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Nonlinear antiresonance vibrating screen

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The issue of research

Biharmonic vibrations are in demand in different technological processes:

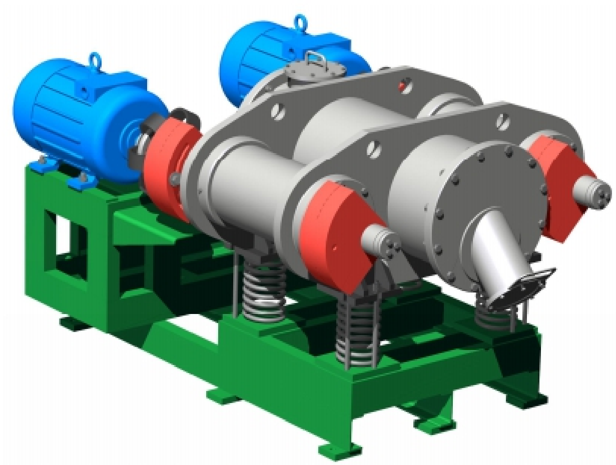
– transportation,

– screening,

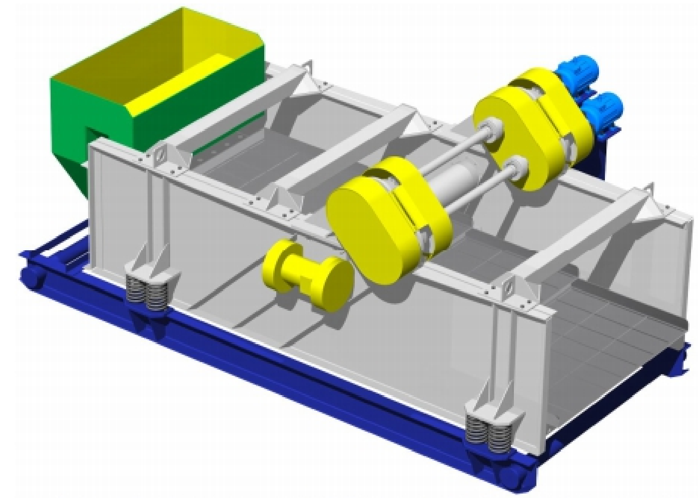
– compacting and so on [1, 2].

Examples of such machines are shown in the figure.

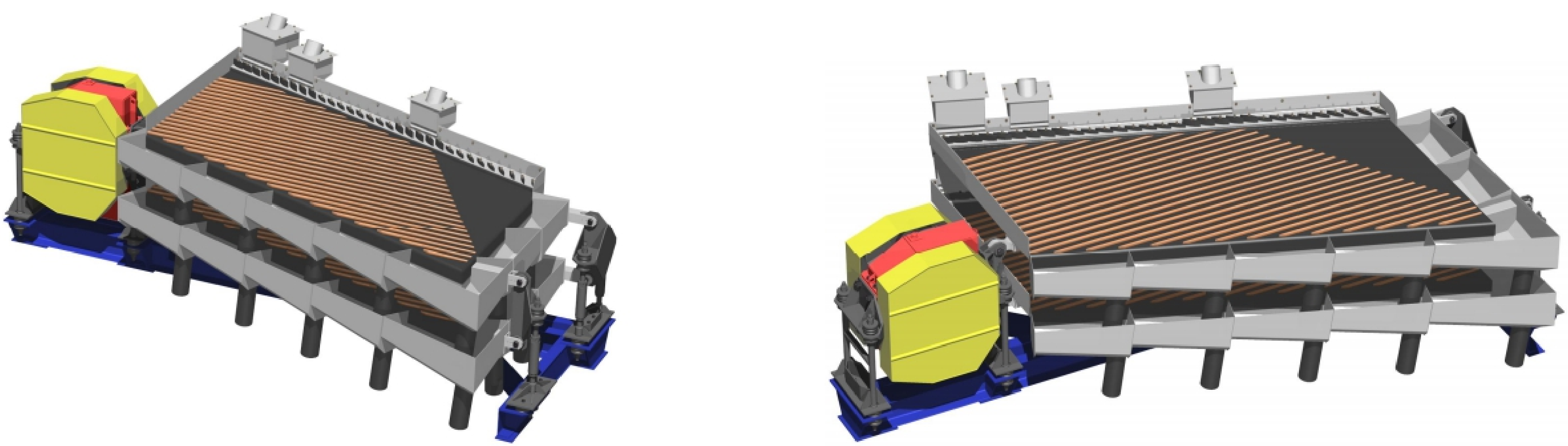
The issue of research



VIBRATORY BIHARMONIC MILL



BIHARMONIC INERTIAL VIBRATING SCREEN



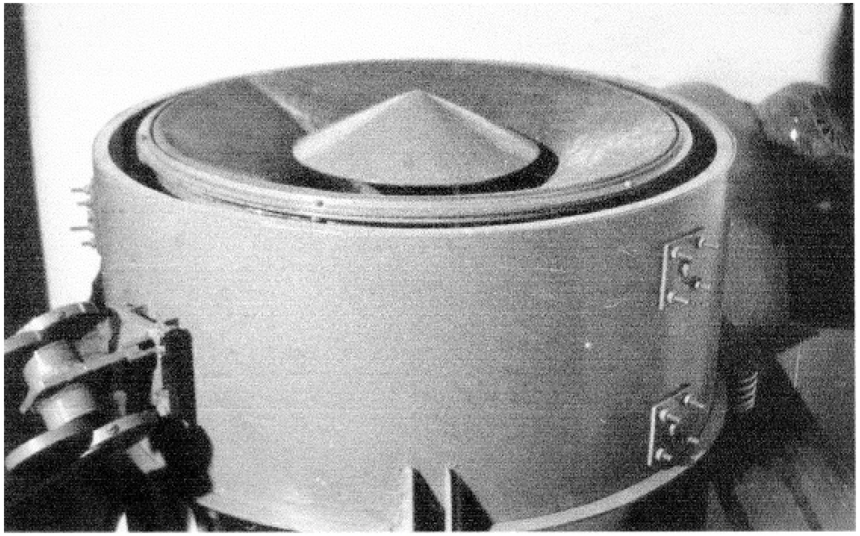
REFERENCE CONCENTRATION TABLE OF BIHARMONIC TYPE

The issue of research

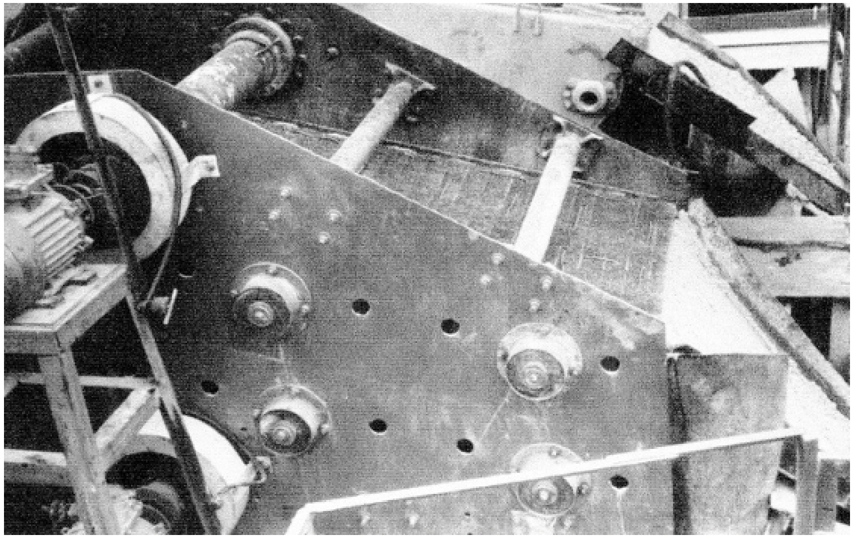
There are known vibrating machines which use the idea of antiresonance for decreasing dynamical forces on foundation [3].

