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Simulation of the crank press dynamics by SimulationX software

Jomartov A.A., Institute of Mechanics and Mechanical Engineering
named after academician U.A. Joldasbekov,
Almaty, Kazakhstan, E-mail: legsert@mail.ru
Tuleshov A.K., Institute of Mechanics and Mechanical Engineering
named after academician U.A. Joldasbekov ,
Almaty, Kazakhstan, E-mail: aman_58@mail.ru
Halicioglu R., Turkish Machine Theory Association,
Gaziantep, Turkey, E-mail: recephalicioglu@gmail.com
Kuatova M. Zh., Institute of Mechanics and Mechanical Engineering
named after academician U.A. Joldasbekov,
Almaty, Kazakhstan, E-mail: kuatova.moldyr@mail.ru

The most important problem of engineering is to increase the productivity of crank presses. It is necessary to increase press drive working velocities. In result, press' dynamic loads in links and its mechanisms sharply increase. Now, the investigation of the dynamics of crank presses is a vital problem and requires preparation of a dynamic model. A dynamic model selection depends on the reliability of the initial information about system parameters and other factors. The preparation of a dynamic model requires preliminary calculations and sometimes experimental studies. For the selection of a successful dynamic model of a machine, the researcher must have an engineering intuition, information on previous dynamic calculation, experimental studies and operating a machine. This paper presents the dynamic simulation of the crank press by using complex SimulationX® software. For simulation of crank press dynamic, an electric motor which has 0.5 kW power, 450 rpm rated speed and 4000 N rated load on the slider was considered. It was founded that the dynamic loads on links of the crank press increase sharply at the time of switching the clutch and clutch moment reach 120 Nm.
Key words: dynamics, crank press, simulation, SimulationX.

SimulationX бағдарламасында қосиінді баспақ динамикасын модельдеу

Джомартов А.А., У.А. Жолдасбеков атындағы механика және машинатану институты,
Алматы қ., Қазақстан, E-mail: legsert@mail.ru
Тулешов А.К., У.А. Жолдасбеков атындағы механика және машинатану институты,
Алматы қ., Қазақстан, E-mail: aman_58@mail.ru
Халисиоглы Р., Түрік машина жасау қауымдастығы,
Газиантеп қ., Түркия, E-mail: recephalicioglu@gmail.com
Куатова М. Ж., У.А. Жолдасбеков атындағы механика және машинатану институты,
Алматы қ., Қазақстан, E-mail: kuatova.moldyr@mail.ru

Машина жасау саласының маңызды мәселесінің бірі қисық қосиінді баспақтардың өнімділігін арттыру болып саналады. Қисық қосиінді баспақтардың өнімділігін арттыру үшін баспақ жетегінің жұмыс жылдамдығын көбейту қажет. Осының нәтижесінде, түйіндердегі және баспақ механизмдеріндегі динамикалық жүктемелер күрт өседі. Қазіргі уақытта қисық қосиінді баспақтардың динамикасын зерттеу өзекті мәселе болып табылады және динамикалық модель құрастыруды талап етеді. Динамикалық моделді таңдауда жүйе параметрлері және басқа факторлар туралы алғашқы ақпараттардың нақтылығына сүйенген дұрыс. Динамикалық моделді құрастыру үшін алдын-ала есептеулер, ал кей уақытта эксперименттік зерттеулер де қажет болады. Машинаның сәтті динамикалық моделін таңдау үшін, инженерлік интуиция, бұрынғы динамикалық есептеулер жөнінде ақпараттар, эксперименттік зерттеулер мен машинаны қолданудағы мәліметтер болуы керек. Жұмыста қисық қосиінді баспақтың динамикасын SimulationX бағдарламалық комплексінде моделдеу қарастырылған. Қисық иінді баспақтын динамикасын модельдеу қуаты 0,5 кВт, номиналдық айналыс жиілігі 450 бір минуттағы айналым және сырғаққа түсетін 4000 Н номиналдық жүксалмағы бар электроқозғалтқышпен жүргізілді.
Түйін сөздер: динамика, қосиінді баспақ, модельдеу, SimulationX.

