Ilmiy tadqiqotlar va ularning yechimlari jurnali
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TEBRANAYOTGAN BALKANING AMPLITUDA-CHASTOTA XARAKTERISTIKASINI ANIQLASH

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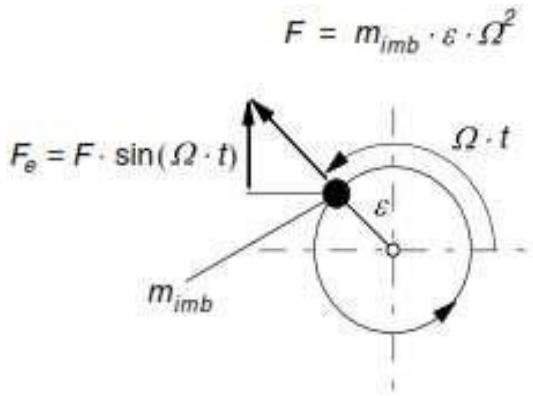
Annotatsiya: Ushbu maqolada tebranayotgan balkaning amplituda-chastota xarakteristikasini eksperimental usulda aniqlash jarayoni TM 155 Erkin va majburiy tebranishlar apparatida tadqiq qilindi. Mazkur tadqiqot mexanik konstruksiyalarda tebranish jarayonlarini chuqur tahlil qilish, ularning barqarorligini oshirish hamda rezonans sababli yuzaga keladigan nosozliklarning oldini olishda muhim ahamiyat kasb etadi. Rezonans holatiga sabab bo’ladigan mexanik konstruksiyalardagi xususiy va majburiy tebranish chastotalari tajribada aniqlanish jarayonlari o’rganilgan Olingan eksperimental natijalar nazariy ma’lumotlar bilan taqqoslanib, ular orasidagi moslik darajasi tahlil qilindi. Maqola mexanika, mashinasozlik va matematik modellashtirish yo‘nalishlarida tahsil olayotgan talabalar hamda ilmiy tadqiqotchilar uchun foydali manba bo‘lib xizmat qiladi.
Kalit so‘zlar: tebranish, balka, amplituda-chastota xarakteristikasi, rezonans hodisasi, xususiy chastota, majburiy tebranish, mexanik tizim, eksperimental tadqiqot, dinamik jarayon, so‘nish koeffitsiyenti, elastiklik, tebranish amplitudasi, matematik modellashtirish.

Annotation: This article investigates the experimental determination of the amplitude-frequency characteristics of a vibrating beam using the TM 155 “Free and Forced Vibrations” apparatus. The study is important for the detailed analysis of vibration processes in mechanical structures, improving their stability, and preventing failures caused by resonance phenomena. The processes of experimentally determining the natural and forced vibration frequencies that lead to resonance in mechanical systems were examined. The obtained experimental results were compared with theoretical data, and the degree of agreement between them was analyzed. This article serves as a useful scientific resource for students and researchers in the fields of mechanics, mechanical engineering, and mathematical modeling.
Keywords: vibration, beam, amplitude-frequency characteristic, resonance phenomenon, natural frequency, forced vibration, mechanical system, experimental research, dynamic process, damping coefficient, elasticity, vibration amplitude, mathematical modeling.

Kirish. Tebranishlar tabiatda va texnikada keng tarqalgan. Ko‘pchilik hollarda ular salbiy ta’sir qiladi. Relslarning qo‘shilish joyidan utayotganda poyezdning g‘ildiraklari beradigan turtkilar ko‘prikning tebranishiga, suzish vintining aylanishi kema tanasining tebranishiga, samolyot qanotlarining tebranishi halokatga olib kelishi mumkin. Bunday hollarda tebranishlarni xavfli chegaragacha kutarilishiga yo‘l qo‘ymaslik uchun tegishli choratadbir ko‘riladi. Shunga qaramasdan tebranishlar texnikaning turli sohalarida muhim ahamiyatga ega. Masalan, radiotexnika tebranma jarayonlarga asoslangan. Tebranayotgan tizimga ko‘rsatilayotgan ta’sir xarakteriga ko‘ra, tebranishlar

erkin tebranishlar, majburiy tebranishlar, avto tebranishlar va parametrik tebranishlarga bo‘linadi. Muvozanat holatidan chiqarilgandan keyin o‘zicha tebranadigan tizimda yuz beradigan tebranishlarga erkin tebranishlar; davriy ravishda o‘zgaruvchi tashqi kuch ta’siri ostida bo‘ladigan tebranishlarga majburiy tebranishlar deb yuritiladi.