Examples of such machines are shown in the figure.

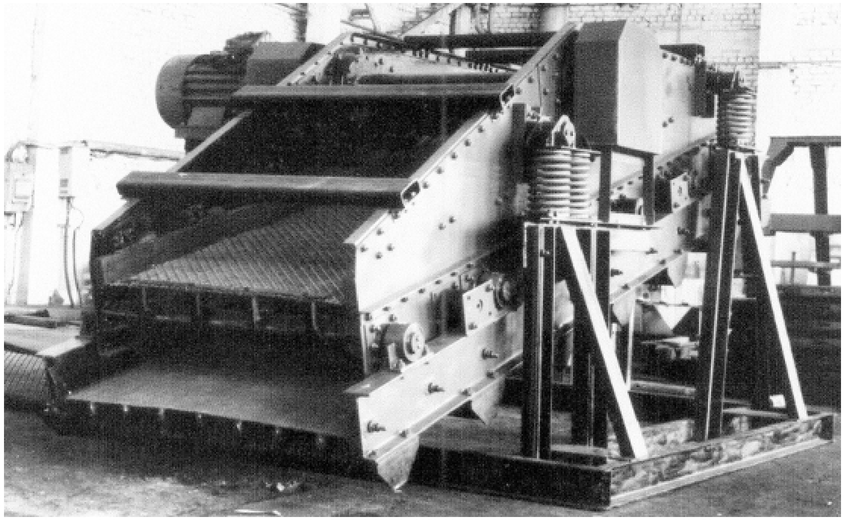
The issue of research



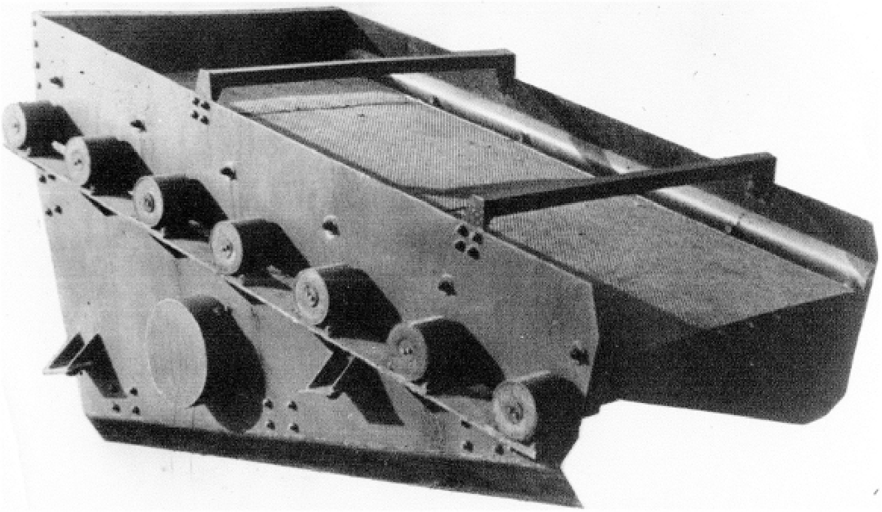
VIBRATING GRANULATOR OF METAL POWDERS



BIHARMONIC VIBRATING SCREEN GIL-42AB

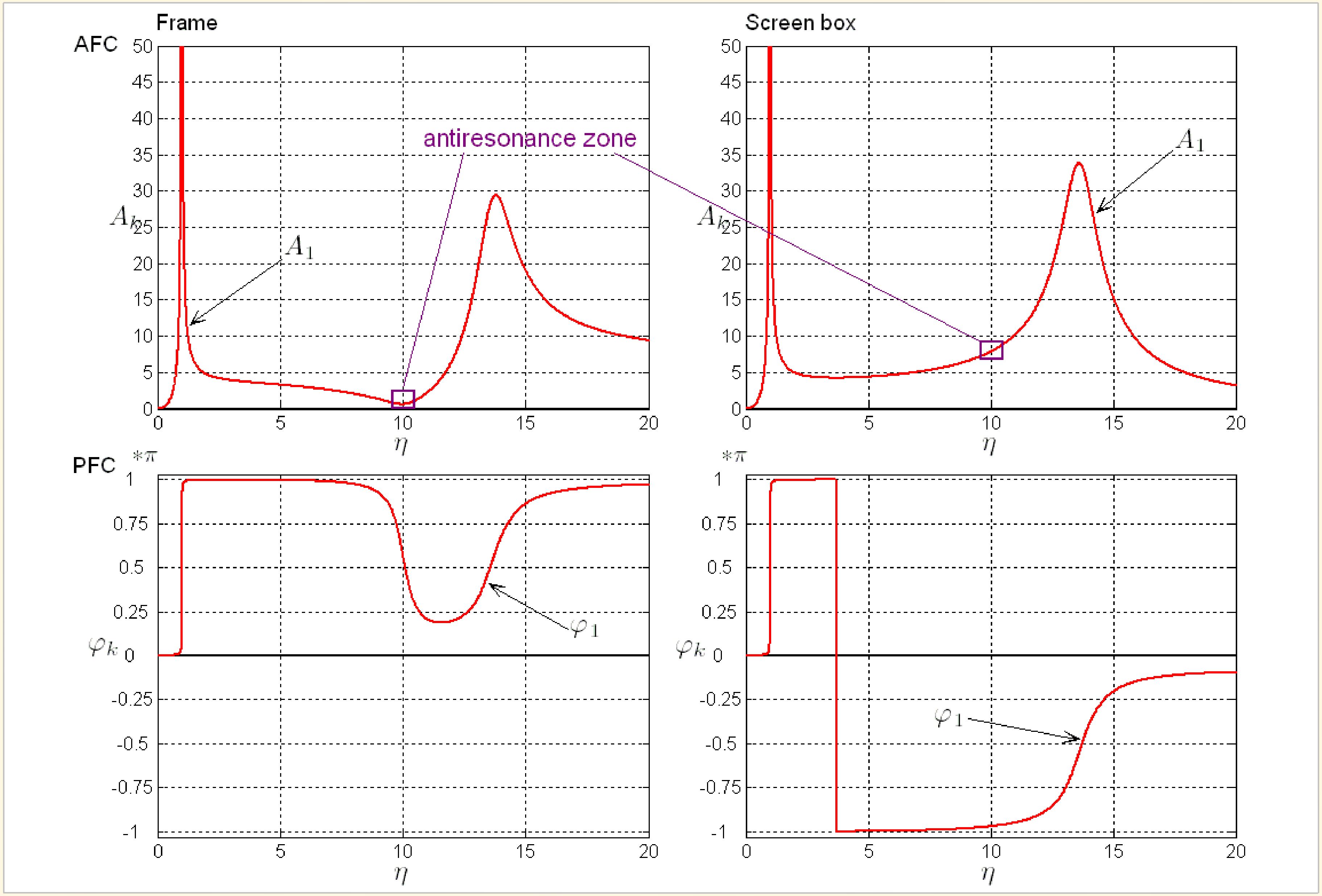


VIBRATING SCREEN GIL-1.75x2



VIBRATING SCREEN GIL-61

The issue of research



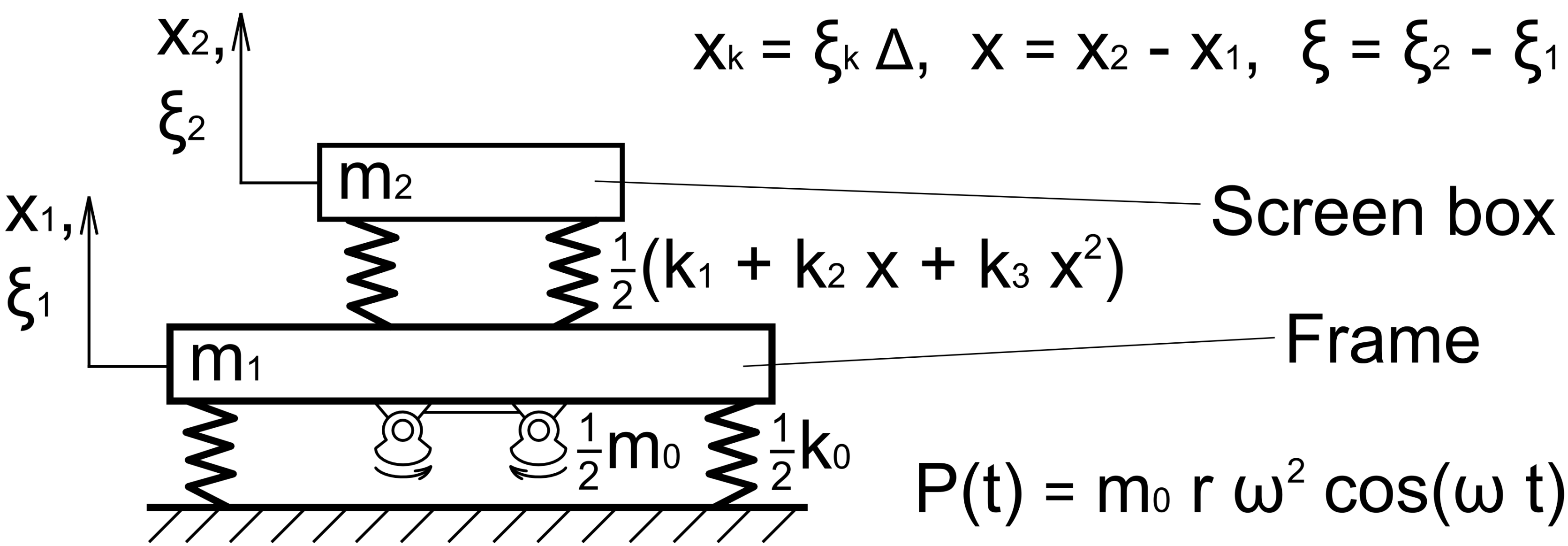
The issue of research

One of the purposes of this work is the investigation of principal possibility of combining these properties in the nonlinear vibrating machine with harmonic excitation at the expense of realization of combination resonances.

The model under consideration

Here it is considered the vibrating two-masses screen with ideal harmonic inertial excitation and polynomial characteristic of the main elastic ties.

$$x_k = \xi_k \Delta, \quad x = x_2 - x_1, \quad \xi = \xi_2 - \xi_1$$



$$P(t) = m_0 r \omega^2 \cos(\omega t)$$

The model under consideration

The equations of its motion may be derived with use of Lagrange equations. In non-dimensional form they have a view:

$$\begin{cases} \dfrac{d^2\xi_1}{d\tau^2}+b_{10}\dfrac{d\xi_1}{d\tau}+b_{11}\dfrac{d\xi}{d\tau}+b_{12}\xi\dfrac{d\xi}{d\tau}+b_{13}\xi^2\dfrac{d\xi}{d\tau}+k_{10}\xi_1+k_{11}\xi+k_{12}\xi^2+k_{13}\xi^3=P_1\cos\eta\tau\,, \\ \dfrac{d^2\xi}{d\tau^2}+b_{20}\dfrac{d\xi_1}{d\tau}+b_{21}\dfrac{d\xi}{d\tau}+b_{22}\xi\dfrac{d\xi}{d\tau}+b_{23}\xi^2\dfrac{d\xi}{d\tau}+k_{20}\xi_1+k_{21}\xi+k_{22}\xi^2+k_{23}\xi^3=P_2\cos\eta\tau\,, \end{cases}$$

