Performance Assessment in Design of High-Speed Automatic Machines Based on Analysis of Their Dynamics

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Abstract. One of the main factors determining the performance of high-speed automatic machines is the oscillatory (dynamic) processes that arise as a result of elastic deformations of their links. The intensity of these processes increases with the growing speed of the mechanisms, the wear of kinematic pairs in the links of the units, the magnitude, and nature of the change in technological forces. The higher the rate of change of external forces acting on the elements of the mechanism, the greater the amplitude of the oscillations of the links and the time of their attenuation due to energy dissipation. The evaluation of the effects of dynamic processes in the design of high-speed automatic machines allows you to determine the degree of consistency of movement and the margin of safety of the elements of mechanisms depending on their speed. The paper discusses the methodology for assessing the impact of dynamic processes on the performance of designed products. The methodology is based on computer modeling of dynamic processes. The software solution proposed by the author allows us to automate the parallel processes of developing an object model, a dynamic model (a system of concentrated masses connected by elastic-dissipative and kinematic bonds), and a mathematical model in the form of systems of second-order nonlinear differential equations. The object of study is the main landing (crank-slide) mechanism, the cut-off mechanism (cam-lever), and their drive, including an electric motor, V-belt drive, shafts, and gears, of the multi-position cold stamping machine AV 1818.

Keywords: Dynamic model · Mass · Moment of inertia · Rigidity · Energy dissipation

1 Introduction

One of the key requirements for the designed automatic machines is the exact coordination of the mechanisms executive links movements under given operating conditions (operating speed, technological forces, wear of kinematic pairs) [1–5]. As a result, the requirement to limit the maximum deviation (positioning accuracy) of the actual executive links movement from the ideal, determined only by its kinematics, is obvious. The solution of a similar problem at the design stage can be carried out on the basis of

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the study mechanism's dynamic, taking into account the elastic-inertial properties of its links [6–10].

This article presents the results of the development and computer implementation of a methodology for studying the dynamics of cyclic action mechanical systems, based on the representation of the designed mechanism as a system of concentrated masses connected by inertialess, elastic-dissipative, stationary, holonomic, piecewise-continuous bonds.

As an object of study, we consider the cut-off mechanism of the cold stamping machine (CSM) model AV 1818 (Fig. 1), designed for the manufacture of nuts by cold forging with a capacity up to 300 products per minute.

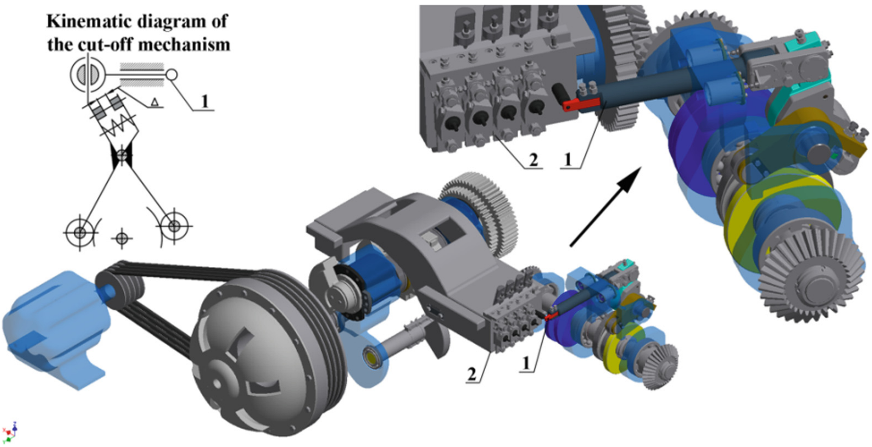

Fig. 1 3D model CSM AV 1818—cut-off mechanisms, the main landing, and their drive. Executive links: 1—the cut-off mechanism (knife stock), 2—the landing gear (slider)

The executive link of the cut-off mechanism (knife stock) moves according to the scheme: dwell—forward stroke—dwell—reverse stroke. An indispensable condition for its operability is the exact transfer of the cut billet by the mechanism executive link to the first stamping position. Violation this requirement leads to damage to both the cut-off mechanism itself and the elements of the upsetting mechanism (punch and die), and possibly other CSM parts—transferring of blanks, pushing (not shown in Fig. 1).

