INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCHERS
ISSN: 3030-332X Impact factor: 8,293 Volume 9, issue 1, December 2024
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DISSIPATIV BIR JINSLI BO'LMAGAN MEXANIK SISTEMALARNING BARQAROR MAJBURIY TEBRANISHLARI

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Annotatsiya: Maqolada silindrik qatlamlarning deformatsiyalanuvchi sistemalar bilan o'zaro ta'sirdagi majburiy tebranishlari qaraladi. Silindrik qatlam va elastik sistemaning garmonik to'lqinlar ta'siridagi barqaror majburiy tebranishlari o'rganiladi. Silindrik qatlam va deformatsiyalanuvchi sistemada hosil bo'ladigan $\sigma_{\theta\theta}$ halqaviy kuchlanishlar amplitudasining silindrik qatlam va muhit parametrlariga nisbatan o'zgarishi o'rganiladi.

Аннотация. В статьи рассматривается вынужденная колебания деформируемых систем при взаимодействие цилиндрическими слоями. Изучается в зависимости геометрических параметров амплитуд кольцевых напряжении при установившиеся вынужденных колебаниях цилиндрического слоя и деформируемой средой под действием гармонических волн.

Kalit so'zlar: Deformatsiyalanuvchi sistema, silindrik qatlam, majburiy tebranishlar, garmonik to'lqinlar, halqaviy kuchlanishlar, amplituda qiymati, muhit parametrlari, dissipativ bir jinsli sistema, dissipativ bir jinsli bo'lmagan sistema, chegaraviy shart, boshlang'ich shart, bir jinsli bo'lmagan algebraik tenglamalar sistemasi, bo'ylama to'lqin tezligi, noma'lum sonlar, ko'ndalang to'lqin tezligi.

Ключевые слова: Деформируемая система, цилиндрический слой, вынужденная колебания, гармоническая волна, кольцевая напряжения, амплитуда напряжения, диссипативно однородная система, диссипативно неоднородная система, скорость продольных волн, скорость продольных волн, алгебраическая система уравнений.

Maqolada dissipativ bir jinsli bo'lmagan mexanik sistemalarning garmonik tebranishlari va qovushqoq elastik muhitda joylashgan silindrik qatlamning garmonik to'lqinlar ta'siridagi tebranishlari o'rganiladi. r=a silindrik qatlamning ichki sirti, r=b silindrik qatlamning tashqi sirti, b/a >. Silindrik qatlamga ta'sir etuvchi tekis garmonik to'lqinlar trigonometrik funksiyalar ko'rinishida ifodalanadi:

$$\varphi^{(p)} = \varphi_0\, \ell^{\,i(\tilde{\alpha}_1 x-\omega t)}; \qquad (1)$$

Silindrik koordinatalar sistemasida ta'sir etuvchi tekis garmonik to'lqinlar (r, z, t) (1) silindrik koordinatalar orqali ifodalanadi:

$$\varphi^{(p)} = \varphi_0 \sum_{n=0}^{\infty} \epsilon_n i^n J_n(\alpha_1 r) cos(n\theta)\, \ell^{\,-i\omega t}\,; \qquad (2)$$

$$\epsilon_n = \begin{cases} 1, & n = 0 \ \ bo'lganda; \\ 2, & n \geq 1 \ \ bo'lganda; \end{cases}$$

$J_n(\alpha_1 r) - n$ tartibli Bessel funksiyalari.

Potensiallarda ifodalangan harakat differensial tenglamalari quyidagi ko'rinishida bo'ladi [1]:

$$\nabla^2 \varphi_j - \frac{1}{c_{pj}^2}\frac{\partial^2 \varphi_j}{\partial t^2} = f_{1j}(t); \qquad (3)$$

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$$\nabla^2\vec{\psi}_j - \frac{1}{C_{sj}^2}\frac{\partial^2\vec{\psi}_j}{\partial t^2} = f_{2j}(t); \qquad (4)$$

Skalyar ko’rinishda (3) quyidagicha yoziladi:

$$\nabla^2\varphi_j - \frac{1}{\tilde{C}_{pj}^2}\frac{\partial^2\varphi_j}{\partial t^2} = f_{1j}(t); \;;$$

$$\nabla^2\psi_j - \frac{1}{\tilde{C}_{sj}^2}\frac{\partial^2\psi_j}{\partial t^2} = f_{2j}(t);$$

$\tilde{C}_{pj} = \sqrt{\frac{\tilde{\lambda}_j+2\tilde{\mu}_j}{\rho_j}}$ – bo’ylama to’lqin tezligi, $\tilde{C}_{sj} = \sqrt{\frac{\mu_j}{\rho_j}}$ – ko’ndalang to’lqin tezligi, – Laplas operatori.