Моделирование динамики кривошипного пресса на SimulationX

Джомартов А.А., Институт механики и машиноведения им. У.А. Джолдасбекова,
г. Алматы, Казахстан, E-mail: legsert@mail.ru
Тулешов А.К., Институт механики и машиноведения им. У.А. Джолдасбекова,
г. Алматы, Казахстан, E-mail: aman_58@mail.ru
Халисиоглы Р., Турецкая Ассоциация Теории Машин,
г. Газиантеп, Турция, E-mail: recephalicioglu@gmail.com
Куатова М.Ж., Институт механики и машиноведения им. У.А. Джолдасбекова,
г. Алматы, Казахстан, E-mail: kuatova.moldyr@mail.ru

Одной из важнейшей задачей машиностроения является повышение производительности кривошипных прессов. Для увеличения производительности кривошипных прессов необходимо увеличение рабочих скоростей привода пресса. В результате этого, динамические нагрузки в узлах и механизмах пресса резко возрастают. Исследование динамики кривошипных прессов, в настоящее время, является актуальной задачей и требует составления динамической модели. Выбор динамической модели зависит от достоверности исходной информации о параметрах системы и других факторов. Для составления динамической модели требуются предварительные расчеты, а иногда и экспериментальные исследования. Для выбора удачной динамической модели машины, необходимо иметь инженерную интуицию, информацию о предыдущих динамических расчетах, данные экспериментальных исследований и эксплуатации машины. В работе рассмотрено моделирование динамики кривошипного пресса на программном комплексе SimulationX. Моделирование динамики кривошипного пресса проводилось с электродвигателем мощностью 0.5 квт, номинальной частотой вращения 450 об/мин и номинальной нагрузкой на ползуна 4000 Н. В результате установлено, что в момент включения муфты динамические нагрузки в узлах кривошипного пресса резко возрастают и значения момента на муфте достигает до 120 Н*м.
Ключевые слова: динамика, кривошипный пресс, моделирование, SimulationX.

1 Introduction

The theoretical study of a machine motion begins with the compilation of a dynamic model in which it seeks to display the most significant factors of the problem under consideration. A dynamic model is an idealized displaying of a considered mechanical system, used in its theoretical study and engineering calculations.

The real mechanical system has an infinite number of freedom degrees. The degree of the real system idealization, in its displaying with the dynamic model, depends on many factors.

Assuming, that the inertial parameters (mass or moment of inertia) of the system focus in single points or sections, which connected by inertia less, elastic-dissipative, geometric bonds, it is possible to compose the dynamic model with a limited number of freedom degrees. The practical using these assumptions bring to the fact that pick out in the system the most massive elements and the most non-rigid parts of the kinematic chain. The inertial, elastic and dissipative properties of other elements are considered by reduced values of corresponding parameters.

A select of the dynamic model depends on the reliability of the initial information about system parameters and other factors. For the preparation of a dynamic model required preliminary calculations, and sometimes experimental studies. For selection of the successful dynamic model of a machine, it is required to have an engineering intuition, information on previous dynamic calculation, experimental studies and operating a machine.

The most important problem of engineering is to increase the productivity of crank presses. For increasing the productivity of crank presses, it is necessary to increase press drive working velocities. In result, press dynamic loads on links and its mechanisms sharply increase. The investigation of the dynamics of crank presses is an important problem today and requires preparation of a dynamic model.

In this study, simulation of crank press dynamic model, analysis and calculation of dynamic parameters as a function of time have been aimed. The press and its components are simulated by using SimulationX software.

2 Literature review

For analyze of dynamic processes in the crank presses, its mechanisms are simulated by multi-mass oscillatory systems, which permit calculate loads associated with shafts torsional oscillations and stress-strain of a connecting rod, a slider, and a press frame. In the study of Telegin (Telegin 2013) dynamic model of the crank press is a concentrated masses system connected by elastic-dissipative bonds. The main difference of this model from the already known is the possibility of research oscillatory processes in the crank press, both taking in view of torsional shaft deformations, stress-strain of a connecting rod, a slider, a press frame, and in view of the bending oscillations of its main shaft. In presented work (Telegin 2013) movement of dynamic model masses describes by twenty-two ordinary, nonlinear, piecewise-continuous differential second-order equations (mathematical model), generated by using Lagrange equation of the second kind with "extra"coordinates. It proves that the mathematical description of these dynamic models is quite laborious.

