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Investigation of ultrasonic stepping motors and nanomanipulator for scanning probe microscopy

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1. Introduction

Nanopositioning is one of the key technologies which determine the development of other technologies. One of them is nanotechnology, which growth is influenced by the development of modern instrumental basis. The growing requirements in microelectronics, optics, and biology set new requirements for instrumental equipment in engineering as well as in metrologists [1]. New technologies such as nanoimprinting, scanning microscopy, scanning instruments for surface research, nanolithography, auto-matic identification systems and micromachining, request for ultraprecision positioning instruments, which would ensure the nanometric accuracy of positioning [2].

The task of nanopositioning machines is to allow the engineering technologies and control (including quality) systems to complete their tasks with the maximum accuracy, flexibility and speed. The problem is that these tasks in great measure have to be integrated with a nanometric positioning accuracy into the existing infrastructure of manufacture, the system working field of which would be tens or even hundreds of millimeters. One more requirement is that nanoinstruments and measuring devices such as nanoprobe, microscopic tube and nanoobjects should be integrated in these systems [3].

Nanopositioning system is much more than just displacement sensor, interpolation circuit or medium step of motor. In nano-world the leading role belongs to powers which are not important in macro or micro world. Such powers are friction, deformation, hysteresis, and to obtain the repetitive movement in nano-metric movement distances becomes a big problem, which is impossible to solve in real world. The old knowledge which was sufficient for the development of micro positioning systems is not enough.

Therefore it is necessary to evaluate the requirements of high-speed while projecting the nanopositioning system. That means that the positioning motor's capability to develop a high acceleration is one of the nanopositioning system parameters. As mentioned above, the highest acceleration is achieved by piezo actuators (PZT motors). They can reach 10.000 g and ensure the reaction to step control signal in 0.1 m s. Usually it is faster than inertia of mechanical system allows. But along with the increasing speed of management speed, the possibility of transitive processes and vibration generation in nanopositioning systems is growing, too. So for positioning system it is much more important the speed of reaching stability, than the speed of system's movement from one position to another.

But the dominating tendency is still the same – it is the usage of piezo technique. Along with traditional piezo actuators, displacement piezo motors in nanopositioning are used. The possibilities of traditional piezo actuators are limited because of their physical nature, working principle – the deformation of material because of piezo effect, and limited positioning distance (up to 100 micron using piezo tubes and up to 500 micron using manual transmission). Stepping motors allow to reach the resolution power of several nanometers and have practically unlimited range of positioning [4, 5]. Their advantage is high positioning speed – up to 250 mm/ sec, and fixation of position when control voltage is switched off [6, 7].

In this work we designed and investigated the stepping motors nanomanipulator and have created two coordinate manipulator control software.

2. Construction of stepping motors

The positioning system of Scanning probe microscopy (SPM) nanomanipulator at the micrometric level in the plane „X-0-Y" consists of two identical piezoelectrical stepping motors (SM) of one coordinate, mounted one on another in such a way that the kinetic/speed trends of their output links were in a square position (Fig. 1). Such peculiarity of the construction enables the output link (table) to make movements in two directions those are in a square position to each other. The table of each stepping motor moves (motion 10±0.5 mm) in rolling ways, which secure a high stability of motion and slight frictional force. The drive link of the stepping motor – vibromotor (Fig. 1) is mounted in the frame of the stepping motor and has a friction contact with the output link of the stepping motor-table.

