11 – ma’ruza

Mavzu: Markazdan qochma tebrangichli mashina agregati

Ma’ruza rejasi:

11.1. Markazdan qochma vibratorli mashina agregatining ishlashi haqida
11.2. Cheklangan quvvatli yurituvchili vibratorlni harakat tenglamasi
11.3. Harakatning statsionar rejimini tadqiqoti
11.4. Rezonansdan o’tish rejimi
11.5. O’z- o’zini tekshirish savollari

Adabiyotlar:

1. В.А. Зиновьев, А.П. Бессонов. Основы динамики машинных агрегатов. Машиностроение, Москва, 1964, с. 104-110.
2. А. Джураев. Моделирование динамики машинных агрегатов хлопкоперерабатывающих машин. Фан, Ташкент, 1984, с. 112- 118.
3. А. Джураев. Динамика рабочих механизмов хлопкоперерабатывающих машин. Фан, Ташкент, 1987, с. 109-118.
4. Н. И. Левитский. «Теория механизмов и машин», Наука, М., 1979, стр. 285-297.

11.1. Markazdan qochma vibratorli mashina agregatining ishlashi haqida

Yurituvchida ishchi mashina valiga aylanma harakatni uzatuvchi tishli mexanizm dinamikasini ko’rilganda yurituvchi rotorining burchak tezligini o’zgarmas deb qabul qilish mumkin edi. Bu tasdiq shunday holarda haqli ediki, qachonki yurituvchi amalda cheklanmagan quvvatga ega bo’lgandagina, shuning uchun mexanizm bo’g’inlariga ta’sir qiluvchi kuchlarni o’zgarishi yurituvchi rotorining barqaror tezligiga ta’sir qilmas edi. Yurituvchining quvvati cheklanganda uning xarakteristikasi nazarga olinishi kerak. Ayniqsa, bu ta’sir rezonansga yaqin harakat rejimida yaqqol namoyon bo’lishi mumkin. Bunday rejimlar vibrator mexanizmga, ya’ni yo’naltirilgan tebranishni yaratuvchi qurilmalarga xarkaterlidir.

11.1 – rasmda oddiy, markazdan qochma vibratorlarni sxemasi ko’rsatil;gan. U m_2 massali bo’g’in, c bikrlik koeffitsiyenrli va m_1 muvozanatlanmagan massali, $J_д$ inersiya momently yurituvchi bilan aylantiriluvchi qayishqoq bog’lanishdan iborat. Massali bo’g’inni x o’qi yo’nalishda tebranishini inersiya kuchini x o’qi bo’ylab yo’nalgan garmonik qonunda o’zgaradigan tashkil qiluvchisi majbur qilgan *tebranish* deb ko’rish mumkin. Shunga mos markazdan qochma vibratorli mexanizm ***inersionli qo’zg’atuvchi tebranuvchi Sistema*** deyiladi.

11.2. Cheklangan quvvatli yurituvchili vibratorlni harakat tenglamasi

Harakat tenglamasini tuzishda m_1 massaning harakati gorizontal tekislikda bo’ladi, “polzun-tayanch” juftligi $F_t=\beta x$ ifoda bilan aniqlanadi deb qabul qilamiz.

Mexanizmning kinetic energiyasi quyidagicha:

$$T=\frac{1}{2}\left(\mathrm{m}_2\dot{\mathrm{x}}^2+J_Д\dot{\varphi}^2+m_1V_A^2\right)$$

bu yerda, $\mathrm{v}_\mathrm{A}^2=\dot{\mathrm{x}}^2+\mathrm{r}^2\dot{\varphi}^2-2\dot{x}r\dot{\varphi}\ \sin\ \varphi$

$m= m_1+ m_2$, $J= J_д$ belgilarini kiritamiz. Harakat tenglamani Lagranjning ikkinchi darajali tenglamasidan (11.1 va 11.2) ni nazarga olib quyidagicha aniqlaymiz:

$$T=\frac{1}{2}\mathrm{m}\dot{\mathrm{x}}^2+\frac{1}{2}\ \mathrm{J}\dot{\varphi}^2\ \text{-}\ \mathrm{m}_1\ \dot{\mathrm{x}}\mathrm{r}\dot{\varphi}\sin\varphi \qquad (11.1)$$

