tashkil etuvchi xarakterlovchi ko‘rsatkichlari.

O‘tkinchi jarayon egri chizig‘i bo‘yicha aniqlangan sifat ko‘rsatkichlarini sistemaning sifatini *bevosita baholash usuli* deyiladi.

O‘tkinchi jarayon egri chizig‘ini tajriba hamda nazariy olish mumkin. Ayrim hollarda yuqori tartibli sistemalar uchun o‘tkinchi jarayon egri chizig‘ini aniqlash ancha qiyinchilik tug‘diradi. Shunday hollarda o‘tkinchi jarayon egri chizig‘ini aniqlamasdan turib shu jarayonning sifatini baholashga imkon beruvchi usulning sifat ko‘rsatkichlarini baholashning *bilvosita usuli* deyiladi.

6.1-misol. Korrektirlangan tizimning uzatish funksiyasi va sifat ko‘rsatkichlari. Chastotaviy usul yordamida rostlagichning ko‘rsatkichlarini hisoblash kerak.

$$W_{н.с.}(p) = \frac{1}{(1.7p+100)(0.25p^2+0.425p+1)};$$

$$\sigma,\% \approx 30\%;\ \ t_п = 1.5c;\ \ \Delta_{ст.}\% = 1\%.$$

Yechilishi. Obyektning LACHX ini quramiz. Avval tutash chastotalar asimptotasini aniqlaymiz:

$$W_{н.с.}(p) = \frac{1}{(1.7p+100)(0.25p^2+0.425p+1)},$$

T_1 = 0.017c, ω_1 = 1/0.017 = 58.8, lgω_1 = 1.8, T_2 = 0.5*c*,

$\omega^2 = 2$, $\lg\omega^2 = 0.3$.

Uzatish koeffitsiyenti (k_0) 1 teng, unda $20\lg k_0 = 20\lg 1 = 0$

Keyin istalgan LACHX ni quramiz. Statik xatolik kattaligi bo‘yicha ochiq tizimning istalgan koeffitsiyenti va rostlagich koeffitsiyenti: $\Delta_{st}\%=1\%$, $1/(1 + k_p) \leq 0.01$, $k_r \geq 99$. $k_r=100$ tanlaymiz. Bu holatda ochiq tizimning uzatish va rostlagichning koeffitsiyentlari teng. Dinamik tizimlarning xossalariga qo‘yilgan talablar bo‘yicha nomogramma yordamida kesik chastota (ω_s) va turg‘unlik zahirasini (ΔL) aniqlaymiz: $\omega_c = 3\pi/1.5 = 6.28$, $\lg\omega_c = 0.8$, $\Delta L = 16\partial$B .

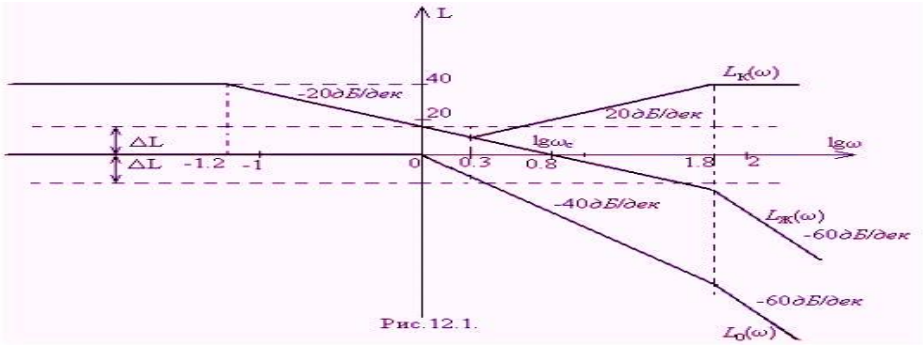
Istalgan LACHX past chastotali (PCH) asimptotasi 0 *dB/dek* qiyalikka ega bo‘lib, $20\lg k_p$ qiymatni aniqlanish darjasi bo‘yicha o‘tadi. O‘rta chastotali (O‘CH) asimptotani –20*dB/dek* qiyalik bilan ω_s orqali o‘tkazamiz. Chapdan O‘CH –asimptotani PCH – asimptota bilan kesishguncha o‘tkazamiz. O‘ngdan PCH asimptotani ΔL_0 orqali ω_1 chastotagacha, shundan keyin asimptota qiyaligi – 60*db/dek* gacha o‘zgaradi. PCH va O‘CH asimptotalar bogliqligi –20*dB/dek* qiyalikka ega bo‘lgan to‘g‘ri chiziq kesmasi yordamida aniqlanadi.

Istalgan LACHX bunday qurilishi rostlagich tartibining kamayishiga imkon beradi. Istalgan LACHX dan korrektirlanmagan tizimning LACHX geometrik ayrib, rostlagichning LACHX ni aniqlaymiz. Olingan xarakteristika orqali noma’lum bog‘langan chastotani aniqlaymiz va rostlagichning uzatish funksiyasini yozamiz: $\lg\omega_3 = -1.2$, $\omega_3 = 0.063$, $T_c = 15.85$,

$$W_{pez}(p) = \frac{100(T_2 p^2 + 2dT_2 p + 1)}{(T_3 p + 1)(T_1 p + 1)}$$

d=0.8 uchun

$$W_{рег}(p) = \frac{100(0.25p^2 + 0.8p + 1)}{(15.85p + 1)(0.017p + 1)}.$$



6.2-rasm. Tizimning logarifmik-chastotaviy xarakteristikasi

Topshiriqlar

Berilgan uzatish funksiyasi va sifat ko‘rsatkichlari (t_p, σ%, Δ % keltirilgan shartlarni qanoatlantirsin) bo‘yicha tizimning asimptotik LACHX ni quring:

6.1-jadval

№	Obyektning uzatish funksiyasi
1.	$w_{yu}(p) = \frac{10}{p(p^2 + p + 1)}$ $t_p \leq 10$s, σ% = 30%, $\Delta^0 \leq 3\%$
2.	$w_{yu}(p) = \frac{20(p + 1)}{2p^3 + 4p^2 + 8p + 6)}$ $t_p \leq 12$s, σ% = 25%, $\Delta^0 \leq 3\%$
	6.1-jadvalning davomi
3.	$w_{yu}(p) = \frac{20(p + 1)}{p(2p^3 + 4p^2 + 8z + 6)}$; $t_p \leq 10$s, σ% = 23%, $\Delta^0 \leq 8\%$

