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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

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DYNAMIC ANALYSES OF A CLUTCH OF CRANK PRESS

Abstract. The paper studies the dynamic of a clutch of crank press. At present, the dynamic study of clutch of the crank presses, with account of interaction with other blocks, is a priority. The crank press contains movable parts and assemblies, the mass of which is from one hundred kilograms to several tons. These parts and assemblies are connected cyclically by clutch of crank press with high speeds and they are subject to large dynamic loads. To simulate and analyze the movement of crank press with clutch, a software package: SimulationX is used. SimulationX is a software package for modeling and analyzing the dynamics and kinematics of cars, industrial equipment, electric, pneumatic and hydraulic drives, hybrid engines, etc. As a result of dynamic calculation, important dynamic parameters of the crank press clutch and working slide are determined. It is shown that dynamic loads sharply increase almost in all blocks of the crank press when the clutch is switched on.
Key words: dynamics, crank press, clutch, slide, moment, oscillations, SimulationX.

Introduction. Crank press is a machine with a slide-crank mechanism, designed for stamping various parts [1-5]. During the work of crank press, significant dynamic loads occur in blocks and mechanisms, especially when it is turned on. These dynamic loads are associated with operational feature of the crank press, which includes shock cyclic loads with sudden, almost immediate stops. In this connection, the study of the dynamics of clutch of the crank presses, is of great interest. Figure 1 shows block diagram of the press [1].

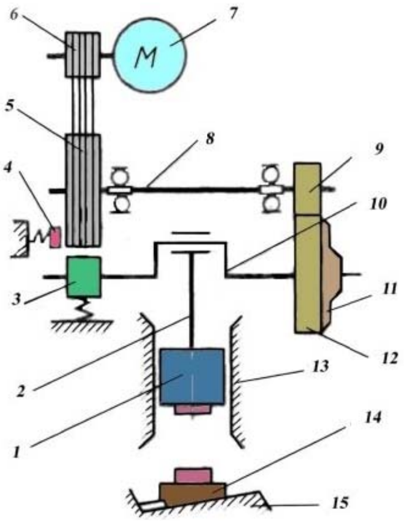


Figure 1 –
Block diagram of crank press:
1 - slide, 2 - crank rod,
3 - brake of crank mechanism,
4 - flywheel brake, 5 - flywheel,
6 - sheave, 7 - electric motor,
8 - drive shaft, 9 - drive gear,
10 - crank shaft, 11 - clutch,
12 - driven gear, 13 - crosshead guide,
14 - wedge-type platten,
15 - press board

Operating principle of the crank press (see figure 1): the crankshaft 10 rotates about an axis and activates through the crank rod 2 a slide 1 with punch. The press drive consists of an electric motor 7, a V-belt drive and a flywheel 5. The press clutch 11 is located on the end of the crankshaft 10. Brake 4 serves to stop the press. Brake 3 serves to stop the crank mechanism of the press.

The drive of the press is carried out from an electric motor with a flywheel. Since the parameters of motion of the actuating link – tool slide, depend only on the kinematic links of the main working mechanism, crank presses are referred to uncontrolled machines with limited movement of the tool slide, equal to the double radius of the crank or double eccentricity of the eccentric. Asynchronous electric drive accelerates with power flywheel and all the guide links with the corresponding moment of inertia to the steady angular velocity during the technological cycle and dispatches kinetic energy of the rotational motion of the flywheel to it. In this case, the crank shaft and all driven members of the crank-slider mechanism are fixed, the slide is in the upwardmost (initial) position. When the clutch 11 is turned on, the crank shaft (cranked axel 10) is rotated, driving and driven members move together, the slide with fixed upper die make a working stroke. After completion of the working stroke, the slide makes a return stroke. If the press works by single stokes, then when the slide reaches its initial position, the clutch 11 is turned off and at the same time the brake 3 is turned on. The slide stops in the upper (initial) position and the work cycle is completed.

Feed clutch of the crank press. Coupling clutches and brakes are provided in the press drive system, which make it possible to transmit motion to the actuator (operating mechanism) from the drive, but at the right time, vice versa, to stop the slide of mechanism without turning off the electric motor [1].

Switching on and off, and interlocking of the clutch and brake are performed using the control system [1]. The clutch, brake and control system form the so-called press start system, on the performance of which the reliability and safety of operation of the press as a whole is depended. The press start system works under difficult conditions – a large number of turning on per unit of time, on-off limited time (<0.1c), absolute security in operation.