Therefore, at present, there is a tendency to use various software for computer simulation of mechanisms dynamics. Bostwick and Szadkowski utilized computer simulation program, which was written in Fortran evaluated a system of nonlinear differential equations of the laboratory facing dynamometer, with initial conditions by the standard Runge-Kutta method. Computer simulation programs for the engagement of actual systems can be utilized as analytical tools for predicting and quantifying the engagement quality in actual vehicles (Bostwick and Szadkowski 1998). Hlavac et al. (Hlavac, Cechura and Kubec 2011) discussed the development of virtual simulation methods used for the construction of mechanical presses frames. Jang et al. formulated a new dynamic model for simulation of the hysteresis and the contact force of automotive clutch damper springs (Jang, Kim and Bae 2013). Jomartov developed a vector model of a timing diagram of an automatic machine, which allows solving of the various dynamic tasks by changing the parameters of a timing diagram of its mechanisms (A. Jomartov 2013). Halicioglu et al. (Halicioglu , Dulger and Bozdana 2014) modeled the slider-crank mechanism by using Matlab/Simulink platform, which was possible to extend motion scenarios for the slider with servo inputs. Chval and Cechura compared the conventional press with power transmission using the crank mechanism and the press with the yoke mechanism by using FEM simulation (Chval and Cechura 2014). In the simulation process of judder oscillations, the structure allowed easy implementation in equation-based multi-body dynamics simulation software applications like ADAMS (Hafele and Kucukay 2014). Li et al. established a theoretical model to interpret the behavior of judder in clutches, and use the vibrations varying with time and their spectrum analysis to verify its validity (Li, Yu-WenHuang and Lin 2015). Li and Singh examined the transient vibration amplification in a nonlinear powertrain system by using 4DOF and SDOF nonlinear models (Li and Singh 2015). Jomartov et al. (Jomartov, Joldasbekov and Drakunov 2015) established a dynamic synthesis of a machine with a slider-crank mechanism by using Maple platform. Akbaria et al. (Akbaria, Fallahib and Pirbodaghia 2016) investigated the dynamic behavior of a slider–crank mechanism with a flexible connecting rod. They derived the equations of motion of the mechanism by using the Euler–Lagrange method and the mode summation technique. Zheng et al. (Zheng, Zhu and Lu 2016) presented an improved dynamic model of flexible multi-link mechanism with clearance and lubrication established by using ADAMS software. Li, Lu et al. developed 4DOF model of the clutch engagement process with nonlinear friction coefficient for discussion of the vibration response characteristics of the clutch engagement and judder mechanism and analysis of the influence of each critical physical parameter. (Li, Lu, et al. 2018).

3 Material and methods

3.1 A crank press

A crank press is a machine with a slider-crank mechanism, which intends for stamping of varying details (Altan 1998), (Bocharev 2008), (Svistunov 2008), (Rej and Monjatovskii 2000), (Zaleskiy 1973), (Zhivov and Ovchinnikov 1973), (Shcheglov, Maksimov and Lints 1979), (Osakada, et al. 2011), (Halicioglu, Dulger and Bozdana 2015).

During the work of the crank press, on the links and mechanisms, there are significant dynamic loads, especially moment on them. These dynamic loads relate with a feature of crank press work, which is the shock cyclic loads with sudden, almost instant stops. In this regard, the investigation of crank press dynamic has a great interest. The structure scheme of the press is shown in Figure 1 (Bocharev 2008).

The operating principle of the crank press (fig. 1): a crankshaft (10) revolves around an axle and through a connecting rod (2) drives a slider (1) with a stamp. The press drive consists of an electric motor (7), a wedge-belt transmission and flywheel (5). A start clutch of the press (11) places at the end of a crankshaft 10. A flywheel brake (4) is for stopping of the press. The slider-crank mechanism brake (3) is for stopping of the crank press mechanisms.

The press is driven by an electric motor via flywheel. As the motion parameters of a function link and a slider depend on only kinematic links of the main work mechanism, the crank press refers to unregulated machines with limited slide displacement, which equals double crank radius or double eccentricity of eccentric.

An asynchronous electric motor power accelerates a flywheel and all driving links with the corresponding moment of inertia to a steady angular velocity during the technological cycle time and informs it the kinetic energy of a flywheel rotational motion. Wherein a crankshaft and all driven links of slider crank mechanism are stationary, a slide is in the extreme upper (initial) position. When clutch (11) start, a crankshaft (10) revolves, drive and driven links move together, a slide with the fixed on top stamp makes work stroke. After ending of work stroke a slide makes returned stroke. If the press works with single strokes, then when a slider gains the initial position a clutch (11) turns off and at the same time slider-crank mechanism brake 3 turns on. A slide stops in the upper (initial) position and the work cycle complete.