where $b_{10}=\dfrac{\mu k_0}{m_1'\omega_1}$, $b_{11}=-\dfrac{\mu k_1'}{m_1'\omega_1}$, $b_{12}=-\dfrac{\mu k_2'\Delta}{m_1'\omega_1}$, $b_{13}=-\dfrac{\mu k_3'\Delta^2}{m_1'\omega_1}$, $b_{20}=-\dfrac{\mu k_0}{m_1'\omega_1}$, $b_{21}=\dfrac{\mu(m_1'+m_2)k_1'}{m_1'm_2\omega_1}$,

$b_{22}=\dfrac{\mu(m_1'+m_2)k_2'\Delta}{m_1'm_2\omega_1}$, $b_{23}=\dfrac{\mu(m_1'+m_2)k_3'\Delta^2}{m_1'm_2\omega_1}$, $k_{10}=\dfrac{k_0}{m_1'\omega_1^2}$, $k_{11}=-\dfrac{k_1}{m_1'\omega_1^2}$, $k_{12}=-\dfrac{k_2\Delta}{m_1'\omega_1^2}$, $k_{13}=-\dfrac{k_3\Delta^2}{m_1'\omega_1^2}$, (1)

$k_{20}=-\dfrac{k_0}{m_1'\omega_1^2}$, $k_{21}=\dfrac{k_1(m_1'+m_2)}{m_1'm_2\omega_1^2}$, $k_{22}=\dfrac{k_2(m_1'+m_2)\Delta}{m_1'm_2\omega_1^2}$, $k_{23}=\dfrac{k_3(m_1'+m_2)\Delta^2}{m_1'm_2\omega_1^2}$, $P_1=\dfrac{m_0 r}{m_1'\Delta}\eta^2$, $P_2=-\dfrac{m_0 r}{m_1'\Delta}\eta^2$,

$\xi_1=x_1/\Delta$, $\xi=x/\Delta$, $x=x_2-x_1$, x_1 – displacement of a frame, x_2 – displacement of a working organ, $\Delta=10^{-3}$ m, $m_1'=m_0+m_1$, m_0 – unbalanced mass, m_1 – mass of a frame, m_2 – mass of a screen box, k_0 – stiffness of isolators, k_1, k_2, k_3 – parameters of elastic ties and k_1', k_2', k_3', – of dissipation, r – eccentricity of an exciter, μ – coefficient of dissipation, $\eta=\omega/\omega_1$, ω – frequency of an vibroexciter, ω_1 – the first natural frequency of a vibromachine, $\tau=\omega_1 t$.

The model under consideration

The parameters of the experimental model are

$m_1 = 700\ kg$, $m_2 = 550\ kg$,

$k_0 = 0.12 \cdot 10^6\ N/m$, $k_1 = 5.5 \cdot 10^6\ N/m$,

$m_0 = 50\ kg$, $r = 0.088\ m$, $\mu = 0.0008\ s$

and the working frequency $\omega = 100\ rad/s$.

