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INVESTIGATION OF THE TECHNOLOGICAL AND DYNAMIC MODE OF A CRANK PRESS OF A NEW STRUCTURE ON THE BASIS OF FOUR-LINK GROUPS

ANNOTATION

Dissertation for a degree
Doctor of Philosophy (PhD) by specialty
6D060300 – “Mechanics”

Relevance of the research topic. The research topic's relevance lies in the predominant use of crank-slider mechanisms in crank forging and stamping machines. The advantages and disadvantages of crank presses are determined by their operational principle, which combines an irreversible electric flywheel main drive with lever-based actuators (e.g., cam-lever or gear-lever arrangements) at extreme positions. These advantages, including high productivity, versatility in stamping tasks, and precise product output due to fixed extreme positions of the movable tool within the elastic deformation range, establish crank presses as dominant in mass and large-scale production in machine-building.

The advantages inherent in crank presses ensure their effectiveness if their disadvantages are mitigated. Enhancing the efficiency of crank presses, particularly in terms of productivity and accuracy, as well as broadening their application scope (e.g., for small-scale production, manufacturing large products, and hot stamping low (hammer) forgings), is unattainable without universal actuators, methodologies, and safety devices. Without these components, the frequency and severity of overloads during stamping and adjustments preclude the attainment of positive economic outcomes. However, the current state of science and technology enables the resolution of this challenge by developing mechanisms to safeguard crank presses against overloads, including through the functional design of actuators.

Technological processes in volumetric stamping demand a relatively small slider working stroke, high deformation resistance with compact die dimensions, and press speed maintenance to prevent forging cooling during hot stamping. Achieving high-precision forgings requires rigid press structures, aligning with the structural and functional characteristics of crank-knee mechanisms supported by the working slider.

Recent research focuses on improving crank press mechanisms' structures and dynamic process analysis, leveraging digital technology tools. The proposed work aims to develop new structures and kinematics/dynamics modeling methods for crank-knee presses based on multi-circuit lever mechanisms, considering volumetric and hot stamping peculiarities. The simulation will address crank press dynamics, accounting for highly loaded link elasticity and kinematic pair friction, serving as a basis for designing a new crank stamping press using modern CAD tools.

Noteworthy studies by Yu.A. Bocharov and E.N. Lanskaya concentrate on crank press parts and assemblies design, and modeling technological processes considering dynamic loads and machine design features. Notable dissertations since 2000, including those by Dvornikova L., Kovalev V.V., Kruk A.T., Bykova P.N., Dibnera Yu.A., Matveeva A.G., Nikitina A.G., Kornilova A.V., Talovir I.V., Bolshakova N.S., and foreign scientists, have explored crank-slider mechanisms and their variations based on two-link groups, although functionally and technically inferior to four-link group-based crank mechanisms proposed in this project. Research led by Tuleshov A.K. focused on project No. AR05134959 "Development of methods and technology for designing power press machines based on new crank actuators" from 2018-2020, centered on the Stephenson II straight crank-slider mechanism.

The object under study is a crank lever press, focusing on new methods of kinematics and dynamics for multi-link crank-knee lever presses with elevated working slide height, along with analysis methods for technological processes and design based on simulation.

Purpose of the project: The dissertation aims to develop methodologies for modeling kinematics and dynamics, analyzing technological processes, synthesizing, and designing new designs of a crank press for stamping, effectively addressing high resistance to deformation, ensuring slider height, and achieving high forging accuracy.

Aligned with the dissertation's objective, the following **research objectives** are outlined**:**

- Analyzing the technological process of volumetric stamping and power characteristics of multi-link double-rod crank presses, including workload graph analysis during stamping;
- Developing methods for kinematic analysis and synthesis of multi-link double-rod actuators for crank-knee presses with elevated working link stand, encompassing speed and acceleration analysis of mechanism links;
- Formulating methods for kinetostatics and dynamics analysis of multi-link double-rod actuators for crank-knee presses;
- Creating methods for analyzing the dynamics of multi-link double-rod crank and crank-knee presses, integrating equations of nonlinear connections and elastic analysis of highly loaded links and forgings;
- Designing the main components and assemblies of double-rod actuators for crank presses.