Switching-on, switching-off, and interlocking of clutches and brakes make with the control system (Bocharev 2008). A clutch, a brake, and a control system are called press switching system, and reliability and operation safety of the whole press depend on efficiency this system.

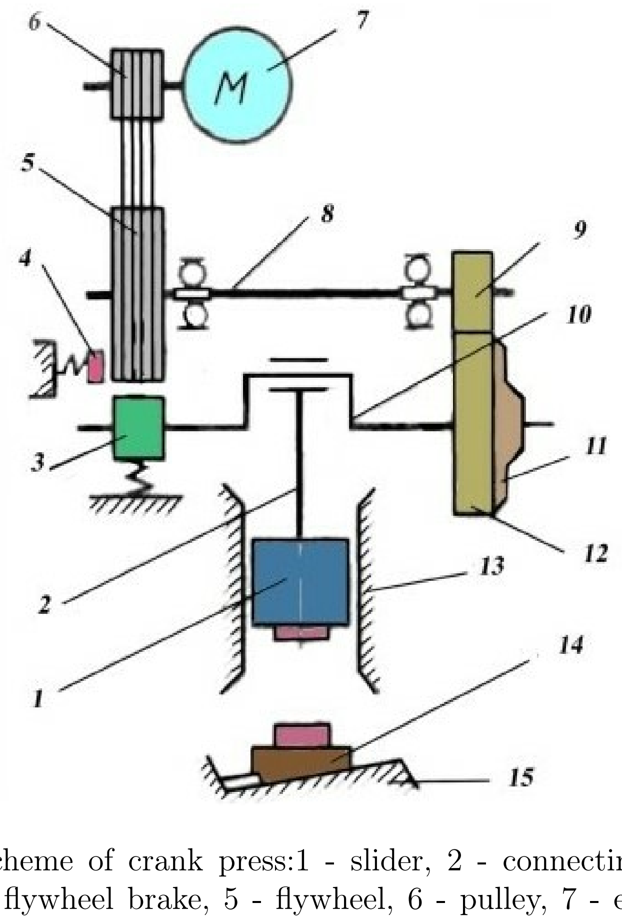


Figure 1: Structure scheme of crank press:1 - slider, 2 - connecting rod, 3 - slider-crank mechanism brake, 4 - flywheel brake, 5 - flywheel, 6 - pulley, 7 - electric motor, 8 - drive shaft, 9 – drive gear, 10 – crankshaft, 11 – start clutch, 12 - driven gear, 13 – slide guides, 14 – wedge table, 15 – press base.

3.2 The dynamic model of crank press on the SimulationX

SimulationX® software was used for simulation and analysis of crank press movement in this study (http://www.simulationx.com/ n.d.). Dynamic of the crank press can be well simulated by using this software. SimulationX® is a multidisciplinary software package for modeling of physical and technical objects and systems, which developed and commercially sold by ITI GmbH from Dresden since 2000 (http://www.simulationx.com/ n.d.). Scientists and engineers, working in industry and education spheres, use this tool for development, simulation, analyze and virtual test of complex mechatronic systems. The software, on a single platform, simulates the behavior and interaction of various physical objects of mechanic (1D and 3D), drive technique, electric, hydraulic, pneumatic and thermodynamic systems, also magnetism, analog and digital control systems.

Most notable, that the main advantage of SimulationX® is quick construction of models from intuitively-understandable objects of mechanics (mass, force, moment, spring, damper, friction, lever, etc.), pneumatics and hydraulics (pneumatic cylinder, valve, throttle etc.), mechanical engineering and electrical engineering (motors, couplings, clutches, gear and other mechanisms, driveshaft, differential, etc.) and controls (sensor-meter, control signals, etc.)

Figure 2 shows the dynamic model of the crank press on the SimulationX® (Jomartov, Joldasbekov and Drakunov 2015), (Jomartov A. and Joldasbekov 2015), (Jomartov and Tuleshov 2018). Figure 3 shows library elements of the SimulationX®, which we use to create the model.

