Hinge-lever mechanisms of variable structure and their applications in engineering

Murat Dzhumataev

Machinery Researching and Automatics Institute the National Academy of Science Kyrgyz Republic,Skryabina St.23, 720055 Bishkek, Kyrgyz Republic.

Abstract. The report discusses the transition of hinge-lever mechanisms from one structure to another and the use of these properties to create machines for various purposes. Our research has shown that when some parameters or their ratios change, conditions are created for a possible change in the structure of the mechanism. One of the schemes of hinge-lever mechanisms of variable structure was used in the design of the drilling module as part of the Luna-24 station for drilling a hole on the surface of the Moon, as a generator of power pulses. A major application of lever mechanisms of variable structure was their use as a working body in pressure presses. The report outlines the stages of creating impact machines based on mechanisms of variable structure, from hand-driven perforators to hammers with high impact energy. The design research was accompanied by studies of the kinematics and dynamics of impact machines with mechanisms of variable structure, the identification of new properties, the synthesis of the most optimal design and operating parameters of the power transmission.

1 Introduction

Hinge-lever mechanisms, if we keep in mind the modern definition of the concept of mechanism, are among the very first mechanisms that were used by people to facilitate their physical labor. Most of the mechanisms used in the technique are hinge-lever mechanisms, the most famous of them are: crank-slider, crank-rocker, two-crank, two-crank, crank-rocker, sinus, tangential. These mechanisms are used both separately, as executive bodies of various machines, and together as part of technological machines. Due to the widespread use of hinge-lever mechanisms, their structure, kinematics and dynamics of machines based on them are quite well studied. However, in the course of research on the possibility of creating impact-rotational machines for drilling in hard-to-reach places, new properties of these mechanisms have been revealed. It was found that under certain conditions, namely, when some parameters or their ratio change, both the structure of the hinge-lever mechanisms, their appearance, and the laws of motion of individual links, as well as the number of movable links, change. Such mechanisms are called variable structure mechanisms.

In the 1970s, the Academy of Sciences of Kyrgyzstan began work on the creation of a drilling machine, which, as part of the Luna-24 station, was intended for drilling holes in order to extract the core without disturbing the stratification of the lunar soil (Figure 1). One of the main components of the drilling machine was a hinge-lever mechanism that transformed the rotational motion of the engine into the translational motion of the impact mechanism. As such a mechanism, a pulse generator with a hinge-lever firing pin was used [1]. The mechanical pulse generator during the acceleration of the striker is a five-link crank-rocker mechanism (Figure 2, a), which during the cocking of the striker works as a crank-slider mechanism (Figure 2, b).

2 Theoretical investigations

To switch from one type of mechanism to another, it is necessary to change one of its geometric parameters, namely the distance between the crank rotation supports and the rocker arm, since changing this distance leads to a change in the rocker arm swing angle. In one of the extreme positions, the rocker arm is captured by a slider that serves as a support, as a result, the mechanism switches to a crank-slider mode of operation (Figure 2, b). In the extreme upper position of the slider, there is no moment of forces jamming the rocker arm. The rocker arm is released, the structure of the mechanism changes, the mechanism switches back to the crank-rocker mode (Figure 2, d). Under the action of the accumulated energy of the spring installed between the rocker arm support and the striker, the latter it is moving downwards rapidly. Thus, a change in the structure is necessary for the firing pin to be cocked, followed by the use of compressed spring energy to accelerate it. It should be noted that the service life of the shock unit is limited by the service life of the spring. For work in a limited time, this mode of operation is quite acceptable.

Fig.1. The layout of the Luna-24 station.

In connection with the curtailment of the lunar exploration program, we began to think about using the results of research on the creation of a shock mechanism in terrestrial conditions. The most suitable were the presses for metal processing by pressure. In mechanical engineering, a huge number of crank-slider presses are used, in which couplings are used to turn the executive body. The same couplings limit the speed of the presses, i.e., its performance. However, the specific working conditions of the executive body of crank presses do not allow them to be replaced by a mechanism of variable structure in the form they were used in drilling machines. Therefore, a new scheme of a hinge-lever mechanism of variable structure was proposed [2], in which the mechanism has two stable modes of operation: crank-rocker and crank-slider (Figure 3). In idle mode, the mechanism operates as a crank-rocker mechanism (Figure 3, a), and in operating mode – as a crank-slider (Figure 3, c). The transfer from one mode of operation to another is carried out by changing the position of the rocker arm support mounted on the slider (Figure 3, b), which, in in turn, it is made with the possibility of moving by a small amount. With the help of force action, the inter-support distance of the crank and the rocker arm of the mechanism changes and the rocker arm swing zone changes. In one of the extreme swing positions, the rocker arm closes on the slider, and with further rotation of the crank, the mechanism switches to the crank-slider mode of operation. The reverse transition of the mechanism is carried out by a force action that opens the rocker arm from the slider (Figure 3, d).

