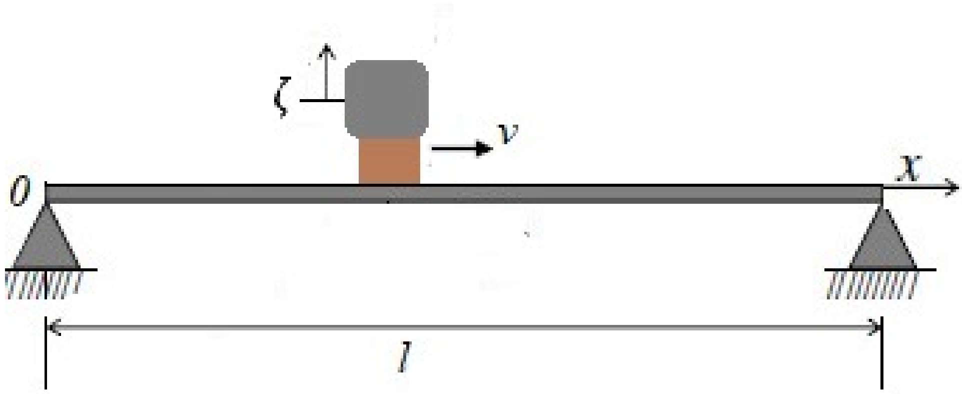
STERJEN VA HARAKATLANUVCHI DINAMIK SO‘NDIRGICHNING BIRGALIKDAGI KO’NDALANG TEBRANISHLARI TAHLILI

Z.S.Yuldosheva
Toshkent davlat iqtisodiyot universiteti Samarqand filali, o‘qituvchisi
yuldoshovazarnigor30@gmail.com

Ushbu ishda gisterezis tipidagi elastik dissipativ xarakteristikali sterjen va harakatlanuvchi gisterezis tipidagi elastik dissipativ xarakteristikali dinamik so‘ndirgichlarning birgalikdagi tebranishlari matematik modellashtirilgan.

Mexanik sistemalarning tebranishlarini matematik modellashtirish va tebranishlarini tahlil qilishga bag’ishlangan bir qancha tadqiqotlar mavjud [1-8].

Gisterezis tipidagi elsatik dissipativ xarakteristikali stejen va uning uzunligi bo‘ylab harakatlanuvchi qattiq jismli dinamik so‘ndirgichning birgalikdagi ko‘ndalang tebranishlarini matematik modellashtiramiz.



1-rasm. *Stejen va harakatlanuvchi dinamik so‘ndirgichli sistema sxemasi*

1-rasmda sxemasi keltirilgan mexanik sistema uchun erkin jism diagrammasidan foydalansak, gisterezis tipidagi elsatik dissipativ xarakteristikali stejenning va uning uzunligi bo‘ylab harakatlanuvchi gisterezis tipidagi elsatik dissipativ xarakteristikali qattiq jismli dinamik so‘ndirgichning birgalikdagi ko‘ndalang tebranishlarida quyidagi munosabatlar o‘rinli bo‘ladi:

$$\frac{\partial^2 M}{\partial x^2} - c(1 + (-\theta_1 + j\theta_2)(D_0 + f(\zeta_{ot})))\zeta\delta(x - vt)H(\frac{l}{v} - t) = -\rho A\frac{\partial^2 w_a}{\partial t^2};$$

$$m\frac{\partial^2 w(x_0)}{\partial t^2} + m\frac{\partial^2 \zeta}{\partial t^2} + c(1 + (-\theta_1 + j\theta_2)(D_0 + f(\zeta_{ot})))\zeta = -m\frac{\partial^2 w_0}{\partial t^2}. \quad (1)$$