The cases of linear ($k'_2 = 0$, $k'_3 = 0$) and nonlinear ($k'_2 = k_2$, $k'_3 = k_3$) dissipation are considered.

Research methods

Analysis of the model is performed with the help of original software worked out as a tool of program MATLAB. Searching of the bifurcation diagrams is based on the harmonic balance method. Stationary solutions of the system are found in the form of finite Fourier expansions

$$\xi_1(\tau)=\sum_{n=-N}^{N} c_n^{(1)} e^{in\eta\tau}, \quad \xi(\tau)=\sum_{n=-N}^{N} c_n e^{in\eta\tau},$$

where *N* is a number of harmonics taken into consideration.

Research methods

After substituting it into the differential equations and equating the coefficients of equal powers the polynomial system for determination of expansion coefficients is produced

$$\begin{cases} \left(k_{10}+b_{10}i\eta n-\eta^2 n^2\right)c_n^{(1)}+\left(k_{11}+b_{11}i\eta n\right)c_n+\sum_{j=-N}^{N} c_j c_{n-j}\left(k_{12}+b_{12}i\eta(n-j)\right)+ \\ \qquad +\sum_{j=-N}^{N}\sum_{m=-N}^{N} c_j c_m c_{n-j-m}\left(k_{13}+b_{13}i\eta(n-j-m)\right)=\begin{cases} P_1/2, & n=\pm1 \\ 0, & n\neq\pm1 \end{cases}, \\ \left(k_{20}+b_{20}i\eta n\right)c_n^{(1)}+\left(k_{21}+b_{21}i\eta n-\eta^2 n^2\right)c_n+\sum_{j=-N}^{N} c_j c_{n-j}\left(k_{22}+b_{22}i\eta(n-j)\right)+ \\ \qquad +\sum_{j=-N}^{N}\sum_{m=-N}^{N} c_j c_m c_{n-j-m}\left(k_{23}+b_{23}i\eta(n-j-m)\right)=\begin{cases} P_2/2, & n=\pm1 \\ 0, & n\neq\pm1 \end{cases}, \end{cases}$$

where $n, n-j, n-j-m\in[-N,\ N]$.

Research methods

Changing one of the parameters of the model and solving algebraic system of equations in step by step one can get the bifurcation curves.

The construction of basins of attraction of periodic regimes is based on the scanning of the domain of initial conditions and implementation of Demidenko-Matveeva method [4].

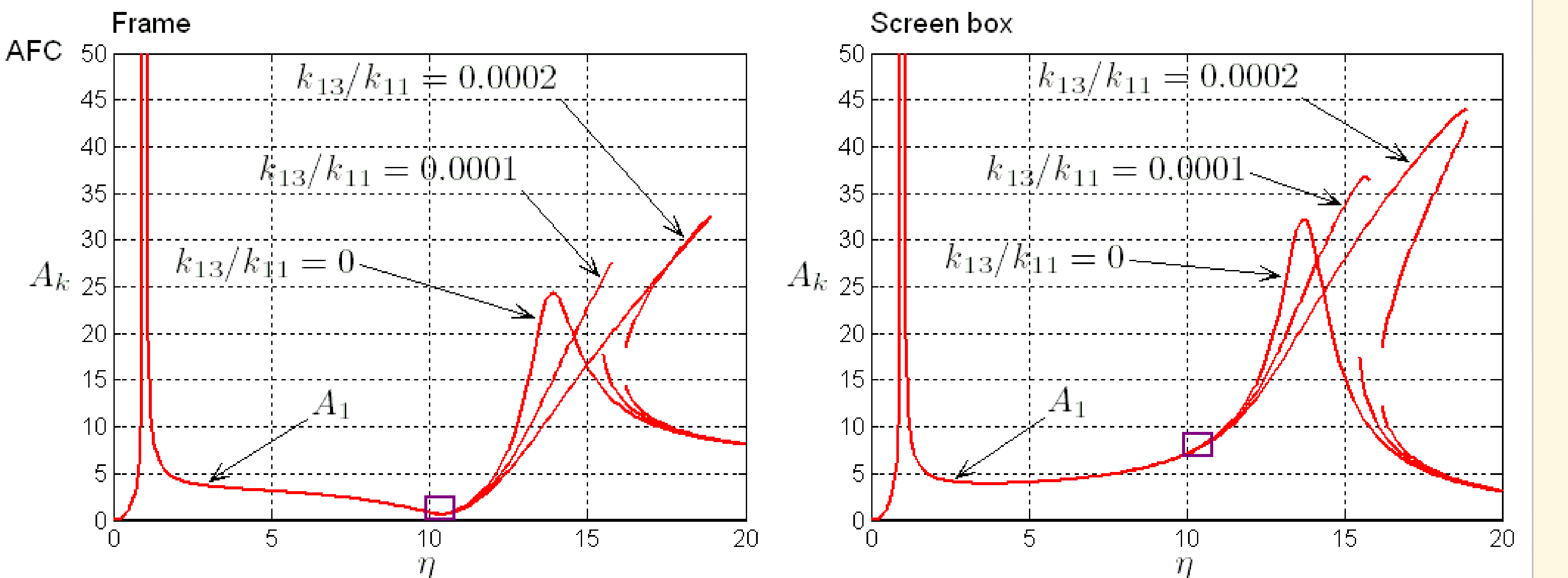
Results

Here are some amplitude- and phase frequency characteristics (AFC and PFC) for the different values of non-linearity of the system $k_{13}/k_{11} = 0, 0.0001, 0.0002$ and $N = 5$ in the finite Fourier expansions.

One may mention that introduction of non-linearity causes usual nonlinear phenomena, – slope of AFC and appearance of zone of ambiguity (Fig. 1).