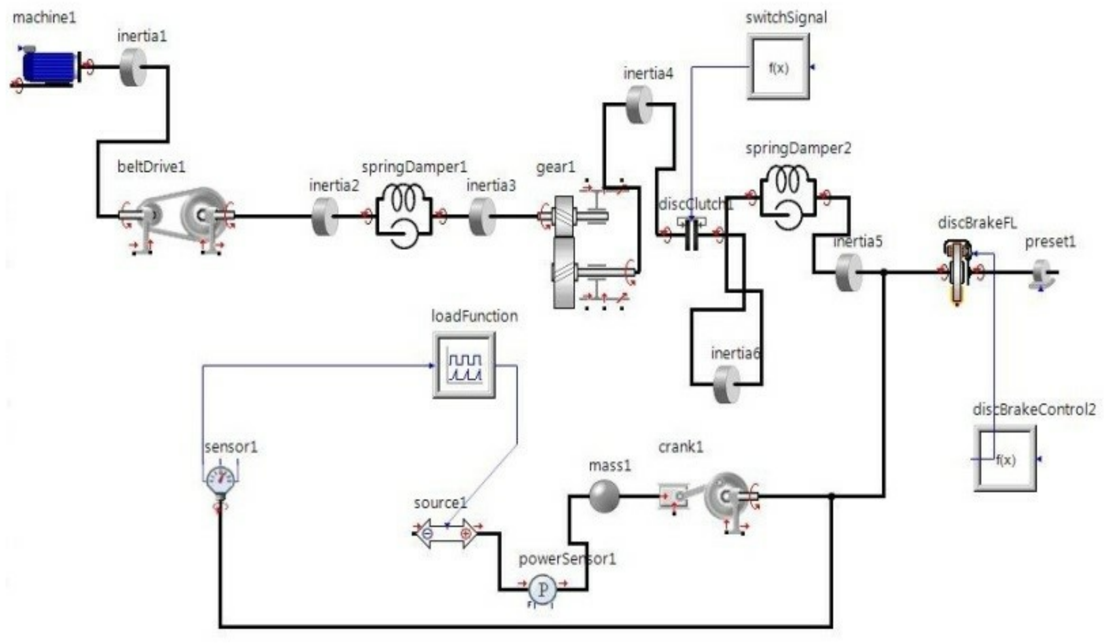


Figure 2: Dynamic model of the crank press on the SimulationX®

List of designations (Fig.3) and description of library elements of the SimulationX®:

1- Asynchronous electric motor. This element simulates simple an asynchronous electric motor. The model based on stationary features of an electric motor. This element simulates

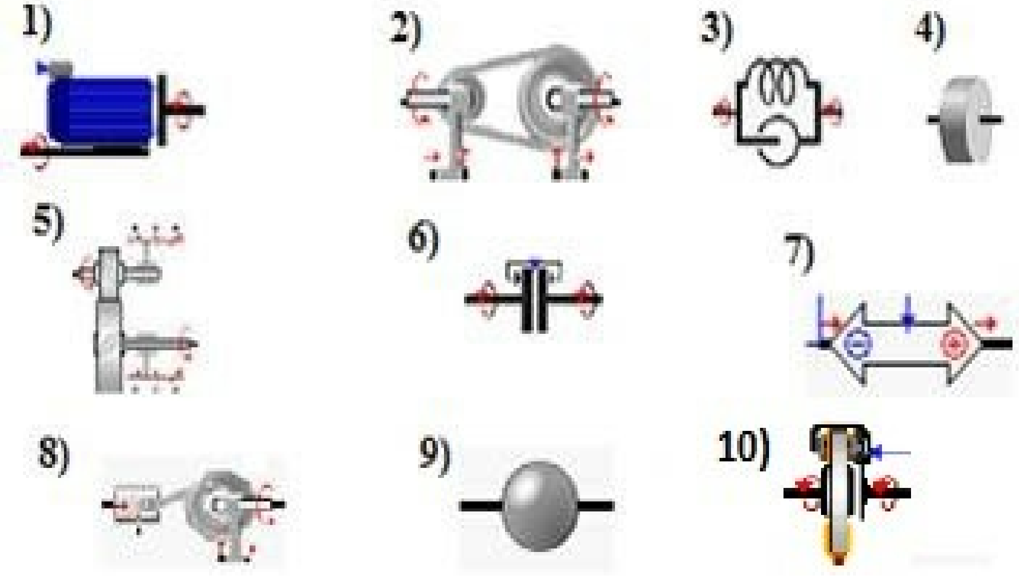


Figure 3: Library elements of the SimulationX®

an asynchronous electric motor with sufficient accuracy in the simulation of machine drive. Here simulate starting a motor, transition and steady processes, depending on loads and shaft rotate velocity.