4.	$$w_{yu}(p) = \frac{3(p+1)}{p^3+3p^2+8p+6};$$ $t_p \leq 15$s, σ% = 18%, $\Delta^0 \leq 2\%$
5.	$$w_{yu}(p) = \frac{p^2+5p+1}{p^3+4p^2+2p+1};$$ $t_p \leq 7$s, σ% = 16%, $\Delta^0 \leq 8\%$
6.	$$w_{yu}(p) = \frac{2p^2+3p}{p^3+4p^2+3};$$ $t_p \leq 10$s, σ% = 28%, $\Delta^0 \leq 4\%$
7.	$$w_{yu}(p) = \frac{12p^2+5p}{4p^3+5p^2+3p+3};$$ $t_p \leq 11$s, σ% = 30%, $\Delta^0 \leq 5\%$
8.	$$w_{yu}(p) = \frac{50}{p(p^2+p+4)};$$ $t_p \leq 20$s, σ% = 10%, $\Delta^0 \leq 3\%$
9.	$$w_{yu}(p) = \frac{30(p+1)}{(2p^3+3p^2+8p+6)};$$ $t_p \leq 24$s, σ% = 14%, $\Delta^0 \leq 4\%$
10.	$$w_{yu}(p) = \frac{20(p+1)}{p(2p^3+4p^2+8z+6)};$$ $t_p \leq 25$s, σ% = 30%, $\Delta^0 \leq 9\%$
11.	$$w_{yu}(p) = \frac{(2p+3)}{3p^3+2p^2+3p+6};$$ $t_p \leq 17$s, σ% = 20%, $\Delta^0 \leq 2\%$
	6.1-jadvalning davomi
12.	$$w_{yu}(p) = \frac{5p+1}{3p^3+2p+8};$$ $t_p \leq 10$s, σ% = 30%, $\Delta^0 \leq 7\%$

13.	$$w_{yu}(p) = \frac{7p^2 + 5p + 5}{3p^3 + 4p^2 + 2p + 1};$$ $t_p \leq 10$s, σ% = 10%, $\Delta^0 \leq 5\%$
14.	$$w_{yu}(p) = \frac{5}{p(p^2 + 2p + 5)}$$ $t_p \leq 22$s, σ% = 25%, $\Delta^0 \leq 7\%$
15.	$$w_{yu}(p) = \frac{2p^2 + 3p}{p^3 + 4p^2 + p + 5}$$ $t_p \leq 10$s, σ% = 32%, $\Delta^0 \leq 9\%$
16.	$$w_{yu}(p) = \frac{4p^3 + 3p}{5p^3 + 2p + 8};$$ $t_p \leq 9$s, σ% = 20%, $\Delta^0 \leq 4\%$
17.	$$w_{yu}(p) = \frac{2p}{2p^2 + 5p + 3};$$ $t_p \leq 10$s, σ% = 20%, $\Delta^0 \leq 4\%$
18.	$w_{yu}(p) = \frac{3p}{p(p^2+p+1)}$ $t_p \leq 18$s, σ% = 14%, $\Delta^0 \leq 3\%$
19.	$$w_{yu}(p) = \frac{20(p + 1)}{2p^3 + 8p + 6};$$ $t_p \leq 20$s, σ% = 20%, $\Delta^0 \leq 2\%$
20.	$$w_{yu}(p) = \frac{20(p + 1)}{p(2p^3 + 4p^2 + 8z + 6)}$$ $t_p \leq 19$s, σ% = 22%, $\Delta^0 \leq 3\%$
	6.1-jadvalning davomi
21.	$$w_{yu}(p) = \frac{2p + 3}{2p^3 + 3p^2 + 3p + 5}$$ $t_p \leq 20$s, σ% = 30%, $\Delta^0 \leq 3\%$

22.	$$w_{yu}(p) = \frac{p^3 + 3p)}{p^3 + 4p^2 + 3}$$ $t_p \leq 30$s, σ% = 30%, $\Delta^0 \leq 3\%$
23.	$$w_{yu}(p) = \frac{12p^2 + 5p}{2p^3 + 4p^2 + 5p + 3};$$ $t_p \leq 10$s, σ% = 20%, $\Delta^0 \leq 6\%$
24.	$$w_{yu}(p) = \frac{10(2p + 3)}{(2p^3 + 3p^2 + 2p + 5)};$$ $t_p \leq 17$s, σ% = 27%, $\Delta^0 \leq 7\%$
25.	$$w_{yu}(p) = \frac{10(p + 1)}{p(3p^3 + 4p^2 + 3p + 6)}$$ $t_p \leq 10$s, σ% = 35%, $\Delta^0 \leq 5\%$
26.	$$w_{yu}(p) = \frac{2p^2 + 3p + 3}{p^3 + 4p^2 + 2p + 6};$$ $t_p \leq 30$s, σ% = 20%, $\Delta^0 \leq 5\%$
27.	$$w_{yu}(p) = \frac{2p^2 + 5p}{3p^3 + 5p^2 + p + 5};$$ $t_p \leq 24$s, σ% = 28%, $\Delta^0 \leq 9\%$
28.	$$w_{yu}(p) = \frac{4p^2 + 3p}{5p^3 + 8p + 3}$$ $t_p \leq 19$s, σ% = 29%, $\Delta^0 \leq 7\%$

7- Amaliy mashg‘ulot

Fazoviy fazo usuli

Bu usul umumiy va samarador usul bo‘lib, jarayon haqida yaqqol geometrik tasvirlash imkonini beradi. U jarayonni ya‘ni sistemaning harakatini fazoda tasvirlashga asoslangandir. Bu yerda faza jarayonning ayrim bosqichlari yoki qismlari deb tushuniladi. Umumiy holda nochiziqli sistemaning dinamikasini quyidagicha yozish mumkin:

$$\Phi(x_1, x_2, ..., x_n; \frac{dx_1}{dt}, \frac{dx_2}{dt^2}, ..., \frac{dx_n}{dt^n}; g, f) = 0. \qquad (7.1)$$

Bu tenglamani birinchi tartibli differensial tenglamalar sistemasi shaklida tasvirlab olish mumkin

$$\left.\begin{array}{l} \frac{dx_1}{dt} = \Phi_1(x_1, x_2, ..., x_n, g, f) \\ \frac{dx_2}{dt} = \Phi_2(x_1, x_2, ..., x_n, g, f) \\ \cdots\cdots\cdots\cdots \\ \frac{dx_n}{dt} = \Phi_n(x_1, x_2, ..., x_n, g, f) \end{array}\right\} \qquad (7.2)$$

bu yerda x_1, x_2, ..., x_n – vaqt bo‘yicha o‘zgaruvchi, ya’ni izlanayotgan vaqt funksiyalaridir (x_1 rostlanuvchi kattalik deyishimiz mumkin va x_2, ..., x_n yordamchi o‘zgaruvchilar); g va f – boshqariluvchi (topshiriq beruvchi) va tashqi (qo‘zg‘atuvchi) ta’sirlar.

Tenglamalar sistemasini yechish uchun boshlang‘ich shartlar ma’lum bo‘lishi kerak. Faraz qilaylik, differensial tenglamaning tartibi n=2 ga teng bo‘lsin. $t = t_0$ vaqtda o‘zgaruvchilar ma’lum qiymatlarga ega bo‘lsin: $x_1 = x_1'$, $x_2 = x_2'$. Bu yerda M nuqta *tasvirlovchi nuqta* deyiladi.

