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Control of the System of Piezoelectric Actuator Devices for Precision Drive Systems

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Abstract
In the work problems related to control of precision piezoelectric actuator devices, piezo actuators in particular, are discussed. Multichannel system of control of piezo actuators is presented. Possibility of using the said control system to control the shape of the space-based large transformed antenna is discussed.

Keywords- Precision actuator devices, Amplifier driver, Microcontroller, Control signal, Piezo actuator, Stroke length, PCB.

1. Introduction
Currently, technical requirements to the precision systems result in the need for search for new technical decisions that would correspond to the requirements at minimum financial expenditures and energy cost though meeting or exceeding its precursors in terms of functionality (Mitin and Krivushov, 2018).

One of such decisions is application of high-accuracy positioning piezo actuators operating based on the inverse piezoelectric effect, i.e. on the conversion of electric power into mechanical one (Kuptsov 2016; Vasil'ev et al., 2017; Choe et al., 2017; Vassiliev et al., 2017). Piezo actuators are structures consisting of several piezo elements, which allows enhancing their functional capabilities, improving travel range in particular (Heijer et al., 2014). Figure 1 gives the scheme of one of the possible piezo actuator version consisting of piezo elements multilayer package.

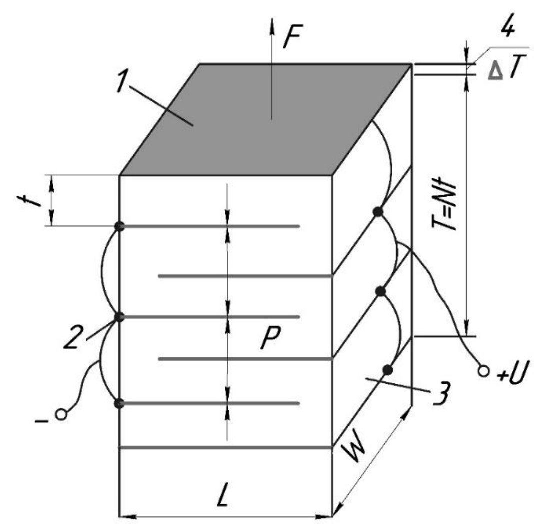

Figure 1. Scheme of piezo actuator consisting of piezo elements multilayer package: 1 – external electrode; 2 – internal electrodes; 3 – piezo material, 4 – piezo material expansion

At application of the external electric field with the difference of potentials coincident with the plate polarisation direction, piezo material expansion takes place over its thickness or along the polarisation axis. The stroke length of the said piezo actuators can be within the range of tens of nanometers through tens of micrometers, and the force' range can make several tens through hundreds of Newtons (Bardin and Vasil'ev, 2014; Halabi et al., 2018).

Use of piezo actuators becomes of special importance in the development of spacecraft where actuation devices should feature rather small mass and size characteristics, possess substantial developed force and allow a separate control object included into the technical system performing precision movements (Matveev et al., 2018). For instance, to arrange the communication channel between the earth-based station and the spacecraft is necessary to accurately form the antenna pattern, since even its smallest deviations can result in substantial losses in signals reception or transmission (Frolov et al., 2018; Kiseleva et al., 2018; Medvedev et al., 2018; Yenuchenko, 2018). Accuracy of the above-mentioned antenna pattern forming can ensure getting the transformed antenna where control of the radio-reflective surface shape is ensured by changes in the cables' length (Zhengrong et al., 2014; Yiqun et al., 2016). Cables are positioned between the reflector' front and rear network (Yiqun et al., 2017).

2. Linear Drive Based on the System of Piezo Actuators

Systems consisting of two, three or more piezo actuators connected with each other can be of the utmost interest. The said approach to the problem allows performing movement at the required distance in one or several needed directions (Bardin and Vasil'ev, 2017; Osipov et al., 2018). Figure 2 shows general view of the developed piezoelectric linear drive intended for changing length of cords of the large-size transformed antenna' shape-forming structure.

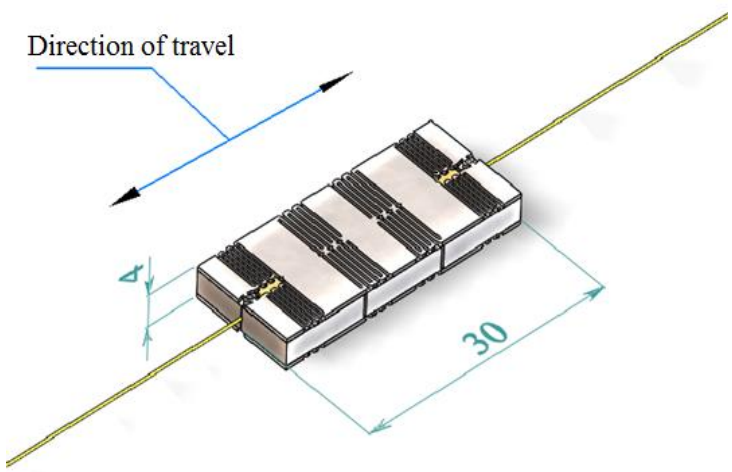

Figure 2. General view of the developed piezoelectric linear drive

The linear drive executes translational motion along the cable structure' cord (Kabanov et al., 2018). One of the cord's end is fixed to the drive body. The end passes through the pulley structure that is fixed on the shape of the frontal network at the base of the control point. At rest, the drive is in the closed loop state, which allows maintaining the pre-set position at power off.

