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# DEVELOPMENT AND SIMULATION OF CRANK PRESS BASED ON SIX-LINKAGE MECHANISMS STEPHENSON II

**thesis for a degree of Doctor of Philosophy (Ph.D.) in specialty 6D060300 - "Mechanics"**

## ANNOTATION

**The study's relevance.** Crank presses are an essential part of the forming system designed to shape metals, alloys, and non-metallic materials under pressure. The criteria for evaluating various crank presses' designs include structure, energy consumption, speed, and efficiency in using consumed energy. The advantages and disadvantages of crank presses are predetermined by their operation principle, based on the combination of the main drive, which is not reversible in operating modes, with a lever actuator having extreme dead positions.

The advantages of crank presses include the highest productivity among machines working with dies or knives; the ability to carry out all types of stamping and elastoplastic separation; the high accuracy of the resulting products due to the fixed extreme working position of the movable tool within the elastic deformation of the system. These advantages ensure the effectiveness of the use of crank presses in production. In addition, the actuators' designs are necessary to enhance crank presses' efficiency, i.e., increase productivity and accuracy.

Improving their performance characteristics (accuracy, durability, efficiency) while generally reducing development and production costs is necessary for increasing the competitiveness of domestic crank presses. Furthermore, it stimulates the transition to modern design methods based on mathematical modeling of the ongoing physical processes throughout the technological cycle and the rational use of modern CAD tools.

At present, the improvement of crank presses with actuators based on new linkages is widespread globally. Progress of crank presses based on new linkage designs requires structural and kinematic analysis and synthesis, kinetostatic and dynamic analysis, and synthesis of linkages. Creating movement models based on modern software systems is necessary to study crank presses' operation based on new linkage designs. Dynamic models of crank presses based on new linkage designs should be compiled, considering the elastic-dissipative characteristics of links, friction forces, viscous resistance, control system, etc. Significant dynamic loads arise in the joints and mechanisms during a crank press operation, mostly when switched on. These dynamic loads are associated with a crank press operation feature

consisting of cyclic shock loads with sudden, almost instantaneous stops. In this regard, the study of the dynamics of crank presses is of great interest. The simulation and analysis of the modern crank presses' movement involve many calculations considering the links' elastic-dissipative characteristics, friction forces, viscous resistance, control systems, etc. The movement computer simulation of complex mechanisms is widely used, considering many factors affecting their work, the so-called multidisciplinary virtual simulation.

Improving crank presses based on new linkage designs is relevant globally and is essential for developing science in this direction.

**The thesis aims** to improve crank presses' efficiency based on developing a crank press with a KWM (Key Working Mechanism) based on the Stephenson II six-linkage using software systems for modeling physical and technical objects and systems.

By this goal, we consider the following **tasks**:

- substantiation of the kinematic scheme choice of the Stephenson II six-linkage mechanism for the key working mechanism (KWM) of the crank press;
- development of methods for kinematic analysis and synthesis of the Stephenson II six-linkage;
- kinematic analysis and synthesis of crank press KWM;
- kinetostatic analysis of the KWM of a prototype crank press based on the Stephenson II six-linkage;
- development and analysis of a movement simulation model of a crank press with a KWM based on the Stephenson II six-linkage on the SimulationX software package;
- development of a crank press 3D model with KWM based on the Stephenson II six-linkage;
- preparation of project-design documentation (PDD) of a crank press prototype with a KWM based on the Stephenson II six-linkage;
- development of a methodology for experimental research of a crank press prototype with a KWM based on the Stephenson II six-linkage.

**The object of study** is a crank press.

**The subject of study** is the key working mechanism design of the crank press.

Using the necessary provisions and methods of the mechanisms and machines theory, using improved software systems for modeling physical and technical objects and systems provides **the study's theoretical basis**.

**The study methods**: theoretical research used the methods of mathematical modeling of multicomponent systems. Using a software package to analyze complex systems' dynamics based on the Maple analytical computation package, which implements the nodal method of automatic compilation and implicit methods for integrating systems of equations, collects mathematical models of design objects. The simulation and 3D dynamic models of complex mechanical systems were completed using the SimulationX and Autodesk Inventor software packages. In addition, experimental studies were carried out using electrical methods for measuring mechanical quantities, using electronic amplifying and recording equipment.

**The scientific novelty of the dissertation work:**

− in the development of a new crank press with a KWM based on the Stephenson II six-linkage;

− development of methods for kinematic, kinetostatic analysis and synthesis of Stephenson II six-linkages;

− in the preparation of simulation and 3D dynamic models of a crank press with a KWM based on the Stephenson II six-linkage;

− in experimental research of a crank press prototype with a KWM based on the Stephenson II six-linkage.

**The theoretical and practical significance of the dissertation work.** The developed numerical and analytical methods for studying the kinematics and dynamics of crank presses, taking into account the design features of the key working mechanisms (KWM) based on the Stephenson II six-linkage mechanism, can be used in theoretical studies for a comprehensive class of mechanisms, machines, and robots containing linkages. The research's practical significance lies in the methodology for developing a crank press prototype with a KWM based on the Stephenson II six-linkage and the methods for conducting its experimental research, which will help design various mechanisms, machines, and robots. The crank press prototype's commissioning work and its experimental studies have shown good performance and the practical absence of jamming under various pressing modes, which provides prerequisites for its further introduction into production.