Tasvirlovchi nuqta vaqt davomida harakatda bo‘ladi. Qaralayotgan to‘g‘ri burchakli koordinatalar sistemasi *fazalar fazosi* deyiladi. Tasvirlovchi nuqta qoldirgan iz esa *fazalar trayektoriyasi* deyiladi.

Sistemaning harakatini bunday tasvirlaganimizda vaqt o‘zgaruvchisi ishtirok etmaydi. Bu esa fazalar fazosi o‘tkinchi jarayoniningmiqdorini emas, balki sifatinigina aniqlash imkonini beradi. Odatda fazalar fazosi koordinatalar o‘qlariga rostlanuvchi kattalikning qiymati emas, balki uni turg‘un qiymatdan farqi qo‘yiladi. Shuning uchun turli boshlang‘ich qiymatlarda turlicha fazalar trayektoriyasi hosil bo‘ladi.

Ma’lumki, sistemaning turg‘un holatida rostlanuvchi kattalik berilgan qiymatga teng bo‘ladi. Uning hosilasi ham «0»ga teng bo‘ladi. Bu esa koordinata boshi sistemaning turg‘un holatiga mos kelishini ko‘rsatadi. Fazalar trayektoriyasini qurish uchun sistemaning dinamikasini ifodalovchi tenglamadan o‘zgaruvchi vaqt olib tashlanadi, ya’ni

$$\begin{cases} \dfrac{dy}{dt} = x, \\ \dfrac{dx}{dt} = \Phi(x, y). \end{cases} \tag{7.3}$$

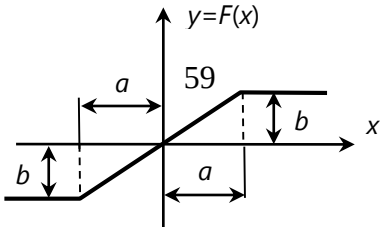
(7.3) tenglamadan quyidagini hosil qilamiz

$$\frac{dx}{dy} = \frac{\Phi(x, y)}{x}. \tag{7.4}$$

Bu tenglama fazalar trayektoriyasining tenglamasi deyiladi.

Shunday qilib, faza fazosi dinamik jarayonlarning geometrik shaklini tasvirlaydi. Bu geometrik tasvirlashda faqat koordinatalar qatnashadi, vaqt esa qatnashmaydi.

7.1-masala. To‘yinish chegaralari 7.1-rasmda keltirilgan statik xarakteristikali nochiziqli element uchun kompleks garmonik uzatish koeffitsiyenti $J(A)$ ni aniqlang:



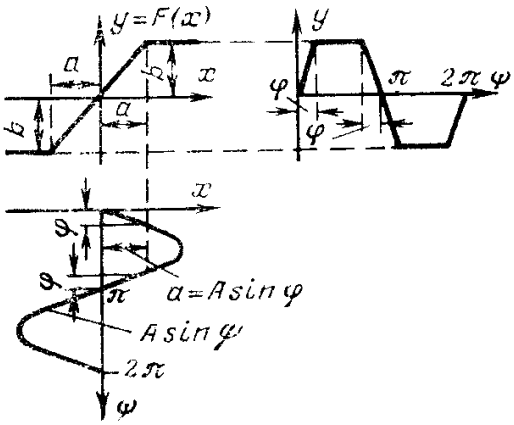
7.1-rasm. Nochiziqli sistemaning statik xarakteristikasi

Yechish.

$A > a$, bo‘lganda $x = A\sin\omega_1 t$ sinusoidal kirish signali uchun chiqishdagi $y = F(x)$ signalning grafigini quramiz (7.2-rasm). Nochiliqlilik bir qiymatli kompleks uzatish koeffitsiyentidan iborat faqat haqiqiy qism

$$J(A) = q(A) = B_1 / A.$$

Furye qatori 7.2-rasmdagi tavsifdan koeffitsiyent uchun formulalardan foydalanib, nochiziqli element chiqishidagi birinchi garmonika sinus tashkil etuvchisidan B_1 amlitudani aniqlaymiz:



a) ***b)***

7.2-rasm. a) nochiziqli sistemaning fazoviy portreti;b) nochiziqli sistemaning garmonik ko‘rinishi

$$B_1 = \frac{1}{\pi}\int_0^{2\pi} F(A\sin\psi)\sin\psi d\psi = \frac{4}{\pi}\left[\int_0^{\varphi} kA\sin^2\psi d\psi + \int_{\varphi}^{\pi/2} b\sin\psi d\psi\right] =$$

$$= \frac{4}{\pi}\left[kA\left(\left|\frac{\psi}{2} - \frac{1}{4}\sin 2\psi\right|_0^{\varphi}\right) - b\left|\cos\psi\right|_{\varphi}^{\pi/2}\right] = \frac{4}{\pi}\left(\frac{kA}{2}\varphi - \frac{kA}{4}\sin 2\varphi + b\cos\varphi\right) \qquad (7.5)$$

bu yerda

$$k = \frac{b}{a};\ \psi = \omega_1 t\ . \qquad (7.6)$$

7.2-rasmni inobatga olgan holda $\sin\varphi = \frac{a}{A};\quad \varphi = \arcsin\left(\frac{a}{A}\right);$

$$\cos\varphi = \sqrt{1 - \frac{a^2}{A^2}}\ . \qquad (7.7)$$

Nochiziqli element parametri a va chiqishdagi signal amplitudasi A ni ikkilamchi sinus burchak deb belgilab olamiz:

$$\sin 2\varphi = 2\sin\varphi\cos\varphi = 2\frac{a}{A}\sqrt{1 - \frac{a^2}{A^2}}\ . \qquad (7.8)$$

(7.2) va (7.4) formulalardan foydalanib, (7.1) tenglikni quyidagicha yozish mumkin:

$$B_1 = \frac{4}{\pi}\left(\frac{kA}{2}\arcsin\frac{a}{A} - \frac{ka}{2}\sqrt{1 - \frac{a^2}{A^2}} + ka\sqrt{1 - \frac{a^2}{A^2}}\right) = \frac{2k}{\pi}\left(A\arcsin\frac{a}{A} + a\sqrt{1 - \frac{a^2}{A^2}}\right)$$

Nochiziqli elementning kompleks garmonik uzatish koeffitsiyenti quyidagicha:

$$J(A) = \frac{B_1}{A} = \frac{2k}{\pi}\left(\arcsin\frac{a}{A} + \frac{a}{A}\sqrt{1 - \frac{a^2}{A^2}}\right).$$

7.2-masala. Garmonik tebranishi $x = A\sin\omega t$ qonuniyat bo‘yicha o‘zgaruvchi nuqta uchun fazoviy portretni quring.

