Automatic control a stiffening of links as a means of adaptation of mechanical systems

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Abstract. The publication presents some technical solutions of mechanical systems created on the basis of gears, the design of which includes additional elements with nonlinear properties.
The characteristics of such elements with automatic control stiffness control allow to implement a universal design approach mechanical systems providing the property of adaptation to variable external loading of mechanical systems at the design stage, while improving the dynamic quality of the system.
Key-words: mechanical system, joint, gear drive, control a stiffening, quasi-zero stiffness, adaptation, control circuit

1. Introduction

It is known that the main dynamic characteristic of a mechanical system is determined by the stiffness of the joints. This dynamic characteristic corresponds to the natural oscillation frequency of the system with a unit joint and to the spectrum of partial frequencies of the system with many joints. To exclude resonances that lead to the development of unacceptable oscillations and loss of stability of the system and to assign operating conditions of the designed systems, it is necessary to know the natural oscillation frequencies of the mechanical system.

2. Problem statement

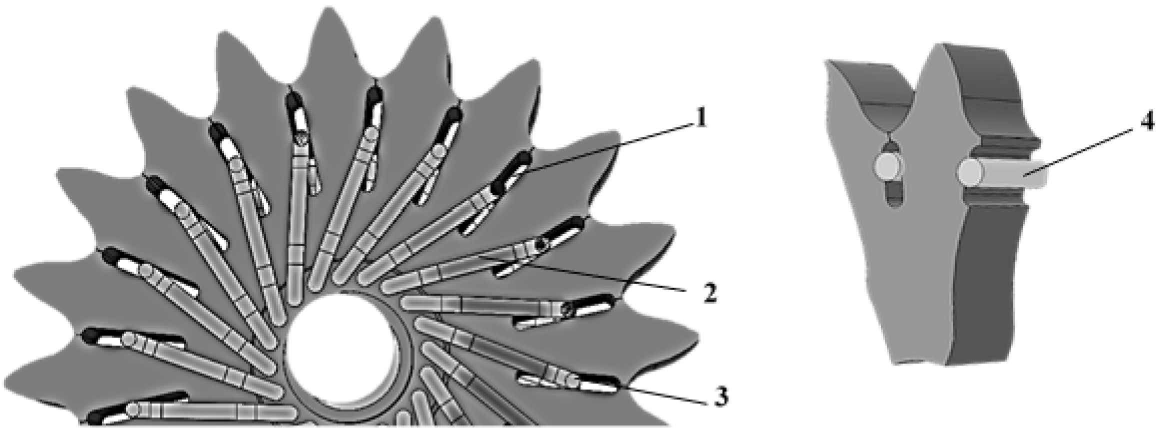
The forced oscillation frequency can vary over a wide range with multi-mode operation of the mechanical system. The search problem a technical solution to the elastic properties of the joints, which automatically change with multi-mode operation is relevant.
This problem of applied mechanics has no universal solution. Constructions of joints with variable stiffness are diverse and depend on the inertial, dimensional, power parameters of the designed systems. A step change of stiffness by the parallel connection of the elastic elements used in the suspension vehicles. Nonlinear pneumatic elements with variable internal pressure are widely used in the suspension of this class of machines in last years. The stiffness of the elements changes smoothly and is controlled by the operator depending on the load and road condition.
On the example of the gear drive show that the automatic control of the stiffness of the joints can be achieved by implementing the developed universal principle of designing mechanical systems, at the design stage giving them the property of adaptation to real parameters.

3. Theory

There are technical solutions of the gear drive [1] and [2] with automatic control of the tooth changeover stiffness depending on the transmitted force loading due to the change in the tooth height and as a consequence of its bending stiffness. By modifying the design of the gear is controlled by this parameter, for this radial slots 1 consisting of two parts (Fig. 1,a) performed on the root of the teeth. The first arched narrow part of the slot adjacent to the root is made of a width (0,2÷0,4) mm and special sliders 3 are placed in the second wider part of the radial slot. The sliders 3 are pivotally connected to the wheel hub by the flexible crank rods 2. To obtain a desired angular shaft displacement relative to the gear rim flexible elastic elements are installed between the shaft and the gear rim.

The angular displacement of the shaft relative to the gear rim is absent at low load. In this case, the flexural stiffness of the tooth will be minimal since the sliders are in the extreme position to the shaft axis. The angular displacement of the gear rim relative to the shaft occurs with an increase in the force flow. The sliders thus move to the open narrow parts of the slots, reducing the height of the tooth and increasing the mesh stiffness. Additional structural elements of the modified gear wheel are a stiffness control circuit that reacts to changes in the transformed force flow and automatically changes the flexural stiffness of the tooth [3].

The technical solution [2] is a simplification of the modified design [1]. Elastomeric inserts, for example, made in the form of elastic cylinders 4 (Fig. 1, b) are placed in special sockets in the second wide part of the radial slot. Automatic change stiffness of the tooth occurs with increasing force flow, due to the nonlinear deformation of elastic cylinders, until there is a closure of the narrow upper part of the slot adjacent to the root between the tooths. The stiffness of gear stepwise increases with the closure the slot and adequately limits the total deformation of the gear rim.



a) b)

Figure 1. Modified design of gear wheel with self-guided mesh stiffness:
a) – that the technical solution [1]; b) – that the technical solution [2].