Balkaning harakat tenglamasi. Tebranishni yuzaga keltrish uchun foydalanuvchi uskina balkaga o‘zgaruvchan chastota va amplituda bilan ta’sir qiladi.



1-chizma

$$F_e = m_{imb} \cdot \varepsilon \cdot \Omega^2 \cdot \sin(\Omega \cdot t) \qquad (1)$$

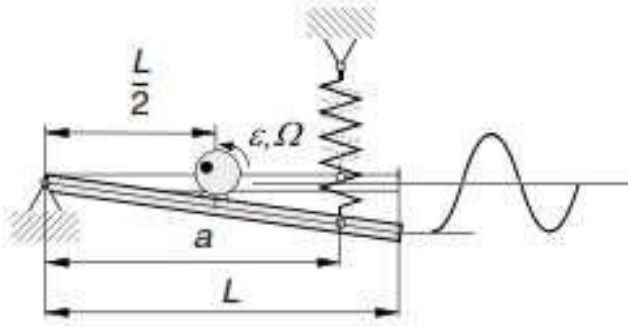
Bu yerda m_{imb} funksiyaning massasi, ε *va* Ω *e*sa uning ekssentrisiteti va chastotasi. Qo‘zg‘atuvchi balkaning $L/2$ markaziga o‘rnatiladi. O nuqtaga nisbatan momentlarning muvozanat shartida buni ham hisobga olsak

$$J_O \cdot \ddot{\varphi} + d \cdot b^2 \cdot \dot{\varphi} + c \cdot a^2 \cdot \varphi = m_{imb} \cdot \varepsilon \cdot \frac{L}{2} \cdot \Omega^2 \cdot sin(\Omega \cdot t) \qquad (2)$$

Bunda $y = L \cdot \varphi$ ni hisobga olsak

$$\ddot{y} + 2 \cdot D \cdot \omega_0 \cdot \dot{y} + \omega_0^2 \cdot y = \frac{m_{imb}}{J_0} \cdot \varepsilon \cdot \frac{L}{2} \cdot \Omega^2 \cdot sin(\Omega \cdot t) \qquad (3)$$

Bunda D va ω_0 oldindan ma’lum bo‘lgan so‘ndrish ko‘rsatkichi va xususiy tebranish chastotasi.



2-chizma

Erkin tebranishlardagidan farqli ravishda majburiy tebranish tenglamasi bir jinslimas bo‘lib uning yechimi

$$y(t)=\dot{y}\cdot\frac{\Omega^2}{\sqrt{\left(1-\left(\frac{\Omega}{\omega_0}\right)^2\right)+(2\cdot D\cdot\frac{\Omega}{\omega_0})^2}}\cdot\sin(\Omega\cdot t+\psi) \qquad (4)$$

Qo‘zg‘atuvchi va tebranuvchi sistema orasidagi fazoviy siljish

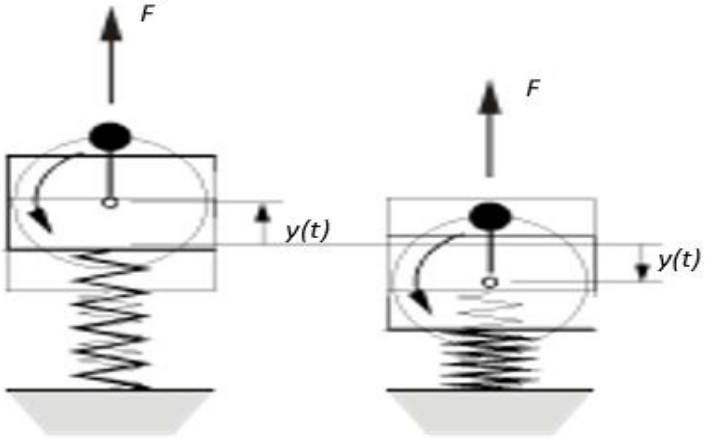
$$\psi=\arctan\frac{2\cdot D\cdot\omega_0}{\omega_0{}^2-\Omega^2} \qquad (5)$$