Crank press's clutches should transmit moment of rotation up to 16 MNm and at the same time ensure the life of the structure and dampen vibrations, arising during the coupling [2]. The presses start systems and friction disc clutches most fully meet these requirements.

Disc clutches may be – single and multiple disc. Single-disc compact clutches with friction inserts are widely used, manufactured from retinax ФК-16А, ФК-24А or ferodo (figure 2). In pair with inserts, discs of steel 5, cast iron СЧ25 are working.

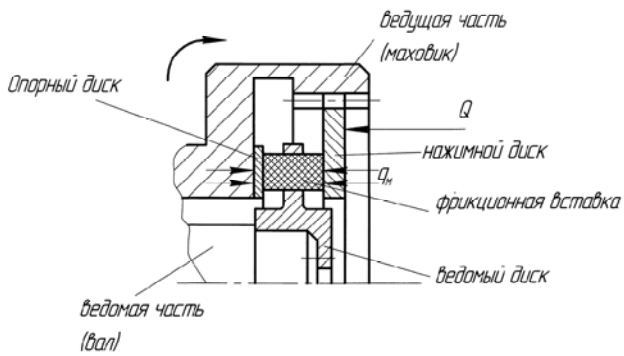


Figure 2 – Scheme of a single-disc friction clutch

The moment transferred by the one-disk frictional clutch (figure 2):

$$M_m = 2f \cdot q_m \cdot R_{cr} \cdot n \cdot F_{bc},$$

where f – friction coefficient f = 0.35; q_m – friction surface pressure q_m = 0,6-1,2 Мпа; R_{cr} – average insert radius; n – number of inserts; F_{bc} – work surface area of insert. Single-disc clutches transfer moment up to 140000 Нм, multiple-disc – up to 100 MNм with ferodo coverings.

The scheme of the multi-disc friction clutch is shown in figure 3.

Moment, transferred by the clutch:

$$M_m = \int_{R_2}^{R_1} 2\pi f \cdot m\rho \cdot d\rho \cdot \rho q_m = \frac{3}{2}\pi(R_1^3 - R_2^3) f q_m m$$

where q_m=0.4-0.6 Мпа (at n_m<180 об/min); q_m=0.3Мпа (at n_m>180 об/min); f=0.35; m

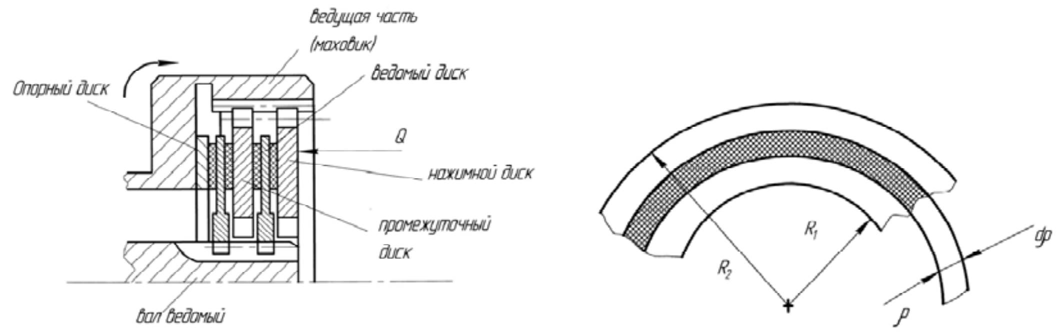


Figure 3 – Scheme of the multi-disc friction clutch

Calculation of disc friction clutches. Calculation of disc friction clutches made on the transmitted torque, specific force on the rubbing surfaces and the value of the wear rate (calculation for heating).

Original for the calculation is the nominal moment M_K^H, operating on the main shaft, which is driven to the clutch shaft. The required torque transmitted by the clutch [1]:

$$M_m^{mp} = \frac{\beta M_K^H}{i_m \eta_m}$$

where β = 1.1-1.3 is a factor of safety, taking into account the inertia and oscillation of the coefficient of friction;

$$M_K^H = m_K^H \cdot P_H,$$

m_K^H - reduced (modified) shoulder corresponding to the nominal angle α_H ; P_H - nominal force; $i_m \eta_m$ - gear ratio and transmission efficiency from the coupling shaft to the main shaft (when installing the coupling on the main shaft $i_m \eta_m$ = 1).