2 Modeling of Mechanical Systems of Automatic Machines

The reasons for the possible inconsistency work of mechanism parts in the automatic machines are their links deformation and increase the gaps in joints when the kinematic pairs are worn.

Any real mechanism is an oscillatory system, the parameters of which are determined by the elastic-inertial properties its elements and the kinematics of their compounds (taking into account gaps), the parameters of dissipation and friction forces, the nature and magnitude of the external and internal forces acting on it [2, 6, 10]. As a result of this, the real movement law of any link in the mechanism, the forces acting on it, do not coincide with the ideal values calculated by the classical methods of mechanisms and machines. The deviation of the real movement parameters of the mechanism from ideal increases with increasing speed, wear of kinematic pairs, and, ultimately, leads to a limitation of the mechanism performance.

The construction of a model of an oscillatory system (dynamic model), which allows calculating the motion parameters of the real mechanism links and forces acting on them, is a rather time-consuming task. Its solution at the stage of designing the mechanism is associated with the calculation of the elastic-inertial link's parameters and the construction systems of differential equations (mathematical model), that describe the element's motion of dynamic model, followed by their numerical solution.

At present, the task of calculating the elastic-inertial parameters of a mechanism link can be solved by applying solid-state modeling methods [11–14] when designing it, for example, in Autodesk Inventor Professional (or some other similar program). The number of software products designed to solve the problems of mechanisms dynamic modeling, taking into account their elastic-inertial properties, is limited.

This article is devoted to the development of a computer implementation methodology for calculating mechanisms based on their modeling by systems of concentrated masses connected by kinematic and (or) inertialess, elastic-dissipative, piecewise-continuous bonds [2].

The proposed solution is based on the idea of representing the mechanism in the form of an interconnected object's set, whose dynamic and mathematical models are known and implemented in the form of difference schemes constructed on the basis of the Runge–Kutta method (computer models). The model of the studied mechanism is created from the models of objects. The set of objects representing the mechanism (object representation in Fig. 2) and the mechanism itself fully correspond to each other. Replacing reality with a model is carried out only at the level of the object. That is, the accuracy of the results is determined solely by models of those objects that are used in these studies [15–20].

When adding a new object to the computer model, functions are added that allow you to take into account the effect of this object on previous objects (the response is Ω) and, conversely, the effect of the previous object on the added object (x).

In the framework of this methodology, the object model is determined by a number of settings, both universal and individual. The first includes the complexity of the model (the number of concentrated masses), functional dependencies not determined by the structural diagram of the mechanism (for example, the laws of profiling cams), the parameters of gaps, friction forces, structural, and technological forces. Individual settings are the parameters of the mechanism, depending on its structure. For example, if it is a central crank-slide mechanism, individual parameters are the values of the crank radius and the connecting rod length.

Figure 3 shows a typical window of computer program for determining the object model parameters.

The elastic-inertial characteristics. Here is the possibility of determining the stiffness, mass, and dissipation parameter for each mass of object model.