Mexanizmning potensial energiyasi:

$$П=\frac{1}{2}\ cx^2. \qquad (11.2)$$

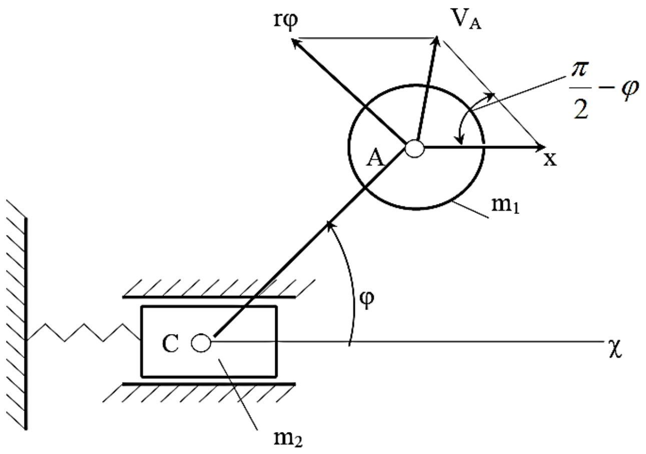
Yurituvchining xarakteristikasini quyidagicha berilgan deb hisoblaymiz:

$$М_Д=М_Д(\dot{\varphi})$$

Harakat tenglamasini Lagranjning ikkinchi darajali tenglamasidan (11.1 va 11.2) ifodalarni nazarga olib quyidagicha aniqlaymiz:

$$\mathrm{m}\ddot{\mathrm{x}}\ \text{-}\ \mathrm{m}_1r\ddot{\varphi}\ \sin\varphi-m_1r\dot{\varphi}^2\cos\varphi=-cx-\beta\dot{x},$$

$$\mathrm{J}\ddot{\varphi}-m_1r\ddot{x}\sin\varphi=\widetilde{M}_Д(\dot{\varphi}). \qquad (11.3)$$



11.1 – rasm. Markazdan qochma vibratorni hisoblash sxemasi

Ikki massali dinamik modelni cheksiz quvvaatli yurituvchi uchun tuzilgan tenglamasidan farqli, (11.3) tenglama birgalikda yechilishi lozim.

(11.3) harakat tenglamani quyidagicha yozish ham mumkin:

$$\ddot{x}+k^2x=a\ddot{\varphi}\sin\varphi+a\dot{\varphi}^2\cos\varphi-h\dot{x}$$

$$\ddot{\varphi}=L(\dot{\varphi})+b\ddot{x}\sin\varphi,$$

$k^2=c/m$, $h=\varphi/m$, $a = m_1r/m$, $b=m_1r/J$, $L(\dot{\varphi})=\widetilde{M}_Д(\dot{\varphi})/J$.

Harakat tenglamasini sekin o'zgaruvchi paramaetrlar metodi bo'yicha standart shaklga keltiriladi. (11.3) dan kelib chiqib *a, b* koeffitsiyentlarning kichik qiymatida va asta sekin o'zgaruvchi $L(\dot{\varphi})$ da *x* siljish garmonik qonunda o'zgaradi, φ tezlanish esa kichik qiymatga ega deb taxminan hisoblash mumkin.

Bunda *x* o'zgaruvchanni izlanadigan yechimini quyidagicha shaklda izlaymiz :

$$X=A\cos(\varphi+\xi), \qquad (11.5)$$

bu yerda, A va ξ - sekin o'zgaruvchi parametrlar quyidagi nisbaat bilan bog'langan

$$\dot{x}=-Ak\sin(\varphi+\xi). \qquad (11.6)$$

Yurituvchi valining aylanish burchagi tezligini $\widetilde{\omega}=d\varphi/dt$ deb belgilaymiz. Yangi o'zgaruvchilar A, ξ va $\widetilde{\omega}$ sekin o'zgaruvchi kattaliklar bo'ladi.