Potensiallarda ifodalangan (3) harakat differensial tenglamalarining yechimlari quyidagi cheksiz qator ko’rinishida qidiriladi:

$$\begin{pmatrix}\varphi(r,\theta,t)\\ \psi(r,\theta,t)\end{pmatrix} = \sum_{n=0}^{\infty}\begin{pmatrix}\varphi_n(r)\\ \psi_n(r)\end{pmatrix}\begin{pmatrix}cos(n\theta)\ell^{-i\omega t}\\ sin(n\theta)\ell^{-i\omega t}\end{pmatrix}; \qquad (5)$$

(4) da

$$\varphi_n(r) = \begin{cases} A_n H_n^{(1)}(\tilde{\alpha}_1 r) \quad r > b \text{ da}, \\ C_n\, H_n^{(1)}(\tilde{\alpha}_2 r) + D_n\, H_n^{(2)}(\tilde{\alpha}_2 r) \quad a \le r \le b \text{ da} \end{cases} \qquad (6)$$

$$\psi_n(r) = \begin{cases} B_n H_n^{(1)}(\tilde{\beta}_1 r) \quad r > b \text{ da}, \\ L_n\, H_n^{(1)}(\widetilde{\beta_n} r) + M_n\, H_n^{(2)}(\tilde{\beta}_2 r) \quad a \le r \le b \text{ da} \end{cases} \qquad (7)$$

$A_n, B_n, C_n, D_n, L_n, M_n$ – noma’lumlar chegaraviy shartlardan aniqlanadi. Ko’chishlar va kuchlanishlarni quyidagi formulalar bilan hisoblanadi [3].

$$U_r = \frac{\partial\varphi}{\partial r} + \frac{1}{r}\frac{\partial\psi}{\partial\theta}; \qquad U_\theta = -\frac{\partial\psi}{\partial r} + \frac{1}{r}\frac{\partial\varphi}{\partial\theta};$$

$$(8)$$

$$\sigma_{rr} = -2\mu[(a\alpha^2 + D_1)\varphi + D_2\psi];$$

$$\sigma_{r\theta} = 2\mu[-D_2\varphi + \frac{1}{2}(\beta^2 + 2D_1)\psi];$$

$$\sigma_{\theta\theta} = 2\mu[(\frac{\lambda}{2\mu}\alpha^2 + D_1)\varphi + D_2\psi];$$

$$D_1 = \frac{1}{r}(\frac{\partial}{\partial r} + \frac{1}{r}\frac{\partial^2}{\partial\theta^2});$$

$$D_2 = \frac{1}{r}\frac{\partial}{\partial\theta}(\frac{1}{r} - \frac{\partial^2}{\partial r^2});$$

$$a = \frac{\lambda + 2\mu}{2\mu};$$

Dissipativ sistemalaring dissipativlik xususiyatlari Boltsman-Volter integral tenglamalari bilan ifodalanadi [2].

$$\tilde{\lambda}_n = \lambda_n[\varphi(t) - \int_0^t R_{\lambda_n}(t-\tau)\varphi(t)d\tau];$$
$$\tilde{\mu}_n = \tilde{\mu}_n[\varphi(t) - \int_0^t R_{\mu_n}(t-\tau)\varphi(\tau)d\tau; \quad (9)$$

Bu yerda, $R_{\lambda_n}, R_{\mu_n}-$ qovushqoq elastik muhitning relaksatsiya yadrolari, Koltunov, Rjanitsin bo'yicha olinadi, t – vaqt, $\varphi(t)-$ ixtiyoriy funksiya, $\tilde{\lambda}_n, \tilde{\mu}_n$ — Lyame operatorlari, j=1,2.