bu yerda M – eguvchi moment; ρ, A – lar mos ravishda sterjen materialining zichligi va ko‘ndalan kesimi yuzi; $w(x_0)$ – dinamik so‘ndirgich joylashgan sterjen nuqtasining ko‘chishi; $x_0 = vt$ - dinamik so‘ndirgich joylashgan nuqta; v - dinamik so‘ndirgich tezligi; t – vaqt; $\delta(x)$ – Dirakning delta funksiyasi; $H(\frac{l}{v})$ – Hevisayd funksiyasi; l – sterjen uzunligi; c, m – lar mos ravishda dinamik so‘ndirgichning bikrligi va massasi; ζ – dinamik so‘ndirgichning nisbiy deformatsiyasi; w_a – sterjenning absolyut ko‘chishi $w_a = w_0 + w$, w_0- asosning ko‘chishi; w – sterjen egilishi; $\theta_1, \theta_2 = \theta_{22}sign(\omega)$ lar dinamik so’ndirgich materialining elastik dissipativlik xossalariga bog‘liq bo‘lgan doimiy koeffitsientlar bo‘lib, gisterezis sirtmog‘idan aniqlanadi; $j^2 = -1$; $f(\zeta_{ot})$ – tebranishlar dekrementi bo‘lib, ζ_{ot} - nisbiy deformatsiya absolyut qiymatining funksiyasi hisoblanadi,

$$f(\zeta_{ot}) = D_1\zeta_{ot} + D_2\zeta_{ot}^2 \dots + D_n\zeta_{ot}^n,$$

$D_0, D_1, \dots, D_n$ - gisterezis tugunining tajribadan aniqlanadigan parametrlari bo‘lib, dinamik so’ndirgich materialining dempferlovchi xossalariga bog‘liq [1].

Sterjen materialidagi kuchlanish va nisbiy deformatsiya orasidagi bog’lanishni Pisarenko-Boginich gipotezasi ko’rinishda olamiz va M moment ifodasini hisoblaymiz. Hosil bo’lgan ifodani (1) differensial tenglamalar sistemasiga qo‘ysak, ega bo‘lamiz,

$$EI\big(1 + C_0(-\eta_1 + j\eta_2)\big)\frac{\partial^4 w}{\partial x^4} + \frac{24}{h^3}(-\eta_1 + j\eta_2)\frac{\partial^2}{\partial x^2}\Big[\frac{\partial^2 w}{\partial x^2}\int_0^{\frac{h}{2}} f(\zeta_o)z^2dz\Big] -$$

$$-c(1 + (-\theta_1 + j\theta_2)\big(D_0 + f(\zeta_{ot})\big))\zeta\delta(x - vt)H(\frac{l}{v} - t) + \rho A\frac{\partial^2 w}{\partial t^2} =$$

$$= -\rho A\frac{\partial^2 w_0}{\partial t^2};$$

$$m\frac{\partial^2 w(x_0)}{\partial t^2} + m\frac{\partial^2 \zeta}{\partial t^2} + c\left(1 + (-\theta_1 + j\theta_2)\big(D_0 + f(\zeta_{ot})\big)\right)\zeta = -m\frac{\partial^2 w_0}{\partial t^2}, \tag{2}$$

bunda $\eta_1, \eta_2 = \eta_{22}sign(\omega)$ lar sterjen materialining elastik dissipativlik xossalariga bog‘liq bo‘lgan doimiy koeffitsientlar bo‘lib, gisterezis sirtmog‘idan aniqlanadi; $f(\zeta_o)$ – tebranishlar dekrementi bo‘lib, ζ_o - nisbiy deformatsiya absolyut qiymatining funksiyasi hisoblanadi,

$$f(\zeta_o) = C_1\zeta_o + C_2\zeta_o^2 \dots + C_n\zeta_o^n,$$

$C_0, C_1, \dots, C_n$ - gisterezis tugunining tajribadan aniqlanadigan parametrlari bo‘lib, sterjen materialining dempferlovchi xossalariga bog‘liq [1].