Yechish*:* Fazoviy portretni qurish uchun x koordinatalaridan hosilani aniqlaymiz

$$\frac{dx}{dt} = A\omega\cos\omega t\,. \qquad (7.9)$$

Fazoviy trayektoriya tenglamasini olish uchun x va $\frac{dx}{dt}$ tenglamadan t vaqtni olib tashlaymiz. $\frac{dx}{dt}$ ni y bilan beligilab, (2.1) tenglamani kvadratga oshiramiz

$$y^2 = A^2\omega^2\cos^2\omega t\,. \qquad (7.9)$$

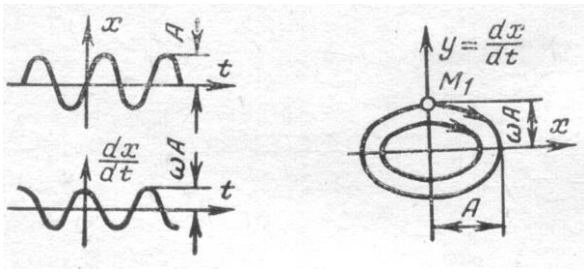
Xuddi shunaqa x tenglamani kvadratga oshirib, ω^2 ga ko‘paytiramiz

$$\omega^2 x^2 = A^2\omega^2\sin^2\omega t\,. \qquad (7.10)$$

(2.2) va (2.3) tenglamaning o‘ng va chap tomonlarini qo‘shib, quyidagiga ega bo‘lamiz:

$$y^2 + \omega^2 x^2 = A^2\omega^2 \quad \text{yoki} \quad \frac{x^2}{A^2} + \frac{y^2}{A^2\omega^2} = 1\,. \qquad (7.11)$$

(7.11) tenglama fazoviy trayektoriyani aks ettiruvchi tenglama hisoblanadi. 7.3-rasmda vaqt funksiyasida x koordinatalar o‘zgarishini aks ettiruvchi nuqtalar va $y = \frac{dx}{dt}$ tezlik hamda fazoviy portret keltirilgan. Fazoviy portret o‘zida ellipislar oilasini aks ettiradi.



7.3-rasm. a) tizimning vaqt xarakteristikasi;

b) tizimning fazoviy portreti

Topshiriqlar

Berilgan matematik modeldan foydalanib, tizimning fazoviy portretini quring.

7.1-jadval

№	Obyektning matematik modeli
1.	$\begin{cases} \dot{x}_1 = 2x_1 - x_2, \\ \dot{x}_2 = -4x_1 + x_2. \end{cases}$
2.	$\begin{cases} \dot{x}_1 = 3x_1 - x_2, \\ \dot{x}_2 = -3x_1 + x_2. \end{cases}$
3.	$\begin{cases} \dot{x}_1 = 2x_1 - x_2, \\ \dot{x}_2 = -x_1 + x_2. \end{cases}$
4.	$\begin{cases} \dot{x}_1 = 2x_2, \\ \dot{x}_2 = -2x_1^2 - 1{,}5x_2. \end{cases}$
5.	$\begin{cases} \dot{x}_1 = 5x_2, \\ \dot{x}_2 = -x_1^2 - 2x_2. \end{cases}$
6.	$\begin{cases} \dot{x}_1 = 7x_1 - 2x_2, \\ \dot{x}_2 = -3x_1 + x_2. \end{cases}$
7.	$\begin{cases} \dot{x}_1 = 2x_1 - x_2, \\ \dot{x}_2 = -5x_1 + 2x_2. \end{cases}$
8.	$\begin{cases} \dot{x}_1 = 8x_1 - 7x_2, \\ \dot{x}_2 = -2x_1 + x_2. \end{cases}$
9.	$\begin{cases} \dot{x}_1 = 4x_2, \\ \dot{x}_2 = -2x_1^2 - 0{,}75x_2. \end{cases}$
10.	$\begin{cases} \dot{x}_1 = 2x_1 - x_2, \\ \dot{x}_2 = -7x_1 + x_2. \end{cases}$
11.	$\begin{cases} \dot{x}_1 = 6x_2, \\ \dot{x}_2 = -x_1^2 - 0{,}15x_2. \end{cases}$
12.	$\begin{cases} \dot{x}_1 = 4x_1 - 2x_2, \\ \dot{x}_2 = -3x_1 + 2x_2. \end{cases}$

	7.1-jadvalning davomi
13.	$\begin{cases} \dot{x}_1 = 5x_1 - 3x_2, \\ \dot{x}_2 = -3x_1 + x_2. \end{cases}$
14.	$\begin{cases} \dot{x}_1 = 3x_2, \\ \dot{x}_2 = -x_1^2 - 1{,}5x_2. \end{cases}$
15.	$\begin{cases} \dot{x}_1 = 2x_1 - x_2, \\ \dot{x}_2 = -5x_1 + x_2. \end{cases}$
16.	$\begin{cases} \dot{x}_1 = 3x_1 - 2x_2, \\ \dot{x}_2 = -6x_1 + 2x_2. \end{cases}$
17.	$\begin{cases} \dot{x}_1 = 4x_2, \\ \dot{x}_2 = -2x_1^2 - 0{,}5x_2. \end{cases}$
18.	$\begin{cases} \dot{x}_1 = 2x_1 - x_2, \\ \dot{x}_2 = -6x_1 + 3x_2. \end{cases}$
19.	$\begin{cases} \dot{x}_1 = 6x_1 - 5x_2, \\ \dot{x}_2 = -4x_1 + x_2. \end{cases}$
20.	$\begin{cases} \dot{x}_1 = 8x_2, \\ \dot{x}_2 = -2x_1^2 - x_2. \end{cases}$
21.	$\begin{cases} \dot{x}_1 = 8x_1 - 7x_2, \\ \dot{x}_2 = -5x_1 + x_2. \end{cases}$
22.	$\begin{cases} \dot{x}_1 = 3x_2, \\ \dot{x}_2 = -2x_1^2 - 2{,}5x_2. \end{cases}$
23.	$\begin{cases} \dot{x}_1 = 3x_1 - x_2, \\ \dot{x}_2 = -5x_1 + x_2. \end{cases}$
24.	$\begin{cases} \dot{x}_1 = 3x_1 - 2x_2, \\ \dot{x}_2 = -4x_1 + 2x_2. \end{cases}$
25.	$\begin{cases} \dot{x}_1 = 8x_1 - 7x_2, \\ \dot{x}_2 = -2x_1 + x_2. \end{cases}$
26.	$\begin{cases} \dot{x}_1 = 3x_2, \\ \dot{x}_2 = -5x_1^2 - x_2. \end{cases}$

8 - Amaliy mashg‘ulot

V.M.Popovning mutloq turg‘unlik mezoni asosida nochiziqli sistemalar turg‘unligini hisoblash

Nochiziqli sistemaning turg‘unligini aniqlash uchun shunday chekli haqiqiy son *h* – ni tanlab olish kerakki, unda hamma *ω>0* bo‘lganda quyidagi tengsizlik bajarilsin:

$$\mathrm{Re}(1+j\omega h)W(j\omega)+\frac{1}{k}>0, \qquad (8.3)$$

bu yerda $W(j\omega)$ – chiziqli sistemaning AFX si.

