High-precision Control System for Piezoelectric Stack Actuators

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Abstract

The paper presents a high-performance, high-efficiency, low-cost complete system for the control of piezoelectric stack actuators with capacitance from 0 to 20 μF. Compared to commercially available low-cost devices this system offers larger bandwidth (in excess of 10 kHz in voltage control mode), lower consumption and lower cost.

1. Introduction

Recent micropositioning applications ask for resolutions in the nanometer scale, with strokes from tens of micrometers to some millimeters, or rotations from a few to one-hundred milliradians. Piezoelectric stack actuators offer micrometer positioning capability while allowing nanometer-level resolution. In order to fully exploit the potential of these actuators, circuits are needed, which can drive capacitive loads at sufficiently high bandwidth across hundreds of volts.

Such actuators are typically driven with the help of circuits based on linear amplifiers. Unfortunately, dissipation power considerations limit the use of these circuits to small capacitance actuators, i.e. piezo-stack actuators with short stroke.

This article presents a switched device designed for piezoelectric stack actuators. It has been successfully tested, with the necessary firmware modifications, also in combination with stick-slip and inch-worm actuators. The device is ready for integration into a commercial high-precision tool machine in which small, high-frequency tool motions are superimposed on large stroke motions.

2. The amplifier

The final stage of the device is based on a half-bridge PWM amplifier as shown in Figure 1. It consists of a circuit realized using low-cost components and specifically designed to achieve precise positioning at bandwidths larger than 10 kHz. In the design, a critical step is the configuration of the final stage. The circuit relies on two P-N channel power MOSFETs (IRF9530BF and IRF634BF supplied by Intersil).

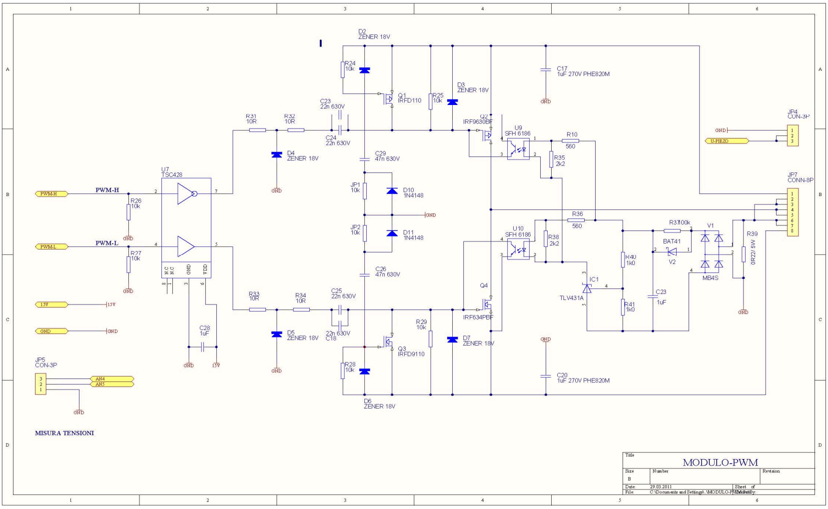

Figure 1: Front-end electronic schematics of the driver

With this specific PWM modulation circuit it is possible to minimize the dead time during switching and to achieve a total harmonic distortion value (THD) close to that of AB class power amplifiers but with a significantly higher efficiency (greater than 0.9). PWM-modulation based commercial solutions usually include a final stage composed of two N-Channel MOSFETs, which has the drawback of causing an increased dead time, and of leading to a higher THD.

A standard switched circuit P-N channel (i.e. amplifier from 3.3 V to 400 V) exploits two MOSFET-drivers: the solution presented here needs only one driver (TSC428 powered by MAXIM) because the capacitors C23-C24-C25-C18 ensure the level shifting of the MOSFET control signal to the desired voltage. Using this strategy it is possible to reduce the final cost of the front-end electronics while maintaining excellent performance. The step response and the resulting Bode diagram for a 10 μF piezo stack actuators is presented in Figure 2. The plots show a slew rate greater than 1200 V/ms and a cut-off frequency exceeding 10 kHz.