Results

Fig. 1



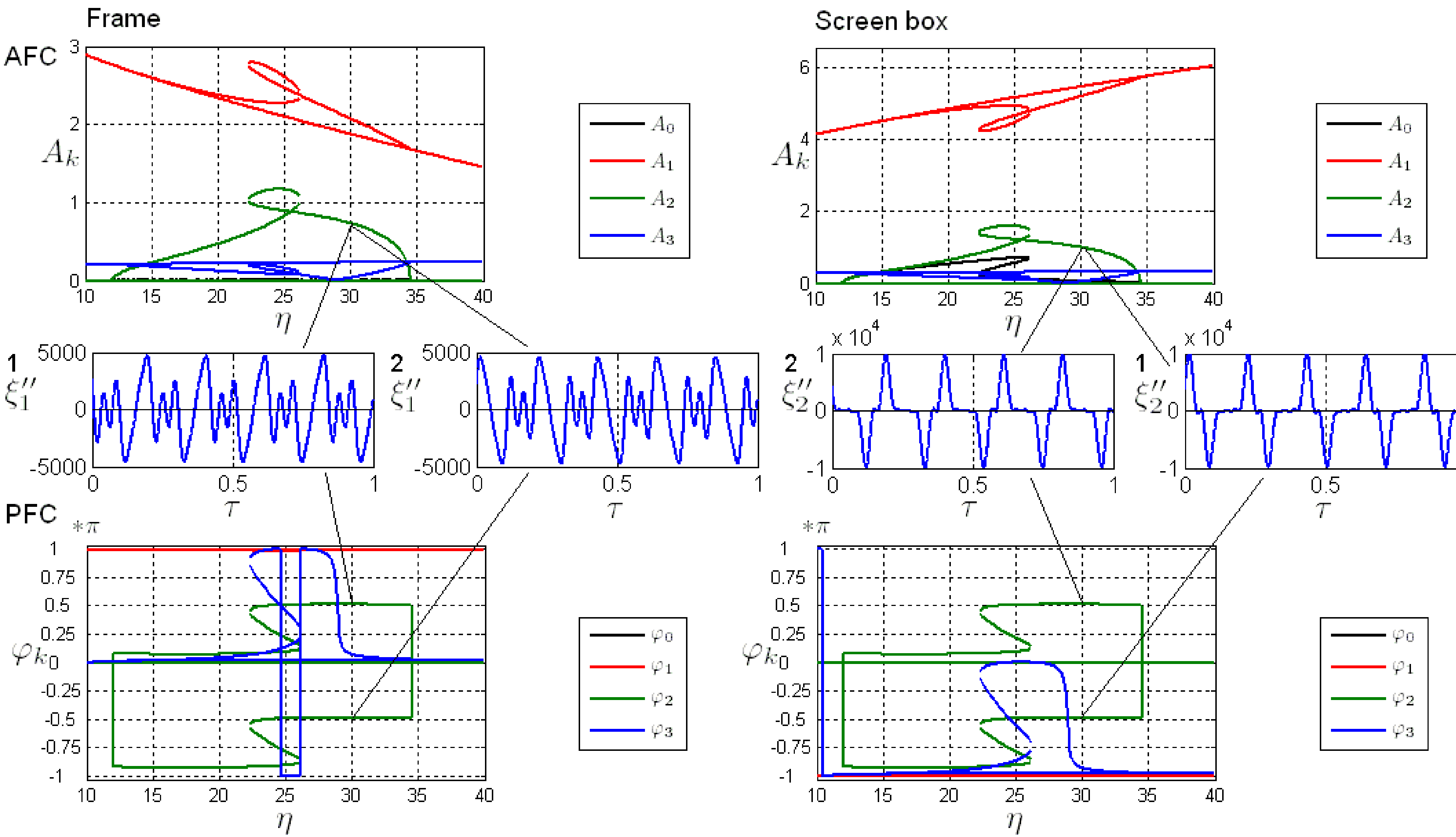
Ak – are the amplitude of *k*-th harmonic

Results

In the zone between natural frequencies ω_1 and ω_2 the different combination resonances are possible ($p\,\omega \approx |\,p_1\,|\,\omega_1 + |\,p_2\,|\,\omega_2$ [5]), where $p, p_1, p_2 \in \mathbb{Z}$. We consider only pure resonances of lower orders ($\omega \approx p_1\,\omega_1$, where $p_1 = 2, 3$ and $p\,\omega \approx p_2\,\omega_2$, where $p = 2, 3$, $p_2 = 1$ and $p = 1$, $p_2 = 2, 3$), namely, the super- and subharmonic resonances of the orders 2:1, 3:1, 1:2, 1:3. Varying the non-linearity k_{13}/k_{11} of elastic ties and scanning the domain of initial conditions we succeed to discovery some of these resonances (Fig. 2 – 2:1; Fig. 3 – 3:1; Fig. 4 – 1:3). Here the case of linear dissipation is given.

Results

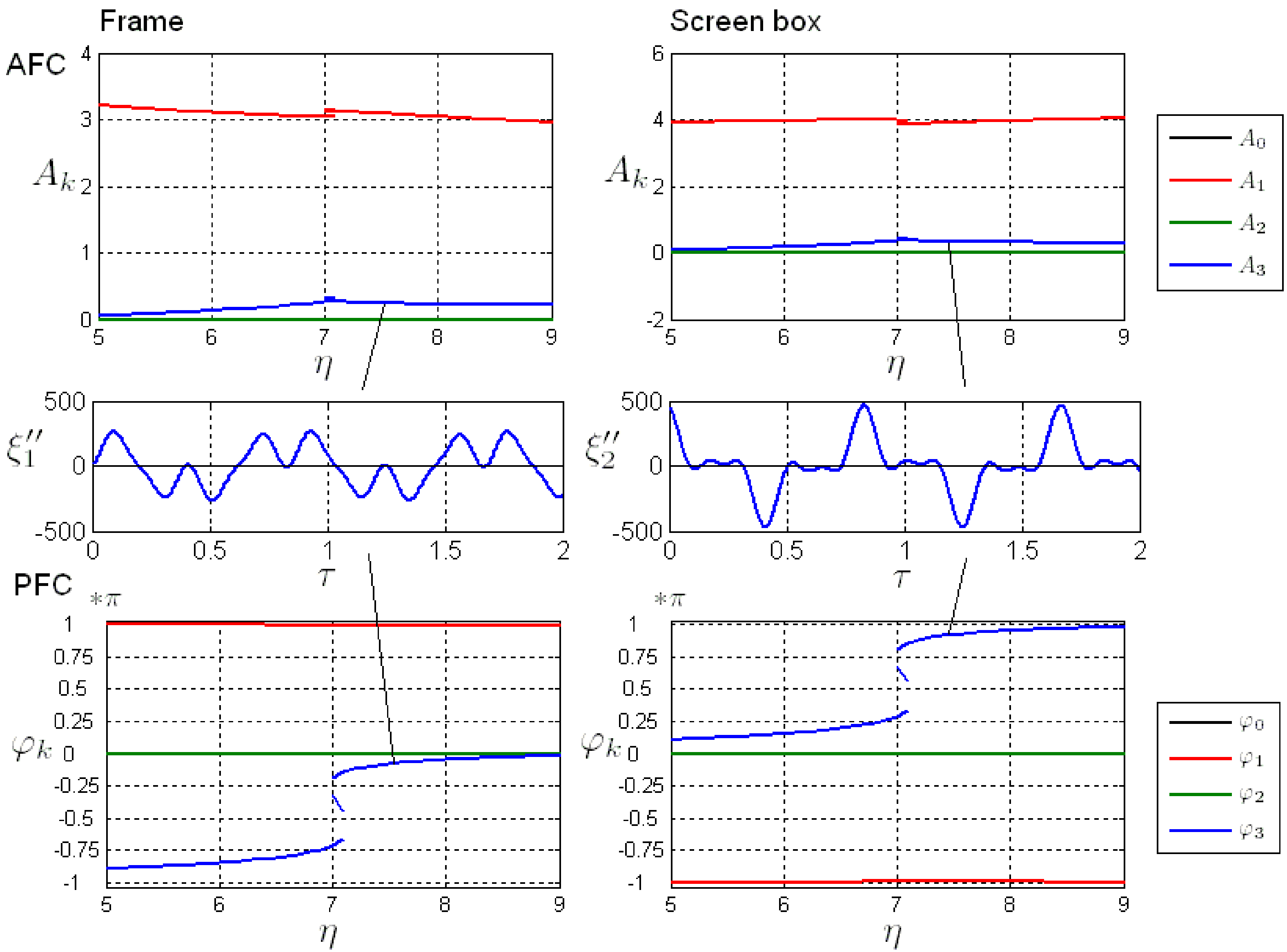
Fig. 2 – resonance 2:1, $k_{13}/k_{11} = 1$