Majburiy tebranish haqida boshlang‘ich tasavvurga ega bo‘lish uchun D=0 deb olamiz va quydagi yechimga ega bo‘lamiz .

$$y(t)=\dot{y}\cdot\frac{\Omega^2}{1-\left(\frac{\Omega}{\omega_0}\right)^2}\cdot\sin(\Omega\cdot t+\psi) \qquad (6)$$

Agar yuqoridagi ifodada chastotalarning nisbati $\Omega/\omega_0=1$ bo’lsa maxraj nolga aylanib ∞ ga intiladi. Bu holda rezonans hodisasi sodir bo’adi. Sondirgich hisobga olinsa amplitudaning qiymati kichikroq bo’ladi.

Agar $\Omega = 0$ fazaviy siljish ψ nolga teng, ya’ni qo’zg’atuvchi va tebranuvchi sistema bir xil fazada bo’ladi. Bu so’nmaydigan sistemalar uchun $\Omega \gg \omega_0$ subkritik sohada o’rinli.



$\Omega \gg \omega_0$ subkritik $\Omega \gg \omega_0$ superkiritik

3-chizma

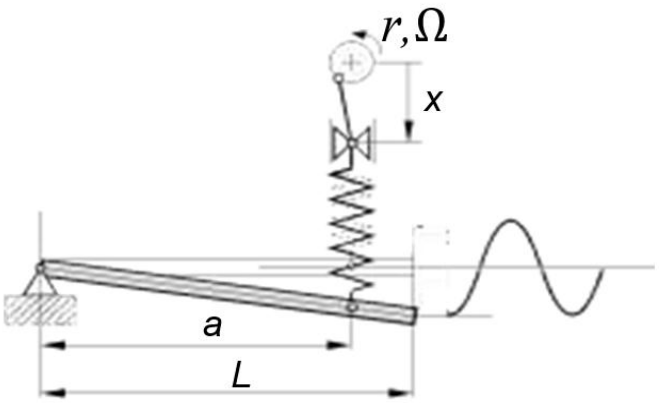
$\Omega \gg \omega_o$ ya’ni superkritik holda fazaviy siljish 180° ga teng. Tebranuvchi sistema fazasi qo’zg’atuvchidan yarim davrga orqada qoladi va ular qarama-qarshi fazada bo’ladilar. Nisbat 1 qiymatni qbul qiladi. Tebranish amlitudasi $\dot{y}$.

Tebranish amplitudasining Ω/ω_0 nisbatdan bog’liq o’zgarish grafiklari rezonans chiziqlari ko’rinishida grafikda keltirilgan.

So’ndirgichning ta’sirini ham so’ndirgich bo’lmagan holga nisbatan taqqoslab tekshirish mumkin. Amplitudalar $\dot{y}$ ning qiymatiga nisbatan normallashtirilgan.

Tashqi quzg’atuvchi

Tebranishni yuzaga keltirish maqsadida krivoshipli mexanizimdan iborat qo’zg’atuvchidan foydalaniladi, bunda garmonik tebranish amplituda va chastotasi o’zgaruvchan bo’ladi.