$\dot{X}$ hosila (11.5) ifodani differensiallash orqali topilishi mumkin:

$$\dot{\mathrm{x}} = \dot{\mathrm{A}}\cos(\varphi+\xi) - (\tilde{\omega}+\dot{\xi})\mathrm{A}\sin(\varphi+\xi). \tag{11.7}$$

(11.6) va (11.7) o’ng qismlarini tenglashtirib quyidagi olamiz :

$$\dot{\mathrm{A}}\cos(\varphi+\xi) - \dot{\xi}\mathrm{A}\sin(\varphi+\xi) = (\tilde{\omega}-k)\mathrm{A}\sin(\varphi+\xi) \;. \tag{11.8}$$

(11.8) differensiallaymiz:

$$\ddot{\mathrm{x}} = -\dot{A}k\sin(\varphi+\xi) - (\tilde{\omega}+\xi)Ak\cos(\varphi+\xi). \tag{11.9}$$

(11.4) harakat tenglamalr sistemasi (11.5), (11.6) va (11.9) ni nazarga olganda quyidagi ko’rinishda bo’ladi:

$$\begin{gathered}-\dot{A}k\sin(\varphi+\xi) - \dot{\xi}Ak\cos(\varphi+\xi) + Ak(k-\tilde{\omega})\cos(\varphi+\xi) = \\ a\dot{\tilde{\omega}}\sin\varphi + a\tilde{\omega}^2\cos\varphi + Akh\sin(\varphi+\xi)\end{gathered} \tag{11.10}$$

$$\dot{\omega} = L(\tilde{\omega}) - b\left[\dot{A}k\sin(\varphi+\xi) + (\dot{\omega}+\dot{\xi})Ak\cos(\varphi+\xi)\right]\sin\varphi\,. \tag{11.11}$$

$\dot{\mathrm{A}}$, $\dot{\xi}$ и $\dot{\tilde{\omega}}$ larni aniqlash uchun (11.8), (11.10) va (11.11) tenglamalar sistemsi ikkinchi tartibli kichik paramaetrlarni: $\mathrm{a}\dot{\tilde{\omega}}$, $\mathrm{b}\dot{\mathrm{A}}$ va $\mathrm{b}\dot{\xi}$ tashlash tyo’li bilan soddalashtirilishi mumkin. Bundan tashqari, (11.8) va (11.10) tenglamalarini $\dot{\mathrm{A}}$ и $\dot{\xi}$ ga nisbatan yechamiz. Bunda birinchi tartibli uchta differensial tenglamalarning quyidagi sistemasini olamiz:

$$\dot{\tilde{\omega}} = L(\tilde{\omega}) - Abk\tilde{\omega}\cos(\varphi+\xi)\sin\varphi\,,$$

$$\dot{\mathrm{A}} = -\frac{1}{\mathrm{k}}[\mathrm{a}\tilde{\omega}^2\cos\varphi + \mathrm{A\kappa h}\sin(\varphi+\xi)]\sin(\varphi+\xi)\,,$$

$$\dot{\xi} = \mathrm{k} - \tilde{\omega} - \frac{1}{\mathrm{Ak}}[\mathrm{a}\tilde{\omega}^2\cos\varphi + \mathrm{A\kappa h}\sin(\varphi+\xi)]\cos(\varphi+\xi).$$

Bu sistemani sekin o’zgaruvchi parametrlar metodida standart shaklga mustaqil o’zgaruvchansifatida φ burchagi va $\mathrm{d}\varphi = \tilde{\omega}dt$ nisbatidan foydalanib keltirish mumkin:

$$\frac{d\widetilde{\omega}}{d\varphi}=\frac{1}{\widetilde{\omega}}\left[L(\widetilde{\omega})-Abk\widetilde{\omega}\,\cos(\varphi+\xi)\,\sin\varphi\right],$$

$$\frac{dA}{d\varphi}=-\frac{1}{k\omega}\left[a\widetilde{\omega}^{2}\,\cos\,\varphi+Akh\,\sin\,(\varphi+\xi)\right]\sin\,(\varphi+\xi),\tag{11.12}$$

$$\frac{d\xi}{d\varphi}=\frac{k-\widetilde{\omega}}{\widetilde{\omega}}-\frac{1}{Ak\widetilde{\omega}}\,\left[a\omega^{2}\,\cos\varphi+Akh\,\sin\,(\varphi+\xi)\right]\cos(\varphi+\xi).$$