A_k, φ_k – are the amplitude and initial phase of k-th harmonic

Results

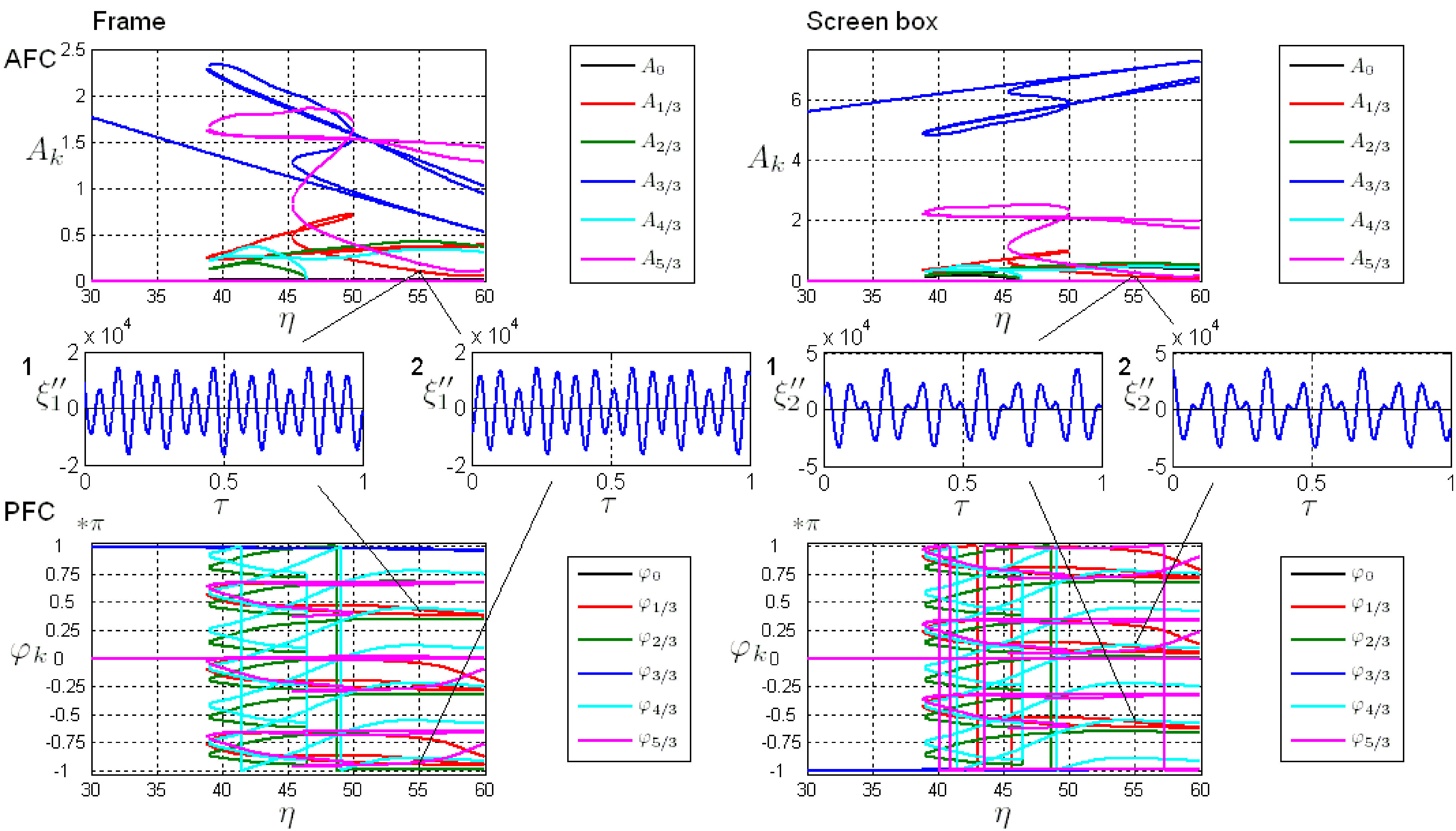
Fig. 3 – resonance 3:1, $k_{13}/k_{11} = 1$



A_k, φ_k – are the amplitude and initial phase of k-th harmonic

Results

Fig. 4 – resonance 1:3, $k_{13}/k_{11} = 1$



A_k, φ_k – are the amplitude and initial phase of *k*-th harmonic

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Results

The resonance of the order 2:1 is seemed to be one of the most perspectives. It gives an opportunity to carry out practically significant biharmonic vibrations:

$A_2/A_1 \approx 0.125 .. 0.250$, $\varphi_2 - 2\varphi_1 \approx 0 .. \pi/3$ [1, 2]

and takes place inside rather broad frequency range.

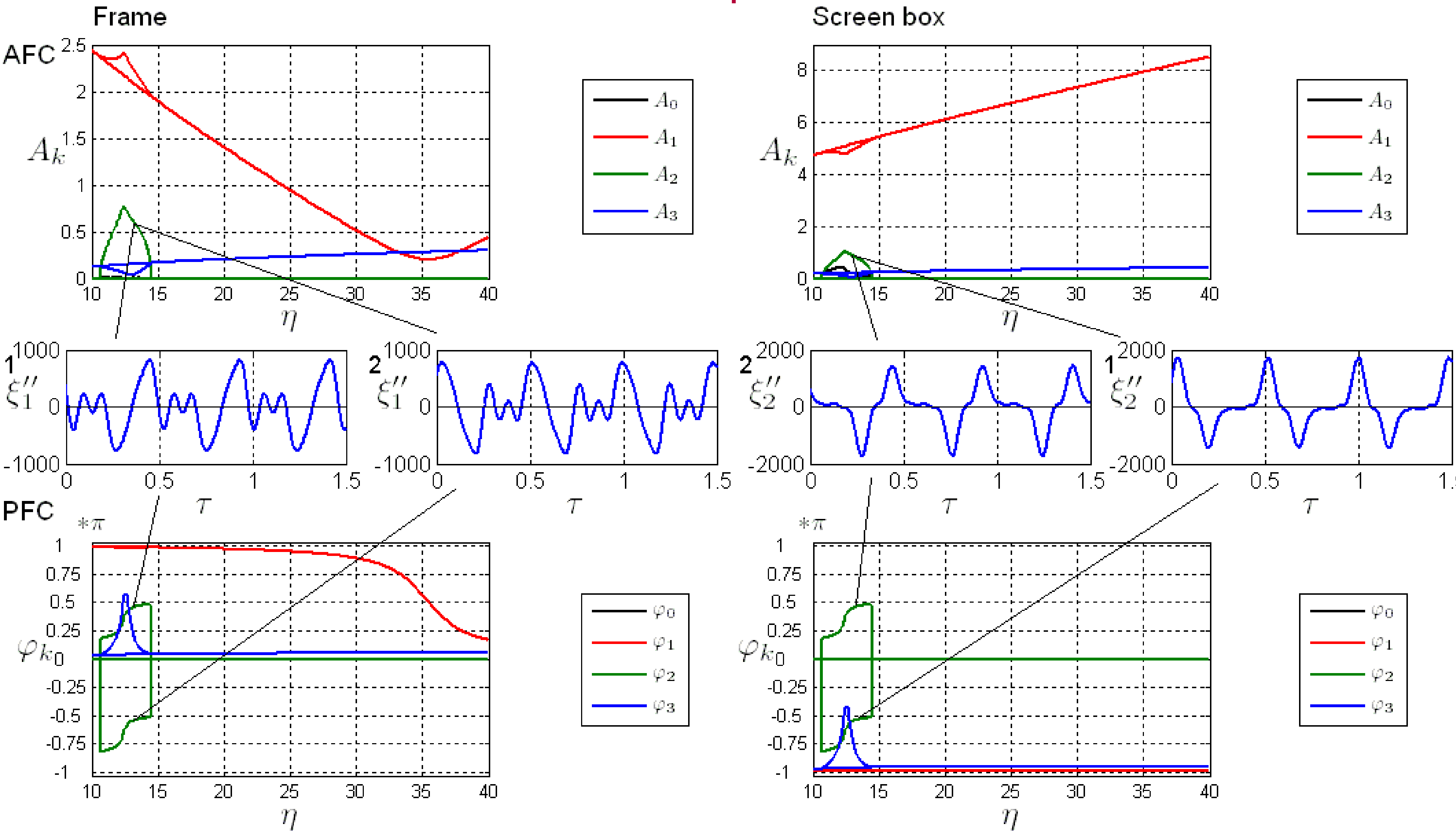
It should be noted one of its peculiarities, – the existence of opposite regimes for symmetric characteristic of elastic ties.