4-chizma

$$x=r\cdot \sin(\Omega\cdot t) \qquad (7)$$

bu yerda r krivoshipli mexanizmning ekssentrisiteti va Ω qo'zg'atuvchining chastotasi. Qo'zg'atuvchi prujina orqali ta'sir qilib tayanchdan a masofada joylashgan. O markazga nisbatan momentlarning muvozanat shartiga ko'ra

$$J_O\cdot\ddot{\varphi}+d\cdot b^2\cdot\dot{\varphi}+c\cdot a^2\cdot\varphi=c\cdot a\cdot r\cdot \sin(\Omega\cdot t) \qquad (8)$$

Yoki, $y=\varphi\cdot L$ ekanligini, sundirish ko'rsatkichi D va ω_0 burchak tezlanishlarini e'tborga olsak ,

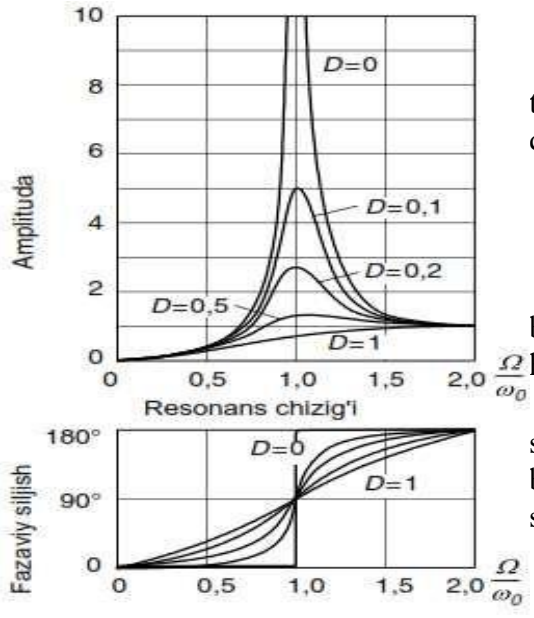
$$\ddot{y}+2\cdot D\cdot\omega_0\cdot\dot{y}+\omega_0^2\cdot y=\frac{L}{2}\cdot\omega_0^2\cdot r\cdot \sin(\Omega\cdot t) \qquad (9)$$

$$y(t)=\dot{y}\cdot\frac{\Omega^2}{\sqrt{\left(1-\left(\frac{\Omega}{\omega_0}\right)^2\right)+(2\cdot D\cdot\frac{\Omega}{\omega_0})^2}}\cdot \sin(\Omega\cdot t+\psi) \qquad (10)$$

$$\dot{y}=\frac{L}{a}\cdot r \qquad (11)$$

Fazoviy siljish esa,

$$\psi=\arctan\frac{2\cdot D\cdot\omega_0}{\omega_0^2-\Omega^2} \qquad (12)$$



5-chizma

Majburiy tebranish haqida boshlang'ich tasavvurga ega bo'lish uchun D=0 deb olamiz. Bu holda quyidagi yechimni olamiz

$$y(t)=\dot{y}\cdot\frac{\Omega^2}{1-\left(\frac{\Omega}{\omega_0}\right)^2}\cdot \sin(\Omega\cdot t+\psi) \qquad (13)$$

Ushbu ifodada $\frac{\Omega}{\omega_0}=1$ bo'lganda maxtaji nolga aylanadi, boshqacha aytganda cheksizlikka intiladi. Bu esa rezonans hodisasidir.

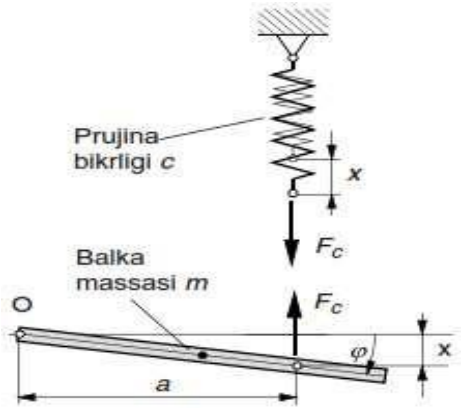
$\Omega=0$ bo'lganda amplituda $\hat{y}$ ga teng bo'ladi. Fazaviy siljish nolga teng bo'lib, qo'zg'atuvchi va tebranuvchi sistema bir xil fazada bo'ladi. Bu holat so'nmaydigan tebranuvchi sistemada subkritik sohada

$\Omega=\omega_0$ qiymatgacha o'rinli.

