The technology of printed circuit board microdrilling

V P Mikhailov*, Tun Lin Aung, A V Kazakov and A A Kopylov
Department of Electronic Technologies in Mechanical Engineering, MT-11, Bauman Moscow State Technical University, 2nd Baumanskaya st. 5, Moscow 105005, Russia.

* mikhailov@bmstu.ru

Abstract. The paper describes the device and operating principle of a high-precision positioning drive based on a magnetorheological (MR) elastomer for micro-drilling blind holes in multilayer printed circuit boards. The results of experimental studies of a drive with a closed control system for step-by-step movement are presented. The operation of the drive in the mode of active vibration isolation is shown and the coefficient of transmission of the vibration displacement amplitude is determined.

1. Introduction
In the production process of multilayer printed circuit boards (MPCB), the minimum required diameter of the transition holes is 50 µm. Nowadays the main drilling instrument manufacturers: (Union Tool (Japan), IND-Sphinx (India), HAM Microprazision (Germany), HPtec (Switzerland) show the drilling instruments for the demanded parameters forming [1]. Nowadays, drilling conditions that are close to optimal can be implemented when drilling holes with a diameter of 150 µm or more in FR-4 glass-fiber composites. For this purpose, high-speed synchronous and asynchronous spindles on-air supports are used, for example, Posalux PS300 and PS325 (Switzerland) with a rotation speed of 300 and 325 thousand rpm, respectively [2].

The average value of the durability of micro-size carbide drills when processing MPCB in glass-fiber plastic is 1000 holes. On the other side, the blind holes forming is a difficult procedure because the hole bottom form leads to the high intensity of drill wear. The hole bottom form is the emergency parameter of the technology, and the drill average durability becomes about 500–700 holes [2].

The new technology of blind holes micro-drilling problem consists of a small depth of hole also as in the necessity to drill copper foil that covers the circuit boards. We must remember, that drill diameter is 50 µm, depth if the blind hole is ±5 µm, demanded error of positioning in the direction of the Z-axis is less ±0.5 µm. The view of blind holes at the optimal depth of the hole in the body of the circuit board is shown in figure 1.

To ensure the high depth precision of the blind holes, it is necessary to use the positioning mechanisms with high precision, and this precision must be on nano–range scale [1–11]. It is necessary to know, that the initial instrument transference system uses positioning for rough processing and precision instrument transference system use positioning for precise final processing.

In our case, the additional high precision positioning table uses chasing-milling system CAM 1020 Active Pro company VHF (Germany) with positioning error about 10 µ (figure 1). The positioning error is on axis X and Y is about ±50 µm, and on-axis Z ±10 µm [3].
So, the experiments show, that magnetorheological elastomer is a perspective material for use as active elements of positioning and vibration-isolating mechanisms to improve the quality of research and technological processes [12–14]. Based on MR elastomers, a positioning table was developed and studied for micro-drilling blind holes of MPCB with positioning accuracy in the nano–range scale.

2. Research of the high-precision drive at step-by-step displacement

The positioning table consists of two plates being joined with four elastic devices with mass correctors also as with four high-precision drive based on magnetorheological elastomer usage. The overview of positioning table based on magnetorheological elastomer damper usage is shown in figure 2 without the upper plate of the table.

The high-precision drive (figure 3) includes magnetorheological elastomer membrane 1 with mobile rigid center 2, housing 3, electromagnetic coil 4, core 5, and base 6. Together with the rigid center, the core forms an air gap. The high-precision drive operates as follows. The supply of the control current to the coil in the electromagnetic system creates an enclosed magnetic field. A radial magnetic field with induction is formed in the membrane; its maximum is close to the rigid center. Under the action of the magnetic induction, membrane 1, with a rigid center, moves axially within the air gap. The magnetorheological elastomer consists of a silicone rubber matrix, within which spherical carbonyl-iron particles (1–10 µm) are distributed [12]. Under the action of the magnetic field, the magnetorheological elastomer may be reversibly deformed and its viscoelastic properties may change. That permits an improvement in the damping in comparison with ordinary viscoelastic systems. In addition, the high-precision drive in the platform may be used as an active damper for the vibration insulated object.
The purpose of the first series of experiments was to study the high-precision drive with a closed control system during the step-by-step movement. A general view of the high-precision drive with the displacement sensor installed is shown in figure 4. To control the high-precision drive, a personal computer with a LabView program was used, a National Instruments USB-6009 ADC/DAC unit, a capacitive displacement sensor with a DT6220 sensor controller (Micro-Epsilon, Germany) with a measurement error of 0.04 µm [15].