(2) tashqi ta'sir etuvchi to'lqinlarni va (5) tanlangan yechimlarni (8) ga qo'yib, matematik shakl almashtirishlarni bajargandan keyin ko'chish va kuchlanishlar quyidagi ko'rinishga keladi:

j=1;

$$\sigma_{rr1} = \sigma_{rr1}^{(p)} + \sigma_{rr1}^{(s)} = \sum_{n=0}^{\infty}\left[\epsilon_n i^n \varphi_0 \varepsilon_{1n}^{(p)} + A_n \varepsilon_{1n}^{(1)}\right]\cos(n\theta)\cdot e^{-i\omega t};$$

$$\sigma_{r\theta1} = \sigma_{r\theta1}^{(p)} + \sigma_{r\theta1}^{(s)} = \sum_{n=o}^{\infty}\left[\epsilon_n i^n \varphi_0 \varepsilon_{2n}^{(p)} + A_n \varepsilon_{1n}^{(1)} + \right.$$
$$\left. + B_n \varepsilon_{2n}^{(2)}\right] sin(n\theta)\cdot e^{-i\omega t}$$

$$U_{r1} = U_{r1}^{(p)} + U_{r1}^{(s)} = \sum_{n=o}^{\infty}[\epsilon_n i^n \varphi_0 \varepsilon_{3n}^{(p)} + A_n \varepsilon_{1n}^{(3)} + B_n \varepsilon_{2n}^{(3)}]\cos(n\theta)\cdot e^{-i\omega t};$$

$$U_{\theta1} = U_{\theta1}^{(p)} + U_{\theta1}^{(s)} = \sum_{n=0}^{\infty}\left[\epsilon_n i^n \varphi_0 \varepsilon_{4n}^{(p)} + A_n \varepsilon_{1n}^{(4)} + B_n \varepsilon_{2n}^{(4)}\right]\sin(n\theta)\cdot e^{-i\omega t};$$

j=2;

$$\sigma_{rr2} = \sum_{n=0}^{\infty}\left[C_n \varepsilon_{3n}^{(1)} + D_n \varepsilon_{4n}^{(1)} + L_n \varepsilon_{5n}^{(1)} + M_n \varepsilon_{6n}^{(1)}\right]\cos(n\theta)\cdot e^{-i\omega t};$$

$$\sigma_{r\theta2} = \sum_{n=0}^{\infty}\left[C_n \varepsilon_{3n}^{(2)} + D_n \varepsilon_{4n}^{(2)} + L_n \varepsilon_{5n}^{(2)} + M_n \varepsilon_{6n}^{(2)}\right]\sin(n\theta)\cdot e^{-i\omega t};$$

$$U_{r2} = \sum_{n=0}^{\infty}\left[C_n \varepsilon_{3n}^{(3)} + D_n \varepsilon_{4n}^{(3)} + L_n \varepsilon_{5n}^{(3)} + M_n \varepsilon_{6n}^{(3)}\right] cos(n\theta)\cdot e^{-i\omega t}$$

$$U_{\theta2} = \sum_{n=0}^{\infty}\left[C_n \varepsilon_{3n}^{(4)} + D_n \varepsilon_{4n}^{(4)} + L_n \varepsilon_{5n}^{(4)} + M_n \varepsilon_{6n}^{(4)}\right] sin(n\theta)\cdot e^{-i\omega t}$$

r=a da silindr ichki sirtida tashqi ta'sir etuvchi to'lqinlar yo'q:

$$\sigma_{rr2} = \sum_{n=0}^{\infty}\left[C_n \varepsilon_{9n}^{(1)} + D_n \varepsilon_{9n}^{(2)} + L_n \varepsilon_{9n}^{(3)} + M_n \varepsilon_{9n}^{(4)}\right]\cos(n\theta)\cdot e^{-i\omega t};$$

$$\sigma_{r\theta2} = \sum_{n=0}^{\infty}\left[C_n \varepsilon_{10n}^{(1)} + D_n \varepsilon_{10n}^{(2)} + L_n \varepsilon_{10n}^{(3)} + M_n \varepsilon_{10n}^{(4)}\right]\cos(n\theta)\cdot e^{-i\omega t};$$

(3.2.9,10)

$A_n, B_n, C_n, D_n, L_n, M_n$ — noma'lumlar uchun r=b kontakt chegarasida ko'chish va kuchlanishlar tengligi sharti (bikr kontakt),

$$U_{r1} = U_{r2}; \quad U_{\theta1} = U_{\theta2}; \quad (11)$$
$$\sigma_{rr1} = \sigma_{rr2}; \quad \sigma_{r\theta1} = \sigma_{r\theta2};$$

hamda r=a ichki sirtda kuchlanishlar hosil bo'lmasligi

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$$\sigma_{rr2} = 0; \quad \sigma_{r\theta 2} = 0; \tag{12}$$

shartlaridan aniqlanadi.