Research methods: The intricate configuration of multi-link double-rod crank presses necessitates the development of methods for kinematic synthesis and analysis. Kinematic analysis involves deducing equations through the closed-loop method and devising a solution methodology via analytical transformations using the driving link replacement technique if required. Kinematic synthesis of the lever mechanism employs an approximation approach utilizing the blocked zone method. A key aspect of synthesizing a crank press lies in ensuring modes of technological stoppage of the working slide for the requisite duration according to the stamping process cyclogram.

The dynamic investigation of a crank press entails two primary phases: firstly, constructing dynamic models, deriving dynamic equations, and simulating resultant motion equations, encompassing platforms such as Maple analytical computing and the SimulationX program; secondly, conducting design, strength analysis, optimizing material consumption, and evaluating performance through virtual modeling on digital platforms. The dynamic model of a crank press incorporates friction in kinematic pairs and the elastic characteristics of highly loaded components and assemblies. Force analysis of the Press-Forging Center (PFC), considering friction forces, is undertaken utilizing the vector method. The derivation of dynamic equations utilizes Lagrange equations with indefinite coefficients (to account for redundant connections), D'Alembert's principle, Coulomb-Amonton and

Hooke laws, along with other principles of theoretical mechanics, mechanisms and machines theory, and mathematical probability and statistics.

The object of study is a crank lever press.

The scientific novelty of the work:

- New diagrams illustrating the main working mechanisms of a crank press machine featuring sliders with stands;
- Structural-kinematic synthesis methods for an eight-link actuator of crank presses incorporating two working links;
- Analytical method for qualitative synthesis of a six-link mechanism, determining the range of parameter variations ensuring technical and technological feasibility;
- Kinematic synthesis method for an eight-link knee-crank mechanism of a crank press, emphasizing extended stay of the working link, with numerical modeling results depicting mechanism diagrams in response to variations in slide eccentricity;
- Analytical methods for dynamic analysis and design of crank and crank-knee presses utilizing four-link structural groups, implemented numerically via Maple analytical calculation package, among others;
- Development of criteria to assess kinematic and dynamic parameters validating the functionality of actuator designs based on four-link structural groups in crank presses;
- Dynamic analysis methods for press mechanisms, considering technological load, process dynamics (e.g., high-speed press), and static characteristics of servo drives;
- Development of programs for kinematics and dynamics analysis of crank and crank-knee press actuators based on four-link groups using analytical calculation packages such as Maple;
- Experimental studies on a six-bar crank press to validate key findings.

Theoretical and practical significance of the study: The theory of mechanisms and machines has flourished as a prominent scientific discipline in Kazakhstan, earning global recognition. Particularly, advancements in the theory of flat and spatial lever mechanisms and parallel manipulators have led to the creation of numerous original and popular designs for robot actuators and machine aggregates. However, the practical application of these designs faces challenges due to the absence of readily available design tools for engineers. Therefore, the development of tools for designing functional lever structures leveraging modern digital technology, spearheaded by Kazakh scientists, promises to propel the theory of lever mechanisms, parallel manipulators, and mechanical engineering into a new developmental stage. This initiative not only expands the technical and technological base of forging machines and equipment but also introduces new designs of actuators with versatile functionality.

Russian, German, Japanese, Chinese, and other global scientists are also actively engaged in the study of spatial lever mechanisms and parallel manipulators, while simultaneously enhancing crank presses based on lever mechanisms. Consequently, the endeavor to improve crank presses in this context holds global relevance and significance for advancing science in this field.

Personal contribution of the author. The author autonomously achieved the results stemming from the dissertation research, particularly the development of methodologies, algorithms, and numerical modeling programs. Task approval, research method development, and system implementation were conducted under the author's guidance, in collaboration with their scientific supervisor and a foreign scientific supervisor. Any utilization of external research findings was appropriately acknowledged through references to relevant literature sources.

