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Peculiarities of vibrational press dynamics with hard-elastic restraints in the working regime of metal powders molding

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Abstract

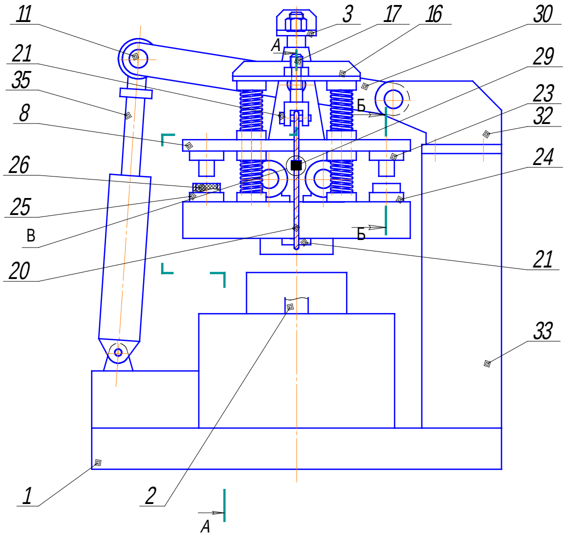
There suggested new construction of vibrational press with hard-elastic restraints for manufacturing of powder stock material of the 1-7-th complexity units. Operating principle of vibrational press is described. The results of theoretical researches of working regime of pressing operation are given and basic parameters of vibrational press, which is fitted with hard-elastic restraints – laws of motion of actuating elements, amplitude of oscillations and angles of phase displacement for asymmetrical moulding conditions depending on the physic-mechanical characteristics and powder stock material, are defined.

Key words: CONSTRUCTION, VIBRATIONAL PRESS, HARD-ELASTIC RESTRAINT, STOCK MATERIAL, WORKING REGIME

Production of powder workpieces of refractory metals is rather effectively fulfilled on vibrational presses. Vibrational presses, as a rule, consist of stand with vertical guides, ram with located on it vibration exciter of circular or directed oscillations, synchronizer providing uniform rotation of unbalance rolls of vibration exciters the other way round, press-form and mobile traverse connected with mechanical or hydraulic compression unit [1, 2]. These presses provide effective pressing of powders and formation from them powder stock material.

However these presses have complex construction, increased metal intensity and low reliability because of usage of tooth synchronizers, which may break down fast at high-frequency oscillations (from 6000 till 18000 oscillations per minute and more [1]), typical for pressing of powders of various grain-size composition, size and shape of metallic particles. Besides, vibration is transmitted to all the construction of vibrational press, which significantly reduces its working service. Considering specified disadvantages of existing equipment, there was developed new construction of vibrational press for pressing of powder workpieces, fitted with hard-elastic restraints [3].

Vibrational press for production of powder stock material by means of hot pressing [3, 4] (figure 1) contains stand 1, with guiding 2 hard connected between each other in the upper part crossarm 3, matrix 4, extracting device 5 with gearing, plate vibrator 6 with vibration exciter of directed oscillations 7. Vibrational press is fitted with reaction plate 8, located on the guiding 2 in the slide bushings 9 and pivotally connected with the help of draft 10 with mechanism of vertical displacements 11. Plate vibrator 6 with fixed on it ram 12 is retained against the reaction plate 8 with the help of coiled springs 13, placed into the nozzles 14 and 15 and pair-wise interlocked cross bars 16. Tensioning devices 17 with flexure element 20 and claw 21 may regulate compression of springs 13, which are placed symmetrically towards the centre of gravity of plate vibrator 6 both in longitudinal and transverse direction. As flexure element 20 there was used steel-wire rope with the diameter 3 mm, ends of which are kicked between two plates, which are squeezed up against each other with the help of bolts. Between reaction plate 8 and plate vibrator 6 there fixed hard- elastic restraints (HER) 22. HER consist of fixed on the reaction plate 8 hard- striking element 23 contacting with fixed on the plate vibrator 6 elastic metal support 24 (figure 1), which is fulfilled as hard nozzle 25, and cushion layer 26 (figure 2). At rest gap between working surfaces of HER 22 is equal to 0.1…0.15 of spring height 13. Herein HER 22 are located symmetrically towards the center of gravity of plate vibrator 6 both in longitudinal and transverse directions. Extracting device 5 is fulfilled as extracting ram 27, arranged on the stiff beam 28, which is fixed on the guides in the slide bushing 29. Matrix 4 is provided with inductive heat electric heaters.