(1) differensial tenglamalar sistemasi yordamida qaralayotgan tebranishlardan himoyalanuvchi sterjenning dinamikasini tahlil qilish maqsadida uzatish funksiyasini aniqlaymiz. Dastlab, buning uchun (1) differensial tenglamalar sistemasini $S = \frac{d}{dt}$ differensial operator yordamida algebraik ko’rinishdagi tenglamalar sistemasiga keltiramiz. $S^2 = -\omega^2$ ekanligini hamda $H(\frac{1}{v} - t)$ Hevisayd funksiyasining $\frac{1}{v} - t > 0$ bo’lganda $H\left(\frac{1}{v} - t\right) = 1$ xossasini hisobga olib, q_i va ζ o‘zgaruvchilarga nisbatan yechamiz.

$$q_i(t) = -\frac{A_1 + jA_2}{B_1 + jB_2}W_0;$$

$$\zeta(t) = -\frac{A_3 + jA_4}{B_1 + jB_2} W_0, \tag{3}$$

bu yerda

$$A_1 = -\omega^2 + (1 + d_i \mu\mu_0 u_{i0}) n_0^2 (1 - \theta_1 (D_0 + f(\zeta_{ot}));$$

$$A_2 = (1 + d_i \mu\mu_0 u_{i0}) n_0^2 \theta_2 (D_0 + f(\zeta_{ot}));$$

$$A_3 = (-\omega^2 + (1 - \eta_1 C_0) p_i^2 - \eta_1 \frac{3EI}{\rho A d_{2i}} \times$$

$$\times \sum_{k=1}^{n} C_k q_{ia}^k \frac{h^k}{2^k (k+3)} \int_0^l u_i \frac{\partial^2}{\partial x^2} \left(\frac{\partial^2 u_i}{\partial x^2} \left| \frac{\partial^2 u_i}{\partial x^2} \right|^k \right) dx) d_i + u_{i0} \omega^2;$$

$$A_4 = d_i \eta_2 (C_0 p_i^2 +$$

$$+ \frac{3EI}{\rho A d_{2i}} \sum_{k=1}^{n} C_k q_{ia}^k \frac{h^k}{2^k (k+3)} \int_0^l u_i \frac{\partial^2}{\partial x^2} \left(\frac{\partial^2 u_i}{\partial x^2} \left| \frac{\partial^2 u_i}{\partial x^2} \right|^k \right) dx);$$

$$B_1 = [-\omega^2 + (1 - \eta_1 C_0) p_i^2 - \eta_1 \frac{3EI}{\rho A d_{2i}} \times$$

$$\times \sum_{k=1}^{n} C_k q_{ia}^k \frac{h^k}{2^k (k+3)} \int_0^l u_i \frac{\partial^2}{\partial x^2} \left(\frac{\partial^2 u_i}{\partial x^2} \left| \frac{\partial^2 u_i}{\partial x^2} \right|^k \right) dx] \times [-\omega^2 +$$

$$+ n_0^2 \left(1 - \theta_1 \left(D_0 + f(\zeta_{ot})\right)\right)] - \eta_2 [C_0 p_i^2 + \frac{3EI}{\rho A d_{2i}} \times$$

$$\times \sum_{k=1}^{n} C_k q_{ia}^k \frac{h^k}{2^k (k+3)} \int_0^l u_i \frac{\partial^2}{\partial x^2} \left(\frac{\partial^2 u_i}{\partial x^2} \left| \frac{\partial^2 u_i}{\partial x^2} \right|^k \right) dx] \times$$

$$\times n_0^2 \left(1 + \theta_2 \left(D_0 + f(\zeta_{ot})\right)\right) - \mu\mu_0 n_0^2 u_{i0}^2 \omega^2 (1 - \theta_1 (D_0 + f(\zeta_{ot}));$$

$$B_2 = [-\omega^2 + (1 - \eta_1 C_0) p_i^2 - \eta_1 \frac{3EI}{\rho A d_{2i}} \times$$

$$\times \sum_{k=1}^{n} C_k q_{ia}^k \frac{h^k}{2^k (k+3)} \int_0^l u_i \frac{\partial^2}{\partial x^2} \left(\frac{\partial^2 u_i}{\partial x^2} \left| \frac{\partial^2 u_i}{\partial x^2} \right|^k \right) dx] \times$$

$$\times n_0^2 \left(1 + \theta_2 \left(D_0 + f(\zeta_{ot})\right)\right) + \eta_2 [C_0 p_i^2 + \frac{3EI}{\rho A d_{2i}} \times$$

$$\times \sum_{k=1}^{n} C_k q_{ia}^k \frac{h^k}{2^k (k+3)} \int_0^l u_i \frac{\partial^2}{\partial x^2} \left(\frac{\partial^2 u_i}{\partial x^2} \left| \frac{\partial^2 u_i}{\partial x^2} \right|^k \right) dx] \times$$

$$\times \left[-\omega^2 + n_0^2 \left(1 - \theta_1 \left(D_0 + f(\zeta_{ot})\right)\right)\right] - \mu\mu_0 n_0^2 u_{i0}^2 \theta_2 (D_0 + f(\zeta_{ot}))\omega^2.$$