2 - Belt drive. This element simulates work of belt drive in view of elastic-dissipative features. The model takes into account reactions and displacements of belt drive pulleys in bearings of support that permits to simulate the interaction of transmission with a base.

3 - Spring–Damper–Clearance. The model presents elastic and/or a damped behavior between rotary links, with a possibility of taking account into clearances. Springs always act in parallel with dampers.

4 - Inertia. This element simulates inertia moment of a rotary link. Also, there is a possibility of variable inertia moment simulation.

5 - Transmission. The element Transmission is an ideal transformer of rotary motions and forces, functioning between two components in a rotating mechanical system. It works like an ideal transformer without accounting dissipation and performs the specified transmission ratio or power balance conditions at input and output. This element permits to simulate fixed and variable ratios for angles or velocities at input and output.

6 - Disk clutch. This model represents a component, which turns on and interrupts a torque flow (and, consequently, power transmission) between components of the drive. The model can be used for simulation of a multi-disc clutch of machine or gearbox. In addition, the friction of the brakes (for example, in automate gearbox) can be simulated. Also, an elasticity, damping and clutch friction parameters can be described. In a transmission of the model, the clutch can be turned on by a switch signal.

7 - External force. This type of element permits to simulate forces between two components or only on one component of the mechanical model. It provides universal, functional force transmission in the mechanical model.

8 - Crank mechanism. The element simulates slider-crank mechanism in view of clearances in joints, elastic-dissipative properties of a connecting rod.

9 - Mass. This element simulates the mass of a linear link. Also, there is a possibility of variable mass simulation.

10 - Disk brake. The model of Disk brake represents a component, which turns on and interrupts a torque flow (and, consequently, power transmission) between mobile and fixed components of the drive. The model can be used for simulation of a multi-disc clutch of machine or gearbox. In addition, the friction of the brakes (for example, in automate gearbox) can be simulated. Also, an elasticity, damping and clutch friction parameters can be described in braking.

3.3 Initial parameters of the model

Rated power and rated speed of the electric motor are considered as 0.5 kilowatts, 450 rpm, respectively. The numerical values of features, inertia moments of crank press links and shafts rigidity were taken from Bocharev study (Bocharev 2008).

The rated force, developing by the slider of the slider-crank working mechanism in a part in front of an extreme lower slider stroke point, simulates by a sinus signal generator (loadFunction) and a linear force (with load) (Fig.4). This loads force depends on an angle of the crank. The maximum value of the force is in the lower slider stroke point and equal to 4000 N. In figures, 5a and 5b present parameters of a start clutch and brakes of the crank press.

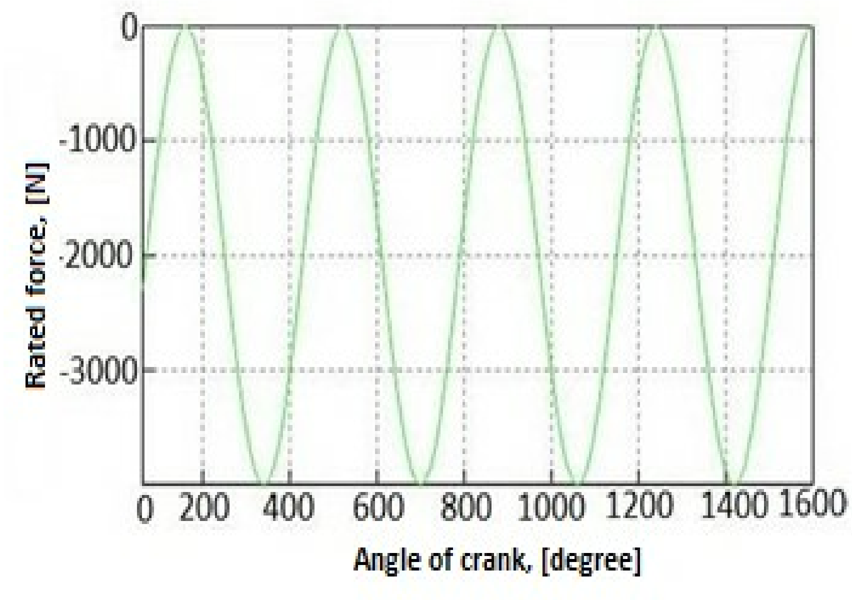
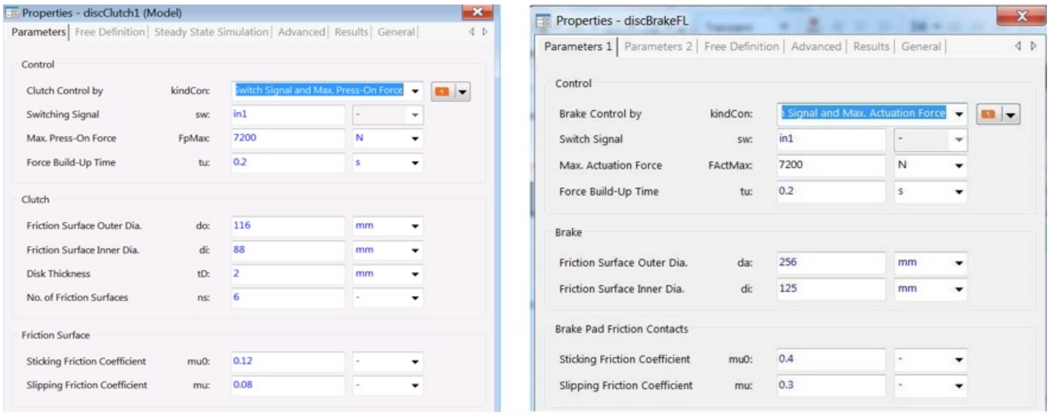