Teoremaning boshqacha ta’rifidan qulay geometrik izohlanadigan chastota xarakteristikasining ko‘rinishini o‘zgartirish bilan bog‘liq.

O‘zgaruvchan ko‘rinishli chastotaviy xarakteristika $W^*(j\omega)$ quyidagicha aniqlanadi:

$$\left.\begin{aligned} U^*(\omega)&=\mathrm{Re}\,W^*(j\omega)=\mathrm{Re}\,W(j\omega),\\ V^*(\omega)&=\mathrm{Im}\,W^*(j\omega)=\omega T_0\ \mathrm{Im}\,W(j\omega),\end{aligned}\right\} \qquad (8.4)$$

$T_0 = 1$ sek normalovchi ko‘paytiruvchi.

(8.3) tengsizlikning chap qismini quyidagicha o‘zgartiramiz:

$$\mathrm{Re}(1+j\omega h)\,W(j\omega)+\frac{1}{k}=\mathrm{Re}\,W(j\omega)-\omega h\,\mathrm{Im}W(j\omega)+\frac{1}{k}>0 \qquad (8.5)$$

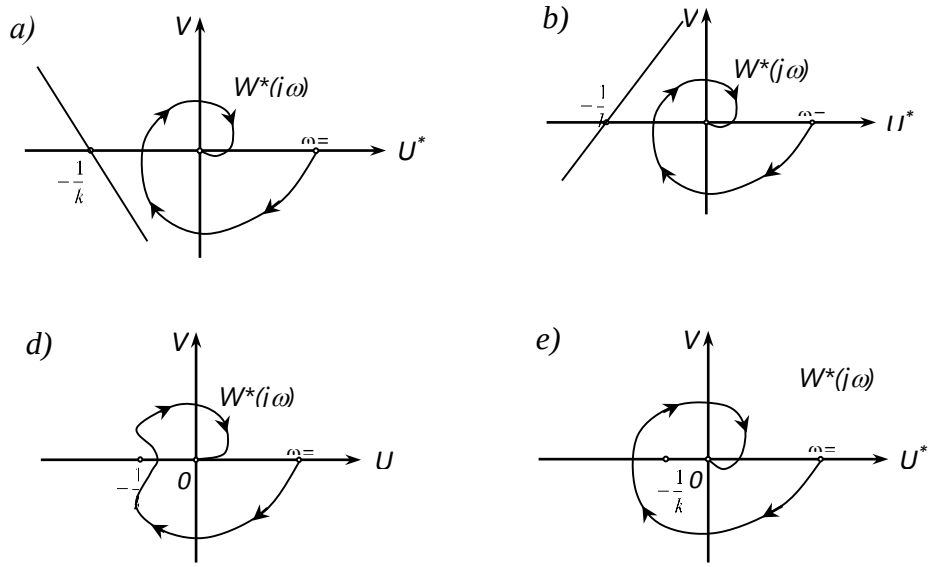
Unda, $W^*(j\omega)=U^*(\omega)+jV^*(\omega)$ va (8.4) chi munosabatlardan foydalanib, (8.5) tengsizikni barcha $\omega\geq 0$ da o‘zgartiramiz:

$$U^*(\omega)-\frac{1}{T_0}V^*(\omega)+\frac{1}{k}=U^*(\omega)-h_0V^*(\omega)+\frac{1}{k}>0 \qquad (8.6)$$

$U^*(\omega)-h_0V^*(\omega)+\frac{1}{k}>0$ bo‘lganda $W^*(j\omega)$ tekisligida to‘g‘ri chiziqni ifodalaydi.

V.M.Popov teoremasining geometrik izohi: *nochiziqli sistemaning turg‘unligini aniqlash uchun* $W^*(j\omega)$ *tekisligida shunday to‘g‘ri chiziqni*

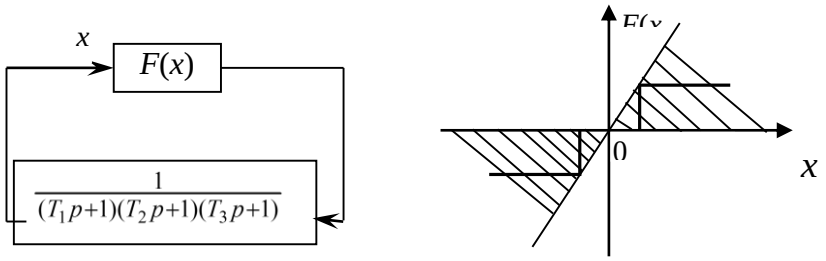
tanlab olish kerakki, u $\left(-\frac{1}{k}, j0\right)$ *nuqtasidan o'tganda* $W^*(j\omega)$ *egri chizig'i bu chiziqning o'ng tomonida yotsin.*



8.2-rasm. a) va b) mutloq turg'un sistema;

v) va g) noturg'un sistema

8.1-masala. Nochiziqli avtomatik sistemaning struktura sxemasi 8.3-rasmda keltirilgan.



a) ***b)***

8.3-rasm. a) nochiziqli zvenoning statistik xarakteristikasi; b) nochiziqli zvenoning turg'unlik holati

Sistemaning chiziqli qismini va nochiziqli zvenoning uzatish koeffitsiyenti $k = k_ч k_н$ shartli ravishda nochiziqli zvenoga kiritilgan. Agar

nochiziqli zveno xarakteristikasi $(0,k)$ sektorda joylashgan bo‘lsa, k-ning qanday qiymatlarida sistema mutloq turg‘un bo‘lishini aniqlang.

Boshlang‘ich ma’lumotlar: sistema chiziqli qismining doimiy vaqtlari T_1=0,5 sek, T_2=0,2 sek T_3=0,1 sek.