It is necessary that the torque transmitted by the coupling $M_m \geq M_m^{mp}$. Based on the moment (torque) transmitted by the clutch (coupling) press M_m, determine the force (effort) on the slider:

$$P_m = \frac{M_m}{m_K}$$

The results of the calculation P_m are entered in the table and build a graph of efforts on the slider based on the moment transmitted by the clutch $P_m = f(\alpha)$. When the clutch is turned on, part of expended energy goes into heat, causing heating of parts, friction inserts and linings. As an indirect thermal calculation, a performance calculation is applied in terms of wear. For this, the work balance is made when the clutch is turned on (at the initial moment, the speed of the driven disks due to slippage is somewhat less). Over a period of turn-on of the coupling t - the leading part transmits the moment M_m, moreover, during this time it turns for angle α_1. The balance of work when the clutch is turned on is as follows:

$$M_m \alpha_1 = \frac{I_{bm} \omega_H^2}{2} + M_c \alpha_2 + A_{mp},$$

where I_{bm} – moment of inertia of clutch's driven parts, reduced to clutch (coupling) shaft; M_c – moment of resistance of the driven parts; α_2 – the angle of rotation of the driven parts in a time t; A_{mp} – work spent on friction in the clutch (coupling). Angles α_1 and α_2 can be determined from the equation of dynamics for the driven parts.

$$I_{bm}\frac{d\omega}{dt}+M_m-M_c$$

take up I_{bm}, M_m, M_c as a constant for the period *t* (turn-on):

$$I_{bm}\omega_M=(M_m-M_c)t$$

from where:

$$t=\frac{(M_m-M_c)}{I_{bm}\omega_M}$$

Angular rotational rate of the driven part (at a known time *t*):

$$\omega_M=\frac{(M_m-M_c)t}{I_{bm}}$$

Turning angle of driven disks (substituting instead *t* its value):

$$\alpha_1=\omega_M t=\frac{I_{bm}\omega_M^2}{M_m-M_c}$$

Turning angle of driven part:

$$\alpha_2=\int_0^t\omega_M t=\int_0^t\frac{M_m-M_c}{I_{bm}}\cdot tdt=\frac{M_m-M_c}{I_{bm}}\cdot\frac{t^2}{2}=\frac{I_{bm}\omega_M^2}{2(M_m-M_c)}$$

substituting in the equation of the balance of work α_1 и α_2 will get:

$$A_{mp}=\frac{M_m}{M_m-M_c}\cdot\frac{I_{bm}\omega_M^2}{2}$$

Taking $\frac{M_m}{M_m-M_c}=\alpha_M$ = 1,05-1,16 (coupling on the main shaft) α_M =1,25-1,35 (coupling on a transmission shaft).

If the friction work is divided by the area of friction surfaces *F* [m^2] and multiplied by the actual number of turn-ons per minute, we get the wear rate [1]:

$$K_{izn}=\alpha_M\cdot\frac{I_{bm}\omega_M^2}{2F}\rho\cdot n_H\le[K_{izn}],$$

where ρ - use factor of number of moves, n_H - calculated speed of the press, the values are given in table 1.

Table 1

Type of equipment	n_H	ρ
1. Sheet-plate stamping press, ventilating, bending, high capacity cutoff	<15	0.7-0.85
2. Also of average capacity	20-40	0,50-0,65
3. Horizontal forging machine, plate cutter (sheet metal shears), shearing and multi-function, sheet metal press of average capacity	25-60	0,55-0,70
4. Hot forging crank driven press, embossing, high capacity varietal shears	70-110	0,30-0,45
5. Also of average capacity	40-70	0,45-055
6. Multi-operated sheet-plate stamping and shearing presses, high speed	90-120	0,20-0,45

[K_{izn}] = 0.7-0.8 M J/м^2 min – single disk clutches with retinax inserts.
[K_{izn}] = 0.4-0.5 M J/м^2 min – multi disk clutches with ferodo plates.

Formula shows that with decreasing ω the wear is reduced (but the moment is growing). After checking the wear rate, the piston diameter is selected based on the pressure in the pneumatic cylinder. p_c = 0,3-0,4MPa.

To improve the operation of the clutch, two-stage feed is made, and the pressure increases until the time of the working operation. [1].

Dynamic model of a crank press with feed clutch. When modeling the dynamics of a crank press with the feed clutch and simulation of the operation of the feed clutch, various software systems are used [6-17].