![Figure 4. High-precision drive with sensor installed.](image)

As a result of the experiments, the dependence of the high-precision drive movement on time in the range of 70 µm with a step of 10 µm was obtained (figure 5). The enlarged scale shows the graphs of transients during movement of the drive in the extreme and middle positions (figure 6). According to the data obtained, it is clear that the nature of the transient processes is the same in all positions. The deviation from steady-state position values in all cases does not exceed ± 1 µm. The time of transient processes decreases slightly (from 200 to 100 ms) when moving from the initial position to the final one, which is explained by the increase in magnetic induction created during control.

![Figure 5. The dependence of the high-precision drive movement on time in the range of 70 µm with a step of 10 µm.](image)
3. Research of the high precision drive in active vibration isolation

To reduce the positioning error of the high precision drive when exposed to external vibrations, various types of vibration isolation systems are used, which are divided into passive and active. Passive systems effectively suppress vibration at frequencies above 50 ... 200 Hz. At the same time, in the low-frequency region, where resonant phenomena predominate, such systems are ineffective [4]. For vibration isolation in the low-frequency range, active vibration isolation systems with the energy of an additional source are used. The most effective are modern systems that combine active and passive vibration isolation. Such systems include the proposed positioning table based on MR elastomers [5,6].

To study the active mode of vibration isolation with a closed control system, an experimental stand was developed, the scheme of which is shown in figure 7. The high precision drive consists of a rigid center 1; elastomer membranes 2; case 3; coils 4; core 5. The stand also contains the base of the drive 6; pusher guide 7; pusher 8; bearings 9; eccentric shaft 10; eccentric 11; coupling 12; gear motor 13 with worm gearbox and frequency regulator; stand base 14; amplifier block 15; capacitive sensors 16, 17; personal computer 18; digital-to-analog converter 19; analog-to-digital converters 20, 21.

Figure 6. Transient graphs when moving the high precision drive in the extreme and middle positions.

Figure 7. Scheme of the laboratory bench for measuring the transmission coefficient of vibration displacement amplitude $k$. 

Figure 8. The external view of the stand.
The stand works as follows. The pusher 8 impacts on the base of the drive 6 and transmits sinusoidally variable periodic vibrations with specified characteristics, generated by the eccentric 11. In this case, the base of the drive 6 performs a vertical reciprocating movement within the required range. The value of committed movements due to the size of the eccentric 11, which is rigidly connected to the base of the drive 6 through the pusher 8. The eccentric 11 is mounted on the eccentric shaft 10 through a sliding bearing, while the pusher 8 is fixed in the housing of the stand on two ball bearings 9. The rotation speed of the eccentric shaft 10 is set by a worm gear motor 13 connected through a coupling 12. The regulation of the rotation speed of the worm gear motor 13 is carried out by a laboratory DC source.

The main parameter that characterizes the vibration isolation system is the coefficient of transmission of the vibration displacement amplitude \( k \), equal to the ratio of the vibration displacement amplitudes of the insulated rigid center 1 and the base of the drive 6 (see figure 7). The automatic control system using analog-to-digital converters 20, 21 receives indications of vibrations from displacement sensors 16 and 17. After processing the received data, the corresponding control signal is generated, which is transmitted through a digital-to-analog converter 19 to the amplifier block 15, from where the signal is fed to the drive coil, creating the necessary movement opposite to the disturbance.

The transmission coefficient of vibration displacement amplitude shows how much of the vibration is transmitted during vibrations from the base of the drive 6 to the rigid center 1. This parameter is important for evaluating the efficiency of the drive, i.e. for evaluating its damping properties:

\[
k = \frac{A_1}{A_0}
\]

where \( A_1 \) – the vibration amplitude of the rigid center 1, and \( A_0 \) – the vibration amplitude of the drive base 6. The transmission coefficient \( k \) should aim at the lowest possible value. For active vibration isolation systems, \( k \) under 0.1 is considered a good indicator.