Yechish: Sistema chiziqli qismining chastotali uzatish funksiyasini quyidagi ko‘rinishga ega:

$$W(j\omega)=\frac{1}{(1+j\omega T_1)(1+j\omega T_2)(1+j\omega T_3)}. \qquad (8.1)$$

Uning haqiqiy va mavhum qismlari mos ravishda quyidagiga teng:

$$U(\omega)=\mathrm{Re}W(j\omega)=\frac{1-\omega^2(T_1T_2+T_1T_3+T_2T_3)}{(1+\omega^2T_1^2)(1+\omega^2T_2^2)(1+\omega^2T_3^2)} \qquad ,(8.2)$$

$$V(\omega)=\mathrm{Im}W(j\omega)=\frac{-\omega(T_1+T_2+T_3)+\omega^3T_1T_2T_3}{(1+\omega^2T_1^2)(1+\omega^2T_2^2)(1+\omega^2T_3^2)} \qquad (8.3)$$

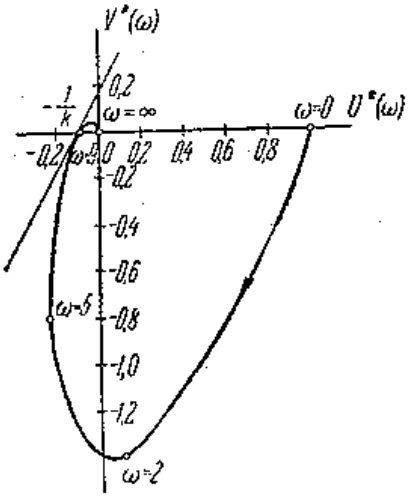
$U^*(j\omega)$ va $V^*(j\omega)$ ga ba’zi funksiyalar kiritamiz:

$$U^*(\omega)=\mathrm{Re}W(j\omega)=\frac{1-\omega^2(T_1T_2+T_1T_3+T_2T_3)}{(1+\omega^2T_1^2)(1+\omega^2T_2^2)(1+\omega^2T_3^2)}, \qquad (8.4)$$

$$V^*(\omega)=\omega\,\mathrm{Im}W(j\omega)=\frac{-\omega^2(T_1+T_2+T_3)+(\omega^4T_1T_2T_3)}{(1+\omega^2T_1^2)(1+\omega^2T_2^2)(1+\omega^2T_3^2)} \qquad .(8.5)$$

(8.4) va (8.5) tengliklar bo‘yicha $V^*(\omega)=f[U^*(\omega)]$ xarakteristikani quramiz (8.4-rasm) va $\left(-\frac{1}{k},\ j0\right)$ bo‘yicha Popov to‘g‘ri chizig‘ini shunday o‘tkazamizki, bunda qurilgan xarakteristika bu chiziqdan o‘ng tomonda yotsin. 8.4-rasmga binoan $\frac{1}{k}\approx 0{,}08$. Shuning uchun sistema $0<k<12{,}5$ sektorda yotuvchi hamma nochiziqli xarakteristikalar uchun mutloq turg‘undir, shu jumladan 8.4- rasmda ko‘rsatilgan rele tipli xarakteristika ham turg‘un.

Shunday qilib, berk nochiziqli sitemaning mutloq turg‘unligining yetarli sharti ochiq holda *k* uzatish koeffitsiyentiga ega bo‘lgan tutash chiziqli sistemaning zaruriy va yetarli sharti bajarilishiga keltirilyapti.



8.4-rasm. Berk nochiziqli sistemaning mutloq turg‘unligi

Topshiriqlar

Quyidagi jadvalda sistema chiziqli qismining chastotali uzatish funksiyasni keltirilgan:

8.1-jadval

№	Obyektning uzatish funksiyasi
1.	$w_{yu}(p) = \dfrac{10}{p+1}$
2.	$w_{yu}(p) = \dfrac{2}{8p+6}$
3.	$w_{yu}(p) = \dfrac{12}{p+8}$;
4.	$w_{yu}(p) = \dfrac{15}{p+5}$;

8.1-jadvalning davomi	
5.	$w_{yu}(p) = \frac{9}{2p+1};$
6.	$w_{yu}(p) = \frac{5}{4p+3};$
7.	$w_{yu}(p) = \frac{3}{5p+3};$
8.	$w_{yu}(p) = \frac{10}{p+4)};$
9.	$w_{yu}(p) = \frac{3}{7p+6};$
10.	$w_{yu}(p) = \frac{10}{p+8};$
11.	$w_{yu}(p) = \frac{4}{3p+6};$
12.	$w_{yu}(p) = \frac{6}{2p+8};$
13.	$w_{yu}(p) = \frac{7}{2p+1};$
14.	$w_{yu}(p) = \frac{5}{p+9}$
15.	$w_{yu}(p) = \frac{5}{2p+5}$
16.	$w_{yu}(p) = \frac{4}{2p+8};$
17.	$w_{yu}(p) = \frac{10}{5p+3};$
18.	$w_{yu}(p) = \frac{3}{p+8}$
19.	$w_{yu}(p) = \frac{8}{8p+6};$
20.	$w_{yu}(p) = \frac{12}{p+9}$

21.	$w_{yu}(p) = \frac{9}{3p+5}$
22.	$w_{yu}(p) = \frac{7}{p+3}$
23.	$w_{yu}(p) = \frac{12}{p+3};$
	8.1-jadvalning davomi
24.	$w_{yu}(p) = \frac{10}{p+4};$
25.	$w_{yu}(p) = \frac{5}{4p+6}$
26.	$w_{yu}(p) = \frac{2}{2p+6};$
27.	$w_{yu}(p) = \frac{3}{6p+5};$
28.	$w_{yu}(p) = \frac{4}{8p+3}$

9 -Amaliy mashg‘ulot

Garmonik balans usulida nochiziqli avtomatik boshqarish sistemalarni tahlil qilish

Bu usul dinamikasi ikki va undan yuqori tartibli nochiziqli differensial tenglama bilan yoziluvchi sistemalarni tekshirish, nochiziqli sistemalarning majburiy harakatini taqriban tahlil qilish, sistemasining turg‘unligini mavjud bo‘ladigan avtotebranishlar parametrlarini aniqlash imkonini beradi.

Avtotebranishni aniqlashning 2 usuli mavjud:

1.Analitik usul.

2.Chastotoviy usul (Goldfarb usuli).

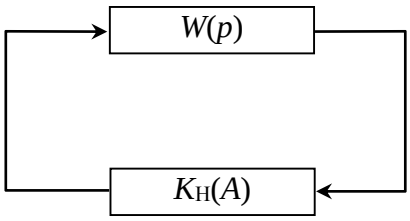
1. Analitik usul. Ushbu usuldan foydalanishda sistemaning strukturasi quyidagi ko‘rinishga keltirib olinadi (9.1-rasm).

Bunda chiziqli qismning ko‘rinishi quyidagiga ega

$$W(p)=\frac{A(p)}{B(p)}.$$

Berk sistemaning uzatish funksiyasi topiladi

$$W_A(p)=\frac{W(p)}{1+W(p)\cdot K_H(A)}.$$



9.1-rasm. Berk sistemaning strukturali sxemasi

Berk sistemaning xarakteristik tenglamasini nolga tenglaymiz

$$1+W(p)\cdot K_H(A)=0,$$
$$1+\frac{A(p)}{B(p)}\left[q(A)+\int q'(A)\right]=0,$$
$$B(p)+A(p)\left[q(A)+\int q'(A)\right]=0.$$

$p\to j\omega$ bilan almashtirib xarakteristik tenglamaning haqiqiy va mavhum qismlar topiladi. Haqiqiy va mavhum qismlar amplituda A va chastota ω ga bog‘liq munosabat ko‘rinishda bo‘ladi, ya’ni

$$X(A,\omega)+jY(A,\omega)=0.$$

Ularni nolga tenglab, tenglamalar sistemasining hosil qilamiz

$$\begin{cases} X(A,\omega)=0, \\ Y(A,\omega)=0. \end{cases}$$

Agarda tenglamalar sistemasini yechimi haqiqiy va musbat qiymatga ega bo‘lsa, sistemada avtotebranish mavjud bo‘ladi.

