

DEVELOPMENT OF POSITIONING OF MECHANISMS WITH PIEZOELECTRIC ENGINES

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Summary. Positioning mechanisms with carts moving in a horizontal plane and with piezoelectric vibroengines analyzed in the article form a group of mechanisms, having elastic and dissipative links and carts moving between deflectors, which interact with the engine without intermediate transference links. Positioning mechanism piezoelectric vibroengine of original construction has been developed, which eliminates looseness, energy losses and acoustic noises.

Introduction. Mechanisms with moving carts are one of the main parts of majority of devices and machines. They differ and often precondition technical progress in various technical areas. However, precision, stability and speed of many such mechanisms depend on input links interconnected by elastic and dissipative elements. Moreover, while increasing precision and sensitivity of mechanisms, undesirable effect of foundation vibrations also increases. Therefore, such control algorithms of moving links must be developed, which would not excite undesirable vibrations in mechanisms [1, 3].

The analyzed positioning mechanisms with moving carts along a horizontal plane and with piezoelectric engines make a mechanisms group, having elastic and dissipative links as well as moving carts between deflectors, which interact with the engine without intermediate transition links. Such equipment of different construction is characterized by common regularities of dynamic processes. Synthesis of designed mechanisms practically means that the cart movement law is set and, pursuant to it, control of a power mechanism is determined [2, 4].

The main requirements of precision positioning mechanisms are as follows: high positioning sensitivity and precision, reaching micron segments in accordance with linear displacements and second segments in accordance with angular displacements; wide range of linear speeds (0 – 100 mm/s); wide range of linear speeds (10 mm – 6 m); multi-regime control; reliability and durability; wide range of cart masses (5 – 200 kg). This requires a high tightness of power mechanism connection with a cart; there should be no intermediate transition links, the cart should move pursuant to several coordinates, control system should be simple.

Control of one degree-of-freedom positioning mechanism. Control system of such mechanisms is developed in a way it could realize the whole of algorithms, which would force elastically and dissipatively interconnected carts to move following the set paths. Moreover, it is required that the set path should have certain marginal conditions in its beginning and the end. For example, when the cart is in transition from a still status to a determined point, it often requires to make a movement when the speed and acceleration levels in the environment of determined points are close to zero. Mathematical content of control task of such positioning mechanisms is such that it requires determining the values of control forces, which would move the cart in accordance with a set path. To solve control task under mathematical attitude is to develop calculation algorithm of control variables (forces), which would realize a determined movement or position of elastically and dissipatively interconnected carts. Technical solution of control task requires realization of values of control forces with executive gears. In other words, executive gears must move the object to a preset position at any moment of time.

It is known [1, 2, 3] that in order to move the cart without transitional processes, speed and acceleration laws must conform to the following conditions: 1. Maximum speed value must be reached in the middle of the path, i.e. $X' \big|_{t=T/2} = X'_{\max}$, $X' \big|_{t=0} = X' \big|_{t=T} = 0$. 2. Maximum acceleration value must be reached at the moment of time $t = T/4$, and minimum – at the moment of time $t = 3T/4$, i.e. $X'' \big|_{t=T/4} = X''_{\max}$, $X'' \big|_{t=3T/4} = X''_{\min}$, $X'' \big|_{t=T/2} = X'' \big|_{t=T} = 0$.

The second condition is best implemented under the following acceleration law:

$$X'' = \begin{cases} 0, & \text{when } t \leq 0, \\ X''_0 \sin(2\pi/T)t, & \text{when } 0 \leq t < T, \\ 0, & \text{when } t \geq T. \end{cases} \quad (1)$$

After integration (1) and considering that in the marked time interval $X'' \big|_{t=0} = 0$, we get the following movement speed law of the cart:

$$X' = \begin{cases} 0, & \text{when } t \leq 0, \\ -X''_0 (T/2\pi) \cos(2\pi/T)t + X''_0 (T/2\pi), & \text{when } 0 \leq t < T, \\ 0, & \text{when } t \geq T. \end{cases} \quad (2)$$

After integration (2) and considering that in the marked time interval $X' \big|_{t=0} = 0$, we get displacement law of a stably moving cart:

$$X = \begin{cases} 0, & \text{when } t \leq 0, \\ -X''_0 (T/2\pi)^2 \sin(2\pi/T)t + X''_0 (T/2\pi)t, & \text{when } 0 \leq t < T, \\ X_T, & \text{when } t \geq T. \end{cases} \quad (3)$$

here X'' , X' , X - acceleration, speed and displacement moment time components of the cart, X''_0 - maximum acceleration value, T - duration of cart shift, X_T - set displacement size of the cart.