$\Omega \gg \omega_o$, ya'ni superkritik holat bo'lsa faza 180° ga siljiydi. Tebranuvchi sistema qo'zg'atuvchidan yarim davr bilan orqada qoladi, ular qarama- qarshi fazada bo'ladilar. Kasr nolga intiladi. Tebranish amplitudasi nolga teng bo'ladi.

Tebranish amplitudasining Ω/ω_0 nisbatga bog'liq o'zgarish grafiklari rezonans chiziqlari ko'rinishida grafikda keltirilgan.

TM 155 Erkin va majburiy tebranishlar aparati yordamida so'nmaydigan majburiy tebranish harakat tenglamasini bilan balkaning xususiy va erkin tbranish chastotalarini hisoblaymiz.



6-chizma

Balakning tebranish teglamasi unga ta'sir etuvchi kuchlarning tayanch nuqtasi bo'lgan O markazga nisbatan momentlarining muvozanati shartidan keltirib chiqariladi.

$$\sum M_o = J_o \cdot \ddot{\varphi} = -F_c \cdot a, \qquad (14)$$

F_C elastik kuch x egilish (prujina cho'zilishiga teng) va c bikrliklarning ko'paytmasiga teng.

Kichik burchaklar uchun egilish φ burchak va a kuch yelkasining ko'paytmasiga teng. Bundan

$$F_C = c \cdot x = c \cdot \varphi \cdot a \qquad (15)$$

Balkaning O markazga nisbatan inersiya momenti

$$J_O = \frac{m \cdot L^2}{3} \qquad (16)$$

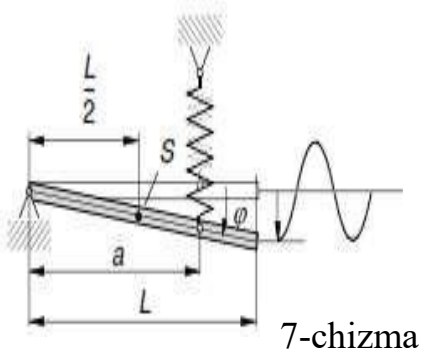
Bularni hisobga olsak bir jinsli oddiy differensial tenglama ko'rinishidagi harakat tenglamasini hosil qilamiz

$$\ddot{\varphi} + \frac{3 \cdot c \cdot a^2}{m \cdot L^2} \cdot \varphi = 0 \qquad (17)$$

Doiraviy ω_0 va xususiy (erkin) f tebranish chastotalari quyidagilarga teng bo'ladi

$$\omega_0^2 = \frac{3 \cdot c \cdot a^2}{m \cdot L^2} \qquad (18)$$

$$f = \frac{1}{2\pi} \sqrt{\frac{3 \cdot c \cdot a^2}{m \cdot L^2}} \qquad (19)$$



7-chizma

Tebranish davri esa $T = 2\pi \sqrt{\frac{3 \cdot c \cdot a^2}{m \cdot L^2}}$ (20)

Eksperiment va natijalar

Bu eksperimentda prujina bikrligi va kuch yelkasining turli qiymatlari uchun erkin tebranish chastotasinining nazariya va tajribada aniqlangan qiymatlarini solishtirish ko'zda tutilgan.

Quyidagi kombinatsiyalar tekshirilgan:

Eksperi-ment raqami	Pruji na raqami	Bikrlik *c*,N/mm	Kuch yelkasi *a*,mm	Erkin tebranish chastotasi *f*, Gts
1	1	0,75	350	2,78
2	1	0,75	650	5,17
3	2	1,50	350	3,94