Figure 4: Rated force, developing by the slider of the slider-crank working mechanism



a) б)

Figure 5: The parameters of a) the crank press start clutch, b) the crank press brakes

4 Simulation Results

The start clutch of the crank press engages for 10 seconds and connects a moving flywheel to the functional mechanism. The transmitted moment by the start clutch is shown in Figure 6. Figures 7 and 8 present the calculated start clutch data of the crank press.

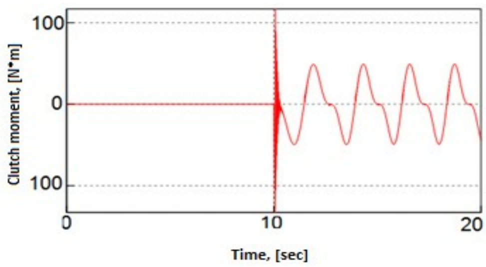
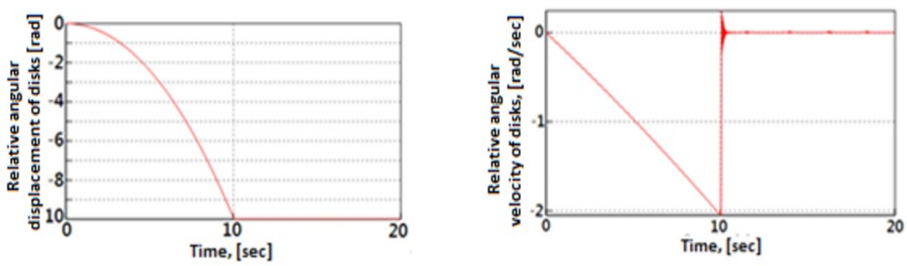


Figure 6: The moment transmitted by the start clutch



(a) (b)

Figure 7: The calculated data of the start clutch: a) relative angular displacement of disks; b) relative angular velocity of disks

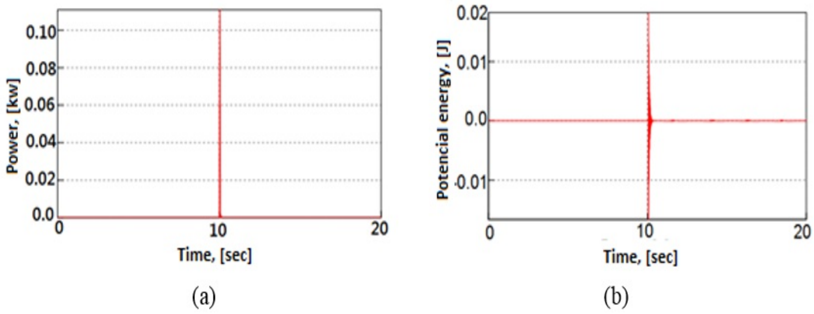


Figure 8: The calculated data of the start clutch: a) power loss when switching-on; b) potential energy change of the clutch

Figures 9a, 9b, 9c, 9d, show displacement, velocity, acceleration and load of the press slider dependence on time, respectively. In figure 10 present moment on the brake when it engages for 8 seconds and the clutch of the crank press off.