Positioning mechanisms with piezoelectric engines. In order to develop precision positioning mechanisms, it is required to develop their element base first. Therefore, the authors developed new technical solutions of the engines, their control systems and new mechanism constructions. Widely used piezoelectric engines, operating principle of which is that high frequency mechanical vibrations are transformed into linear or angular movement of the cart. The scheme of piezoelectric engines is as follows. Operating part of the engine is pressed to a moving part of the cart. Due to a friction contact of the moving part with a vibrating element, movement moment is created. By canceling electrical high frequency signal, and when piezoelectric element halts its vibrations, the cart is forced to stop. This happens because the same piezoelectric element firmly connected to the frame, is pressed by a friction gear to the moving part. Therefore, these piezoelectric engines may be successfully used to implement different regimes of the mechanisms.

Piezoelectric vibroengine of a linear movement has been developed. One electrode of a piezoelectric plate of the device is divided into four symmetric parts, and the other electrode is left undivided. In the ends of plate between electrodes rectangular vibration concentrations are glued. Besides, plate is pressed through concentrators to cart. Pressing mechanism is "II"-shaped holder with a cut in the middle where plate is installed. One end of holder is firmly assembled to foundation by bolt, another end with a cut leans to an adjustable bolt through elastic spacer and spring. Moreover, parts of the divided electrode are correspondingly glued at the junction to four electrodes with terminals, and the other non-divided electrode is glued at the center to electrode also with a terminal. All electrodes are firmly intercollected into a package by isolators. Positioning device with a cart moving along one coordinate, piezoelectric engine of which determines the optimal cart speed has been developed. Positioning device where the optimal control law of the cart movement is used has been developed. Device for information accumulation positioning in the plane has been developed, which has been used in optical information recording and reading systems. Here information accumulation planes are shifted by lines in automatic continuous regime. It may be also used for positioning of various objects along the plane. The device contains two coordinate positioning mechanisms with piezoelectric vibroengine and photoelectric raster displacement transducers as well as a control unit. Technical characteristics of this device are as follows: minimum positioning plane – 90 x 90 mm.; distance between lines – 6 μm ; speed of movement along the line – 90 mm/s; positioning error – 1 μm . Positioning mechanisms with a control system having piezoelectric vibroengines and feedback circuits under displacements has been developed. Construction of positioning mechanism is such that the cart independently moves along perpendicular directions in the plane and two identical control systems register position of the cart on the plane at any point of positioning field at a maximum speed and without slipping. The suggested device considerably increases evenness of movement speed and precision of position registering when the cart stops or when it moves under the unknown program. Moreover, stabilization of cart speed enables to decrease positioning pace. Precision high-speed two-coordinate positioning mechanism controlled under the program has been developed and analyzed, which has been used for mechanical processing and correction of resistor schemes. This device has control unit connected to computer. Movement speed increase zone of the cart reaches 60 μm . Stopping zone of the cart moving at speed of 40 mm/s reaches 100 μm . Unevenness of movement speed of the cart is 1 %, and slipping size after halt does not exceed 0,5 μm . In addition, technical characteristics of the mechanism are as follows: positioning plane 90x90 mm; stabilized speed 2 – 40 mm/s; displacement pace 1 μm .

Conclusions Suggested algorithm of positioning mechanism cart discrete shift without transition processes and formulated control task enabled to determine law dependencies of controllable forces effecting elastically and dissipatively interconnected carts on system parameters. Developed control devices of positioning mechanisms with piezoelectric vibroengines, which form the optimal control law of cart shift, considerably increase mechanism precision and movement speed as well as significantly decrease displacement pace, as they eliminate cart slipping during "start – stop" regimes and maintain a constant acceleration, independently from the length of the path. An original precision positioning device with displacement transducer, vibroengine and controllable feeding voltage formation scheme, which considerably increases speed evenness and precision of cart position registration while shifting the cart under a freely chosen program, has been developed. Minimum displacement pace has reached 1 μm at movement speed of 40 mm/s. Speed growth zone has made 0 μm , and stopping zone – 100 μm . Speed unevenness has reached 1 %, and slipping size after halt does not exceed 0,5 μm . Developed positioning mechanisms piezoelectric vibroengine of original construction considerably increases precision, useful effect ratio and reliability, as looseness, energy losses and acoustic noises are being eliminated.

References

- [1] Higuchi K: A piezoelectric linear motor driven by superposing standing waves with phase difference. Structures, structural dynamics & materials conf., 1995.
- [2] Helmsel T., Wallaschek J.: Piezoelectric linear motor. Actuator 2000, 7th International Conference on New Actuators, 2000.
- [3] Ueha S., Tomikawa Y. Ultrasonic Motors Theory and Applications. Oxford, 1993.
- [4] Kurosawa M., Higuchi T. Surface acoustic wave linear motor. Mechatronics and Advanced Motion Control, 3rd International Heinz Nixdorf Symposium, 1999.