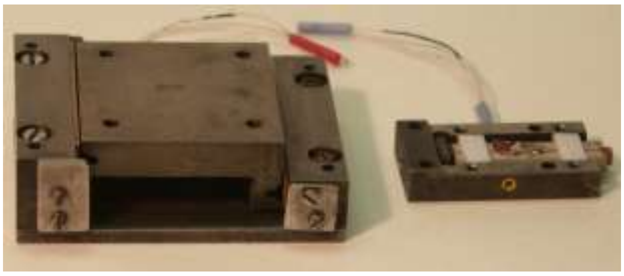


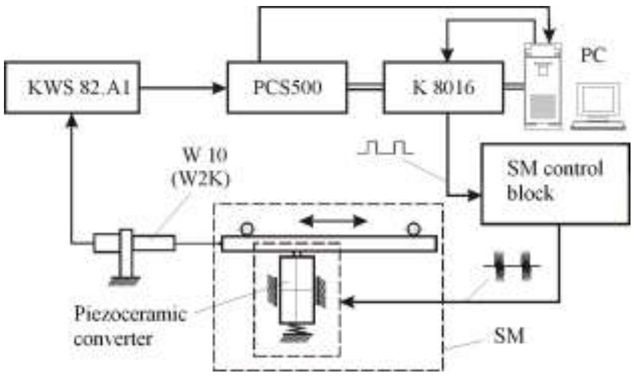
Fig. 1 General views of SPM nanomanipulator piezoelectric stepping motor on one coordinate (on the right – vibromotor of the stepping motor)

The exciting voltage rating of the vibromotor piezoceramics is 43.8 kHz and depending on the amplitude of the exciting voltage, the vibromotor develops attractive force up to 25 N. The motion of the vibromotor is regulated through the modulation of exciting voltage with an impulse and motion regimes are formed through the exchange of the modulation impulse duration and their frequency rate.

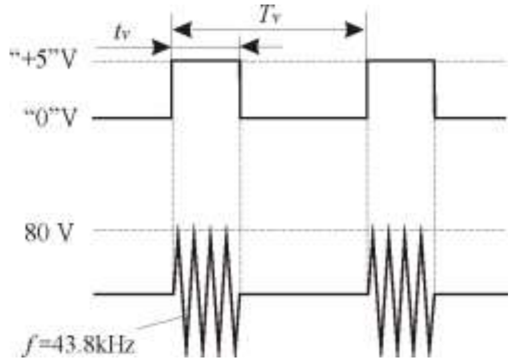
3. Research in stepping motors

The adjustment of stepping motors (SM) was carried out applying the equipment indicated in Fig. 2 a and the software „MaNo“, created during the execution of the programme, using which and applying a PC functional unit K 8016 (Fig. 2, a), it is possible to change the duration t_v of “the “package of the vibromotor exciting voltage, formed with an original control unit of stepping motor (Fig. 2, a) and their frequency period T_v (Fig. 2, b).

The shifts of the stepping motor (SM) output link were registered with the equipment „Hottinger Baldwin Messtechnik“(Fig. 2) and presented graphically (Fig. 3) and in a text file.



a

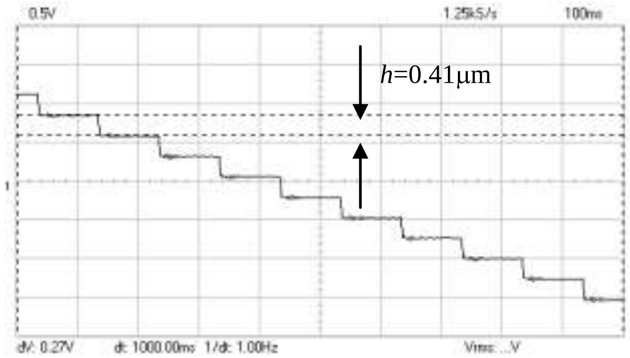


b

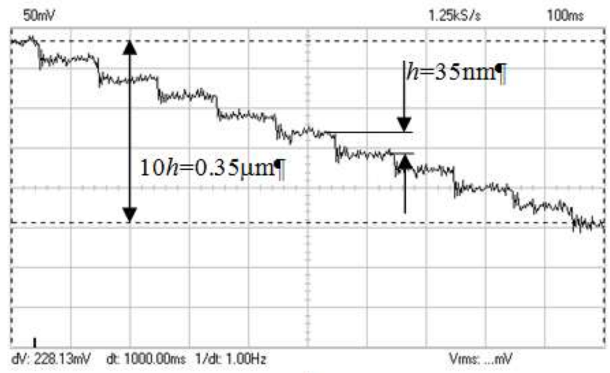
Fig. 2 The stand scheme of research – adjustment for the motion regimes of the piezoelectrical stepping motors (a) and signal characteristics for the stepping motor control (b): KWS82.A1 – „Hottinger Baldwin Messtechnik“ measurement amplifier; PCS500 - „Velleman Instruments“ PC oscilloscope; K 8016 – „Velleman Instruments“ PC function generator; PC – personal computer; W10, W2K – inductive shift converters; SM – stepping motor; t_v – control impulse duration; T_v – the sequence period of control signal; +5V – control signal level; f = 43.8 kHz, 80 V – proportionately, the rate and amplitude of the exciting voltage of the piezoceramic converter in the stepping motor