2. Goldfrarb usuli.

Bu usul uncha murakkab bo‘lmagan sistemalar uchun qo‘llanilib, chiziqli qism filtrlil xususiyatiga ega bo‘lishi kerak. Bunda sistema ikki qismga ajratib olinadi: chiziqli va nochiziqli.

Avtotebranishni topish algoritmi quyidagidan iborat:

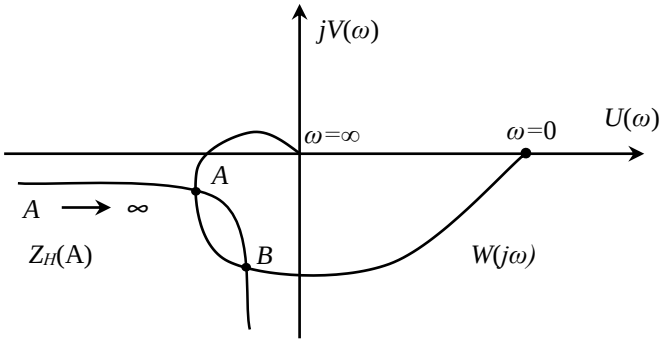
1. Chiziqli qismning AFXsi quriladi.

2. Nochiziqli elementning teskari uzatish funksiyasi topiladi:

$$Z_H(A) = -\frac{1}{K_H(A)} = -\frac{1}{q(A) + jq'(A)}.$$

Amplitudani 0 dan ∞ gacha o‘zgartirib, nochiziqli elementning teskari AFXsi quriladi.

2.Popov mezoni: Agarda ikkala AFX o‘zaro kesishsa sistemada o‘zaro avtotebranish mavjuddir.

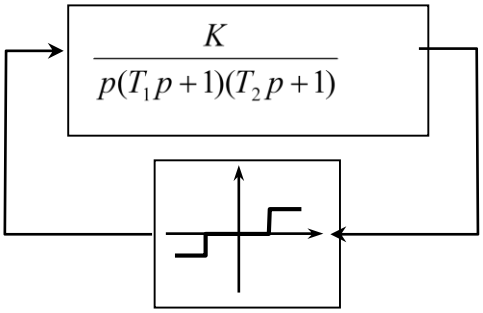


9.2-rasm. Sistemani avtotebranish grafigi

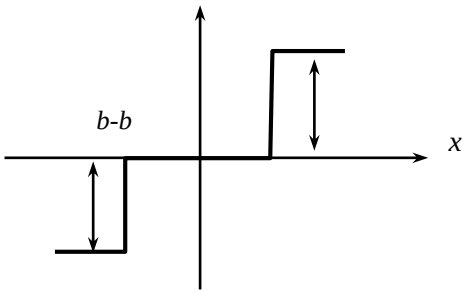
Agarda amplituda 0 dan ∞ ga o‘zgarganda nochiziqli elementning AFXsi chiziqli qismning AFXsining konturiga kirsa shu nuqtada noturg‘un avtotebranish mavjud. Konturdan chiqadigan nuqtada turg‘un avtotebranish mavjud.

9.1-misol. Agar chiziqli qism parametrlari k=0,82 sek^{-1}, T_1=T_2=0,05 sek va nochiziqli zveno (b=0,25, c=110) statistik xarakteristikasi 9.3-

rasmdagi kabi bo‘lsa, 9.4-rasmda keltirilgan struktur sxemali nochiziqli sistemaning turg‘unligini tadqiq qiling.



9.3-rasm. Nochiziq sistemaning strukturali sxemasi



9.4-rasm. Nochiziq sistemaning statik xarakteristikasi

Yechish: Sistemaning chiziqli qism $W_ч(j\omega)$ amplituda-faza chastotaviy xarakteristikasi va garmonik chiziqlantirilgan nochiziqli zveno $-Z(a) = -\frac{1}{W_н(a)}$ ning gadografni quramiz.

Strukturali sxemaga asosan sistemaning chiziqli qism chastotaviy uzatish funksiyasi

$$W_ч(j\omega) = \frac{k}{j\omega(1+T_1 j\omega)(1+T_2 j\omega)},$$

uning moduli

$$|W_ч(j\omega)| = \frac{k}{\omega\sqrt{(1+T_1^2\omega^2)(1+T_2^2\omega)}}$$

va fazasi

$$\varphi(\omega) = -90^\circ - arctg\,\omega T_1 - arctg\,\omega T_2$$

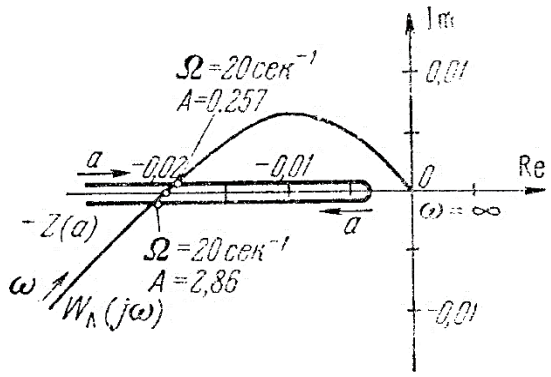
ni yozishimiz mumkin.

Son qiymatlarini quyib, quyidagiga ega bo‘lamiz:

$$|W_ч(j\omega)| = \frac{0{,}82}{\omega\sqrt{(1+0{,}00025\omega^2)}}, \qquad (9.1)$$

$$\varphi(\omega) = -90^\circ - 2arctg\,0{,}05\omega. \qquad (9.2)$$

$0 \le \omega \le \infty$ o‘zgartirib, sistemaning chiziqli qism AFXsi $W_ч(j\omega)$ quramiz (9.5-rasm).