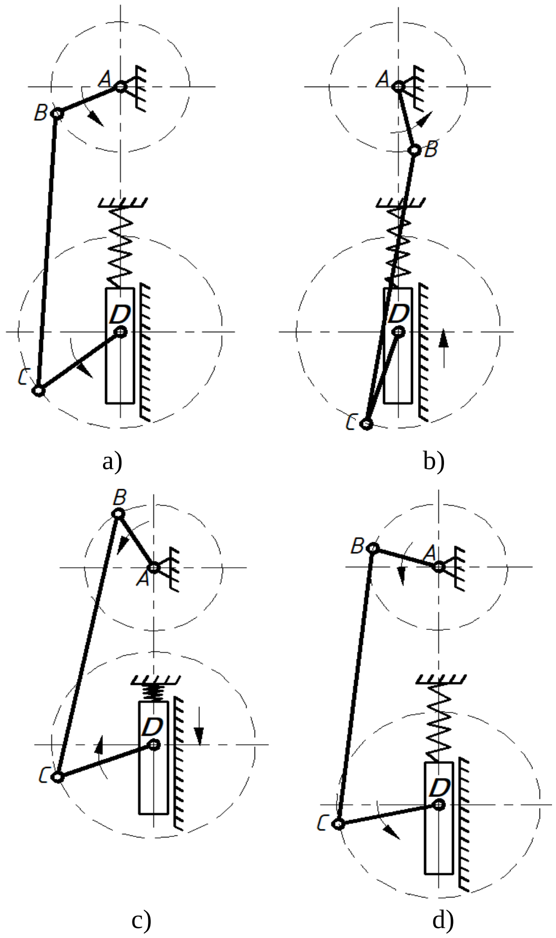


Fig.2. Mechanical generator of power pulses.

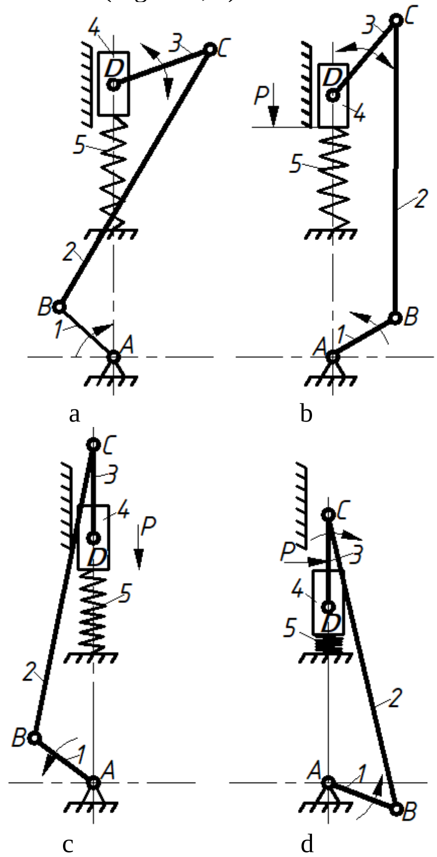


Fig.3. Kinematic diagram of the executive body of the press machine.

It should be noted that the use of a fundamentally new technical solution made it possible to create a number of new designs of presses for metal forming, including high-speed automatic presses.

Hinge-lever mechanisms of variable structure are widely used in percussion machines for various purposes, ranging from hand tools to attachments. Research them kinematics has shown that with certain ratios of the lengths of the links of the hinge-lever mechanisms, the gear ratio from the leading link to the slave reaches large values (Figure 4).

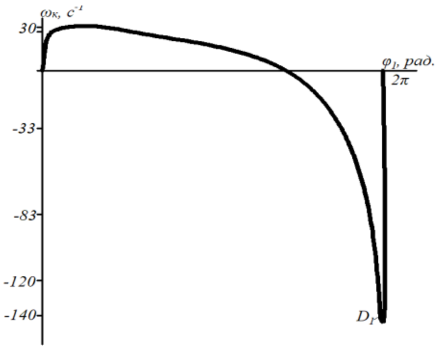


Fig. 4. Dependence of the angular velocity of the rocker arm on the angle of rotation of the crank.