Apart from the key SM parameters – exciting rate (43.8 kHz), the amplitude of exciting voltage 80 V, there are developed forces up to 25 N, and for the designed stepping motor there is significant the following characteristics – minimal movement step that determines the sensitivity of the stepping motor. In Fig. 3, b there is introduced the characteristics of SM step movement of SPM nanomanipulator where there is recorded a stable movement in 35 nm steps.

The summarized dependencies of SM motion are provided in the 5th paragraph, in research of the stepping motor work, controlled with a personal computer and the adjustment of the designed software.



a



b

Fig. 3 Regime characteristics for stepping motion of SM: a – control impulse duration t_v is close to the period of exciting vibration of piezo-stepping motor (t_v = 25 ms); b – t_v is less than the period of exciting vibration (t_v = 12 ms); h – movement step

4. The design of the electrical control part for SPM manipulator

The construction of SPM manipulator consists of two functional units (Fig. 4) – nanoscanner that aids at the execution of scanning and carrying the function of sensor observation on the object surface and SM unit that performs the positioning of the nanoscanner in accordance with the assigned law in micrometric accuracy. Operational regimes of nanoscanner are formed programmably with SPM functional unit B1011MT by NT-MDT company (Fig. 4), selecting exciting voltages for PZK actuators in the range ±150 V.

There has been designed an original electronic device for the control of SM motion control of a nanomanipulator that transforms the sequence of PC signals into high frequency 43.8 kHz, the “packages” of 80 V amplitude the duration of which and frequency rate is equal to relative characteristics of control signal (Fig. 5).

There is foreseen the separation of an electric PC and exciting signal tract with an optical pair – phototransistor 4N26 (Fig. 5) for the security of hardware in the SM chain of control. SM exciting generator and amplifier are filled under the basis of integral schemes.

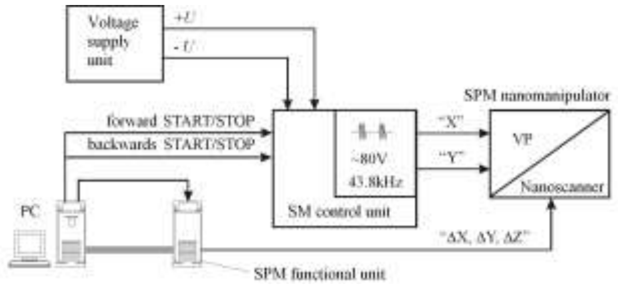


Fig. 4 Principal control scheme of SPM nanomanipulator: X, Y – shifts of piezoelectrical SM on the plane „X-Y“; ΔX, ΔY, ΔZ – shifts of the nanoscanner table

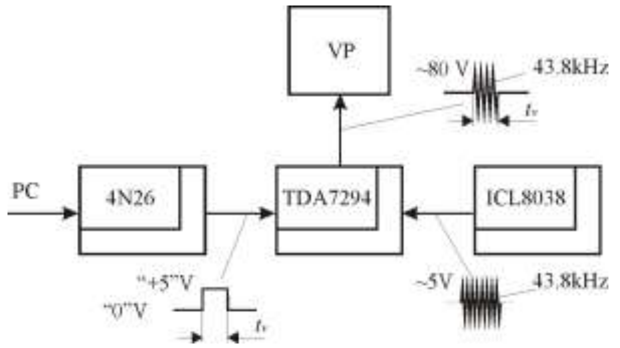


Fig. 5 Single channel unit scheme of the SM control unit: PC – signal input of computer control; t_v – control impulse duration; 4N26 – phototransistor (optical pair); TDA7294 – controllable 100W amplifier; ICL8038 – precision signal generator in the shape of sine; SM – stepping motor

The mounting/ installment of both SM control and power supply voltage units was completed applying the systematic body – 04012 chassis.