(3) ifoda gisterezis tipidagi elastik dissipativ xarakteristikali sterjen va harakatlanuvchi gisterezis tipidagi elastik dissipativ xarakteristikali dinamik so‘ndirgich bilan birgalikdagi ko’ndalang tebranishlarining amplituda-chastota xarakteristikasi hisoblanadi.

Faraz qilaylik, harakatlanuvchi dinamik so'ndirgich $v = 0.125\ \frac{m}{s}$ chiziqli tezlik bilan harakatlanayotgan bo'lsin. U holda $t = 1; 2\ s$ bo'lganda qaralayotgan sistemaning amplituda-chastota xarakteristikalarini tahlil qilamiz.

Sterjen materialining gisterezis tugunining tajribadan aniqlanadigan parametrlarini quyidagicha olamiz.

$$C_1 = 6.760624;\ C_2 = -8278.5937; C_3 = 5894761;$$

$\eta_1 = \frac{3}{4}; \eta_2 = \frac{1}{\pi}$. Harakatlanuvchi dinamik so'ndirgichning elastik dempferlovchi elementi uchun quyidagilarni qabul qilamiz:

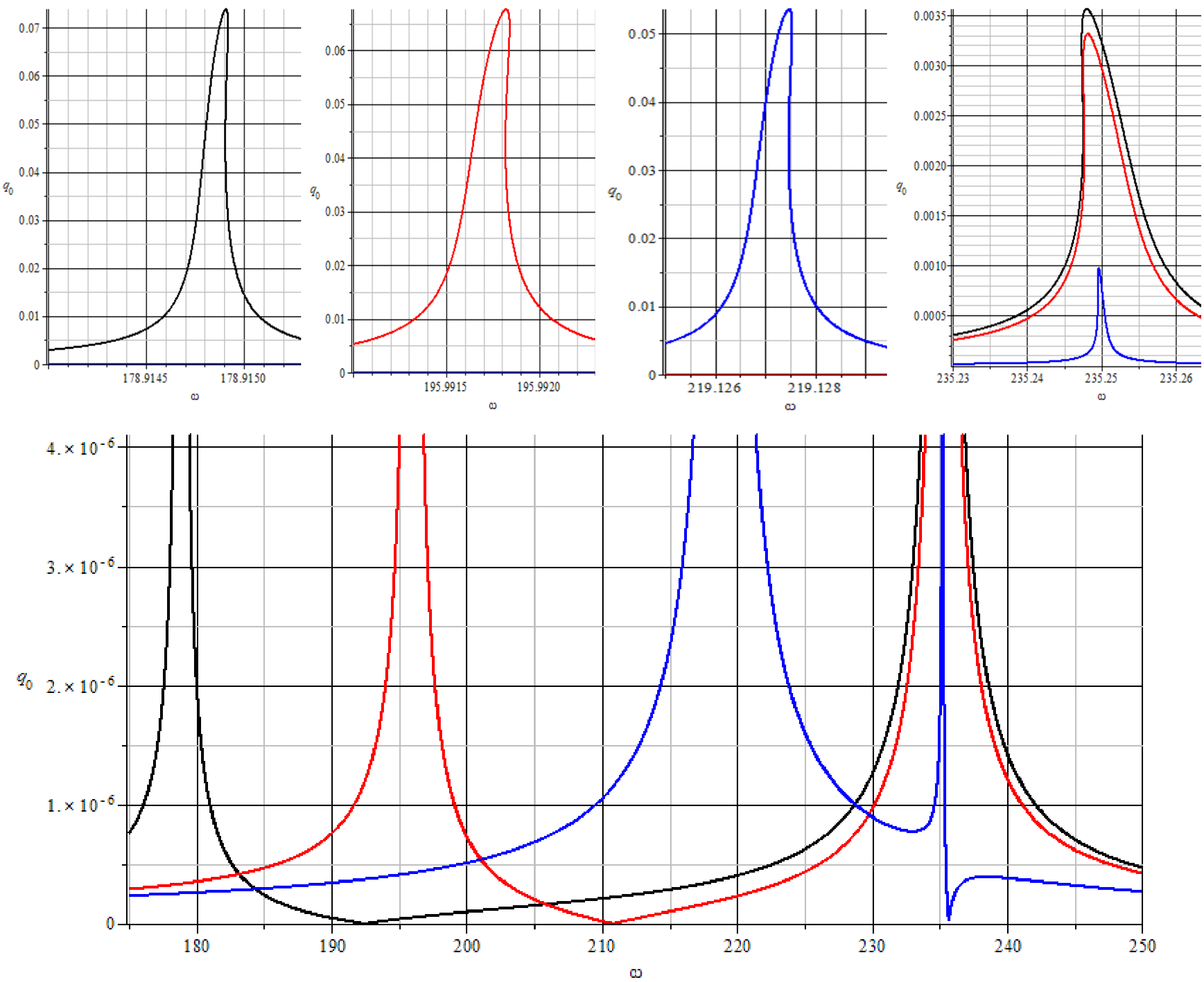
$$\theta_1 = \theta_2 = 0, D_0 = 0, D_1 = 0, D_2 = 0.$$