To simulate and analyze the movement of a crank press with the feed clutch, this work uses a software package: SimulationX [18].

SimulationX – is software for modeling and analyzing the dynamics and kinematics of automobiles, industrial equipment, electric, pneumatic and hydraulic actuators, hybrid engines, etc. It is used for the design, modeling, simulation, analysis and virtual testing of complex mechatronic systems. It simulates the behavior and interaction of various physical objects of mechanics (1D and 3D), driving equipment, electrical, hydraulic, pneumatic and thermodynamic systems, as well as magnetism and analog and digital control systems. It performs the following tasks: system modeling in the time and frequency domains; simulation of transient processes in linear and nonlinear systems or stationary simulation to calculate a model in a periodic state (nonlinear or linear). Model libraries are divided by simulated physical applications. Tools and interfaces complement SimulationX for integrated analysis of systems and structure.

Figure 4 shows dynamic model of a crank press with feed clutch on the SimulationX software package [19-22].

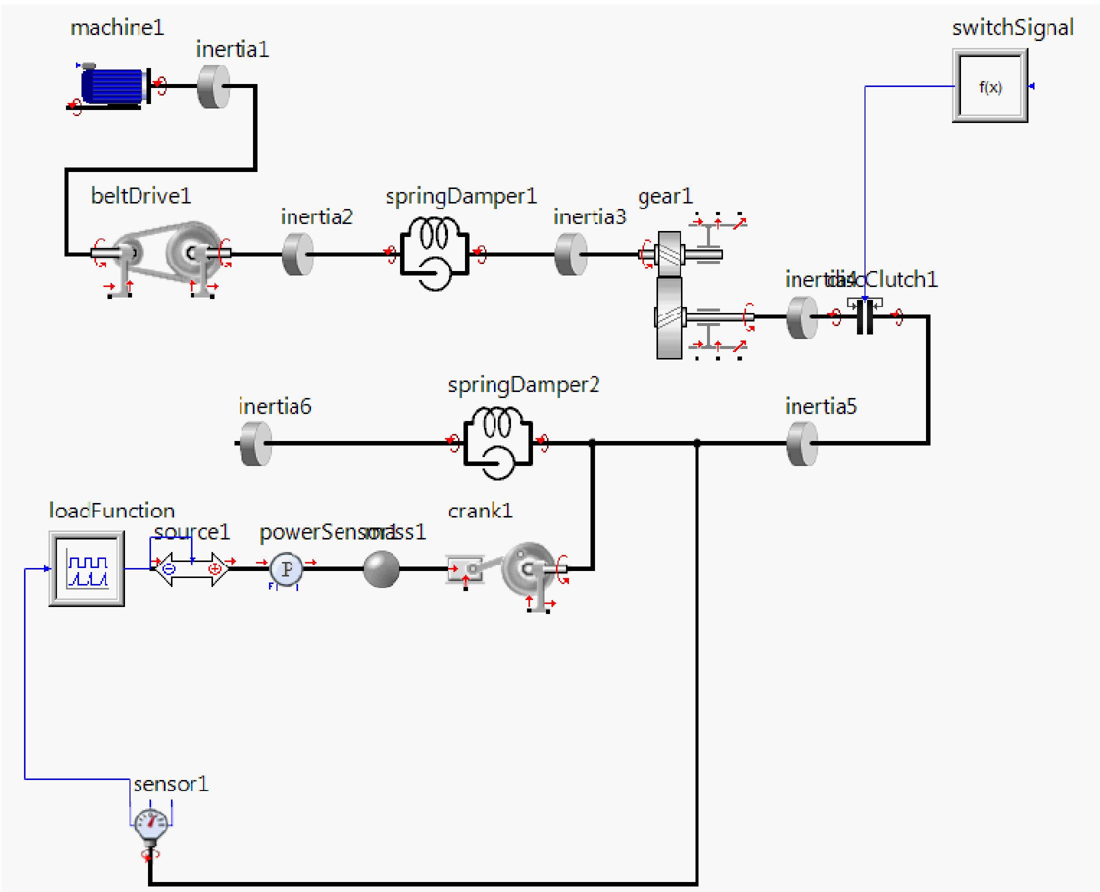


Figure 4 – Dynamic model of a crank press with feed clutch on the SimulationX software package

The elements of the SimulationX library that were used to compile the model are shown in figure 5.