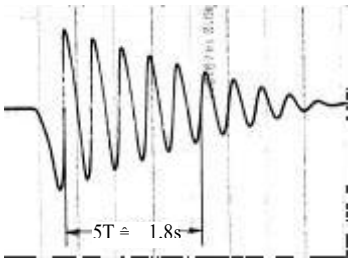
4	2	1,50	650	7,31
5	3	3,00	650	10,34

1-jadval. Prujina bikrligining ta’siri. Hisoblangan erkin tebranish chastotalari

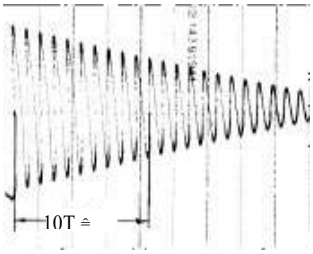
Eksperiment o’tkazish uchun ko’rsatma

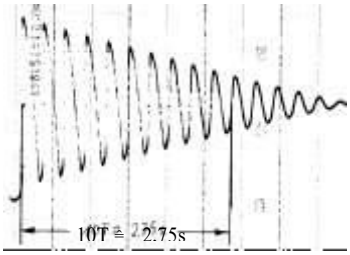
- Jadvalga mos keluvchi prujinani ehtiyotkorlik bilan mahkamlang.
- Balkani gorizontal holatga keltiring.
- Markerni o’rnating.
- Registratorni ishga tushiring.
- Balkani qo’l bilan eging va tebranish toxtaguncha kuzating.
- Registratorni to’xtating.

Boshqa prujinalar bilan va kuch yelkalari uchun eksperimentlarni davom ettiring.

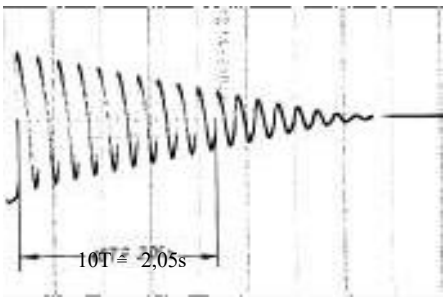


5.1-chizma. 1-Eksperiment



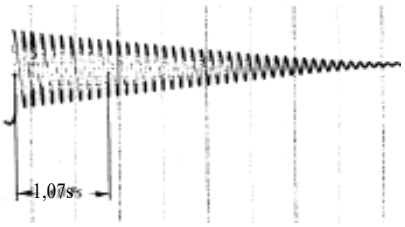


5.2-chizma. 2-Eksperiment



5.3-chizma. 3-Eksperiment

5.4-chizma. 4-Eksperiment



5.5-chizma. 5-Eksperiment

Tebranishlar jarayoni registratorda qayd etilgan quyidagi original grafiklarda ketirilgan. Markerning ishqalanishi hisobidan tebranish so’nmoqda.
5-10 marta tebranish uchun talab qilingan vaqt registratordan aniqllanadi.

Aniqlangan chastotalar nazariy natijalar bilan yuqoridagi jadvalda keltirilgan.

Xulosa

Olingan taqiqot natijalardan rezonans hodisasiga sabab bo'ladigan mexanik xaraktreskalar, tebranishga uchragan konstruksiyalarda amplituda-chastota xarakteristikasi muhim mexanik ko'rsatkichlar hisoblanadi. (6) ifodada tashqi ta'sir etuvchi kuch chastotasi va xususiy chastota nisbati birga teng bo'lishi bilan maxraj cheksizlikga intilsa rezonans hodisasiga sabab boladi.

(13) ifodadan $\Omega=0$ bo'lganda amplituda $\dot{y}$ ga teng bo'ladi. Fazaviy siljish nolga teng bo'lib, qo'zg'atuvchi va tebranuvchi sistema bir xil fazada bo'ladi. Bu holat so'nmaydigan tebranuvchi sistemada subkritik sohada

$\Omega=\omega_0$ qiymatgacha o'rinli. $\Omega \gg \omega_o$, ya'ni superkritik holat bo'lsa faza 180° ga siljiydi.

Eksperiment raqami	Eksperiment		Nazariya
	Tebranish davri *T*, s	Chastota *f*, Gts	Chastota *f*, Gts
1	0,38	2,63	2,78
2	0,20	4,88	5,17
3	0,26	3,85	3,94
4	0,13	7,69	7,31
5	0,10	10,00	10,34

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