Connection of the dissertation work with other research works. Projects AP05134959 “Development of methods and technology for designing power press machines based on new crank actuators” for 2018-2020 and AP14972874 “Development of research methods and design of a crank-knee press with a technological stop (output link dwell) of the working slider” are being implemented within the framework of the project “ Zhas Galym" for 2022-2024 under the leadership of Professor Tuleshov A.K.

The reliability and validity of scientific statements, **conclusions, and results of the dissertation** are ensured through rigorous implementation of the project's main stages. These stages encompass mathematical modeling and determination of key input parameters for the main working mechanism of press machines and their components, the development of a design tool incorporating existing CAD and novel timing models of the main working mechanism, and the design and construction of an automatic press machine (COP). Furthermore, the project involves testing a prototype of the timing press machine under various technological conditions of the main working mechanisms. The Institute of Mechanics and Engineering named after U.A. Dzholdasbekov possesses an experimental setup and installations dedicated to testing crank presses, facilitating the validation of research outcomes.

Publications. Based on the results of the research work, 10 scientific articles were published, 2 article in international peer-reviewed scientific journals with a non-zero impact factor included in the Scopus database (percentile 75%, 36%), 3 articles in publications recommended by CQFSHE MSHE RK, 1 article in the journal “Bulletin of the National Academy of Engineering”, 4 articles at other international conferences.

Approbation of work. The dissertation research findings were presented and discussed at various venues to ensure their thorough examination and validation. Seminars were conducted at the Institute of Mechanics and Engineering named after U.A. Zholdasbekov and the Department of Mechanics at the Kazakh National University Al-Farabi. Additionally, the results were disseminated at prominent international conferences, including the VI International Scientific and Practical Conference "GLOBAL SCIENCE AND INNOVATIONS 2019: Central ASIA" in Nur-Sultan, Kazakhstan, and the International Scientific Conference "FARABI ALEMI" in Almaty, Kazakhstan. Furthermore, the research findings were shared at the "Fundamental and applied scientific research: current problems, achievements and innovations" collection of articles at the XXXIII International Scientific and Practical Conference in Penza, Russia. These approbation efforts ensure the robustness and credibility of the dissertation's outcomes within the scientific community.

Dissertation structure and volume. The dissertation consists of an introduction, 4 parts, a conclusion, and a list of references. The total volume of work is 107 pages, 49 figures, 4 tables, the list of used literature consists of 73 titles.

The main content of the work:

The introduction sets the stage by delineating the significance of the dissertation work and outlining the stages involved in problem formulation and resolution.

In the first section, an examination of the design and technological nuances of crank press actuators is provided, alongside insights into methods for exploring kinematics and dynamics. A discernible trend towards the development of crank press actuators with enhanced functionality relative to the traditional four-bar crank-slider mechanism is identified through an analysis of existing scientific literature.

In the second section, a geometric and kinematic analysis of crank press mechanisms based on the Stephenson kinematic chain with two connecting rods is conducted. Additionally, a numerical and functional analysis of the kinematics of double-rod mechanisms, featuring a link height based on the improved layout of the knee-crank press engine, is undertaken.

In the third section, an analytical method for synthesizing a six-link Stephenson mechanism is devised, rooted in the extremum conditions of the pressure angle. Furthermore, a synthesis method for a six-link mechanism of a knee-crank press, employing a quadratic approximation with Lagrange multipliers, is developed. Structural-kinematic synthesis of a two-rod eight-link mechanism of a crank-knee press, emphasizing long dwell time, coefficient of average speed change, and acceptable transmission angle, is executed. Dynamic assessments of press mechanisms based on predetermined criteria are also conducted.

In the fourth section, a force analysis method for the stamping mechanism of a crank knee press is formulated, alongside an examination of technological forces. The average steady-state speed, unevenness coefficient, and flywheel moment of inertia of crank presses are determined. Furthermore, a simulation of the stamping process for a two-rod six-link mechanism of a crank press is conducted, considering the elasticity of connecting rods and forgings. An experimental study of crank presses based on a six-bar mechanism is devised and executed.

In the conclusion, the primary outcomes of the dissertation work are summarized, culminating in the final findings and conclusions of the research.

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