It is known from [4] the dynamic load arising in the meshing and contributing to the generation of forced with natural frequency of the tooth changeover is defined as

$$P_{\partial u н} = Av\sqrt{m(\delta+\Delta p)\cdot c}\,, \tag{1}$$

where A is a coefficient of proportionality (its value is not important for a quality process estimate); v is a peripheral speed at the initial wheel cylinders transmission (m/s); m is a gear drive mass reduced to a polar point; δ is a static flexural deformation of a tooth under loading (a power error of a base pitch); Δp is a primary error of the base pitch; c is the mesh stiffness.

By controlling the mesh stiffness, the dynamic interaction of the tooth during the tooth changeover can be significantly changed or reduced, as follows from (1).

Natural resonance frequencies f should be determined taking into account the shafts stiffness and the stiffness of the tooth to exclude possible resonant modes of gear. Next, compare the results with the forced oscillation frequency p of the system, which is defined as

$$p = \frac{nz}{60}, \tag{2}$$

where n is a number of rotations of the wheel, min; z is a number of tooth at the wheel.
Variable flexural stiffness of the tooth leads to a change in the natural oscillation frequency of tooth. The natural oscillation frequency f in such a mechanical system is determined by a known formula:

$$f = \sqrt{\frac{c}{m}}, \tag{3}$$

where c is the stiffness of the double tooth contact; m is reduced the specific mass of the wheels.
The resonance of the system is caused by the coincidence of the frequency of meshing p with one of the natural frequencies and this is unacceptable. By controlling the stiffness parameter according to (1) and (3), namely by reducing it, it is possible to provide optimal operating conditions of the mechanical system by reducing the associated level of dynamic and vibration processes. In this case, the characteristics of nonlinear elements will be different in each specific design. As a whole the proposed solutions are the implementation of universal methods of creating systems with adaptive properties.
Technical solutions of joints with automatically controlled stiffness built on linear elements are of great interest. Mechanical systems with quasi-zero stiffness noted, for example, in [5] and [6] are of interest at present. The concept of quasi-zero stiffness was introduced by Professor P. M. Alabuzhev [7] and means that the strength characteristic of stiffness in a certain working area is zero. On this basis, a class of vibration protection systems using quasi-zero stiffness vibration isolators was developed. Some schematic diagrams of such vibration protection systems using elastic linear elements are shown in Fig. 2. The working area is determined by the static draft of the system and the geometry of the arrangement of linear elements in the aggregate creates a total stiffness $c_{\Sigma} = 0$. Such structures can be used in many connections of mechanical systems for various purposes.

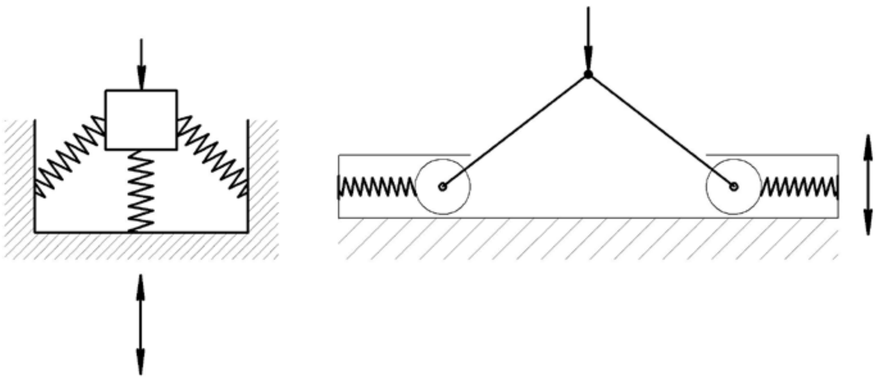


Figure 2. Schemes of vibration protection systems with quasi-zero stiffness [7].

The system becomes "soft" at zero stiffness $c=0$ and the energy of forced oscillations is not transmitted through the joins to the structural elements of the mechanical system and resonance phenomena are absent. This is promising for the technical implementation of such joints in many systems.

4. Results discussion

Gear drive with small flexural stiffness of the tooth minimizes vibration activity during single-mode operation. Stiffness control depending on the level of the transformed power flow should be provided in multi-mode operation.
Connections with quasi-zero stiffness on the basis of linear elements are promising in the synthesis of vibration-proof and vibration-insulating mechanical systems.

5. Conclusions

1. Automatic change of stiffness in mechanical gearing for various purposes can be achieved by universal methods of adaptation of mechanical systems, using the correct structure of the systems and additional to the main movement of the links, performed by the control circuit.

2. Mechanical systems using connections with quasi-zero stiffness are promising and provide vibration-free operation of the system with the minimization of mechanical interaction in the joints.

6. References

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