[C].{g}={P} ko'rinishdgi kompleks koeffitsiyentli, bir jinsli bo'lmagan algebraik tenglamalar sistemasi tuziladi:

[C]- noma'lumlar oldidagi koeffitsiyentlar matrissasi;

{g}- noma'lumlar matrissasi;

[P] - tashqi kuchlar matrissasi;

{g}, [P] – matrissalar transponirlangan ko'rinishda keltirilgan.

$$[C] = \begin{bmatrix} \varepsilon_{1n}^{(3)} \varepsilon_{2n}^{(3)} - \varepsilon_{3n}^{(3)} - \varepsilon_{4n}^{(3)} - \varepsilon_{5n}^{(3)} - \varepsilon_{6n}^{(3)} \\ \varepsilon_{1n}^{(1)} \varepsilon_{2n}^{(1)} - \varepsilon_{3n}^{(1)} - \varepsilon_{4n}^{(1)} - \varepsilon_{5n}^{(1)} - \varepsilon_{6n}^{(1)} \\ \varepsilon_{1n}^{(4)} \varepsilon_{2n}^{(4)} - \varepsilon_{3n}^{(4)} - \varepsilon_{4n}^{(4)} - \varepsilon_{5n}^{(4)} - \varepsilon_{6n}^{(4)} \\ \varepsilon_{1n}^{(2)} \varepsilon_{2n}^{(2)} - \varepsilon_{3n}^{(2)} - \varepsilon_{4n}^{(2)} - \varepsilon_{5n}^{(2)} - \varepsilon_{6n}^{(2)} \\ 00 - \varepsilon_{9n}^{(1)} - \varepsilon_{9n}^{(2)} - \varepsilon_{9n}^{(3)} - \varepsilon_{9n}^{(4)} \\ 00 - \varepsilon_{10n}^{(1)} - \varepsilon_{10n}^{(2)} - \varepsilon_{10n}^{(3)} - \varepsilon_{10n}^{(4)} \end{bmatrix}$$

$$\{g_n\} = \{A_n, B_n, C_n, D_n, L_n, M_n\}^T$$

$$\{P\} = \varepsilon_n i^n \phi_0 \left\{\varepsilon_{3n}^{(p)}, \varepsilon_{1n}^{(p)}, \varepsilon_{4n}^{(p)}, \varepsilon_{2n}^{(p)}, 0,0\right\}^T$$

$$\varepsilon_{1n}^{(p)} = (\tilde{\lambda}_1 + 2\tilde{\mu}_1) J_n''(\tilde{\alpha}_1 b) + \tilde{\lambda}_1 / b \left[J'_n(\tilde{\alpha}_1 b) - \frac{n^2}{b^2} J_n(\tilde{\alpha}_1 b) \right];$$

$$\varepsilon_{2n}^{(p)} = \frac{2\tilde{\mu}_1}{b} n \left[- J_n'(\tilde{\alpha}_1 b) + \frac{n}{b} J_n(\tilde{\alpha}_1 b) \right];$$

$$\varepsilon_{3n}^{(p)} = J_n'(\tilde{\alpha}_1 b); \quad \varepsilon_{4n}^{(p)} = -\frac{n}{b} J_n(\tilde{\alpha}_1 b);$$

$$\varepsilon_{1n}^{(1)} = (\tilde{\lambda}_1 + 2\tilde{\mu}_1) H_n^{(1)''}(\tilde{\alpha}_1 b) + \tilde{\lambda}_1 / b \left[H_n^{(1)'}(\tilde{\alpha}_1 b) - \frac{n^2}{b^2} H_n^{(1)}(\tilde{\alpha}_1 b) \right];$$

$$\varepsilon_{1n}^{(2)} = \frac{2\tilde{\mu}_1}{b} \left[-n H_n^{(1)'}(\tilde{\alpha}_1 b) + \frac{1}{b} H_n^{(1)}(\tilde{\alpha}_1 b) \right];$$