Qolgan parametrlar quyidagicha bo'ladi:

$$d_1 = 0.3183098862; d_2 = 0.25; d_i = 1.273239545; \mu = 0.1; \mu_0 = 2.0$$

$$u_{i0} = u_{10} = 1; I = 1.066666667 \cdot 10^{-10} m^4; \varepsilon p_0 = 10^{-\frac{5}{2}}\, m.$$

$t = 2\ s$ bo'lganda harakatlanuvchi dinamik so'ndirgich sterjenning $x_0 = 0.25\, m$ nuqtasida bo'ladi. Yuqorida keltirilgan parametrlarning qiymatlari asosida sistemaning amplituda-chastota xarakteristikasi grafigini chizamiz.



1-rasm. *Amplituda-chastota xarakteristikasi* ($x_0 = 0.25\ m$).

1-rasmda gisterezis tipidagi elastik dissipativ xarakteristikali sterjenning $x_0 = 0.25\,m$ nuqtasida bo'lgan harakatlanuvchi dinamik so'ndirgich bilan birgalikdagi ko'ndalang tebranishlarida dinamik so'ndirgich o'rnatilgan nuqtasining amplituda-chastota xarakteristikasining dinamik so'ndirgich bikrligiga bog'liq holda o'zgarishi keltirilgan. Bu grafiklardan shuni aytish mumkinki, dinamik so'ndirgich bikrligining otrishi bilan xuddi $x_0 = 0.125\,m$ nuqtadagidek uning chastotasi sterjenning xususiy chastotasiga yaqinlashadi va rezonans egri chizig'i chastota o'qi bo'ylab chapdan o'ngga siljiydi (c $= 10 \cdot 10^2 \frac{N}{m}$ (qora), c $= 12 \cdot 10^2 \frac{N}{m}$ (qizil), c $= 15 \cdot 10^2 \frac{N}{m}$ (ko'k)). Bu bikrlik qiymatlarida rezonans chastotasi atrofida amplitudalarning eng katta qiymatlari mos ravishda $q_0 = 0.0036; 0.0033; 0.00099\,m$ bo'ladi. Bundan c $= 15 \cdot 10^2 \frac{N}{m}$ qiymat dinamik so'ndirgich bikrligi uchun optimal qiymat degan xulosani aytish mumkin.

XULOSA

Olingan harakat differensial tenglamalar sistemasi sistema parametrlarining turli qiymatlarida qaralayotgan tebranishlardan himoyalanuvchi gisterezis tipidagi elastik dissipativ xarakteristikali sterjenning ko'ndalang tebranishlari dinamikasini baholash va ustuvorligini tekshirish imkonini beradi.

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