Moreover, the gear ratio reaches the greatest value at the time of the so-called indefinite position of the mechanism, when the links of the mechanism line up. Using this effect, we have developed impact machines based on mechanisms of variable structure, ranging from hand-driven variable structure, ranging from hand-driven punchers to hammers with high impact energy. Fig. 5 shows one of the schemes of a shock machine with a hinge-lever mechanism of variable structure [4], which implements the pattern shown in Fig. 4.

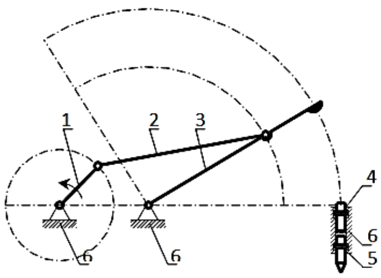


Fig.5. Schemes of a shock machine with a hinge- level mechanism of variable structure.

The design studies were accompanied by studies of the kinematics and dynamics of impact machines with variable mechanisms structure, identification of new properties, synthesis of the most optimal design and operating parameters of the power transmission [4, 5]. Mathematical models of these machines have been developed that describe the interaction of the elements of the power transmission: engine, gears, executive body, as well as models of the interaction of the transmission with the treated medium. It should be noted that the conducted experimental studies have confirmed the adequacy of the developed dynamic models and the possibility of their use in the analysis and synthesis of new designs of machines with mechanisms of variable structure.

Here is a fragment of the calculation of the impact node of one of the schemes for the implementation of a hinge-lever mechanism of variable structure – a jackhammer with a two-crank-slider mechanism. Usually, impact machines, during operation, perceive large dynamic loads on the supports, which lead to breakage of the elements of the support unit [3, 4]. New technical solutions were used in this mechanism, which significantly reduce the dynamic loads on the supports. The principle of operation of the mechanism is that when the cranks rotate, the piston moves inside the slider-striker, informing it of translational movement along the axis of the barrel. To reduce dynamic loads in the end sections of the piston stroke, there are air chambers "A" and "B" in the slider-striker, in which air cushions are formed. From the piston, the movement of the slider-striker is transmitted through compressed air formed in the chambers. The presence of an air cushion reduces the resulting dynamic loads when changing the direction of movement of the slider-striker from the working stroke to idle and back. The peculiarity of this mechanism is that at the moment of striking the tool, the slider-striker is kinematically not connected with the piston, i.e., with the drive, which protects the drive elements from the effects of reactive forces.

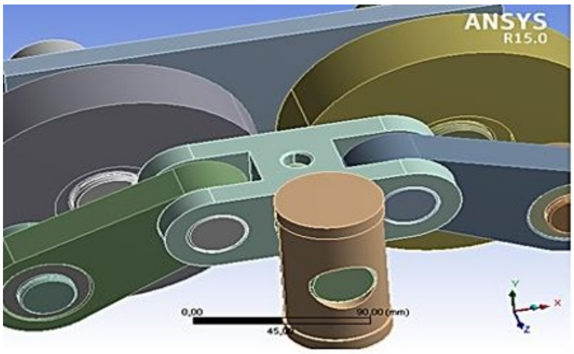


Fig. 6. Hammer impact assembly.

To analyze the effect of reactive forces on the support units during the operation of the mechanism and to present a picture of the loaded sections of the shock unit (Figure 6), the stress-strain state of the shock unit was calculated using the computer program ANSYS Workbench 15.0. The calculation results (Figure 7) showed that the greatest stress falls on the bearing units. The minimum value is 0.0004 MPa and it falls on the flywheel zone, and the maximum value is 138.6 MPa, on the bearing assembly connecting the flywheel and connecting rod.

The highest stress perceived by the shaft connecting the gear wheel and the flywheel is 1.3 MPa (1 Pa = 10^{-6} MPa). During the life tests of the jackhammer, one of the reasons for the shutdown was the breakdown of the rolling bearing (Figure 8, b) exactly at the place where the program indicates the maximum stress value. Which shows that the calculated values correspond to the experimental results. The various stress values are shown in Figure 8, which are highlighted in the corresponding colors. The calculation results showed the probable location of the sliding bearing failure, identified as a result of the theoretical calculation of durability. As can be seen, the results of the calculation and the experiment coincide, which indicates the adequacy of the obtained results of static calculation.