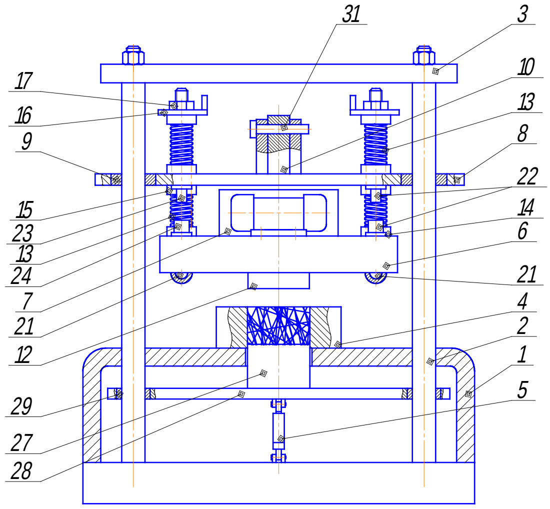


Figure 1. Construction arrangement of vibrational press with HER

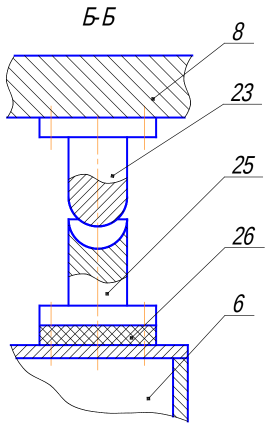


Figure 2. HER construction

Mechanism of vertical displacements 11 is fulfilled in the form of two-arm heaver 30 towards the axis 31 of draft 10, herein one end of the heaver 30 is pivotally connected with the frame 32 located at the separate basement 33, and the second its end – with hydraulic cylinder piston 35. Heaver 30 is made from two parallel plates, where through grooves are made, through which it is connected with the draft 10 by axis 31. Relation of the length of the first heaver end 30 to the length of the second end is equal to 1/5…1/8.

Work of vibrational press is fulfilled as follows. Initially hydraulic-cylinder rod 35 is fully extended, reaction plate 8 together with plate vibrator 6 and extrusion ram 12 are turned up and working surfaces of HER 22 are out of contact with each other. Into working surface of the matrix 4 there fed preliminary sorted-out mixture of metal powder and SAS. After this pump station (not specified schematically) feeds power fluid into rod chamber of hydraulic cylinder 35, in result of which the heaver 30 moves reaction plate 8 with the help of draft 10 along the guides 2 down and brings the ram 12 down on the surface of powder blend in the matrix 4. Floating suspension allows the ram 12 to rest on the powder surface providing necessary evenness of work piece surface. In such position matrix 4 together with powder and ram 12 are heated to the sintering temperature.