$$\varepsilon_{2n}^{(2)} = \frac{2\tilde{\mu}_1}{b} n \left[H_n^{(1)'}(\tilde{\beta}_1 b) - \frac{1}{b} H_n^{(1)}(\tilde{\beta}_1 b) \right]$$

$$\varepsilon_{2n}^{(p)} = -\frac{2\tilde{\mu}_1}{b} n^2 \left[H_n^{(1)}(\tilde{\beta}_1 b) \right] \tag{13}$$

$$\varepsilon_{1n}^{(3)} = H_n^{(1)'}(\tilde{\alpha}_1 b); \quad \varepsilon_{2n}^{(3)} = \frac{n}{b} H_n^{(1)}(\tilde{\beta}_1 b);$$

$$\varepsilon_{1n}^{(4)} = -\frac{n}{b} H_n^{(1)}(\tilde{\alpha}_1 b); \quad \varepsilon_{2n}^{(4)} = - H_n^{(1)'}(\tilde{\beta}_1 b);$$

$$\varepsilon_{3n}^{(1)} = (\tilde{\lambda}_2 + 2\tilde{\mu}_2) H_n^{(1)''}(\tilde{\alpha}_2 b) + \tilde{\lambda}_2 / b \left[H_n^{(1)'}(\tilde{\alpha}_2 b) - \frac{n^2}{b^2} H_n^{(1)}(\tilde{\alpha}_2 b) \right];$$

$$\varepsilon_{4n}^{(1)} = (\tilde{\lambda}_2 + 2\tilde{\mu}_2) H_n^{(2)''}(\tilde{\alpha}_2 b) + \tilde{\lambda}_2 / b \left[H_n^{(2)'}(\tilde{\alpha}_2 b) - \frac{n^2}{b^2} H_n^{(2)}(\tilde{\alpha}_2 b) \right];$$

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$$\varepsilon_{5n}^{(1)} = \frac{2\tilde{\mu}_2}{b} n \left[H_n^{(1)''}(\tilde{\beta}_2 b) - \frac{n}{b} H_n^{(1)}(\tilde{\beta}_2 b)\right];$$

$$\varepsilon_{6n}^{(1)} = \frac{2\tilde{\mu}_2}{b} n \left[H_n^{(2)''}(\tilde{\beta}_2 b) - \frac{n}{b} H_n^{(2)}(\tilde{\beta}_2 b)\right];$$

$$\varepsilon_{3n}^{(2)} = \frac{2\tilde{\mu}_2}{b} \left[\frac{n}{b} H_n^{(1)}(\tilde{\alpha}_2 b) - nH_n^{(1)'}(\tilde{a}_2 b)\right];$$

$$\varepsilon_{4n}^{(2)} = \frac{2\tilde{\mu}_2}{b} \left[\frac{n}{b} H_n^{(2)}(\tilde{\alpha}_2 b) - nH_n^{(2)'}(\tilde{\alpha}_2 b)\right];$$

$$\varepsilon_{5n}^{(2)} = -\frac{2\tilde{\mu}_2}{b} n^2 \left[H_n^{(1)}(\tilde{\beta}_2 b)\right]; \quad \varepsilon_{3n}^{(3)} = H_n^{(1)'}(\tilde{\alpha}_2 b);$$

$$\varepsilon_{6n}^{(2)} = -\frac{2\tilde{\mu}_2}{b^3} \left[H_n^{(2)}(\tilde{\beta}_2 b)\right]; \quad \varepsilon_{4n}^{(3)} = H_n^{(2)'}(\tilde{\alpha}_2 b);$$

$$\varepsilon_{5n}^{(3)} = \frac{n}{b} H_n^{(1)}(\tilde{\beta}_2 b); \qquad \varepsilon_{6n}^{(3)} = \frac{n}{b} H_n^{(2)}(\tilde{\beta}_2 b);$$

$$\varepsilon_{3n}^{(4)} = -\frac{n}{b} H_n^{(1)}(\tilde{\alpha}_2 b); \quad \varepsilon_{4n}^{(4)} = -\frac{n}{b} H_n^{(2)}(\alpha_2 \tilde{b});$$

$$\varepsilon_{5n}^{(4)} = H_n^{(1)'}(\tilde{\beta}_2 b); \qquad \varepsilon_{6n}^{(4)} = H_n^{(2)'}(\tilde{\beta}_2 b);$$