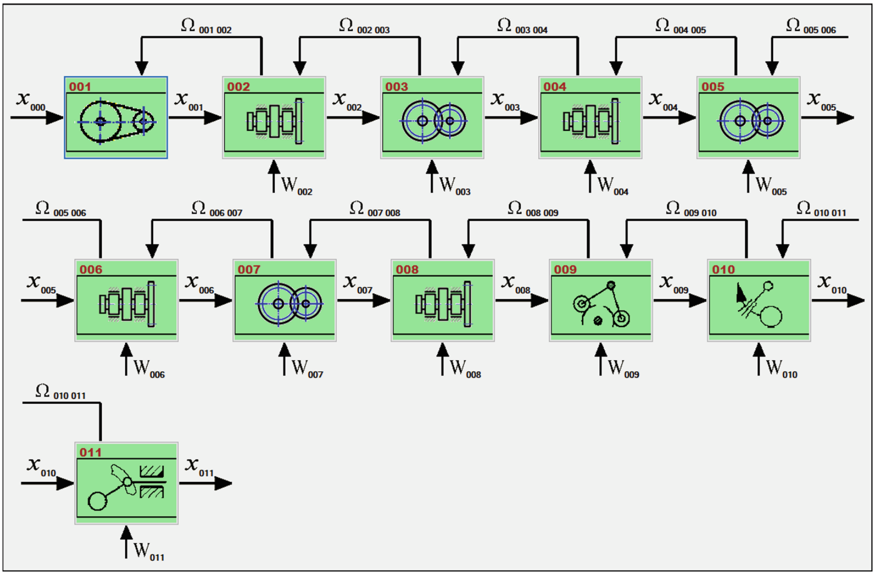

Fig. 2 The object model of the cut-off mechanism CSM AV 1818: 001—v-belt drive, 002—drive shaft, 003—gearing (cylindrical), 004—main (eccentric) shaft, 005—gear (cylindrical), 006—camshaft, 007—gearing (bevel), 008—cam shaft, 009—cam mechanism, 010—upper arm of the forward lever, 011—knife stock (executive link of the cut-off mechanism)

The position function. In Fig. 3 this mode is active. Currently, these functions are divided into four blocks: forward stroke—dwell—reverse stroke—dwell. In this version of the computer program, their number is limited (Fig. 3). With the position functions, there is an option for the accuracy of their execution.

The Accuracy tool. In this tool block, you can determine the gap parameters in the kinematic pair.

External loads. Here, technological, structural loads and friction forces affecting the masses of the model's elements can be determined.

When designing the mechanism, decisions can be made on changing the designs of certain elements, the object parameters are changed accordingly, and the results of these changes are analyzed.

3 Analysis Results of the Mechanical Systems Dynamics

The study of the mechanical system dynamics allows in the general case to solve two problems [15]:

1. Performance assessment depending on the speed of work (productivity), as well as, possibly, on the mechanism settings. In this particular case, this is the tightening force of the spring connecting the levers of forward and reverse stroke cut-off mechanism,