In the developed piezoelectric linear drive system, control of piezo actuators' stroke value is assigned by pulse repetition frequency of the control signals from the microcontroller' outputs (Chi and Xu, 2014; Varlamov et al., 2018; Varlamov et al., 2019). Piezo actuators adjacent to the cable operate in synchronous manner and form a pair having the single control signal. The control

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algorithm is based on the phase difference between the channels where control signals of the end pairs of the drive' piezo actuators are in antiphase, while the control signal of the internal pair of the drive' piezo actuators has several microseconds propagation delay. Pulses duration is determined by electrical capacitance of the certain piezo actuator models. Figure 3 gives the control algorithm' general view.

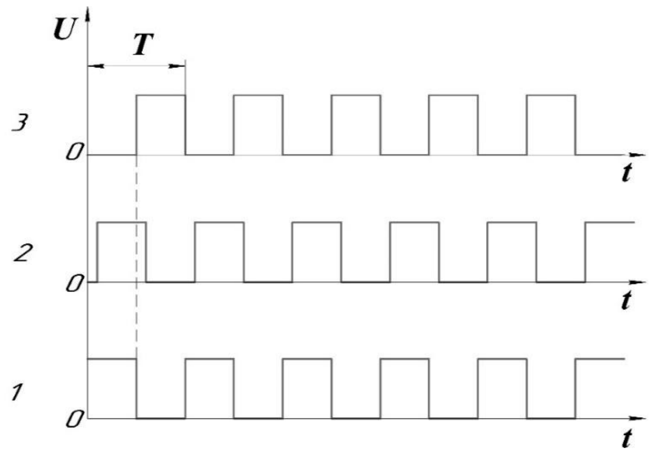

Figure 3. General view of the control algorithm

3. Amplifier Driver for the Drive Based on the System of Piezo Actuators

As a rule, piezo actuators feature high power supply voltage and low current consumption values. That is why the most relevant objective faced by the developers eager to integrate this type of actuators into the technical system being designed is development of the amplifier driver ensuring the required voltage and the stroke length control capability (Kabanov et al., 2018).

The amplifier driver developed and proposed for discussion allows converting input 2.7 V DC voltage into pulsating voltage with 160 V amplitude at the output. At the external microcontroller connection, 3 square waves are formed at the output ensuring the possibility of controlling the piezo actuators' stroke value. The amplifier device scheme includes DC-DC converter, H-bridge scheme, voltage multiplier, and power MOSFET-transistor switches. It should be noted that power MOSFET-transistor switches components are to be individually selected, i.e. for each specific piezo actuator model. For the converter' microcircuit, MC34063 universal microcircuit for typical pulse converters was selected. Step-down, step-up or inverting converters can be created based on the said microcircuit without using any external switching transistors. The MC34063 circuit' principal technical specifications are as follows:

- Wide range of input voltage values, from 3 to 40 V;
- High output pulse current, up to 1.5 A;
- Adjustable output voltage;
- Converter frequency up to 100 kHz.

Figure 4 demonstrates the microcircuit structure.

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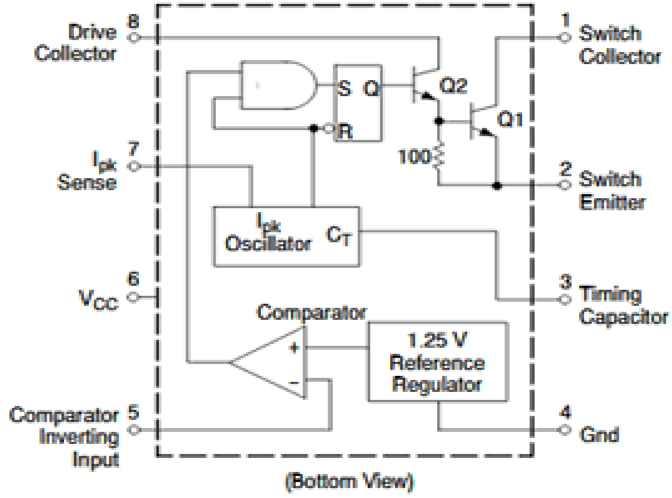