Positioning equipment is controlled with impulses issued by the parallel port of computer. The software foresees possibilities to push the manipulator table under the assigned path, direction and distance and issue unitary impulses manually. The software must have a possibility to change the control impulse duration, their frequency rate and the number of impulses necessary for a shift. The shift of the positioning table in a real time is recorded under the aid of a digital signal processor.

5. Outcomes

The dependencies of the table shift on the duration of control impulses and the number of impulses are provided in Figs. 6-8. Currently the table is controlled applying permanent/fixed duration impulses. The number of impulses is estimated following the necessary change of coordinates. There is used the third rank polynomial for estimations. In the Fig. 9 there are provided theoretical and experimental dependencies of the positional change on the number of impulses.

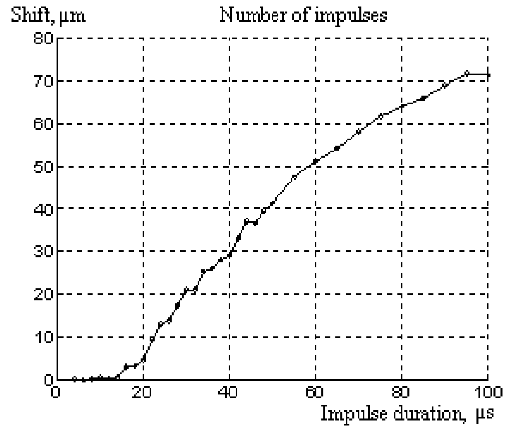


Fig. 6 The shift dependence on the impulse duration when the number of impulses is equal 50

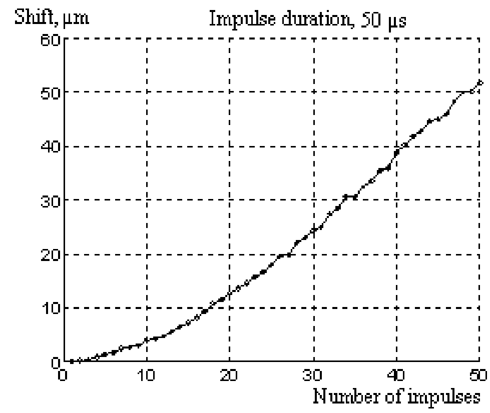


Fig. 7 The shift dependence on the number of impulses when the impulse duration is 50 µs

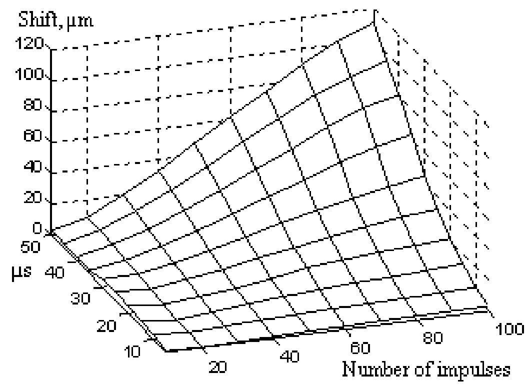


Fig. 8 The shift dependence on the number of impulses and the impulse duration

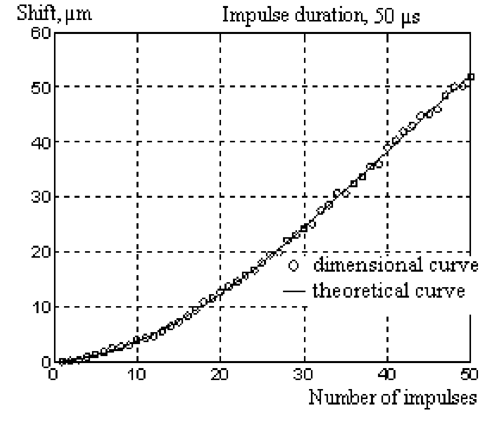


Fig. 9 Theoretical and experimental dependence of the positional change on the number of impulses