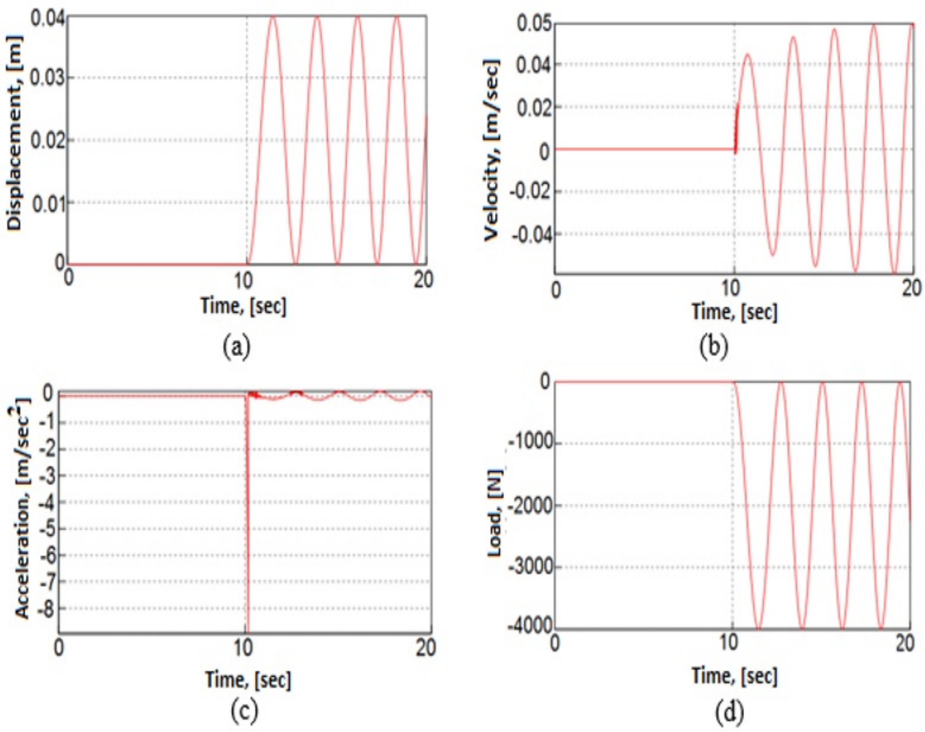


Figure 9: The calculated data of the press slider: a) displacement; b) velocity; c) acceleration; d) load

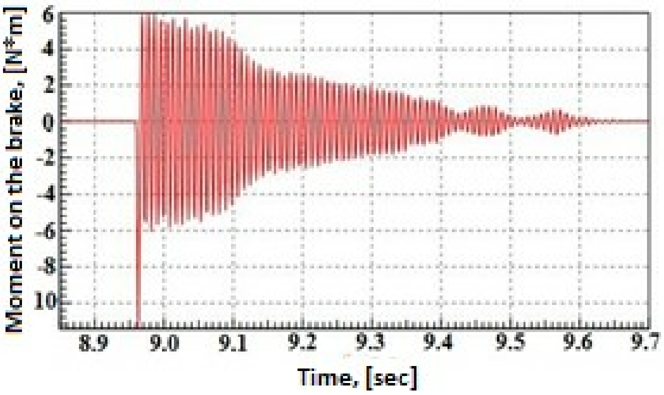


Figure 10: Moment on the brake when switching-on

5 Conclusions

• Simulation of the crank press dynamics with the interaction with its entire links was performed by using SimulationX® software.
• In result of crank press dynamic calculation, the values of the moment, transmitted by the start clutch; relative angular displacement of disks; relative angular velocity of disks; power loss when switching-on and potential energy change of the clutch were obtained. Also, the values of the displacement, velocity, acceleration, and load of the crank press slider at the moment of the clutch switching-on and after motion were determined.
• At the moment of the clutch switching-on and working of a brake, the dynamic loads in links of the crank press sharply increased.
• The visibility of models and graphical results are especially useful for students and engineers when studying the dynamics of the crank press.

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