The Dynamic Reactions of the Piston Machines Mechanical Drive Joints

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Abstract. On the basis of the mechanics fundamental provisions the high-speed cycle machines mechanical system joints backlashes are shown to be shifted. This is the impact process in which the dynamic reactions joints become greater by the values of kinetic and static reactions and it should be taken into account when carrying out the engineering calculations of machine elements. The importance of determining the impact speed as the criterion for the impact zone materials plastic deformation starting is represented. For reducing the impact process harmful influence on the joints potential, the wide use of engineering solutions concerning the automatic adjustment of developing joints backlashes is recommended.

Key-words: mechanical system, joints, backlash, impact process, dynamic reactions

1. Introduction

The joints kinetic and static reactions take into account the rings variable external and inertial loadings and in the absence of (not considering) the mechanical system joints backlashes express the nature of rings and joints loading of the ideal system movement as a first approximation, which, in most cases, would be enough for the general-purpose machines mechanical system design stage. Having completed the system with forces and friction forces moments of joints, the second approximation of the system construct strength loading is obtained.

In movable geometric constraints of the real mechanical systems, the backlashes growing during the machine operation due to the joints surfaces non-repairable wear are normalized depending on the type of the active surfaces matching. The joints backlashes cause the additional dynamic loading of the joints elements.

Due to the cycle machines mechanical system backlashes shift, the additional dynamic loading is impacting in nature, the impact loads amounts of the high-speed systems can multiply exceed the kinetic and static reactions values, their knowledge is absolutely necessary for the engineering calculation of joins elements, as well as for the development of the growing backlashes automatic adjustment devices, impact energy dampening devices and, generally, for the development of the engineering solutions on the force impact process harmful effect reducing, which occurs in all the cycle machines mechanical systems joints.

The examination of the extremely undesirable conditions possible occurrence of the joints active surfaces plastic deformation starting and their destruction has the particular importance when defining the impact process parameters.

2. The problem statement

The problem defining the impact process parameters when shifting the single joint backlash is stated and solved using the example of the numerical calculation, thus, the similar study algorithm is
represented, the impact loading comparative estimation is given, as well as the joint active surfaces plastic deformation possible start conditions examination is conducted.

3. Theory
For the impact process parameters defining, the fundamental regularities based on the momentum conservation principle are used. In order to determine the impact speed at the backlash shifting, the ideas of the complex motion decomposition into the components will be used.

The postulates of the solids impacting classical theory are used as the assumptions. The solids are considered as rigid, and if the bodies interaction is instantaneous, then the impact force is assumed to be infinitely great. In our calculations the restitution coefficient \( R \) is taken to be zero which corresponds to the perfectly inelastic impact conditions.

Moreover, the hypothesis having been experimentally confirmed \([1, 2]\) that metals and alloys elastic characteristics (modulus of elasticity, Poisson ratio) do not depend on the loading speed, while the yield point, consequently the plastic deformations threshold depend on the impact speed, which limit value is absolutely possible to be calculated, is accepted in the study.

![Figure 1](image_url)

**Figure 1.** To the calculation of the slider inertia forces in the extreme positions:

1 – crankshaft, 2 – connecting rod, 3 – slider.

For calculation the actual mechanical systems joints reactions, the study of the motion conversion kinematic model motion parameters of the particular reciprocating mechanism in which the reciprocating motion of one ring is realized, is considered.

The elementary crank-slider scheme used as the main mechanism of compressors, internal and external combustion engines and other machines without restrictions is chosen as an example (Fig. 1).

The scheme parameters: the slide (piston) \( H \) stroke 3 equals to 80 mm, therefore, the crankshaft kinematic size is \( \ell = R = 40 \text{ mm} \); \( \ell = 120 \text{ mm} \); the crankshaft maximum rotation speed is \( n_{\text{max}} = 5500 \text{ rpm} \); the slider mass \( m \) is 0.5 kg, the slider diameter is 80 mm.

The backlash shifting only in connection of the connecting rod 2 with the slide 3 is examined, having taken the backlash size as follows \( \Delta = 0.1 \text{ mm} \).

It is evident that the backlash is shifted in all kinematic pairs including the rectilinear pair «slider-shaft» as demonstrated by hodographs and kinetic and static reactions diagrams built during the mechanism operation cycle.
Figure 1 shows two extreme positions of the slider 3 in which the examined joint backlash is shifted and the slider speed direction is reversed. Linear acceleration of the point B is defined according to the known vector equation:

\[ \bar{a}_B = \bar{a}_d + \bar{a}^n_{BA} + \bar{a}^C_{BA}. \quad (1) \]

In the considered extreme position (figure 1a), \( a_B^n = \frac{V_B^2}{\ell_{OA}} \), but \( V_B = \omega \cdot R = 23 \text{ m/s} \), then \( a_B^n = 4408 \text{ m/s}^2 \), and \( a_B^C = 0 \). Having folded the equally directed accelerations \( \bar{a}_d \) and \( \bar{a}^n_{BA} \), \( a_B = 17633 \text{ m/s}^2 \) is derived.

In the mechanism position in figure 1b, the point B acceleration determines the components values difference: \( a_B = 13225 \text{ m/s}^2 - 4408 \text{ m/s}^2 = 8817 \text{ m/s}^2 \).

Subsequently, by using the value \( a_B = 17633 \text{ m/s}^2 \) and considering it to be constant in the backlash sample motion \( \Delta \), \( \Delta = a_B t^2/2 \) or \( t^2 = 2 \Delta/a_B \) are obtained having substituted the initial data numerical value, the impact time is derived \( t = 0.0001 \text{ s} \) or \( t = 10^{-4} \text{ s} \), that corresponds to the values given in [1-4].

The impact speed is \( V = a_B t = 1.7 \text{ m/s} \).

4. Results discussion

The conducted study has shown the real high-speed cycle machines mechanical system joints backlashes to be adjusted and this process is an impact one at which the joints dynamic reactions have values exceeding the kinetic and static reaction ones.
Besides, the hypothesis that mechanical system rings and joints inertial loading is possible to exceed the strength loading by the values by the useful loading from the machine operating member, is confirmed. It should be considered when carrying out the machine elements design calculations.

The impact process characteristics are largely determined by the impact time, therefore the automatic adjustment techniques of the growing backlashes in operation are relevant for the high-speed machines during the implementation, such techniques have been developed and engineering solutions for their implementation exist.

5. Conclusions

- By applying the case study, the backlash adjustment process examination algorithm is represented and the backlashes shifting of the high-speed cycle machines mechanical system joints is proved to have the impact character.
- The real mechanical systems joints dynamic reactions values exceed the kinetic and static reactions ones and it should be taken into account in conducting the design calculations of machine elements.
- The joints elements plastic deformation process possible start control is necessary and relevant as the variety of construction materials is constantly expanding, and limiting impact speed knowledge is the defining criterion both in determining the initial backlash and in forecasting the operational connection resource.

6. References

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