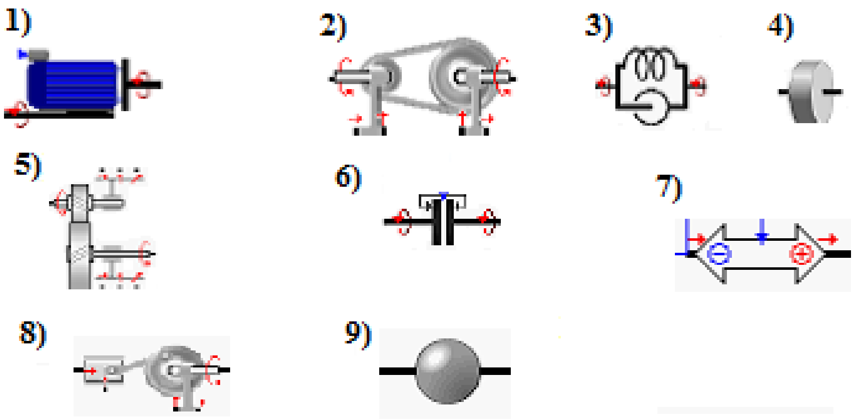


Figure 5 – The elements of the SimulationX library

List of symbols (see figure 5) and description of the elements of the SimulationX library:

1 – Asynchronous motor. This element simulates the simple asynchronous motor. The model is based on the stationary characteristics of the motor. This element models the asynchronous motor with sufficient accuracy when simulating the drive of a machine. It simulates engine starting, transient and steady-state processes, depending on the load and the speed of rotation of the shaft.

2 – Belt drive. This element models the operation of belt transmission, with the account of elastic-dissipative characteristics. The model takes into account the reactions and movements in the bearings of the pulleys of the belt drive that allows you to simulate the interaction of the transmission with the base.

3 – Spring - Damper – backlash. The model represents elastic and / or damped behavior between the rotational links, with the possibility of taking into account backlash. Springs always acts in parallel with the dampers.

4 - Inertia. This element models the moment of inertia of a rotary link. It is also possible to simulate a variable moment of inertia.

5 – Gear. The Transmission element is an ideal converter of rotational movements and forces operating between two components in a rotating mechanical system. It works as an ideal converter without taking into account dissipation and, fulfills the specified gear ratio or the conditions of power balance in input and output. The Transmission element allows you to model fixed and variable ratios for angles or velocities in input and output.

6 – Disc clutch. The Model Disc Clutch is a component that turns on or interrupts the flow of torque (and therefore power transmission) between the drive components. The model can be used to simulate multi-plate clutch of machines or gearboxes. In addition, it is possible to simulate the friction of the brakes (for example, an automatic transmission). Elasticity, damping and clutch friction parameters can be considered. In transmission of the models, the clutch can be activated by a signal from the switch.

7 – External force. This type of element allows you to simulate the forces between two components, or only on one component of the mechanical model. It provides universal, functional power transfer in the mechanical model.

8 – Crank mechanism. The element models a slide-crank mechanism, taking into account the backlash in the hinges, the elastic-dissipative properties of the connecting rod.

9 – Mass. This element models the mass of a linear link. Variable mass modeling is also possible.

Initial parameters of the model:

Crank press motor power W=0.5 квт, rated engine speed n=450 rpm. The numerical values of the dimensions, moments of inertia of the nodes of the crank press and the stiffness of the shafts are taken from [1].

The nominal force developed by the slide of the slide-crank working mechanism in the area before the extreme low point of the slide's stroke is modeled by a sine-wave signal generator (loadFunction) and linear force (load) (figure 6). This load force depends on the angle of the crank. The maximum force is reached at the lower point of the slide’s stroke and is equal to 4000n.

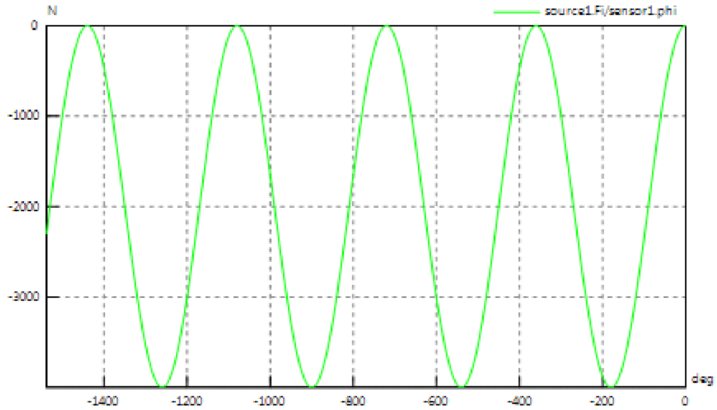


Figure 6 – The nominal force, developed by the slide of the slide-crank working mechanism

Parameters of the feed clutch of the crank press are shown in figure 7.