11.3. Harakatning statsionar rejimini tadqiqoti

(11.12) tengl;amalar sistemasini soddalashtirilishini davom ettrish mumkin, agar φ burchagini 0 dan 2π gacha o’zgarish davrida $\widetilde{\omega}$, A va ξ kattaliklarni o’zgarishi kichik va ularni φ burilishi burchagiga nisbatan hosilasini ularni o’rtacha qiymatiga teng deb hisoblash mumkin bo’lganda quyidagicha bo’ladi:

$$\frac{d\widetilde{\omega}}{d\varphi}=\frac{1}{2\pi\widetilde{\omega}}\int_{0}^{2\pi}L(\widetilde{\omega})\,d\varphi\,-\frac{Abk}{2\pi}\,\int_{0}^{2\pi}\cos(\varphi+\xi)\,\sin\varphi\,d\varphi$$

$$\frac{dA}{d\varphi}=\frac{a\widetilde{\omega}}{2\pi k}\int_{0}^{2\pi}\cos\varphi\sin(\varphi+\xi)\,d\varphi-\frac{Ah}{2\pi\widetilde{\omega}}\,\int_{0}^{2\pi}\sin^{2}(\varphi+\xi)\,\sin d\xi$$

$$\frac{d\xi}{d\varphi}=\frac{1}{2\pi\widetilde{\omega}}\int_{0}^{2\pi}(k-\omega)\,d\varphi\,-\frac{a\widetilde{\omega}}{2\pi Ak}\int_{0}^{2\pi}\cos\,\varphi\,\cos\,(\varphi+\xi)\,d\varphi-\frac{h}{\widetilde{\omega}}\int_{0}^{2\pi}\sin\,(\varphi+\xi)\cos\,(\varphi+\xi)d\varphi$$

$\widetilde{\omega}$, A и ξ kattaliklarini o’rtalash jarayoni bajarilishida o’zgarmas deb qabul qilamiz:

$$\int_{0}^{2\pi}\cos\,\varphi\,\sin\,\varphi\,d\varphi=0,\qquad\frac{1}{2\pi}\int_{0}^{2\pi}\sin^{2}\varphi\,d\varphi=\frac{1}{2\pi}\int_{0}^{2\pi}\cos^{2}\varphi\,d\varphi=\frac{1}{2}\,,$$

integrallashdan so’ng quyidagini olamiz:

$$\begin{aligned}
&\frac{d\tilde{\omega}}{d\varphi}=\frac{1}{\tilde{\omega}}\left[L(\tilde{\omega})+\frac{b}{2}\ Ak\tilde{\omega}\ \sin\ \xi\right],\\
&\frac{dA}{d\varphi}=-\frac{a\tilde{\omega}}{2k}\sin\xi-\frac{Ah}{2\tilde{\omega}},\\
&\frac{d\xi}{d\varphi}=\frac{1}{\tilde{\omega}}\ (k-\tilde{\omega}-\frac{a\tilde{\omega}^2}{2Ak}\ \cos\ \xi.
\end{aligned}\tag{11.13}$$

(11.13) taxminiy tenglamalar sistemasi $\tilde{\omega}$, A va ξ o’zgaruvchilarni o’tish rejimida sonli integrallash yo’li bilan aniqlashda foydalanilishi mumkin. Keyinchalik harakatning statsionar yechimini tadqiqi bilan chegaralanamiz, bunda $\tilde{\omega}$, A va ξ kattaliklarini ko’rilgan qiymatl;aridagi harakat rejimini, ya’ni yurituvchining doimiy burchak tezligida va vibrator polzunini garmonik tebranishida tushunamiz.

Statsionar rejimni naoyon bo’lish sharti:

$$\mathrm{d}\tilde{\omega}/d\varphi=0,\ dA/d\varphi=0,\ d\xi/d\varphi=0$$

Bunday sharoitda statsionar harakat rejimini tenglamasi quyidagi ko’rinishda bo’ladi:

$$\begin{aligned}
&\mathrm{L}(\tilde{\omega})+\frac{\mathrm{b}}{2}\ \mathrm{Ak}\dot{\omega}\sin\xi=0,\\
&\mathrm{hA}+\frac{\mathrm{a}\tilde{\omega}^2}{k}\sin\ \xi=0,\\
&\mathrm{k}\ \text{-}\ \tilde{\omega}\ \text{-}\ \frac{\mathrm{a}\tilde{\omega}^2}{2\mathrm{Ak}}\cos\xi=0
\end{aligned}\tag{11.14}$$