Results

The realization of the resonance of 2:1 is also possible and for smaller values of non-linearity (Fig. 5 – $k_{13}/k_{11} = 0.2$, Fig. 6 – $k_{13}/k_{11} = 0.5$, linear dissipation). These oscillations are resistant to dissipation (Fig. 7 – $k_{13}/k_{11} = 0.5$, non-linear resistance) and the asymmetry of elastic ties gives an opportunity to intensify the regimes of one of the symmetric groups (Fig. 8 – $k_{13}/k_{11} = 0.5$, $k_{12}/k_{11} = 0.5$).

Results

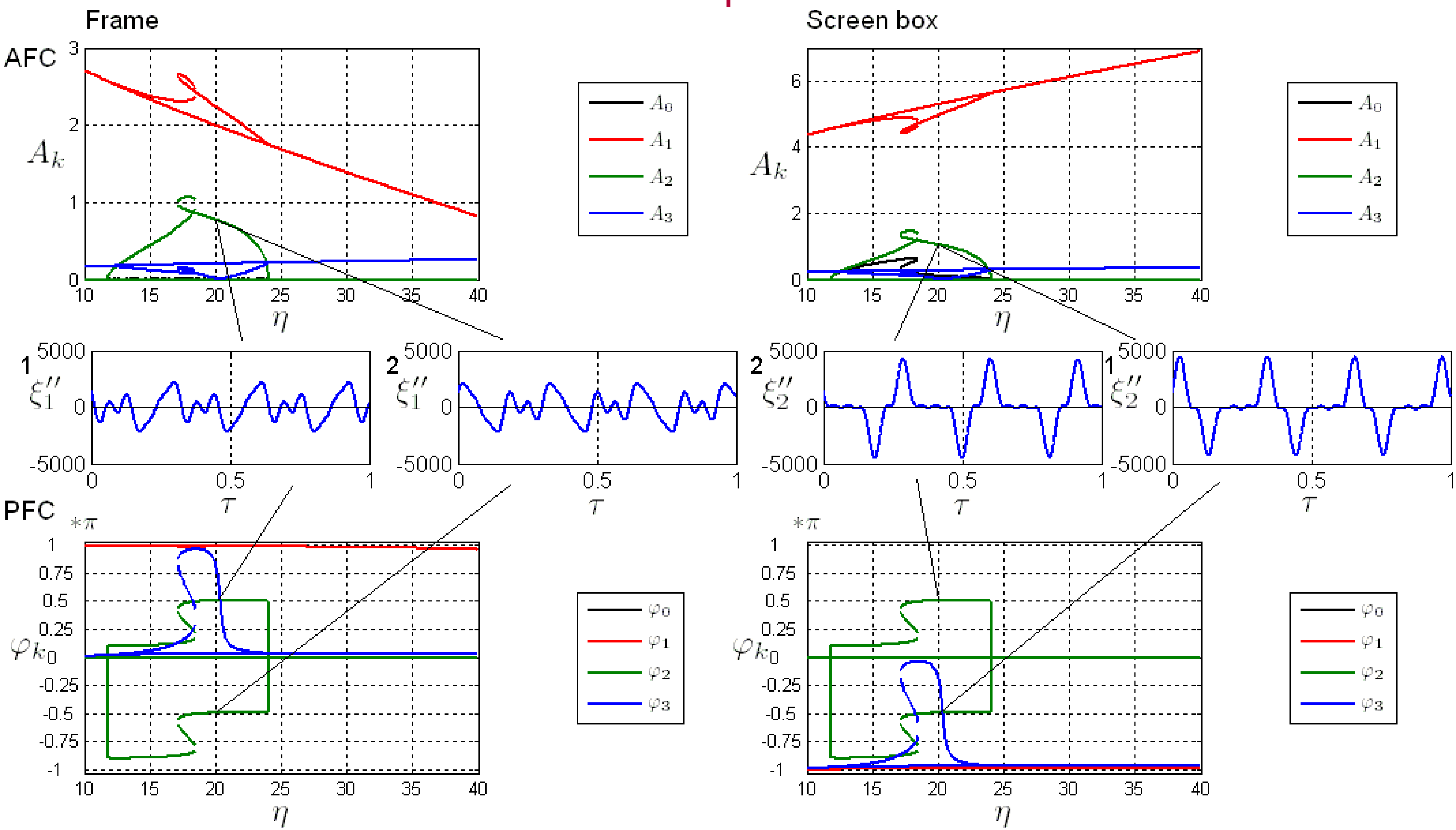
Fig. 5 – resonance 2:1, $k_{13}/k_{11} = 0.2$, linear dissipation



A_k, φ_k – are the amplitude and initial phase of k-th harmonic

Results

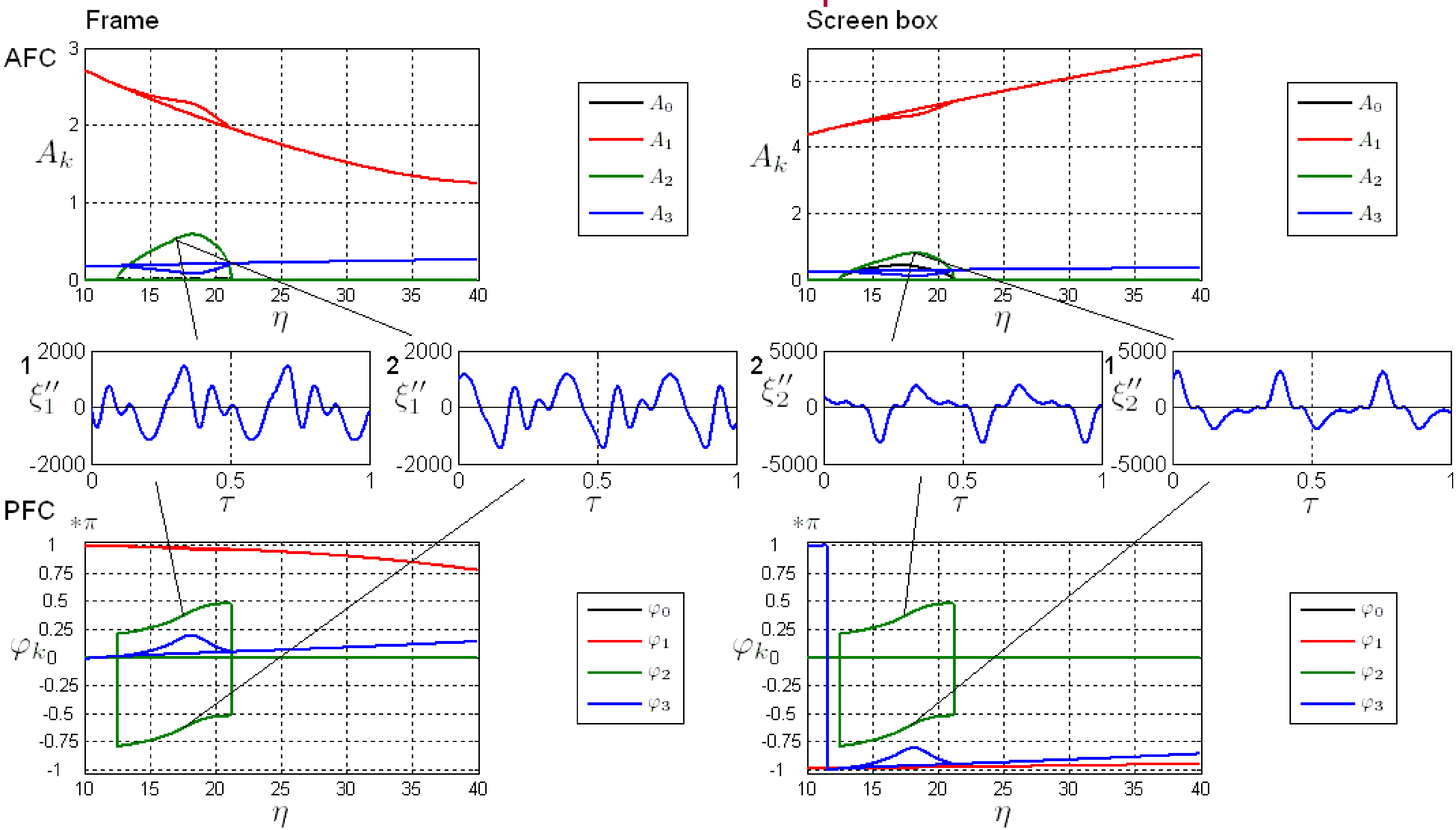
Fig. 6 – resonance 2:1, k_{13}/k_{11} = 0.5, linear dissipation