$$\varepsilon_{9n}^{(1)} = (\tilde{\lambda}_2 + 2\tilde{\mu}_2) H_n^{(1)''}(\tilde{a}_2 a) + \tilde{\lambda}_2 / a \left[H_n^{(1)'}(\tilde{a}_2 a) - \frac{n^2}{a^2} H_n^{(2)}(\tilde{a}_2 a)\right];$$

$$\varepsilon_{9n}^{(2)} = (\tilde{\lambda}_2 + 2\tilde{\mu}_2) H_n^{(1)''}(\tilde{\alpha}_2 a) + \tilde{\lambda}_2 / a \left[H_n^{(2)'}(\tilde{\alpha}_2 a) - \frac{n^2}{a^2} H_n^{(2)}(\tilde{\alpha}_2 a)\right];$$

$$\varepsilon_{9n}^{(3)} = \frac{2\tilde{\mu}_2}{a} n \left[H_n^{(1)'}(\tilde{\beta}_2 a) - \frac{1}{a} H_n^{(1)}(\tilde{\beta}_2 a)\right];$$

$$\varepsilon_{9n}^{(4)} = \frac{2\tilde{\mu}_2}{a} n \left[H_n^{(2)'}(\tilde{\beta}_2 a) - \frac{1}{a} H_n^{(2)}(\tilde{\beta}_2 a)\right];$$

$$\varepsilon_{10n}^{(1)} = \frac{2\tilde{\mu}_2}{a} \left[-nH_n^{(1)'}(\tilde{a}_2 a) + \frac{n}{a} H_n^{(1)}(\tilde{a}_2 a)\right];$$

$$\varepsilon_{10n}^{(2)} = \frac{2\tilde{\mu}_2}{a} \left[-nH_n^{(1)}(\tilde{\alpha}_2 a) + \frac{n}{a} H_n^{(2)}(\alpha_2 \tilde{a})\right];$$

$$\varepsilon_{10n}^{(3)} = -\frac{2\tilde{\mu}_2}{a^3} n^2 H_n^{(1)}(\tilde{\beta}_2 a); \quad \varepsilon_{10n}^{(4)} = -\frac{2\widetilde{\mu_2}}{a} n^2 H_n^{(2)}(\tilde{\beta}_2 a);$$

$$\tilde{\alpha}_j = \omega^2 / \widetilde{c_{p_j}^2}; \quad \tilde{\beta}_j = \omega^2 / \tilde{c}_{s_j}^2;$$

ρ_j — materialning zichligi.

$\sigma_{\theta\theta}$ — xalqadagi kuchlanishni eng katta amplituda qiymatlarini izlaymiz:

$|A_\sigma| = max|\sigma_{\theta\theta}|$; ($\theta = \pi/2;\ \nu_1 = 0,2;\ \nu_2 = 0,25;\ E_1 = 0,1;$ $E_2 = 1;\ \rho_1 = 0,1;\ \rho_2 = 1.$)

Dissipativ bir jinsli sistema, $R_1 \neq R_2 \neq 0$;

Yechimlardan ko'rinadiki, xalqadagi kuchlanish a/b nisbatning o'zgarishiga nisbatan monoton o'zgaradi. Shu masala dissipativ bir jinsli bo'lmagan sistema R_2=0; uchun o'rganilganda, natija boshacharoq bo'ladi. Xalqadagi kuchlanish a/b nisbatning o'zgarishiga nisbatan nomonoton o'zgaradi. $\sigma_{\theta\theta}$ — Xalqadagi kuchlanish aniq (minimal) eng kichik

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qiymatga erishadi. Bu eng kichik qiymat dissipativ bir jinsli sistemada amplituda (chastota) qiymatlari bir-biriga yaqinlasgan a/b ning sohasiga to’g’ri keladi. Shuning uchun ham, dissipativ bir jinsli bo’lmagan sistemalarni o’rganish, bunday sistemalar uchun minimal qiymatlarni aniqlash, minimal qiymatlarga erishadigan sistemalarni tanlash ahamiyatlidir.

Foydalanilgan adabiyotlar:

1. Amenzade Yu.A. Teoriya uprugosti. M. Visshaya shkola.
2. Rabotnov Yu.N. Elementi nasledstvennoy mexaniki tverdix tel. M. Nauka.
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