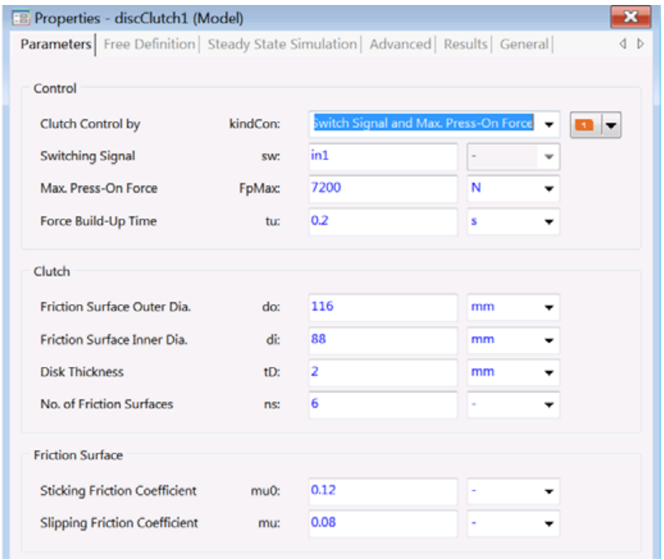


Figure 7 – Parameters of the feed clutch of the crank press

Simulation results: Feed clutch of the crank press is activated on the 10^{th} second and connects the moving flywheel to the actuator. Figure 8 shows the moment transmitted by the feed clutch.

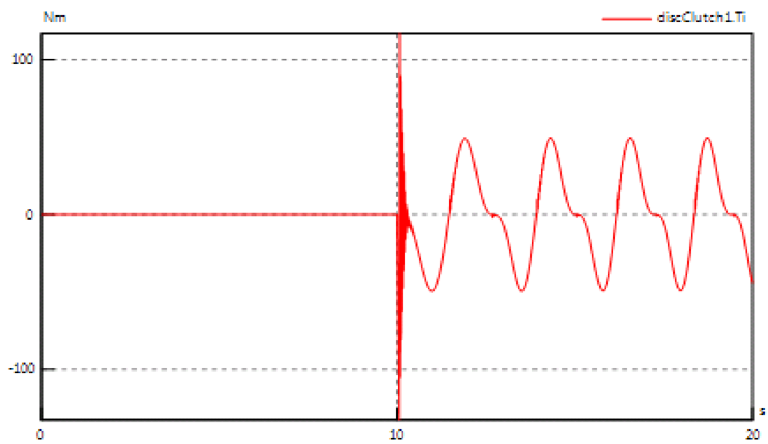
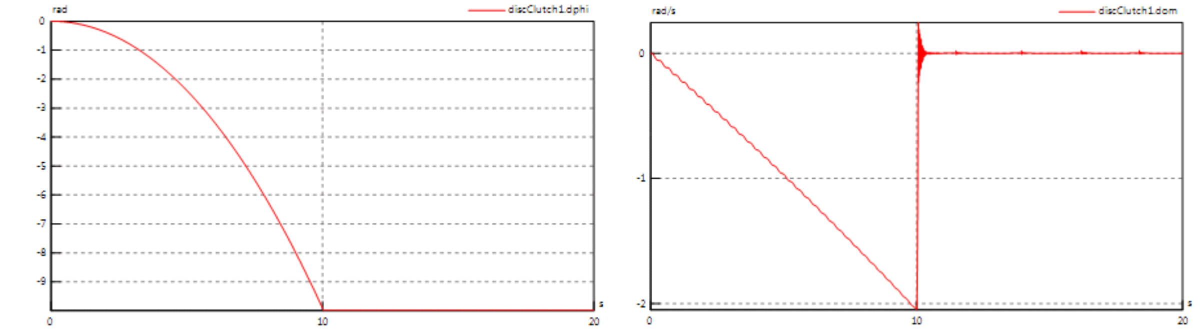