The studies carried out using new methods of modeling and calculating the stress-strain state of structural elements made it possible to identify the nodes that perceive the greatest dynamic loads, as well as to establish the permissible number of work cycles of the most critical links used in the impact mechanism. These results are confirmed by tests of experimental samples of impact machines with mechanisms of variable structure. The ways of increasing the working resources of impact machines with variable structure mechanisms using new technical solutions that significantly reduce the dynamic loads perceived by the support nodes are proposed.

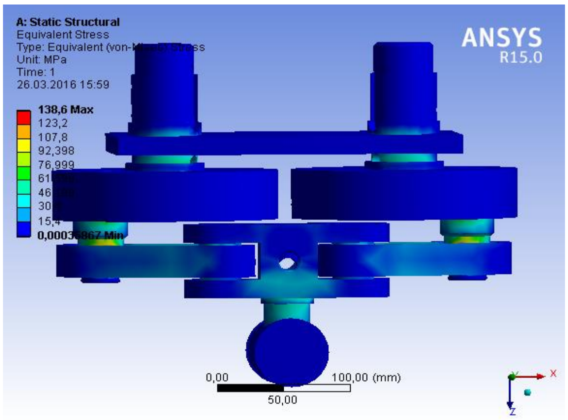
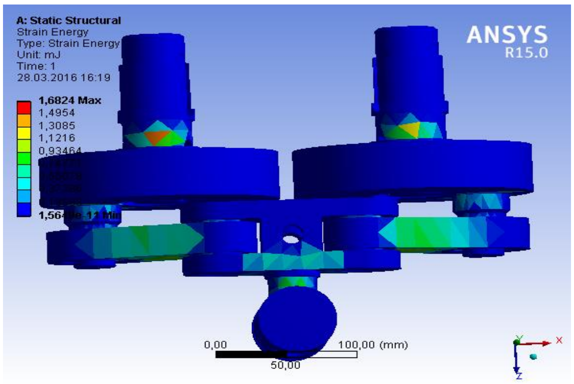
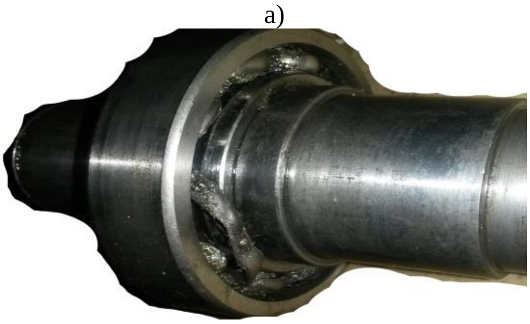


Fig. 7. Results of the analysis of the stress state of the shock node.



a)



b)

Fig.8. Stress state analysis and characteristic rolling bearing failure.

3 Conclusions

The results of the research have shown that hinge-lever mechanisms of variable structure, acquiring new properties, make it possible to create machines and mechanisms on a fundamentally new basis. The new properties of these mechanisms expand the boundaries of their use, significantly increasing their efficiency. The use of new methods of modeling and calculating the dynamics of machines makes it possible to determine the most loaded places that require increased attention, which in turn contributes to a better design of mechanical impact machines that provide a high degree of reliability and durability.

References

1. Alimov O.D., Manzhosov V.K., Filipovsky V.P. Mechanical pulse generators with a hinge-lever gripping device. Frunze, Ilim.(1975).
2. Alimov O.D., Abdraimov S. Fundamentals of the theory of presses with mechanisms of variable structure (on the example of creating presses “USTA"). Chipboard. Frunze, Ilim, 294 p.(1988).
3. Abdraimov S., Dzhumataev M.S. Hinge-lever mechanisms of variable structure. Bishkek, Ilim, 179 p.(1993).
4. Dzhumataev M.S., Abdrakhmanov I.A., Urkunov Z.A. Hinge-lever shock mechanisms with kinematic decoupling of the shock node. Bishkek, Ilim, 85 p. (2007).
5. Dzhumataev M.S., Karimbaev T.T., Bayaliev A.Zh. Impact mechanisms with a splitting striker. Bishkek, Ilim.(2015).