9.5-rasm. Sistemaning chiziqli qism amplituda-faza xarakteristikasi

Nochiziqli zvenoning garmonik chiziqlantirilgan uzatish funksiyasi quyidagicha:

$$W_н(a) = q(a) = \frac{4c}{\pi a}\sqrt{1-\frac{b^2}{a^2}}, \quad a \ge b.$$

Bundan

$$-Z(a) = -\frac{1}{W_н(a)} = -\frac{\pi a^2}{4c}\frac{1}{\sqrt{a^2-b^2}}.$$

Nochiziqli zvenoning son qiymatlarini qo‘ygandan so‘ng quyidagiga ega bo‘lamiz:

$$-Z(a) = -\frac{\pi a^2}{440}\frac{1}{\sqrt{a^2-0{,}0625}}. \qquad (9.3)$$

a ning qiymatini $a = b = 0{,}25$ dan ∞ gacha o‘zgartirib, nochiziqli zveno $-Z(a)$ ning godografini quramiz (1.3-rasm). Ushbu holda bu godograf musbat haqiqiy yarim o‘q bilan ustma-ust tushadi va ikki o‘ramli bo‘ladi. $-Z(a)$ funksiya modulining minimal qiymati $a = b\sqrt{2} \approx 0{,}352$ ga teng bo‘lganda

$$|Z(a)|_{\min} = \frac{\pi b}{2c} = \frac{\pi \cdot 0.25}{2 \cdot 110} \approx 0{,}0036$$

ga erishadi.

$W_ч(jw)$ va $-Z(a)$ larning godograflari ikki nuqtada kesishadi.

$$W_ч(j\omega) = -\frac{1}{W_н(a)} = -Z(a)$$

Bu tenglama 1.3-rasmga asosan $\Omega = 20\ сек^{-1}$, $A_1 = 0{,}257$, $A_2 = 2{,}86$ ikkita davriy yechim

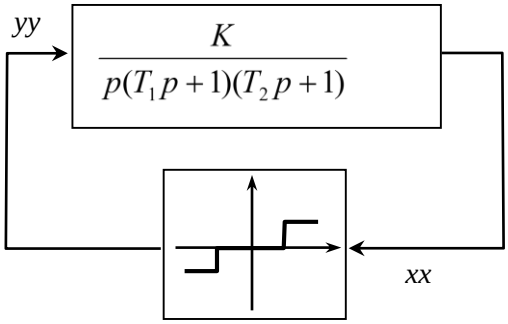
$$\left.\begin{aligned} x &= A_1 \sin \Omega t \\ x &= A_2 \sin \Omega t \end{aligned}\right\} \qquad (9.4)$$

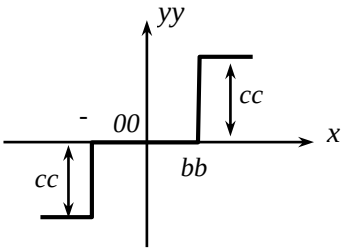
ga ega bo‘ladi.

Davriy yechim turg‘un bo‘lishi uchun sistemaning chiziqli qism $W_ч(j\omega)$ AFX si kichik amplitudaga mos keluvchi $-Z(a)$ godograf qismini o‘rab oldi. Shuning uchun, (4) tenglamaning birinchi yechimi noturg‘un hisoblanadi, ikkinchi yechimi esa turg‘undir. Shunday qilib, sistemada amplitudasi $A = 2{,}86$ va chastotasi $\Omega = 20\ сек^{-1}$, $x = 2{,}86 \sin 20t$ bo‘lgan avtotebranish hosil bo‘ldi.

Topshiriqlar

Agar chiziqli qism parametrlari k=0,82 sek^{-1}, T_1=T_2=0,05 sek va nochiziqli zveno (b=0,25, c=110) statistik xarakteristikasi 9.2-rasmdagi kabi bo‘lsa, 1-rasmda keltirilgan struktura sxemali nochiziqli sistemaning turg‘unligini tadqiq qiling.





9.7-rasm. Nochiziq sistemaning
struktura sxemasi

9.1-jadval.

№	**Chiziqli qism parametrlari**		
	k, sekund	**T_1**, sekund	**T_2**, sekund
1.	0.8	0.3	0.4
2.	0.2	0.3	0.5
3.	1	0.5	0.5
4.	0.3	0.2	0.3
5.	0.56	0.3	1
6.	0.6	0.5	0.5
7.	0.1	0.2	1.2
8.	0.8	1.02	0.65
9.	1	0.45	0.32
10	0.3	0.32	0.45

			9.1-jadvalning davomi
11	0.45	0.3	0.4
12	0.6	0.5	0.7
13	0.8	0.89	0.98
14	0.23	0.2	0.5
15	0.9	0.45	0.2
16	0.56	0.6	0.2
17	0.1	0.58	0.3
18	0.3	0.98	0.1
19	0.45	1	0.15
20	0.18	0.16	1
21	1	0.97	1.02
22	0.2	1.03	0.5
23	0.9	0.58	0.8
24	0.45	0.9	0.8
25	0.1	0.47	0.75
26	0.25	0.26	0.62
27	0.32	0.31	0.34
28	0.64	0.25	0.15
29	0.9	0.6	0.78
30	0.87	0.46	1.02
Nochiziqli zvenoning statistik xarakteristikasi			
b	***c***	***b***	***c***
0.25	110	1.6	102
0.2	100	0.87	98

			9.1-jadvalning davomi
0.3	110	1.08	100
0.1	90	1.02	110
0.5	120	0.96	99
0.6	95	0.5	105
0.25	110	0.6	106
0.37	100	0.32	110
0.42	98	0.15	98
0.58	102	0.28	100
0.9	105	0.45	103
1	100	1.4	105
1.2	103	1.6	102

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MUNDARIJA

Kirish…… 3

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fanidan amaliy mashg‘ulotlar bajarish uchun

USLUBIY KO‘RSATMALAR

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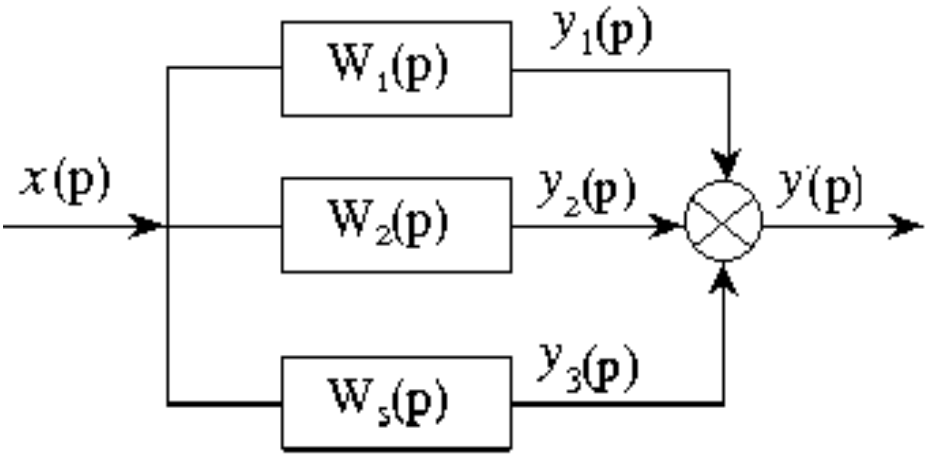

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