Bulardan tebraish fazasi va amplitudasini topamiz:

$$A=\frac{a\tilde{\omega}^2}{\sqrt{4k^2(k-\tilde{\omega})^2+k^2h^2}};\qquad tg\ \xi=\frac{h}{2(\tilde{\omega}-k)}.$$

a, *h* va *b* o’zgarmaslarni mexanizm parametrlari bilan ifodalangan qiymatlarini qo’yib, quyidagini olamiz:

$$A = \frac{m_1}{m} \frac{r\tilde{\omega}^2}{\sqrt{4k^2(k-\tilde{\omega})^2 + k^2\beta^2 m^2}}, \tag{11.15}$$

$$tg\,\xi = \frac{\beta}{m(\tilde{\omega} - k)}. \tag{11.16}$$

Yurituvchining valine $\tilde{\omega}$ burchak tezligini majburiy tebranishlarning doimiy chastotasi deb, taxminiy hisoblab (11.14) sistemani bireinchi tenglamasidan aniqlaymiz:

$$\mathrm{L}(\tilde{\omega}) - \frac{\mathrm{bh}}{2\tilde{\omega}\mathrm{a}}\ \mathrm{A}^2\mathrm{k}^2 = 0,$$

yoki

$$\tilde{M}_Д(\tilde{\omega}) - \frac{\beta}{2\tilde{\omega}} A^2 k^2 = 0.$$

Bu tenglamani *A* amplitude qiymatini (11.15) formula bo’yicha qo’yib quyidagini olamiz:

$$\tilde{\mathrm{M}}_Д(\tilde{\omega}) - S(\tilde{\omega}) = 0 \tag{11.11}$$

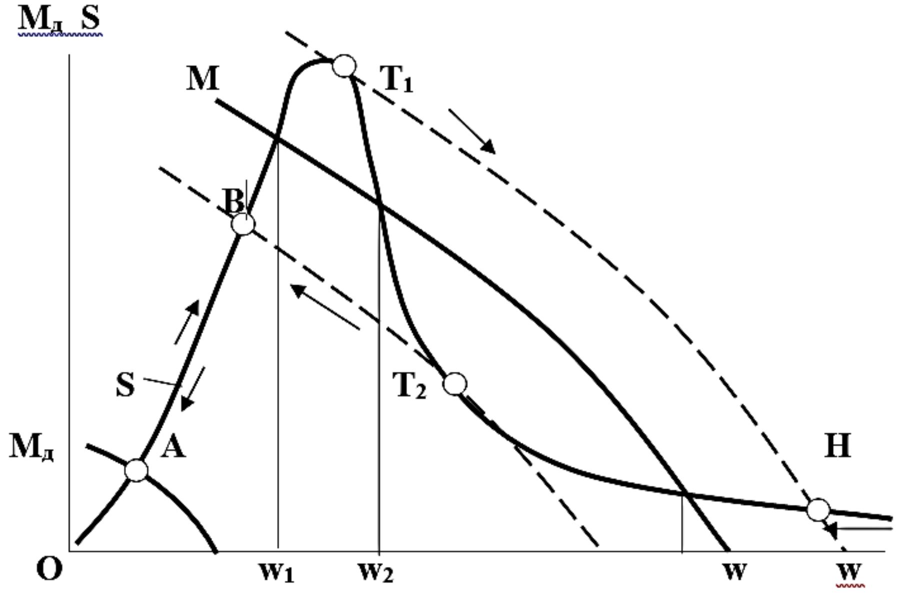
$$S(\tilde{\omega}) = \frac{\beta}{2}\left(\frac{m_1}{m}\right)^2 \frac{r^2\tilde{\omega}^3}{4(k-\tilde{\omega})^2 + \beta^2/m^2}$$

(11.18)

11.4. Rezonansdan o’tish rejimi

(11.11) tenglama yuirtuvchini statsionar rejimida burchak tezligini aniqlovchi bitta yoki bir nechta ildizlarga ega bo’lishi mumkin.

11.2 – rasmda $S(\omega)$ kattaligini (11.18) formula bo’yicha mexanizmni doimiy parametrlarini β, m_1, m, k^2, r^2 ba’zi kombinatsiyasi uchun o’zgarish grafigi keltirilgan.