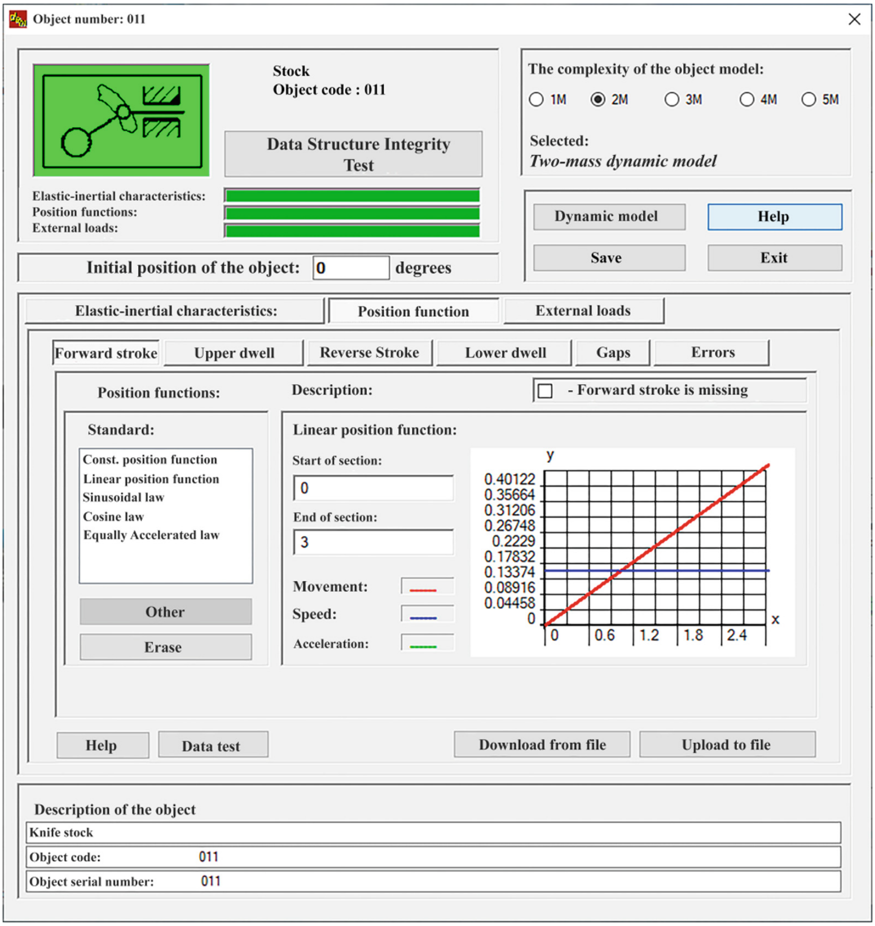

Fig. 3 Program window for entering data of the object model: "Stock"

the magnitude of its deformation, the force from the side of the pneumatic cylinders, designed for a constant selection of gaps in its elements.

2. Correction of structural elements of the mechanism, affecting its kinematic parameters (for example, the law of profiling cam tracks), and elastic-inertial parameters (geometry of the mechanism links).

In this paper, we consider only the question of studying the operability of the mechanism at various speeds of its operation and the degree of kinematic pair wear in joint: forward stroke lever—knife rod.

In Fig. 4 shows the computer program main window for calculating and analyzing the results of studying the cut-off mechanism dynamics in the dam system [15]. The graph is shifted down vertically due to the influence of the structural force from the side of the pneumatic cylinders. CSM productivity is 260 moves per minute. The rotation speed of the electric motor is 2080 rpm.

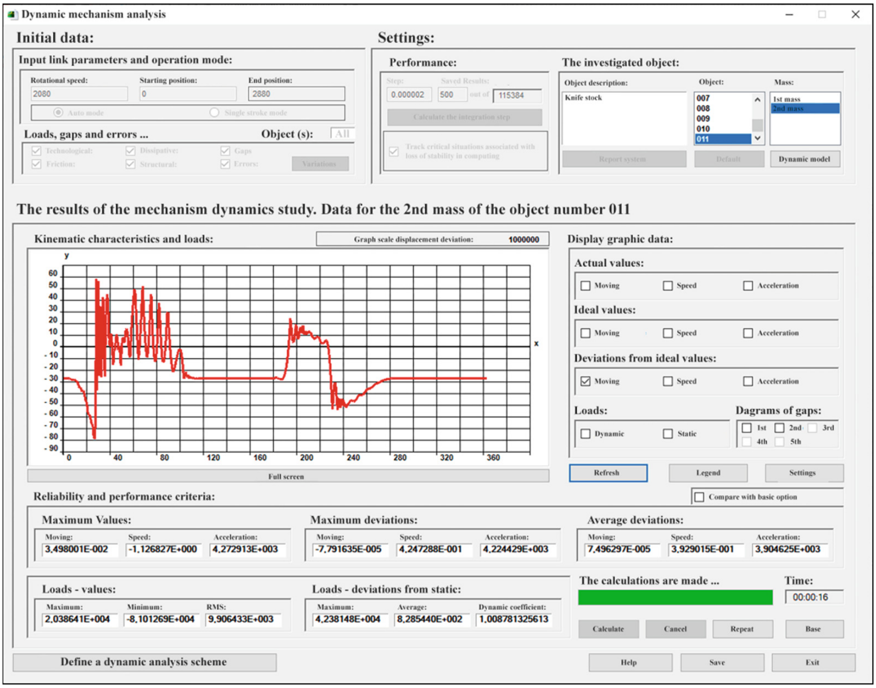

Fig. 4 Dynamics study results of the cut-off mechanism CSM AV 1818—a graph of changes in the accuracy of knife stock positioning (μm)

The stamping operation begins when the main shaft rotation angle is equal 85°. The deviation of the knife rod position from the projected at this moment is approximately ±30 μ.