After this vibration exciter 7 is turned on, under the influence of which the ram 12 makes directional oscillations and subjects powder to vibroimpulsive impact. Herein reaction plate 8 goes on moving down along the guides 2 in result of which the springs 13 in plate vibrator sag rod 6 are squeezed and working surfaces of HER 22 approach. When hard striking elements 23 hit with steel support 24, the ram 12 changes to vibroimpulsive asymmetrical operating mode. In result of this its swing amplitude increases and while motion downwards the ram 12 has more intensive vibrational influence on the powder. In the moment of full interaction of working surfaces of HER 22, vibrational load is damped out and ram 12 amplitude of oscillations is equal to zero. Herein reaction plate 8 continues moving down together with the ram 12 squeezing statically the powder workpiece with the pressure 5 MPa by evolutionary mechanism of vertical displacements 11. When hydraulic fluid power develops maximum steady-state force of pressing, motion of reaction plate 8 downwards stops and vibration exciter 7turns off. Power fluid is fed into piston chamber of hydraulic cylinder 35 in result of which the piston with rod moves upwards, moving the heaver 30 itself of mechanism of vertical motions 11 together with reaction plate 8 along the guides 2 up. Springs 13 in the sag rod 6 come loose, working surfaces of HER 22 come out of the contact and ram 12, breaking away from the surface of powder workpiece, goes up. At this moment drive gear of extracting device 5, in result of which stiff beam 28 together with extrusion ram 27 moves upwards along the guides 2 and rise powder pieces on the surface of matrix 4. After extraction of powder workpiece matrix 4 is filled with powder material and working cycle is repeated.

In such a way on this vibrational press there successively realized first symmetrical vibroimpulsive moulding condition with simultaneous static ramming, then asymmetrical vibroimpulsive moulding condition with static ramming and regime of static pressing in the home stretch of formation [5].

However for effective work of such equipment, one should investigate its dynamics, study the press behavior in working regime and reasonably select its operation parameters depending on the physico-mechanical characteristics of pressing powder workpiece.

The main aim of real researches is investigation of dynamics of suggested vibrational press, determination of motion laws of its actuating elements for choice of such parameters as amplitude of oscillations, angular rate of forced oscillations, efforts of static ramming providing the quality and equal density of powder workpieces.

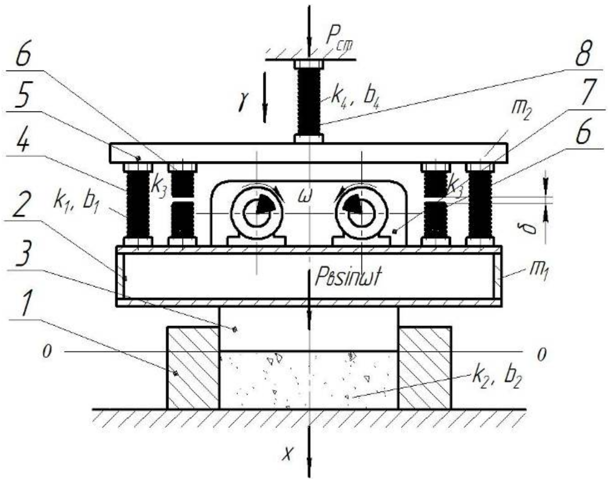


Figure 3. Calculation scheme of dynamic system of vibrating press with hard-elastic restraints

For this let us assume vibrational press with HER as dynamic system (figure 3), which turns on the matrix 1 with powder, which has rigidity rate k_2 and dissipative resistance coefficient b_2 of plate vibrator 2with ram 3 with the mass m_1, spring-mounted 4 with rigidity rate k_1 and dissipative resistance b_1 to reaction plate 5 with the mass m_2 , HER 6 with rigidity k_3, vibration exciter of oscillations 7, draft 8 with rigidity rates k_4 and dissipative resistance b_4. Dithering in the form of vertical harmonic force $P_{\text{v}} \sin \omega t$ from vibration exciter 7 acts on the ram 3. Simultaneously to the reaction plate 5 by means of draft 8 there given vertical motion under the influence of applied static force P_{st}.

Calculation of motion of ram 3 we will execute from the position 0-0, which corresponds to the initial contact of the ram 3 with powder surface.

Behavior of two-mass dynamic systems during symmetrical regime of vibrational impact is known [6, 7]. Asymmetrical regime of vibrational impact is of practical and scientific interest, under which there occur interaction of working surfaces of HER with simultaneously realized static ramming.

During periodic impact force of working surfaces of HER there appear another reaction. The law of change of reaction let us represent in the form shown in the figure 4 and suggested in the work [8]. In the working regime the gap between working surfaces of HER will vary from the greatest value to zero. That is why value δ in the figure 4 will be determined by the size between HER surfaces.