11.2 – rasm.

(11.11) tenglamaning izlanadigan ildizi S (ω) grafigini yurituvchining xarakteristikasi $\widetilde{M}_Д(\omega)$ bilan kesishishida aniqlanadi.

11.2 – rasmda $\widetilde{M}_Д(\omega)$ xarakteristikasi uchun yaxlit ko’rsatilgan chizig’ida uchta kesimini nuqtalari bor, tegishlicha, (11.11) tenglamaning uchta ildizi: ω_1, ω_2 va ω_3 ni tadqiqi shuni ko’rsatadiki, OT_1 yoki $T_2\infty$ uchastkasidagi kesishish nuqtalarini joylashishida harakat ustuvor,T_1T_2 –da ustuvor emas. Doimiy tokli tokli yurtiuvchili markazdan qochma vibrator whosil qiladigan tebranma chastotalarini rostlash qo’zg’atuvchi zanjirdagi tokni o’zgartirish orqali bajariladi. Tokning turli qiymatlarida olinadigan xarakteristikalar ***rostlovchi xarakteristikalar*** deyiladi. 11.2 – rasmda shtrix chiziqlar bilan ikkita xarakteristikalar ko’rsatilgan. Ularadn biri S (ω) egri chizig’ini T_1 nuqtasiga, boshqasi esa T_2 nuqtasiga to’g’ri keladi. Ko’rsatilgan chegaraviy egri chiziqlar orasida joylashgan rostlovchi xarakterisikada vibratorning harakati ustuvorligini tadqiqi tajribada ko’riladigan rezonansdagi o’tishdagi “uzilish” hodisasini tushuntirishga imkon beradi. Masalan, $\widetilde{M}_Д(\omega)$ va S

(ω) egri chiziqlarni *OT_1* uchastkasida *A* kesishish nuqtasiga to’g’ri keluvchi ba’zi qiymatdan boshlab yurituvchining brchak tezligi asta-sekin oshishi chegaraviy rostlovchi xarakteristikani *T_1* nuqtasiga erishishidan so’ng tebranish tezda (“sakrashli” yoki “uzilishli”) boshqa o’sha chegaraviy xarakteristikani *S (ω)* egri chiziq bilan *H* kesishish nuqtasiga mos statsionar rejimga o’tadi. ω burchak tezligi oshib borganda statsionar rejim ko’zga tashlanadi, bunda $\tilde{M}_Д(\omega)$ va *S (ω)* egri chiziqlarning kesishish nuqtasi unga uzoqlashadi. Demak, yurituvchi tezliginibunday oshishida, *S (ω)* egri chizig’ini *T_1H* uchastkasiga to’g’ri keluvchi statsionar harakatning hamma rejimlari tushiob qoladi. Yurituvchining tezligi kamayganda, masalan *H* nuqtaga to’g’ri keluvchi rejimdan boshlab ustuvor statsionar rejimlar namoyon bo’ladiki, $\tilde{M}_Д(\omega)$ va *S (ω)* egri chiziqlarning kesishish nuqtasi *T_2* nuqtaga tushmaguncha davom etadi. Bunda yana tebranishlarning “uzilishi ” bo’ladi, chunki chegaraviy rostlovchi xarakteristika *T_2* tutashish nuqtasidan tashqari yana *S (ω)* egri chizig’I bilan *B* kesishish nuqtasiga ega.

Yurituvchining tezligini kamayishi davom etganda $\tilde{M}_Д(\omega)$ va *S (ω)* egri chiziqlarning kesishish nuqtasi *S (ω)* egri chiziq bo’ylab chapga harakat qiladi. Demak, yurituvchining tezligi kamayganda *S (ω)* egri chiziqni *T_2B* uchastkasiga mos statsionar harakatning hamma rejimini chiqarishi mumkin.

11.5. O’z- o’zini tekshirish savollari

1. Markazdan qochma vibrator qanday ishlaydi?
2. Vibtarorli mashina agregatini harakat tenglamasini tuzish tartibini tushuntiring.
3. Vibratorning tebranish massasi yechimi qanday amalga oshiriladi?
4. Statsionar rejimda tebranish amplitudasi va chastotasi qanday bajariladi?
5. Rezonansdan o’tish sharti qanday xarakterlanadi?