The designed control software for the nanomanipulator is integrated as insertion into the control software of open code scanning microscopy GXSM (Gnome X Scanning Microscopy), allocated to Linux operating system that is applied in the Research Centre for Microsystems and Nanotechnology at KTU. The positioning equipment, controlled with impulses, issued through a parallel port of the computer. The software foresees a possibility to control the manipulator table with the assigned path, direction and distance; there is also present a possibility to change the control impulse duration, its frequency rate and the number of impulses, necessary for a shift. The shift of the positioning table in a real tine is recorded under the aid of the digital signal processor. The designed operating system desktop view, with one of the software equipment windows for SPM Linux, is provided in Fig. 10.

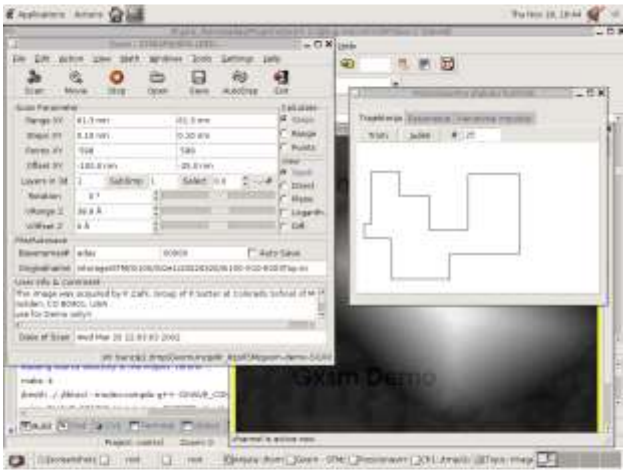


Fig. 10 The designed software window on Linux SPM software desktop

The view of the designed SPM with a nanomanipulator is provided in Fig. 11.

Fig. 11 SPM with nanomanipulator

5. Conclusions

1. There was designed one coordinate piezoelectric stepping motor of SPM nanomanipulator: the exciting voltage rate of SM piezoceramics - 43.8 kHz, the amplitude of the exciting voltage 80 V, and there is developed the attractive force up to 25 N.

2. There was researched the characteristics of SM step movement of SPM nanomanipulator where there was recorded a stable position of a 35 nm step.

3. There was designed control software for the SPM nanomanipulator table allocated to Linux operating system and the following software was tested with the designed manipulator.

4. There was carried out a computerized research in the characteristics of SPM nanomanipulator, i.e. the dependence of the table shift dependence on the control impulse duration and the dependence of the table shift on the number of impulses.

Acknowledgement

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INVESTIGATION OF ULTRASONIC STEPPING MOTORS NANOMANIPULATOR FOR SCANNING PROBE MICROSCOPY

S u m m a r y

In the following article there is analyzed the designed one coordinate piezoelectronic stepping motor of the scanning probe microscopy (SPM) nanomanipulator, allocated to the positioning. For such a system, apart from the basic parameters: exciting rate and the amplitude of the exciting voltage, there are developed forces and there turns to be significant the motion characteristics of the stepping motor minimal step of SPM nanomanipulator that was determined experimentally.

In order to control the positioning equipment accurately, there was designed control software of the SPM nanomanipulator for Linux operating system. Agreeably with its aid it is possible to control the nanomanipulator table under the assigned path, direction and distance, to change the control impulse duration and the number of impulses, necessary for the shift. Applying a computerized research, there was determined the dependence of the table shift on the control impulse duration and the dependence of the table shift on the number of impulses.

Key words: Nanomanipulator, ultrasonic stepping motor, nanopositioning, scanning probe microscopy.

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