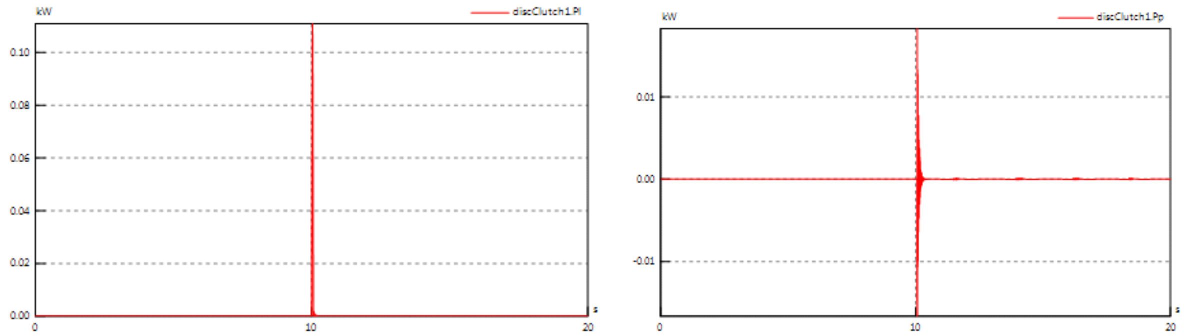
Figure 8 – moment transmitted by the feed clutch

Figures 9 and 10 show the various data of the feed clutch of the crank press



(a) (б)

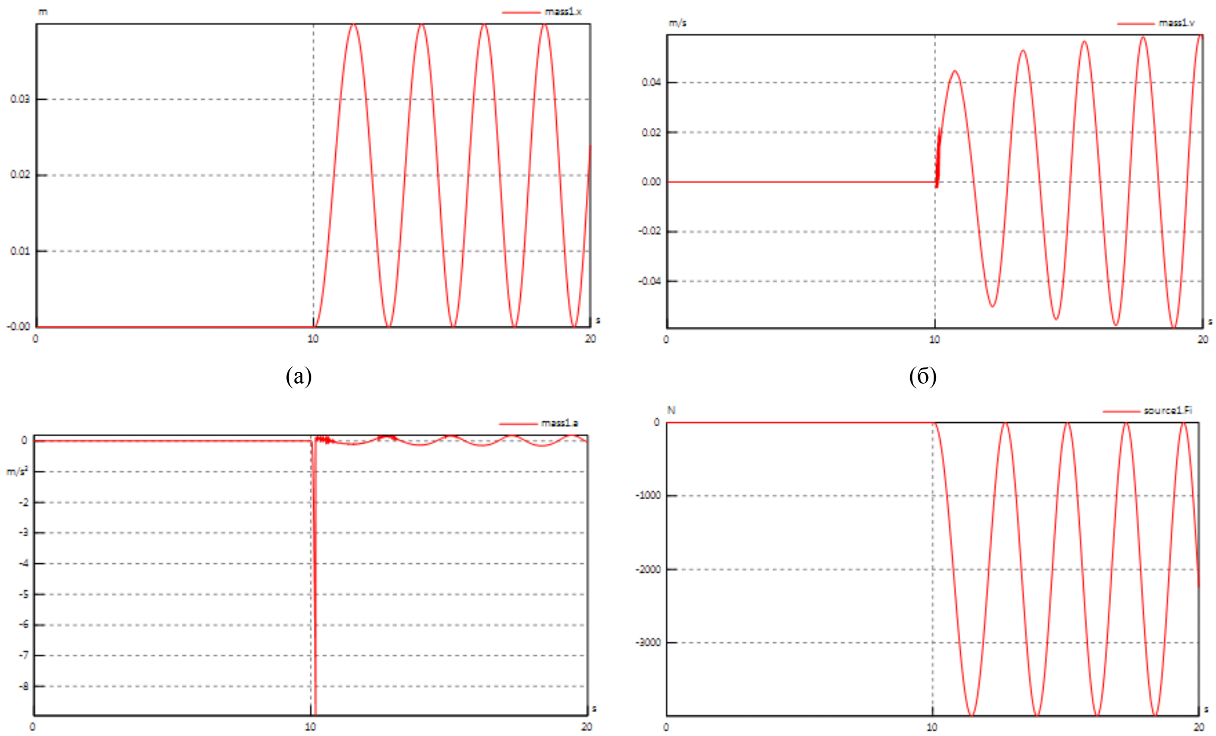
Figure 9 – Calculated data of the feed clutch a) relative angular displacement of the discs; b) relative angular velocity of the disks



(a) (б)

Figure 10 – Calculated data of the feed clutch a) turn-on power loss; б) potential energy change of the clutch

Figure 11 a, b, c shows movement, speed, acceleration and load of the press slide.