The main features of the developed and implemented as a software product methodology for assessing the health of a mechanism based on its dynamic analysis:

- calculation kinematic parameters of mechanism links movement;
- calculation forces arising in the elements of the mechanism during its operation;
- calculation performance criteria to perform a comparative analysis of various options for structural solutions at the design stage of the mechanism;
- possibility of studying the dynamics of the mechanism of the presence of such factors as the level (“Variations” tool) of loads (technological, structural), friction forces, energy dissipation, gaps in kinematic pairs, manufacturing errors at various speed work modes;
- saving the results of calculating the mechanism design as a basic option, followed by using these results to evaluate various options for structural changes of the mechanism;
- comprehensive analysis of dynamics based on the calculation of ten performance criteria (including maximum acceleration, average acceleration, maximum, root-mean-square value load, and others) when two separate parameters of the mechanism (for example, speed and gap) change within specified limits (the tool “Define a dynamic analysis scheme”).

Figure 5 presents the results of the mechanical system study in the “Define a dynamic analysis scheme” mode. An analysis was made the operability of the cut-off mechanism on the variation interval of the rotational electric motor speed from 1040 to 4160 rpm, which corresponds to the performance of the CSM rotary gearbox from 130 to 520 strokes per minute (gear ratio between electric motor and the CSM main shaft is 8).

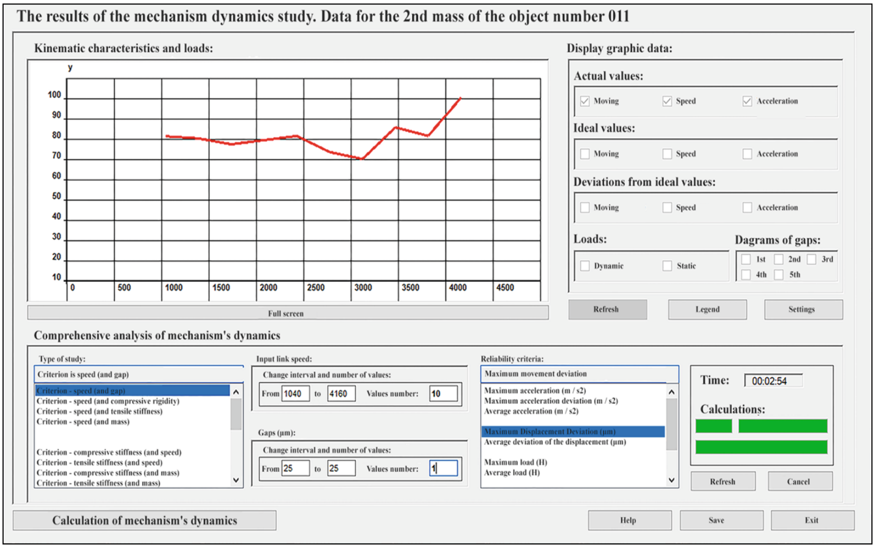

Fig. 5 The comprehensive dynamics analysis of the cut-off mechanism: the interval of main shaft speed variation 130–520 rpm, the gaps in the kinematic pairs in accordance with the manufacturing tolerance (≈25 μm)

An analysis of the obtained data allows us to conclude that the system (cut-off mechanism—main landing gear) is guaranteed to work stably up to slide’s speed 375 moves per minute.

4 Conclusion

The developed methodology for a comprehensive study of the mechanical systems’ performance assessment based on an analysis of their dynamics is presented in the form of a registered software product. Its use, together with 3D modeling programs (for example, Autodesk Inventor Professional) allows you to quickly assess the advantages or disadvantages of various working options for design solutions when designing high-speed automatic machines.

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