In this zone, find the maximum and minimum values of movement, and calculate the amplitude of vibrations using the formula:

\[
A = \frac{\delta_{\text{max}} - \delta_{\text{min}}}{2}
\]

where \( A \) – the vibration amplitude, \( \delta_{\text{max}} \) – the maximum value of the coordinate, \( \delta_{\text{min}} \) – the minimum value of the coordinate.

During the research, an experiment was conducted, based on the obtained data from sensors 16 and 17, a graph of the time dependence of the displacement was constructed, the graph is presented in figure 9.

**Figure 9.** Graphs of the time dependence of the drive displacement: 1 - with active vibration isolation; 2 - without active vibration isolation.
Based on the results of the experiment, the transmission coefficient of the vibration displacement amplitude was determined, which is approximately 0.05...0.10. The obtained results show that the proposed drive effectively reduces the amplitude of vibration displacements at a frequency of about 1 Hz.

4. Conclusions
It was shown, that to ensure the high accuracy of the depth of blind holes when micro-drilling multilayer printed circuit boards, it is necessary to use the additional high-precision drive based on the magnetorheological elastomer with positioning accuracy in the nano-scale range. It was shown also, that magnetorheological elastomer usage is perspective for active damper, positioning, and vibration insulators devices in the technology of precise cutting (drilling). It was shown, that the high precision drive based on MR elastomer provides step-by-step movement in a given range, for example, 70 μm with a step of 10 μm increments with a positioning error of no more than ± 1 μm and a speed of 100 ... 200 ms. It was shown also, that the high precision drive based on MR elastomer provides a transmission coefficient of the amplitude of vibration displacements in the range of 0.05 ... 0.10, which shows the high efficiency of the closed-loop control system at low vibration frequencies (about 1 Hz). At the same time, the vibration amplitudes decreased from 250 μm to 10 ... 20 μm.

References
[1] Hidehito W, Hideo T and Masami M 2008 Precision Eng. 32 329 – 35
[2] Posalux Mechanical Drilling / Milling / Routing (https://www.posalux.com/micro-drilling-and-routing/).
[3] VHF Products CNC milling machine Active Pro (https://www.vhf.de/cnc-fraesmaschinen/maschinenbaureihen/active-pro.html)
[4] W. Wigglesworth and S. Jordan. 2009 Semicond. Int. 32(10) 4–26
[5] Accurion Active Vibration Isolation (http://www.accurion.com).
[6] Holger Böse Wü and Rene Röder G Magnetorheological elastomers and use thereof (US Patent No. US20080318045A1. Appl. No. 11/574397, 25.08.2005, Date of Patent 27.08.2004.)
[7] Gruzevich Yu K, Soldatenkov V A, Achil’diev V M, Levkovich A D, Bedro A N, Komarova M N and Voronin I V 2018 J. Opt. Tech. 85(5) 308–13
[8] Ovcinnikov I and Brancevich P 2017 Procedia Eng. 176 610–17
[9] Krestnikovskiy K V, Panovko G Y and Shokhin A E 2016 Vibroeng. Procedia. 8 208–12
[10] Panovko G, Shokhin A and Eremyekin S 2016 Vibroeng. Procedia 8 174–78 (in Russian)
[11] Chernikov S A 2015 J. Mach. Manufact. Reliab. 44 439-44
[12] Mikhailov V P, Bazinenkov A M 2017 J. Magn. Magn. Mat. 431 266–68
[13] Mikhailov V P, Bazinenkov A M, Dolinin P A and Stepanov G V 2018 Instr. Exper. Tech. 61(3) 427–32
[14] Mikhailov V P, Bazinenkov A M, Dolinin P A and Stepanov G V 2018 Russ. Eng. Res. 38(6) 434–37
[15] Micro-Epsilon capaNCDT Micro-Epsilon capaNCDT 6200 operating instructions manual (https://www.microepsilon.com/download/manuals/man--capaNCDT-6200--en.pdf, (date accessed: 16.05.2019)).