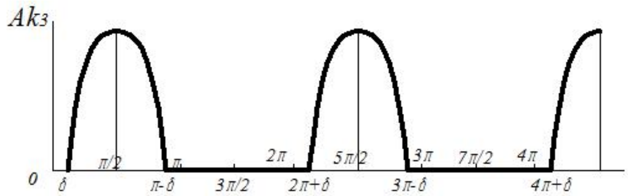


Figure 4. Law of change of reaction during interaction between striking elements and elastic steel supports of HER.

Let us describe represented in the figure 4 function $f(x)$ with period 2π [9]:

at $0 < x \le \delta$, $f(x) = 0$; at $\delta < x \le \pi - \delta$, $f(x) = Ak_3 \sin x$; at $\pi - \delta < x \le 2\pi$, $f(x) = 0$. (1)

where A – the range of deformation of cushion layer 26 in the construction of HER.

Let us expand the function $f(x)$ into Fourier's series [10] and find coefficients of expansionin the form [9]:

$$a_0 = \frac{1}{\pi}\int_0^{2\pi} f(x)\cdot dx = \frac{1}{\pi}\int_{\delta}^{\pi-\delta} Ak_3 \sin x dx = = \frac{2Ak_3}{\pi}\cdot\cos\delta \quad (2)$$

$$a_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\cdot\cos nx dx = \frac{1}{\pi}\int_{\delta}^{\pi-\delta} Ak_3 \sin x \cos nx dx = \frac{Ak_3}{\pi\left(n^2-1\right)}[-\left(-1\right)^n \cos\delta\cos\delta n - n(-1)^n \sin\delta\sin\delta n +$$

$$+ n\sin\delta\sin\delta n - \cos\delta\cos\delta n] = \begin{cases} 0, & \text{at n ordinal} \\ -\dfrac{Ak_3\cdot(2\cos\delta\cos\delta n)}{\pi(n^2-1)} & \text{at n } 2, 4, 6... \end{cases}; \quad (3)$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\cdot\sin nx dx = \frac{1}{\pi}\int_{\delta}^{\pi-\delta} Ak_3 \sin x \sin nx dx = \frac{Ak_3}{\pi\left(n^2-1\right)}[\left(-1\right)^n \cos\delta\sin\delta n - n(-1)^n \sin\delta\cos\delta n -$$

$$-\cos\delta\sin\delta n+\sin\delta\cos\delta n]=\begin{cases}0, & \text{at n evenl}\\ \dfrac{Ak_3\cdot(2\sin\delta\cos\delta n)}{\pi(n^2-1)} & \text{at n ordinal}\end{cases}; \qquad (4)$$

Force interaction of working surfaces of HER will look as follows [11]:

$$f(t)=\frac{Ak_3\cos\delta}{\pi}+\frac{Ak_3}{\pi}\left[\frac{\sin 2\delta\sin\omega t}{1}-\frac{2\cos\delta\cos 2\delta\cos 2\omega t}{2^2}+\frac{2\sin\delta\cos 3\delta\sin 3\omega t}{3^2}-\frac{2\cos\delta\cos 4\delta\sin 4\omega t}{4^2}\right] \qquad (5)$$

Elastic characteristic of this system will look as represented in the figure 7. In case of non-symmetric elastic characteristic, ram deviations on either side of equilibrium position will be different [8]. That is why modules of stated deviations A_{11} and A_{12} are connected between each other by known formula[8]:

$$\int_{-A_{11}}^{A_{12}}F(x)dx=0, \qquad (6)$$

from which one may express one of the deviations by means of another one. Function $F(x)$ for characteristic represented in the figure 5, one may describe with the integral:

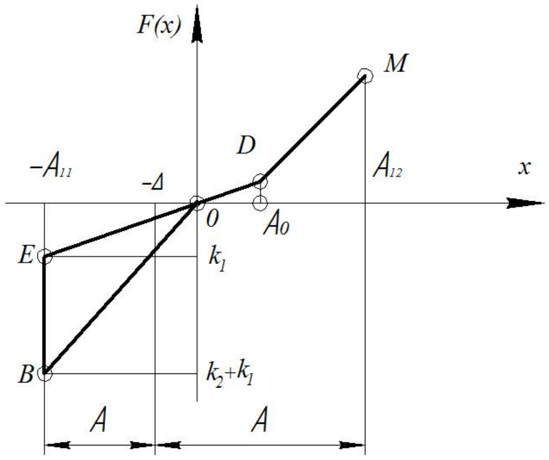


Figure 5. Elastic characteristic of dynamic system during interaction of HER

$$\Phi=-(k_1+k_2)\sqrt{A_{11}^2-(k_1+k_2)^2}-2k_1k_2-k_1\sqrt{A_{11}^2+k_1}\times\left(\frac{A_0^2}{A_{11}^2}-1\right)+A_{12}^2k_1-A_0^2k_1+k_3(A_{12}-A_0)^2=0\cdot \qquad (7)$$

Reasoning similarly [7], let us express one deviation with the help of another one:

$$A_{12}=A_{11}\sqrt{\frac{(k_1+k_2)\cdot\sqrt{A_{11}^2-(k_1+k_2)^2}+2\cdot k_1\cdot k_2-k_1\cdot\sqrt{A_{11}^2+k_1^2}}{A_{11}^2\cdot\left[(k_1+k_3)\cdot(1-k_a^2)\right]-k_a^2\cdot k_1\cdot\sqrt{A_{11}^2+k_1^2}}}. \qquad (8)$$

where k_a – coefficient of proportionality.

The center of oscillations is outdented from the beginning of coordinates on the value:

$$\Delta=\frac{1}{2}A_{11}\cdot\left(1-\sqrt{\frac{(k_1+k_2)\cdot\sqrt{A_{11}^2-(k_1+k_2)^2}+2\cdot k_1\cdot k_2-k_1\cdot\sqrt{A_{11}^2+k_1^2}}{A_{11}^2\cdot\left[(k_1+k_3)\cdot(1-k_a^2)\right]-k_a^2\cdot k_1\cdot\sqrt{A_{11}^2+k_1^2}}}\right). \qquad (9)$$

Motion equation of ram and reaction plate in vertical plane under the condition that working surfaces of HER interact with each other, will be represented by the system:

$$\begin{cases}(m_1)\cdot\ddot{x}_1+(b_1+b_2)\cdot(\dot{x}_1-\dot{x}_2)+\left(k_1+k_2+\dfrac{k_3\cdot\cos\delta}{\pi}\right)\cdot(x_1-x_2)=\\ =-\left[k_1+k_2+\dfrac{k_3\cdot\cos\delta}{\pi}\right]\cdot\Delta+P_в\sin\omega t-\dfrac{Ak_3}{\pi}\cdot[(\sin 2\cdot\delta)\cdot\sin\omega t-\\ -\dfrac{(2\cos\delta\cos 2\delta)\cdot\cos 2\omega t}{4}-\dfrac{(2\sin\delta\cos 3\delta)\cdot\sin 3\omega t}{9}-\dfrac{(2\cos\delta\cos 4\delta)\cdot\cos 4\omega t}{16};\\ m_2\cdot\ddot{x}_2+(b_4+b_1)\cdot\dot{x}_2-b_1\cdot\dot{x}_1+\left(k_4+k_1+\dfrac{k_3\cdot\cos\delta}{\pi}\right)\cdot x_2-\left(\left[k_1+\dfrac{k_3\cdot\cos\delta}{\pi}\right]\right)\cdot x_1=0,\end{cases} \qquad (10)$$

solution of which for steady-state oscillations of dynamic system looks as follows:

$$x_1 = -\Delta + A_1' \sin(\omega_1 t - \theta_1') + A_1'' \cos(\omega_2 t + \theta_1'') + A_1''' \sin(\omega_3 t - \theta_1''') + A_1'''' \cos(\omega_4 t + \theta_1''''), \quad (11a)$$

$$x_2 = -\Delta + A_2' \sin(\omega_1 t - \theta_2') + A_2'' \cos(\omega_2 t + \theta_2'') + A_2''' \sin(\omega_3 t - \theta_2''') + A_2'''' \cos(\omega_4 t + \theta_2''''), \quad (11b)$$

where A_1', A_1'', A_1''', A_1'''' and A_2', A_2'', A_2''', A_2'''' – amplitude of oscillations of ram and reaction plate respectively at angular rate ω_i, where $i = 1 \ldots 4$;

$$\omega_1 = \omega; \quad \omega_2 = 2\omega; \quad \omega_3 = 3\omega; \quad \omega_4 = 4\omega; \quad (12)$$

$\theta_1', \theta_1'', \theta_1''', \theta_1''''$ и $\theta_2', \theta_2'', \theta_2''', \theta_2''''$ – angles of phase displacement between amplitude of disturbance and motion along the corresponding harmonic curve.

$$A_1' = \frac{P_в - \frac{Ak_3}{\pi}(\sin 2\cdot\delta)\cdot\sqrt{a^2+b^2}}{q(1)}; \quad (13)$$

$$A_1'' = \frac{\frac{Ak_3}{\pi}\cdot\frac{(2\cos\delta\cos 2\delta)}{4}\cdot\sqrt{a^2+b^2}}{q(2)}; \quad (14)$$

$$A_1''' = \frac{\frac{Ak_3}{\pi}\left(\frac{2\sin\delta\cos 3\delta}{9}\right)\cdot\sqrt{a^2+b^2}}{q(3)}; \quad (15)$$

$$A_1'''' = \frac{\frac{Ak_3}{\pi}\cdot\left(\frac{2\cos\delta\cos 4\delta}{16}\right)\cdot\sqrt{a^2+b^2}}{q(4)}; \quad (16)$$

$$A_2' = \frac{P_в - \frac{Ak_3}{\pi}(\sin 2\cdot\delta)\cdot\sqrt{c^2+d^2}}{q(1)}; \quad (17)$$

$$A_2'' = \frac{\frac{Ak_3}{\pi}\cdot\frac{(2\cos\delta\cos 2\delta)}{4}\cdot\sqrt{c^2+d^2}}{q(2)}; \quad (18)$$

$$A_2''' = \frac{\frac{Ak_3}{\pi}\cdot\left(\frac{2\sin\delta\cos 3\delta}{9}\right)\cdot\sqrt{c^2+d^2}}{q(3)}; \quad (19)$$

$$A_2'''' = \frac{\frac{Ak_3}{\pi}\cdot\left(\frac{2\cos\delta\cos 4\delta}{16}\right)\cdot\sqrt{c^2+d^2}}{q(4)}; \quad (20)$$

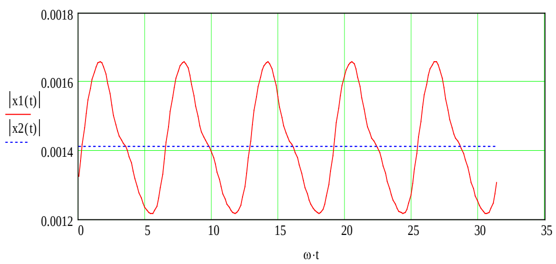
$$a = C_{22} - M_{22(i)}\cdot\omega_i^2; \quad b = B_{22(i)}\cdot\omega_i; \quad c = C_{12}; \quad d = B_{12}(i)\cdot\omega_i;$$

$$q(i) = (C_{11} - M_{11(i)}\cdot\omega_i^2)\cdot(C_{22} - M_{22(i)}\cdot\omega_i^2) - C_{12}^2 - \omega_i^2\cdot(B_{11(i)}\cdot B_{22(i)} - B_{12(i)});$$