(в) (г)

Figure 11 – Estimated data of the press slide a) movement; б) speed; в) acceleration; г) load

Conclusion.

1. The SimulationX software package allows one to simulate the dynamics of the feed clutch of the crank press, taking into account its design parameters as part of the crank press, and the interaction with all its nodes.

2. As the result of the dynamic calculation following is determined; moment transmitted by the feed clutch, relative angular displacement of disks, relative angular velocity (speed) of the disks, turn-on power loss and potential energy change of the clutch. The displacement, speed, acceleration, and load of the slide of the crank press are determined at the moment of clutch turn-on and after movement.

3. Dynamic loads in the nodes of the crank press sharply increase at the moment of clutch turn-on.

4. When studying the dynamics of a crank press, it is necessary to take into account the design features of the feed clutch, especially plate wear and adjustment, which requires further research of this unit.

5. Visibility of the models and graphical results are especially useful for students and engineers in the study of the feed clutches of the crank presses.

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ҚОСИІНДІ БАСПАҚҚА ҚОСЫЛҒАН ЖАЛҒАСТЫРҒЫШТЫҢ ДИНАМИКАЛЫҚ ЗЕРТТЕУІ

Аннотация. Жұмыста қос иінді баспаққа қосылған жалғатырғышты динамикалық түрде зертелді. Қазіргі кезде басқа түйіндердің өзара әсерін ескеріп, қос иінді баспаққа қосылған жалғастырғышты динамикалық зерттеу маңызды мәселе болып отыр. Қос иінді баспақ массасы 100 килограммнан бірнеше тоннаға дейін болатын қозғалмалы бөлшектер мен түйіндерден тұрады. Үлкен динамикалық жүктемемен үлкен жылдамдықпен әсер ететін қос иінді баспаққа қосылылған жалғастырғышқа осы бөлшектермен түйінде циклді түрде қосылып отырады. Қосылылған жалғастырғышты қос иінді баспақтың қозғалысын моделдеп және талдау үшін SimulationX бағдарламалық комплекс қолданылды. SimulationX бағдарламалық комплексі - өнеркәсіптік жабдықтар, электр,- пневмо,- гидрожетектер, гибридті қозғалтқыш, автокөліктердің кинематикасы мен динамикасын талдап және моделдеу үшін пайдаланылды. Динамикалық есептеу нәтижесінде жұмысшы бұлғақтың және қос иінді баспаққа қосылылған жалғастырғыштың маңызды динамикалық параметрлері анықталды. Жалғастырғышты қосқан сәтте қос иінді баспақтың барлық түйіндерде динамикалық жүктеме ұлғая бастағаны көрсетілген.

Түйін сөздер: динамика, қосиінді баспақ, жалғастырғыш, бұлғақ, момент, тербеліс, SimulationX.

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ДИНАМИЧЕСКОЕ ИССЛЕДОВАНИЕ МУФТЫ ВКЛЮЧЕНИЯ КРИВОШИПНОГО ПРЕССА

Аннотация. В работе исследуется динамика муфты включения кривошипного пресса. В настоящее время динамическое исследования муфт включения кривошипных прессов с учетом взаимодействия с остальными узлами является актуальной задачей. Кривошипный пресс содержит подвижные детали и узлы, масса которых от ста килограмм до нескольких тонн. Данные детали и узлы циклически подключаются муфтой включения кривошипного пресса с большими скоростями и на них действуют большие динамические нагрузки. Для моделирования и анализа движения кривошипного пресса с муфтой включения используется программный комплекс: SimulationX. SimulationX – программный комплекс для моделирования и анализа динамики и кинематики автомобилей, индустриального оборудования, электро-, пневмо- и гидроприводов, гибридных двигателей и т.д. В результате динамического расчета определены важные динамические параметры муфты включения кривошипного пресса и рабочего ползуна. Показано, что динамические нагрузки практически во всех узлах кривошипного пресса резко возрастают в момент включения муфты.

Ключевые слова: динамика, кривошипный пресс, муфта, ползун, момент, колебания, SimulationX.

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