Figure 4. The microcircuit structure

Nominal values of the typical application circuit' components were computed considering the possibility of increasing the output voltage up to 40 V from the supply voltage of 2.7 V;

$$V_{out} = 1.25(1 + \frac{R_2}{R_1}),$$

$$t_{on} / t_{off} = \frac{V_{OUT} + V_F - V_{IN(\min)}}{V_{IN(\min)} - V_{sat}},$$

$$I_{PK(swith)} = 2I_{out(\max)}[(t_{on} / t_{off}) + 1],$$

$$C_o = \frac{I_{OUT} t_{on}}{V_{ripple(p-p)}},$$

$$L_{(\min)} = \frac{V_{IN(\min)} - V_{sat}}{I_{PK(swith)}} t_{on(\min)}.$$

Here

V_{sat} – Saturation voltage of the output switch

V_f – Forward voltage drop of the output rectifier

V_{IN} – Nominal input voltage

V_{out} – Desired output voltage

I_{out} – Desired output current

V_{ripple} – Desired peak to peak output ripple voltage.

The developed driver advantages are as follows:

- Capability of the output power adjustment;
- The structure assignment to minimize the weight and size characteristics.

Capability of the output power adjustment is achieved by recomputation of the components of the typical application circuit nominal values and frequency of the MC34063 converter microcircuit, as well as by adding or decreasing voltage multiplier cascades. The said capability renders unique character to the developed concept of the amplifier driver' circuit making it the universal device for ensuring the required power and the required control of various piezoelectric actuator devices, piezo actuators in particular. The driver assignment to minimize the weight and size characteristics is ensured by the possibility of the PCB implementation on the smd components. Figure 5 demonstrates 3D model of the developed driver' PCB design.

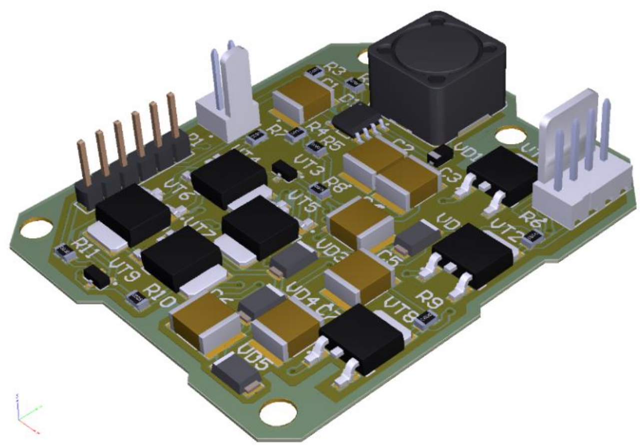

Figure 5. 3D model of the developed driver' PCB design

Topology of the PCB Top layer is presented in Figure 6.

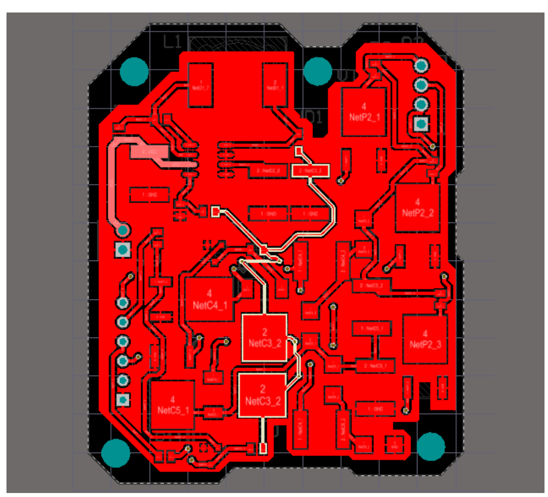

Figure 6. Topology of the PCB top layer

Table 1 gives the principal technical specifications of the developed driver.

Table 1. The developed driver' principal technical specifications

Specification description	Numeric value
Control signals number	3
Input voltages range	+2.7 V...+5 V
Output voltage	100-160 V
Operating temperature range	-20 °C...+ 45 °C
PCB area	~18 cm^2
Mass	~20 g

Currently, work is being performed aimed at upgrading the amplifier driver' technical specifications. The principal trends in the device development are as follows:

- Minimisation of the size and mass characteristics;
- Improvement of the functioning reliability;
- Expansion of the operating temperature range.

4. Conclusion

Requirements to the mechanisms of the large antenna shape correction drives can present the developers with a number of tasks to be solved through accomplishing thorough analyses, calculations and designing. The principal tasks are development of the required force, precise positionability, and the structure' lightness and smallness. In this case development of the piezo actuators-based drives become the optimum solution.

To implement the linear drive control system, it is necessary to develop an amplifier driver that would ensure the required operating voltage and capability of multi-channel control of the piezo actuators' stroke value.

The designed amplifier driver ensures required power supply and control of piezo actuators of the developed precision linear drive presented here.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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