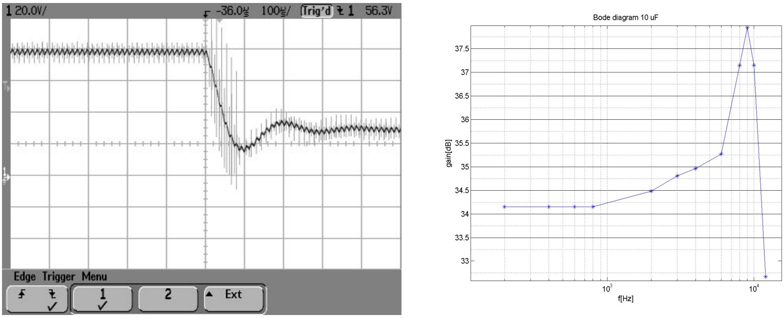

Figure 2: Behavior of the amplifier with a 10 μF piezo stack actuator. Closed-loop slew-rate plot (left), and open-loop Bode diagram (right).

The amplifier design was optimized to drive capacitive loads above 20 nF. For smaller capacitances a circuit based on Bipolar Junction Transistor as presented in [1] is more suitable.

3. Control

The control architecture is based on an inner control loop for tracking a given voltage and of an outer loop for tracking the reference position (see Figure 2).

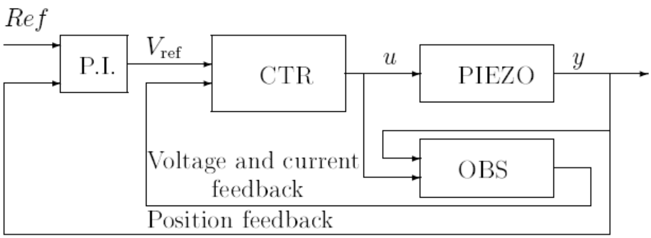

Figure 3: Control loop with inner and outer feedback loops.

The inner loop has been designed based on a state-feedback controller (CTR). In order to achieve a smooth control signal despite of the current and voltage noise, the state-feedback controller relies on the filtered estimation of the state-space variables through a full-state observer for linear systems. The parameters of the state-feedback controller and of the observer are computed at start-up thanks to an identification procedure able to identify the dynamic model of a simple LCR circuit. In order to identify the model, the drive generates a Pseudo Random Binary Signal and, based on an ARX approach, identifies the parameters *L*, *C* and *R* through a least-square recursive routine.

The outer loop has been realized using a simply P.I. controller: the user tunes the *P* and *I* parameters with the help of a simple interface. The control platform includes a fixed point DSP and has been developed using low-cost components.

4. Spatial response

Figure 4 presents two examples of the response of a 10 μF piezo stack. Note that the electrical noise due to the PWM modulation present in Figure 2 has no effect on the piezo stack actuator displacement.

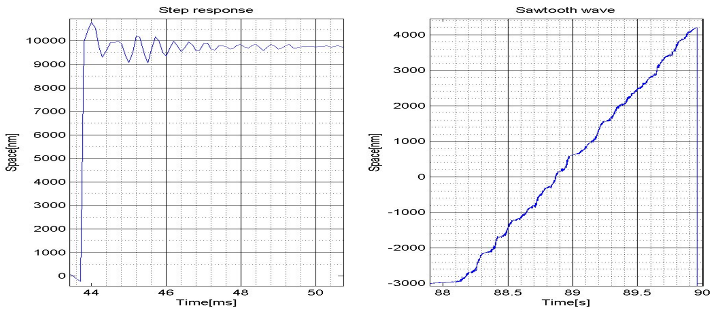

Figure 4: Spatial step-response (left) and sawtooth wave (right)

5. Conclusion

The presented driver realizes a complete low-cost piezo-stack control system with performance comparable to that of expensive drivers. The front-end electronics is particularly suited for medium capacitance piezoelectric motors (from 200 nF to 20 μF). The control strategy and an automatic parameters identification procedure provide robustness and user friendliness.

References

[1] High-performance amplifier for stick-slip piezoeletric motors, *Gianluca Montù, Gian Carlo Dozio, Ridha Ben Mrad, Silvano Balemi,* Proceedings of the 8th euspen International Conference, 2008