**Scientific positions submitted for defense:**

− substantiation of the kinematic scheme choice of the Stephenson II six-linkage mechanism for the key working mechanism (KWM) of the crank press;

− methods for kinematic, kinetostatic analysis and synthesis of Stephenson II six-linkages;

− simulation and 3D dynamic models of a KWM crank press based on Stephenson's II linkage;

− a prototype of a KWM crank press based on the Stephenson II six-linkage;

− method of experimental study of a crank press prototype with a KWM based on the Stephenson II six-linkage.

**The reliability and validity of the scientific provisions, conclusions, and results of the dissertation work** are confirmed by using proven mechanics and mechanics and machine theory methods, using proven software systems Maple, SimulationX, and Autodesk Inventor. The results reliability is confirmed by developing and manufacturing a crank press prototype with a KWM based on the Stephenson II six-linkage, the tests of which showed good agreement with theoretical results at various pressing modes.

**Communication of dissertation work with other research works.** This dissertation work was carried out within the framework of a scientific project for grant financing of fundamental and applied scientific research on scientific and (or) scientific and technical projects for 2018-2020 MES RK "Development of methods and technology of designing of power press-machines based on new crank operating mechanisms"(GR No. 0118RK0077, the project IRN: AP05134959).

**Approbation of dissertation work.** The main provisions and results of the dissertation work were reported and discussed at the following scientific events:

- at the International Conference “XII All-Russian Congress on Fundamental Problems of Theoretical and Applied Mechanics (2019, Ufa, Russia);
- at the International Conference "6th IFToMM International Symposium on Robotics and Mechatronics (ISRM 2019)" (2019, Taipei, Taiwan);
- at the International Conference "The 15th IFToMM World Congress" (2019, Krakow, Poland);
- at the International Conference "23rd CISM IFToMM Symposium on Robot Design, Dynamics and Control" (2020, Sapporo, Japan);
- at scientific seminars of the U.A. Dzholdasbekov Institute of Mechanics and Mechanical Engineering SC MES RK and the Mechanics Department of Al-Farabi Kazakh National University (Almaty 2018-2019).

**Publications.** On the topic of the dissertation work, the author published 11 publications, including 2 articles in scientific journals recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for the publication of the main results of scientific activity; 5 articles and book chapters in scientific journals with a non-zero impact factor (IF) and proceedings of International conferences indexed by Scopus and Web of Science databases, 1 article in proceedings of the XII All-Russian Congress on fundamental problems of theoretical and applied mechanics; 1 article in a peer-reviewed journal, indexed by the RSCI database; 1 monograph; 1 patent of the Republic of Kazakhstan for an invention.

**The personal contribution of the author**. The author independently obtained the main scientific results of theoretical and applied research, and the conclusions set out in the dissertation. In the works published in co-authorship, the applicant owns a significant part related to the formulation of problems, the development of algorithms and models, and their software implementation and experimental research.

**The dissertation work structure.** The thesis consists of a title page, content, a list of designations and abbreviations, an introduction, six chapters, a conclusion, a list of references, and applications. The total thesis volume is 122 pages, including 65 illustrations and 3 tables.

**The main content of the dissertation work.**

The **introduction** contains a description of the problem, a brief overview of the subject area. Then, the thesis's urgency is substantiated, the formulation of the problem and the stages of their solution are formulated.

The **first** chapter devotes to the current state of research methods for the study of crank presses. First, there is the substantiation of the kinematic scheme choice of the crank press's key working mechanism.

The **second** chapter deals with the kinematic analysis and synthesis methods of the crank press KWM. Here are carried out the kinematic analysis and synthesis of the Stephenson II six-linkage. The development of a KWM for a crank press based on the Stephenson II six-linkage is presented.

The **third** chapter presents a kinetostatic analysis of the crank press KWM. First, the vector method of the Stephenson II six-linkage kinetostatic analysis has been developed. Then, the kinetostatic analysis of the KWM of a crank press based on the Stephenson II six-linkage is carried out. Finally, the kinetostatic analysis of the KWM of a prototype crank press based on the Stephenson II six-linkage is shown.

The **fourth** chapter devotes the development of the movement simulation model of a crank press with a KWM based on the Stephenson II six-linkage on the SimulationX software package. Then, the dynamic model of a KWM crank press based on the Stephenson II six-linkage on SimulationX is presented. Finally, modeling a crank press with a KWM mechanism based on the Stephenson II six-linkage on SimulationX is shown.

The **fifth** chapter discusses developing a prototype crank press with a KWM based on the Stephenson II six-linkage. First, the 3D model of a KWM crank press based on the Stephenson II six-linkage has been developed. Then, based on a 3D model, the project-design documentation (PDD) of a crank press prototype with a KWM based on the Stephenson II six-linkage is obtained. Finally, producing a crank press prototype with a KWM based on the Stephenson II six-linkage is shown.

The **sixth** chapter consists of an experimental study of a crank press prototype with a KWM based on the Stephenson II six-linkage. The method for tensiometric research is shown. Experimental studies of a crank press prototype with a KWM based on the Stephenson II six-linkage have been carried out.

The **conclusion** presents the principal results and decisions of the dissertation study obtained at work.