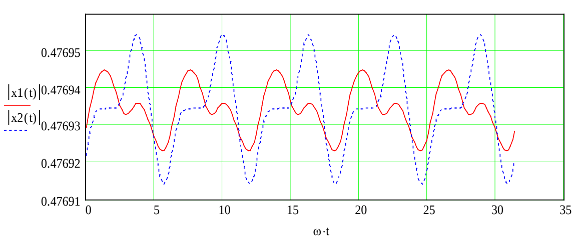
$$M = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}; \quad B = \begin{bmatrix} B_{11} B_{12} \\ B_{21} B_{22} \end{bmatrix} = \begin{bmatrix} b_1 + b_2 & -(b_1+b_2) \\ -b_1 & (b_4+b_1) \end{bmatrix}; \quad C = \begin{bmatrix} C_{11} C_{12} \\ C_{21} C_{22} \end{bmatrix} = \begin{bmatrix} k_1 + k_1 & -(k_1+k_2) \\ -k_1 & (k_4+k_1) \end{bmatrix};$$

$$\theta^i{}_1 = arctg(ib/a); \quad \theta^i{}_2 = arctg(id/c). \quad (21)$$

In the figure 6 there shown laws of ram motion and reaction plate in the case of interaction of working surfaces of HER. Data obtained with the help of laboratory sample of vibrational press with the following main parameters: mass of ram together with vibration plate and vibration exciters $m_1 = 71$ kg, mass of reaction plate $m_2 = 70{,}2$ kg, amplitude of disturbance $P_B = 10000$ N, total spring stiffness in plate vibrator sag rod $k_1 = 235440$ N/m; total stiffness of HER $k_3 = 200000$ N/m, stiffness of draft on the reaction plate $k_4 = 3\cdot 10^9$ N/m, draft damping coefficient $b_4 = 594575$ N·s/m, angular rate of oscillations $\omega = 1465$ rad/s [9].



a)



b)

Figure 6. Laws of motion of ram $x1(t)$ and reaction plate $x2(t)$ of vibrational press depending on the angular coordinate ωt

a) – at dynamic module of powder elasticity $E = 2{,}5 \cdot 10^6$ Pa and density $\rho = 1020$ kg/m^3;

b) – at dynamic module of powder elasticity $E = 26 \cdot 10^9$ Pa and density $\rho = 1250$ kg/m^3. Laws of motion are developed for the case of pressing of cylindrical sample with the diameter *d=0.04* m and height *H=0.03* m from the titanium powder with average particle size of spherical form 2 mkm.

On the base of existing analogues there suggested new construction of vibrational press with HER for manufacturing of powder workpieces of 1-7-th groups of complexity by means of hot pressing. It has low energy content (it is completed with two electromechanical vibrators with total capacity 0.5 kW and capacity of pump station motor exceeds 2.5 kW). Usage in construction of vibratinal press of coiled springs, located according to differential circuit, is enough and reliable for manufacturing of workpieces, it allows to amortize vibrational load from vibration exciters. There increases swing amplitude at closing phase of pressing due to impact interaction of HER working surfaces (herein there excluded mass of loading plate). In opposed equipment, vibration is transmitted to all the construction.

Analysis of given dependencies shows that in case of HER usage, location of dynamic system is moved from the equilibrium position on the value Δ (fig. 5). This means that dynamics system chooses new equilibrium position. Simultaneously there rises asymmetry of ram oscillations towards the equilibrium position. In dynamic system there developed impact impulse phenomena, which lead to the fact that compression stress, arising in powder workpiece, exceeds tensile stress. These phenomena significantly intensify pressing process due to acceleration intensification, which are being developed in each isolated vibratory impulse. Besides, the pause between impacts creates so called effect of “unloading”, which gives the possibility to reduce residual stress in powder workpiece, increase its “elasticity” and contributes closer packing of metal particles.

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