A_k, φ_k – are the amplitude and initial phase of k-th harmonic

Results

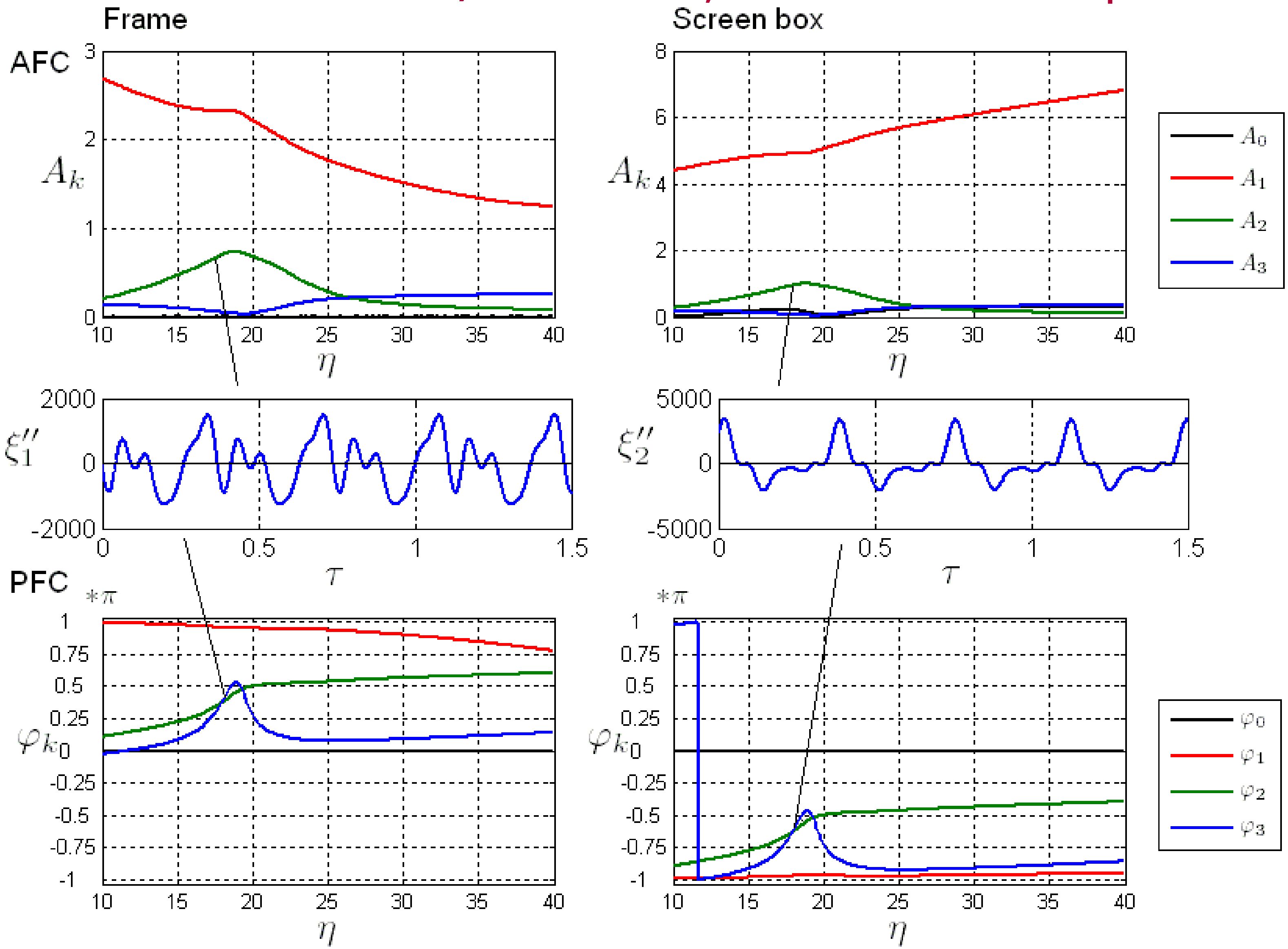
Fig. 7 – resonance 2:1, $k_{13}/k_{11} = 0.5$, non-linear dissipation



A_k, φ_k – are the amplitude and initial phase of k-th harmonic

Results

Fig. 8 – resonance 2:1, k_{13}/k_{11} = *0.5*, k_{12}/k_{11} = *0.5*, non-linear dissipation



A_k, *φ_k* – are the amplitude and initial phase of *k*-th harmonic

Results

It may be mentioned that for the given frequency of an exciter such oscillations may be realized by definite choosing the stiffness k_1 of the main elastic ties from the correlations

$$\omega_1^2 = \frac{\omega^2}{\eta^2} = \frac{k_{10} + k_{21} - \sqrt{(k_{10} - k_{21})^2 + 4k_{11}k_{20}}}{2}.$$

and expression (1) (see Slide 9).

For example, for $\eta = 17$ and $\omega = 100$ *rad/s* the value of k_1 must be taken as $\approx 0.36 \cdot 10^6$ *N/m*.

Conclusions

1. Realization of superharmonic resonance of the order 2:1 in the two masses vibrating machines gives an opportunity to form biharmonic oscillations which may be used for practical purposes, these oscillations exist for different values of nonlinearity and level of dissipation.

2. For the given frequency of an exciter the setting of this resonance may be carried out by definite choice of stiffness of the main elastic ties.

Conclusions

The nearest problems: The design of non-linear elastic ties and the conduct experiment.

Perspective problem: Studying of the influence of non-ideal exciter on the superharmonic vibrations is important for practical applications.

Literature

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